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GEOLOGICAL SURVEY RESEARCH 1965

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 525–A

GEOLOGICAL SURVEY RESEARCH 1965

WILLIAM T. PECORA, *Director*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 525

Significant results of investigations for fiscal year 1965, accompanied by short papers in the fields of geology, hydrology, and related sciences. Published separately as Chapters A, B, C, and D.

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, Secretary

GEOLOGICAL SURVEY

William T. Pecora, Director

GEOLOGICAL SURVEY RESEARCH 1965

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 525-A

A summary of recent significant scientific and economic results accompanied by a list of publications released in fiscal 1965, a list of geologic and hydrologic investigations in progress, and a report on the status of topographic mapping.

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FOREWORD

"Geological Survey Research 1965" is the sixth annual review of the economic and scientific work of the U.S. Geological Survey. As in previous years the purpose of the volume is to make available promptly to the public the highlights of Survey investigations. This year the volume consists of 4 chapters (A through D) of Professional Paper 525. Chapter A contains a summary of significant results, and the remaining chapters are made up of collections of short technical papers.

Many of the results summarized in Chapter A are discussed in greater detail in the short papers or in reports listed in "Publications in Fiscal Year 1965," beginning on page A259. The tables of contents for chapters B through D are listed on pages A253–A258.

Numerous Federal, State, county, and municipal agencies listed on pages A205–A210 cooperated financially with the Geological Survey during fiscal 1965 and have contributed significantly to the results reported here. They are identified where appropriate in the short technical papers, but generally are not identified in the brief statements in chapter A.

Many individuals on the staff of the Geological Survey have contributed to "Geological Survey Research 1965." Reference is made to only a few. George Phair, Geologic Division, was responsible for organizing and assembling chapter A and for critical review of papers in chapters B–D, assisted by Frank W. Trainer, Water Resources Division. Marston S. Chase, Publications Division, was in charge of production aspects of the series, assisted by Jesse R. Upperco in technical editing, and William H. Elliott and James R. Hamilton in planning and preparing illustrations.

The volume for next year, "Geological Survey Research 1966," will be published as chapters of Professional Paper 550. Previous volumes are listed below, with their series designations.

Geological Survey Research 1960–Prof. Paper 400
Geological Survey Research 1961–Prof. Paper 424
Geological Survey Research 1962–Prof. Paper 450
Geological Survey Research 1963–Prof. Paper 475
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William T. Pecora

WILLIAM T. PECORA,
Director.

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GEOLOGICAL SURVEY RESEARCH 1965

INVESTIGATIONS OF NATURAL RESOURCES

The U.S. Geological Survey as created by Act of Congress in 1879 was charged with the "classification of the public lands," and with the "examination of the geological structure, mineral resources and products of the national domain." A scanning of the highlights of the Geological Survey's program reported here will make it plain that resource studies, broadly interpreted, provided the keynote and the impetus for the greater part of the Survey's research in 1965 as it has each year since the agency's inception.

Although categories necessarily overlap, the separate sections of this summary may be said to be concerned in varying degrees with the *"what?" "where?"* and *"why?"* surrounding the natural occurrences of the Nation's mineral and water resources. In essence this first section attempts to answer the question *"what* are the distinguishing characteristics and economic importance of individual occurrences of specific commodities?" The section entitled "Regional Geology" is concerned with the total geologic environment, and attempts to answer the question *"where* within that environment are useful resources likely to be found?" The section entitled "Investigations of Principles and Processes" brings modern field and laboratory tools to bear upon the genetic processes that gave birth to the rocks and minerals of the earth's crust, and in so doing concentrated ores, fuels, and waters; it attempts to answer the question *"why* did these useful concentrations form where they did?"

MINERAL RESOURCES

Minerals and fuels, the fundamental ingredients of the American industrial economy, have been prime targets of the U.S. Geological Survey's work from its establishment in 1879. Developments in 1965 pinpoint some of the urgent resource problems currently brought into sharp focus by the demands of a growing population and economy, and illustrate some of the measures being taken to solve them. Among the problems are scarcities that are developing among a few key metals as domestic consumption outstrips production and depletes world supplies. Silver, mercury, and gold are prime examples; industrial consumption of gold (to say nothing of monetary needs) now exceeds domestic production. Appalachia, an area depressed in part by the consequences of an overspecialized exploitation of its resource base, represents another kind of resource problem. The establishment of the Wilderness system illustrates still another: the competition of a growing population for diverse resources on lands where the exploitation of one seems to prevent the use of others.

Discovery of new supplies constitutes one of the prime solutions to the scarcity problem, and the Survey's work contributes importantly in this area by providing knowledge and methods that aid in prospecting for concealed deposits. For example, in May the Newmont Mining Corp. opened a gold deposit at Carlin, Nev., found by drilling beneath a thrust plate to test favorable environments identified by R. J. Roberts.[1] It promises to be the second largest gold mine in the United States. New rapid methods of analysis for gold, silver, and mercury, developed respectively by H. W. Lakin and H. M. Nakagawa (p. C168–C171),[2] by Nakagawa and Lakin (p. C172–C175), and by W. W. Vaughn, W. G. Cramer, and W. N. Sharp (p. B151–B154) should aid in prospecting for deposits of these metals. Identification of silver-bearing black calcite (D. F.

[1] R. J. Roberts, 1957, Major mineral belts in Nevada [abs.]: 1957 Pacific Southwest Mineral Industry Conf., Reno, Nev., Abstracts, p. 4.

R. J. Roberts, P. E. Hotz, James Gilluly, and H. G. Ferguson, 1958, Paleozoic rocks in north-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 12, p. 2813-2857.

R. J. Roberts, 1960, Alinement of mining districts in north-central Nevada: Art. 9 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B17–B19.

[2] See "Contents of Geological Survey Research 1965, Chapters B, C, and D" (p. A253–A258). This report is listed in the contents for chapter C (p. A255–A256).

Hewett and others, 1–65)[3] points to a kind of silver deposit that has not been much prospected previously and suggests that silver, like uranium, may be found to occur in significant quantities in other types of deposits besides those mined in the past.

As a part of the Appalachia program, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Mines and various State agencies, has begun studies aimed ultimately at developing a complex of local mineral resources that may serve as a base for new industries within Appalachia. Following initial emphasis on compilation and analysis of available resource data, work will focus on field studies to develop leads for prospecting.

The Wilderness Act directs the Geological Survey and Bureau of Mines to undertake surveys of Wilderness Areas to determine their mineral values. Primitive and other areas to be considered for inclusion in the system are also to be examined. The purpose of these surveys is to provide an objective description of potential resources that others can use in recommendations and decisions concerning the classification of the areas. Work has begun in seven of the Primitive Areas.

Salient results of the mineral-resource studies in 1965 are summarized in the following pages.

RESOURCE COMPILATION

Current knowledge of the mineral and water resources of Colorado, Idaho, Nevada, and New Mexico has been summarized in four reports prepared jointly by the U.S. Geological Survey and various State agencies. These reports describe known mineral deposits, and in addition make available the syntheses of much recent work pointing toward areas favorable for further exploration.

Resources of Colorado

The report on Colorado (U.S. Geol. Survey, 12–64) points out that major metallic resources have come largely from a narrow 250-mile-long mineralized belt extending diagonally across the State from the La Plata mineral district northeastward to the Jamestown district at the front of the Rockies in Boulder County. Throughout its length the Colorado Mineral Belt is characterized by bodies of Tertiary intrusive igneous rocks, many of which are related to concentrations of ore deposits. Favorable source rocks and possible reservoirs of petroleum and natural gas are described, and areas are indicated that have not yet been adequately tested.

[3] See "Publications in Fiscal Year 1965" (p. A259–A322). This report is the first citation for 1965 under entries for D. F. Hewett, and is listed on p. A285.

Resources of Idaho

The report on Idaho (U.S. Geol. Survey, 16–64) notes that the Idaho batholith clearly constitutes a tungsten province and thus offers a promising field for prospecting and a reasonable chance for new discoveries. Other metallic mineral deposits in the central part of the State, particularly the productive lead-silver deposits, have long been regarded as related to the Idaho batholith. There is, however, ample evidence that many of these deposits stem from an early Tertiary epoch of mineralization, that is in turn associated with intrusions of a later age than the batholith. The search for new deposits should be guided by these associations.

Resources of Nevada

Most of the metallic deposits in Nevada, the summary volume (U.S. Geol. Survey, 17–64) concludes, are related to intrusive rocks, generally granodiorite to quartz monzonite in composition. The mining districts are not randomly distributed; many of the deposits are alined along belts that trend northwestward, east-west, and northeastward across the State. More than 95 percent of the past production of copper, lead, zinc, gold, and silver has come from these belts. The distribution of deposits along the belts is not accidental but reflects fundamental stratigraphic and structural controls. These belts should be the best places to look for new ore deposits.

Resources of New Mexico

In New Mexico a similar beltlike distribution of the major metallic deposits is reported (U.S. Geol. Survey, 7–65). This belt extends from the southwestern corner to the north-central part of the State. Favorable targets within this zone are described. Energy resources in New Mexico are very large, and there are excellent chances of discovering new oil and gas fields.

Mineral fuels of eastern Montana

The future growth potential of eastern Montana's economy is based on unusually abundant resources of mineral fuels, according to a joint study of the U.S. Geological Survey and the U.S. Bureau of Mines (U.S. Geol. Survey, 6–65). One-eighth of the coal resources of the Nation, some 215 billion tons, is in eastern Montana; of this amount, 128 billion tons are of subbituminous rank and 87 billion tons are lignite. About a third of the subbituminous coal is in beds more than 10 feet thick, and about 3 percent of its lies in beds less than 120 feet below the surface, most of which can be recovered by open-pit mining methods. Thermal power plants are the largest consumer of this stripping coal. Eastern Montana produces significant quantities of petroleum and natural gas, and many areas outside the known fields still are relatively untested. Oil has been produced from 17 known formations and gas from several different zones. The present density of testing outside known oil fields is only about 1 well for every 55 square miles.

Domestic resources of mercury analyzed

Domestic mercury resources and economic trends of the mercury industry have been analyzed by E. H. Bailey and R. M. Smith (4–64). After a number of years of declining prices, most of the domestic producers have terminated exploration and closed most of the mines. Domestic production in 1963 provided less than a fourth of the national consumption. However, the price of mercury advanced dramatically from $180 a flask in 1963, to more than $500 a flask by the end of 1964. This study shows that potential resources exist and that with resumption of exploration, the discovery of new deposits and expansion of production can be expected.

Domestic resources of silver evaluated

An analysis of domestic silver resources and economic trends has been made by T. H. Kiilsgaard (1–64). Because silver occurs in a variety of ore deposits in association with other metals, an economic analysis of silver production also must consider the production of the other metals, particularly the base metals lead and zinc. Significant changes in demand for these associated metals have direct impact on the output of silver. The increasing demand for silver for industrial usage has stimulated the search for new deposits by new exploratory techniques (p. C172–C175).

World thorium resources

In reviewing geology and resources of thorium in the United States and the world, J. C. Olson and W. C. Overstreet (1–64) point out that if moderately rich resources of thorium in the United States, expressed as tons per square mile in areas of igneous and high-grade metamorphic rock, are representative of worldwide distribution, corresponding world resources should be at least 3.6 million tons.

HEAVY METALS

IRON

Northwestern Adirondack Mountains, N.Y.

In a comprehensive report on the ore deposits of the St. Lawrence County magnetite district, New York, B. F. Leonard and A. F. Buddington (1–64) describe two principal types of hypogene iron oxide deposits: magnetite deposits in skarn or marble, and magnetite deposits, with or without hematite, in microcline granite-gneiss. The ore bodies are interpreted as high-temperature replacement deposits genetically related to a "younger granite" series that intruded metasedimentary rocks of the Grenville Series. Earlier the metasediments had been intruded by anorthosite, gabbro, and quartz syenite. Renewed exploration and study of this district during and following World War II led to the discovery, under private and Government auspices, of 23 promising new deposits, as compared with 8 that were known from outcrops at least as early as 1840. None had been discovered in the intervening century. Magnetic surveys led to this success; among the finds was the first deposit located in North America by the then-new airborne magnetometer.

Michigan

Recent ground magnetometer surveys by J. E. Gair in the Palmer district, Marquette County, Mich., delimited two areas of anomalously high magnetic readings caused by iron-formation that may be of economic importance. The larger of the two anomalies lies at the east end of the district in secs. 26 and 27, T. 47 N., R. 26 W. and is as much as 27,000 gammas above background. The total extent of the area registering 3,000 gammas or more above background is about 2,800 feet by 1,200 feet. A smaller anomaly is centered near the northwest corner of the village of Palmer at the west end of the district. Maximum readings over this anomaly are about 3,500 gammas above background.

W. C. Prinz reports that some of the Ironwood Iron-Formation in the western half of T. 47 N., R. 44 W., in the East Gogebic Range, Mich., contains sufficient iron to make it of potential economic importance. Results of his recent geologic and magnetic survey, combined with data from old diamond drill holes, show that the middle few hundred feet of the formation is magnetite-rich and contains more than 35 percent iron for a strike length of at least 3 miles. Beneficiation tests were run on one sample of this rock by the Institute of Mineral Research, Michigan Technological University, but a concentrate of acceptable grade could not be made because the magnetite is poorly liberated. However, this sample represents only the uppermost 35 feet of the magnetic unit; the beneficiation properties of the remainder of the unit are unknown because of the lack of exposures. Thin sections from one drill hole that penetrated the lower part of the magnetic unit showed coarse-grained magnetite for an interval of about 250 feet, suggesting that the lower part may be more amenable to concentration than the upper part.

Elongate and arcuate magnetic anomalies as high as 5,000 gammas in amplitude are prominent features of the southern half of the aeromagnetic map of part of Gogebic and Ontonagan Counties, Mich. (G. R. Boynton and J. L. Vargo, 5–64). From the continuity and broad bends in these anomalies, J. E. Case, C. E. Fritts, and W. C. Prinz infer that the anomalies represent folded magnetic units (locally iron-formation), presumably of Animikie age. If this interpretation is correct, the anomalies of higher amplitude merit further investigation as potential iron-ore sources.

MANGANESE

Significance of zoning in manganese veins

In the third of a series of comprehensive papers on the manganese oxides, D. F. Hewett (1–64) presents data that further support his earlier conclusion that many of the veins of manganese oxide in the Western States are of hypogene origin. He concludes that these veins formed near the surface where hot waters from great depth, containing manganese in the manganous state, met the zone of ground water that carried free oxygen. His data also indicate a genetic relation among several of the epithermal deposits in which manganese oxide veins nearest the surface will be succeeded in depth (1) by veins with abundant barite, (2) by those with abundant fluorite, (3) by veins of the epithermal gold-silver type, and finally (4) by veins of the epithermal base-metal type. If the above hypothesis is correct, Hewett notes that holes drilled to reach depths 500 to 1,000 feet below existing workings on manganese oxide veins may strike veins of manganese carbonate and silicate with barite, fluorite, and sulfide minerals that carry enough silver and gold to warrant exploitation.

Permian manganese nodules resemble deep-sea types

Manganese nodules that occur in rock of Permian age about 15 miles southwest of Dillon, Mont., are reported by R. A. Gulbrandsen to be remarkably similar to modern deep-sea manganese nodules. The nodules are in an approximately 2-foot-thick sandstone bed of the Franson Member of the Park City Formation and are located only about 3 feet below the base of the Retort Phosphatic Shale Member of the Phosphoria Formation. They tend to be spherical in shape with irregular surfaces; most are 2–4 centimeters in diameter. Cross sections of the nodules show many concentric rings of variable width. Semiquantitative spectrographic analyses of one nodule show the presence of 1.5 percent nickel and 0.2 percent cobalt, amounts of these elements that are characteristic of modern manganese nodules. Content of some elements differs markedly, however; for example, 0.02 percent copper in the nodule is unusually low, and 5 percent zinc is high. The nodules are considered to be of syngenetic origin like their modern-day counterparts.

MOLYBDENUM

New occurences of potential economic importance in Colorado

Two mineralized areas containing molybdenum in amounts sufficient to justify further exploration have been delimited during the course of areal mapping in the Sawatch Range, according to Maurice Brock and Fred Barker. The minerals molybdenite, beryl, pyrite, and fluorite form an equilibrium assemblage in pegmatites, greisens, and high-temperature veins that represent the close of igneous activity in the Twin Lakes batholith. Field evidence indicates little or no time lapse between the magmatic pegmatites and the postmagmatic greisen and vein zones. This mineral assemblage is confined to an area of about 1 square mile in the batholith and is spatially related to small plutons of a porphyry that contains conspicuous quartz phenocrysts. Adjoining the Twin Lakes batholith is an extensive hydrothermally altered area containing molybdenite in a stockwork of closely spaced silicified fractures. Knowledge gained from a study of this deposit resulted in discovery of another similar molybdenite deposit in the vicinity of Tincup. This mineralized rock is limited to an area of less than a square mile, as indicated by molybdenum analyses of stream sediments in the area of limited outcrop.

COPPER

Structural study results in major discovery in Arizona

Recent diamond drilling in the Pima district, Arizona, by the Banner and Anaconda Mining Cos., has disclosed the presence of a concealed copper deposit of major commercial significance. This discovery is a result of an exploration program that was based in large part on an interpretation of the geologic structure of the Pima area made by J. R. Cooper, of the U.S. Geological Survey.[4] Cooper pos-

[4] J. R. Cooper, 1960, Some geologic features of the Pima mining district, Pima County, Arizona: U.S. Geol. Survey Bull. 1112–C, p. 63–103.

tulated that a large plate of rock in the northeastern part of the Pima district, which contains the Mission, Pima, and Palo Verde mines, was displaced about 6½ miles to the north-northwest along a nearly horizontal fault called the San Xavier thrust. The Anaconda Mining Co. is sinking a shaft to test drilling results and obtain large samples of ore for metallurgical tests, in preparation for open-pit mining. This deposit is believed by Cooper to be the roots of the displaced Mission, Pima, and Palo Verde ore bodies.

A smaller concealed deposit, discovered by Bear Creek Mining Co. about 4 miles northwest of Anaconda's deposit, is now held by Continental Materials Corp. which is sinking a shaft in preparation for underground mining. The Continental Materials ore body is 1½ miles from any previously known deposit; it is evidently in a slice of rock that was dragged into the San Xavier thrust zone. Other deposits of the same type probably occur within other parts of the thrust zone but may lie as much as 1,000 feet or more below the surface.

Geology of San Manuel copper deposit described

S. C. Creasey (1–65) described the geologic setting of the San Manuel area in Pinal County, Ariz., and, in a section prepared jointly with J. D. Pelletier, he related the copper deposit to the intrusive rocks, structure, and alteration halos. San Manuel is one of the major porphyry copper deposits of the country; its discovery resulted in part from earlier studies by the U.S. Geological Survey and the U.S. Bureau of Mines. Copper mineralization is closely associated with zones of potassium enrichment (probably in Late Cretaceous time) of Precambrian quartz monzonite and Cretaceous(?) granodiorite porphyry. In contrast, zones of agrillized rock have abundant pyrite but very little copper.

LEAD-ZINC

Drill-core data on East Tennessee zinc district analyzed

Statistical treatment of drill-core data from the West New Market area in the East Tennessee zinc district confirms previous qualitative evaluation of the relationship of the amount of sphalerite to the stratigraphic thicknesses of limestone and dolomite units in the Kingsport Formation. In a preliminary report Helmuth Wedow, Jr., and J. R. Marie (p. B17–B22) show that the data are compatible with development of the ore-localizing breccia zones by thinning of soluble limestone beds and collapse of less soluble dolomite, with concomitant dilatance of the dolomite. The dolomite thickens about a third of a foot for every foot of thinning of the underlying limestone, and zinc abundance increases logarithmically to the inverse thickness relation.

Computer analysis aids in exploration for base metals

A computer program has been used for trend-surface analysis of data on vertical stratigraphic thickness and metal-abundance in the Mascot-Jefferson City zinc district, Tennessee. The program has shown that simple geometric surfaces of the 2d and 3d degree, fitted by the least-squares method, account for a significant portion of the total variability of the selected data sets, according to current studies by Helmuth Wedow, Jr. In the case of widely spaced reconnaissance drilling, the trends of these surfaces point to areas of greater probability for favorable ore-bearing structures. Where drill holes are closely spaced to establish the limits of a particular ore body, the 2d-degree surface reveals the elliptical paraboloid habit of the collapse structure, with the long axis of the ellipse indicating the probable trend of the fracture system that localizes the structure.

Geology and ore possibilities in Antler Peak quadrangle, Nevada

R. J. Roberts (4–64) has described the stratigraphy and structure in a key area of the Antler Peak quadrangle where thrust faults of great magnitude superposed a western, eugeosynclinal sedimentary facies over an eastern, miogeosynclinal facies. Roberts and D. C. Arnold (2–65) have described the copper-gold, gold-silver, lead-zinc-silver, and silver and antimony deposits of the quadrangle, related their distribution to the intrusive rocks and structure, and made a number of suggestions for further prospecting. They report that the Duval Corp. has already had some success in recent exploration.

MERCURY

New association for mercury at Yellow Pine district, Idaho, reported

B. F. Leonard (p. B23–B28) reports that appreciable quantities of mercury as cinnabar occur in a stibnite deposit in the Yellow Pine district, central Idaho. Deposits of both antimony and cinnabar have been mined in this district, but this is the only deposit yet known in which the two metals occur together. The deposit is in a silicified zone associated with granite porphyry dikes that intrude the Idaho batholith. The amount of cinnabar is variable; specimens of antimony ore containing conspicuous cinnabar contain about 0.5 to 1.0 percent mercury. Other antimony veins in the district should be tested for mercury.

Composition of natural waters closely associated with quicksilver and copper-lead-zinc-silver deposits

The thermal and mineral fluids now most closely associated with mercury deposits are characterized by relatively high content of Na^{+1}, HCO_3^{-1}, boron, and NH_4^{+1}; by modest content of sulfide and total dissolved constituents; and by nearly neutral pH, according to D. E. White. The widely held theory of alkaline sulfide transport is not excluded completely by present evidence; other possible transport mechanisms more compatible with the mineralogy and presently associated fluids include the bisulfide, ammonia, and organic complexes, and thermal instability of HgS in sulfide-bearing water and vapor at temperatures about 150° C. Magma and thermally affected sedimentary and metamorphic rocks may all be sources of mercury, with proportions differing from place to place.

In the same study D. E. White also concludes that the rare fluids convincingly related to base-metal-silver deposits are probably brines of high salinity containing Na, Ca, and Cl. These brines generally may be sulfur-deficient, and effective ore formation may depend on some supplementary source of sulfur. Highly saline brines seldom if ever reach the surface in undiluted form because of their density: even when hot, they are much above the density of normal surface waters. Brines of the Na-Ca-Cl type may form in at least three ways: (1) Late-stage magmatic processes, (2) heating of connate waters after deep burial in sedimentary rocks, and (3) reaction of meteoric water + evaporates + rocks in a geothermal environment. Each may be a potent solvent for available base metals and silver.

Association of mercury and ammonia

The association of mercury and ammonia was confirmed by E. H. Pampeyan and R. C. Erd in the Palo Alto quadrangle, California, where the ammonium feldspar buddingtonite, previously recognized only in the Sulfur Bank quicksilver mine in Lake County, northern California, occurs with cinnabar and other metallic minerals in a dike which cuts Eocene sedimentary rocks. Two other ammonia-bearing minerals have been tentatively identified from this dike but are not yet fully described. Although the ammonia alteration has affected the enclosing rocks, the metallic mineralization is confined to the dike rock. At another locality in the quadrangle, ammonia is present in the glass shards of a Miocene diatomaceous tuff. The source of ammonia and the time of its introduction are uncertain, but they are presumed to be related to Miocene volcanic activity.

(For use of mercury as an indicator of ores of various types see the section "Techniques of Mineral Exploration.")

ANTIMONY

Ore-bearing fault zone extension noted in central Idaho

Mapping by B. F. Leonard has shown that the Meadow Creek fault zone, which localizes the antimony, gold, and tungsten ore bodies formerly exploited at the Yellow Pine and Meadow Creek mines, continues 2 miles southward from Stibnite, Idaho, to meet the Big Chief silicified zone. The 2-mile extension is concealed by glacial deposits but is indicated by Leonard's regional mapping of the area. Apparent right-lateral horizontal displacement along the Meadow Creek–Big Chief zone is estimated to be a mile or more. Shearing along this major structure probably controlled the development of an adjoining zone of fault blocks and of a nearby belt of northeast-trending fractures occupied by the Little Pistol dike swarm.

GOLD AND SILVER

USGS studies lead to major gold discovery near Carlin, Nev.

Mapping in north-central Nevada by a number of U.S. Geological Survey workers over a period of many years has recently been summarized in several major publications, which, through the guidance they have provided to private industry, have led to discovery of at least one important new ore deposit: the Carlin mine, near Carlin, Nev., opened in May 1965, by the Newmont Mining Corp. The target area was first suggested in a report by R. J. Roberts, P. E. Hotz, James Gilluly, and H. G. Ferguson,[5] and more specifically in another article by Roberts, in "Geological Survey Research 1960".[6] Newmont acquired claims in 1961, found gold in 1962, and presently estimates reserves of open-pit ore at 11 million tons containing 0.32 ounces of gold per ton. At its installed capacity of 2,000 tons per day, the anticipated annual yield of more than 200,000 ounces makes this mine the second largest gold producer in the United States, as well as the first major gold discovery in Nevada since 1902.

[5] R. J. Roberts, P. E. Hotz, James Gilluly, and H. G. Ferguson, 1958, Paleozoic rocks of north-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 42, p. 2813–2857.

[6] R. J. Roberts, 1960, Alinement of mining districts in north-central Nevada: Art. 9 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B17–B19.

Finely divided gold found in Pinyon and Harebell Formations, Wyoming

In northwestern Wyoming the Pinyon Conglomerate of Paleocene age and conglomerate in the Harebell Formation of Late Cretaceous age have been found to carry finely divided gold. In the course of a study of lead isotopes in gold, J. C. Antweiler tested more than 40 samples for gold content, using the analytical method developed by H. W. Lakin and H. M. Nakagawa (p. C168–C171) and found gold in both formations in values ranging from a few cents to a dollar per cubic yard. The Pinyon Conglomerate has long been known to contain gold, but gold has never before been reported in the Harebell Formation. Present evidence strongly indicates that both formations are major sources of gold in gravels of the Upper Snake River and its Wyoming tributaries. Little attention has been given to these formations because the finely divided river gold has seldom been profitably recovered, and the conglomerates themselves are very difficult to prospect.

Black calcite as potential source of silver

D. F. Hewett, Arthur Radtke, and Charles Taylor (1–65) noted that black calcite is widespread in many manganese deposits of the West. They found the black color to be due to a few percent of dispersed grains of a manganese oxide. Spectrographic analyses of the black residues remaining after acid decomposition of the calcite matrix in seven samples from districts in Utah, Nevada, Arizona, and New Mexico revealed, in addition to major amounts of manganese, measurable silver ranging up to 5 percent, or 1,500 ounces per ton. The host for the silver in the highest grade sample was found by electron-microprobe study to be a crystalline silver manganate. These results, when considered in the light of the well-known association of silver with manganese minerals in mining districts throughout the West, suggest that deposits containing black calcite should be given special attention in the urgent search for silver ore now underway.

LABORATORY STUDIES OF SULFIDE ORE MINERALS

Effects of minor elements in system Fe-S

P. B. Barton, Jr., has shown experimentally that the addition to pyrite-pyrrhotite charges of sufficient quantities of Mo, Pb, Zn, and Bi to form independent phases of each metal does not measurably affect the temperature of the reaction pyrite = pyrrhotite + sulfur liquid, in the presence of vapor. As noted by other workers, enough Cu to stabilize chalcopyrite does lower the temperature of the reaction a few degrees. Some workers had attributed large effects to Pb and Mo, but Barton's findings refute these statements.

Barton has also studied the effect of a large number of elements on the (102) d-spacing of pyrrhotite; his data show that $d_{(102)}$ may be used safely to determine the metal : sulfur ratio of natural pyrrhotites, except for those unusually rich in Mn, Co, or Ni. Cu, in amount sufficient to form chalcopyrite or cubanite, influences the pyrrhotite $d_{(102)}$ spacing only above 550° C.

Metallogenetic grid constructed

P. B. Barton, Jr., and Priestley Toulmin 3d, have constructed a "metallogenetic grid" for ore minerals, analogous to Bowen's well-known petrogenetic grid for silicate and carbonate rocks. The metallogenetic grid describes the stability fields of sulfide mineral assemblages in terms of sulfur fugacity (f_{S_2}) and temperature. Data for the grid were taken from the literature and from Barton's and Toulmin's experimental work. Supplementing older determinations in the systems Fe-S, Ni-S, and Cu-Fe-S, by Barton and Toulmin, Barton in the past year has determined 4 equilibria in the system Fe-As-S, 5 in Fe-Sb-S, and 1 in Cu-Fe-S. As more data accumulate, the grid should prove increasingly useful in interpreting the conditions of origin of sulfide ore bodies.

Ideality and nonideality in sulfide minerals

Determination of activity-composition relations in solid solutions in the systems Fe-S (pyrrhotite), Fe-Zn-S (sphalerite), and Cu-Fe-S (chalcopyrite with Cu : Fe = 1 : 1), by P. B. Barton, Jr., and Priestley Toulmin 3d, suggests the general rule that substitutional sulfide solid solutions behave thermodynamically as nearly ideal solid solutions, while defect-structure solid solutions depart very strongly from ideality. This generalization, which is still being tested, may be of considerable significance in predicting thermodynamic behavior of minerals of variable composition.

Calculation of activities of elements in binary sulfides

Motoaki Sato and C. L. Christ have applied electrochemical methods to phase-equilibria studies of sulfide minerals. The general equation for a binary sulfide is:

$$E_{M_2S_j} = E^\circ{}_{M_2S_j} + \frac{RT}{4j\mathrm{F}} \ln \left[\frac{(a_{M^j})^2{}_{\mathrm{aq}}}{(a_{S^{2-}})^j{}_{\mathrm{aq}}} \cdot \frac{(a_S)^j M_2S_j}{(a_M)^2 M_2S_j} \right],$$

where E equals the electromotive force (EMG in volts) for a given cell and F equals Faradays. From these results the activities of the elements in a binary sulfide can be determined. Two samples of covellite, CuS, from Butte, Mont., indicated sulfur activities of $10^{-2.07}$ and $10^{-1.63}$. Such large variations in EMF result from small variations in chemical composition. Calculated variations are: Ag_2S, 208; CuS, 61; Cu_2S, 386; PbS, 480; SnS, 427. Measured are Ag_2S, 235; and PbS, 483. The EMF is strongly temperature dependent, and hence is a valuable tool in the construction of phase diagrams. Ag_2S and PbS equilibrated at 200°C were assembled into an EMF cell and produced zero EMF at 200° ± 5°C. For natural sulfide pairs, the method could yield minimum temperatures of recrystallization.

Inversion of high-pressure tetragonal CuS

B. J. Skinner demonstrated that high-pressure tetragonal CuS (density, 5.932 ± 0.006 grams per cubic centimeter) inverts to chalcocite (density, 5.840 ± 0.010 g/cc) through a zero-order reaction. The reaction is temperature dependent, decreasing from 25°C to 100°C, at which temperature there is no inversion. These results indicate that tetragonal Cu_2S may be stable over a very small temperature range at 1 atmosphere pressure.

Covellite and djurleite found to coexist in nature

E. H. Roseboom found coexisting covellite and djurleite in natural specimens, contrary to the equilibrium synthetic system which implies that the two minerals should react to form either digenite-djurleite or digenite-covellite assemblages. A sample of covellite-digenite-djurleite from the Jumbo mine, Kennecott, Alaska, reacts to form djurleite + digenite in 24 hours at 95°C. At 60°C the reaction is two-thirds complete after 4 months. Roseboom suggests that the covellite formed as a supergene alteration of original djurleite.

Unquenchable high-temperature phases in system Cu-Ag-S

In studies of the system Cu-Ag-S, B. J. Skinner found unquenchable high-temperature phases which vary over wide ranges in composition. X-ray powder diffraction data suggest that the cation disordered structure proposed by Buerger and Wuensch[7] for the high-temperature hexagonal polymorph of Cu_2S is also true for the phases found in Cu-Ag-S. These phases are structures with disordered cations that are in a liquid-like state set in arrays of sulfur atoms which are hexagonal closest packed, cubic closest packed, and body-centered cubic.

7 M. J. Buerger, and B. J. Wuensch, 1963, Distribution of atoms in high chalcocite, Cu_2S. Science, v. 141, p. 276–277.

LIGHT METALS AND INDUSTRIAL MINERALS

EVAPORITES

Bromine as a salinity indicator, Paradox Basin, Utah

O. B. Raup has used the bromine content of halite to estimate the salinity of the environment in which four halite units were formed in the upper part of the Paradox Member of the Hermosa Formation (Pennsylvanian), near Cane Creek, Utah. If further studies of other beds are equally successful, bromine may become a useful indicator pointing to horizons of high salinity, at which exploration for potash deposits may be fruitful. Samples of halite were collected from drill core at 2-foot intervals through the total thickness of each salt bed. The bromine content, as determined by X-ray fluorescence, ranges from 0.008 to 0.035 weight percent. The results show a systematic increase in bromine content, and thus in salinity, from the bottom to the top of each of the salt beds. The regularity of this increase indicates that each of the salt beds was deposited during a continuous period, and it can be inferred that there was neither a major change in depositional conditions nor subsequent metamorphism of the salt.

Borate deposits in Death Valley, Calif., lie along magnetic trough

The alinement of the main Tertiary borate deposits in the Furnace Creek area of Death Valley, Calif., mapped by J. F. McAllister, coincides with a conspicuous trough of low magnetic intensity shown plunging southeastward on an aeromagnetic map by G. E. Andreasen and F. A. Petrafeso.[8] This relationship extends for 16 miles. The quantity of higher grade ore in exposed deposits increases, in a general way, with decrease of magnetic intensity to the southeast. That a regional structural element controls the locations of borate deposits is suggested further by a Bouguer gravity anomaly map covering an area from Death Valley to the Colorado River. The variations caused by low-density Cenozoic material have been removed from the map so that the gravity contours as shown reflect density contrasts within the basement rocks.[9] A major zone of gravity highs parallel to Death Valley and another along the Colorado River are connected by a lesser zone of gravity highs curving southward. The connecting zone contains the arc of borate deposits from Fur-

8 G. E. Andreasen and F. A. Petrafeso, 1963, Aeromagnetic map of the east-central part of the Death Valley National Monument, Inyo County, California; U.S. Geol. Survey Geophys. Inv. Map GP–428.

9 W. H. Diment, S. W. Stewart, and J. C. Roller, 1961, Crustal structure from the Nevada Test Site to Kingman, Arizona, from seismic and gravity observations: Jour. Geophys. Research, v. 66, p. 201-214.

nace Creek across Amargosa Valley to Calleville Wash and White Basin east of Las Vegas, Nev.

Borates in California older than previously thought

W. C. Smith reports that vertebrate fossils discovered in beds that overlie the main sodium borate ore body at Kramer, Calif., throw new light on the age of the borate-bearing section at Kramer, heretofore assigned to the upper or Pliocene(?) part of the Tropico Group. R. H. Tedford finds that the fossils are early middle Miocene in age, and thus the borate section is substantially older than previously supposed. Definitive evidence of the age of the colemanite-bearing shales at East Kramer is still lacking, but from a few mollusks found in drill core D. W. Taylor suggests a late Cenozoic age.

Borate resources of California evaluated

A review of resource data by W. C. Smith indicates that the California borax industry can sustain production at recent rates (exceeding 300,000 tons of B_2O_3 per year) for about a hundred years. Kramer and Searles Lake account for about half of these reserves. In addition, some deposits of calcium-bearing borate, now worked on a small scale, are potentially important sources of boron products. Their estimated total reserves probably exceed 5 million tons of B_2O_3, equal to about 15 years of current production.

PHOSPHATE

Occurrence of phosphate in Beaufort County, N.C.

The phosphorite unit of Beaufort County, N.C., which has been named the Pungo River Formation by J. O. Kimrey, was deposited in an east-trending basin, open to the sea on the northeast. The formation thickens from 20 to about 100 feet from west to east, but the thickening is due to intercalation of barren clay and dolomite beds. Phosphate sand makes up 50–75 percent of the Pungo River Formation in the economic part of the district. J. B. Cathcart finds that the phosphate mineral is a carbonate fluorapatite containing excess CO_2 and fluorine; most samples have between 28 and 31 percent P_2O_5. The zeolite mineral clinoptilolite is widespread in the Pungo River Formation, but absent in the overlying Yorktown and underlying Castle Hayne Formations; it may be useful as a means of correlation.

Large reserves of phosphate in north Florida and south Georgia

Phosphorite now being explored by several companies in north Florida and adjacent parts of Georgia represents some scores of millions of tons of reserves. J. B. Cathcart notes that, although the age of this phosphorite is unknown, its geology is reminiscent of the land-pebble field of south Florida. The base of the phosphorite is probably unconformable with the underlying Hawthorn Formation, and the overburden is only a thin Pleistocene(?) sand. Reserves are all in a concentrate of about 32 percent P_2O_5; the pebble fraction is minor in amount and too low in grade to be economic.

Enrichment of Bone Valley Formation in two stages documented

A comprehensive review of the genesis of the Bone Valley Formation in Florida by Z. S. Altschuler, J. B. Cathcart, and E. J. Young (1–64) documents the development of a major economic phosphorite through a two-stage secondary enrichment of low-grade, highly dispersed phosphate originally present in the limestones and dolomites of the Hawthorn Formation. Enrichment was first effected by residual accumulation and by solution and reprecipitation of apatite during subaerial weathering of the Hawthorn Formation. Marine transgression terminated the first stage of enrichment and initiated the second. The concentrate produced by earlier weathering was reworked, further enriched, and redeposited as extensive well-bedded deposits during marine recycling. In the process the P_2O_5 content of the individual pebbles and nodules was substantially upgraded.

Phosphate in Mississippian and Permian rocks of Utah

In the Morgan 15-minute quadrangle, in north-central Utah, R. J. Hite has mapped 3 miles of outcrop of the phosphate-bearing Park City Formation of Permian age and also a zone of phosphatic rock of Mississippian age. The area is about 6 miles southeast of Huntsville, Utah, in a faulted and otherwise structurally complex region. Two phosphorite units in the Park City Formation, sampled by E. M. Schell, are of economic interest: the lower one is 8.4 feet thick and averages 26.39 percent P_2O_5; the upper one is 5.5 feet thick and averages 28.69 percent P_2O_5. The best zone of phosphate in the Mississippian rocks, as sampled by Schell, is a unit 1.2 feet thick that averages 27.79 percent P_2O_5.

Phosphate in the Maquoketa Shale, Iowa, deserves study

C. E. Brown has collected samples from the zone of phosphatic nodules, pellets, and depauperate fossils in the lower few feet of the Maquoketa Shale near Dubuque, Iowa, and in adjacent parts of southwestern Wisconsin and northwestern Illinois. The few samples thus far analyzed show that the lower 3 feet of the shale near Dubuque contains as much as

17 percent P_2O_5. Furthermore, a sample of 8.5 feet of dolomitic beds 10 to 15 feet above the base of the shale also contains 17 percent P_2O_5. The lower part of the Maquoketa Shale is widely exposed, and the possibility that local topographic conditions have somewhere resulted in residual concentration of phosphatic material is worth examining.

CLAY AND LIGHTWEIGHT AGGREGATE

Clay in eastern Washington, its composition and utilization

X-ray fluorescence studies by J. W. Hosterman indicate a large variation in the alumina content of the clay deposits in Spokane County, Wash. Residual clay derived from basalt has an average of 22 percent Al_2O_3, and a few samples have as much as 35 percent. The Latah Formation averages only about 20 percent, but one sample has 39 percent Al_2O_3. Residual clay from igneous and metamorphic rocks also averages about 20 percent, but no individual sample exceeds 30 percent. These three types of clay are composed of either kaolinite or endellite, and the alumina content could be raised substantially if the nonclay minerals were removed by beneficiation. Clays in the Palouse Formation and in Pleistocene lake beds contain large amounts of montmorillonite and as a result contain less Al_2O_3.

Tests made in collaboration with the staff of the Norris, Tenn., Research Laboratory of the U.S. Bureau of Mines indicate that some of the clay is suitable for making refractory products. Pyrometric-cone equivalent tests show that residual clay derived from the older igneous rocks would make high-heat-duty refractory products (P.C.E. 31–33), and if the clay were beneficiated, it would make super-heat-duty refractory products (P.C.E. above 33). The clays of the Latah Formation would make intermediate-heat-duty refractory products (P.C.E. 26–31), and the residual clay derived from basalt would make low-heat-duty refractory products (P.C.E. below 26).

Slate from Martinsburg Shale as a potential source of lightweight aggregate

Five large samples of slate from the Martinsburg Shale (Ordovician) collected by A. A. Drake, Jr., from outcrops near the Delaware River in New Jersey and Pennsylvania were fired in a rotary kiln by M. V. Denny and the late H. P. Hamlin, of the U.S. Bureau of Mines (p. D156–D162). The material formed bloated products comparable to presently used commercial material in strength, lightness, and low water absorption. The results suggest that most if not all of the claystone of the formation would be suitable for lightweight aggregate.

BERYLLIUM

Binary distribution of minor elements at Spor Mountain, Utah

At the Roadside No. 5 beryllium deposit near Spor Mountain, Utah, one group of elements including Li and Sn is distributed evenly and widely at certain stratigraphic horizons, whereas another group of elements including Be, Zn, Pb, and Tl appears to be concentrated close to certain faults as well as along particular stratigraphic horizons. This binary distribution of elements suggests to D. R. Shawe a multiple-source hypothesis in which Li and related elements accumulated early in tuffaceous lake sediments, and Be and related elements were introduced by hot waters following faulting.

Unique mineral association of bertrandite near Gold Hill, Utah

W. R. Griffitts has called attention to several unusual characteristics of the recently discovered large bertrandite deposits near Gold Hill, Utah. These are in quartz monzonite host rocks, lacking the calcareous materials of the host rocks present in other nonpegmatitic beryllium districts, yet the deposits themselves contain much calcite. Furthermore, the deposits lack fluorite, and thus the beryllium cannot have been carried during mineralization as a complex fluoride, but may have been carried as a complex carbonate instead. This mechanism is reflected in the small suite of accessory elements in the deposits.

Beryllium belt in New Mexico and Arizona worth exploring

About a dozen occurrences of beryllium minerals fall in a well-defined belt extending from Socorro County, N. Mex., southwest into the southeast part of Arizona. They mark a province in which D. R. Shawe finds geologic characteristics that suggest that the region should be explored for volcanic-associated deposits similar to those at Spor Mountain, Utah. Like the Utah belt, the New Mexico–Arizona belt contains numerous fluorspar deposits, silicic volcanic rocks with unusually high beryllium content, and topaz-bearing rhyolites associated with thick sections of volcanic rocks containing permeable water-laid tuff. At one Tertiary volcanic locality the beryllium mineral bertrandite has been detected.

Beryllium at Lake George, Colo., related to Redskin Granite

In the Lake George beryllium area, Colorado, C. C. Hawley has found that the fine- to medium-grained

Redskin Granite, a late member of the Pikes Peak magma series, forms small stocks on the southwest flank of the Pikes Peak batholith, near a large bend in the batholith contact. Beryllium deposits are associated with these stocks. Spectrographic and chemical analyses show that the earlier, coarse-grained Pikes Peake Granite of the batholith is characterized by Ba, Sr, rare earths, and Zr. The finer grained Redskin Granite contains more of such elements as Be, Li, Sn, and Rb, which are also found in the beryllium deposits of the area. Thus it seems that the processes which enriched these elements in late members of the Pikes Peak magma series ultimately contributed Be and related elements to solutions that formed the beryllium deposits of the Lake George area.

Average beryllium content of large intrusions in Colorado

From analyses of 120 representative samples by gamma activation, W. N. Sharp has calculated an average value of 7.7 parts per million of beryllium in the Mount Antero leuco-granite stock and 5.6 ppm of beryllium for the Pikes Peak granite batholith in Colorado. The few analyses from samples that contain beryllium minerals have more than 30 ppm of beryllium. In granite containing less than 30 ppm, the beryllium is probably held in feldspar and mica.

Preliminary analyses of a rich blue, strongly pleochroic beryl from Mount Antero show it to have 6 to 8 percent Fe_2O_3. This amount of iron, if verified by additional analyses, is most unusual for beryl.

Beryllium in thorite veins, Wet Mountains, Colo.

Samples from two thorite veins, collected by D. R. Shawe from the Wet Mountains, Colo., contain 0.02 to 0.2 percent beryllium. These lie within a few thousand feet of small bodies of Tertiary rhyolite intrusives that contain unusually high amounts of Be (6–16 parts per million), and may be genetically related to the veins.

Localization and zonation of beryllium, Lost River, Alaska

The Rapid River fault, according to C. L. Sainsbury, is the most important ore localizer for beryllium-fluorite deposits in the Lost River area, Alaska. The fault is mineralized for almost half of its extent over a distance of 8 miles. A strong zonation exists among the beryllium-fluorite deposits: the beryllium mineral helvite occurs nearest the granite in banded fluorite-magnetite skarn, succeeded by a zone of beryllium-fluorite-tin-sulfide veins in which chrysoberyl is the main beryllium mineral, and then by beryllium-fluorite veins containing chrysoberyl, fluorite, euclase, hematite, and little or no tin or sulfide minerals.

ZEOLITES

Diagenesis of zeolites in Mohave Desert, Calif.

A conspicuous bedded tuff near the middle of the Ricardo Formation of Pliocene age in the El Paso Mountains of southern California has afforded R. A. Sheppard and A. J. Gude 3d, the opportunity to study the stages of diagenetic alteration from fresh rhyolitic glass to complete replacement of vitric material by clinoptilolite, opal, and montmorillonite (p. D44–D47). Tuff above an elevation of 3,000 feet generally is fresh, but the same tuff below 3,000 feet is altered. The tuff dips 10° to 20° northwest, and zeolitic alteration probably was accomplished by subsurface water after the Ricardo Formation had been tilted. Solution and hydrolysis of rhyolitic glass by the downward-moving subsurface water would increase the pH and salinity of the water, thereby providing a chemical environment more favorable for the formation of zeolites.

In altered rhyolitic tuffs of the Barstow Formation, zeolites that have been identified include analcime, chabazite, clinoptilolite, erionite, mordenite, and phillipsite. These are in nearly monomineralic beds or associated with other zeolites, clay minerals, opal, and potash feldspar. Chabazite is of particular interest because it is only rarely reported from sedimentary environments.

Preliminary study of tuffs from the Pleistocene Lake Tecopa indicates that vitric material is preserved only in the vicinity of fresh-water inlets. Elsewhere the tuffs are altered to zeolites and potash feldspar.

Zeolite makes up Chalk Cliffs at Mount Princeton, Colo.

Leonhardite, a calcium zeolite, has been found by W. N. Sharp to form the white chalky matrix surrounding fractured and crushed fragments of Mount Princeton Quartz Monzonite in the Chalk Cliffs at the site of the Mount Princeton hot springs on the west side of the Arkansas River valley near Buena Vista, Colo.

Zeolite replaces tuff in McMullen County, Tex.

Extensive deposits of white claylike altered tuff in McMullen County, Tex., consist largely of clinoptilolite associated with opal, montmorillonite, and a trace of quartz. D. H. Eargle regards this as probably the basal part of the Jackson Group (Eocene). The clinoptilolite was recognized from X-ray analyses by Dr. Shoichiro Hayashi, visiting Japanese geologist, and the abundance of it and other constituents was determined by A. D. Weeks and M. L. Lindberg.

RADIOACTIVE MINERALS

URANIUM

Deposits in White Canyon and Elk Ridge areas, Utah, described

The uranium deposits close to the base of the Chinle Formation in the adjoining White Canyon and Elk Ridge areas, San Juan County, Utah, are described by R. E. Thaden, A. F. Trites, Jr., and T. L. Finnell (1–64) and by R. Q. Lewis and R. H. Campbell (1–65). In the White Canyon area the deposits are in sandstone and some interbedded mudstone that fill channels cut into the underlying Moenkopi Formation. In the Elk Ridge area most of the deposits are in similar bodies of rock that rest on the Moenkopi rather than in channels cut into it; ore does not occur in sandstone lenses of the Chinle where such lenses are separated from the Moenkopi by mudstone. Lewis and Campbell suggest that ore was deposited from solutions which migrated mainly through siltstone in the upper part of the Moenkopi and entered the host rocks at places where they were in contact with the Moenkopi.

The deposits of both areas are in a broad belt which extends eastward from the Colorado River at least to the Comb Ridge monocline and may extend into the adjoining Abajo Mountains area where, however, the Chinle Formation is buried by younger rocks (I. J. Witkind, 1–64).

Prelaccolithic age of uranium deposits in Abajo Mountains, Utah

The known uranium deposits in the Abajo Mountains area, Utah, are in the Salt Wash Sandstone Member of the Morrison Formation. Because one of these deposits is displaced by small faults, I. J. Witkind (1–64) suggests that the deposits were emplaced before the sedimentary rocks were domed and faulted by intrusion of the igneous rocks that form the laccoliths of the Abajo Mountains.

Uranium-bearing pipe formed by solution and collapse of limestone

Features observed by C. G. Bowles at the uranium-bearing pipelike structure at the Orphan mine on the South Rim of the Grand Canyon, Ariz., and at other pipes in the eastern part of the Grand Canyon area strongly suggest that the pipes originated prior to cutting of the canyon as the result of collapse of caverns formed by solution of the Redwall Limestone of Mississippian age. When the caverns collapsed the pipes were formed by stoping of overlying rocks as high stratigraphically as the Coconino Sandstone of Permian age.

Map of Moab quadrangle locates uranium deposits

The geologic setting and distribution of uranium deposits in the important Lisbon Valley area, Utah, and the Uravan mineral belt, Colorado, are shown on a map of the Moab quadrangle covering 1° of latitude and 2° of longitude at a scale of 1:250,000 (P. L. Williams, 1–64). (For further details, see the section "Regional Geology, Colorado Plateau.")

Uranium deposits in Powder River Basin, Wyo.

Uranium deposits in the Powder River Basin, Wyo., are in sandstone mainly in the Wasatch Formation of Eocene age (W. N. Sharp and others, 1–64; W. N. Sharp and A. B. Gibbons [10]). The deposits are in sandstone which is relatively coarse grained and forms lenses elongate in a northerly direction. Much of the sandstone is drab yellowish gray, but the deposits are confined to a zone within which some lenses and parts of others are colored red to pink. The zone of partly red rocks is nearly 70 miles long and alined with the subsurface axis of the basin. Most of the uranium is concentrated in drab sandstone immediately adjacent to the edge of the red sandstone, and the principal deposits occur very near the general boundary of the zone of partly red sandstone. The uranium-bearing rock forms various shaped bodies that conform to the irregular shape of the color contact. The intimate relation between uranium deposits and the edge of red sandstone suggests that both features are results of the same sequence of events.

Crescent-shaped ore bodies in Gas Hills and Crooks Gap areas, Wyoming

From study in the Gas Hills uranium district, Fremont and Natrona Counties, Wyo., F. C. Armstrong infers that the principal ore bodies are all along or near the same irregular sinuous contact between altered and unaltered rock that was once continuous throughout the district.

Known uranium deposits are distributed along three subparallel zones, the west, central, and east ore-trends, which are oriented west of north. The ore bodies are sinuously elongate in the direction of the ore trends, and at many places are irregularly crescent shaped in cross section. Altered rock occurs on the concave side of the crescent, and unaltered rock on the convex. Characteristically, thick high-

[10] W. N. Sharp and A. B. Gibbons, 1964, Geology and uranium deposits of the southern part of the Powder River Basin, Wyoming: U.S. Geol. Survey Bull. 1147–D, p. D1–D60.

grade ore occupies the body of the crescent, and thin lower grade ore occurs as tabular bodies in the greatly extended lower horn of the crescent (lower limb ore). The crescents are convex southwestward in the west trend and northeastward in the central trend. Drilling shows that between these two ore trends is a thick prism of altered rock that is bounded, as though by parentheses, by crescent-shaped ore bodies. The orientation of the crescents in the two trends and the continuity of altered rock between them, strongly suggest that the north ends of the trends were once connected along a segment of contact that has been removed by erosion.

A corollary of this hypothesis is that only the thin lower-limb mineralized zone is present, beneath altered rock, in the area between the west and central trends. Locally this lower limb may be of sufficient thickness and grade to form small- to moderate-sized ore bodies. The same line of reasoning suggests that the south ends of the central and east ore trends are connected southward beneath cover. The area between the trends would be occupied by unmineralized and unaltered rock between convexly opposed crescents.

F. C. Armstrong also reports that an ore body of crescent-shaped cross section has been recognized by company geologists in the Reserve shaft mine of Continental Materials Corp. in the Crooks Gap area, Fremont County, Wyo. Uranium ore bodies of this form have been previously recognized and are common in the Shirley Basin and Powder River Basin areas. The similarity in shapes of ore bodies and in relative positions of altered rock, ore, and unaltered rock in all four areas suggest that the uranium deposits were all formed in the same manner.

Environments of roll ore bodies of uranium

In a review of information about discordant curved layers of uranium ore in sedimentary rocks, commonly called rolls, D. R. Shawe and H. C. Granger (1–65) suggest that environmental differences permit the distinction of two types. Rolls in the Colorado Plateau region are surrounded by a wide halo of reduced altered rock. They were probably formed before or during maximum burial of enclosing strata prior to major structural deformation. Rolls in the Tertiary basins of Wyoming are bounded on one side by relatively oxidized rock and on the other by relatively reduced rock. They were probably formed near the surface following deformation, uplift, and denudation.

Uranium deposits in Gulf Coastal Plain, Tex.

D. H. Eargle has noted that relatively unoxidized uranium ore in the Galen mine, Karnes County, Tex., adjoins a tongue of bleached sand similar in color to altered sand adjacent to ore in some deposits in Wyoming. Coffinite, not previously known in Texas deposits, has been identified as one of the ore minerals by A. D. Weeks. Molybdenum and selenium minerals occur in 1 to 2 feet of sand overlying uraniferous sand.

Uranium deposits in Front Range Colo., fit zoning pattern

Uranium deposits in the Front Range, Colo., described by P. K. Sims and D. M. Sheridan (3–64), appear to be zonally arranged with respect to the Colorado mineral belt, as indicated by their distribution and size, and by systematic differences in mineralogy, structure, and texture of veins between deposits within the belt and those outside of it. The largest and most valuable ore bodies are in epithermal deposits marginal to the belt.

THORIUM

Thorium-bearing veins and rocks in New Mexico

Some of 45 feldspar-rich bodies in the southern Caballo Mountains, Sierra County, N. Mex., studied by M. H. Staatz, J. W. Adams, and N. M. Conklin (p. D48–D51) contain thorite. Uranophane and bastnaesite, a rare-earth mineral, are sparsely present in one body. The bodies are irregular in shape and range from a few feet to 300 feet in length.

Thorium-bearing veins, which occur in Dakota Sandstone and phonolite near Loughlin Peak, Colfax County, N. Mex., are reported by M. H. Staatz to contain a varied mineral assemblage which includes plumbogummite, zircon, xenotime, lepidocrocite, geothite, hematite, jarosite, quartz, and a rhabdophane-like thorium-bearing mineral. One vein from 1 to 1.5 feet thick and at least 600 feet long has an average grade of about 0.4 percent thorium.

Wet Mountains thorium area, Colorado, extended

Discovery by Q. D. Singewald of a complex pattern of felsite dikes mineralized with thorium in the southeast part of the Rosita quadrangle, Custer County, Colo., and of anomalous radioactivity along veins in the west half of T. 19 S., R. 71 W., Fremont County, greatly enlarges the areas in the vicinity of the Wet Mountains where rocks are known or suspected to be mineralized by thorium. The dikes in the Rosita quadrangle cut Precambrian rocks but are absent in areas of Tertiary volcanic rocks. The radioactivity of the dikes ranges from 2 to 3 times background where they are unaltered to many times background where they are veined by later minerals. In places the radioactivity exceeds 5.0 milliroentgens per hour, the highest reading on a scintillation detector.

MINOR ELEMENTS

Use of absorption spectra to identify rare earths

The detection of rare-earth elements by their absorption spectra, although a method long known, has modern practical application in the investigation of rare-earth-bearing minerals. Recently J. W. Adams (2–65) has described in detail the absorption spectra of certain rare-earth minerals as determined by the hand spectroscope and microspectroscope. By the use of this convenient method many rare-earth minerals may be recognized in the field or laboratory and a distinction commonly can be made between dominantly cerium- or yttrium-group species.

Rare-earth-rich shear zone traced in Wet Mountains, Colo.

As part of his study of thorium resources, M. H. Staatz has traced a shear zone containing discontinuous rare-earth- and thorium-bearing veins for more than 1,500 feet in the Road Gulch area of the northern Wet Mountains, Colo. Selected samples from the veins contain as much as 19 percent rare earths and 1.1 percent thorium. Minerals that make up the veins include dolomite, siderite, calcite, quartz, hematite, goethite, barite, rutile, chlorite, fluorite, bastnaesite, monazite, thorite, zircon, and fergusonite.

ORGANIC FUELS

Studies that deal directly with the discovery, delineation, evaluation, and interpretation of coal, petroleum and natural gas, oil shale, and humate deposits are reported in this section. Related investigations that are concerned primarily with the geology and (or) geophysics of potential areas of production of such fuels are reported under other headings.

COAL

Rocky Mountains region

Projection of current trends in the use of coal for the production of coke and electricity has led Paul Averitt (1–65) to conclude that coal mining in the Rocky Mountains region will increase about 50 percent by 1970. An upward trend in mining began in 1958 and 1959 and terminated a postwar downtrend.

North-central New Mexico

A zone of subbituminous coking coal in the nearly flat lying Upper Cretaceous and Paleocene Raton Formation has been discovered and mapped by C. L. Pillmore (1–65, 2–65) in the Catskill NE and SE quadrangles, Colfax County, north-central New Mexico. This coal zone crops out near the crests of flat ridges at an altitude of about 7,200 feet in a 16-square-mile area near the confluence of the Vermejo River and Gachupin Canyon, about 25 miles west of Raton, N. Mex. The overburden is generally less than 100 feet and commonly less than 50 feet thick. The zone averages about 7 feet in thickness and generally contains about 48 inches of coal. Near the mouth of Ancho Canyon in the eastern part of its outcrop area, however, the zone exceeds 15 feet in thickness and contains more than 100 inches of coal in beds as much as 30 inches thick.

Southwestern Oregon

The correlation of bituminous coal beds in the Tyee Formation of middle Eocene age between the Eden Ridge coal field and Squaw Basin, its southward extension, in Coos County, southwestern Oregon, is reevaluated by R. G. Wayland (1–65). On the basis of new core-hole data, brief field study, and photogeologic interpretation, the known coal beds in Squaw Basin are concluded to be of limited lateral extent and older than those at Eden Ridge. Squaw Basin is regarded as a possible source of strippable coal.

Western Arkansas

Original coal reserves in the Lower Hartshorne coal bed of the McAlester Formation of Pennsylvanian age in the Scranton, New Blaine, and Greenwood quadrangles, Logan and Sebastian Counties, western Arkansas, have been revised by B. R. Haley and T. A. Hendricks on the basis of new geologic data. Original reserves are estimated to be about 83 million tons of coal in the Scranton and New Blaine quadrangles and about 316 million tons of coal in the Greenwood quadrangle. These more reliable, new estimates differ by only 20 percent or less from previous estimates that were used in compiling the total coal reserves of the State (B. R. Haley [11]).

Eastern Pennsylvania

The original coal reserves in Pennsylvanian rocks of the Western Middle anthracite field of eastern Pennsylvania totalled more than 6.7 billion tons in beds exceeding 14 inches in thickness, according to a recent appraisal by H. H. Arndt. About 1.8 billion tons of anthracite and semianthracite had been mined or lost through mining operations as of January 1, 1963. Of the remaining 4.9 billion tons of reserves, about 2.8 billion tons are categorized as probable recoverable reserves.

[11] B. R. Haley, 1960, Coal resources of Arkansas: U.S. Geol. Survey Bull. 1072–P, p. 795–831.

Northwestern Alaska

Low-volatile bituminous coal in steeply dipping rocks of Early Mississippian age on the Lisburne Peninsula, northwestern Alaska, is described and evaluated by I. L. Tailleur (p. B34–B38). The coal is found in 13 seams 2½ feet or more thick and has an aggregate thickness of 70 feet. Analyses (on an as-received basis) of representative samples indicate that the coal is composed of 13–21 percent volatile matter, 68–80 percent fixed carbon, and 3–16 percent ash. The heating value of the coal ranges from 11,800 to 14,300 Btu. The coal has an important potential as a local source of fuel for the village of Point Hope, only 30 miles from the closest seams.

Eastern Montana

Recent information on the coal resources of eastern Montana is given in the section "Resource Compilation" under the side heading "Mineral Fuels of Eastern Montana."

PETROLEUM AND NATURAL GAS

Navajo Reservation, northeastern Arizona

The lower third of the Cutler Formation of Permian age probably includes marine rocks in the subsurface of northeastern Arizona, between the Monument and De Chelly upwarps. Subsurface correlation by R. B. O'Sullivan suggests that this part of the Cutler is continuous with part of the Supai Formation of Pennsylvanian and Permian age, which has yielded major shows of oil and gas in central Arizona. Although only a single slight show of oil and gas has been recorded to date from the lower third of the Cutler, a large area of northeastern Arizona that is underlain by this unit may have an oil- and gas-producing potential.

Denver Basin, northeastern Colorado

Porosity rather than structure may have localized accumulations of oil and gas in the Upper Cretaceous "D" sand of the Denver Basin, south of Fort Morgan, Colo. Unconnected, lenticular zones in the "D" sand that have greater effective porosity than lithologically similar enclosing beds of the same sand have been recognized by H. L. Cullins. These lenticular zones generally are about one mile long, half a mile wide, and 8 to 14 feet thick. Within a single oil and gas field, apparently anomalous gas pools that are structurally lower than oil pools, and oil or gas pools that are structurally lower than nonproductive areas probably are controlled by these zones. Recognition and exploration of these porous zones may increase substantially the oil- and gas-producing potential of the Denver Basin.

OIL SHALE AND HUMATE DEPOSITS

Oil shale, northern Alaska

New data obtained by H. A. Tourtelot and I. L. Tailleur from recently collected samples may help interpret the possible origin of rich oil shale in northern Alaska. Samples that yield about 50 to 140 gallons of oil per ton consist almost entirely of a sporelike microfossil *Tasmanites*, identified by J. M. Schopf, at two localities (I. L. Tailleur,[12] p. D132, No. 2 and 5). Quartz and barite are the only accessory minerals in these samples. Semiquantitative spectrographic analyses of the ash of three samples show 0.1–3.0 percent barium, 150–700 parts per million of molybdenum, and 100–500 ppm of vanadium.

Shallow humate deposits, northwestern Florida

Widespread lenticular layers of coastal and near-coastal sands in northwestern Florida have been found to contain organic matter that is 95 to 99 percent humate. This humate, which is entirely and readily soluble in slightly alkaline water, has an average composition of 55 percent carbon, 4.4 percent hydrogen, 38.5 percent oxygen, 1.4 percent nitrogen, and 0.7 percent sulfur. According to estimates by V. E. Swanson and J. G. Palacas, 0.1 to 1 million tons of humate per square mile is present at a depth of less than 35 feet along a 3-mile-wide coastal strip between Pensacola and Apalachicola in northwestern Florida. The total content of easily soluble organic matter in this area of 300 to 500 square miles is estimated to be about 100 million tons.

TECHNIQUES OF MINERAL EXPLORATION

Tellurium and mercury as indicators of ore

In the Cripple Creek district, Colorado, a telluride-gold district, tellurium is widespread but is most concentrated in areas that have been mined for gold. According to G. B. Gott and J. H. McCarthy, Jr., mercury, tellurium, and silver seem to be associated with the Cripple Creek gold deposits, and the presence of any 2 of these 3 elements is indicative of higher than normal concentrations of gold. By way of contrast, tellurium concentrations in the vicinity of the Comstock lode are lower than expected, according to D. F. Davidson and H. W. Lakin, and seem to show no pattern of distribution that is strongly related to the silver deposits.

Mercury seems to be associated with all of the epithermal metal deposits studied to date by G. B. Gott and J. H. McCarthy, Jr. These include poly-

[12] I. L. Tailleur, 1964, Rich oil shale from northern Alaska: Art. 148 *in* U.S. Geol. Survey Prof. Paper 475-D, p. D131–D133.

metallic deposits in the Ely, Nev., and Park City, Utah, areas; silver deposits at Hamilton, Nev., and the gold deposits at Cripple Creek, Colo.

According to J. L. Jolly and A. V. Heyl (1–65) mercury anomalies may indicate concealed base-metal deposits. They report that 11 sphalerite samples from the central Kentucky and central Tennessee mineral districts contain from 1 to 10,000 parts per million of mercury. This is the first known occurrence of mercury in sphalerite east of the Mississippi River. The mercury probably occurs in the sphalerite lattice rather than as a discrete element, and its presence strongly suggests deposition by slightly alkaline solutions at a temperature range of 70° to 100°C. Mercury-bearing geochemical halos above concealed deposits of base metals are suggested by selected samples from wallrock suites in the central Kentucky district and in the Austinville, Va., district. At the Faircloth mine, Woodford County, Ky., the mercury content of the wallrock ranges from 0.17 ppm in dolomite adjacent to the vein minerals to 0.01 ppm in unaltered limestone. At the Ivanhoe mine in the Austinville district, a wallrock suite, consisting of partly altered carbonate rock in and near ore, contains 1.5 to 3.5 ppm of mercury in contrast to 0.03 ppm of mercury in normal or ordinary limestone. The presence of higher than background amounts of mercury in sphalerite and wallrock of the eastern and midwestern United States base-metal districts suggests the possibility of using mercury as a prospecting guide in these areas. The mercury-bearing sphalerite samples also contain 0.01 to 0.1 percent germanium and 1 to 2 percent cadmium.

Tellurium and mercury as indicators of "productive" jasperoid

Ninety-three samples of jasperoid from 22 areas, including 14 mining districts, were analyzed for tellurium by H. W. Lakin and for mercury by J. H. McCarthy, Jr., using sensitive methods capable of detecting 4 parts of tellurium and 1 part of mercury per hundred million. These samples had previously been classified by T. G. Lovering and J. C. Hamilton[13] into "productive" and "nonproductive" types.

Tellurium content of these samples ranged from 200 to 0.04 parts per million, and mercury content from 90 to 0.02 ppm. In order of decreasing affinity, tellurium showed a statistically significant association with arsenic, bismuth, silver, antimony, lead, copper, mercury, and barium. Mercury, in order of decreasing affinity, showed a statistically significant association with silver, lead, copper, tellurium, zinc, antimony, arsenic, bismuth, and molybdenum. Tellurium in concentrations of > 1 ppm and mercury in concentrations > 4 ppm were found to be indicators of jasperoid of the productive type.

Trace metals associated with gold deposits

As part of a study of geochemical halos, R. L. Erickson has learned that the low-grade gold deposits of north-central Nevada have a characteristic trace-metal suite of mercury, arsenic, and antimony. Small but anomalous amounts of tungsten are also common. Mercury seems to be most directly associated with gold, whereas arsenic and antimony may form halos around the most intense gold mineralization. The detection of anomalous amounts of these metals in soils and rocks is a useful exploration tool in the search for concealed gold ore.

Selenium as an indicator of uranium in Shirley Basin, Wyo.

Analyses of samples collected across roll-type bodies of uranium ore in the Shirley Basin, Wyo., show, according to E. N. Harshman, that selenium is notably concentrated at the contact of oxidized barren sandstone with ore-bearing sandstone. Because selenium is most readily moved in slightly alkaline relatively oxidized solutions and is precipitated by a decrease in pH (H. W. Lakin,[14] p. 11–12), the distribution of selenium-rich rock suggests that slightly acidic conditions prevailed at the sites of deposition.

Accessory minerals in igneous rocks as indicators of ore

G. J. Neuerburg is studying patterns of distribution of minor accessory minerals in igneous bodies in the attempt to trace ore materials from the presumed source, through palimpsest channels of movement, toward areas of possible deposition. The distribution of accessory sulfides and magnetite, but not zircon, definitely appears to be related to skarn deposits of tungsten peripheral to the Asgood quartz monzonite stock, Humboldt County, Nev. Of the 15 deposits actually worked, 9 are adjacent to the alleged points of exit of the ore fluids. The principal objective of this mineralogic approach as a prospecting tool is to locate areas of higher-than-average ore potential, which could then be prospected intensively by a variety of other methods.

[13] T. G. Lovering and J. C. Hamilton, 1962, Criteria for the recognition of jasperoid associated with sulfide ore: Art 63 *in* U.S. Geol. Survey Prof. Paper 450–C, p. C9–C11.

[14] H. W. Lakin, 1961, Geochemistry of selenium in relation to agriculture, *in* M. S. Anderson, and others, Selenium in agriculture: U.S. Dept. Agriculture, Agriculture Handbook 200, p. 3–12.

Zinc-rich manganese-iron oxides cause spurious anomalies

On the basis of geochemical prospecting surveys of streams in Maine, F. C. Canney, E. V. Post, and W. H. Dennen report that some heavy-metal anomalies are apparently not related to mineral deposits but are derived, instead, from the zinc-rich nodules and coatings of manganese-iron oxides found to be plentiful in many stream courses. Sediment samples from streams draining mineralized areas, however, have above-average heavy metal: manganese ratios; thus this ratio appears to be a useful criterion for distinguishing between significant and nonsignificant anomalies.

New rapid analytical methods for gold and silver developed

New colorimetric procedures for the determination of silver and gold in geologic materials have been developed which should greatly aid in prospecting for those two elements. In the method reported by H. M. Nakagawa and H. W. Lakin for silver (p. C172–C175) the sample is digested with nitric acid and the silver is extracted with triisooctyl thiophosphate (TOTP) in benzene and stripped from the organic phase with dilute hydrochloric acid. Silver is then measured indirectly by its catalytic action on the persulfate oxidation of manganous ion to permanganate. The lower limit of sensitivity of the method is 0.01 parts per million. About 80 determinations can be made per man-day. In the method reported by Lakin and Nakagawa for gold (p. C168–C171), the gold in the sample is dissolved with sodium bromate and hydrobromic acid and then is extracted from dilute hydrobromic acid with ethyl ether. The ether is evaporated to dryness and the residue is taken up in water after which the solution is buffered and then extracted with a solution of 4,4′-bis (dimethylamino) thiobenzophenone (TMK) in isoamyl alcohol, forming a red gold-TMK complex. Absorbance of the complex is proportional to the amount of gold present. Thallium when present in relatively large amounts is an interference. As little as 0.02 ppm of gold can be determined, and about 25 analyses can be made per man-day.

Gamma-ray spectrometer used to locate zones of alteration

A truck-mounted gamma-ray spectrometer has been used by R. M. Moxham, R. S. Foote, and C. M. Bunker[15] to make in situ analyses of uranium, thorium, and potassium in hydrothermally altered zones associated with copper and copper-lead-zinc deposits in central Arizona. Equating the field spectrometric data with chemical analyses of samples collected at the spectrometer stations gave standard errors of 0.6 percent potassium, 3 parts per million of thorium, and 10 ppm of uranium for the outcrop analyses with the spectrometer. Potassium in the more intensely altered zones is about twice that in unaltered areas. There is no corresponding increase in thorium, so a higher potassium: thorium ratio also results from alteration; an abnormally high uranium content, locally in secular disequilibrium, was measured at the Bagdad, Ariz., porphyry copper deposit. The amount of potassium introduced by hydrothermal alteration is thought sufficient in quantity to be generally detectable by either surface or aerial spectrometry; spectrometric detection of anomalous uranium is probably marginal, owing to secular disequilibrium. The potassium: thorium ratio may provide a means of distinguishing, in such surveys, between hydrothermally altered high-potassium zones and unaltered extrinsically high-potassium intrusives.

[15] R. M. Moxham, R. S. Foote, and C. M. Bunker, 1965, Gamma-ray spectrometer studies of hydrothermally altered rocks: Econ. Geology, v. 60, no. 4, p. 653–671.

Geobotanical prospecting in Alaska

H. T. Shacklette has found that many bryophyte (mosses and liverworts) species are associated in Alaska with concentrations of minerals, but only one species, *Gymnocolea acutiloba,* appears to function as an indicator on a regional scale. This species was found to grow only on substrata having a high copper content. Another species, *Cephalozia bicuspidata,* seems to be a local indicator of mineral deposits; it grew on a galena and sphalerite ore vein that contained 12.9 percent lead and 34.0 percent zinc, whereas other species at the site could not tolerate such high concentrations of these elements. Bryophytes appear to be indifferent to the concentrations of mercury, antimony, arsenic, limonite, nickel, and chromium that occur in rock outcrops in Alaska.

WATER RESOURCES

The U.S. Geological Survey investigates the occurrence, availability, and quality of surface and underground waters and the sediment discharge of streams. A hydrologic-data network which extends throughout the country provides continuing series of several types of basic data. During 1965, discharge and water-level data for surface waters were collected at about 8,000 stream-gaging stations and about 800 lake-level stations. Continuous or periodic measurements of ground-water levels were made in about 16,000 observation wells. The quality of surface waters was monitored at about 1,670 stations; chemical, temperature, and sediment data were collected.

These basic hydrologic data are compiled and published in the following Water-Supply Paper series of the Geological Survey:

"Surface Water Supply of the United States,"
"Ground-Water Levels in the United States,"
"Quality of Surface Waters of the United States," and
"Quality of Surface Waters for Irrigation, Western United States."

The Surface Water Supply series, formerly published annually, is to be published at 5-year intervals beginning with the period 1961–65. Each report is in 16 parts: 14, determined by drainage basins, for the 48 conterminous States, and 2 for Alaska and Hawaii. Interim annual reports by States are being published. The reports on water quality are published annually, but conversion to 5-year publication, with interim annual reports, is anticipated. The water-quality records are grouped in terms of the same drainage basins used for the reports on surface-water supply. The reports on ground-water levels, also published at 5-year intervals, are in 6 parts which represent geographical sections of the country. In addition to these reports, a series of Water-Supply Papers is published which describes the magnitude and frequency of floods for the entire country, by drainage-basin areas, and another series describes notable floods each year.

Areal investigations of water resources are made largely in cooperation with State, local, or Federal agencies listed on page A205. These studies include the various aspects of the geologic and hydrologic environment that relate to the occurrence and movement of water on the surface and underground. Such studies of water resources stress the evaluation of sources of supply, chemical and physical composition, computation of the quantity available for use, description of the direction and rate of movement, evaluation of fluctuations in flow, and determination of disposition of the supply as use, waste, or outflow.

Diversified water-resources investigations are in progress in nearly every State. These fall into two general categories: "area" and "systems" studies. Area studies cover investigations of specific hydrologic problems within an area, generally comprising a political subdivision—the problems of a municipality, a county, or a State. Systems studies, on the other hand, are investigations of the hydrologic environment of natural units such as a river basin or isolated valley or a major aquifer, whose area may include a number of political subdivisions. The purpose of these investigations is to determine the effect on the hydrologic system of changes in any part of it; for example, to predict how use of ground water in one municipality may influence streamflow in another part of a river system.

Investigations stressing the economic aspects of water as a resource are treated in the following section under four areas (fig. 1), which correspond to the administrative subdivisions of the Water Resources Division.

OFFICE OF WATER-DATA COORDINATION

An Office of Water-Data Coordination has been established in the Water Resources Division of the U.S. Geological Survey to implement Circular A–67 of the Bureau of the Budget. This circular establishes guidelines for coordinating Federal activities in collecting water data and for developing a national plan to acquire these data. It assigns these coordinating and planning functions to the Department of the Interior, which in turn has assigned this responsibility to the Geological Survey.

Circular A–67 stresses the importance of participation in the planning of these activities by all Federal agencies concerned with the collection and use of water data. It identifies three principal functions of coordination:

(1) Design and operation of a national network for the collection of water data.

(2) Coordination of national-network and specialized water-data activities.

(3) Maintenance of a central catalog of information on national-network and specialized water data, and on Federal activities being planned or conducted to acquire such data.

Among the chief purposes of Circular A–67 are assurance that (a) water information flows freely to those who require it for the effective development and management of water resources; (b) data are collected in a timely, effective, and economical fashion; and (c) information is readily accessible to all users of water information from a single focal point.

ATLANTIC COAST AREA

Moderate to plentiful supplies of water are commonly available in the Eastern States. Water-

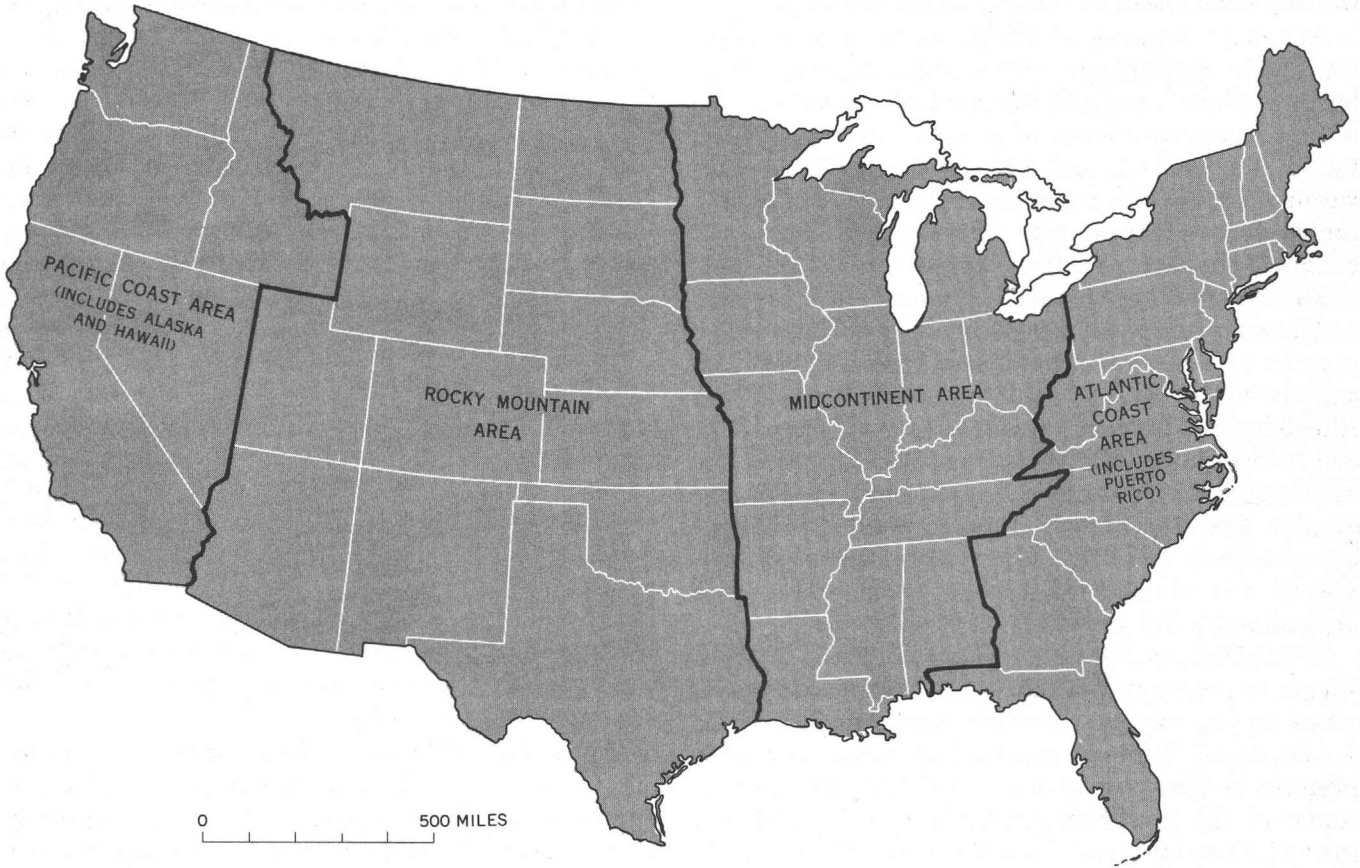

FIGURE 1.—Index map of the United States, showing areal subdivisions used in discussion of water resources.

resources investigations of the U.S. Geological Survey in the Atlantic coast area have as their objective the description and interpretation of the occurrence of water, with emphasis on problems which affect water use. These problems relate to temporary excesses caused by floods and deficiencies due to drought such as that which persisted through the fiscal year in the Northeastern States; to natural variations in supply which reflect local and regional differences in rocks and soils, vegetation, and climate; and to natural quality of the water and changes in quality brought about, directly or indirectly, as a result of our use of this resource.

The results of project investigations summarized below illustrate the variety of studies in progress in this region of diverse geologic and hydrologic environments.

INTERSTATE STUDIES

Hydrologic atlas of Appalachia

Water will be an important resource in the proposed program for economic development of the Appalachian Region, according to W. J. Schneider and others (1–65), because the combination of availability of water and accessibility by highways will largely determine the locations of future industrial areas. However, water problems already present—floods, acid mine drainage, and stream pollution—will become more serious with the further economic development unless remedial measures are taken. Maps in the new report by Schneider and others, published in 1965, show that an average of 150 billion gallons of water leaves the region each day as streamflow. Based on national averages this is enough to meet all water needs for more than six times the present population of the region. This flow, however, is extremely variable from place to place and year to year, resulting in floods and water shortages throughout the region. Ground water is also available in Appalachia for development, with small to moderate amounts available almost everywhere. Large supplies of up to 42 million gallons per day can be obtained from wells in some broad valleys in northern Pennsylvania and in the upper Ohio River Valley.

Ground-water resources of upper Ohio River basin

Abundant supplies of ground water are available for future development within the Allegheny River basin of New York and Pennsylvania, according to a reconnaissance survey of ground-water conditions by Morris Deutsch and J. C. Wallace. The northwestern part of the basin is particularly well suited for large-scale ground-water development because it contains aquifers of highly permeable glacial outwash sand and gravel that are underlain by water-yielding sandstones of the Pocono Formation. Large supplies of ground water are also available in glacial and alluvial sediments along the entire course of the Allegheny River from its source to Pittsburgh, Pa., and in the valleys of tributary streams draining the unglaciated area upstream from Tionesta, Pa. South of the Clarion River, serious quality problems brought about by coal mining and interaquifer leakage of salt water will impede future large-scale ground-water developments.

In the Monongahela River drainage basin of West Virginia, Pennsylvania, and Maryland, a reconnaissance survey of ground-water conditions by P. R. Jordan and G. D. Dove showed that moderately large supplies of ground water are available from sandstones of the Pottsville and Allegheny Formations. In the industrial areas along the lower Monongahela and Youghiogheny Rivers near Pittsburgh, Pa., moderately large supplies of ground water can be pumped from the alluvium underlying the flood plains. Unfavorable ground-water conditions preclude large-scale development of ground water in the western third of the basin. New sources of large ground-water supplies in the central third of the basin could be found by extensive test drilling to locate areas of high yield from the lower part of the Conemaugh Formation, and to locate tracts outside their outcrop areas where the Pottsville and Allegheny Formations contain fresh water.

A reconnaissance survey of ground-water conditions in the Kanawha and Little Kanawha River drainage basins of North Carolina, Virginia, and West Virginia by G. D. Dove and J. C. Wallace revealed that the greatest potential for further development of ground water is in the alluvium along the lower reaches of the major streams. Care will be needed in the development of this source to prevent contamination of the water by industrial wastes from the rivers. The study also showed that moderately large ground-water supplies can be obtained from sandstones of the Pottsville and Allegheny Formations in a wide band across the central part of the Kanawha River basin.

Large ground-water supplies in Connecticut River basin

A map of the availability of ground water in the Connecticut River basin in New Hampshire and Vermont, being prepared by D. J. Cederstrom and A. L. Hodges, Jr., working in cooperation with the U.S. Army Corps of Engineers, shows where supplies of ground water of 1 to 5 million gallons per day can be obtained from tributary valleys, and where larger amounts are available at places along the Connecticut River itself. Yields greater than 1 mgd have been reported from individual deep wells. Some shallow gravelly deposits have very high permeability; yields greater than 200 gallons per minute have been obtained from wells less than 40 feet deep. Deep alluvial fill has been found in many tributary valleys. At Woodstock, Vt., for instance, a well which extends 140 feet below present stream level does not reach bedrock. These observations, which suggest that streams in upper New England formerly had a base level considerably below that of the present, indicate that thick water-bearing deposits are more common in these stream valleys than has previously been realized.

Hardness of ground water in Susquehanna River basin

P. R. Seaber and E. F. Hollyday, working in cooperation with the U.S. Army Corps of Engineers, (2–64) have related the hardness of ground water to the lithology of glacial drift, the direction of glacial movement, the topographic setting, and the history of the glacial deposits in the Susquehanna River basin in New York and Pennsylvania. Four distinct areas of ground-water hardness occur in the basin. The hardness is highest in areas underlain by drift containing many limestone erratics and is lowest in areas of few or no such erratics. The hardness data substantiate previous mapping of surficial deposits in the basin.

Natural sand filters protect ground water in Florida and Georgia

Many of the solution cavities and sinkholes in recharge areas of the productive Tertiary and Quaternary limestones in Florida and Georgia are filled with unconsolidated permeable deposits of Pleistocene and Recent age. V. T. Stringfield finds that much of the recharge to the limestones is through these permeable deposits, which are chiefly silica sand and which serve as filters by removing undesirable turbidity and contaminants. Presence of the unconsolidated deposits in solution cavities in the Miami area of Florida also retards the lateral movement of the water in the limestones, and thus helps maintain a fresh-water head and prevent salt-water encroachment.

NEW ENGLAND

Seismic studies aid delineation of potential aquifers

S. J. Pollock reports that seismic investigations in the Assabet River basin, in northeastern Massachusetts, have made possible the delineation of sites which appear to be most favorable for ground-water development. The two most promising areas are in the towns of Hudson and Stow, where beds of saturated sand and gravel appear to be as thick as 50–70 feet. It is estimated that properly constructed wells in these areas would yield up to several hundred gallons per minute; elsewhere in the basin, wells are likely to yield less than 150 gpm.

Ground water in Ten Mile and North Taunton River basins, Massachusetts

More than half the area of the Ten Mile and North Taunton basins, in southeastern Massachusetts, is underlain by alluvium and outwash deposits which are generally less than 100 feet thick, according to J. R. Williams. Most municipal and industrial water supplies are obtained from gravel in these deposits which, in places, yield as much as 1,000 gallons per minute to wells. Industrial and domestic wells in sedimentary rocks of Pennsylvanian age generally yield ½–20 gpm, but a few yield as much as 200 gpm.

Aquifers in Housatonic River basin, Massachusetts

Studies of the Housatonic River basin in western Massachusetts, by R. F. Norvitch, indicate that ice-contact deposits along the valley walls are locally good sources of ground water. Channel-fill deposits generally have a better ground-water potential in the upper reaches of the tributaries than in the main valley. Because of its cavernous nature the Stockbridge Limestone, which is the bedrock along part of the western side of the basin, may prove to be a highly productive aquifer.

Ground water in southern New Hampshire

Recent studies by J. M. Weigle indicate that a total sustained ground-water yield of 10 million gallons per day may be possible from glacial sand and gravel at places in the towns of Winchester, Swanzey, and Keene, in southwestern New Hampshire. Several times that much may be available where infiltration can be induced from the Ashuelot River and its tributaries. Glacial-lake deposits as thick as 100 feet underlie parts of the Keene basin, however; where the deposits are fine grained their potential yield to wells is considerably lower. At some places in the Ashuelot River basin the yields of individual wells may exceed 1 mgd, but probably most individual wells will yield not more than 0.1 mgd. Preliminary investigation of the Salem-Plaistow area, in southeastern New Hampshire, indicates that ground-water supplies sufficient for domestic needs can be obtained for many years in most towns in that area.

NEW YORK

Low flow of streams in Genesee River basin

Data collected at more than 500 sites in September and October 1964 by B. K. Gilbert, J. C. Kammerer, and F. J. Keller show that the flow of most unregulated streams in the 2,500-square-mile Genesee River basin, in western New York, is between 0.01 and 0.30 cubic feet per second per square mile of drainage area during month-long periods of little or no autumn rainfull. These low flows, which are exceeded more than 95 percent of the time, contrast with average annual flows estimated to be between 0.9 and 1.2 cfs per square mile. Preliminary interpretation suggests that dry-season flow of small streams draining mainly shale and glacial till is less than 0.1 cfs per square mile, whereas higher dry-weather flow characterizes small streams draining mainly glacial deposits of sand and gravel.

Discharge measurements made during the same period indicated that Spring Creek at Mumford, in the northern part of the basin, had a flow more than 40–100 times that of any other small stream in the basin. This stream is fed by limestone springs which evidently are recharged by precipitation over a much larger area than the drainage area (about 1 square mile) defined on topographic maps.

Streams lose flow above waterfalls in central New York

Streams in central New York have been found by I. H. Kantrowitz to lose flow in the reaches immediately above waterfalls. As much as 25 percent of the base-flow discharge of the streams moves under the falls. Drilled wells which tap carbonate-rock aquifers near the waterfalls yield up to 1,400 gallons per minute. The loss of streamflow and the high well yields are attributed to widening of vertical joints in the carbonate rocks near the falls by stream water charged with atmospheric carbon dioxide.

Downward ground-water flow in wells in Niagara County

Temperature profiles, periscope surveys, and water levels in wells studied by F. W. Trainer indicate that downward flow of water between fractures or groups of fractures occurs in many wells in flat-lying Lockport Dolomite in Niagara County, western New York. In areas of numerous and closely spaced wells the downward flow appears to have important implications for recharge of deeper water-bearing zones in the dolomite, which in turn will lead to modification of the chemical quality, and local contamination, of water in the deeper zones. Under natural conditions the water in the deeper zones is more highly mineralized than that in the upper part of the dolomite.

NEW JERSEY

Ramapo River recharges an alluvial aquifer

Measurements of flow in the Ramapo River, analyzed by John Vecchioli, indicate that the stream is influent along part of its reach in New Jersey. All tributary inflows and the discharge at several places along the main channel were determined under conditions of high, intermediate, low, and very low flow during 1964. The observed seepage loss to an alluvial aquifer ranged from a few to several cubic feet per second, or a large part of the total pumpage from the aquifer (average, about 6 cfs, or 4 million gallons per day).

MARYLAND

Water resources in Patuxent River basin

Study of the Patuxent River basin by Deric O'Bryan and J. W. Crooks reveals that of the 1,960 million gallons per day of water brought to the Patuxent River basin from precipitation, about 64 percent, 1,260 mgd, is lost through evapotranspiration. The remainder, 700 mgd, is discharged from the basin as streamflow. The average flow from the basin ranges from about 630 to 780 mgd. Approximately 1 mgd of the total runoff is contributed by artesian aquifers in the lower part of the basin. Streamflows of 95-percent duration range from 0.03 to 0.15 mgd per square mile. Up to 40 mgd of water is transported out of the basin as public water supply for the Washington, D.C., metropolitan area.

Most of the water in the basin, except for tidal flow, can be used for public supplies and industrial purposes after minor treatment. The water generally is dilute in the Piedmont section of the basin and more highly mineralized in the coastal plain. Objectionable concentrations of iron are found in some ground-water supplies. Restrictions on waste disposal to streams are imposed by the State of Maryland, but objectionable levels of pollution exist in some small reaches of streams. The effect is not cumulative, however, and decreases generally downstream.

Preliminary estimates indicate that about 130,000 tons of sediment is discharged from the basin each year. Average sediment yield in undisturbed areas of the Piedmont section of the basin is about 150 tons per square mile per year. Sediment yield in the coastal plain averages less than 100 tons per square mile per year. Small tributaries draining areas undergoing active urbanization yield sediment at rates up to 50,000 tons per square mile per year.

Water resources of Dorchester and Talbot Counties

F. K. Mack, R. A. Gardner, and W. E. Webb report that ground water provides most water supplies in Dorchester and Talbot Counties, in eastern Maryland. Most wells tap aquifers of Eocene or younger age at depths less than 600 feet, but a few are completed in aquifers of Late Cretaceous age at depths of about 1,000 feet. Fresh surface-water resources are limited because major streams of the two counties are tidal estuaries of the Chesapeake Bay. Studies of the specific conductance and the chloride content of water in the Choptank and Nanticoke Rivers, at times of lowest runoff, reveal that saline water moves several miles farther upstream than had been indicated by earlier studies.

Buried valley near Salisbury a source of ground water

D. H. Boggess and H. J. Hansen have mapped a 2-mile section of a deep buried channel that is located midway between Salisbury, in eastern Maryland, and the Delaware State line. A series of test holes across this paleochannel indicates that it trends east-west, extends about 200 feet below mean sea level (240 ft below land surface), and ranges in width from about 1,800 feet at the eastern end to about 4,800 feet at the western end. The channel is thought to have been incised into the Miocene surface, and refilled, during late Pleistocene time. The saturated sediments in the paleochannel appear to be a major potential source of good-quality ground water. Specific capacities of wells exceeding 50 gallons per minute per foot of drawdown are not uncommon, and well yields in the range of 2,000–5,000 gpm appear feasible.

WEST VIRGINIA

Water resources in Monongahela River basin

Studies in the Monongahela River basin by E. A. Friel and B. M. Wilmoth reveal that average annual runoff ranges from 0.75 million gallons per day per square mile in the northwestern part of the basin to 2 mgd per sq mi along the southern and southeastern parts of the basin. Over the entire basin, the lowest yearly runoff generally amounts to a little more than half the mean annual runoff. The median 7-day low flow, based on records for the period 1916–61, ranges from less than 0.013 mgd per sq mi in the western part of the basin to more than 0.13 mgd per sq mi in the headwaters of the Blackwater River. The annual water loss (difference between precipitation and surface runoff) ranges from about 17 to 30 inches.

More than 1,500 square miles in the central part of the basin has good potential for the development of moderately large supplies of ground water. Present development of the aquifers is small; in large areas they are untapped. Small supplies can be obtained in the outcrop areas of all rock units. Most shortage problems occur in the western part of the basin, on hills and ridges underlain by shale. Areas of shallow saline ground water, in which the brine occurs in part naturally and in part as a result of gas-well operations, have been delineated, mostly beneath major stream valleys in the western part of the basin. The effects of coal mining on ground water and on the low flow of streams are relatively small except locally near mines, where low flows are increased and the quality of the water has deteriorated.

SOUTH CAROLINA

Ground-water system beneath coastal-plain sediments

An artesian system defined by G. E. Siple consists of fractures in crystalline rock that lies beneath 1,000 feet of coastal-plain sediments. The upper confining layer is a bed of saprolite 40 to 60 feet thick. Natural discharge is probably to streams in the boundary region of the Coastal Plain and Piedmont provinces where the confining bed has been partially or completely removed. The dissolved-helium content of water from the rock wells appears to vary directly with the proximity of the well to these discharge areas.

GEORGIA

Zone of low permeability in Glynn County

Water-level behavior resulting from occasional reduction in industrial pumping indicates a zone of low permeability between the Brunswick Peninsula and St. Simons and Jekyll Islands, in southeastern Georgia. This zone, as delineated by D. O. Gregg, was further substantiated by a map showing water-level declines from October 1962 to December 1963 caused by an increase of 36.7 million gallons per day in industrial pumping.

Ground water in Rockdale County

Ground-water studies by M. J. McCollum show that Rockdale County, in north-central Georgia, is underlain by weathered metamorphic rocks of Precambrian (?) age that have been intruded by granite and by pegmatite and diabase dikes. Ground water in these rocks is more readily available where weathering is pronounced. The quality of the water is directly related to the composition of the rocks in which it occurs; thus, the water of best quality occurs in the Lithonia Gneiss of Watson (1902)[16] and that with the highest iron concentration occurs in amphibolitic gneiss.

Lower part of aquifer in Cook County poorly productive

C. W. Sever reports that the drilling of a 870-foot test well at Adel, in Cook County, south-central Georgia, disclosed that the lower part of the principal artesian aquifer system between depths of about 440 and 850 feet consists of dense dolomitic limestone that yields practically no water.

Ground water in Floyd and Polk Counties

A ground-water investigation in the Paleozoic area of Georgia by Charles Cressler shows that in Polk County, in northwestern Georgia, yields of more than 1,000 gallons per minute can be obtained from wells in limestone. Limestone is less abundant in adjacent Floyd County, and ground-water conditions are less favorable, but yields up to 500 gpm are probable in some places. Eleven unused springs in the 2 counties discharge a total of more than 28 million gallons per day. The discharge of individual springs ranges from 0.5 to 15 mgd. The spring water is moderately hard and has a low iron content, making it suitable for many industrial uses.

FLORIDA

Ground-water circulation in Marion County, Fla.

Study of the quality of water in large springs in Marion County and vicinity, in north-central Florida, suggests to F. N. Visher that most of the circulation of ground water is through large solution openings in the upper few tens of feet of the carbonate rocks. The remainder of the circulation is through evaporite beds deep in the Floridan aquifer, where the solution of salt and other evaporites has produced a zone of very high permeability. The rest of the carbonate-rock sequence is less permeable and, except in local areas, is undergoing little solution at this time. In discharge areas, waters ascending from the evaporite beds mix with the water in the overlying carbonate rocks, resulting in a deterioration of the quality of the water in these areas. Water from evaporite beds is thought to be the principal source of dissolved material in poor-quality waters in much of the State.

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[16] T. L. Watson, 1902, A preliminary report on a part of the granites and gneisses of Georgia: Georgia Geol. Survey Bull. 9-A, p. 54, 125-127.

Water budget of mid-Gulf Coast basins

Preliminary estimates by R. N. Cherry of evapotranspiration, surface runoff, and ground-water runoff from the mid-Gulf Coast basins in the west-central coastal area are 35, 15, and 5 inches, respectively. The Floridan aquifer, which is composed of about 1,000 feet of limestone and dolomite ranging in age from Eocene to Miocene, underlies the basin. In 1963, St. Petersburg pumped about 22 million gallons per day from this aquifer.

Floridan aquifer tested at Key Largo

Information obtained by H. J. McCoy from a 1,070-foot well at the north end of Key Largo, drilled into the Floridan aquifer, the principal artesian aquifer of Florida, showed that the piezometric surface was 38 feet above mean sea level (or more than 15 feet higher than the level at which it had previously been). The water, although brackish, was relatively fresh, considering the distance offshore. The artesian water is being blended with fresher water piped from the Florida mainland and is used for golf-course irrigation. The economic feasibility of using conversion units to produce potable water from the brackish water in quantity, to supply the Florida Keys, is under study by the Florida Aqueduct Commission.

Aquifers in Myakka River basin

B. F. Joyner, Horace Sutcliffe, Jr., and J. D. Warren report that ground-water supplies in the Myakka River basin in southwestern Florida are obtained from the Hawthorn Formation and the Tampa, Suwannee, and Avon Park Limestones. The Hawthorn (youngest) Formation generally yields 50 gallons per minute or less of water that is of good quality except for fluoride, which ranges in concentration from 1.5 to 3 parts per million. The Tampa Limestone yields up to 1,000 gpm of water of good quality except that the fluoride locally exceeds 2.0 ppm. Wells which tap the Suwannee Limestone yield up to 1,000 gpm of water having dissolved-solids concentration exceeding 800 ppm and a sulfate concentration exceeding 500 ppm; those in the Avon Park Limestone yield 1,000–2,500 gpm of water having a dissolved-solids concentration of 850–2,000 ppm and a sulfate concentration of 500–1,500 ppm.

Water levels recover 200 feet near Panama City

J. B. Foster reports that water levels in the Floridan aquifer near Panama City, in western Florida, recovered a maximum of about 200 feet during 1964 as a result of abandonment of an industrial well field. The well field had been in operation for 34 years, and the rate of pumping during the 5 years preceding 1964 was more than 11 million gallons per day.

Underseepage of Lake Okeechobee dikes caused by excavations

Studies by F. W. Meyer around the southern half of Lake Okeechobee indicate that seepage beneath the Hoover Dike is significant in the area between Clewiston and Moore Haven. The seepage is related to the excavation of borrow canals on either side of the dike. Increases in seepage can be expected all along the southern half of Lake Okeechobee if drainage canals in the adjacent agricultural areas are excavated parallel to and adjacent to the dike.

Wide range in flow and dissolved solids of Shark River Slough

Preliminary hydrologic studies of the Shark River Slough, in southern Florida, by B. F. Hartwell, Howard Klein, and F. B. Joyner (1–64) revealed wide ranges, from wet to dry years, in surface runoff and in dissolved solids. During the 10-year period prior to October 1962 median monthly flows ranged from 21 to 1,020 cubic feet per second; the average total yearly flow was about 250,000 acre-feet. The content of dissolved solids (about 500 parts per million) in areas of fresh ground water is more than three times greater during dry periods than during wet periods. The increase during dry weather, which is chiefly in calcium and carbonate, is thought to reflect lesser dilution of the ground water by recharge during dry periods than during wet ones.

CARIBBEAN REGION

Ground water overdeveloped in Ponce area, Puerto Rico

Study of the Ponce area, on the south coast of Puerto Rico, by N. E. McClymonds shows that the ground water is overdeveloped. Sustained pumping of wells as far as 2 miles from the coast has caused water levels to decline 10 to 20 feet below sea level in the major aquifer, a cavernous limestone. A layer of poorly permeable alluvium about 50 feet thick, overlying the limestone, seems to be holding sea water from encroaching inland to the area of depressed water level except southwest of Ponce, where there is evidence of encroachment. By the end of 1964, a drought year, water levels in many wells were down to the level of the pumps.

Surface-water supplies are extensively developed in the Ponce area, but considerable additional development is possible if storage reservoirs can be provided.

Water resources of Virgin Islands

D. G. Jordan and O. J. Cosner found from test drilling in the Virgin Islands National Park, St. John, that 1,000–15,000 gallons per day of fresh ground water are available from fractured volcanic tuffs and breccias. In coastal areas of the island, however, the threat of sea-water encroachment will impede development of ground-water supplies.

Small but significant quantities of fresh water have been discovered in St. Thomas as the result of test drilling. Three areas—on the north slopes of the Island, in Tutu Valley, and at the race track—warrant development of small public supplies. The total minimum yield from these areas is estimated to be 0.8 million gallons per day.

Development of ground water for public supplies on the Island of St. Croix is limited largely to alluvial and limestone aquifers in an area of about 6 square miles along the south-central coast. These aquifers will produce several million gallons per day of potable water, but they generally contain brackish water at depths of 40 to 100 feet below sea level. In areas underlain by fractured volcanic rock, supplies of from 1–10 gpm generally can be obtained. In nearly a third of the island, ground water is saline or is not present in usable quantities.

Surface-water runoff in the Virgin Islands appears to average less than 5 percent of the annual rainfall, or about 2 inches. Runoff from even large storms, much less than would be expected in an area where the slope of the land surface generally exceeds 200 feet in 1,000 feet, reflects the permeable rocks and deposits at and near the land surface.

MIDCONTINENT AREA

In the midcontinent area, water-resources investigations of the U.S. Geological Survey are directed toward solution of problems associated with distribution and increasing development of the available water. These studies include (1) appraisal of the available water resources in terms of location, quantity, and quality; (2) investigation of specific problems to provide hydrologically sound guidelines for their solution; and (3) facilitation of water-management practices by improving our understanding of the hydrologic environment.

In a few studies, previously unknown ground-water sources have been discovered that add significantly to the available supply. For example, fresh ground water has been found at depths as great as 2,600 feet below sea level in Pointe Coupee Parish, La. Other studies bear on declining ground-water levels, deficient streamflow, and local overdevelopment of water sources. Thus, the need for an alternate and supplemental supply for the city of New Orleans has led to exploration and confirmation of large reserves of ground water in deep aquifers underlying Lake Pontchartrain. New alltime low ground-water levels in Madison and Shelby Counties, Tenn., followed increase in pumpage. Continuing deficiency of streamflow in part of the area emphasizes the need for water-shortage facilities and coordinated use of ground- and surface-water resources.

Significant results of these and other studies are reported below.

INTERSTATE STUDIES

Aquifers correlated in Louisiana and Texas

As a part of the compilation and analysis of data for the construction of an analog model of the aquifers in the Gulf Coast area of southeastern Texas and southwestern Louisiana, A. N. Turcan, Jr., Chabot Kilburn, and Roger Baker remapped the boundary between the Evangeline (Pliocene) and Chicot (Pleistocene) aquifers and correlated them between Houston, Tex., and the Atchafalaya River in Louisiana. In this interstate area the name "Jasper aquifer" has been proposed for deeper sediments of Miocene age that form an aquifer which is a mappable hydrologic unit, is composed of alternating beds of sand and clay, and contains fresh water in parts of the project area.

Water resources of Mississippi embayment region

R. L. Hosman, T. W. Lambert, and A. T. Long find that Tertiary aquifers are important sources of ground-water supplies in a total area of about 75,000 square miles, or about three-fourths of the entire Mississippi embayment. As a group, these aquifers are capable of sustaining much larger withdrawals than the present rate, which is in excess of 500 million gallons per day. Some of the aquifers are not tapped by wells, in large areas where they are known to contain usable water, because supplies are available from shallower aquifers. They will become increasingly important in these areas when eventually they are utilized to avoid or delay depletion of the shallower supplies. Most of the aquifers are in the Wilcox and Claiborne Groups, and the largest total withdrawal is from Claiborne aquifers. The most extensively developed is the Sparta Sand, which yields about 25 percent of the total withdrawals from Tertiary aquifers. The piezometric surface in the Sparta Sand shows several large cones of depression caused by large withdrawals. A few of these cones have coalesced, and others seem to be coalescing and will probably form one large depression eventually. Use of deeper aquifers could help alleviate this situation in much of the area.

M. S. Hines, M. E. Janson, and P. R. Speer report that streams in the Quaternary alluvium along the Malden-Kennett Prairie and the west side of Sikestone Ridge, most of which are in dredged channels, have higher base flows than streams in any other part of the alluvium in the Mississippi embayment section of Missouri and northern Arkansas. Streams in the alluvium between lat 35° N. and 36° N. have the lowest base flows in the area studied. Streams that originate in Paleozoic rocks outside the embayment have well-sustained base flows except where the streams have not eroded deeply enough to expose productive Paleozoic aquifers. Sands of the Wilcox Group or Formation and the McNairy Sand in Crowleys Ridge are important contributors to the base flow of streams draining the east side of the ridge north of Marmaduke, Ark.

Upper Mississippi River basin

Reconnaissance studies by P. G. Olcott, in Missouri and Illinois, indicate that unconsolidated glacial-drift and alluvial aquifers in buried bedrock valleys beneath the Mississippi, Kaskaskia, and Cache Rivers and the headwater diversion canal generally yield from 400 to 1,000 gallons per minute of water to wells and are the aquifers of greatest yield in the upper Mississippi River basin south of the Illinois River. Bedrock aquifers consisting largely of dolomites of Cambrian Devonian age generally yield up to 400 gpm of water to wells in the area west of the Mississippi River. An abundant supply of ground water, greater than the present demand, is commonly available from these aquifers.

Ohio River valley

The Ohio River valley between Pittsburgh, Pa., and Marietta, Ohio, contains thick deposits of permeable gravel and sand, and the river provides a perennial source of recharge for development of large ground-water supplies. P. R. Jordan, in a reconnaissance survey, also found conditions favorable for ground-water development in the sandstones of the Mississippian System in the northern parts of the Beaver and Mohoning River basins. Most of the ground water in this area has mineral concentrations that are within limits recommended for drinking water, although softening and iron removal are generally desirable. The effect of gross contamination of surface water in the basin on the quality of the ground water cannot be assessed without additional data.

MINNESOTA

Statewide study of ground-water quality

A study of the chemical quality of water in the major aquifers in Minnesota by M. L. Maderak indicates that water in the Jordan Sandstone tends to be more uniform in chemical type from area to area and from year to year than water in the other Paleozoic aquifers or in the glacial drift. Water in any one Paleozoic aquifer generally is of a distinct type, whereas water in the glacial-drift aquifers is of several different types. Except for extreme southwestern Minnesota, the water in all aquifers tends to have a higher concentration of dissolved constituents in the southern part than in the central and northern parts of the State.

WISCONSIN

Water in Wisconsin River valley

In the lower part of the Wisconsin River valley, additional large-capacity wells yielding 1,000 gallons per minute or more of good-quality water can be constructed in thick alluvial sand and gravel, or in the underlying extensive sandstone aquifer, according to studies by L. J. Hamilton and T. R. Dosch. The flow of the lower Wisconsin River, stabilized by an upstream network of 23 reservoirs, is an additional large potential source of good-quality water. Decreased streamflow and declines of ground-water levels in aquifers during 1962–64 are attributed to deficiencies in precipitation rather than to increased pumpage of ground water. Withdrawal of ground water can be greatly increased without seriously affecting either streamflow or ground-water levels.

Ground water in Racine and Kenosha Counties

Piezometric mapping of the deep sandstone aquifer in Racine and Kenosha Counties, in southeastern Wisconsin, by R. D. Hutchinson indicates that the ground-water divide between the Milwaukee and Chicago cones of depression extends from east to west through central Kenosha County. Water levels in wells tapping this important aquifer continue to drop 4 to 7 feet per year. Brackish water has been found in wells more than 2,000 feet deep in Racine. Mapping of water levels in the shallow Niagara aquifer indicates that the principal recharge area is near the Fox River valley, and that the water is confined in more than half the area by clay till that reaches a thickness of nearly 300 feet.

The quality of the water is generally acceptable for most uses.

MICHIGAN

Drought in southern Michigan

Streamflow records show that runoff for the 1964 water year in the southern half of the Lower Peninsula was generally the lowest since streamflow records began at the turn of the century. Mean monthly levels of Lakes Michigan and Huron were at a record low for each month of the 1964 calendar year, with the alltime record low occurring in March. Levels in 5 of 11 lakes that have been gaged for 15 years or more declined to new lows. Water levels in representative observation wells were at low or record-low stages in 1964. A protracted deficiency in precipitation is the principal cause of the drought. At Lansing the deficiency for the period January 1962 to June 1964 amounted to nearly 21 inches.

Water resources in Marquette iron range

Water-resources investigations in the Marquette iron range area, in northwestern Michigan, indicate total water supply ample for present and expected needs. Only about 1½ inches of the estimated annual average runoff (14 inches) is used at present (1964), and most of the water now used is available and fit for reuse. About 190 cubic feet per second is available in the principal streams of the 610-square-mile area during 90 percent of the time. With storage, these streams could supply a firm flow of about 450 cfs. The ground-water potential is best in the glacial-outwash deposits. In the extensive outwash plain south and east of Goose Lake, for example, it is estimated that at least 15 cfs could be developed from the northern part of the outwash plain alone. The quality of the surface and ground waters is generally good to excellent.

Suspended-sediment concentrations as high as 45,400 parts per million have been measured in the tailings discharge from the Humboldt mine, Marquette County, where the discharge enters the McKinnon Lake settling basin, according to Russell F. Flint. The suspended material had a specific gravity of 3.07; it was 33 percent sand, 60 percent silt, and 7 percent clay. Suspended-sediment concentrations in the outflow from the settling basin, measured a quarter of a mile downstream, were observed to be 92 ppm or less during 1961–64. Measurements of suspended sediment at the gaging station on the Black River near Republic, about 7 miles downstream from McKinnon Lake, indicated no significant increases in concentration or sediment yield during the period.

OHIO

Preglacial drainage in Miami River valley

A. M. Spieker has mapped the bedrock surface in the Great Miami River valley, between Middletown and Hamilton in southwestern Ohio, largely on the basis of the results of a seismic-refraction survey, and has found two buried valleys separated by a bedrock high. The older valley, 250 to 300 feet deep and extending through Trenton, Busenbark, and Overpeck, is believed to have been formed during an interglacial period prior to the onset of the Illinoian Glaciation. This valley is 1½ to 2 miles wide. The younger valley, which underlies the present course of the Great Miami River, is only about 100 feet deep and is believed to have been formed when the Wisconsin ice sheet blocked the older valley, situated about 2 miles to the northwest. The younger valley is but half a mile wide. Both valleys are filled with permeable sand and gravel and are considered to be excellent sources of ground water.

Cuyahoga River water quality in Cleveland area

Water quality in the navigable portion of the Cuyahoga River at Cleveland varies greatly within the 25-foot depth of the river as well as longitudinally and in cross section. According to recent work by M. E. Schroeder and C. R. Collier, stratification of the water is caused by industrial and municipal wastes but is complicated by seiching of Lake Erie. Stratification of the water is greatest in the lower 2-mile reach of the river. For example, in one set of measurements at the Center Street bridge, 4,500 feet upstream from the mouth of the stream, the conductance ranged from 1,560 micromhos at the surface to 530 micromhos at a depth of 25 feet; the corresponding range in temperature was 76°F to 62°F. In the upper reach of the navigable channel (2 to 6 miles from the mouth), however, conductance at that time ranged from 1,510 to 1,240 micromhos and temperature from 84°F to 76°F.

Ground water in Berea Sandstone

A regional study of the Berea Sandstone by J. J. Rau indicates that it consistently yields more water to wells than do the other consolidated-rock units of Devonian and Mississippian age in northeastern Ohio. The Berea Sandstone is an important aquifer in parts of Trumbull, Portage, Ashtabula, Geauga, Lake, Cuyahoga, Summit, and Lorain Counties, where its thickness ranges from a few feet to 235 feet and averages about 50 feet. The average specific capacity in 344 wells is 1.5 gallons per minute per foot of drawdown. The highest transmissibility values were recorded in southeastern Ashtabula County and central Trumbull County, to the northeast, and the lowest values in Summit and Lorain Counties to the southwest. The average depth to which wells penetrate the aquifer is 30 feet, and the average yield of these wells as reported by drillers is 14 gpm.

Ground water in Muskingum and Hocking River basins

A reconnaissance study by G. D. Dove shows the Muskingum River basin in southeastern Ohio to be rich in ground water. Wells drilled into outwash deposits along the Walhonding and Tuscarawas Rivers, the principal tributaries of the Muskingum, yield as much as 1,200 and 2,000 gallons per minute, respectively, and as much as 1,500 gpm is obtained from the deposits along the course of the Muskingum River. In the central and eastern parts of the Muskingum River basin, away from the stream valleys, the principal sources of ground water are the sandstones of Pennsylvanian age. Most ground water in the basin is not highly mineralized and may be used for most purposes with little treatment.

Large supplies of ground water are also available along the course of the Hocking River. In the glaciated northwestern part of the Hocking River basin, near Lancaster, individual wells yield more than 500 gpm, but south of Lancaster the outwash deposits are thinner, less permeable, and consequently yield less water.

INDIANA

Water resources of Delaware County

R. E. Hoggatt and J. D. Hunn find that water supplies now available in Delaware County, in east-central Indiana, will be adequate for most foreseeable agricultural, municipal, and industrial purposes if developed properly. Most streams in the south half of the county, regardless of size, can be depended on to yield more than 0.013 million gallons per day per square mile 90 percent of the time. On the other hand many streams in the north half of Delaware County having less than 10 square miles of drainage area, including the headwaters of larger streams, go dry frequently. The principal sources of ground water are sand and gravel deposits of Pleistocene age and the upper 100 feet of the dolomite bedrock of Silurian age. The areas of greatest potential are in the south-central and southeastern parts of the county. Each aquifer is capable of yielding as much as 500 gallons per minute to individual wells in these areas.

MISSOURI

Surface-water quality

The overall quality of Missouri surface water is good, according to C. T. Taylor (1–64) in a statewide study of the quality of water. In general, the surface water is hard and moderately mineralized, but it may be used with limited treatment for most purposes. For irrigation purposes, the water is classified as a low-sodium water with medium to low salinity suitable for the irrigation of most plants without special practices for salinity control.

The most highly mineralized water is found in the northern glaciated plains and the western plains. Here the average dissolved-solids content found during a 12-month study was 274 parts per million, and the average hardness was 194 ppm. A distinctive feature of surface-water quality in this area is a relatively high sulfate content (average 59 ppm). The sulfate is believed to have been derived from shale and coal deposits in the bedrock, which is predominantly of Pennsylvanian age.

The western Ozark region, underlain by relatively pure Mississippian limestone, comprises an area in which a high (average 8.2) calcium-magnesium ratio is typical of the surface water. The average dissolved-solids content was 200 ppm, and the average hardness was 165 ppm. On the other hand, in the central and eastern Ozark highlands, a region underlain by Cambrian and Ordovician dolomite, a low calcium-magnesium ratio (average 1.0) is typical of the surface water. The average dissolved-solids content here was 168 ppm, the lowest in the State; the average hardness was 157 ppm.

Drainage anomalies

The basins of North Fork River and Bryant Creek, which adjoin one another in Douglas and Ozark Counties in south-central Missouri, have similar drainage areas, basin shapes, topography, and climate. However, the base flow of the lower reach of North Fork River is about twice that of Bryant Creek. E. J. Harvey and John Skelton find that karst features are well developed in the basin of North Fork River but poorly developed in that of Bryant Creek, and attribute the higher base flow to a more effective underground drainage system. A system of springs increases the base flow of North Fork River about 150 percent in a 500-foot reach of the stream in Ozark County.

ARKANSAS

Low flow of Arkansas streams

A study by M. S. Hines reveals the duration of daily flow and the frequency of low flows at 65 gaging stations and 97 partial-record sites in Arkansas. Major streams such as the White, Saline, Ouachita, and Black Rivers, and tributary streams in the northeastern part of the coastal plain, in the Springfield-Salem Plateau, in the Novaculite uplift, and in the Athens-Piedmont Plateau, are most likely to be dependable sources of water supply during dry periods. Tributary streams in the central and southern part of the coastal plain, in the Boston Mountains, in the Arkansas Valley, and in the Fourche Mountains do not have dependable flow during dry periods, and many of them often go dry.

Ground water in Jackson and Independence Counties

A water-resources study of Jackson and Independence Counties, in northeastern Arkansas, by D. R. Albin and M. S. Hines has shown that as much as 2,000 gallons per minute can be obtained from individual wells in alluvial deposits but that yields from other deposits seldom will exceed 50 gpm. Ground water generally is available throughout both counties, but in the area within the Ozark Plateaus users requiring more than about 50,000 gallons of water per day generally will be limited to supplies developed from streams.

KENTUCKY

Fresh-water–saline-water interface

Mapping of the fresh-water–saline-water interface by H. T. Hopkins, as part of the larger study of saline water in Kentucky, shows that the ground-water flow pattern in the limestones of the Mississippian Plateau and Blue Grass regions, in central Kentucky, is controlled by the relatively deeply incised streams and that the interface is lowest below these streams. In the western and eastern coal fields, in contrast, and in the Jackson Purchase region, in westernmost Kentucky, the interface reflects structural lows and highs.

Water supply for Louisville is adequate

The water supply for the Louisville area appears to be adequate for many years to come, according to E. A. Bell. The principal sources of supply are the Ohio River and ground water from deposits of sand and gravel adjacent to the river. The minimum daily flow on record for the Ohio River was 1.3 billion gallons in 1930, more than 6 times the average daily use of 211 million gallons in 1962. Of the fresh water used in 1962, 40 mgd was from the ground and 171 mgd from the Ohio River. Public-supply systems furnished 91.3 mgd, and industries and commercial establishments supplied 119.7 mgd for their own use from private systems. The principal water problems are problems of management, and are associated with the distribution of supplies, the quality of water, drainage, and waste disposal.

Ground-water movement in Mammoth Cave area

Continued investigation of the ground-water resources of the Mammoth Cave area by R. V. Cushman has furnished greater detail on the pattern of circulation in the cavernous limestones. The available information suggests that the gradient of the water table is controlled in part by the structure of the underlying Paleozoic rocks, and particularly the Chattanooga Shale, which forms the base of the zone of unconfined water. A marked steepening of the gradient of the water table in the vicinity of the Dripping Springs escarpment coincides with a monoclinal fold in the underlying bedrock. The regional gradient and direction of water movement in the carbonate rocks are from the Pennyroyal Plain northwest to the Green River. The pattern of the subsurface drainage is dendritic, the major part of the flow being concentrated in several large conduits as it nears points of discharge into the Green River.

Eocene aquifers in Jackson Purchase region

Geologic and hydrologic studies in the Jackson Purchase region, in westernmost Kentucky, by R. W. Davis, T. W. Lambert, and A. J. Hansen, Jr., show that Eocene aquifers of probable Claiborne age are saturated with water of good quality above the altitudes of most of the local streams and maintain perennial flows of water in Mayfield Creek downstream from Mayfield, Obion Creek downstream from Pryorsburg, and Bayou du Chien downstream from the vicinity of Water Valley. Most wells which tap Eocene aquifers yield more than enough water for domestic use: properly constructed wells should yield more than 100 gallons per minute.

Water in alluvium of Ohio River valley

An investigation by J. T. Gallaher and W. E. Price, Jr., shows the existence of a large perennially available supply of ground water in the alluvium of the Ohio River valley in Kentucky. Yields as great as 1,000 gallons per minute are obtained by induced infiltration from wells penetrating the coarse basal alluvium near the river. Poorest ground-water conditions are found where the relatively coarse Ohio Valley alluvium has been replaced by or mixed with the clay, silt, and fine sand of tributary streams, although in some of those areas there is a coarse-grained basal deposit capable of yielding more than 200 gpm to properly developed wells.

TENNESSEE

New low ground-water levels

New alltime-low water levels recorded in Madison and Shelby Counties, in southwestern Tennessee, reflect increasing pumpage at Jackson and Memphis, respectively, according to R. H. Bingham. An observation well at Crosstown, 25 miles northeast of the center of withdrawal at Memphis, recorded effects of Memphis pumpage for the first time in 1964. The water level in this well reached a new alltime low of 199.33 feet below land surface and 0.77 feet below the previous low.

Ground-water development in Memphis area

Analysis of hydrologic data from the new Lichterman well field, in the "500-foot" sand aquifer at Memphis, by D. J. Nyman shows that the water-level gradient developed after the well field goes into operation will cause part of the aquifer within and to the east of the field to change from an artesian condition to either a semiartesian or a water-table condition. Because of the great variation in thickness of the capping clay, each of these three hydraulic conditions will exist at some places within a radius of a few miles of the center of pumping.

The natural isolation of the "500-foot" sand in the Memphis area from overlying and underlying aquifers affords a high degree of protection for the water, which is of generally excellent quality, but the possibility of recharge through adjacent aquifers cannot be ignored. Studies by E. A. Bell indicate that slight changes in chemical quality of the water in the "500-foot" sand, particularly increases in hardness and dissolved solids, correspond to changes in hydrologic conditions that reflect man's activities. The large extent of the "500-foot" sand and the slow rate of migration of water through this sand in the Memphis area are favorable for identifying potential changes of chemical quality of the water before it reaches points of discharge.

ALABAMA

Water-quality anomaly in Coker Formation

A study of the quality of artesian ground water in the Coker Formation of Late Cretaceous age in Tuscaloosa County, in west-central Alabama, by J. G. Newton shows the anomalous occurrence of ground water containing as much as 2,000 parts per million of chloride and 900 ppm hardness. The mineralized water is found in a well-defined belt 2 to 3 miles wide that trends southwestward, parallel to the regional dip of the Cretaceous formations and to the trend of major faults and folds in the Paleozoic rocks of eastern Tuscaloosa County.

Surface water in southwestern Alabama

L. B. Peirce and S. M. Rogers have outlined present and probable future surface-water conditions in an area of 15 counties in southwestern Alabama.

The average annual rainfall in the area studied ranges from 51 to 65 inches, and annual runoff ranges from 15 to 28 inches. These values reflect the considerable range in climatic and physiographic conditions in the area. On the average, evapotranspiration consumes about two-thirds of the annual rainfall. The average flow of the streams ranges from 1 to 2 cubic feet per second per square mile of surface drainage area. Low flows are considerably more variable, however, reflecting the diverse lithology and structure of coastal-plain aquifers. The low flow for 7 consecutive days that occurs every other year, on the average, ranges from no flow to more than 1 cfs per sq mi. Streams draining permeable sand and gravel in the coastal counties have the highest dry-weather flow; streams draining impermeable chalk of the Prairie Belt frequently cease flowing. Floods are likely in any month but are most common from February through April. Floods on the Alabama and Tombigbee Rivers rise and fall slowly and may last from 1 to 3 weeks or longer.

The stream waters are generally of good chemical quality; they are soft and have low dissolved-solid content. With few exceptions the waters of the area are of a quality suitable for most industrial or domestic uses. Stream temperatures range from low values of 38°–44°F in January and February to high values of 80°–92°F in July and August. The Alabama and Tombigbee Rivers furnish an abundant year-round supply of water at temperatures suitable for most industrial purposes.

MISSISSIPPI

Deepest fresh ground water in Mississippi

The deepest fresh ground water in Mississippi is indicated at 3,500 feet by electric logs in Smith County, in south-central Mississippi, according to Roy Newcome, Jr. Deep-lying fresh-water aquifers constitute potential sources of large water supplies in most parts of the Pascagoula River basin. The Wilcox Group in the northern part of the basin is virtually untapped. Miocene formations in the southern part of the basin contain thick aquifers at depths greater than those of present wells.

Ground water in delta area

B. E. Wasson has concluded, on the basis of several aquifer tests in the Mississippi River alluvium of the delta area in northwestern Mississippi, that very large quantities of water can be developed from shallow wells (100–150 feet deep) in most of the 22 counties of the area. The aquifer is readily recharged by precipitation (which totals about 52 inches per year) and by perennial streams that cross the delta. The combination of wide areal occurrence, ability to transmit water, and high recharge potential make the Mississippi River alluvium one of the major aquifers in the Nation.

Fresh water in Cretaceous aquifers

Investigations of Cretaceous aquifers in northeastern Mississippi by E. H. Boswell have shown that large supplies of fresh ground water are available in most of an area of about 3,500 square miles delineated on previous maps [17] as being underlain by highly mineralized water. Predictions based on interpretation of electric logs and hydrologic data have been confirmed by recent drilling which has resulted in the development of five new public water supplies and construction of wells in recreational areas; several additional public water-supply wells are being drilled or planned. The aquifers being developed are in sand and gravel of the Tuscaloosa Group. Wells range in depth from about 1,800 feet to more than 2,400 feet and yield several hundred gallons per minute. The dissolved-solids content of the water ranges from less than 500 parts per million to nearly 1,000 ppm. The aquifers contain fresh water considerably farther downdip than was previously thought possible, and at depths of more than 3,000 feet below the surface. The part of Mississippi in which aquifers yield less than 50 gpm or contain water having a dissolved-solids content higher than 2,000 ppm is now restricted to an area of less than 200 square miles in extreme northeastern Lauderdale and southeastern Kemper Counties, in the east-central part of the State.

High-production wells in Hancock County

Studies by Roy Newcome, Jr., and others reveal that water wells capable of yielding 5,000 gallons per minute or more each can be developed in deep-lying aquifers in Hancock County. Recently completed wells at the National Aeronautics and Space Administration rocket-test facility are 1,500–1,900 feet deep and have been tested at discharge rates of 1,100–5,000 gpm. Static water levels stand 80 to 104 feet above the land surface. The temperature of water in the deepest aquifer is 100°F. Pumping tests reveal aquifer transmissibilities as great as 200,000 gallons per day per foot. Dissolved-solids content increases with depth but is less than 350 parts per million in all deep aquifers sampled.

[17] C. L. McGuinness, 1963, The role of ground water in the national water situation: U.S. Geol. Survey Water-Supply Paper 1800, p. 445–446 and pl. 1.

LOUISIANA

Aquifers in Pointe Coupee Parish

Fresh ground water is available in southern Pointe Coupee Parish in south-central Louisiana to depths of about 2,600 feet below sea level, and in as many as 10 to 12 separate aquifers at one location. However, preliminary data reported by M. D. Winner, Jr., indicate that heavy withdrawals of ground water in the nearby Baton Rouge area are beginning to affect water levels in certain aquifers in southern Pointe Coupee Parish that are hydraulically connected with aquifers in the Baton Rouge area. Water-level declines of about 2 to 3 feet per year in excess of local pumping effects are being noticed in the southeastern corner of the parish.

High-chloride water in alluvium

Preliminary study of the Mississippi River alluvial aquifer in Franklin Parish, in northeastern Louisiana, by J. R. Marie indicates the presence of a zone of chloride-contaminated water within the aquifer. The chloride zone trends north-south and is 35 miles long; it is 2 to 4 miles wide and has a core of highly mineralized water flanked by zones of progressively less mineralized water. The greatest recorded chloride concentration is 4,090 parts per million.

Methane in ground water in Louisiana

A. H. Harder, and W. R. Holden of Louisiana State University (1–65), have described methods of detecting methane gas and determining its concentration in well water; and Harder, H. M. Whitman, and S. M. Rogers (2–65) have mapped the distribution of methane in the Chicot and Evangeline aquifers in southwestern Louisiana and have studied the potential explosion hazard of the gas. In most of the area studied the ground water now pumped from wells contains less than 1 part per million of methane. However, the concentrations found range from 0.0 to 40 ppm. Organic matter in the aquifers is believed to be the principal source of the methane, but some of it may have migrated from oil and gas sands near the producing fields. Theoretically, pumping water that contains more than 1.1 ppm methane at 74°F and at atmospheric pressure into poorly ventilated air spaces constitutes an explosion hazard.

Aeration of the water before use and adequate ventilation of air spaces in which the water is stored and used should eliminate the possibility of explosions of the methane.

ROCKY MOUNTAIN AREA

Inadequate distribution and supply continued to be the most serious water problems in the Rocky Mountain area, which includes all the States encompassing the Rocky Mountains, except Idaho, and the plains States from North Dakota to Texas. The most critical areas are those of large withdrawals of ground water for use in irrigation and, locally, for use in rapidly expanding municipalities.

The quality of both surface water and ground water has deteriorated locally because of (1) leaching of salts from the soils by irrigation, (2) induced flow from areas of high mineralization to areas of lower mineralization as a result of increased water-table gradients caused by heavy pumping, and (3) contamination by oil-field brines and other pollutants.

Increased competition between users of surface water and ground water in river valleys where the shallow ground water and the river constitute a single water resource has led to detailed studies of the entire water system in some basins. The data collected are now being used in the construction of analog models that simulate the system and facilitate more intelligent management of the supply.

Some of the significant results of investigations by the U.S. Geological Survey of water supplies in the Rocky Mountain area are described in the following section.

INTERSTATE STUDIES

Aquifer defined in Colorado River valley

A newly recognized aquifer of possible economic significance has been defined broadly by geologic mapping and test drilling in the Parker-Blythe-Cibola area, along the Colorado River in southwestern Arizona and adjacent California. Although a few wells near Parker have obtained part of their supply from this aquifer for many years, not until a recent study by D. G. Metzger (p. C203–C205) was the aquifer differentiated from much younger deposits and demonstrated to extend throughout the area. The aquifer, a fanglomerate of possible Miocene age, crops out in the vicinities of Parker and Cibola, but is buried throughout most of the area beneath estuarine deposits of possible Pliocene age. Further tests are needed to estimate potential well yields and to define the water quality.

Suspended sediment in Niobrara River

Analysis by M. L. Maderak and H. D. Stephens of streamflow and suspended-sediment data from the Niobrara River basin, in Nebraska, South Dakota, and Wyoming, indicates that 98 percent of the time the mean daily suspended-sediment concentration of the main stem ranges from 14 to 500 parts per million; 50 percent of the time the concentration is 79–1,500 ppm; and 0.2 percent of the time the concentration is 5,000–6,800 ppm. Data on the chemical quality of water indicate that, because of the large amounts of ground-water inflow, the relative proportion of the individual constituents tends to remain fairly uniform regardless of the flow.

MONTANA

Industrial pumping will affect artesian pressure in aquifer west of Cedar Creek anticline

An investigation by O. J. Taylor of an aquifer in the Fox Hills Sandstone and basal part of the Hell Creek Formation, on the western flank of the Cedar Creek anticline in eastern Montana, indicates that proposed industrial use of ground water from the aquifer will affect the artesian head in wells west of the anticline and the water table in the outcrop area. The response of the hydrologic system to the withdrawals was calculated using a proposed pumping schedule and known aquifer characteristics. Values of drawdown to be expected after 5, 10, and 21 years of pumping under this schedule were plotted on maps. The pressure in some domestic and stock wells will be affected by the drawdown during the first 10 years of pumping. Municipal wells in the area will be affected only slightly. Owing to reduction in the pumping rate with time, the artesian pressure will largely have recovered by the end of the proposed 21-year pumping period.

Aquifer tests reveal presence of fracture permeability

Fracturing has caused an irregular distribution of permeability in the Virgelle Sandstone in Glacier and Toole Counties, in northwestern Montana. Aquifer tests by R. G. McMurtrey and E. A. Zimmerman revealed coefficients of transmissibility in excess of 20,000 gallons per day per foot in some parts of the consolidated sandstone aquifer. The Virgelle, which provides stock and domestic water to many and widespread wells, has recently been tapped to provide water for secondary recovery of oil. This industrial use has now been largely suspended because of concern over possible depletion and unsatisfactory well performance.

Artesian water available in Blood Creek syncline area

Artesian water suitable for livestock use can be obtained from wells tapping the Judith River Formation in the Blood Creek syncline area of north-central Montana. W. R. Osterkamp and N. J. King have compiled contour maps of the top of the Judith River Formation and of its potentiometric surface from measurements taken at numerous wells in the area. The study indicates that flowing wells with yields up to 15 gallons per minute can be developed at depths of 300 to 1,000 feet.

NORTH DAKOTA

Water-level decline near Minot

According to W. A. Pettyjohn, the ground-water level in the Minot aquifer, in the Souris River valley at Minot, in north-central North Dakota, has declined more than 70 feet since 1915 and, in some areas, more than 20 feet since 1961. During 1963, water was withdrawn from the aquifer for the Minot municipal supply at an average rate of 3.8 million gallons per day, and the peak demand was over 7 mgd. Test drilling has shown that the areal extent of the aquifer is substantially less than was previously indicated. The aquifer will probably produce water at a rate of only 3 mgd under existing conditions without additional lowering of the water level.

Recharge to Heimdal outwash channel

Test drilling in Foster and Eddy Counties, in east-central North Dakota, has shown that segments of the present James River channel overlie the buried Heimdal outwash channel, which contains aquifers capable of large yields. Thus, flow in the James River may furnish part of the recharge to the Heimdal aquifers. According to Henry Trapp, Jr., two test holes drilled in the deep part of the Heimdal channel penetrated no significant thickness of sand or gravel, showing that the aquifers are not necessarily coextensive with the deepest parts of the channel.

Thick glacial drift overlies Missouri River valley

C. A. Armstrong reports that test drilling in Divide County, in the northwest corner of the State, revealed that as much as 638 feet of glacial drift overlies the ancestral Missouri River valley. Coefficients of transmissibility of buried outwash deposits range from about 13,500 to more than 10,000 gallons per day per foot. The ground water from the glacial drift is generally very hard and, except in areas of glacial outwash, contains more than 1,000 parts per million of dissolved solids.

Water levels decline near Fargo

R. L. Klausing reports that water levels in the West Fargo artesian aquifer, near Fargo, at the eastern edge of North Dakota, continue to decline because of increased industrial and municipal pumpage. The water level has declined from a high of about 26 feet in 1937 to the present record low of 108 feet below land surface. Near the center of the cone of depression the water level has declined below the top of the aquifer.

Undeveloped aquifer in Williams County

E. A. Ackroyd reports that alluvial deposits of sand and gravel in 120 square miles of the Little Muddy Creek valley, in northwestern North Dakota, yield ground water under artesian conditions. The maximum thickness of the aquifer is 137 feet. Only a small part of the available water is currently being withdrawn from the aquifer—mainly for domestic and stock use.

Productive aquifers found in Burleigh County

Studies by P. G. Randich show that aquifers adjacent to the Missouri River and in melt-water channels underlie an area of 230 square miles in southern Burleigh County in south-central North Dakota. Aquifer tests indicate that coefficients of transmissibility range from 10,000 to 350,000 gallons per day per foot. Approximately 7 million acre-feet of water is in storage in these aquifers, and it is estimated that 8,000 acre-feet per year moves from the aquifer to the Missouri River valley near Bismarck. According to J. L. Hatchett, most of the water has a high salinity hazard and a residual sodium carbonate classification of marginal to unsuitable for irrigation. These facts will require careful evaluation of the effect of this water on land and crops where it is currently being used for irrigation.

WYOMING

Ground water in Laramie County

In water-resources study of Laramie County, in southeastern Wyoming, M. E. Lowry and M. A. Crist determined that the water table has declined significantly only in the vicinity of the Cheyenne municipal well fields. Withdrawal of ground water for irrigation in the Pine Bluffs area has increased from about 1,500 acre-feet in 1936 to an estimated 17,000 acre-feet in 1964, with no significant water-level decline. Deep wells drilled recently in the central part of the county show that yields as great as 300 gallons per minute can be developed in many areas where only small-yield stock wells had been drilled previously.

Extensive aquifer in Great Divide basin

A reconnaissance of a 10,500-square-mile area, chiefly in Sweetwater County, in southwestern Wyoming, by G. E. Welder and L. J. McGreevy, indicates that about a third of the area is underlain by water of fair to good quality. The most promising aquifer with respect to both quantity and quality of water is in the Battle Spring Formation, in the eastern Great Divide basin. Deep wells tapping the Battle Spring at favorable locations would probably yield more than 500 gallons per minute of water having less than 300 parts per million of dissolved solids.

SOUTH DAKOTA

Undeveloped artesian water supplies

Rocks of pre-Cretaceous age in the Black Hills and southern Williston basin have been described by M. J. Ellis and C. F. Dyer as constituting the greatest potential source for development of large, permanent water supplies in western South Dakota. Nine rock units are known to be water bearing, and three of them, the Whitewood Dolomite (and equivalent Red River Formation), the Pahasapa Limestone (and equivalent Madison Group), and the Minnelusa Formation, have good to excellent potential for development. The strata are, in general, deeply buried and have been reached by very few water wells except near the Black Hills.

Glacial-outwash aquifers in Campbell County

Preliminary studies by N. C. Koch and L. S. Hedges indicate that a fifth of Campbell County, in north-central South Dakota, is covered by glacial-outwash aquifers. A buried valley extends from the Oahe Reservoir near Pollock east-southeastward to Herreid and then southward to the vicinity of Mound City. The valley is eroded more than 100 feet below the general bedrock surface and is filled with glacial sediments.

Large ground-water storage in Clay County

J. C. Stephens reports that more than 5 million acre-feet of ground water is contained in transient storage in glacial and alluvial material that underlies three-fourths of Clay County, in southeastern South Dakota. Preliminary analysis of aquifer-test data indicates that the average coefficient of transmissibility of the aquifer may be as high as 500,000 gallons per day per foot.

Ground water in Beadle County

Aquifers more than 25 feet thick in the glacial drift in Beadle County, in east-central South Dakota, contain more than 4,500,000 acre-feet of water in transient storage, according to Lewis Howells and J. C. Stephens; an additional 700,000 acre-feet of water is stored in aquifers 10 to 25 feet thick. Aquifer tests of the major aquifers in the drift disclosed that the coefficient of transmissibility ranges from 13,000 to 500,000 gallons per day per foot. The rate of withdrawal of water is estimated to have been more than 10 million gallons per day in 1962; of this total, nearly 3 mgd was from aquifers in the drift, and about 7 mgd was from bedrock aquifers.

NEBRASKA

Water level declines near Alliance

C. F. Keech reports that ground-water withdrawals for irrigation in an area north of Alliance, in western Nebraska, have lowered the water table as much as 40 feet since 1946. Recent measurements of water levels in 35 wells indicate that the water table has declined more than 20 feet over an area of 40 square miles and more than 40 feet in about 20 percent of the area.

UTAH

Large ground-water development in Utah

Ted Arnow reports that there are now 59 areas of known or potential ground-water development in Utah. The aquifers are consolidated rocks in 8 areas and unconsolidated rocks in 51 areas. Approximately 35,000 wells have been drilled in the State, and all except about 500 obtain water from the unconsolidated aquifers. The withdrawal of water from wells in the unconsolidated aquifers of the 19 most important areas totals nearly 600,000 acre-feet annually.

Large water discharge in Sevier Desert

R. W. Mower and R. D. Feltis estimate the minimum ground-water discharge in the Sevier Desert basin during 1964 to have been 165,000 acre-feet; of this total only 29,000 acre-feet was discharged by wells and 136,000 acre-feet was discharged principally by evaporation and by native phreatophytes. Decline of water levels in observation wells since 1950 was partly because of increased draft by wells and partly because of below-normal precipitation and attendant smaller quantities of recharge. Although discharge by wells increased from 1,500 acre-feet in 1950 the ground-water reservoir can be developed further, and with judicious selection of well sites it may be possible to increase withdrawal severalfold over that of 1964, without serious consequences.

Increased recharge in Pavant Valley

Water levels declined less than half as much in observation wells in the Kanosh district of Pavant Valley during 1964 as during any of the 4 previous years, according to R. W. Mower, although there were no significant changes in pumpage. The less-than-normal decline apparently was due to greater-than-normal recharge caused by runoff from a local thundershower on September 13, 1963, and by melt water from a thick snowpack (estimated to have attained 150 to 200 percent of the normal) during the last week of March 1964. The amount of water reaching a low area near the west-central part of the district, that contains several small sinkholes, was estimated to be 3,000–5,000 acre-feet. The ponded water disappeared within a short time after it had collected, apparently chiefly by draining through the sinkholes to recharge the shallow underlying basalt aquifer. These observations confirm an earlier conclusion that this low area is a major recharge area.

Water quality in Skull Valley

Data on the quality of ground water in Skull Valley, which extends southward from the southwest side of Great Salt Lake, indicate a wide range of water quality. According to Osamu Hattori, ground water in the northern part of Skull Valley is a sodium chloride water having about 1,000–7,000 parts per million of dissolved solids. The southeastern fourth of the valley contains calcium-bicarbonate or calcium-sodium-bicarbonate waters having generally less than 500 ppm of dissolved solids.

Ground water in solution channels in Scipio Valley

Ground-water levels in Scipio Valley, a topographically closed subbasin in western Utah, are unusual in that their depths change abruptly near the middle of the valley from about 50 to about 300 feet below land surface. L. J. Bjorklund and G. B. Robinson, Jr., report that the deeper water levels are in a zone of sinkholes formed by the solution of limestone along faults and joints in the North Horn Formation and in the Flagstaff Limestone, and by the subsequent collapse of overlying sediments. The faults traverse the valley in a northeasterly direction, and the sinkholes are alined along the faults. The deeper ground water moves along the solution channels toward the points of discharge at Moulten and Blue Springs, about 8 miles northeast of the middle of Scipio Valley. The springs control the elevation of the deeper water levels.

COLORADO

Water resources of Arkansas River valley

Additional data and the reevaluation of past records have furnished a dependable basis for the construction of an electrical analog model of the Arkansas River valley between Canon City and the State line, according to J. E. Moore and C. T. Jenkins. Measurements of coefficients of transmissibility and storage, water levels, the application of water for irrigation, withdrawals of ground water, and river gains and losses have been programmed into the analog model to simulate the hydrologic system. The amount of surface water applied, changes in ground-water level, and river gain and loss correspond closely. Stream reaches having the greatest loss are in the areas of greatest withdrawal of ground water and of greatest decline of ground-water level. Conversely, gaining reaches are in areas of little pumpage and steady or rising water level.

Ground-water supply and pumpage in Black Squirrel Valley

A study by E. D. Jenkins and H. E. McGovern defines the alluvium of Black Squirrel Creek valley in a part of El Paso County near Ellicott, in east-central Colorado. The sandy channels of Black Squirrel Creek and tributaries are dry most of the time but may carry large quantities of water during periods of excess precipitation, much of which percolates through the permeable sandy channel to the water table. Calculations show an annual recharge of about 10,000 acre-feet, with about 400,000 acre-feet of ground water in transient storage. During 1964, 7,000 acre-feet of ground water was pumped for irrigation and 5,200 acre-feet was pumped to Colorado Springs for municipal use. The chemical quality of the water is suitable for most uses.

KANSAS

Water quality in Walnut River

Four surveys were made to determine the chemical quality of base runoff of the Walnut River and most of its tributaries, in south-central Kansas, over a range of water discharge representing antecedent conditions of above-normal precipitation and of drought. As a result of the surveys, R. B. Leonard found that about 60–70 percent of the dissolved-solids load in the lower reaches of the Walnut River was derived from soluble rock. Most of the remainder, consisting largely of sodium and chloride, was probably residual salt leached from soil and shallow aquifers contaminated by oil-field-brine disposal installations, most of which have been abandoned.

Streamflow at most data-collection sites on the main stem was generally unsatisfactory for drinking water and was suitable for irrigation only on well-drained soils from which accumulated salts are leached periodically.

Seepage inflow to South Fork Solomon River

M. W. Busby reports a change in seepage inflow to the lower reach of South Fork Solomon River, in north-central Kansas, after development of the Webster Irrigation Unit. The inflow below the diversion dam increased from 7.8 cubic feet per second in 1959, before the Unit was in operation, to 10.5 cfs in 1964 after 4 years of operation. This represents a 35-percent increase in inflow during a period when there was a decrease in rainfall. Ground-water levels in the irrigated area adjacent to the stream were as much as 8 feet higher in 1964 than in 1959.

Ground water in Neosho Valley

W. L. Jungmann reports that test drilling and pumping tests in the Neosho River valley in Labette and Cherokee Counties, in the southeast corner of the State, suggest the general availability of as much as 50 gallons per minute of good-quality water in alluvial deposits of Illinoian and Wisconsin ages. This is an area in which only relatively low-yielding domestic and stock wells have been developed previously. As much as 50 gpm of water containing less than 500 parts per million of chloride is available from deep (about 800 feet) Ordovician rocks in a local area in southeastern Labette County. Elsewhere, these rocks generally yield highly saline water.

Ground water in Finney County

Unconsolidated deposits of Tertiary and Quaternary age constitute the most productive ground-water reservoir in Finney County, according to W. R. Meyer, E. D. Gutentag, and D. H. Lobmeyer. Pumpage from wells increased from approximately 71,000 acre-feet in 1940 to approximately 295,000 acre-feet in 1963, and the total discharge from 73,000 to 297,000 acre-feet. Total storage in the reservoir is computed to be approximately 20 million acre feet. Maps showing net changes in water level indicate that only 16 percent of the water pumped in the period 1940–64 was derived from the change in storage. The average recharge to the ground-water reservoir was about 2½ inches per year or approximately 121,000 acre-feet per year for this period. The annual discharge from wells is now exceeding recharge and is causing an average decline of approximately 1 foot per year over the county, whereas in the early portion of the period, recharge exceeded discharge and water levels were rising.

ARIZONA

Ground water resources of Kingman area

J. B. Gillespie and C. B. Bentley report that about 40,000 acre-feet of ground water is pumped annually for domestic and industrial supplies in the Sacramento and Hualpai basins of northwestern Arizona. There are 200 wells in the area; yields are as large as 2,000 gallons per minute. Water levels are from 400 to 1,000 feet below land surface in the central parts of the basins and 50 to 100 feet in some marginal areas.

NEW MEXICO

Paving a small watershed

Runoff after thunderstorms ranged from 16 to 67 percent of the precipitation on a 9-acre area that had been paved with asphaltic materials, according to W. C. Ballance. Runoff from an adjoining 9-acre tract having a natural surface ranged from 0 to 3.4 percent, and it occurred only when runoff from the paved area exceeded 40 percent of the precipitation. Most or all of the precipitation on the area with natural surface returned to the atmosphere through evapotranspiration; runoff from the paved area flowed into an excavated earthen tank, from which most of the water percolated to the ground-water reservoir.

Ground water in Roswell area

Restudy of subsurface geology of the Roswell artesian basin, in southeastern New Mexico, by G. E. Maddox and J. D. Hudson indicates that the shallow aquifer is not as large as was formerly believed. Many irrigation wells that were previously thought to be developed in the shallow aquifer are developed in an aquitard that lies between the shallow and artesian aquifers.

The direction of flow between the shallow and artesian aquifers in the Roswell basin has been reversed and now is from the shallow to the artesian aquifer. Ground-water discharge to the Pecos River in the Roswell basin now occurs only from the shallow aquifer.

OKLAHOMA

Ground water in cavernous gypsum

A study by C. E. Steele and J. E. Barclay indicates that ground-water resources in the southwestern corner of Oklahoma may now be overdeveloped. Cavernous gypsum in the Dog Creek Shale and Blaine Formation in Harmon and adjacent parts of

Greer and Jackson Counties forms one of the most productive solution-channel aquifers in the State. Although the aquifer contains about 336,000 acre-feet of water in storage in the irrigation area, annual pumpage of about 50,000 acre-feet appears to be greater than the average rate of replenishment. Water levels in the aquifer continued to decline during the relatively wet period from 1958 to 1962.

Ground water in Cleveland and Oklahoma Counties

P. R. Wood and L. C. Burton report that the principal source of ground water for municipal and industrial use in Cleveland and Oklahoma Counties, in the central part of the State, is the Garber Sandstone and the Wellington Formation. In these two counties the Garber and Wellington are estimated to contain about 34 million acre-feet of fresh water in available storage—more than 80 times the 400,000 acre-feet of water that has been withdrawn from the aquifer since pumping began in the early 1900's. Recharge averages about 72,000 acre-feet per year.

TEXAS

Iron in ground water in east Texas

In a study of the ground water in Camp, Franklin, Morris, and Titus Counties, in northeastern Texas, M. E. Broom, W. H. Alexander, Jr., and B. N. Myers found a general stratification of the ground water with respect to pH, hardness, and dissolved iron. The ground-water reservoir includes a shallow zone of oxidation, A; a deep zone of reduction, C; and an intermediate and unstable zone, B, in which the waters from above and below mix. Ground water from zones A and C generally is relatively free of iron, whereas water from zone B generally contains objectionable amounts of iron. Wells constructed to draw only from zones A or C should yield water relatively free of iron.

Vertical movement of ground water

E. T. Baker, Jr., found that in Jackson County, a heavily irrigated area along the Gulf coast of Texas, the shallow parts of the Gulf coast aquifer which are lightly pumped supply large quantities of water to the deeper, heavily pumped zone. The transfer of water to the heavily pumped zone from shallow sands was observed in a multiscreened irrigation well by spinner surveys using a deep-well current meter. When water levels were lowest, near the end of the irrigation season, the survey showed that 42 gallons per minute was continually being transferred through the well from the shallow sand to various deeper sands within the zone of heavy pumpage. After the irrigation wells in the area had been shut down for several months the transfer of water to the heavily pumped zone through the well had diminished to 14 gpm. The surveys indicate that the heavily pumped zone was effectively being repressured or replenished with water between the irrigation seasons.

Water of good quality in San Jacinto River basin

L. S. Hughes and Jack Rawson found that surface water in the San Jacinto River basin, in eastern Texas, is of excellent chemical quality and is suitable for most uses. The dissolved-solids concentration of most streams in the basin is generally less than 200 parts per million. Runoff from the outcrop areas of the Catahoula Sandstone, Lagarto Clay, and Oakville Sandstone in the upper part of the basin has dissolved-solids concentrations ranging from 100 to 200 parts per million; water draining from the outcrop areas of younger formations is less mineralized.

PACIFIC COAST AREA

The Pacific coast area includes the States of Alaska, California, Hawaii, Idaho, Nevada, Oregon, and Washington. It is an area in which precipitation ranges from zero in some desert areas of southern California and Nevada to nearly 500 inches annually on the slopes of Mount Waialeale on the Island of Kauai in Hawaii. It includes much of the Great Basin, from which no flow reaches the sea, and regions of the contrasting heavy flows of much of the Columbia River system and of the Yukon. The area has known searing droughts and devastating floods and includes problem areas of land subsidence and of sea-water intrusion, both related to ground-water withdrawals. The first commercial application of geothermal steampower in the United States was made in the region.

Land use in the Pacific coast area ranges from intensive agriculture and heavy industrial development to great National Parks and Primitive Areas set aside to be left perpetually in their wild state. The activities of man have caused, and are continuing to cause, major changes in the hydrologic regimen of the region. Inevitably there are large and growing problems resulting from concentration of population in areas of relative water shortage, and from the quantities of waste that impose loads upon some streams greater than the streams can carry without massive deterioration in quality.

The U.S. Geological Survey is making water-resources studies in each of the States in the Pacific coast area. These studies cover a broad spectrum of problems related to quantitative evaluation and continuing inventories of surface-water and ground-water supplies, of their chemical quality, and of the sediment loads of streams. Basic-data networks have been operative throughout the area for many years and are being expanded as need arises. The hydrology of selected river basins is being studied to develop a fuller understanding of the characteristics of the system to provide an improved base for planning of water-development projects. Special studies in limnology, glaciology, land subsidence, and geochemistry, for example, support the investigations of surface-water discharge, flood studies, ground-water evaluation, chemical quality of water, and sediment transport.

Some of the many water-resources activities in the Pacific coast area are described below.

ALASKA

Greater Anchorage area

The predicted water-supply demand of 60 million gallons per day for the year 1980 in the Greater Anchorage area can be supplied adequately through use of both surface and ground waters. Hydraulically connected streams and aquifers offer conditions suitable for the coordinated use of the total water resources, with an opportunity for artificial and induced ground-water recharge. Loss of considerable portions of the extensive artesian-aquifer system by sea-water intrusion and contamination through leakage of septic-tank effluents from the shallow water-table aquifer in the recharge areas pose the greatest potential hazards, according to D. A. Sommers.

Potential water sources on Annette Island, southeastern Alaska

At least two levels of raised beach deposits are present on Annette Island in extreme southeastern Alaska. M. V. Marcher points out that locally the beach deposits are the source of seeps and springs and may be a significant source of water to properly constructed wells or infiltration galleries. Test drilling has verified the presence of ground water in the sand and gravel beds.

Water from crystalline rocks

Although crystalline rocks have not been considered favorable for drilling in southeastern Alaska, M. V. Marcher reports that test wells on Annette Island show that ground water is available from highly fractured igneous rocks near Tamgas Harbor and Annette Island airport, and from phyllite and schist underlying the village of Hoonah. In interior Alaska test drilling at the hotel in Mount McKinley National Park showed that small amounts of ground water can be obtained from schist in that area. At the Wonder Lake Ranger Station, also in the park, a well yielded about 1 gallon per minute from fractured schist below 190 feet of permafrost.

PACIFIC NORTHWEST

The Pacific Northwest comprises the States of Idaho, Oregon, and Washington. The mountainous areas are extensive and well watered, with precipitation reaching a high of about 200 inches per year in a few spots along the Washington coast and a peak of 100 to 120 inches elsewhere along the coast. East of the coastal mountains, however, precipitation declines rapidly, and in each of the three States there are areas which receive only about 8 inches of precipitation per year. Thus, runoff is abundant in many areas but semiarid conditions prevail in parts of each State. In December 1964 and January 1965 serious floods occurred in western Oregon.

Because of international agreements relative to water of the Columbia River and interstate agreements relative to water of the Snake River, the basic-data networks related to the discharge and chemical quality of these streams have long been important.

Hydrology of Snake River Plain, southern Idaho

A study by E. H. Walker suggests that the Snake River Plain aquifer of southern Idaho received about 3,260,000 acre-feet per year of recharge in the mid-1950's by infiltration from lands irrigated with surface water. These new estimates were made in cooperation with the U.S. Bureau of Reclamation, for design of an electric-analog model of the aquifer. The contribution from irrigation was about 47 percent of the total recharge, 6,940,000 acre-feet per year, and 80 percent as much as the total recharge to the aquifer in the early 1900's before man had appreciably altered the natural regimen of the aquifer. Present conditions are not greatly different from those of the mid-1950's.

Electric-analog model studies in southeastern Idaho

J. G. Crosthwaite, M. E. Mundorff, and E. H. Walker used a steady-state analog model analyzer developed by R. W. Stallman to estimate seepage losses from a proposed reservoir site on the lower Teton River in southeastern Idaho. The study indicates that seepage losses would not exceed 4 percent of the average annual flow of the river.

Ground water resources of Island County, Wash.

An appraisal by H. W. Anderson of the ground-water resources of Island County, in Puget Sound, shows that throughout most of the county, wells can supply enough water to satisfy municipal and rural domestic and irrigation demand. Virtually all ground water now developed or capable of being developed occurs in permeable glacial or interglacial deposits of Pleistocene age. A major water-bearing zone lies near sea level, extending just above and below it throughout much of the county.

Ground water in Baker County, Oreg.

According to G. L. Ducret and D. B. Anderson, large quantities of water are available for irrigation and other uses from wells tapping alluvial deposits in Baker Valley, Oreg., and from basalt aquifers in nearby areas east of the valley. Wells yielding as much as 1,000 gallons per minute tap sand and gravel aquifers in valley alluvium and alluvial-fan deposits, and wells yielding as much as about 1,500 gpm tap lava rock and cinders.

Donald Price found that the three main agricultural segments of the Burnt River valley, in Baker County in eastern Oregon, are underlain by fine-grained fluviolacustrine deposits of Miocene and Pliocene age that yield only small quantities of water to wells and springs in the valley. However, permeable gravel layers and intercalated lava flows known to be present locally may yield moderate to large quantities of water to wells, provided that the flows and layers extend below the water table.

Ground water in Eola–Amity Hills area, Oregon

Because of the diversity of geologic conditions the availability and quality of ground water vary considerably within the 230-square-mile Eola-Amity Hills area of the northern Willamette Valley, Oreg. Donald Price reports that young alluvium of the Willamette River yields large quantities of good-quality water to wells. In contrast, marine sedimentary rocks, which underlie much of the western half of the area, yield only small quantities of water to wells, and the water generally contains a relatively large concentration of chloride.

NEVADA

Nevada probably receives less moisture per square mile from precipitation than any other State in the Union. A small available supply is its first water problem. Streamflow from the Sierra Nevada and rights to share in water of the Colorado River partly alleviate the problems of supply. In addition, some valleys in the State are presently at a stage of modest development which leaves existing supplies of ground water adequate for existing needs. Important basic-data networks were continued and augmented.

Reconnaissance ground-water studies continued

Reconnaissance ground-water studies have been completed or were in progress in 11 valleys during the year. Preliminary estimates of perennial yield, based on estimates of average annual recharge to and discharge from the ground-water reservoir for several of the valleys, are as follows: 10,000 acre-feet for Smith Creek valley, Lander County (D. E. Everett and F. E. Rush, 1–64); 6,000 acre-feet for Ione Valley, Nye County (Everett and Rush, 1–64); 13,000 acre-feet for Grass Valley, Pershing County (Philip Cohen and D. E. Everett, 5–64); 21,000 acre-feet for Monitor Valley, Nye and Lander Counties (F. E. Rush and D. E. Everett, 2–64); 4,000 acre-feet for Antelope Valley, Eureka County (Rush and Everett, 2–64); 16,000 acre-feet for Kobeh Valley, Eureka County (Rush and Everett, 2–64); 37,000 acre-feet for Upper Reese River valley, Lander and Nye Counties; and 2,000 acre-feet for locally derived ground water in the Oreana subarea of Lovelock Valley, Pershing County; and about 70,000 acre-feet for Spring Valley, White Pine County.

Regional ground-water system identified

A regional ground-water system in the White River valley area in eastern and southeastern Nevada has been defined more fully than before (T. E. Eakin, 1–64; T. E. Eakin and I. J. Winograd, 3–64); I. J. Winograd and T. E. Eakin, 1–64). The 7,700-square-mile area which comprises the system includes 13 valleys along and adjacent to the Pleistocene channel of the White River. Although interbasin movement has been described in eastern and southern Nevada in recent years, the extent of the system was not previously understood. Carbonate rocks of Paleozoic age which occupy much of a large miogeosynclinal area of eastern and southern Nevada and western Utah and which have been subjected to a very complex structural history appear to be the principal media for the regional transmission of ground water. Superimposed over the bedrock aquifer are alluvial aquifers of the Basin and Range type. Water-budget studies of the alluvial aquifers, the most important type in the State, are complicated by the fact that the carbonate rocks may carry water from one basin to another through the bounding mountains. Most alluvial valleys in the Basin and Range province can be considered to be discrete hydrologic units except for such streams and shallow alluvial channels as may connect them.

Humboldt River project completed

The interagency Humboldt River Research Project study near Winnemucca, Nev., by Philip Cohen (2–64, 3–64) and others, completed in 1964, indicates that the average annual inflow to the area studied was about 250,000 acre-feet in water years 1949–62. Of this amount, about 68 percent was Humboldt River streamflow, 23 percent was precipitation on the area, 6 percent was subsurface ground-water inflow, and about 3 percent was tributary streamflow. The average annual surface-water outflow was about 155,000 acre-feet, or about 17,000 acre-feet less than the surface-water inflow. The total average annual evapotranspiration loss was about 115,000 acre-feet.

Surface-water resources of Nevada

R. D. Lamke and D. O. Moore estimate that the average annual runoff within Nevada is 3,500,000 acre-feet. The average annual streamflow for the 1912–63 reference period was 1,500,000 acre-feet entering the State and 850,000 acre-feet leaving the State. The estimated average annual water supply available to Nevada is 4,100,000 acre-feet. The estimated average annual precipitation over the entire State is slightly more than 9 inches, or about 54,000,000 acre-feet. The statewide runoff is thus about 6½ percent of the precipitation.

An inventory of the better-known Nevada springs indicated that the total annual springflow may average more than 300,000 acre-feet. There was 170,000,000 acre-feet of water stored in lakes and reservoirs in and bordering Nevada as of October 1, 1963. About 30,000,000 acre-feet was contained in lakes and reservoirs wholly within Nevada.

Ground-water storage depleted in Quinn River area

A study of the Quinn River valley area in northern Nevada by C. J. Huxel shows that since 1950, pumping of ground water for irrigation has resulted in depletion of ground-water storage by about 120,000 acre-feet and an average water-level decline of about 22 feet. The moderately large water-level decline is caused by the concentration of pumping in the southern part of Quinn River valley. During the past 5 years, pumpage has increased from 23,000 to 40,000 acre-feet per year.

Water regimen changing in Kings River valley

Investigation by G. T. Malmberg of the manageable water resources of Kings River valley in Nevada and Oregon indicates that the average annual surface-water inflow is about 7,300 acre-feet; the average annual recharge to the ground-water reservoir is nearly 20,000 acre-feet. Although most of the surface water was diverted for irrigation, only about one-third is consumptively used. Most of the remaining 5,000 acre-feet infiltrates to the ground-water reservoir.

In 1964 the pumpage, about 22,000 acre-feet, was used to irrigate about 6,000 acres. During the period 1956–63, the net depletion by pumping and natural discharge of ground water in storage totaled about 60,000 acre-feet. The water table has been declining progressively at about 3 feet per year since pumping began, but the rate probably will increase due to the effects of bedrock boundaries. If pumping is continued at the same rate as in 1964, the water table at the pumping centers can be expected to drop about 30 feet in 10 years, thereby reversing the hydraulic gradient and causing practically all ground water in the northern half of the valley to move toward the pumped area.

CALIFORNIA

Water problems in California varied in degree rather than in kind during the year. In southern California, runoff continued below average. However, during December 1964 and January 1965 severe floods occurred in the north, causing loss of life and heavy destruction of private property and of public facilities. At one key station on the North Fork American River, discharge in December 1964 was 2,190 percent of the median for the month. Tens of gaging stations, part of the surface-water basic-data network, were damaged or totally destroyed by floodwaters. These have been restored to operation as rapidly as water and weather conditions allowed. Special attention has been given during the year to collection of basic data on ground-water levels and chemical quality in the Mojave Desert region.

Work continued on studies of land subsidence, effects of urbanization on the hydrology of small watersheds, and the hydrologic regimen of individual ground-water basins. The status of water supplies for numerous military installations throughout the State was again assessed as part of a continuing inventory made in cooperation with the U.S. Department of Defense.

Relation between ground water and surface water in Santa Ana River valley

In a study of the reach of the Santa Ana River between Riverside and Prado Dam, in southern

California, J. J. French, E. R. Hedman, and L. C. Dutcher found that the net ground-water contribution to surface flow has decreased during the period 1933 to 1964. Both surface-water inflow to the reach and evapotranspiration losses in the bottom lands along it have remained relatively constant during this period, but the water table has declined.

Multiple piezometers installed in central California

J. F. Poland reports that a multiple-piezometer observation well constructed in a subsidence bowl near Pixley, in the southern San Joaquin Valley, is providing data on artesian head in six well-defined individual beds of sand and gravel. These strata are the principal aquifers in an alluvial aquifer system, 500 feet thick, which is heavily pumped through fully perforated gravel-packed irrigation wells and is compacting as a result of head decline. The piezometers have demonstrated that significant head differences exist among the several aquifers, both in response to pumping and during prolonged intervals of no pumping. During the irrigation season a normally downward vertical gradient through the aquifer system is reversed.

Areal ground-water studies, Santa Barbara County

An investigation by K. S. Muir indicates that there is about 280,000 acre-feet of potable ground water in storage in the aquifers underlying the city of Santa Barbara and the adjacent area of Montecito, in coastal southern California. This ground water is stored in fine-grained deposits in a zone between the altitudes of 250 feet above sea level and 200 feet below sea level.

Study of inflow-outflow relationships in the Lompoc subarea of the Santa Ynez River basin by R. E. Evenson, for the period 1957–62, indicates a possible perennial supply of 22,000 acre-feet. The amount actually produced in the future may be less than this estimate, however, because of two factors: (1) reduction in amounts of water pumped for irrigation, and (2) changes in water quality due to recycling of irrigation water and the inflow of poor-quality connate water from the consolidated rocks that might require reduced draft in some parts of the subarea.

A ground-water appraisal in the Santa Ynez Upland area by G. F. LaFreniere has led to the following results: (1) the extent of the upland area as defined by J. E. Upson in 1952 has been increased about 40 square miles bordering Happy Canyon, by recognition of the hydrologic continuity of water-bearing deposits in the two areas; the upland is important as a recharge area in the Santa Ynez subarea of the Santa Ynez River Valley; (2) evidence has been found that only a minor amount of recharge can be expected to the basin from Cachuma Reservoir which presently inundates the Paso Robles and Careaga Formations in Cachuma and Santa Cruz Canyons; (3) an estimate has been made of 10 million acre-feet of water in storage in the entire ground-water basin, but a perennial yield probably not exceeding 8,000 acre-feet.

HAWAII AND GUAM

The high permeability of most of the volcanic-rock aquifers of the Hawaiian Islands promotes rapid recharge but inhibits development of sizable surface runoff in most areas. All ground-water bodies in the islands are probably in contact with sea water. As a result it is necessary to maintain a safe and sometimes delicate balance between recharge and the withdrawal of water so as to minimize mixing of fresh and salty water and to preserve the usefulness of pumped supplies.

The U.S. Geological Survey maintains continuing data-collection programs to monitor surface-water, ground-water and chemical-quality conditions on the islands. Areal hydrologic studies were a significant part of the investigations. During the year, personnel of the Hawaii district also participated in water-supply studies on the Island of Guam. Results of some of the studies are presented below.

Ground water studies on Oahu, Hawaii

Between 7 and 15 million gallons per day of irrigation water is recharging the shallow ground-water body in the coastal part of the Mokuleia area, in northwestern Oahu. Aquifer tests and allied investigations by J. C. Rosenau, E. R. Lubke, and R. H. Nakahara indicate that up to 5 mgd of this might be intercepted through the pumping of large-diameter shallow wells dug in the permeable limestone and dune-sand deposits of the shore area. Beneath this shallow aquifer the deeply buried lavas of the Waianae Volcanic Series discharge perhaps as much as 10 mgd to the sea.

In a study of ground water in the coastal part of the Kahuku area in northern Oahu, K. J. Takasaki and Santos Valenciano have found that the water in the upper part of the fresh-water lens has a higher content of chloride and nitrate than water deeper in the lens. The high chloride content results from infiltration of irrigation water pumped from wells affected by sea-water intrusion; the nitrate is contributed by fertilizers applied to the irrigated sugarcane fields.

Water resources of the Hilo-Puna area, Hawaii

Although rainfall is abundant up to an altitude of 5,000 feet in the Hilo-Puna area of Hawaii, there is but little runoff of surface water, according to George Yamanaga and D. A. Davis, because of the highly porous nature of the lava-flow terrane. Most of the discharge into the sea is at many springs along the shore. In the Hilo area, the visible flow of springs amounts to several hundred million gallons of water having low salinity. Locally in the Puna area the ground water is characterized by high temperature and high salinity which are thought to be due to volcanic activity along the southeast rift of Kilauea.

Hydrology of Guam

Studies in Guam by P. E. Ward, S. H. Hoffard, and D. A. Davis [18] show that the average runoff to the sea in the southern half of the island is roughly 250 million gallons per day. This amounts to about half the daily rainfall on the drainage basins, which are underlain by volcanic rock having generally low permeability. The northern half of the island is a highly permeable limestone terrane in which virtually all the flow of water to the sea is underground through a fresh-water lens near sea level. Sea-level fluctuations resulting from tides and storm waves are transmitted far inland through the permeable rock and cause mixing of the fresh water with sea water. Consequently, ground water in the limestone is brackish in most of the coastal area.

MANAGEMENT OF NATURAL RESOURCES ON THE PUBLIC LAND

In order for the standard of living to keep pace with population expansion, wise management of the Nation's resources is essential. The lands owned by the Federal Government make up an important percentage of this Nation's resource base (fig. 2) and as a result require increasing attention to keep up with development needs. Management control is exercised by several agencies of the Government, depending upon the type of resource, the kind of ownership, and the various legal authorizations involved. The Conservation Division of the U.S. Geological Survey performs a number of important tasks in this connection. Through its Branches of Mineral Classification and of Waterpower Classification the division classifies the public lands for leasable mineral values and for waterpower purposes. Through

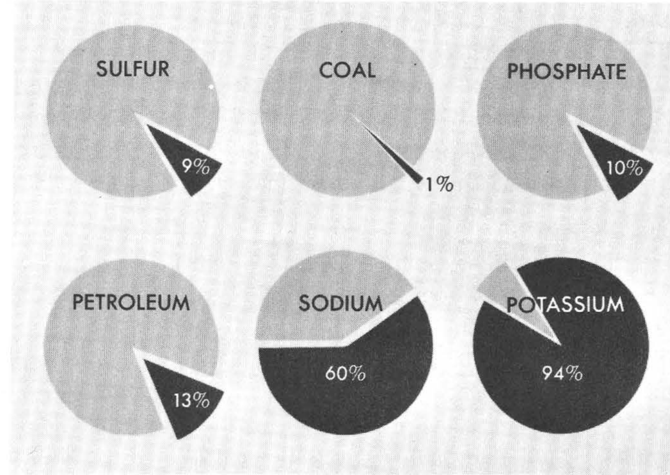

FIGURE 2.—Percentage of total United States mineral production that comes from Federal land.

its Branches of Mining Operations and of Oil and Gas Operations it supervises prospecting, development, and recovery of minerals from wells and mines under leases, permits, or licenses on Federal and Indian lands.

Field offices of the Division are listed on page A211. Geologic and hydrologic work in progress by geologists and engineers of the Conservation Division is given in the list of investigations starting on page A217, under the categories of geologic mapping, glaciology, waterpower classification, and various commodities such as coal and petroleum and natural gas. Scientific and economic results of these investigations are published as books and maps in the regular series of Geological Survey publications. Important scientific findings of current interest by Division geologists are included in the section "Regional Geology."

CLASSIFICATION OF MINERAL LANDS

The principal leasable minerals are oil, gas, oil shale, coal, phosphate, sodium, and potash. Since 1906, public lands believed to contain leasable minerals have been withdrawn from entry by the Secretary of the Interior, on the advice of the U.S. Geological Survey, pending their classification as mineral or nonmineral lands. Much of the task has been completed, but at present about 41 million acres of land is so withdrawn.

In order to classify land for its mineral value, the geology must be mapped in detail, usually at a scale of 1:24,000. Existing geologic maps are used where of suitable quality and scale. Mapping for mineral-land classification differs in some details from gen-

[18] P. E. Ward, S. H. Hoffard, and D. A. Davis, 1965, Hydrology of Guam: U.S. Geol. Survey Prof. Paper 403-H. [In press]

eral geologic mapping in that more measurements of stratigraphic sections per quadrangle are required to show thicknesses of coal or other leasable minerals, and more frequent sampling is necessary to determine mineral quality. Drill-hole cuttings or cores and electric or radioactivity logs provide subsurface data for classification. Samples obtained from surface and subsurface operations are analyzed in the laboratory. When the areal extent, thickness, and grade of mineral deposits are established, the land containing them is classified as to its value for mineral resources. The geologic maps produced for classification purposes are published in the standard map series of the Geological Survey.

WATERPOWER CLASSIFICATION

Classification of public lands to conserve and utilize water resources was begun in 1888, to preserve reservoir sites for irrigation. It has been continued chiefly for hydroelectric development. Present activity includes stream-basin investigations, a review of land classifications and reserves, and the measurement of selected glaciers.

The program of stream-basin investigations is a systematic search for basins and subbasins where water projects can be developed in the future to serve the needs of a growing population. Sites that meet the criteria for classification are set aside by the Secretary of the Interior on the recommendation of the Geological Survey, through procedures established by Congress and the Department of the Interior. Land set aside by these procedures may be disposed of only according to procedures which provide that it may be reacquired by the Government for purposes of waterpower development without cost. Some 16 million acres are presently involved in this program.

A program to reassess all land classifications and reserves was begun in 1956. Many classifications and reserves had been made before 1920 under Congressional and departmental urging for immediate protection of sites for waterpower development. Because of this urgency many of the classifications were based on inadequate mapping and hydrologic data. Under the present program all reserves are being reevaluated and classified by rigorous standards. Lands that do not qualify as waterpower sites are removed from the reserves and are opened to disposition under the public-land laws. Progress through fiscal 1964 on this program indicates that as much as 50 percent of lands now reserved for waterpower may eventually be eliminated from the reserves.

River and lake basins are mapped mostly at a scale of 1:24,000. Contours of lake bottoms are compiled by precise sounding surveys. The results of investigations are published as river survey maps, a regular Geological Survey map series.

A special project to gather information on the rates of ablation and the recession or advance of selected glaciers was started in 1951 on Nisqually Glacier in Mount Rainier National Park, Wash., and in 1944 on Grinnell and Sperry Glaciers in Glacier National Park, Mont. Annual measurements are made at monumented cross sections, and the glaciers are mapped completely at 5-year intervals. In 1961, at the request of and in cooperation with the U.S. Bureau of Reclamation, measurements were begun on Barrier Glacier, Mount Spurr, Alaska, to determine what effect the growth or shrinkage of the glacier has on fluctuations in the level of Lake Chakachamna.

SUPERVISION OF PROSPECTING, DEVELOPMENT, AND RECOVERY OF MINERALS

Supervision of operations under mineral leases entails the investigation of lands and deposits under application for mineral leases, oil and gas leases, and prospecting permits; recommendation of lease terms and unit areas; enforcement of operating regulations and measures to assure the safety and welfare of workmen; maintenance of production records; and determination and collection of royalties and rentals. The mineral supervisory branches of the Conservation Division also act as advisors to the Secretary of the Interior, to other bureaus of the Department, and to other Government agencies concerned with the administration of the Mineral Leasing Laws.

Royalties from public lands are distributed 52½ percent to the reclamation fund, 37½ percent to the States in which the minerals or fuels are produced (except for Alaska, which receives 90 percent), and 10 percent to the Federal Treasury. Royalties from other land categories are distributed in many different ways as provided by law, but the largest share of these royalties is returned directly to the Federal Treasury.

Mining operations

The Branch of Mining Operations supervises operations concerned with discovery, development, and production of coal, oil shale, phosphate, potassium, solid and semisolid bitumen, and sodium from public land; and of sulfur from public land in Louisi-

Mineral production, value, and royalty

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other[1] (tons)	Value (dollars)	Royalty (dollars)
Public	181,726,000	641,276,000	484,478,000	26,470,000	765,910,000	80,754,000
Acquired	9,747,000	24,067,000	342,000	321,000	43,223,000	4,620,000
Indian	35,584,000	100,143,000	129,204,000	9,371,000	139,711,000	17,157,000
Military	2,857,000	63,617,000	74,327,000	----------	19,755,000	3,789,000
Outer Continental Shelf.	128,656,000	636,150,000	----------	1,050,000	527,083,000	92,051,000
Naval Petroleum Reserve No. 2.	4,000,000	5,800,000	10,500,000	----------	14,873,000	1,925,000
Total	362,570,000	1,471,053,000	698,851,000	37,212,000	1,510,555,000	200,296,000

[1] All minerals except petroleum products; includes coal, potassium, sodium, and so forth.

ana and New Mexico. The Branch also supervises (1) the production of silica sand on certain lands in Nevada; (2) mercury on certain Spanish land grants; (3) all minerals except oil and gas on restricted, allotted, and tribal Indian lands; and (4) all minerals recoverable in commercial quantities, except oil and gas, on acquired lands.

The column entitled "other" in the preceding table shows production of minerals from leased Federal lands under supervision of the Branch of Mining Operations for the fiscal year ending June 30, 1965.

Oil and gas operations

The Branch of Oil and Gas Operations supervises the discovery, development, and production of crude oil and natural gas and associated products from leased public, acquired, Indian, Outer Continental Shelf, and Naval Petroleum Reserve lands.

The table shows the production of crude oil and gas, the value of all mineral products, and the royalties received from supervised leases on the various categories of Federal and Indian lands during fiscal 1965.

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND PUBLIC HEALTH

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

Nuclear reactors and underground nuclear explosions release radioactive products to the geologic and hydrologic environments. In the interest of public safety, the distribution, movement, and concentration of these products must be determined and the potential hazard evaluated. Large nuclear explosions may produce excessive ground motion and the geology of the affected areas must be evaluated in the planning stage in the interest of public concern. In addition, the engineering and construction of facilities for nuclear reactors and underground nuclear explosions at proposed sites present difficult problems requiring a thorough knowledge of the geologic and hydrologic conditions in a variety of natural environments.

Since 1956 the U.S. Geological Survey has provided geologic and hydrologic information and evaluation of sites for underground nuclear explosions at the Nevada Test Site, and at sites for PLOWSHARE (peaceful uses of nuclear explosions). In connection with these programs the Geological Survey performs a broad range of studies ranging from detailed evaluation of specific sites and the geologic and hydrologic effects of explosions at specific sites, to areal geologic studies of areas contiguous to test sites.

SITE EVALUATION

Tunnel-site development, Nevada Test Site

Many of the military effects of nuclear explosions are studied by means of explosions in tunnels at the Nevada Test Site. Very detailed geologic exploration and appraisal is required to ensure that the tunnels are properly located. Several examples of this type of appraisal are given below:

At one test site a shear zone was discovered during exploration of a proposed working point. On the basis of detailed study, R. E. Davis concluded that the proposed working point was unsuitable. A reappraisal of the geology of the area by W. L. Emerick and T. L. Prather established a new working-point location free of faulting.

In a tunnel on Rainier Mesa two sites were relocated in an area of the tunnel that is relatively free from jointing and faulting to allow tunnel construction with a minimum of mining difficulties.

J. R. Ege made the geologic studies necessary for the location and construction of a test site in the Climax granitic stock. During the course of exploratory drilling at the site he devised a system of drill-core classification which serves as a basis for determining the suitability of the underlying rock for tunnel construction. As a result of careful study of the fractures in the tunnel and vicinity, Ege was also able to determine a major joint set which was used to determine the position of a cavity constructed at this site.

Velocity layering of rock surrounding tunnels in the Climax stock

Seismic studies were made in tunnels in the Climax granitic stock, Nevada Test Site, to determine the thickness of a layer of low-velocity rock that has been found to exist around tunnel openings. It is believed that these layers develop by different mechanisms in different rock types. In compressible, porous rock such as sandstone and tuff, it has been shown that velocity depends on porosity and pressure. In these rock types the low-velocity layer probably develops as decreased pressure permits the rock to expand and interstitial porosity to increase. Secondary fracturing along joints and bedding planes probably also affects the velocity in the zone of expansion. In rocks of low interstitial porosity such as limestone and granite, the low-velocity layer is probably caused by the enlargement of existing fractures and the formation of new ones along planes of weaknesses as the rock expands inward in response to stress relief.

J. H. Scott and R. D. Carroll made in-hole and refraction seismic measurements to determine variations in the thickness and velocity of the low-velocity layer surrounding tunnels constructed in quartz monzonite and granodiorite of the Climax stock. Measurements were made in different qualities of rock, with fracturing ranging from minimum to severe. In general the thickness of the low-velocity layer ranged from 0 to 8 feet, and its velocity ranged from 5,000 to 14,000 feet per second. Velocity of normal rock behind the low-velocity layer ranged from 14,000 to 25,000 fps. Ranges of thickness and velocity were about the same for quartz monzonite and granodiorite. The lowest velocities were associated with rock that was most severely fractured, and the thickness of the low-velocity layer appeared to be affected by the direction as well as the density of fracturing. The present preliminary study provided only semiquantitative relationships between fracturing, velocity, and thickness of the low-velocity layer. Future detailed studies are planned from which quantitative correlations of the parameters of interest in various rock types may be made.

Evaluation of the LONG SHOT site, Amchitka Island, Alaska

The geology of Amchitka Island in the Aleutian Islands was studied by L. M. Gard to evaluate the suitability of the island for Project LONG SHOT, which is a proposed underground nuclear explosion for improving detection of underground nuclear explosions. These field investigations aided in deciphering the subsurface geology at the site. Exploration of the site to a depth of 2,600 feet was accomplished by core holes drilled by the U.S. Army Corps of Engineers.

The site is located in a thick sequence of gently dipping Tertiary volcanic detritus cut by linear fracture zones. The rocks are partly altered basaltic volcanic breccias of the Oligocene to Miocene Banjo Point Formation containing two andesite sills near the working point. Hydrologic testing showed that the fracture zones and sills are much more permeable than the bulk of the Banjo Point Formation.

Byproducts of the fieldwork resulted in revision of knowledge of the stratigraphic sequence on Amchitka Island. The Banjo Point Formation, previously described as older than the Chitka Point Formation, was found to conformably overlie and interfinger with the Chitka Point Formation. Rocks of the Amchitka Formation, thought to be the oldest exposed on the island, because they are intensely altered and recrystallized, were found to be merely rocks of the Chitka Point and Banjo Point Formations that have been locally metamorphosed near large intrusive bodies.

The Chitka Point and Banjo Point Formations contain many turbidites (submarine mudflows) not previously described from the island.

The island was revisited shortly after the 7.5-magnitude (Richter scale) earthquake of February 3, 1965. Only slight damage was found to have occurred in the form of slumping of road fills. Evidence was seen that a tsunami (seismic sea wave) had moved flotsam about 6 feet above high tide.

PLOWSHARE PROGRAM

The aim of the PLOWSHARE Program of the U.S. Atomic Energy Commission is to develop peaceful uses of nuclear explosions. The U.S. Geological Survey participates in and contributes to this effort in various ways, including selection of sites potentially useful for experiments, making detailed studies of the geology and hydrology of explosion sites, and making feasibility studies of beneficial applications of nuclear explosions in the field of natural resources.

Applications of nuclear explosions to water-resources development

Potential applications of nuclear explosives to water-resource development and management have been appraised by A. M. Piper and F. W. Stead (1–65) and F. W. Stead (1–64). Nuclear explosions fully contained underground may offer very substantial advantages and economies under certain limited hydrologic situations; however, much more must be learned about the phenomena of such detonations before their effects can be adapted to each particular situation, with assurance that the seeming advantage can be realized in full while undesirable side effects are constrained as circumstances require.

GEOLOGIC AND HYDROLOGIC EFFECTS OF NUCLEAR EXPLOSIONS

Explosion-produced fractures in Yucca Flat, Nevada Test Site

Underground testing of nuclear devices has been, and is currently being, conducted in Yucca Flat, at the U.S. Atomic Energy Commission's Nevada Test Site. Yucca Flat is an alluvium-filled valley underlain by tuff which is in turn underlain by generally more competent sedimentary rocks. Most of the devices tested to date were detonated either in alluvium or tuff. D. D. Dickey has studied maps of the fracturing, at the surface, produced by the explosions and concludes that the surface fracture pattern is influenced by the rock surrounding the explosion. Tests in the northern part of Yucca Flat show particularly well a symmetrical pattern of radial and concentric fractures in alluvium for explosions in alluvium, whereas explosions in the underlying tuff produce fractures in alluvium with a strong asymmetrical northeast-trending pattern, with many northeast-trending fractures. The northeast direction is parallel to a strong set of northeast-trending pre-explosion joints in the bedrock at the northeast edge of Yucca Flat. In instances where the cavity from an explosion in tuff has collapsed and a crater or sink allowed to form in the alluvium at the surface, the resulting fracture pattern is that of the characteristic northeast-trending pattern for explosions in tuff, superimposed upon a pattern characteristic for explosions in alluvium.

Activation of Yucca fault, Nevada Test Site, by underground nuclear explosions

Underground nuclear explosions in Yucca Flat have caused displacement along the Yucca fault. The formula $S = \frac{D}{W^{1/3}}$ can be applied to determine if the fault will show additional displacement as a result of a particular underground nuclear explosion. In the above formula, S is scaled distance, D is distance in feet from the explosion point to the fault, and W is the yield of the device in kilotons equivalent TNT. Where S for a particular explosion is less than 1,000 the Yucca fault is expected to be activated as a result. Certain factors, such as rock type, abundance of fractures, or any condition that affects the distribution of energy between the explosion and the fault, would require some adjustment of the formula. Also where displacement along the fault has occurred as a result of a past explosion, there appears to be a loss of sensitivity; in other words more energy may be required to trigger the fault.

It is presently believed that the fault movement is triggered by explosions that relieve tectonic stress. First-order surveys across the Yucca fault before and after a recent explosion which activated it showed not only a downdropping on the east side, but an absolute rise in elevation of 24/1000 of a foot on the west side. Release of tectonic stress also is suggested from comparison of U.S. Coast and Geodetic Survey calculations of seismic energy measured for different explosions. Two explosions with which accompanying fault movement was recorded had a greater percentage of seismic energy than did 17 others with which no fault movement was associated.

Hydrologic characteristics of the BILBY chimney

The hydrologic characteristics of a rubble chimney created by the BILBY event—the first nuclear explosion within a water-saturated zone at the Nevada Test Site—and the surrounding area were studied by W. E. Hale, W. A. Beetem, and M. S. Garber. The device, having a yield of more than 200 kilotons, was detonated in September 1963 in a thick porous tuffaceous aquiclude with a fracture transmissibility of about 10 to 50 gallons per day per foot. The collapse which followed the explosion created a "rubble chimney," with a radius of about 280 feet, partly within the zone of saturation. Measurements of the rise of water in, and pumping tests of, the rubble chimney were made in a hole drilled and cased into the center of the chimney. Analyses of the rates of water-level rise before, during, and after 2 pumping tests indicate that the effective porosity of the rubble in the chimney—at a level about 700 feet above the point of detonation—is slightly less than 2 percent; the preshot effective fracture porosity was a fraction of a percent. Subsequent measurements of water-level change should yield estimates of the rubble porosity at shallower depths. The transmissibility of the rubble chimney is about 30,000 gpd per ft, or 10^3 that of the undisturbed rock.

Effect of the SALMON event, Tatum salt dome, Mississippi, on nearby aquifers and streams

The SALMON event, a nuclear explosion of about 5 kilotons, was fired at a depth of about 2,700 feet in the Tatum salt dome on October 22, 1964. A part of the Geological Survey's hydrologic program involved the measurement of water levels in nearby wells and flow of streams in the area through a period before and after the SALMON event.

Four wells within 1¼ miles of the emplacement hole were instrumented with pressure transducers to record short- and long-term water-pressure response to the SALMON event. The movement of water within each well was constrained for a few days prior to and following the detonation by placing packers just below the static water level. Two of the equipped wells, E–9 and HT–3, were finished in the calcite caprock in the depth interval of 950–1,100 feet, overlying the salt dome and at distances of 1,700 and 1,780 feet from the device hole. Another equipped well, HT–5, 1,800 feet from the device hole is finished in a sand aquifer about 100 feet thick and 200 feet above the calcite caprock. The remaining equipped well, HT–2, is off the dome, 6,180 feet southwest of the device hole. This well taps a limestone and sandstone aquifer in the depth interval of 1,809–2,059 feet.

W. E. Hale, M. S. Garber, and F. C. Koopman report that the initial pressure-pulse response in the different wells began in the time interval from 0.27 and 0.6 seconds after the detonation. The early response was in part cyclic, but a gradual and persistent net increase in water pressure began within a second in the three closer wells. In well E–9, the net increase in pressure, equivalent to 15 feet of water, was reached in about 3 minutes; after a day the pressure began to decline and within a period of approximately 25 days had returned to the predetonation head. A somewhat similar history of water-pressure fluctuations was recorded in well HT–3, but the maximum rise in pressure was only equivalent to 8.8 feet of water. The maximum pressure increase in well HT–5 was equivalent to about 5 feet of water. The inferred cause of the net pressure increase in these three close-in wells is a slight compaction of the aquifer skeleton and concurrent compression of the water in the aquifer, resulting from ground motion caused by the detonation. In time, this water-pressure increase is dissipated by movement of water away from the compressed volume. The compaction of the aquifer, required to give increase in pressures equivalent to 5 to 15 feet of water, ranges between 1 and 2 thousandths of a percent.

In well HT–2, more than a mile from the dome, the initial pressure response was a net decrease equivalent to about 1 foot of water. During the following day the water pressure increased, equivalent to an estimated elevation of 1.7 feet above the pre-explosion level, and thereafter decreased to the preshot level within about 6 days. No interpretation of the pressure response in this well has been made.

Half Moon Creek, which drains the immediate area of Tatum dome, was instrumented with a recording gage at a point near the mouth of the stream about 1.5 miles north of the emplacement hole for the SALMON event. The gage was operated through a period several weeks before the detonation and for several days after the event to record changes in streamflow related to the detonation. Half Moon Creek is tributary to the westward-flowing Lower Little Creek which has several other tributaries in the vicinity of Half Moon Creek. A recording gage about 3 miles northwest of Tatum dome has been in operation on this stream for a few years.

C. P. Humphreys, Jr., and R. E. Taylor report that a temporary but significant increase in discharge past the recording gages on Half Moon Creek and Lower Little Creek occurred following the SALMON event. Prior to the SALMON event, the streamflow at the two recording gages was remarkably stable. No rain had fallen in the drainage basin since the heavy rains accompanying hurricane Hilda on October 4 and 5, 1964. Prior to the detonation the base flow on Half Moon Creek was about 14 cubic feet per second and that on Lower Little Creek at the gage about 32 cfs.

On October 22, 1964, 1 hour and 35 minutes after the SALMON event, the discharge on Half Moon Creek began to increase. During the following interval of 3 hours and 45 minutes, the discharge increased a total of 1.5 cfs. A nearly steady flow of 15.6 cfs was maintained for the following 13 hours after which the discharge began to decrease. By noon on October 24, the discharge was near the predetonation rate. In all, the increased discharge amounted to about 150,000 cubic feet.

On Lower Little Creek, an increase in the discharge rate began about the same time as that on Half Moon Creek. The discharge increased by about 6.3 cfs during the following 9 hours. Thereafter the discharge began to decrease but did not decline to the predetonation discharge rate before additional runoff occurred in the area from showers. The increased discharge on Lower Little Creek attributable to effects from the SALMON event is estimated to be 1 million cubic feet.

Compaction of saturated near-surface sediments by the seismic motion from the SALMON event probably was the major cause for the observed temporary increased discharge at the two recording stations on the Lower Little Creek drainage basin. The compaction of sediments that produced the nearly instantaneous discharge of water from storage is believed to have been in areas where the water table was very near the surface.

BASIC GEOLOGIC STUDIES

Pahute Mesa, Nevada Test Site

Identification and correlation of subsurface geologic units from additional drill-hole data on Pahute Mesa are revealing an increasingly complex picture of its volcanic stratigraphy and structure. Positive identification of ash-flow tuffs and rhyolitic lavas, from the Black Mountain volcanic center to the west and the Timber Mountain caldera to the south, in the subsurface of Pahute Mesa has outlined further the distribution pattern of the ash-flow tuffs and has provided information about the paleotopographic surface of pre-Timber Mountain time.

A third major volcanic center, probably a caldera buried by the later volcanic flows, recently has been outlined under Pahute Mesa. The east-central part of Pahute Mesa was, for several years, believed to be the center of extrusion for the Belted Range Tuff. Subsurface data from approximately 20 exploratory holes, gravity data from D. L. Healey and C. H. Miller, and detailed petrographic studies by F. M. Byers and K. A. Sargent, now indicate the existence of a buried probable caldera which centers in the SE¼ of the Silent Butte quadrangle. The caldera is roughly circular with a rim diameter of approximately 12 miles and has a cumulative structural relief of as much as 7,000 feet. Calculation of the volume of rock believed to be related to the main subsidence of the caldera indicates that 80 cubic miles of tuff, mainly Belted Range Tuff, and a nearly equivalent volume of alkaline rhyolitic lavas are genetically related to the buried volcanic center. The lavas appear to be emplaced along ring fracture zones to the east and northeast of the center of the structure. Further work shows that rhyolitic and quartz latitic lava flows and tuffs intermediate in age between the Belted Range Tuff and the Paintbrush Tuff are present in the western part of the caldera and may have originated beneath Pahute Mesa. Limited correlation of the oldest rocks penetrated under Pahute Mesa has been made with ash-flow tuffs and rhyolites to the north in the Kawich, Belted, and Cactus Ranges.

Regional stratigraphy and structure of the Amargosa Desert area

A geologic map of the Amargosa Desert area is being prepared to provide a geologic framework for ground-water studies of the Nevada Test Site and vicinity. The map is being compiled from existing sources and supplementary reconnaissance mapping. The mountains surrounding the Amargosa Desert Basin, as well as the desert floor, that are being mapped include Bare Mountain and the Beatty area in the northwest, parts of the Grapevine, Funeral, and Greenwater Ranges in the west; the Resting Spring Range, northern Nopah Range, and the hills north of Pahrump in the south; and the northern Spring Mountains, Specter Range, and western Spotted Range in the east and northeast.

The stratigraphic section includes, above the crystalline Precambrian basement rocks, a virtually conformable sedimentary sequence of Precambrian to Permian age and includes, at the top, middle and late Tertiary sedimentary and volcanic rocks and Quaternary basin fill. Although thickness changes and facies relations are important in all parts of the Precambrian and Paleozoic sedimentary sequence, the same principal stratigraphic units are recognizable throughout the sequence except for the Mississippian System. In the eastern and southern part of the area, the Mississippian consists largely of fossiliferous limestone; in the northern part of the area, the sequence is mainly argillite, quartzite, and chert-pebble conglomerate.

Tertiary stratigraphic units, principally ash-flow tuffs, are traceable across the northern part of the area from the Nevada Test Site to the Daylight Pass area in California. These volcanic rocks are underlain by an unnamed sedimentary sequence consisting principally of tuffaceous, locally fish-bearing, shale and sandstone. In the Funeral and Grapevine Mountains, this sequence in turn overlies lower Oligocene conglomerate. Tuffaceous shale and sandstone similar to those beneath the ash-flow sequence occur in the Ash Meadows area. Another Tertiary sedimentary unit, not yet correlated with certainty, is present in the southeastern Funeral Mountains.

The northeastern edge of the area is crossed by the Las Vegas Valley shear zone; the southwestern part of the area includes part of the Furnace Creek fault zone. Both of these structures are northwest-trending right-lateral shear zones. Another parallel but apparently smaller right-lateral fault has been recognized near the northern end of Stewart Valley. The amount of displacement on that fault has not yet been accurately determined, but there appears to be more offsetting by drag along the zone than by the faulting. This right-lateral shear zone projects northwestward through the central part of the Amargosa Desert Basin. The Precambrian and Paleozoic sequence is broken by many thrust faults including several of major displacement. There is some evidence that the crystalline Precambrian basement may have been involved in at least some of the major thrusting. The Tertiary rocks define a basin-range deformational style, with antithetic normal fault blocks tilted generally eastward.

Relation of gravity to mineralized areas, south-central Nevada

Geologic reconnaissance mapping of the Las Vegas Bombing and Gunnery Range by E. B. Ekren, R. E. Anderson, and C. L. Rogers has delineated a widespread Tertiary ash-flow tuff sheet that rests on an erosional surface of considerable relief. Several topographically high areas of hydrothermally altered and mineralized rocks were not covered by this tuff sheet and have been prospected and mined in the past. It seems likely that other mineralized areas may be concealed by this post-ore tuff sheet and by alluvium.

Studies made by D. L. Healey and others show that gravity anomalies here, as elsewhere in the

Basin and Range province, are generally high over the ranges and low over the basins. Gravity-high anomalies also correlate closely with known mineralized areas (Goldfield, Gold Crater, Cactus Range, and south of Cactus Range); this close correlation leads to the conclusion that additional mineralized areas may be postulated from the gravity data. One such anomaly is centered in Stonewall Flat, which is a structural basin. The surface geology of the areas surrounding Stonewall Flat offers no clues either to the presence of a structural high or to the rock type causing the anomaly. Depth calculations based on an aeromagnetic survey of the Las Vegas Bombing and Gunnery Range indicate a depth of 300 to 500 feet to the top of the rocks causing the gravity anomaly (G. D. Bath, written communication, 1964). The gravity high is apparently an expression of a structural dome that may reflect a buried volcanic center similar to that at Goldfield or Tonopah.

Magnetic properties of volcanic rocks, Nevada Test Site

Measurements by G. D. Bath of the remanent magnetization of volcanic rocks from the Nevada Test Site tend to confirm the current hypothesis that during geologic time the geomagnetic field has undergone periodic reversals. A rock cooling in the earth's magnetic field acquires a magnetism direction that is parallel to the field, and therefore a record of the fossil direction of the field is preserved in the magnetic properties of the rock. Investigations of properties of welded tuff, rhyolite, and basalt units reveal uniform directions of magnetism, but these directions may be either along or opposite to the present geomagnetic field.

The presence of rocks with normal and reversed polarities provided a basis for stratigraphic correlation that was applied successfully by (1) measurement of magnetic properties in the field, and (2) interpretation of the aeromagnetic survey of the Nevada Test Site. After establishing polarities for many important units, rapid techniques were used to determine polarities in the field while geological studies were underway. Strongly magnetized and thick units with reversed polarities give distinctive magnetic anomalies, and in several instances the effects of a particular unit could be seen in the aeromagnetic data. For example, the negative anomalies that follow the Reveille Range come from the tuff of White Blotch Spring, and those along the Kawich Range come from the tuff of Trailer Pass. Many of these anomalies arise from source rocks that are covered by alluvium or younger strata. Here the anomalies not only identify but also give the approximate depth of the magnetized rock.

K. A. Sargent (p. B142–B145) found that magnetic-susceptibility data combined with grain-density measurements provided a useful tool for distinguishing between lithologically similar olivine basalt flows.

Zeolite studies, Nevada Test Site

X-ray diffraction studies by D. L. Hoover and A. O. Shepard of samples from drill holes and outcrops indicate that zeolite zoning is persistent throughout much of the Nevada Test Site. Chabazite forms an upper, sporadic zone. Clinoptilolite, mordenite, and analcime form progressively deeper, but overlapping zones on Pahute Mesa and Rainier Mesa. The mordenite zone has not been found in Yucca Flat, Frenchman Flat, or Jackass Flat. Thinning of zones with thinning sections of rocks susceptible to zeolitization and the presence of the same zones at greatly differing depths indicate that the zoning is probably related to downward changes in ground water rather than to temperature and pressure.

Compilation of bulk densities of vitric rocks and their zeolitized equivalents has shown that bulk densities of ash-fall tuffs increase and that those of dense lava flows decrease during zeolitization. Chemical analyses of selected pairs of vitric and zeolitized rocks corrected for differing bulk densities show not only major differences in Si, K, Na, Ca, Mg, and H_2O, but also 10 to 20 percent differences in Al.

DISPOSAL OF RADIOACTIVE WASTES

Research related to the disposal of radioactive wastes included (1) theoretical and analytical studies of flow phenomena controlling the time and space distribution of radiocontaminants in surface streams and through geologic media; (2) studies of the fate of radioactivity discharged from waste-generating facilities; and (3) geohydrologic evaluations of existing and planned nuclear installations. Most of the work was done in cooperation with the U.S. Atomic Energy Commission.

TRANSPORT OF RADIONUCLIDES

Diffusion in surface streams

In an exploratory laboratory study of lateral turbulent diffusion at the surface of an alluvial channel, W. W. Sayre and A. R. Chamberlain (1–64), by studying the spread of small floating polyethylene particles, demonstrated a means of evaluating successfully the lateral diffusion coefficient and of quantitatively estimating fundamental turbulence properties such as the intensity and LaGrangian integral scale of turbulence in an alluvial channel. They found that the coefficient of lateral turbulent diffusion increases initially with increasing distance downstream from the source, but that it tends toward a constant limiting value in a distance that is very small compared to the length scale of most diffusion phenomena in natural streams of practical interest.

Transport through earth materials

The transport of radionuclides through earth materials is a complex physicochemical phenomenon. Akio Ogata (1–64) studied the mechanics of dispersion analytically and experimentally and defined the problem in terms of the following major factors controlling dilution: (1) mechanical or hydrodynamic dispersion, (2) adsorption, and (3) heterogeneity. Correlation between experimental and theoretical results for the spread of a tracer was fair.

Ogata (2–64) also contributed to the solution of waste-transport problems in a theoretical analysis of the effect of a reacting medium on the dispersion of fluids. He considered the effects of the dispersion process to be of the same order of magnitude as those of the adsorptive process and, using an assumed linear adsorption isotherm, developed solutions to the differential equations that describe the two processes.

STUDIES AT NUCLEAR-ENERGY FACILITIES

Radioactivity in water, Brookhaven National Laboratory, New York

Wallace de Laguna (1–64) has studied chemical and radiochemical analyses of more than 300 water samples collected at Brookhaven National Laboratory, New York, between 1948 and 1953. The samples were intended to provide norms for problems of water contamination that might arise in the future. No samples of ground water showed alpha activity; only 14 showed beta activity, the maximum being 5×10^{-8} microcuries per milliliter. Beta activity found in 55 surface-water samples (maximum of 3.7×10^{-7} microcuries per milliliter) is attributed to fallout from nuclear-weapons tests. Widespread contamination of ground water from the leaching of fertilizer in intensively farmed areas, and local contamination from cesspools, are indicated by high nitrate concentrations in ground water.

Permeability of weathered crystalline rocks in Georgia

At the Georgia Nuclear Laboratory J. W. Stewart (2–64) studied the infiltration characteristics and permeability of weathered crystalline rocks in relation to the use of seepage pits for disposal of low-level liquid radioactive wastes. Water was found to move along the schistosity, mostly along the strike but also along (up and down) the dip. Computations of ground-water velocity based on Darcy's law indicated rates of flow of 0.1 foot to 3 feet per day. Rates measured with chloride and nitrate tracers ranged from 0.4 foot to as much as 25 feet per day.

Extensive unsaturated deposits at National Reactor Testing Station, Idaho

The subsurface geology of the National Reactor Testing Station, in Idaho, was described by E. H. Walker (3–64). The station is underlain, to depths still unknown, by basalt flows of the Snake River Group. The basalt is overlain by surficial unsaturated unconsolidated sedimentary rocks more than 50 feet thick under about 175 square miles of the station; a total of more than 4 cubic miles of such material lies beneath the station. Since most of these materials are fine grained, they can be used in the relatively dry Idaho climate as temporary storage reservoirs for low-level liquid radioactive wastes. However, this practice is followed in only a very small part of the station.

FATE OF RADIOACTIVE LIQUID EFFLUENT

Radionuclides in Columbia River and Columbia River estuary

In the Columbia River below Pasco, Wash., W. H. Haushild, H. H. Stevens, Jr., and G. R. Dempster, Jr., found that about 90 percent of the combined annual load of the 6 dominant radionuclides is transported in solution and 10 percent is transported sorbed on sediments. However, for certain radionuclides, the annual load transported by sediments exceeds the load transported in solution by as much as 570 percent. A gross budget of the radionuclide load in the Columbia River indicates that the total load at Vancouver, Wash., is about 75 percent of the total load at Pasco, Wash. (Vancouver is 224 river miles downstream from Pasco). That part of the radionuclide load at Pasco which is not transported to Vancouver or accounted for by loss by radioactive decay varies with season and is largest during the annual spring high water.

In their studies of radionuclide movement in the Columbia River estuary, D. W. Hubbell, E. A. Prych, and J. L. Glenn have developed (1) a vibratory sampler for obtaining cores in sandy bed material, (2) a system for sampling large volumes of water-suspended sediment mixture at stream velocity, and

(3) a sled-mounted radiation-detection system for continuously measuring radioactivity in the bed along traverse lines. Radiation measurements indicate that the most abundant radionuclides in the bed material of the estuary are chromium-51 and zinc-65. The level of activity varies widely from place to place, and the highest activities are associated with the finest bed materials.

Radionuclides in the Clinch River, Tenn.

In an inventory of principal radionuclides in bottom sediments of the Clinch River downstream from White Oak Creek, P. H. Carrigan, Jr., found that 77 percent of the identified radioactivity was cesium-137 (155 curies). Quantities of other major radionuclides were: cobalt-60, 17.5 curies; ruthenium-106, 15.5 curies; strontium-90, 2.9 curies; and about 10 curies of rare earths. Approximately 95 percent of the radioactivity is in the 15 downstream miles of the 21-mile reach studied.

R. J. Pickering found that the vertical distribution of cobalt-60 in cores of Clinch River bottom sediment is similar to that of cesium-137. The pattern of distribution of cesium-137 reflects the pattern of annual releases of waste, but that of colbalt-60 does not. Hence, it is inferred that, unlike cesium, most of the cobalt-60 released to the river is not associated with sizes of suspended solids that will settle.

E. A. Jenne and S. S. Wahlberg report that most of the cobalt-60 scavenged by the sediment of White Oak Creek, Tennessee (through which low-level waste from the Oak Ridge National Laboratory passes to the Clinch River) is found in a metal-oxide reducible fraction. Reducible manganese and iron oxides contain approximately equal amounts of the scavenged cobalt-60. A small portion of the cobalt-60 is contained in an organic fraction.

Disposal of liquids in Bandelier Tuff

According to W. D. Purtyman and F. C. Koopman, the physical and hydrologic characteristics of the Tshirege Member of the Bandelier Tuff in New Mexico are favorable to the injection and storage of liquid wastes such as treated low-level radioactive wastes. An injection rate of about 28,400 gallons per day into a moderately welded tuff would be possible by use of a properly perforated 12-inch-diameter well 100 feet deep.

FLOW OF AIR IN TUFF

At the Los Alamos Scientific Laboratory, in New Mexico, the movement of air into and out of the ground under natural barometric gradients is being studied in an effort to establish the feasibility of using the Bandelier Tuff for storage of gaseous radioactive wastes. The duration of air exhaust or intake cycles indicates that the pressure within the tuff does not adjust readily, but that instead the rock is compressed or expanded with these changes. Analysis of the effects of barometric pressure changes has also shown that there is a deformation of the rock caused by tidal effects. This deformation causes a change in the void ratio of the formation and influences the flow of air to or from the ground.

WATER-CONTAMINATION STUDIES

Development of water resources is restricted or complicated in many areas by the spread of waste products into water supplies. The continuing growth of population and industry leads to the production of an increasing volume and variety of waste products, and to increasing problems of contamination.

Patterns of contaminated zones in ground

The patterns of zones of ground water contaminated by wastes placed in the ground have been studied by H. E. LeGrand (2–65). Many factors, including the degree to which each contaminant decreases in potency by (1) decay or some other die-away mechanism, (2) sorption on earth materials, and (3) dilution, determine the size and shape of contaminated zones in the water-table aquifer. Most contaminated zones do not extend to wells or streams, although contaminated waters from some waste sites do reach enough wells to cause problems of major concern. Where the decrease in potency is only by dilution, the contaminated zone is likely to be greatly elongated in the direction of ground-water flow, and the contaminated water may reach perennial streams. In spite of the fact that many hundreds of thousands of contaminated zones occur in the water-table aquifers of the United States, only a few have been mapped.

Amino acid content of sewage greatly reduced by primary treatment

Raw sewage entering the Denver sewage treatment plant, and effluent from sewage-treatment facilities at Denver, Colo., Chicago, Ill., Trenton, N.J., and Hamilton County, N.J., were analyzed for amino acid content by Lloyd Kahn and C. H. Wayman (1–64). Total removal of amino acids in sewage was accomplished by means of activated-sludge treatment; primary treatment alone removed 65 percent of the proteinaceous matter. It is expected that even primary sewage treatment will sufficiently lower the amino acid and protein content in sewage plants to prevent contamination of surface waters.

Long-term changes in quality of Passaic River, N.J.

P. W. Anderson and S. D. Faust (p. D214–D218) showed, by analysis of streamflow and chemical-quality data for the Passaic River at Little Falls, N.J., a general increase in content of dissolved solids and a 20-percent decrease in dissolved-oxygen content over the period 1947–64. They attributed this deterioration of quality to the disposal of increasing volumes of municipal and industrial wastes in the river.

DETERGENTS AND PESTICIDES IN WATER SUPPLIES

LABORATORY STUDIES

Bacterial degradation of ABS

A study by C. H. Wayman, J. B. Robertson, and C. W. Hall (2–64) of bacterial degradation of detergent compounds showed that alkylbenzenesulfonate (ABS) with a branched alkyl chain was not degraded significantly under either aerobic or anaerobic conditions. ABS with a straight alkyl chain, the new biodegradable type, was degraded very slowly under anaerobic conditions but somewhat more rapidly than the branched-chain ABS. The straight-chain ABS was degraded rapidly under aerobic conditions and in some instances was totally destroyed in 2 days. Degradation in all instances occurred faster at 35°C than at 20°C or 10°C. The study indicated that the new straight-chain ABS would be broken down in aerobic sewage-treatment processes but that in anaerobic systems it would be little broken down and would be a potential water pollutant.

Adsorption of ABS on clay minerals

A report by C. H. Wayman and J. B. Robertson (3–64) summarized a study of the adsorption of the common detergent compound, alkybenzensulfonate (ABS), on the soil clay minerals kaolinite, illite, and montmorillonite. The study showed that these minerals adsorbed only minor amounts of ABS as compared with activated carbon or colloidal alumina. Adsorption increased with increasing ABS concentrations, according to Freundlich or Langmuir isotherms. ABS with a C_{15} alkyl chain was adsorbed more readily than that with a shorter C_{12} chain. Adsorption was stronger at pH 4 than at pH 7 or 10. The presence of chloride salts of Al^{+3}, Ca^{+2}, and Na^{+1} in solution increased ABS adsorption, the $AlCl_3$ salt having the greatest effect. It was concluded that the minerals studied would not adsorb significant amounts of ABS under natural conditions.

Hydrogen isotopic-exchange reaction in the system aldrin–water

M. C. Goldberg and R. L. Wershaw have studied the hydrogen isotopic-exchange reaction in the system aldrin–water in order to determine whether there is detectable ionization of aldrin. The data obtained indicate that if aldrin ionizes, its ionization constant is less than 10^{-30}. Cyprex, a water-soluble fungicide that has detergent properties, was shown to be utilized as the sole source of carbon by an *Achromobacter* species and by a *Flavobacterium* species of soil bacteria. Degradation of this compound by soil micro-organisms was substantiated by exposing C^{14}-labelled cyprex to river muds collected in the Denver, Colo., area. The bioactive river muds metabolized solid-state cyprex to CO_2, whereas sterile muds did not.

FIELD STUDIES

Movement of detergents in ground water

An investigation by J. C. Chemerys of the movement of contaminants from septic tanks in housing developments near Raleigh, N.C., suggests that chloride and nitrate ions move farther in the ground-water flow system than do detergents. However, in the areas studied, none of these constituents were found in concentrations approaching maximum safe concentrations recognized by the U.S. Public Health Service for public water supplies.

ACID MINE WATER

Anthracite mine drainage in Pennsylvania

Monitoring of the gravity overflow of mine water from water-filled anthracite coal mines under Scranton, Pa., for 3 years indicates that the total load of dissolved solids in the overflow increases after the levels of the mine-water pools rise and the inundated area becomes larger. W. T. Stuart reports that the overflow rate varies seasonally and that the smaller flows are more concentrated than larger flows. The yields of dissolved material decrease with time—rapidly at first and slowly thereafter—apparently as the acid-forming minerals in the mine are depleted. At one site, where the overflow was stopped and impounded for 6 weeks in 1963, the concentration of acid in the water almost doubled, and the sulfate, iron, and manganese increased about 10 percent after the overflow was resumed. The coal-bearing area contributing water to the abandoned mines is about 56 square miles, and the area of the mine-water pool within the coal-bearing area is 34 square miles. In 1963, discharge of water from the pool area averaged 35,500 gallons per minute, and yielded 15 tons of sulfate per day, 1.1 tons of iron, 0.2 tons of manganese, and an equivalent of 2.6 tons of sulfuric acid if neutralized to pH 8.0.

Acid mine drainage in Maryland

In a reconnaissance study of the chemical characteristics of Maryland streams J. D. Thomas found that acid mine drainage in the headwaters of the Potomac River basin affects the quality of water in the Potomac River. Ground-water samples collected in that area were of the calcium bicarbonate type, but the surface water, of calcium sulfate type, showed the influence of acid mine drainage. In the vicinity of Hancock, in western Maryland, the Potomac water begins to change to a calcium bicarbonate sulfate type because of inflow from the South Branch Potomac River and the Cacapon River, which contain water of the calcium bicarbonate type. Still farther downstream, below the mouths of the Shenandoah River and of Antietam and Conococheague Creeks, the Potomac water is of the calcium bicarbonate type.

Acid mine drainage in Kansas

W. J. Seevers reports that acid mine drainage from abandoned underground coal mines is the principal source of acid pollution in the Cherry Creek drainage basin in Cherokee County, Kans. The principal sources of acid mine drainage were found, by measuring the pH and the water temperature at points along the stream, to be two mine-drainage shafts. An anomalous distribution of alternating riffles and pools, and peculiar meander patterns, found near these shafts appears to be the result of increased acidity. It is believed that the reduction of pH and the increase in streamflow directly below points of effluence cause flocculation and deposition of a portion of the stream load, which results in a change in meander patterns of the stream. Surface runoff from the extensive spoil dumps of strip mines in the Cherry Creek basin contributes only minor amounts of acid water to the streams.

INDUSTRIAL EFFECTS

Thermal loading of a river in Pennsylvania

Dissolved oxygen in the West Branch of the Susquehanna River in Pennsylvania was investigated by K. V. Slack and F. E. Clarke (p. C193–C195) at stations above and below a steam-electric powerplant. The river receives strip-mine drainage and moderate quantities of municipal wastes above the powerplant. When studied in October, a diurnal fluctuation in dissolved-oxygen content occurred only above the plant. Tests with river water in light and dark bottles indicated no production of oxygen above the powerplant and a net loss of oxygen below the plant. A significant quantity of oxygen is thought to be added to the river above the powerplant by streambed plants but not by phytoplankton. Below the heated outfall, the reduced abundance of riverbed algae is probably a result of the effects of chemical and fine-sediment wastes from the plant. The shallow depth and slow rate of organic decomposition in the acid water also contribute to high concentrations of dissolved oxygen in this river.

BRINE AND SALINE WATER

Natural brine in Upper Brazos River basin, Texas

An investigation of the occurrence, movement, and discharge of natural brine in the Upper Brazos River basin, Texas, by P. R. Stevens and W. F. Hardt has shown that natural brine occurs at relatively shallow depth in rocks of Permian age throughout the area. The brine in most places is overlain by relatively fresh, circulating ground water. A sharp interface separates the brine and fresh water into discrete hydraulic units. The freshwater head influences the configuration of the interface but does not control flow conditions in the brine system, which is relatively static compared to the overlying system of circulating fresh ground water. Regional topography, climate, and geology are the principal controls on the movement and discharge of the brine; circulation of infiltrated rainwater in local systems is a minor factor in the evolution of the brine. Discharge of brine occurs where the interface between brine and fresh water intersects the land surface. Methods to reduce or prevent discharge of natural brine into the Brazos River and its tributaries, and thereby to improve the utility of Brazos River water, are receiving great impetus. The investigation thus far has shown that remedial measures based upon impoundment of the natural brine in its area of discharge, and other control measures based upon the assumption that brines are generated by circulation of infiltrated rainwater in local systems, cannot be effective.

Chemical quality of water in Neches River basin, Texas

In a reconnaissance of the chemical quality of surface water in the Neches River basin in Texas, L. S. Hughes and D. K. Leifeste found that streams draining a part of the East Texas oil field contained water of high chloride content and great acidity, with pH as low as 3.2. They showed that the source of the acidity could be hydrogen ions adsorbed on clay minerals near the land surface and transferred to shallow ground water as the result of base exchange with oil-field brine. Adsorbed hydrogen ions can be displaced from clay when the latter is wetted by a solution containing a preponderance of sodium ions. When clay samples from the area were leached with oil-field brine, which was neutral (neither acid nor alkaline), they yielded acid solutions similar in chemical composition to the acid water in the streams.

Contamination by brine in Caldwell County, Tex.

On the basis of a study of the ground-water resources of Caldwell County, Tex., C. R. Follett reports an example of contamination of fresh ground water by oil-field brine, and the later improvement in the quality of the water by stopping the contamination at the source. As early as 1928, brine which had been produced with oil was discharged on the surface of the Leona Formation, a highly permeable water-bearing unit. Contamination over a period of several years increased the chloride content of the water in the Leona in a triangular-shaped area whose apex was at the source of contamination and which extended at least 2½ miles downgradient. The contaminant evidently traveled the 2½ miles in less than 10 years, for in 1938 the chloride content of water from a well in the Leona, 2½ miles from the source of contamination, was 211 parts per million, or more than twice the content of the normal uncontaminated water. By 1943, the chloride content of water in that well had increased to 604 ppm. After the source of contamination was discovered the oil field was closed and facilities were installed for injection of the brine into deep salt-water sands. After the contamination was stopped at the source the quality of the ground water steadily improved, and by 1963 the chloride content was 101 ppm—a quality approaching that of the normal uncontaminated water.

Salt load of Pecos River reduced by pumping from aquifer

E. R. Cox and J. S. Havens report that the salt load has been reduced in the Pecos River downstream from Malaga Bend in Eddy County, southeastern New Mexico, by the Malaga Bend Experimental Salinity Alleviation Project. The 3-mile reach of the river at Malaga Bend is the natural discharge area for an artesian-brine aquifer, at a depth of about 200 feet, near the base of the Rustler Formation of Permian age. Brine from a well that taps the brine aquifer is now pumped to a nearby depression at a rate of 450 gallons per minute. The head in the aquifer has been lowered, and the brine-discharge rate has been reduced. The average downstream gain in chloride load in the Malaga Bend reach of the river declined from 168 tons per day (July 16–17, 1963, before pumping began) to 59 tons per day (August 12–13, 1964).

Brine contamination in Morrow County, Ohio

Contamination by oil-field brine was observed in Morrow County, in north-central Ohio, during 1964. According to P. G. Drake, Whetstone Creek, a tributary of the Scioto River which drains the area of greatest oil production, carried chloride concentrations of more than 700 parts per million during low-flow periods. Prior to oil-drilling operations the concentrations were about 30 ppm. Ground-water contamination also was observed, particularly in shallow wells adjacent to brine drainage pits and ditches. Two public-supply wells of the City of Cardington, in which chloride concentrations of 3,750 ppm and 500 ppm were observed, were shut down because of the brine contamination.

Saline ground water migrates upward into Ocala Limestone at Brunswick, Ga.

According to R. L. Wait, salt water (with chloride concentrations as high as 1,000 parts per million) is present in the Ocala Limestone in a small area at Brunswick, in southeastern Georgia, between depths of 560 and at least 1,300 feet below the surface. Fresh ground water occurs in the overlying Miocene rocks and in part of the underlying middle Eocene limestone. Evidence from C–14 analyses presented by B. B. Hanshaw, William Back, Meyer Rubin, and R. L. Wait (1–65) confirms earlier conclusions that the saline water is derived by upward flow from the underlying Claiborne rocks rather than from the ocean. This upward movement of salt water is also confirmed by a water-table decline map prepared by D. O. Gregg. Northward movement of the 150-ppm isochlor suggests movement of about half a mile since late 1962. An increased hydraulic gradient resulting from an increase of 36.7 million gallons per day in pumpage in late 1962 has caused the salt water to move more rapidly than previously.

Change in water quality after damming of Econfina Creek estuary, Florida

Water in a saline estuary of Econfina Creek, in Bay County in the Florida panhandle, freshened to

250 parts per million chloride in about 2 months after construction of a dam at Deer Point to form Deer Point Lake. The rate of freshening with respect to the volume of the lake and inflow to the lake was calculated by L. G. Toler, R. H. Musgrove, and J. F. Foster (1–64), and an empirical formula was derived which may have application to other similar water bodies. Some contamination of ground water occurred in the sand aquifer adjacent to the lake, but the saline water was flushed from the aquifer as a result of a general rise in ground-water levels surrounding the lake.

Sources of chloride in ground water, Nassau County, N.Y.

F. A. DeLuca, J. F. Hoffman, and E. R. Lubke have compiled records of chloride concentrations and temperatures of the waters of Nassau County, Long Island, N.Y., from about 1895 to 1962 and have concluded that most of the natural fresh ground water contains 10 parts per million or less of chloride. Ranges in chloride concentration in the ground water sampled were 2–9,200 ppm in the upper Pleistocene deposits, 2–12,900 ppm in the Jameco Gravel, 1–16,700 ppm in the Magothy(?) Formation, and 1–2,800 ppm in the Lloyd Sand Member of the Raritan Formation. Concentrations in excess of 10 ppm generally are attributable to 1 or more of 5 principal sources of contamination: (1) sea water, (2) fertilizer, (3) domestic wastes, (4) industrial wastes, and (5) salt used for dust or de-icing control on roads.

DISTRIBUTION OF MINOR ELEMENTS AS RELATED TO PUBLIC HEALTH

An increasing interest in the distribution of elements in plants, soils, rocks, and water, and the relation between this distribution and problems in public health has been made particularly evident in 1964 by the inclusion of symposia on these subjects at the meetings of both the American Public Health Association, and the American Association for the Advancement of Science. Scientists of the U.S. Geological Survey have been taking leading parts in field and laboratory studies of these relationships, and in arranging interdisciplinary meetings at which the results of studies are presented. Some current work by Survey scientists is summarized below.

Element distribution in plants and soils of New Mexico and Maryland

H. L. Cannon has compared the inorganic compositions of samples of soils and of native and cultivated vegetation from San Juan County, N. Mex., (an area probably low in incidence of cancer and heart disease) with the compositions of similar samples from Washington County, Md., (an area of higher cancer and heart disease rate). Iron, titanium, manganese, chromium, copper, lead, potassium and NO_3^{-1} contents are higher in the samples from Maryland.

Radium in ground water in Gas Hills uranium district, Wyoming

R. C. Scott and F. C. Armstrong have collected and analyzed for radium ^{226} 20 samples of water from wells and mines of the Gas Hills uranium district. Three were of water from wells in the Cretaceous Cloverly Formation, 2 from wells in the Pennsylvanian Tensleep Sandstone, and 11 from mines and 4 from wells in the middle member of the Eocene Wind River Formation, the host rock of the uranium deposits.

Analyses of the samples by the Water Resources Division of the U.S. Geological Survey show that in this area the Cloverly is a source of water suitable for continuous domestic use. Ra^{226} content of water from the Cloverly ranged from 0.7 ± 0.1 to 1.8 ± 0.4 picocuries per liter (picocuries per liter = micromicrocuries per liter). The maximum permissible concentration of Ra^{226} recommended by the U.S. Public Health Service in domestic water for continuous use is 3 pc/liter.

In contrast, analyses of water from the Tensleep and Wind River Formations show that in this area these waters, with one exception, are suitable for industrial use, such as process water in the uranium mills, but not for continuous domestic use. The Ra^{226} content of the two samples from the Tensleep was 69 ± 14 and 120 ± 20 pc/liter. The Ra^{226} content of well water from the Wind River Formation in areas believed to be devoid of uranium mineralization ranged from 5.1 ± 1.0 to 23 ± 5 pc/liter. The Ra^{226} content of 10 mine-water samples from the Wind River Formation ranged from 70 ± 14 to $2{,}400\pm500$ pc/liter. One sample of water from the Wind River Formation, which contained only 1.9 ± 0.4 pc/liter of Ra^{226}, suggests that in some places in the Gas Hills the Wind River Formation may be a source of water suitable for continuous domestic use. The other samples from the Wind River Formation indicate, however, that water from this formation should be analyzed before use as a domestic supply, and that thereafter the supply should be sampled and analyzed periodically.

PROBLEMS IN ENGINEERING GEOLOGY AND HYDROLOGY

Geology of tunnels along Interstate Highway 70 in Colorado

Analysis of geologic and engineering data from the pilot bore for the Straight Creek highway tunnel beneath the Continental Divide shows that the magnitude of the rock load to be supported is directly related both to geologic factors and to engineering practices in tunneling. According to C. S. Robinson and F. T. Lee, geologic factors include density of fractures, amount and kind of clay minerals produced by alteration, and the width of fractured and altered zones. Tunneling practices resulting in excessive overbreak, a decrease in the rate of advance of the heading, and reexcavation of parts of the bore because of inadequate support all tend to increase rock loads over those predictable from the geologic conditions. The quantity of ground water entering the pilot bore was least in zones of alteration and where fractures are closely spaced, and greatest in relatively competent rock adjacent to sheared and altered zones. During construction of the pilot bore, fault gouge containing clay with high swelling pressures was encountered. Subsequent tests of this gouge in the laboratory of the Engineering Geology Branch and in the sedimentary mineralogy laboratory revealed a direct correlation between estimated montmorillonite content and calculated swelling pressures. If such tests were made during tunneling, the need for additional tunnel support might be anticipated.

Geologic mapping by M. H. Bergendahl has revealed that a shear zone consisting of highly fractured granite will be crossed for a distance of about 1,100 feet by a proposed highway tunnel on a projected route of Interstate Highway 70 through the Gore Range. If the zone continues at depth, it may cause problems in excavation and support of this part of the tunnel.

Forecast of coal-mine bumps at Sunnyside, Utah

General areas and times of severe bumps in the coal mines of the Sunnyside district between November 17 and 23, 1964, were forecast 4 days in advance by F. W. Osterwald and C. R. Dunrud. The forecast was based on a very pronounced increase in number and amplitude of seismic tremors recorded November 10 and 11 on the Sunnyside seismograph network. During this period the foci of many of the large-amplitude tremors were apparently along two faults 5 to 7 miles from an area later affected by severe bumps. On November 12, dangerous bumps were forecast when epicenters of large-amplitude tremors shifted to map locations above abutment pillars and mined-out areas within the Sunnyside coal mines. These large tremors continued through November 16 and coincided with a period of decreasingly abundant but increasingly strong tremors. Dangerous bumps then followed in active mining areas and along haulageways from November 17 to 23.

Seismic tremors were very abundant during the first 3 months of 1965, when 215 tremors ranging in magnitude from 1.3 to 4.0 originated within or near the Sunnyside mining district. An increasing proportion of the epicenters of tremors larger than magnitude 2.5 were along or near faults 1 to 10 miles from the closest mine workings. Many tremors with epicenters near faults in the mining area failed to cause noticeable damage in the mines, which suggests that their foci probably were below the mine level.

Gravel deposits in Beltsville quadrangle, Maryland

Geologic mapping by C. F. Withington (p. B39-B42) in the northeastern part of the Washington, D. C., metropolitan area has outlined the distribution of gravel deposits within the Patuxent Formation of Early Cretaceous age. Knowledge of the distribution of this important resource will help insure its utilization before areas underlain by it are preempted by highways and housing developments.

Rockfalls, debris flows, and eruptions at Mount Rainier, Wash.

Rockfalls in December 1963, possibly triggered by a small steam explosion on the northeast side of Mount Rainier volcano, caused at least seven avalanches of rock debris. Some of these moved as far as 4.3 miles at a velocity of perhaps 100 to 300 miles per hour, and ended as close as 2,000 feet from an unoccupied campground in Mount Rainier National Park. Long distance of movement on a low gradient at the downvalley end of the avalanches was attributed by D. R. Crandell and R. K. Fahnestock to cushions of compressed air being formed beneath the debris as it hurtled off the steep front of a glacier.

Studies by D. R. Crandell and D. R. Mullineaux of debris flows, lava flows, and deposits of pumice and pyroclastic rock debris at Mount Rainier indicate that debris flows present the greatest hazard to man. If the spasmodic postglacial activity of the volcano continues, an eruption of pumice, lava, or rock debris may be expected no more often than about once every thousand years. Debris flows are more hazardous because they are more frequent and some may travel many miles down valley floors where human habitations, campgrounds, and highways are concentrated.

LAND SUBSIDENCE

Studies of land subsidence caused by decline in artesian head are continuing in California, Nevada, Arizona, and Texas. These studies are contributing to knowledge of the physical and hydraulic properties of leaky aquifer systems, the storage characteristics of semipervious interbeds and confining beds, the change in the coefficient of storage with time and change in effective stress, and the inability of most well casings to resist the compacting forces.

Tilting and subsidence near Bakersfield, Calif.

According to B. E. Lofgren, the analysis of leveling of bench marks in the mountains south of the San Joaquin Valley, resurveyed periodically by the U.S. Coast and Geodetic Survey, indicates tectonic movement in this area where one of California's major earthquakes occurred in 1952. Available leveling data suggest a continuing tilt that increases northward toward the valley from an axis of flexure 2 miles south of Grapevine. This gradual tilting of the mountain block, together with the possibility of differential subsidence due to ground-water pumping in the valley, is of prime concern in the design and construction of two large pumping plants and an aqueduct system of the State in the immediate area.

Subsidence and earth cracks in southern Arizona

In the Salt River valley and at several other localities in southern Arizona, according to William Kam (p. B122–B125), decline of the water level has caused compaction of fine-grained valley fill and land-surface subsidence. He suggests differential compaction of such deposits as a possible cause of associated earth cracks. The sudden occurrence of these fissures intersecting natural drainage courses establishes new, locally lowered base levels, and permits increased headward erosion of the upstream segments of the drainage. Headward cutting along the drainageways produces gullies.

D. E. Peterson (1–64) in a study of earth fissures in the Picacho area of Pinal County in south-central Arizona, reports that the fissures appear to be the result of tensile and shear forces, with shear forces predominating, which are related to differential subsidence of the valley alluvium. The mountains and alluvium-covered pediments have remained stable while the valley alluvium has subsided. The subsidence has been caused or accelerated by large changes in hydraulic head across fine-grained materials, largely silt and clay, which are the predominant sediments in the basin below a depth of approximately 600 feet. The horizontal permeability of these sediments appears to be significantly greater than the vertical permeability. As a consequence, the hydraulic gradients caused by intensive pumping increase the effective load on the fine-grained materials, thereby creating the compacting forces. Releveling of a U.S. Coast and Geodetic Survey level line between Picacho Peak and the Casa Grande Mountains by the U.S. Bureau of Reclamation in October 1964 suggests maximum subsidence of 5.1 feet since 1962. The bench mark of maximum subsidence is C 279, about 1½ miles northwest of Eloy. This is an area of intensive pumping and declining water levels. Subsidence has been occurring in this area for at least 20 years, but the rate apparently has accelerated considerably.

Rate of subsidence increasing in Houston area, Texas

R. K. Gabrysch has analyzed releveling by the U.S. Coast and Geodetic Survey in 1964 and reports that subsidence has accelerated slightly in the period 1959–64. Subsidence of the land surface in the Houston Ship Channel area increased from a rate of 1.0 foot per 5-year interval (1954–59) to 1.2 feet per 5 years (1959–64). Introduction of surface-water supplies to this area in 1954 permitted a reduction in pumpage. Recovery of water levels of as much as 25 feet between 1954 and 1959 occurred a few miles west of the ship-channel area. From 1959 to 1964, however, levels declined as much as 30 feet. It is not likely that there will be appreciable decrease in the present rate of decline of water levels in the next few years, because additional surface water will not be available for several years.

EVAPORATION SUPPRESSION

Monomolecular film increases net seepage rates from stock pond

A field test using monomolecular films to control evaporation from a 1-acre stock pond near Laredo, Tex., has been in progress since April 1964. The monomolecular films are formed from an aqueous dispersion of eicosanol and docosanol alcohols, and are dispensed from a new type of underwater dispenser which was designed by G. E. Koberg. Evaluation of the effectiveness of the film, by a comparison of the water budgets of the treated pond and of an untreated pond nearby, indicates that in this experiment the net seepage rates from the treated pond are increased more than the amount by which the film reduces evaporation. A comparison of the water-surface temperatures of the two ponds shows that the treated water is generally 2°C warmer than the untreated water, which indicates an approximate reduction in evaporation of 25 percent. The increase in the net seepage rate for the treated pond is attributed to the transport of some alcohol into the ground with the water, and to the consequent reduction in surface tension and in resistance to flow as the alcohol moves through the voids. This effect seems to be greater in incompletely saturated ground (such as that inundated by a sudden rise in pond level) than in saturated ground, and G. E. Koberg believes that introduction of surfactants may present a possible method of increasing infiltration rates for short-duration storms.

FLOODS

Three major categories in the study of floods by the U.S. Geological Survey are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods or by floods having specific recurrence intervals. The following section, accordingly, is subdivided into discussions of outstanding floods of 1964–65, flood frequency, and flood mapping.

OUTSTANDING FLOODS OF 1964–65

Floods of December 1964 in far western States

The floods of December 1964 in the far western States, the most damaging in the history of the area, were outstanding for record-breaking peak discharges and for the unusually large area involved —Oregon, northern California, western Nevada and Idaho, and southern Washington—according to S. E. Rantz and A. M. Moore (2–65). The floods resulted from a series of storms in late December, but primarily from warm torrential rainfall of December 21–23. They took a total of 47 lives and caused damage of almost half a billion dollars.

Precipitation in the form of rain, ranging from 20 to 30 inches, fell in the Sierra Nevada up to altitudes of 10,000 feet during the major storm period, December 19–23, 1964. In Idaho, Washington, and parts of Oregon, melting snow augmented rain that fell on frozen ground. In December 1955 most of the same streams had rampaged wildly to create unprecedented disaster. The 1964 floods did not extend as far south as did those of 1955, but they covered a much larger area in Oregon and Idaho, and peaks at some gaging stations in the flood area were considerably greater than those for the 1955 flood. Peaks on some streams in 1964 closely approached or even exceeded those from the almost-legendary floods of 1861–62, which occurred before the region was heavily settled.

Severe floods in Oregon, January 1965

Heavy rain and snowmelt, a repetition of conditions that had caused the disastrous floods in December 1964, again produced severe floods in Oregon during the last week in January. Peaks at some sites exceeded the December peaks, but major flooding in January was not areally so extensive as that during December.

Floods of April 1964 in Mississippi

Intense rain that totalled as much as 12 inches in a 12-hour period on April 5–6 fell in a band 10 miles wide that extends 60 miles across east-central Mississippi into Alabama. The rain produced the highest floods known on many small streams which drain areas covering as much as 500 square miles. Damage to highways and railroad fills was extensive. Peak discharge exceeded the 50-year discharge at many gaging stations.

During a 29-hour period on April 26–27, 11.69 inches of rain fell at Gulfport, and similar amounts fell along the coast from New Orleans, La., to Mobile, Ala. The recurrence interval for the peak discharge at many measured sites ranged between 25 and 50 years.

Floods of May 25 and June 16, 1964, in Nebraska

Heavy rains occurred May 25 in a band across eastern Nebraska from Genoa to Plattsmouth. The storm center was 8 miles northwest of Genoa, where unofficial reports indicate that a total of 8 to 9 inches of rain occurred during a 2-hour period. Emil Beckman reports peak runoff rates ranging from 1,180 to 1,670 cubic feet per second per square mile from small drainage basins. On June 16, 1964, thunderstorms extended along a path 10 to 20 miles wide across northeastern Nebraska from Boyd County to Cass County, a distance of over 200 miles. Hail, wind, and flood damage were locally severe. The most intense precipitation occurred in the Omaha metropolitan area, where 7 lives were lost and estimated property damages exceeded $6 million. The maximum precipitation totals and peak runoff rates for these storms indicate recurrence intervals much greater than 100 years.

Floods of June 1964 in northwestern Montana

Floods that greatly exceeded previous maxima from mountain areas in northwestern Montana occurred on June 8–10, 1964. The recurrence interval for peak flows at many sites exceeded 100 years. Antecedent conditions which set the stage for extreme floods were a snow cover 25 to 50 percent thicker than the average, below-average runoff in April and May, and extremely heavy rainfall concurrent with a rapid rise in temperature. During a 36-hour period, rainfall (locally as much as 16 inches) was centered along 100 miles of the Continental Divide in the northern half of Montana. Dams on two irrigation reservoirs failed, adding their contents to streams already in flood. The death toll reached 34, and property damage was estimated to be greater than $62 million.

Texas floods of September 1964

Torrential rains on September 19–27 caused flooding in parts of eastern and southwestern Texas. Upper White Rock Creek at Dallas had record-breaking floods. On September 19–20 as much as 17 inches of rain fell in the upper Nueces River basin, causing near-record flooding.

Floods of September 1964 in eastern Virginia

Rains from tropical storm Cleo caused widespread flooding in eastern Virginia. The Hampton Roads area was swamped on September 1 following extremely heavy rains of as much as 13.7 inches in 24 hours at nearby Virginia Beach. Two persons lost their lives, and property damage was extensive. Elsewhere, flooding occurred in the Dan, middle Roanoke, and Chowan River basins. Several bridges on secondary roads were destroyed.

Hurricane floods of October 1964 in North Carolina and Louisiana

Rains associated with two great storms—hurricane Hilda, and hurricane Isabel—caused record-high and near-record floods on many streams, mostly those rising in the mountains of western North Carolina. More than 17 inches of rainfall occurred at Rosman, N.C., in the French Broad River basin, on October 4–5, during hurricane Hilda. The recurrence interval of flood peaks ranged in general from 50 to greater than 100 years.

According to a report by A. S. Lowe (1–64), torrential rains accompanying hurricane Hilda caused a flood on October 3–4 near Baton Rouge, La., that inundated an area similar to that inundated by floods of April 27–29, 1962. The recurrence interval for the peak discharges is about 50 years. Peak stages for the 1964 flood were higher at some points and lower at others than stages for the 1962 flood.

FLOOD FREQUENCY

Nationwide flood-frequency reports

Thirteen reports have been completed in the nationwide series of 19 reports on the magnitude and frequency of floods, and the remaining 6 reports are scheduled for completion by December 31, 1965. Each report is for a part corresponding to a drainage-basin subdivision used by the U.S. Geological Survey. Six reports had previously been published, and one was published this year: Part 1-A, Water-Supply Paper 1671 (A. R. Green, 1–64), for basins in the region from Maine to Connecticut.

Flood-frequency synthesis for small streams in Alabama

Methods of synthesizing flood-frequency curves for small watersheds are being studied in Alabama. According to L. B. Peirce a hydrometeorological approach using available long-term rainfall records to provide the necessary time sampling offers promise for study of 5- to 15-square-mile drainage basins. A relation between storm-rainfall characteristics and peak discharge has been defined on the basis of 3 to 10 years of concurrent rainfall and streamflow records. Amount and duration of rainfall, the antecedent rainfall, and a seasonal factor are used as independent variables from which an array of annual peaks is computed for a site by graphical multiple regression.

Flood-flow characteristics of small drainage basins in Massachusetts

A report by C. E. Knox and C. G. Johnson, Jr. (*in* A. R. Green, 1–64) describes methods for estimating the magnitude of a flood of any frequency between 1.1 and 100 years for any site, gaged or ungaged, on most unregulated streams in Massachusetts. Formulas were derived through multiple-regression techniques that relate flood peaks to drainage area, slope, and an orographic factor. The formulas apply only to sites for which the drainage area is more than 10 square miles and the usable upstream storage is less than 4.5 million cubic feet per square mile.

FLOOD MAPPING

Flood maps of urban areas

Flood-inundation maps showing the limits of inundation by major floods, flood profiles, stage-frequency relations, and descriptive text have been published during the current year as Hydrologic Investigations Atlases for the following areas: Mount Vernon, Ohio (HA–40, revised); Newark, Ohio (HA–44, revised); Chillicothe, Ohio (HA–45); Zanesville, Ohio (HA–46); Circleville, Ohio (HA–48); Hinsdale, Ill. (HA–86); Libertyville, Ill. (HA–88); Joliet, Ill. (HA–89); Harvey, Ill. (HA–90); Baton Rouge, La. (HA–126); Jackson, Miss. (HA–127); Toa Alta, Toa Baja, and Dorado, P. R. (HA–128); Geneva, Ill. (HA–142); Lombard, Ill. (HA–143); and Wadsworth, Ill. (HA–144).

Effect of a bridge on flood elevations

Crest-water surfaces were mapped by K. V. Wilson and B. L. Neely, Jr., at four bridges in central Mississippi during the flood of April 6, 1964. Preliminary analysis of the data indicates that water-surface elevations at various places in the vicinity of a bridge may vary by several feet. Elevations at the downstream side (the usual location of a gaging station) were found to be as much as a foot higher than elevations along the downstream side of the highway fills near the bridge abutments. Results of the study emphasize the importance of careful site location when gages are established on or near bridges.

Flood mapping in Delaware River basin

A flood-inundation study of a 12.6-mile reach of the Delaware River in the vicinity of Easton, Pa., and Phillipsburg, N.J., by G. M. Farlekas and J. A. Bettendorf discloses a relatively small increase in areal extent of flooding with increase in flood magnitude. Floods ranging in recurrence interval from 11 to 130 years inundated areas ranging from 0.88 to 1.29 square miles. The range in stage for this range in flood magnitude was 6 to 16 feet above flood stage. Results show that for the reach studied, which is constricted by steep valley walls, depth of flooding is more significant than areal inundation.

Flood-plain inundation study, Princeton, N.J.

Height-frequency relations for New Jersey floods, as determined by D. M. Thomas (2–64), were verified by J. A. Bettendorf for the lower 10-mile reach of Story Brook in the vicinity of Princeton, N.J. Heights for floods of 1½- and 35-year recurrence intervals were estimated, using procedures developed by Thomas; the estimated heights were compared with measured heights based on flood profiles defined by surveyed high-water marks. Estimates for 9 of the 10 sites, which are within ±23 percent of measured values for a 1½-year flood and within ±13 percent for a 35-year flood, are significantly better than the expected limits of accuracy defined by Thomas.

EFFECTS OF THE 1964 ALASKA EARTHQUAKE

INVESTIGATIONS OF GEOLOGIC EFFECTS

Geological Survey contributes to reconstruction effort

In the wake of the 1964 Alaska earthquake the Federal Reconstruction and Development Planning Commission appointed the Scientific and Engineering Task Force. U.S. Geological Survey geologists were assigned to the task force and its field team, which had primary responsibility for making recommendations to the Commission as to where, and where not, Federal funds should be spent for reconstruction. In the carrying out of the program, fieldwork by R. W. Lemke was instrumental in selecting a new more stable location for dock and harbor facilities at the head of Resurrection Bay at Seward; investigations by H. W. Coulter and R. R. Migliaccio figured prominently in the decision to relocate the city of Valdez from its pre-earthquake site to the Mineral Creek area; and the U.S. Geological Survey geologists were instrumental in the selection of new sites required in the rebuilding of parts of Anchorage.

Lake seiches investigated

In a study of earthquake-induced seiches, and slides from the edges of deltas, at Kenai Lake on the Kenai Peninsula, D. S. McCulloch determined that water-level oscillations occurred at the natural period of the lake basin. The direction, run-up height, and inshore limit of wave action were determined; it was firmly established that subaqueous slides as well as seiches caused destructive local waves.

Submarine slides generate destructive sea waves

Studies by George Plafker of wave distribution along the shores of Prince William Sound and the Kenai Peninsula indicate that violent waves of local origin occurred at numerous localities during the earthquake. The surface work, supplemented by submarine studies by the U.S. Geological Survey and U.S. Coast and Geodetic Survey at selected localities and by eyewitness accounts, indicates that most of the waves were generated by precipitous earthquake-triggered submarine landslides. Using a sonaprobe loaned by G. G. Shor of the Scripps Institution of Oceanography, G. A. Rusnak was able to identify deposits of large submarine slides triggered within Prince William Sound. Seiche waves and waves generated by subaerial landslides apparently did not contribute significantly to the shoreline damage.

Inferred buried fault zone on Kenai lowland

Regional mapping of earthquake effects in the

Cook Inlet area by T. N. V. Karlstrom and H. L. Foster has delineated a linear fractured zone in the surficial deposits of the Kenai lowland. It appears to reflect a major buried sheared zone, or fault, that was reactivated during the 1964 earthquake. The fractured zone trends northeast or parallel to major steeply dipping thrust faults with recent right-lateral strike-slip displacements.

Recent movement in bedrock at depth beneath the fractured zone is suggested by a concentration of micro-aftershock activity beneath the zone, and by the zone's alinement with epicenters of past earthquakes. A buried fault of probable post-Cretaceous, pre-middle Tertiary age is suggested by scattered subsurface data. At one point beneath the zone, seismic evidence indicates a major fault of unknown strike but with large vertical offset.

The inferred fault passes close to the producing oil fields on the Kenai lowland. All production lies northwest of the inferred fault; numerous dry holes have been drilled southeast of the structure.

Land–sea level changes in Cook Inlet region

Observations of coastal geology by T. N. V. Karlstrom and personnel of the U.S. Fish and Wildlife Service indicate the following changes in sea-level datum along Cook Inlet: plus 4–6 feet near Hope; plus 3–4 feet near Chickaloon Bay; no change or less than 1 foot upward between the Point Possession and Anchor Point on the Kenai Peninsula and along the west shore of Cook Inlet near Tyonek; and plus 1–2 feet along the slumped front of the Susitna River delta. The geologic estimates of sea-level change at the localities along the south shore of Turnagain Arm are of the same order of magnitude as the changes determined for bedrock bench marks on the north shore by U.S. Coast and Geodetic Survey relevelling from datum control points at Seward and Valdez. The relevelling and observational results differ by about 1 foot from postearthquake, short-term records from tide gages, reported from both Anchorage and Nikishka. (Similar discrepancies between levelling and tide-gage records in the Cook Inlet region, observed in the past, were thought to reflect the presence of a sloping sea-level datum slope in Cook Inlet resulting from the restricted estuary environment and the high tidal range.)

Line of zero change in Cook Inlet

The combined geologic and relevelling data in Cook Inlet analyzed by T. N. V. Karlstrom indicate that the eastern part of the region subsided, with the maximum subsidence closely coinciding with the arcuate axis of the Chugach-Kenai Mountain range. In the upper Turnagain Arm area subsidence reached a maximum of about 6 feet, and became progressively less to the northwest. The line of zero change separating the area of subsidence from the area of stability or minor uplift on the continental side is still not precisely located. Present data suggest that the line of zero change lies somewhat north of the Matanuska valley within the Talkeetna Mountains and passes southwestward across the Susitna River lowland through a point near Tyonek and into Cook Inlet. Here it appears to extend roughly parallel to the Aleutian Range coastline into the Shelikof Straits area.

Tilted lake basins

Observations on pre-earthquake high-water marks relative to present water levels in the basins of Tustumena, Skilak, and Eklutna Lakes by T. N. V. Karlstrom indicate that differential regional tilting to the southeast was probably less than 2–3 feet over the length of each lake.

Ground breakage in Copper River Basin area

Field investigations by O. J. Ferrians, Jr., indicate that ground breakage was widespread in the Copper River Basin area within a radius of 100 miles of the main epicenter of the earthquake. Ground cracks formed in flood plains of rivers, in deltas, and along the toes of alluvial fans. They also occurred locally in low terraces adjacent to flood plains, in highway and other fill material, along the margins of lakes, along the face of steep slopes of river bluffs and hillsides, and in areas cleared of vegetation for several years. Their overall distribution indicates that local geologic factors primarily controlled their distribution. The ground cracks were restricted to areas underlain by unconsolidated deposits where one or more of the following conditions existed: (1) permafrost was absent or deep lying, (2) the water table was near the surface, (3) bedrock was relatively deep lying, and (4) slopes were steep. In addition, at the time of the earthquake (March) the thickness of seasonal frost differed somewhat from place to place throughout the area.

Pre- and post-earthquake elevations related to gravity anomalies

Comparison of pre- and post-earthquake gravity observations by D. F. Barnes indicate that negative gravity changes are related to positive elevation changes, and suggests that the changes are accompanied by rearrangement of masses at depths shallow enough to affect the gravity observations. The gravity data do not seem to indicate that chemical reactions, phase changes, or elastic changes not accompanied by horizontal deformation are causes of the elevation changes.

Barnes also reports that recently completed reconnaissance gravity surveys combined with previous years' surveys now provide coverage in a north-south traverse belt across the entire State. Preliminary analyses of these data and of geomorphic observations suggest that counterisostatic elevation changes similar to those during the Alaska earthquake are also probably occurring at much slower rates throughout southern Alaska as far north as the Yukon and Tanana Rivers. Thus positive isostatic anomalies are associated with increasing elevations in the Alaska Range and Talkeetna Mountains.

Deformation of Kodiak Island

On the basis of 23 estimates of land-level change on Kodiak Island, G. W. Moore defined the deformation that occurred there at the time of the Alaska earthquake. The island was downwarped along a broad northeast-trending asymmetrical syncline with its axis passing about 10 kilometers southeast of the city of Kodiak. The city was depressed 1.6 meters below its former level, whereas Narrow Cape to the southeast was elevated 1.2 m. The gentle northwest flank of the syncline slopes 2 centimeters per kilometer toward the axis, and the southeast flank slopes 20 cm per km. The synclinal axis plunges 1 cm per km to the northeast, and a parallel anticline lies next to the syncline off the southeast shore of Kodiak Island.

Origin and extent of Bootlegger Cove Clay

Failure of the Bootlegger Cove Clay in the Anchorage area during the Alaska earthquake, and the landsliding and catastrophic damage related to this failure, as reported by Arthur Grantz, George Plafker, and Reuben Kachadoorian[19] renewed the interest of geologists and engineers in this deposit. Recent study of samples from exposures at the type locality by R. A. M. Schmidt[20] showed the presence of marine fossils except in the uppermost part of the section. P. J. Smith has examined samples from three cores, as an aid in clarifying the problem of the environment of deposition of the formation. Marine faunas were present throughout the sections studied, which extend through most of the formation. The faunas are similar to those of the present-day cold shallow (±25 meters) water of Cook Inlet. The water salinity inferred for the base of the section is normal for marine water, becoming lower toward the top.

F. W. Trainer and R. M. Waller (p. D167–D174), in a study of the glacial drift at Anchorage based chiefly on subsurface data, found that the Bootlegger Cove Clay is the youngest of several clays deposited in the area during Pleistocene time. Locally it is more than 200 feet thick, and in much of the area it is more than 100 feet thick. Its areal extent and the configuration of its base and upper surface show that it was deposited in, and retained the form of, a basin which had persisted from earlier in the Pleistocene.

Southern Alaska Continental Shelf tectonics

D. F. Barnes accompanied the USCGS ship *Surveyor* on a marine geophysical reconnaissance of the southern Alaska Continental Shelf following the 1964 earthquake. On this cruise the Patton Bay fault found by the U.S. Geological Survey on Montague Island was traced approximately 30 miles offshore, and similar evidence of old or recent faulting was found approximately 100 miles farther southwest along the approximate strike of the fault. Gravity data obtained on the same cruise show that a large free-air and isostatic gravity high covers the portion of the Continental Shelf where new emergent shorelines were found after the earthquake. Inasmuch as the earthquake did not decrease the gravity anomaly, the anomaly is believed to be the result of counterisostatic processes.

Crust deformed by 1964 Alaska earthquake

Studies of the tectonic deformation associated with the Alaska earthquake by George Plafker and other U.S. Geological Survey geologists indicate that: (1) vertical movement occurred over an area of at least 50,000 square miles, with a maximum observed uplift of 33 feet and a maximum subsidence of 7½ feet; (2) the deformation consists of a coastal zone of uplift that includes much, if not all, of the Continental Shelf and is bordered on the inland side by a zone of subsidence; and (3) vertical displacements result largely from crustal warping with superimposed local surface faulting on Montague Island and the adjacent Continental Shelf. The main fault along which the earthquake occurred is not exposed at the surface. It is inferred to be related to the Aleutian Arc, and to dip at a low angle beneath the continental margin from the Aleutian Trench.

[19] Arthur Grantz, George Plafker, and Reuben Kachadoorian, 1964, Alaska's Good Friday earthquake, March 27, 1964: U.S. Geol. Survey Circ. 491, 35 p.

[20] R. A. M. Schmidt, 1963, Pleistocene marine microfauna in the Bootlegger Cove Clay, Anchorage, Alaska: Science, v. 141, p. 350–351.

Uplift of Continental Shelf initiates ocean waves

George Plafker suggests that the train of long-period seismic sea waves that followed the earthquake was impulsively generated by rapid uplift of the Continental Shelf. Distribution of wave damage, and calculated travel distance of the initial crests, based upon reported arrival times along the coast of south-central Alaska, indicate that the major zone of wave generation is along a line at least 180 kilometers long that extends southwestward from Montague Island. The northern end of this zone coincides with the area of maximum known uplift off the southwest tip of Montague Island.

INVESTIGATIONS OF HYDROLOGIC EFFECTS

Effects in Alaska

The earthquake produced unusual and significant hydrologic effects in Alaska. According to R. M. Waller, preliminary analysis of water-level changes in artesian-aquifer systems composed of glaciofluvial deposits indicates an apparently permanent lowering of artesian-pressure level in parts of some basins. The lowered levels appear to represent either increases in the transmissibility of the aquifers or increases in the rate of discharge from them. A. J. Feulner, using cyclic tidal stage-ratio and time-lag methods, has tentatively determined an increase in transmissibility at two wells at Anchorage. L. L. Dearborn and M. V. Marcher collected data on 100 wells in the Anchorage area and found that about 70 percent were affected by the earthquake: in 25 percent the water level had declined noticeably, while in about 40 percent the water had been muddied for periods ranging from a few hours to a month. A few wells were extensively damaged by breaking of the casing or screen or by the surging of mud up through open-end casing. R. M. Waller believes that shallow water-table aquifers, capped by seasonal frost, played an important role in extensive fracturing of surficial deposits and extrusion of sand and mud. The lower slopes of alluvial fans, the outer edges of deltas, the channels of braided streams, and swampy areas were the principal sites of this fracturing and extrusion. The ice covers of lakes and streams were broken or cracked to distances of at least 400 miles from the earthquake epicenter.

In many streams, flow was greatly reduced temporarily, according to M. J. Slaughter, as a result of (1) the loss of water into fractures, damming by landslides or snowslides; and (2) the sloshing of water from lakes. In other streams, flow increased, probably because of the release of water from ice-choked reaches. Preliminary appraisals suggest no changes in long-term trends of stream discharge, however, except perhaps in areas of maximum uplift or subsidence. Several stream gages on Kodiak Island and in southeastern Alaska recorded seismic sea waves that travelled far upstream; and those gages on Kodiak Island now regularly record ocean tides, as a result of the subsidence of Kodiak Island. L. S. Leveen reports that the sediment load in the Matanuska River, which began its spring runoff immediately after the earthquake, increased to about five times that recorded at comparable rates of water discharge in previous years. The increase lasted through April; sediment discharge then returned to normal as most of the slide debris along the banks and the sand and silt extruded upon channel bars were removed.

Effects outside Alaska

The earthquake also caused important hydrologic changes outside Alaska. R. C. Vorhis has tabulated seismic water-level fluctuations recorded in 661 wells in 44 of the 50 States, and in 4 wells in Puerto Rico and 1 in the Virgin Islands. (Water-level fluctuations caused by this earthquake were also recorded in wells in Canada, Great Britain, Belgium, and Libya.) The largest recorded fluctuation, 23 feet, occurred in a well at Belle Fourche, S.Dak. The earthquake was recorded in 70 wells in Florida; in some wells, especially near Tampa, the movement was so violent that float cables were thrown from the pulleys of the recorders. Perhaps the most unusual hydrologic effect of this earthquake has been an apparently permanent change in the water-level at some localities. In the south Georgia basin, for example, water levels in some wells rose during a 3-week period after the quake, and the maximum rise recorded was about 3.3 feet. On the other hand, a well that penetrates a recharge area in Clay County, Fla., showed a reverse effect—the water level began to decline at the time of the quake and dropped 4 feet over a 3-week period. Similar local changes in water level following the earthquake occurred in Illinois, Michigan, Nevada, Pennsylvania, and Utah. These changes in water levels, which appear to be permanent, may reflect strains developed in the earth's crust as a result of the earthquake. A. M. Piper[21] and others have suggested that earthquakes might cause strains that produced hydrologic changes.

[21] A. M. Piper, 1933, Fluctuations of water-surface in observation-wells and at stream-gaging stations in the Mokelumne area, California, during the earthquake of December 20, 1932: Am. Geophys. Union Trans., 14th Ann Mtg, p. 471–475.

The Alaska earthquake generated seismic seiches in many parts of the conterminous United States. Surface-water records collected by the Geological Survey and tabulated by R. C. Vorhis show that in Texas 69 gages recorded seiches; the maximum fluctuation had a double amplitude of 0.68 feet. In Georgia the maximum fluctuation recorded by 24 gages was 0.22 feet. Other States in which seiches were recorded include Alabama, Arkansas, Illinois, Indiana, Kentucky, Louisiana, Missouri, Ohio, Pennsylvania and Tennessee. Most of the seiches recorded were in the south-central and southeastern States. Many swimming pools in the Gulf Coast States sloshed water at the time of the quake, but no reports of seiches have been received from the Atlantic Coast States.

REGIONAL GEOLOGY

Much of the geologic and geophysical work of the U.S. Geological Survey consists of the mapping of specific areas, mostly for publication as quadrangle maps at scales of 1:62,500 and 1:24,000. Some of these studies are for the purpose of extending the detailed geologic knowledge in areas of known economic interest; some are to gain detailed knowledge at localities or areas for engineering planning or construction. Still other mapping studies are carried on with paleontology, sedimentary petrology, or some other specialized topic as the primary objective.

The systematic description and mapping of rock units to show local and regional relations likewise constitute a major scientific objective. Mapping the geology of the United States is a mandate of the Organic Act establishing the Geological Survey, and the completion of geologic maps for the country at scales that will fulfill foreseeable needs and uses is a long-range goal. A summary of recent results of this mapping, especially in the fields of stratigraphy, structural geology, and regional geophysics, is discussed here according to subdivisions of the conterminous United States shown on figure 3.

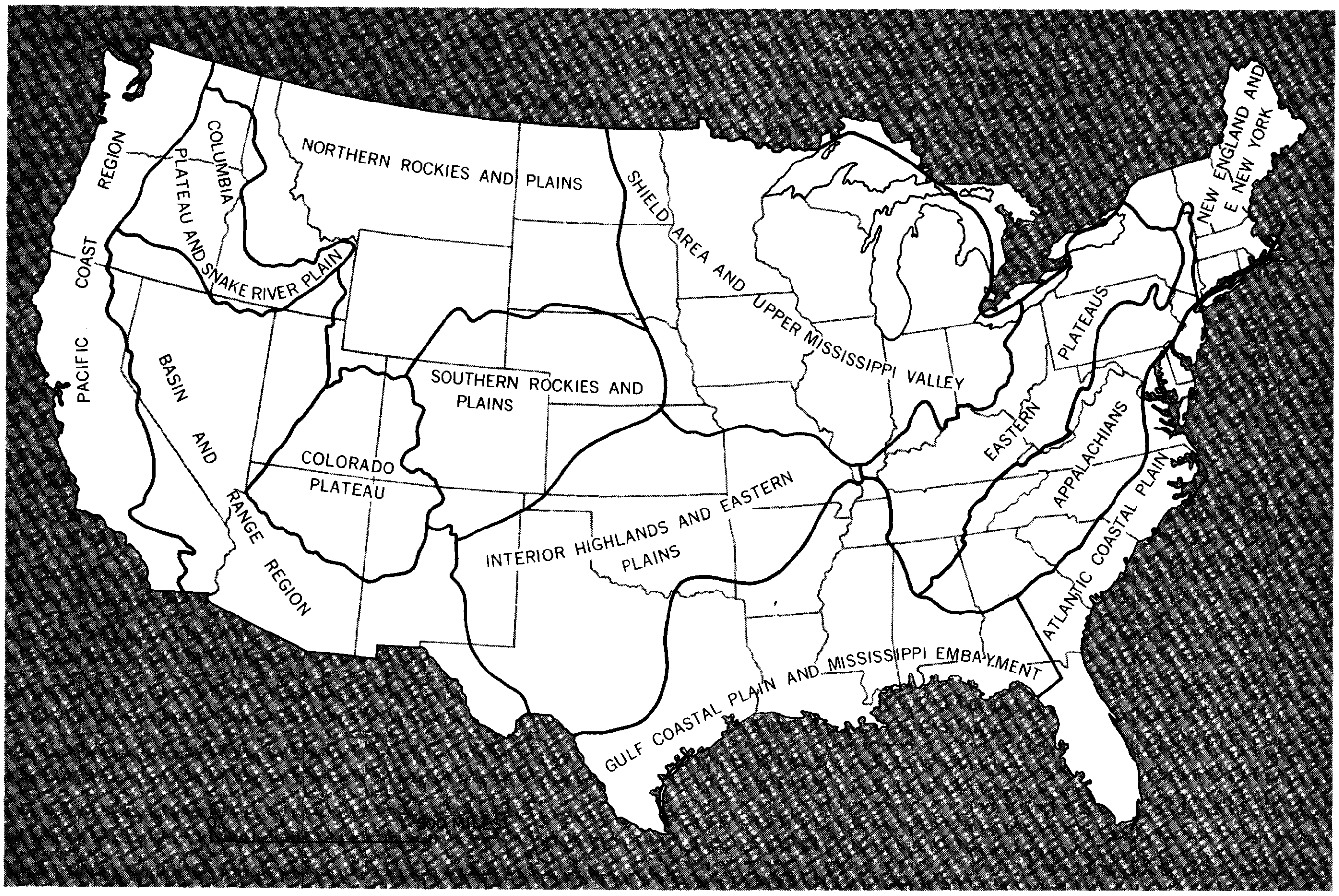

FIGURE 3.—Index map of the conterminous United States, showing boundaries of regions referred to in discussion of regional geology.

INTERMEDIATE-SCALE GEOLOGIC MAPS

Geologic mapping at a scale of 1:250,000 on 1° by 2° topographic base maps comprises a new formal element of the U.S. Geological Survey's program. Geologic mapping at this scale has formed a small but significant part of the Survey's geologic studies for many years—notably in long-range programs to complete geologic coverage in Alaska, Oregon, Nevada, and the Colorado Plateau. The value of intermediate-scale geologic maps is also recognized by State Geologic Surveys, many of which have 1:250,000-scale geologic-map programs underway or completed. This joint attack by the Federal and State Surveys on a nationwide problem promises to provide complete intermediate-scale geologic map coverage of the United States at a rapid pace.

Coordinated geologic-mapping programs at this scale are well underway in the States of Alaska, Oregon, Nevada, Colorado, and Nebraska, and single-sheet 1° by 2° geologic maps have been started for Montana, Idaho, Wyoming, Washington, and the southern Appalachian region.

Although not a substitute for the standard inch-per-mile geologic map program, the 1:250,000-scale studies will indicate areas where the need for larger scale maps is most critical, and will direct attention to larger segments of the earth's crust. The ready availability of uniform coverage at intermediate scale promises more realistic priority assignments for new starts in inch-to-the-mile geologic mapping. The 1:250,000-scale maps have already proved to be ideal for geologic analysis of broad tectonic and stratigraphic problems, for analysis of mineral provinces, and for relating broad geophysical anomalies to surface geology.

MAPS OF LARGE REGIONS

Cooperative projects

Maps of national or international scope are prepared as a regular and important part of the Geological Survey program. Such maps utilize studies by Geological Survey personnel, published information and unpublished information supplied by State Geological Surveys, private companies, and universities. Some of the maps are prepared and published by the Geological Survey in collaboration with national and international scientific organizations.

A Bouguer gravity-anomaly map of the United States, exclusive of Alaska and Hawaii, scale 1:2,500,000, was published in November 1964. This map was compiled by the Special Committee for Geophysical and Geological Study of the Continents, American Geophysical Union, G. P. Woollard, University of Hawaii, chairman, and was published by the Geological Survey, H. R. Joesting, coordinator. It shows relative gravity values, which reflect variations in thickness and density of rocks in the earth's crust; the contour interval is 10 milligals. The map is available in two editions: one is on translucent parchment paper for overlaying on the "Tectonic Map of the United States" or on other maps using the standard 1:2,500,000 base, and the other is on standard map paper.

Other cooperative maps currently in preparation that are to be published by the Geological Survey include:

1. Geologic map of North America, scale 1:5,000,000, multicolor in 2 sheets, each measuring 40 x 58 inches. This map was compiled by a committee of the Geological Society of America, E. N. Goddard, University of Michigan, chairman. It is planned for publication by the Geological Survey in late 1965, on a two-color base (black for culture and geography and blue for water). The base prepared by the Survey also shows depth of water in offshore areas by contours drawn at 200 meters, 500 meters, and at 500-meter intervals thereafter. More than 120 different geologic units are shown by overprinting screens and patterns of 6 colored inks.
2. Tectonic map of North America, scale 1:5,000,000. This map is being compiled for the Subcommission for the Tectonic Map of the World, International Geological Congress, under the guidance of P. B. King, U.S. Geological Survey. Compilation of the southern half of the map is completed; the northern half is still in compilation stage. The work ultimately will contribute data about North America for the "Tectonic Map of the World," at a scale of 1:15,000,000, a cooperative international undertaking sponsored by the International Geological Congress.
3. Basement map of North America between latitudes 20° and 60° N., scale 1:5,000,000. Compilation of this map is by the Basement Rock Project Committee of the American Association of Petroleum Geologists, P. T. Flawn, University of Texas, chairman, using part of the new base map of North America. The map will show the altitude of the upper surface of the basement as determined from wells, geophysical measurements, and geologic inference. The basic well data compiled by the committee in preparing the basement map of North America will be pub-

lished by the American Association of Petroleum Geologists.

4. Basement rock map of the United States, scale 1:2,500,000. This map is sponsored by the Advanced Research Project Agency, Department of Defense, under the direction of W. R. Muehlberger, University of Texas. Compilation of the basement rock map is virtually completed. Colors and patterns will show the age and lithologic types of both the exposed and buried basement rocks. Some internal structures of the rocks, where known, will also be shown by symbols.

Paleotectonic maps

A long-term program to compile and publish paleotectonic maps of the conterminous United States for each of the geologic systems is continuing. The magnitude and sequence of tectonic events and the history of sedimentation are reconstructed on these maps by subdividing the system under investigation into intervals that can be broadly correlated for the country as a whole. Objective maps at a scale of 1:5,000,000 show the present extent, thickness, and lithofacies of each stratigraphic interval. Interpretive maps, most at a scale of 1:10,000,000, reconstruct the former extent of the interval, show the principal tectonic elements influencing deposition, identify some of the environments of deposition, and show other features of importance to regional geology. Folios of the Jurassic and Triassic Systems have been published; the folio for the Permian System has been compiled and is being readied for publication. Maps for the Pennsylvanian and Mississippian Systems are in preparation.

A map showing the total thickness of Pennsylvanian rocks has been compiled for the part of the conterminous United States west of long 95° W. Pennsylvanian rocks cover most of this area except for Washington, Oregon, California, and eastern Nevada, where Pennsylvanian rocks are present locally but for the most part have either been destroyed by igneous activity or are deeply buried by younger rocks. The map shows that Pennsylvanian rocks are thickest in a series of disconnected en echelon troughs lying in a northwest-trending band from southeastern Oklahoma to southern Idaho.

Catalog of aerial photographs

A catalog of aerial photographs in stereographic pairs illustrating geologic features in the 50 States and Puerto Rico is being prepared under the direction of C. S. Denny. Currently, entries have been made for about 300 sets of photographs; most entries include reference to a geologic report and to a topographic and geologic map of the area shown in the photographs. A list of the photographs, where they can be obtained, and other pertinent information is in preparation.

National Atlas

The Geological Survey is one of several government agencies and private groups that are providing maps and text for a National Atlas. The National Atlas is being prepared under the direction of A. C. Gerlach, staff geographer, on loan from the Library of Congress and will be published under the auspices of the Department of the Interior. Maps will be at a scale of 1:7,500,000, or smaller. Maps of a geologic nature that are the responsibility of the Geological Survey and the geologists in charge of their preparation are as follows: (1) seismology and gravimetry tectonic features of the conterminous United States, and tectonic features of Alaska, P. B. King; (2) geologic history, L. C. Craig; (3) geologic map, D. M. Kinney; (4) glacial geology, C. S. Denny; and (5) karst areas and caves, W. E. Davies.

For further information see the writeup on "National Atlas" in the section, "Topographic Surveys and Mapping."

COASTAL PLAINS

ATLANTIC COASTAL PLAIN

Form of pre-Cretaceous basement in New Jersey

H. E. Gill reports that deep test drilling in Ocean and Burlington Counties, in the coastal plain of central New Jersey, has more precisely defined the pre-Cretaceous basement. In detail this surface is more irregular than was heretofore thought. Test wells penetrated the basement several hundred feet lower at Island Beach State Park in Ocean County, and higher to the west at Butlers Place, Burlington County, than was predicted from previously published data. The new data indicate the presence of a structural high, trending northwest-southeast, which had a strong influence on the lithologic character and distribution of deposits of the adjacent transitional sequence of Cretaceous marine deposits.

Miocene folding and faulting in Georgia

Structure contours of the top of the Suwanee Limestone of Oligocene age, drawn by C. W. Sever, show that this aquifer is folded into a northeast-plunging syncline near Meigs, in southwestern Georgia, and into a southwest-plunging anticline near Brunswick, at the Atlantic coast. A northeast-trending high-angle fault named the Ochlockonee extends between these folds. Displacement across the fault is as much as 190 feet, with the southeast side upthrown. Thickening and displacement of the formations across the Ochlockonee fault show that the folding and faulting occurred periodically during early and middle Miocene time.

Surface expression of coastal-plain structures in New Jersey

Detailed mapping by J. P. Minard and J. P. Owens has outlined two well-defined domal structures in the coastal-plain sediments east of Trenton, N. J. The sediments known to be involved in the folding range in age from Late Cretaceous (Companian) through middle Miocene. The structures are elliptical and each measures approximately 1.5 by 4 miles. The long axes of the ellipses are alined northeast-southwest, parallel to the regional strike of the formations. The presence of these folds and of other smaller structures throughout this area suggests widespread minor folding of the coastal-plain formations.

Ordovician shale found in basement rock in Florida

Recent examination by Jean Berdan of cuttings from a well in Suwannee County, in northern Florida, confirms the existence of a belt of Middle Ordovician black shale trending southeast-northwest beneath the middle of the county at depths between 3,000 and 4,000 feet. The Middle Ordovician rock is overlain to the northeast by black shales of Silurian age, and it is underlain to the southwest by quartzitic sandstones of Early Ordovician age.

Stratigraphic studies in South Carolina

A water well drilled near Orangeburg, in south-central South Carolina, penetrated 930 feet of coastal-plain sediments. Projection of known stratigraphic relationships into this region shows that the lower 500 feet of sediments should be Late Cretaceous in age, and approximately 400 feet should be assignable to the Tuscaloosa Formation (Woodbine age). G. E. Siple and W. D. Paradeses report, however, that the sediments are lithologically similar to the younger Black Creek or Ellenton Formations (Austin to Navarro in age). A pronounced thinning of the Tuscaloosa section in this region is thus indicated. A possible explanation is that the axis of deposition for the Upper Cretaceous sediments in this particular basin is alined more nearly in a northeast-southwest direction than northwest-southeast, as had heretofore been postulated, and that the sediments near Orangeburg represent a change to a thinner facies than the Tuscaloosa.

As part of a study of the distribution of permeable sands in central South Carolina, Siple and Paradeses have mapped hitherto unreported bodies of indurated coarse quartz sandstone with tan-colored claystone inclusions up to 20 centimeters in diameter, underlain by beds of claystone (prodelta clay?), in the Gilbert (15′) and Batesburg S.E. (7½′) quadrangles. Although the sand bodies are probably of Eocene age, they form residual hills standing about 25–30 feet above the surrounding plain which is formed of lower to middle Tertiary rocks. The sandstones are coarsely crossbedded and weathered to dark gray. Smooth-walled ovate cavities occur along the more or less horizontal bedding planes along the topsets or bottomsets, and their major axes are parallel to this bedding; presumably they were originally filled by clay balls.

Cretaceous microfaunas and heavy minerals along Chattahoochee River, Georgia and Alabama

During paleontologic and petrologic studies of the Blufftown Formation, Cusseta Sand, Ripley Formation, and Providence Sand in the section along the now-inundated Chattahoochee River in Georgia and Alabama, Harlan Bergquist and J. E. Johnston found an excellent microfaunal assemblage of about 60 species of Foraminifera and 7 or 8 species of ostracodes. A few planktonic species of Foraminifera occur in all the formations; arenaceous species appear to be most common in the Blufftown and Ripley Formations. Preliminary determinations indicate that the faunas are largely assemblages of Austin to Taylor age but represent Late Cretaceous stages from Santonian to Maestrichtian. Of particular note is a relatively high percentage of phosphate in the fine size of the heavy-mineral fractions of the Cusseta Sand.

Subsurface stratigraphic studies of Georgia coastal plain

Recent subsurface stratigraphic studies by S. M. Herrick show that Pliocene(?) sediments definitely underlie Glynn, Charlton, and Camden Counties, in southeastern Georgia, as indicated by the presence of certain varieties of the genus *Ammonia*. Between Liberty and Glynn Counties the lithologic section of upper Cretaceous (mid-Taylor age) to lower Tertiary (base of the middle Eocene) rocks changes from unconsolidated clastic rocks to a limestone facies. The sequence of carbonate rocks strongly resembles the limestones of similar age in peninsular Florida. Northeast of Liberty County, lower Eocene rocks are absent from sections penetrated in Geological Survey test holes in Chatham County, Ga., and on Parris Island, S.C. This absence may be due to up-faulting of these rocks and their subsequent removal by subaerial erosion.

Pollen in Pleistocene terrace deposits at Washington, D.C.

Palynological study of the lower terrace deposits at Washington, D.C., by A. S. Knox has revealed that several changes in climate and sea level occurred in the area during Pleistocene time. The evidence suggests that two interglaciations, the Sangamon and the Yarmouth, and two glaciations, the Wisconsin and the Illinoian, are represented. The interglacial deposits, with abundant pollen of broad-leaved deciduous trees, indicate a climate as warm as or warmer than that of the present; the glacial-age deposits contain abundant spruce pollen and indicate temperatures much lower than those of the present.

Buried Pleistocene(?) valley on Long Island, N.Y.

Julian Soren reports that deep drilling about a mile west of Lake Ronkonkoma, in the mid-island region of Suffolk County, Long Island, N.Y., has disclosed the presence of a deep buried valley cut in Cretaceous deposits. The valley trends about N. 45° W. from Long Island Sound, and is more than 300 feet below present sea level.

Significant finds of vertebrate fossils in Virginia and Florida

Two mammalian fossils recently given to the Survey for identification have raised questions concerning the correspondence of age classifications of the coastal-plain sediments based on vertebrate and on invertebrate fossils, respectively. A single lower horse molar, collected from the Yorktown Formation (upper Miocene) at Cobham Wharf, Va., has been identified by F. C. Whitmore, Jr., of the U.S. Geological Survey and M. F. Skinner, of the Frick Laboratory, American Museum of Natural History, as *Hipparion* cf. *H. eurystyle* Cope, of Clarendonian or early Hemphillian (early or early middle Pliocene) age. The possibility that part of the Yorktown may be of Pliocene age is further supported by the finding in 1960, at Hampton, Va., of a baleen whale of a type that seems too advanced for the Miocene.

Part of a horse skull, found in the Caloosahatchee Formation in its type area near Labelle, Fla., has been identified by Whitmore as *Equus*, probably a mid-Pleistocene species. This find is of particular interest because the rich invertebrate fauna of the Caloosahatchee is generally regarded as being of Pliocene age.

GULF COASTAL PLAIN AND MISSISSIPPI EMBAYMENT

Paleontologic data suggest northward Paleocene transgression across Mississippi embayment

Studies of Foraminifera by S. M. Herrick have shown that the Clayton Formation in Hardeman County, Tenn., although containing several "key" species that are reportedly limited elsewhere in the region to the Clayton Formation or its stratigraphic equivalents, contains 32 species that are reported by Cushman [22] from the Matthews Landing Marl Member of the Porters Creek Formation that overlies the Clayton Formation in Alabama. These paleontologic data suggest to Herrick that the sea in which the Clayton was deposited was transgressive northward and that the Clayton Formation is of late Paleocene age in Tennessee.

Recently incised meanders and older terraces along Alabama River

The Alabama River between Montgomery and Selma, Ala., is reported by L. C. Conant to be bordered on one side or the other by 10- to 20-foot banks cut into the Eutaw Formation and Selma Group of Late Cretaceous age. The cut banks indicate that most or all of the present meanders are recently incised and are not subject to lateral shifting. Older downcutting is shown by the presence of broad thick terrace deposits of gravel, sand, and clay which were noted by Conant a few miles north of the flood plain, along this segment of the river, as much as 200 and 300 feet above the flood plain. Terraces of similar composition were earlier recognized by Monroe (p. 43–44 [23]) at comparable levels on the south side of the river but at considerably greater distances from the flood plain.

Jurassic stratigraphy, tri-state area of Arkansas, Louisiana, and Texas

Isopach mapping by K. A. Dickinson has revealed that the Buckner Member of the Haynesville Formation in northeast Texas, southwest Arkansas, and northwest Louisiana is composed of two genetically different units. The areas of deposition of both units were limited on the south by barriers consisting largely of two series of salt-cored gravity-flow anticlines. The barrier for the lower unit extends from the Linden oil field, in south-central Cass County, Tex., through the McKamie oil field in cen-

[22] J. A. Cushman, 1951, Paleocene Foraminifera of the Gulf Coastal region of the United States and adjacent areas: U.S. Geol. Survey Prof. Paper 232, 75 p. [1952]

[23] W. H. Monroe, 1941, Notes on deposits of Selma and Ripley age in Alabama: Geol. Survey of Alabama Bull. 48, 150 p.

tral Lafayette County, Ark., and thence eastward through Columbia and Union Counties, Ark. The upper unit, which represents a less saline depositional environment than that of the lower unit, overlapped the barrier of the lower unit and extended southward to a barrier that trends from the Rodessa oil and gas field in northern Marion County, Tex., and Caddo Parish, La., eastward along the Louisiana State Line to the Haynesville oil field in northern Claiborne Parish, La.

NEW ENGLAND AND EASTERN NEW YORK

Glacial chronology of New England

The chronology of the glaciation of New England has been summarized in a review of published and unpublished data by J. P. Schafer and J. H. Hartshorn. The last glaciation (Wisconsin) was preceded by (1) a widespread glaciation that appears to be of post-Sangamon and pre-classical Wisconsin age, (2) by the deposition of the Gardiners Clay of Sangamon age, and (3) by the formation of still older drifts of uncertain correlation. The last ice sheet reached its maximum advance along the coast of southern New England, probably in early Woodfordian (Tazewell) time. Readvances in southern New England, northern Vermont, and southwestern Maine are not well dated, but may be approximately of Cary, Port Huron, and perhaps Valders age. The last ice masses in New England were a possible local icecap on the White Mountains and in western Maine, and cirque glaciers on Mount Katahdin.

EASTERN NEW YORK

Five major units in northwest Adirondacks form refolded anticlinorium

Stratigraphic reconstruction by A. E. J. and C. G. Engel shows five major units in the northwest Adirondack Mountains. Three of the units are carbonate formations, one is a graywacke sandstone, and the other is a thick basal quartzite. These formations apparently form a refolded anticlinorium metamorphosed at progressively higher grades in the direction of the central Adirondack massif.

Migration of elements during metamorphism, northwest Adirondacks

The progressive metamorphism of marble, graywacke, pelite, quartzite, and basalt in the northwest Adirondacks involves progressive dehydration, decarbonation, and loss of alkalis, silica, and cogenetic trace elements. At the pressure and temperature conditions of the upper amphibolite facies, anatectic magma is formed by partial melting of clastic sediments. The mineralogy of the metamorphic rocks has been explored in detail by A. E. J. and C. G. Engel. The volume of Mn, Fe, Ti, Pb, and Zn mobilized from the sedimentary column is in excess of that concentrated in the known economic concentrations of these elements in the northwest Adirondacks. Most mineral deposits in these rocks appear to be derived in large part by the metamorphic mobilization of the elements from the enveloping and subjacent country rock.

RHODE ISLAND

Geology of Chepachet quadrangle studied

Work by A. W. Quinn in the Chepachet quadrangle, northwestern Rhode Island, indicates that a series of syntectonic intrusive rocks invaded the Blackstone Series, and probably other older rocks. The intrusives range from diorite and amphibolite in the central part of the quadrangle to quartz diorite gneiss, granodiorite gneiss, and granite gneiss in the western half of the quadrangle. The gneisses appear, at least in part, to be equivalent to the Northbridge Granite Gneiss of Massachusetts.

MASSACHUSETTS

Stratigraphy and igneous geology in northeastern Massachusetts

R. O. Castle (p. C81–C86) has divided gneissic rocks in the South Groveland quadrangle, northeastern Massachusetts, into the Boxford Formation and the Fish Brook Gneiss. The Boxford is thought to be correlative with the Rye Formation of southeastern New Hampshire, and perhaps with the Marlboro Formation of eastern Massachusetts. The Fish Brook is either an isolated intrusive rock predating the subalkaline intrusive series in this area, or an ancient "dome" gneiss similar to those of western New England. The subalkaline intrusive series of C. H. Clapp [24] is revised into four units (p. C74–C80): (1) Sharpners Pond Tonalite, (2) Newburyport Quartz Diorite, (3) a "younger subalkaline series" defined by Priestley Toulmin 3d [25], and (4) Andover Granite. The Andover Granite is included with the subalkaline series rather than the alkaline series (C. H. Clapp [24]) because of the continuity between the Andover and the pre-"alkalic" Sharpners Pond Tonalite.

[24] C. H. Clapp, 1921, Geology of the igneous rocks of Essex County, Massachusetts: U.S. Geol. Survey Bull. 704, 132 p.

[25] Priestley Toulmin 3d, 1964, Bedrock geology of the Salem quadrangle and vicinity, Massachusetts: U.S. Geol. Survey Bull. 1163–A, p. A1–A79.

Parting in gabbro at Nahant induced by shear during folding

Medium-grained gabbro at Nahant, Mass., examined by C. A. Kaye (p. C12–C19) is broken by closely spaced parallel partings (pseudobedding-plane partings) and the rocks have been deformed into a series of anticlines and synclines. The spacing of the partings varies with the tightness of the folding, and in the crests of small folds there are as many as eight partings per inch. The partings are thought to have been produced by shear failures on the concave side of flexed layers of gabbro. Initially, these layers were formed by well-developed sheeting-type jointing. Shear-induced tension may also have produced the sheeting joints and probably was caused by movement along a still-uncovered sizable reverse fault.

Reverse polarization noted in dikes of Boston Basin

Many mafic dikes in the Boston Basin have been found by C. A. Kaye to have a very high remanent polarization that is reverse to the present magnetic poles. The effect of local "hot spots" produces a complete reversal of a Brunton compass needle, even when held as far as 8 feet from outcrops.

Shelburne Falls dome exhibits "anomalous" gravity high

Continued analyses of the geophysical data of the Shelburne Falls gneissic dome and other similar structures in the western part of Massachusetts by R. W. Bromery indicate that the amphibolites associated with the Shelburne Falls dome produce an anomalous geophysical expression that contrasts with the patterns about other domes. For example, the Plainfield dome is characterized by a small gravity low and a pronounced magnetic low, whereas the Shelburne Falls dome has an associated pronounced gravity low and a pronounced magnetic high.

Folded early Paleozoic depositional basin in northwestern Massachusetts

A depositional basin involving rocks between the Cambrian Hoosac Schist and the Ordovician Moretown Formation has been found in part of the North Adams and Rowe quadrangles by N. L. Hatch. The basin is roughly 2½ miles wide and 3,000 feet deep, and the rocks here are from 3 to 5 times thicker than in the surrounding area. The basin appears to have been the site of relatively intense folding, and difficulties in tracing units across this area are probably due to a combination of two or more stages of deformation as well as to complex sedimentary facies relations.

Fossil indicates Early Cambrian age for Weymouth Formation

A. R. Palmer has identified *Scenella,* a form not previously reported from the locality in a collection of fossils obtained by K. G. Bell from the Weymouth Formation in Nahant, northeastern Massachusetts. The fossils indicate an Early Cambrian age for the Weymouth Formation.

Fault separates Triassic rocks from metamorphic units in western Massachusetts

A dome outlined by three superadjacent distinctive metamorphic units has been mapped in the western part of the Southwick quadrangle, western Massachusetts, by R. W. Schnabel. The Triassic rocks covering the eastern two-thirds of the quadrangle are bounded on the west by a high-angle fault of at least 200-feet displacement.

Silurian fossils date Newbury Formation in northeastern Massachusetts

Two new fossil localities have been found by N. P. Cuppels in the Newbury Formation in the Georgetown quadrangle, northeastern Massachusetts. The fossils, which are whole and undeformed, include *Salopina* sp., *Protochonetes* sp., *Nuculites* sp., *Hermanino* sp., and indeterminate rhynchonellid and pterioid genera. They are identified as Late Silurian fauna, and the Newbury is thus probably equivalent to the Pembroke Formation of eastern Maine.

Artifacts and ventifacts in Cape Cod dunes

Wind-cut Indian artifacts associated with exhumed soil horizons in the Provincetown sand dunes were found by J. H. Hartshorn during a study of the Provincetown quadrangle. In the same area, ventifacts have been formed in a few tens of years on beaches that have been shut off artificially from the sea.

Deglaciation in Berkshires resulted in ice-dammed lakes

Continued investigation of glacial-lake features in the Berkshire Hills of western Massachusetts by G. W. Holmes has confirmed parts of F. B. Taylor's unpublished hypotheses of a complex of temporary ice-dammed lakes during deglaciation. A partial and tentative chronology is now suggested: (1) a small lake in the East Canaan, Conn., area, possibly connecting at a later stage with (2) a shallow lake in the Sheffield Falls Village lowland in the Housatonic valley; (3) glacial Lake Housatonic of F. B. Taylor, a large lake with several stages, dammed at the narrows of the Housatonic River near Glendale, and extending into Stockbridge Bowl and to the vicinity of Tyringham; (4) a small lake or arm of a lake in the Dalton area, possibly connected at one time with Lake Bascom in the North Adams and Williamstown areas. Small glacial lakes probably also existed in the South Egremont, Hancock, Shaker Village, and Lake Onata areas.

Origin of stratified drift in northern Cape Cod

Mapping of the North Truro and Wellfleet quadrangles by Carl Koteff, R. N. Oldale, and J. H. Hartshorn suggests that all the stratified drift in that area originated from the South Channel ice lobe to the east. The deposits are thought to have been laid down in a glacial lake dammed by the Sandwich moraine to the south and ice to the east and north. The Highland clay is part of this lacustrine late-glacial sequence, and is not correlative with the Gardiners Clay on Long Island as suggested by earlier workers. Marine shell fragments in the drift, with radiocarbon ages of 20,000 years or more, are presumed to have been picked up during the advance of the ice over marine deposits.

CONNECTICUT

Aeromagnetic data indicate major structural break in Connecticut

Interpretation by R. W. Bromery of aeromagnetic data in eastern Connecticut shows a pronounced linear anomaly belt striking east through the northern parts of the Uncasville, Old Mystic, and Ashaway quadrangles. This magnetic feature is interpreted as indicating a major fault or geologic discontinuity because the magnetic anomaly patterns north and south of the linear anomaly belt are markedly different. The magnetic data show that this feature continues west and east of the boundaries of the Uncasville and Ashaway quadrangles, respectively.

Radiometric ages provide time scale for eastern Connecticut

Synthesis of radiometric and field data by R. E. Zartman, G. L. Snyder, T. W. Stern, R. F. Marvin, and R. C. Buckman (p. D1–D10) for eastern Connecticut indicate that: (1) the Tatnic Hill Formation and underlying rocks are probably Middle(?) Ordovician or older; (2) the Scotland Schist and Hebron Formation are Lower Devonian or older; (3) the Canterbury Gneiss, a related quartz monzonite dike, and the gabbro of Lebanon were intruded during the Acadian orogeny in Early Devonian time; and (4) older pegmatites were intruded over a time span ranging from possibly Middle Ordovician to Middle Devonian. The area was regionally dynamothermally metamorphosed in the Acadian (Devonian) and thermally remetamorphosed in the Alleghenian (Permian) orogenies. Younger pegmatites were intruded in Permian(?) time.

A new member near the middle of the Brimfield Schist, believed to be equivalent to the Fly Pond Member of the Tatnic Hill Formation, has been mapped by G. L. Snyder in the Marlborough and Columbia quadrangles.

MAINE

Fossils indicate margin onlap during Llandovery to Ludlow time

Basal Silurian calcareous units that uncomformably overlie Cambrian and Ordovician metamorphic rocks mapped by E. L. Boudette and D. S. Harwood in northwestern Maine contain diagnostic shelly faunas that have been studied in detail by A. J. Boucot. The spatial relationship of an assemblage containing *Strictlandia lens ultima* found on the south side of East Kennebago Mountain in the Kennebago Lake quadrangle to a younger assemblage containing *Eccentricosta* found near Parmachenee Lake in the Cupsuptic quadrangle indicates a northwestward margin onlap over Cambrian and Ordovician rocks in the region during a period spanning late Llandovery to Ludlow time. A distinctive, very coarse polymictic conglomerate, lithologically comparable to the Rangeley Conglomerate of Smith (1923)[26], is associated with the upper Llandovery rocks at Blanchard Ponds, Kennebago Lake quadrangle. A minimum late Llandovery age (assuming onlap) may thus be established for the hitherto undated Rangeley Conglomerate, which underlies a narrow belt that strikes east-northeast about 8 miles southeast of the dated locality.

Large faults may predate consolidation of Silurian strata

Faults of large displacement that probably predate metamorphism and possibly complete lithification of the strata they cut are major structures found in the Rangeley and Phillips quadrangles, west-central Maine; by R. H. Moench. One fault separates Ordovician(?) strata on the northwest side from Silurian strata; 5,000 to 10,000 feet of Silurian strata is missing. In one outcrop, the fault zone is about 6 inches thick; it has the appearance of a recrystallized, smeared mixture of sandy and pelitic material. Adjacent metasedimentary rocks show no sign of rupture; a small metasandstone dike extends from the adjacent bed to the southeast into the fault zone. These features suggest that the sands

26 E. S. C. Smith, 1923, The Rangeley conglomerate: Am. Jour. Sci., 5th ser., v. 5, p. 147–154.

were unconsolidated after faulting. Two other faults of probably similar character are recognized in younger parts of the stratigraphic sections. They are defined by the absence of probably several thousands of feet of strata on their southeast sides; outcrops have not been found. It is possible that the faults are surfaces of gravity sliding, which took place when regions to the north were uplifted in Silurian and possibly Early Devonian time.

Silicic intrusions found to border Moxie mafic pluton on the east

Continuing study in the vicinity of the Moxie mafic pluton in west-central Maine by G. H. Espenshade shows that an irregular curving valley and lowland that trends eastward from Moosehead Lake for about 22 miles is underlain by gabbroic rocks of the Moxie pluton in the western 10 miles, by quartz diorite in the center, and by quartz monzonite at the eastern end. The quartz monzonite seems to be an offshoot of the Katahdin granite pluton to the north, and is probably the youngest of the three groups of rocks on the basis of K-Ar radiometric ages by Henry Faul; all the intrusions are probably Early Devonian. Contact-metamorphosed slates, siltstones, and sandstones of probable Silurian to Devonian age border the intrusions and form irregular ridges and knobs adjacent to the valley.

Brachiopods put limits on extent of pre-Silurian strata

Fossil brachiopods found by G. H. Espenshade a few thousand feet west of Bear Pond, in the northeastern part of First Roach Pond quadrangle, central Maine, have been identified by A. J. Boucot as late Llandovery to Wenlock in age. Presumably this would restrict the area of pre-Silurian rocks to the country north of Farrar Mountain; these older rocks were formerly thought to extend about 12 miles farther southwest.

Tin content of stream sediments highest near biotite granite

Tin has been determined spectrographically in some 3,800 stream-sediment samples taken by E. V. Post and W. H. Dennen in west-central and southeastern Maine. It is detectable in only 4 percent of the samples from west-central Maine but in more than 13 percent of the samples from southeastern Maine. In west-central Maine, tin is common only in sediment of streams draining the Katahdin Quartz Monzonite. In southeastern Maine, tin is widespread, but highest values are found in the sediment of streams that drain plutons of gray to pink biotite granite. This relationship appears significant because of the presence in southern New Brunswick of the Mount Pleasant tin deposit near the north margin of the St. George biotite granite pluton.

Evidence for pre-Taconic orogeny in northern Maine

An orogeny of Cambrian(?) to Early Ordovician age (pre-Taconic) is suggested by R. B. Neuman on the basis of data from northern Maine and adjacent Quebec, together with information from the Shin Pond quadrangle to the south; this orogeny was probably responsible for much of the structural contrast generally attributed to the Taconic orogeny (Late Ordovician–Early Silurian). Taconic structural contrasts in the Shin Pond-Stacyville area are relatively minor, but at this time the major anticline of the area began to rise, and subsequent Silurian sedimentation was controlled by its presence.

Heavy metals in stream sediments related to granitic plutons

Anomalous amounts of heavy metals in stream sediments, according to work by E. V. Post, are distributed peripherally to granitic plutons east of Lincoln, Maine, and between the Passadumkeag Mountains (Saponac quadrangle) and Tomah Mountain (Waite quadrangle). These anomalies in east-central Maine appear to be a northeasterly continuation of a belt of anomalies found to the east of the Penobscot River and also considered to be related to granitic plutons.

New evidence proves presence of Ordovician and Silurian rocks

Reconnaissance geologic mapping by Louis Pavlides in the Mattawamkeag Lake quadrangle in eastern Maine has shown that, contrary to previous beliefs, Ordovician rocks are present in this area. Also, discovery of a Silurian graptolite locality in the northern part of the quadrangle represents the first paleontologic evidence supporting the presumed Silurian age for a wide belt of micaceous quartzites and siltstones in this region.

APPALACHIAN REGION

STRUCTURAL AND STRATIGRAPHIC STUDIES

Upper Cretaceous alluvial clay in southern Pennsylvania

Nonmarine lignitic clay containing pollen and spores identified by R. H. Tschudy as Late Cretaceous in age (see "Paleontology, Cretaceous pollen in the Appalachian Mountains") was collected by K. L. Pierce from dumps of a 19th-century iron-mining area at Pond Bank, near Chambersburg, Franklin County, in southern Pennsylvania. According to mine records and published descriptions, the lignitic clay is 40 feet below ground and overlies at least 170 feet (possibly 335 feet) of clayey residuum on the Tomstown Dolomite. Pierce suggests (p. C152–C156), on the basis of the proportion of insolubles in the dolomite and of recent estimates of total erosion of the Appalachian Highlands since Cretaceous time, that at least 140 feet of residuum has accumulated since the lignitic clay was deposited. The Pond Bank deposit may be a remnant of a more extensive nonmarine alluvial cover deposited at least 1,400 feet above the present ground surface, or several hundred feet above the highest mountains in the area. If this is true, the deposit is considerably older than any of the existing geomorphic features.

Mauch Chunk red beds increase southeastward in eastern Pennsylvania

Stratigraphic studies in Luzerne County, in eastern Pennsylvania, by M. J. Bergin and J. F. Robertson show that southeastward thickening of the Mauch Chunk Formation is accompanied by a regular increase in the amount of red beds within the formation. In Susquehanna Gap, north of Pittston, the formation is 255 feet thick and contains no red beds. The thickness increases to 550 feet north of Kingston, where red-bed sequences as much as 20 feet thick make up about 25 percent of the formation. Red-bed sequences as much as 100 feet thick make up 40 to 50 percent of the formation north of Nanticoke and on Penobscot Mountain south of Ashley, where the Mauch Chunk is respectively 670 feet and 1,000 feet thick. The underlying Pocono Formation also thickens southeastward at the somewhat lower rate of about 25 feet per mile.

Underthrusting in Pennsylvania anthracite region

Structural analyses by G. H. Wood, Jr., indicate that the low-angle thrust and underthrust faults of the southern part of the Anthracite region of eastern Pennsylvania are located principally at horizons which separate thick sequences of competent and incompetent rocks. The forces that developed these faults were transmitted differentially according to the relative competency of the sequences. Competent sequences overlying less competent sequences commonly have been thrust over older rocks for considerable distances, the fault planes paralleling the attitudes of the overlying competent sequences and truncating underlying crumpled sequences. Where competent sequences lie below less competent ones, however, they commonly have been underthrust from the troughs of synclines toward the crests of anticlines. The planes of the underthrust faults generally parallel the attitudes of the underlying competent sequences and truncate overlying crumpled, less competent sequences; this is the reverse of the relation common on the thrust faults.

Revision of faults by new mapping in southwestern Virginia

Geologic mapping by R. L. Miller and J. B. Roen in the coal fields of Wise and Lee Counties, in southwestern Virginia, has demonstrated that two large faults formerly thought to have eliminated up to 1,500 feet of beds of the Norton and overlying formations at the surface are nonexistent. In Wise County a sharp flexure with only minor fracturing and slippage of beds is present where the Pigeon Creek fault was thought to be. In Lee County, a similar sharp flexure where the North Fork fault was supposed to be manifests no fracturing or displacement whatever. The lower mined coals in Lee County, supposedly in the Wise Formation, are in reality in the Norton Formation. In Wise County there are no economically important coals close to the belt where the Pigeon Creek fault was supposed to be.

Probable presence of Pine Mountain fault in Wise County, Va.

Mapping by R. L. Miller has demonstrated, at the head of Powell Valley in Wise County, southwestern Virginia, the presence at the surface, over a wide area, of intensively deformed black shale of the Chattanooga shale (Devonian), which suggests strongly that the Pine Mountain fault or a branch of it is close to the surface in this region.

Pocahontas Formation extended in Virginia

Stratigraphic studies by K. J. Englund and A. O. DeLaney indicate that the Pocahontas Formation and several economically important coal beds within it are more widespread in southwest Virginia than was previously known. Recognition of beds containing fossil plants of the *Neuropteris pocahontas* zone (zone 4 of Read and Mamay [27]) has been useful in the local and regional correlation of the Pocahontas Formation.

Barite deposits related to paleokarst in Virginia

From field examination of mines and prospects in the Clinch River barite district in Tazewell and Russell Counties, southwestern Virginia, Helmuth Wedow, Jr., concludes that bedrock occurrences of barite, fluorite, and sulfides, chiefly pyrite, are in

[27] C. B. Read and S. H. Mamay, 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geol. Survey Prof. Paper 454–K, p. K1–K35.

solution-collapse breccias of the Kingsport and Longview Formations in the upper part of the Knox Group. As elsewhere in the southern Appalachian Valley, these breccias are localized along the interface between the uppermost thick limestone of the group and overlying fine-grained dolomite. The close association of the breccias with the post-Knox unconformity is well illustrated by the occurrence of red dolomites of the basal Middle Ordovician Blackford Formation as a breccia matrix and solution-channel filling through a zone several hundred feet thick.

Late Precambrian volcanism in southwestern Virginia

Volcanic rocks of the Mount Rogers Volcanic Group in the Blue Ridge province of southwestern Virginia and northwestern North Carolina are of late Precambrian age, and range from basalt through latite to rhyolite, according to D. W. Rankin. A major center for the extrusion of rhyolitic rocks was in the area of the Mt. Rogers massif, Virginia. Rankin has mapped two rhyolite units there: a lower one characterized by 0 to 10 percent phenocrysts; and an upper, porphyritic rhyolite containing 30 percent phenocrysts of quartz and alkali feldspar. The lower unit is about 2,000 feet thick and occurs largely as highly spherulitic lava flows with some welded-ash flows. The upper, porphyritic unit is probably thicker and consists largely of welded-ash flow sheets. A suggested volcanic history of the rhyolites begins with the relatively quiet eruption of hot, relatively dry magma, resulting in the lower, phenocryst-poor spherulitic lavas. With subsequent crystallization in the magma chamber, an increase in the vapor pressure may have given rise to relatively violent eruptions of porphyritic ash-flow sheets that constitute the upper rhyolite unit. Volcanic breccias consisting of fragments of the older, phenocryst-poor rhyolite in a matrix of porphyritic rhyolite crop out on the Mt. Rogers massif within the outcrop area of the younger rhyolite. These breccias which are interpreted as breccia pipes, support the general location of the volcanic center and the concept of late violent eruptions.

Clinchport fault in eastern Tennessee and southwestern Virginia

Mapping and detailed facies studies of the Cambrian rocks along the Clinchport and Hunter Valley faults in eastern Tennessee and southwestern Virginia by L. D. Harris (p. B49–B53) has helped to determine the structural relations between these faults. By comparing stratigraphic thicknesses of the Maryville Limestone and Rogersville Shale between Clinchport, Va., and Tazewell, Tenn., he has been able to show that the Clinchport thrust plate, with a thick section of Maryville and a thinner one of Rogersville, has overridden parts of the Hunter Valley thrust plate, in which these relative thicknesses are the reverse. This relation and reconnaissance mapping in other key areas suggest that the Clinchport fault is one of the major through-going faults of the southern part of the Valley and Ridge province.

Algal stromatolites in Copper Ridge Dolomite, Tennessee

Unusual wave-washed exposures of the Upper Cambrian Copper Ridge Dolomite, accessible during the low-water stages of Norris Lake in Claiborne and Union Counties, in northeastern Tennessee, were studied by L. D. Harris. These exposures reveal that perhaps as much as 60 percent of the formation in that area consists of algal stromatolites which form extensive bioherms 5 to 140 feet thick. Details of algal growth and relations to the enclosing clastic material are remarkably well displayed. Vugs occur locally in the central portions of algal heads and along growth layers within the heads. A petroliferous odor is commonly detected when the algal material is freshly broken, and the algal beds are therefore of special interest because of their possible bearing on the porosity and petroleum content of the dolomite.

Gold Hill fault zone in west-central North Carolina

Geologic mapping in the northwestern part of the Carolina slate belt in Rowan and Davidson Counties, N.C., by H. W. Sundelius, A. A. Stromquist, and A. R. Taylor has shown that most of the mines and prospects of the Gold Hill and Silver Hill mining districts lie between two fault zones within the slate-belt rocks. The rocks adjacent to and between the faults are highly sheared slate, phyllite, and schist which have been hydrothermally altered in many places. They locally contain small bodies of sheared, coarse-grained diorite. The faults cut across major folds in less metamorphosed volcanic and pelitic sedimentary rocks on the east. Structural relations of the rocks of the Charlotte belt adjoining on the west are still problematical.

Ordovician age of Rockmart Slate in Georgia established

Charles Cressler has found graptolites in the Rockmart Slate of Hayes (1894)[28] in Polk County, in northwestern Georgia, which are of middle Ordovician age. Prior age assignments for the Rockmart

[28] C. W. Hayes, 1894, Geology of a portion of the Coosa Valley in Georgia and Alabama: Geol. Soc. America Bull., v. 5, p. 465–480.

were Ordovician and, after 1937, Mississippian. After this discovery R. A. Laurence learned from field notes that M. R. Campbell discovered graptolites in the Rockmart in 1890; but the find never was published and was forgotten. Thus, the confusion over the age of the Rockmart resulted because fossils were not rediscovered until the present.

GEOPHYSICAL STUDIES

Magnetic instability of Pennsylvania diabase

Geophysical investigations in the Gettysburg-Newark basin, Pennsylvania, by M. E. Beck, Jr., have provided a partial explanation for instability of remanent magnetic moments in the diabase of that area. Results to date indicate that (1) there is a marked correlation between instability of remanent magnetization and weak total magnetic moment, including both susceptibility and remanence; (2) unstable, weakly magnetized samples have a higher-than-average concentration of late magmatic or hydrothermal material, especially vermicular granophyre. These observations apply to comparisons between separate samples from the same locality as well as to contrasts between localities. Grain-size differences, variations in titanium content of magnetite, or a combination of these factors could also account for the observed range of magnetic properties.

Magnetic and radioactivity data in mapping Virginia Piedmont

A detailed aeromagnetic and aeroradioactivity survey was completed for 980 square miles of the Piedmont province in eastern Virginia to aid in geologic mapping of an area of complex lithology and scarce outcrops. The area studied consists of sixteen 7½-minute quadrangles in Spotsylvania, Culpeper, Orange, Louisa, Caroline, Hanover, and Stafford Counties. S. K. Neuschel reports that correlation between airborne geophysical data and relatively recent 1:62,500 geologic mapping in the Piedmont of Maryland is excellent. On the Virginia State geological map (scale 1:500,000) information is of necessity very generalized, and the geophysical data exhibit many features which the State map does not explain. The results of detailed fieldwork to date in the Spotsylvania area, however, show good correlation with the geophysical data. There, high radioactivity and low magnetic intensity over granite distinguish this rock from granitic gneiss. Also, mafic rocks not previously mapped have been located on the basis of low radioactivity and high magnetic intensity. Much of the Spotsylvania area consists of rocks having alternating plagioclase-muscovite-chlorite-magnetite and quartz-plagioclase-muscovite assemblages. These two rock types can be delineated by using the geophysical data in conjunction with geologic mapping.

Gravity and magnetic fields in eastern Tennessee and southeastern Kentucky

J. S. Watkins has described (1–64) a geologic interpretation of gravity and magnetic data for 10,000 square miles of eastern Tennessee and southeastern Kentucky. Some gravity and magnetic anomalies associated with basement rocks in this area trend more nearly northward than do surface structural features, reflecting the pre-Appalachian structural grain of the area. A northeast-trending basement lineament marked by gravity and magnetic anomalies parallels the western margin of the Valley and Ridge province from west-central Alabama to northern Tennessee. This lineament seems to be a transition zone between a tectonically active Appalachian crustal block and a stable cratonic block. Magnetic data and well records indicate that the basement surface in the Valley and Ridge province is relatively flat in this area and lies generally less than 15,000 feet below sea level. The absence of magnetic or gravity anomalies along the major thrust faults suggests that they do not penetrate the basement.

EASTERN PLATEAUS

PENNSYLVANIA

Coal-basin deposition in Washington area

Statistical studies by B. H. Kent, J. P. Schweinfurth, and J. B. Roen of more than 350 core logs of Pennsylvanian strata in the Washington area in southwestern Pennsylvania have led to preliminary conclusions concerning coal-basin sedimentation. The stratigraphic interval between the bases of successive major coal beds (for example, the 310-foot interval from the base of the Pittsburgh coal bed to the base of the Waynesburg coal bed and the 130-foot interval from the Waynesburg coal bed to the Little Washington–Washington coal complex) has most promise for revealing relationships between sediment-distribution patterns and the distribution, thickness, and character of coal beds. The thicknesses of these intervals vary rapidly and locally, and vary reciprocally with the thicknesses of constituent coal beds and limestone units; if the coal beds and limestone units are thick, the interval is thin. Where the Pittsburgh-to-Waynesburg interval is thin, the Waynesburg coal zone is thick and unusually complex; characteristically, the Waynesburg coal zone contains several partings and thin beds of coal below the main bench, and the main bench is thicker than usual for that local area.

Mauch Chunk Formation and Pottsville Group in north-central Pennsylvania

Recent mapping by G. W. Colton in parts of Lycoming, Clinton, Tioga, and Potter Counties, in north-central Pennsylvania, has demonstrated that (1) the Upper Mississippian Mauch Chunk Formation and the Lower and Middle Pennsylvanian Pottsville Group underlie appreciably larger areas than are shown on the 1960 geologic map of Pennsylvania; (2) some, at least, of the Mauch Chunk and Pottsville sediments were transported into this area from the north; and (3) the boundary between the two systems is a disconformity or a gentle angular unconformity, as was shown by earlier workers to the west. These conclusions are based on detailed mapping of distinctive soil and float material, regional stratigraphic relationships, measurement of pebble diameters, and measurement of foreset beds in the scant exposures present.

KENTUCKY

Glacial drift of Nebraskan age in northern Kentucky

Studies by L. L. Ray have shown that glacial drift of Nebraskan age, overlain by drift of Kansan age, is present on the uplands of Boone County in northern Kentucky a few miles southwest of Cincinnati, Ohio. The Nebraskan drift was deposited by an ice sheet whose effects have been hitherto unrecognized east of the Mississippi River valley. The character of the advanced profiles of weathering developed on the drift indicates weathering in place under poor drainage conditions on the upland surface prior to deposition of the overlying Kansan drift. A similar profile of weathering on the younger Kansan drift was modified later under better drainage conditions resulting from dissection of the uplands in post-Kansan time. Along the Ohio River valley to the west, where there was some dissection of the uplands in post-Nebraskan, pre-Kansan (Aftonian) time, drift of Nebraskan age is present in Kentucky only on remnants of the dissected uplands. Its profile of weathering differs from that of the undissected uplands of Boone County, reflecting the better drainage conditions following deposition. Here, drift of Kansan age does not overlie the Nebraskan drift but is present at subsummit positions in stream valleys tributary to the Ohio and on bedrock benches along the river valley. Present studies suggest that the maximum extent of glaciation in northern Kentucky was in Nebraskan time.

Shoals and islands during deposition of Pennsylvanian strata in eastern Kentucky

Geologic mapping by W. F. Outerbridge in the Paintsville, Offutt, and Inez quadrangles, in Johnson and Martin Counties in eastern Kentucky, indicates that a northeastward-trending zone of islands and shoals existed during Pennsylvanian time [29] and influenced deposition of the Magoffin Beds of Morse (1931)[30], which are in the Breathitt Formation. The shoals and islands formed on pre-Magoffin sediments and seemingly separated brackish-water marshes and lagoons on the northwest from marine waters to the southeast. Beach sediments (disarticulated and unoriented shells mixed with plant debris in a thin calcareous sandstone bed) are present north of the southwest end of the line of shoals and islands. The Magoffin Beds are thin and locally ripple marked where deposited along the crests of the shoals, and are missing where there were islands. Linguloid brachiopods are abundant and fresh-water clams are present at the northeast end of the shoals. They are associated with a 1-inch to 6-inch layer of canneloid coal indicative of deposition in a marsh. Brachiopods, crinoids, pelecypods, and gastropods have been found on both sides of the shoals, but cephalopods have been found only on the southeast side. Siderite is abundant on the northwest side of the shoal line and scarce on the southeast, suggesting the presence of brackish water to the northwest.

Volcanic origin of flint clay in eastern Kentucky

The Fire Clay coal bed of Pennsylvanian age contains a thin parting of flint clay that occurs extensively within the Breathitt Formation in eastern Kentucky and in correlative strata in adjacent states. In recent thin-section studies of the clay from near Hazard, Ky., V. M. Seiders (p. D52–D54) has recognized grains of quartz and clastic sanidine in a groundmass of clay, part of which P. D. Blackmon identified by X-ray diffraction as kaolinite. A volcanic origin of the flint clay is indicated by the

[29] W. F. Outerbridge, 1965, Magoffin Beds of Morse in three eastern Kentucky quadrangles [abs.]: Geol. Soc. America Southeastern Section Mtg., April 8–10, 1965, Program, p. 31.

[30] W. C. Morse, 1931, The Pennsylvanian invertebrate fauna of Kentucky *in* Paleontology of Kentucky: Kentucky Geol. Survey, ser. 6, v. 36, p. 293–348.

clearly clastic nature of the grains of sanidine, by embayed quartz, and by the absence of any obviously nonvolcanic debris except argillaceous matter. Seiders concludes that the fire clay was formed by the in-place alteration of volcanic ash.

Cyclical deposits in Mississippian limestones, western Kentucky

Depositional cycles in the upper part of the Ste. Genevieve Limestone and in the lower part of the overlying Girkin Formation, both of Late Mississippian age, have been recognized in western Hart County, Ky., by C. A. Sandberg and C. G. Bowles (2–65). Crossbedded calcarenite (clastic limestone), which forms the base of each cycle, is derived partly from rounded fragments of crinoids, echinoids, and other fossils, and partly from subangular limestone and chert fragments reworked from underlying beds. The highest bed of calcarenite in the Ste. Genevieve Limestone comprises noncurving cross-beds that are suggestive of torrential or deltaic deposition and have initial dips of 16° to 22°. The middle of each cycle consists of light-colored limestone that is partly fossiliferous and partly oolitic. The top of each cycle is characterized by dark limestone and limestone intraformational breccia containing round, accretive, armored nodules of broken black chert.

Movement of Lower Early Mississippian sediments across Cincinnati arch

The Borden Formation of Early Mississippian age, along the western flank of the Cincinnati arch in central Kentucky, consists of sediments that seemingly were transported southwestward across the site of the arch. The Borden in this area is made up of two members, the lower consisting of siltstone and shale, and the upper—the Muldraugh Member—consisting of siltstone, dolomite, and limestone. Geologic mapping by R. C. Kepferle and W. L. Peterson in Nelson, Hardin, and Larue Counties has delineated a 1- to 2-mile-wide zone across which the lower member thins southwestward from 280 feet to 55 feet as the overlying Muldraugh Member thickens from 60 feet to 280 feet. This zone trends N. 55° W. to N. 60° W. across the Elizabethtown, Nelsonville, Hodgenville, New Haven and Howardstown 7½-minute quadrangles. The inclined contact between the two members and the southwestward inclination of many beds of limestone within the Muldraugh Member are considered to represent initial dips which are perpendicular to the trend of the zone.

The strike of the zone is parallel to that of limestone reefs described by Thaden and others [31] in the Fort Payne Formation, which is about the stratigraphic equivalent of the Borden Formation, west of Columbia in south-central Kentucky. The reefs occur in an arcuate belt, south of a linear body of sandstone (C. H. Maxwell and W. B. Turner, 1–64) that seemingly was deposited shoreward of the reefs (U.S. Geol. Survey, 11–64, p. A85). Along the east side of the arch, generally south of Berea, Ky., beds of siltstone in the Borden Formation have been shown by G. W. Weir, J. L. Gualtieri, and S. O. Schlanger to have a pronounced southward initial dip. A generally south and southwestward movement of sediments across the arch during Early Mississippian time is thus indicated.

Facies in Ordovician strata, Cincinnati arch

Mapping and stratigraphic studies of Middle and Upper Ordovician strata on and along the flanks of the Cincinnati arch in Kentucky have revealed complex facies within the rocks and demonstrated some of the facies relations. Work by E. R. Cressman, D. F. B. Black, W. C. MacQuown, J. S. Pomeroy, and others has shown, for example, that in the Frankfort area, Kentucky, a southeastward-striking band of crossbedded bioclastic calcarenite near the top of Middle Ordovician strata grades abruptly southwestward into interbedded shale and calcilutite. It interfingers northeastward with very fossiliferous argillaceous limestone which interfingers to the northeast with interbedded shale and sparsely fossiliferous calcilutite. Seemingly, the crossbedded calcarenite was deposited on the windward side and the fossiliferous limestone on the lee side of a low bank. The distribution of these facies was not controlled by the Cincinnati arch.

G. W. Weir, W. L. Peterson, and J. H. Peck have traced Upper Ordovician rocks, on lithologic evidence, from central Kentucky along the east and west flanks of the Cincinnati arch into areas of Ohio and Indiana where the classical work on paleontology and stratigraphy of the Upper Ordovician (Cincinnatian) strata was done. In general, dolomite, dolomitic mudstone, and limestone deposited in shallow water grade northward into shale and limestone that were deposited in deeper waters. The rocks of these facies strike generally eastward, and their distribution seems not to have been influenced by the Cincinnati arch.

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31 R. E. Thaden, R. Q. Lewis, J. M. Cattermole, and A. R. Taylor, 1961, Reefs in the Fort Payne Formation of Mississippian age, south-central Kentucky: Art. 39 *in* U.S. Geol. Survey Prof. Paper 424–B, p. B88–B90.

TENNESSEE

Movement along Jacksboro fault at southwest edge of Cumberland overthrust

Work by K. J. Englund in Campbell County, Tenn., indicates that there has been approximately 11 miles of strike-slip movement along the Jacksboro fault at the southwest edge of the Cumberland overthrust sheet. The amount of movement, which has generally been considered by previous workers to be of smaller magnitude, was determined from stratigraphic studies and thickness maps of formations on opposite sides of the fault.

SHIELD AREA AND UPPER MISSISSIPPI VALLEY

Subsurface structure of western Lake Superior region

W. S. White has analyzed the subsurface structure of the western Lake Superior region using a combination of surface geology and aeromagnetic, gravity, and paleomagnetic data. Surface attitudes and map patterns suggest that the upper Keweenawan sedimentary rocks have the general form of a lens thickening southeastward away from a featheredge along the Minnesota shore of Lake Superior. Graphic subtraction of the assumed gravitational effect of this sedimentary lens from the Bouguer anomalies of the region leaves a residual anomaly due primarily to the mafic lavas and intrusive rocks.

The analysis leads to recognition of the following stages in the tectonic history of the region. (1) Accumulation, during middle Keweenawan time, of a thick series of lava flows and mafic intrusives in two basins or troughs, separated by a positive area trending more or less north-south across the Bayfield Peninsula, Wis., in which the lavas are thin or absent. The Duluth Gabbro Complex, in the more westerly trough, probably pinches out southeastward beneath the lavas somewhere near the Minnesota shore. (2) Evolution of the present Lake Superior basin, with axis trending northeast, during late Keweenawan time. (3) Development of the Ashland syncline and the major faults of the region (Douglas, Keweenaw, Lake Owen) still later in Keweenawan time.

MICHIGAN

Geology in eastern part of Gogebic district reinterpreted

Regional stratigraphy and structure at the east end of the Gogebic iron-bearing district, Michigan, have been reinterpreted by C. E. Fritts using results of recent detailed mapping in conjunction with earlier data recorded by the Michigan Geological Survey. The Tyler Slate of Animikie age trends generally eastward to Lake Gogebic where it wraps around the nose of an east-plunging anticline, continues westward for about 5 miles, and is terminated by a fault of southwest strike. The Tyler on the south limb of this fold conformably underlies a thick sequence of metasedimentary and metavolcanic rocks that probably conformably underlies the Michigamme Slate with which the Tyler is not equivalent as now interpreted. The sequence that is apparently between the Tyler and Michigamme Slates contains graded bedding and pillow structures that are right side up, and the overall structure is a south-dipping monocline rather than a fold in part overturned, as has been previously proposed. Lean iron-formation at the Banner exploration is stratigraphically above the Tyler Slate and is in a south-plunging open synclinal flexure rather than in a tight fold. Similarly, the so-called Turtle range and an inferred eastern extension of the Marenisco range are stratigraphically above the Tyler and are not belts of tightly folded rocks.

Three kinds of rock of different ages have been recognized in what formerly was mapped as Presque Isle Granite. A banded gneiss and an equigranular granite are unconformably overlain by the Tyler Slate and are interpreted as pre-Animikie in age. A granitic to quartz monzonitic gneiss intrudes Animikie strata, and an increase of metamorphic grade southeastward toward a broad area underlain in part by this gneiss indicates that metamorphism probably accompanied and perhaps followed its emplacement.

WISCONSIN

Paleomagnetism sets limit to age of gabbro in Wisconsin

Kenneth Books has found that paleomagnetic field directions in the gabbro intrusion and associated lava flows near Mellen, northern Wisconsin, throw light on the time of intrusion of the gabbro. After removal of extraneous components of magnetization from the paleofield directions by demagnitization runs on 40 samples of gabbro and lava from 8 sites, it was observed that the mean remanence directions from Fischer statistical analyses when uncorrected for the regional geologic dip of 60°–70° NW. are all scattered in a direction similar to the direction of remanence, also uncorrected for regional dip, in the Duluth Gabbro at Duluth, Minn.[32] The agreement between all site mean remanence directions when uncorrected for regional geologic dip suggest (1)

[32] P. M. Dubois, 1962, Paleomagnetism and correlation of Keweenawan rocks: Canada Geol. Survey Bull. 71, p. 42–43.

that the lava flows adjacent to the gabbro intrusion at Mellen were heated through the Curie point by the intrusion, and (2) that the gabbro intrusion at Mellen occurred near the end of regional deformation in the area.

Diatomite discovered in Driftless Area, Wisconsin

G. W. Andrews has found a 6-inch bed of diatomite in the late Pleistocene alluvium of the Trempealeau Valley near Hixton, Wis., the first diatomite deposit to be reported from the Driftless Area of the upper Mississippi Valley. The diatom assemblage consists of 23 genera and 74 species of which 3 species are new. The assemblage is unusual in that it is dominated by a large number of individuals of a single minute form—*Fragilaria construens* var. *venter*. The diatomite is closely associated with an underlying deposit of spruce wood and matted organic debris, dated at about 11,000 years B.P., by Meyer Rubin using the radiocarbon method. The diatoms were probably deposited in a shallow pond during regional cooling of the climate brought about by the ice advance of the Valders Stade.

MINNESOTA

Aeroradioactivity map reflects glacial geology

An aeroradioactivity map compiled by S. K. Neuschel, covering a 10,000-square-mile area that centers about Minneapolis and St. Paul, shows good correlation with glacial geology; little or no correlation is shown with bedrock, which is exposed only at a few scattered places, mostly along major streams. Numerous small elongate areas of low radiation: (1) are present over morainal deposits; (2) have a north-south to northeast-southwest trend, as do most of the existing lakes; (3) average about 2 miles in width; (4) range from 5 to 10 miles in length; and (5) are best developed in the area northeast of the Mississippi River. Low radiation is present also over swampy areas and silted-in former glacial lakes. The map indicates that the number of lakes was formerly three to four times that of today, and also indicates the former courses of some of the existing drainage.

NEBRASKA

Map of bedrock geology and thickness of overburden compiled for southeastern Nebraska

A map showing bedrock geology and thickness of Quaternary overburden for an area of 8,400 square miles in southeastern Nebraska has been prepared cooperatively by G. E. Prichard, of the U.S. Geological Survey, and E. C. Reed, V. H. Dreezen, and R. R. Burchett, of the Nebraska Geological Survey.

INTERIOR HIGHLANDS AND EASTERN PLAINS

Age and correlation of old gravels in Val Verde County, Tex.

J. A. Sharps and V. L. Freeman have mapped extensive deposits of gravel in the southern half of the Feely quadrangle, Val Verde County, Tex. The oldest deposits, not terrace deposits related to the present river system, can be divided into two units of approximately the same age. One unit contains gravel composed solely of limestone and chert deposited from a southward-flowing stream. The other unit contains gravel from a limestone terrane as well as characteristic pebbles of fine-grained igneous and metamorphic rocks deposited from an eastward-flowing stream. The area 5 to 10 miles southeast of Comstock in the Feely quadrangle is probably the junction area of the 2 streams.

No direct evidence of age of these older gravels has been found. Their topographic position and the position of the Uvalde Gravel to the southeast suggests an equivalence. The Uvalde is generally called Pliocene(?) in age. Since the deposition of the Uvalde Gravel and the possible equivalent gravels of the Feely quadrangle there has been major uplift of the Edwards Plateau, including its westward extension the Stockton Plateau, and of the adjacent region in Mexico. The southern part of the Edwards Plateau, north of the Balcones Fault zone, probably has been tilted northward. The region along the Rio Grande, west of a line between Cline and Laredo, probably has been tilted eastward. This uplift and tilting are here considered Pleistocene in age.

Sedimentary slump(?) structure related to folding in Arkansas

A large-scale sedimentary flow feature in the lower part of the Savanna Formation of Middle Pennsylvanian age has been mapped by B. R. Haley in the western half of sec. 9, T. 7 N., R. 24 W., in Logan County, western Arkansas. Here a rock unit about 10 feet thick and composed mostly of sand along the limbs of the east-trending Paris syncline thickens along the axis of the syncline to a unit about 60 ft thick composed of mixed sand, silt, and clay. This feature is best explained by postulating preconsolidation sedimentary slump or flow immediately after the deposition of the sand. The sedimentary flow could have resulted from a gradient established by the folding of the Paris syncline during Savanna deposition. Sandstone units in the underlying McAlester Formation become finer grained northward, either thin or pinch out northward, and converge northward across the syncline, indicating that the start of the folding in this area predates Savanna time.

Diagenesis of Pennsylvanian oolitic limestones in Arkansas

L. G. Henbest has found microtextural evidence indicating that diagenetic changes in the oolitic limestones of the Pennsylvanian Morrow Series in Washington County, Ark., can be grouped in the following 3 stages. (1) Formation of microstylolites, before lithification, by solution interpenetration at points of contact between ooliths. (2) Secondary enlargement through growth as euhedral crystals of quartz sand grains that were nucleii of ooliths or that touched ooliths accompanied by etching of those quartz grains exposed to the matrix. (3) Because insufficient carbonate was mobilized in stages 1 and 2 to account for all the reconstruction of the matrix, a third and later stage of cementation is suggested.

These diagenetic processes play a prominent role in the evolution of marine limestones and influence their behavior as reservoirs of oil or of water.

NORTHERN ROCKY MOUNTAINS AND PLAINS

WASHINGTON

Covada Group of northeastern Washington revised

High-grade metamorphic rocks in the Twin Lakes quadrangle were originally included in the Covada Group, of probable Devonian to Mesozoic age, by J. T. Pardee,[33] but recent mapping by G. E. Becraft suggests that they are much older, possibly as old as Precambrian. These old rocks (high-grade gneisses interlayered with schists and white quartzite) are separated from younger less metamorphosed rocks of the Covada Group (phyllitic graywacke, phyllite, slate, and impure bluish-gray quartzite) by an eastward-dipping fault. Rocks of the Covada Group are intensely folded and faulted, but layering and foliation in the older high-grade metamorphic rocks dip gently to the west. The old metamorphic rocks are similar to the metamorphic rocks of Tenas Mary Creek in the Curlew quadrangle to the northeast.

[33] J. T. Pardee, 1918, Geology and mineral deposits of the Colville Indian Reservation, Washington: U.S. Geol. Survey Bull. 677, 186 p.

"Syncline" in northeastern part found to be a tilted fault block

R. C. Pearson has interpreted an 8- to 12-mile-wide belt of Tertiary rocks in the Bodie Mountain quadrangle, northeastern Washington, to be a tilted fault block rather than a syncline as shown on the tectonic map of the United States. The west side is bounded by numerous north- to north-northeast-trending faults with small displacement, and the east side is marked by high-angle faults with major movement as well as inferred low-angle normal(?) faults that may extend the length of the quadrangle and beyond.

IDAHO

Drainage reversed on Lemhi River during Pleistocene

The direction of ancestral drainage in the intermontane trenches of east-central Idaho has long been a subject of controversy, but E. T. Ruppel believes that stream patterns and the distribution of surficial deposits provide conclusive evidence for reversal of the Lemhi River in Pleistocene time. The Lemhi presently flows northwestward, and empties into the Salmon River. Before arching in Pleistocene time reversed the flow in the northern segment of the river it must have flowed southeastward, to empty into the Snake River. This conclusion suggests that the parallel and very similar Pahsimeroi River was reversed at the same time, and that the Salmon River was formed concurrently as erosion, stimulated by arching and faulting, combined segments of many streams into the present Salmon River canyon.

Pull-apart theory not applicable to Gem Valley

Although Gem Valley, in southeastern Idaho, has been thought to be a pull-apart or tensional rift on the back edge of a thrust plate, S. S. Oriel suggests (p. C1–C4) that the marked contrasts in thicknesses and facies of Paleozoic stratigraphic units flanking the central and southern parts of the valley make it unlikely that original sites of deposition were ever any closer together than they are now.

Volcanic rocks once considered Precambrian may be Tertiary

The Bannock Volcanic Formation, as redefined by Ludlum (1942),[34] was once thought to be of Precambrian age and the oldest unit in the vicinity of Pocatello, Idaho, but D. E. Trimble believes that field relations of the rocks indicate that they are much younger, perhaps as young as early Tertiary. In at least one locality the Bannock Volcanic Formation

[34] J. C. Ludlum, 1942, Precambrian formations at Pocatello, Idaho: Jour. Geology, v. 50, no. 1, p. 85–95.

overlies Precambrian quartzite. The volcanic rocks appear to be both undeformed and unaltered, except for extensive propyllitization. Their attitude is discordant with adjoining rocks and they appear to have been erupted onto a topography that was not greatly different from that of the present.

First evidence of Precambrian rocks in Idaho batholith

Geologic studies by B. F. Leonard and isotope analyses by T. W. Stern provide the first evidence for Precambrian deformation and intrusion in old rocks preserved in the central part of the area now occupied by the Idaho batholith. Isotope dilution analysis by Stern gives a discordant Pb^{207}/Pb^{206} age of 680 million years for zircon from uncontaminated syenite of the pre-Idaho batholith Ramey Ridge Complex described by Leonard.[35] Other measured ages for the same zircon are: Pb^{206}/U^{238} 574 m.y., Pb^{207}/U^{235} 596 m.y., Pb^{208}/Th^{232} 538 m.y. The measured age of 680 m.y. is a minimum age for this intrusive complex, and for the tight northwest-trending folds in metasedimentary and metavolcanic rocks that it cuts. Hornblende from pegmatitic syenite of the complex has a K-Ar age of 93 m.y., according to R. F. Marvin; this is close to the Pb/α age of 108 ± 12 m.y. previously established by Larsen and others [36] for the Idaho batholith, which intrudes the Ramey Ridge Complex. If radiogenic lead loss is assumed to have occurred at 93 m.y., the discordia age of the syenite zircon is 725 m.y. Some lead loss may have occurred still earlier. Unless occult contamination affected the dated zircon, both the syenite complex and one major episode of folding are of Precambrian age.

MONTANA

Deformation and crustal shortening in eastern Rocky Mountains

The total crustal shortening on the thrust faults and folds in a section 17½ miles long in the Sun River Canyon area of the disturbed belt of Montana have been computed by M. R. Mudge to be about 29 miles.

In the Wolf Creek area, R. G. Schmidt has mapped three small klippen that show that the El Dorado thrust sheet once extended at least 3 miles east of its present trace. The klippen consist of Meagher Limestone of Middle Cambrian age, and lie on rocks of the St. Mary River Formation of Late Cretaceous age; they are thought to have been dragged along beneath a thrust plate that moved Belt rocks of Precambrian age eastward over rocks of Late Cretaceous age.

Sequence of thrusts records decreasing deformation

Mapping by G. D. Robinson and W. B. Myers in the northern Big Belt Mountains shows that the younger members of an overlapping sequence of major Laramide thrust faults have been deformed progressively less than the older by contemporaneous uplift of the Big Belt dome. The oldest thrust recognized dips northeastward on the northeast flank of the uplift and in places is very strongly deformed. Overlapping this, two successively younger thrusts show progressively less deformation. The El Dorado thrust, the youngest in the area, generally maintains the regional southwestern dip but is itself deformed on a small scale. Highly plastic deformation, notably in the axial region of the dome and in the floor of the oldest thrust, indicate both continued eastward thrusting and the uplift of the Big Belt dome.

Down-dropped blocks in diatremes near Bearpaw Mountains

Mapping southeast of the Bearpaw Mountains by B. C. Hearn, Jr., and C. P. Sabine has shown that diatremes as small as 150 feet in diameter contain sedimentary rocks of early Tertiary age 3,000 to 4,500 feet below their normal stratigraphic position. Hearn and Sabine suggest that diatreme-type volcanic activity is a possible mechanism for emplacement of isolated down-dropped fault blocks.

Correlation of rock units in western Montana

Reconnaissance mapping of Precambrian Belt Series rocks west of Anaconda by M. R. Klepper indicates that the Newland Formation of the Philipsburg area is almost certainly an equivalent of the Helena Dolomite, and not of the Newland of the type area. A calc-hornfels unit of the Precambrian mapped by Klepper and H. W. Smedes in the Highland Mountains south of Butte probably is also an equivalent of the Helena Dolomite.

In the Alberton area, west of Missoula, a nearly pure pink and white quartzite, 60 to 100 feet thick, has been correlated tentatively with the Cambrian Flathead Quartzite by J. D. Wells. The quartzite rests, in part, on diabase sills and, in part, overlies with apparent regional unconformity different horizons of the upper part of the Missoula Group (gray-green micaceous siltite and argillite, and pink and white micaceous, feldspathic quartzite with conspicuous crossbedding). In nearby areas similar pure quartzite that has been included in the Pilcher

[35] B. F. Leonard, 1963, Syenite complex older than the Idaho batholith: U.S. Geol. Prof. Paper 450-E, p. 93-97.

[36] E. S. Larsen, Jr., and others, 1958, Lead-alpha ages of the Mesozoic batholiths of western North America: U.S. Geol. Survey Bull. 1070-B, p. 35-62.

Quartzite of Precambrian age is probably also correlative with the Flathead Quartzite.

WYOMING

Marker horizons in Eocene rocks

Recent stratigraphic studies of the Wind River Formation of early Eocene age in the western Wind River Basin by J. F. Murphy have revealed a continuous mappable 20- to 40-foot tuffaceous sandstone sequence 500 to 700 feet above the base of the formation, which can be used effectively to divide the Wind River Formation into two mappable units.

A distinctive assemblage of vertebrate and invertebrate fossils has been discovered by W. L. Roher and C. L. Gazin (p. D133–D138) in a claystone bed in the lower Eocene Willwood Formation about 750 feet below its upper contact in the Big Horn Basin about 35 miles east of Cody, Wyo. This bed is mappable and provides stratigraphic control where control has been lacking. The bed contains fossil vertebrates common to both the Gray Bull and Lysite faunal zones; the Gray Bull fauna occurs below this bed and the Lysite fauna occurs above. The invertebrates in the bed are fresh-water mollusks.

Present-day canyons have Eocene ancestry

J. F. Murphy has shown that the boulder deposits of the Wind River Formation of early Eocene age that are found along the eastern flank of the Wind River Range are actually fan deposits, the apices of which point into, or are in, present-day canyons. The position of these deposits indicates that many of the present canyons were cut before or during early Eocene time.

Underground connections in Daisy geyser group, Yellowstone Park

J. J. Rowe, R. O. Fournier, and G. W. Morey (p. B184–B186) used sodium iodide as a tracer to prove the existence of underground connections linking several geysers and a pool of the Daisy group at Yellowstone Park. After adding sodium iodide to Splendid Geyser, water samples were taken at frequent intervals at Splendid, Daisy, and Comet Geysers and at Bonita Pool. Iodine determinations made in the field using a battery-operated photoelectric colorimeter showed that: (1) connections exist among all four features, (2) the connection among Splendid, Bonita, and Comet are relatively shallow (indicated by the rapidity of transfer of water containing iodide), (3) a reservoir of about 71,000 gallons is situated under Splendid, and (4) a small geyser east of Bonita is not connected by shallow channels to the Daisy group.

Devonian fish support paleogeographic connection between formations

The discovery by C. A. Sandberg and J. F. Murphy of fossiliferous Lower Devonian rocks at Bull Lake Canyon, on the east flank of the Wind River Range, supports a paleogeographic connection, postulated by C. A. Sandberg,[37] between continental and marginal marine beds of the Beartooth Butte Formation on the east and nearshore marine beds of the Water Canyon Formation on the west. The fossils are well-preserved heterostracan fish remains collected from a channel-fill deposit of the Beartooth Butte Formation. This locality is 125 miles due south of the closest outcrop and type section of the Beartooth Butte Formation and 115 miles east of the nearest outcrop of the correlative Water Canyon Formation of Utah and Idaho.

Regional correlations of the Darby Formation

Regional stratigraphic studies of Devonian rocks by A. L. Benson, J. F. Murphy, and C. A. Sandberg in west-central Wyoming have demonstrated that the type Darby Formation[38] on Sheep Mountain, on the west flank of the Wind River Range, includes limestone and shale correlative with the Madison Limestone of Mississippian age and with a dark shale unit of Late Devonian and Early Mississippian age. The remainder of the type Darby is correlative with, and continuous with, the lower member of the Jefferson Formation (Sandberg, 1–65). On the east flank of the Wind River Range the dark shale unit at the top and beds equivalent to the Maywood Formation of Late Devonian age at the base have been mapped with the Darby by Murphy and Richmond.[39] Lithologic and paleontologic data demonstrate that the dark shale unit, which locally overlies older rocks in angular unconformity, is a basal facies of the Madison, and is in part Devonian in age.

Regional unconformity within the Mesaverde Formation

A widespread unconformity at the base of the Teapot Sandstone Member of the Upper Cretaceous Formation has been defined by J. R. Gill in the Bighorn, Wind River, and Hanna Basins. The unconformity increases in magnitude from east to west and appears to reflect broad gentle uplift in western Wyoming modified by intense local uplift in some areas such as the Lost Soldier–Lamont area at the

[37] C. A. Sandberg, 1961, Widespread Beartooth Butte Formation of Early Devonian age in Montana and Wyoming and its paleogeographic significance: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 8, p. 1301–1309.

[38] Eliot Blackwelder, 1918, New geological formations in western Wyoming: Washington Acad. Sci. Jour., v. 8, no. 13, p. 417–426.

[39] J. F. Murphy and G. M. Richmond, 1965, Geologic map of Bull Lake West quadrangle: U.S. Geol. Survey Quad. Map GQ–432.

southeast end of the Wind River Range (Zapp and Cobban [40]). In south-central Wyoming, M. W. Reynolds finds that this unconformity cuts downward across the Mesaverde Formation from south to north; 1,400 feet of strata has been eroded below the Teapot Member between Rawlins and Separation Rim, and the Camp Creek syncline. Reynolds also recognizes an unconformity in post-Teapot, pre-Lewis time in which the Lewis Shale overlies successively older beds of the Mesaverde northward and ultimately rests on the Cody Shale. Both unconformities increase in magnitude toward the Sweetwater arch, suggesting that the arch was tectonically active in Late Cretaceous time.

According to Gill the regression in western Wyoming represented by the basal Teapot unconformity appears to have taken place concurrently with transgression of the sea into western Montana marginal to the Elkhorn Mountains volcanic field. This activity culminated during the range span of *Baculites compressus* (late Campanian) in the Upper Cretaceous. The absolute time of this event can be postulated from a potassium-argon date of about 75 million years obtained for biotite from a bentonite occurring in the zone of *Baculites compressus* reported by Folinsbee and others.[41]

Structural relief of Precambrian surface inferred from gravity data

Geologic and gravity profiles drawn by J. E. Case and W. R. Keefer transect the area from the deep part of the Wind River Basin to the crest of the Owl Creek Range, west of Wind River Canyon, and show that structural relief of the Precambrian surface along the line of profile from the basin to the crest of the uplift is on the order of 21,000 feet. The steep gravity gradient across the southern front of the Owl Creek Range indicates that the bordering major fault zone dips at a high angle. The gravity data support earlier interpretations, based upon regional stratigraphic and structural studies by Keefer, that movements between basin and mountain provinces in central Wyoming during the Laramide were predominantly vertical.

NORTH AND SOUTH DAKOTA

Precambrian stratigraphy in central Black Hills, S. Dak.

A working stratigraphic section of the Precambrian rocks in the Hill City and Medicine Mountain quadrangles of the central Black Hills has been established by J. C. Ratté. The section is 30,000 to 50,000 feet thick and consists of the following units, in ascending order: (1) biotite-quartz schist, 1,000 to 1,500 feet thick; (2) a heterogeneous unit of quartz-feldspar gneiss and quartzite that includes metaconglomerate and arkose, tremolite-carbonate schist, and other metamorphosed calcareous sediments, graphitic quartzose schist, sugary quartzite, and beds of carbonate iron formation, 5,000 to 6,000 feet thick; (3) thin-bedded highly sheared phyllite and schist containing small bodies of metagraywacke, 20,000 to 30,000 feet thick; unconformity at base marked by irregularities in thickness and overlap of quartzite beds of unit 2; (4) principally thick-bedded metagraywacke and quartzose schists, 5,000 to 10,000 feet thick, correlated with the Bugtown Formation of the Fourmile and Berne quadrangles to the southwest. Unconformities may exist at the base of units 2 and 4. Pegmatitic granite intrudes the entire metasedimentary section. The recognition of this stratigraphic section will permit reasonable stratigraphic and structural interpretations of the central Black Hills.

Glacial features are channel fill, not lake deposits

C. H. Baker, Jr., has studied a series of short ridges of sand and gravel that lie above the highest shoreline of glacial Lake Agassiz. These ridges are part of a long sinuous deposit of sand and gravel, generally occupying a topographic low, which extends southeastward from the southernmost bend in the Sheyenne River in North Dakota to Lake Traverse, S. Dak. The sand and gravel seem to have been deposited by streams in an ice-margin channel rather than as beach deposits in hypothetical Lake Milnor as postulated by earlier workers. Baker suggests that the name "Lake Milnor" be changed to "Milnor Channel" and the name of the sand and gravel ridges that border the channel be changed from "Milnor beaches" to "Milnor Channel deposits."

SOUTHERN ROCKY MOUNTAINS AND PLAINS

GEOLOGY OF PRECAMBRIAN ROCKS

Mafic and ultramafic rocks in two alkalic complexes, Wet Mountains, Colo.

Detailed mapping by R. L. Parker and D. R. Shawe have shown that the mafic and ultramafic rocks associated with the alkalic intrusions of Gem Park and Iron Mountain east of Hillside, in the northern Wet

[40] A. D. Zapp and W. A. Cobban, 1962, Some Late Cretaceous strandlines in Wyoming: Art. 134 *in* U.S. Geol. Survey Prof. Paper 450–D, p. D52–D55.

[41] R. E. Folinsbee, Halfdan Baadsgaard, and J. Lipson, 1961, Potassium-argon dates of Upper Cretaceous ashfalls, Alberta, Canada, *in* J. L. Kulp, ed., Geochronology of rock systems: New York Acad. Sci., Annals, v. 91, art. 2, p. 352–363.

Mountains, Colo.,[42] form two discrete stratiform complexes. The complex at Iron Mountain underlies about 3½ square miles and that at Gem Park about 2 square miles. Both complexes are distinctly layered. The layers consist of gabbro, olivine gabbro, pyroxenite, pyroxene-olivine rocks, and dunite and are inclined toward the centers of the complexes. The gabbro layers show many features such as rhythmic banding, scour-and-fill structures, and crossbedding which are typical of the classic Skaergaard intrusive, Greenland, and of the Stillwater Complex, Montana.

Metasedimentary rocks in northern Front Range, Colo.

Studies by W. A. Braddock have shown that the metasedimentary rocks in the vicinity of the Thompson Canyon in the northern Front Range, Colo., were folded and metamorphosed twice during Precambrian time. The early deformation produced large isoclinal folds with axial-plane schistosity. Although bedding in the hinges of the folds was obliterated by the axial plane schistosity, the folds can be identified by the orientation of graded bedding in the limbs. Metamorphism produced quartz-albite-muscovite phyllites in at least part of the area, but it is not known whether a zonal pattern of higher grade mineral assemblages was also formed during this first period.

During the second period of folding, the rocks were deformed primarily by pervasive displacements along two conjugate sets of slip cleavage planes. The beds that previously had been tilted to steep angles were deformed into steeply plunging folds whose axial planes make large angles with the axial planes of older folds. After this folding the rocks were again metamorphosed, producing a zonal pattern of mineral assemblages that probably reflects a temperature gradient. Biotite, garnet, staurolite, andalusite, sillimanite-muscovite, and sillimanite-microcline zones have been recognized.

Quartz diorite similar to the Boulder Creek Granodiorite probably was emplaced during the older period of deformation. Tonalite (Mount Olympus Granite) and granodiorite (Sherman Granite) was intruded after the second period of deformation; at a still later time, quartz monzonites of the St. Vrain and Log Cabin batholiths were intruded.

Isoclinal folding in central Front Range, Colo.

A symmetrical pattern of Precambrian metasedimentary rock units in the Squaw Pass quadrangle in the central Front Range, Colo., is interpreted by D. M. Sheridan to be the result of an early period of isoclinal folding. The axial area of a major fold is believed to lie in a west-northwest-trending major belt of hornblende gneiss, which is bordered successively to the north and south by parallel major belts of sillimanitic biotite gneiss, hornblende gneiss, and microcline gneiss. Marker layers of cordierite-sillimanite-biotite gneiss and a distinctive feldspathic calc-silicate gneiss, apparently unique to this area, form a symmetrical pattern within the central belt of hornblende gneiss. Lineations of the area plunge predominantly west-northwest at a low to moderate angle parallel to the inferred major axis of folding. The isoclinal folding is considered to be the oldest of three periods of Precambrian deformation recognized in this region.

[42] R. L. Parker and F. A. Hildebrand, 1963, Preliminary report on alkalic intrusive rocks in the northern Wet Mountains, Colorado: Art. 181 *in* U.S. Geol. Survey Prof. Paper 450-E, p. E8-E10.

STRATIGRAPHY AND STRUCTURAL GEOLOGY

Age of Sangre de Cristo Formation, New Mexico

Detailed mapping by E. H. Baltz in the Montezuma and El Porvenir quadrangles in the Sangre de Cristo Mountains near Las Vegas, N. Mex., has shown that the upper part of the arkosic limestone member of the Madera Limestone grades northward into shales and arkoses of the lower part of the Sangre de Cristo Formation. Fusulinids collected from the arkosic limestone member indicate a Missouri and Virgil (Late Pennsylvanian) age for the part of the member that grades into the Sangre de Cristo, thus confirming the Pennsylvanian and Permian age of the Sangre de Cristo Formation in the region to the north. South of Las Vegas, the Madera Limestone was deformed into several large folds in latest Pennsylvanian or Early Permian time, and the Permian part of the Sangre de Cristo Formation lies with angular unconformity on the arkosic limestone member of the Madera. Major Laramide folds and faults are oriented generally parallel to the late Paleozoic folds.

Red-bed deposition in New Mexico

Red-bed deposition in the late Paleozoic began at different times in different places in central New Mexico. In the north-central Oscura Mountains, G. O. Bachman has found minor red beds in strata of Missouri (Late Pennsylvanian) age; in the Manzano Mountains, D. A. Myers reports that although the first red beds were deposited in early Virgil (Late Pennsylvanian) time, large-scale red-bed deposition did not occur until late Virgil or Early Permian time. In the southern San Andres Mountains, Bachman and Myers have found that the lowest red beds are above the Hueco Limestone of Permian age.

Widespread regional unconformity of Jurassic age

An unconformity marked by a distinctive chert-pebble zone has been traced by G. N. Pipiringos from the Black Hills in South Dakota throughout central and southeastern Wyoming, northwestern Colorado, eastern Uinta Mountains, and into the Colorado Plateau, where it had been recognized earlier by other workers. In southeast Wyoming the chert-pebble zone marks the base of the Canyon Springs Sandstone Member (Upper Jurassic) of the Sundance Formation. In central Wyoming it lies at the top of the Gypsum Spring Formation (early Middle Jurassic) and locally underlies beds of probable late Middle Jurassic age. In the Uinta Mountains the chert-pebble zone lies at the top of the Glen Canyon Sandstone and is overlain by either the Carmel Formation or the Entrada Sandstone. The chert-pebble zone is thus a regional feature in the Jurassic sequence from the Black Hills westward through the Uinta Mountains, and southward through the Colorado Plateau at least to the Zuni Mountains, N. Mex.

Late Cretaceous uplift and erosion in San Juan region, Colorado

An unconformity marking a period of uplift and erosion has been mapped by R. G. Dickinson within a sequence of Upper Cretaceous sedimentary and volcanic rocks in the Cimarron Ridge area, along the northwestern flank of the San Juan Mountains, Colo. The unconformity bevels Upper Cretaceous marine and nonmarine rocks and is overlain by newly discovered volcanic sediments dated as Late Cretaceous by plant fossils. After the Mancos sea had withdrawn (in late Campanian time) and at least 800 feet of conformable nonmarine sediments had been deposited, the area was uplifted and deformed. Erosion removed several thousand feet of rock from the uplifted area and cut a surface of low relief before volcanism began near the end of Cretaceous time and deposited an undetermined thickness of volcanic debris.

Stratigraphic relations between Morrison Formation and Dakota Sandstone

An unconformity separates the Morrison Formation and Dakota Sandstone throughout the North Park area, Colorado, but probably is absent farther south, in western Middle Park, according to W. J. Hail. As observed in the Lake Agnes and Gore Pass quadrangles south of Rabbit Ears and Muddy Passes, the contact appears to be conformable; claystones typical of the Morrison Formation intertongue with sandy strata typical of the Dakota Sandstone.

Ilse fault in Wet Mountains, Colo., extended

Geologic reconnaissance by Q. D. Singewald in the northern Wet Mountains of Colorado extended the Ilse fault 6 miles northward from its previously known northern limit near Grape Creek into a previously known fault between Precambrian and Mesozoic rocks near Parkdale. The Ilse fault, long inferred to be the leading dislocation in the central part of the Wet Mountains, has Precambrian rocks on both walls along the segment hitherto mapped; hence neither the direction nor amount of displacement could be determined. The new data reveal that the east wall of the Ilse fault moved up relative to the west wall; the amount of vertical displacement remains indeterminate, but was of the magnitude of hundreds, if not thousands of feet.

Elk Mountain thrust fault south of Aspen, Colo.

In the Conundrum Creek valley 9 miles south of Aspen, Colo., Bruce Bryant has mapped a structurally complex block of hornfelsed sedimentary rocks underlying a much less deformed section of the Maroon Formation of Pennsylvanian and Permian age. On the southwest the complex structures in the lower rocks are truncated by a fault occupied by a sill, whereas on the north they pass upward transitionally into simpler structures of the Maroon Formation. The complexly deformed rocks below may represent a window beneath the Elk Range thrust fault, which crops out 7 miles to the southwest, and extends northwest-southeast for at least 25 miles. After faulting, Tertiary granodiorite invaded the fault zone and metamorphosed the rocks above and below.

Monoclines in southeastern Colorado

Reconnaissance studies by G. R. Scott have shown that the generally flat-lying strata in the La Junta 1° by 2° quadrangle in the Plains in southeastern Colorado are disturbed by a number of monoclinal folds of diverse trends. These folds range in length from 2 to 40 miles, and many have a sinuous pattern. Commonly the folds are paired, forming structural terraces. The monoclines are believed to be surface manifestations of deep-seated faults, although a laccolithic origin cannot be ruled out.

GEOLOGY OF VOLCANIC AND HYPABYSSAL INTRUSIVE ROCKS

New volcanic center in Wet Mountains, Colo.

Fieldwork by Q. D. Singewald in the Wet Mountains in Custer County, Colo. has disclosed a previously unreported intrusive body more than a square mile in area, mainly in sec. 19, T. 23 S., R. 69 W. The intrusive opens upward and eastward into andesite that resembles Tertiary extrusive rocks farther south and west in the Wet Mountains, and thus may be one of the feeders for the volcanic material. A belt of the igneous rocks about 2,000 feet wide and 5,000 feet long is hydrothermally altered, impregnated by pyrite, and transected by pyritic veins containing small quantities of gold.

Age of volcanic activity in central Colorado

A black vitrophyre at the base of a thick rhyolitic welded tuff mapped by R E. Van Alstine in the Poncha Springs quadrangle, central Colorado, was dated by the K-Ar method (analysts H. H. Thomas, R. F. Marvin, Paul Elmore, and H. Smith). An age of 34 million years (± 3 million years) was obtained both from a biotite separate and from the glass matrix, and the volcanic rocks are considered to have been erupted in the Oligocene. The welded tuff is more widespread than was previously realized and may correlate with similar rocks in southwestern South Park, dated by other workers as early Oligocene on the basis of vertebrate and invertebrate fossils in intertonguing sediments.

Dike systems in southern Colorado

Reconnaissance mapping by R. B. Johnson in the Trinidad 1° by 2° quadrangle in southern Colorado has shown that many dikes cut the sedimentary rocks of Cretaceous age east and northeast of the Spanish Peaks. These dikes belong to a large system of subparallel dikes that cuts the dikes of the Spanish Peaks radial system and trends normal to the strike of the folded sedimentary rocks of the Raton Basin. In contrast to the relatively siliceous porphyry dikes of the Spanish Peaks system, the younger dikes are mainly syenitic lamprophyres (minettes and vogesites) and several are more calcic lamprophyres and diabases. Some dikes of diabase near the New Mexico–Colorado boundary may be related to the Pleistocene and Recent flows, plugs, and volcanoes that make up the Raton Mesas and associated volcanic terrane.

GEOPHYSICAL INVESTIGATIONS

Gravity anomalies in San Luis Valley, Colo.

A series of echelon gravity highs mapped by J. R. Gava and D. E. Karig in the central and western San Luis Valley, Colo., have been interpreted as expressions of horsts of Precambrian rock covered by basin fill. Subparallel gravity lows in the eastern part of the valley are believed to reflect a graben filled with perhaps as much as 30,000 feet of sedimentary and volcanic rocks. A gravity low over volcanic rocks in the Bonanza mining district, Colorado, at the northeast corner of the San Juan volcanic field was interpreted by Karig as a collapse caldera (p. B9–B12). The caldera is elliptical in outline with axes of 8 and 10 miles, and is filled with about 8,000 feet of low-density material.

Gravity survey of North Park, Colo.

Preliminary results of a gravity survey of the North Park basin in north-central Colorado by J. C. Behrendt disclosed gravity minimums of about −270 milligals over the basin, compared with about −215 mgal over the adjacent mountains. This suggests thicknesses of relatively low-density sedimentary rocks of about 4 kilometers within the basins.

QUATERNARY GEOLOGY

Pleistocene and Recent surfaces near Badger Creek, Colo.

Three pediment surfaces and a terrace have been recognized by C. T. Wrucke in the Badger Creek drainage in the Cameron Mountain quadrangle, central Colorado. The oldest and best developed pediment lies about 280 feet above Badger Creek and truncates Precambrian granite and Tertiary conglomerate; the intermediate and lower pediments, respectively 40 to 60 and 10 to 30 feet above the streams, bevel Tertiary tuff and conglomerate. The terrace is 2 to 10 feet above the streams. A strongly developed soil containing a reddish-brown B horizon formed on gravel resting on the highest surface indicates a pre-Wisconsin age for that pediment. The geomorphic position of the lower pediments suggests that they are of Wisconsin age. The terrace is probably of Recent age.

Glacial spillover through McClure Pass, Colo.

Glacial deposits along Colorado Highway 133 south of Glenwood Springs contain boulders derived from the Treasure Mountain dome, in the Crystal River drainage, as indicated by studies of L. H. Godwin. The boulders, at McClure Pass and westward down Lee Creek, indicate that ice from glaciers in the Crystal River canyon spilled through the pass more than twice. The spillovers are assigned to glaciations in the middle or early part of the Pleistocene sequence, when the Crystal River canyon was much shallower than now. As the canyon deepened, later glaciers were confined with it, and at least three existed since the last ice flowed through McClure Pass.

Pleistocene sequence near Leadville, Colo.

Studies by Ogden Tweto of samples from test holes drilled by the Bureau of Reclamation in the upper Arkansas Valley west of Leadville, Colo., show that the large, sharply defined horseshoe-shaped end moraine at Lake Fork is built up of as many as four different tills derived from the Sawatch Range to the west. These tills are each less than 50 to 150 feet thick and are separated by weathered zones. These end-moraine tills, which extend to depths of as much as 175 feet below the present valley floor, rest on a sequence of deposits of much greater areal extent derived wholly or in large part from the Mosquito Range to the east. From the top downward, this lower sequence consists of (1) Malta Gravel, generally less than 50 feet thick; (2) ancient glacial drift, with or without a heavy red gumbo zone at its top, depending on accidents of erosion or preservation; (3) local deposits of valley alluvium, some of which contain thin layers of volcanic ash, and bouldery channel deposits; and (4) the Pliocene Dry Union Formation. The stratigraphic relations established by superposition in the end-moraine and subjacent sequence confirm a Pleistocene history previously deduced indirectly from geographic and topographic relations at the surface.[43]

Quaternary stratigraphy in Durango, Colo. area revised

G. M. Richmond (p. C137–C143) has restudied the type deposits of Quaternary stratigraphic units in the Durango area, San Juan Mountains, Colo., and has correlated them with the standard sequence of glacial events for the Rocky Mountain area as established in the Wind River Mountains of Wyoming. Moraines formerly called Wisconsin are of Pinedale age; some moraines formerly assigned to the Durango Glaciation are of Bull Lake age, but the type Durango moraine represents the earlier Sacajawea Ridge Glaciation. The Florida Gravel is outwash of Sacajawea Ridge age, and the Oxford Gravel is reworked colluvium derived from fluvioglacial gravels of pre-Sacajawea Ridge age. The Bridgetimber Gravel has the characteristics of fluvioglacial deposits, and probably was deposited during two pre-Sacajawea Ridge glaciations. Some deposits called Bayfield Gravel may correlate with the Bridgetimber Gravel, but others may be residual deposits weathered from underlying conglomerate beds in the Animas Formation.

[43] Ogden Tweto, 1961, Late Cenozoic events of the Leadville district and upper Arkansas Valley, Colorado: Art. 56 *in* U.S. Geol. Survey Prof. Paper 424-B, p. B133–B135.

COLORADO PLATEAU

GEOLOGIC STUDIES

Multiple periods of Precambrian deformation in Uncompahgre uplift

In the continuing investigation of the Precambrian crystalline rocks comprising the core of the northwestern Uncompahgre uplift, Utah and Colorado, J. E. Case has recognized two ages of folding in the ancient feldspathic and biotitic gneisses and amphibolites. In the earlier deformation, folds formed around axes that trend approximately north. In the later deformation, the early folds were warped around axes that trend from east to northeast. A set of folds that trends northwest has not yet been related to either period of deformation.

Surface expression of basement structure in Paradox basin

Field evidence and subsurface studies of drill data lead R. J. Hite to suggest that a series of northeast-trending structures extend through and beyond the margins of the Paradox salt basin in southeastern Utah and southwestern Colorado. These structures are expressed at the surface by small faults, fractures, bands of mineralized and altered rock adjacent to fissures, and by zones of drag folds. From their geometry, they are believed to overlie basement wrench faults, at least some of which had large left-lateral displacement.

Northwest transport of coarse components of Moenkopi Formation

The coarse fraction of the Triassic sediments now comprising the Moenkopi Formation moved generally northwestward across the area of the Colorado Plateau according to R. A. Cadigan. The sediments were derived from crystalline rocks in areas inferred to have been rising slowly in southwestern Colorado, southwestern New Mexico, and southern Arizona. Each of the areas included local sources of tuff. This resultant direction of sediment transport is suggested by trend-surface analyses (computed linear surfaces) of statistical measures of grain-size distribution of many widely scattered representative samples. Median grain size, skewness, and kurtosis decrease in a northwest direction across the Colorado Plateau, and sorting improves.

Nonmarine fossils in Straight Cliffs and Wahweap Sandstone

The Tropic Shale and the overlying marine sandstone in the lower part of the Straight Cliffs Sandstone appear to record the last incursion and withdrawal of the Late Cretaceous sea in the Nipple Buttes area of the Kaiparowits Plateau, Utah. Fossils collected by Fred Peterson, H. A. Waldrop, G. W. Horton, and R. L. Sutton from the lower part of the Straight Cliffs contain marine fossils diagnostic of the *Collignoniceras hyatti* faunal zone, according to W. A. Cobban. Overlying rocks in the middle and upper part of the Straight Cliffs Sandstone and in the shaly lower part of the overlying Wahweap Sandstone contain small but varied faunal assemblages including gastropods, pelecypods, ostracodes, and fish and reptile tooth and bone fragments. These fossils identified by Cobban, I. G. Sohn, and G. E. Lewis suggest nonmarine environments of deposition from the top of the lower part of the Straight Cliffs upward.

Key fossil zones in Lewis Shale

Key fossil zones of Late Cretaceous (Montana) age have been recognized in the Lewis Shale on the eastern side of the San Juan basin in northern New Mexico. At least 6 ammonite zones that are known in eastern Colorado and the northern Great Plains were identified by W. A. Cobban in fossils collected by Cobban, C. H. Dane, and E. R. Landis.

Southeast margin of Eocene Lake Uinta

The southeastern limit of oil-shale deposition in western Colorado has been identified by J. R. Donnell near the east end of Grand Mesa, Delta County. Well exposed at Mount Darlene are two 1-foot beds of lean oil shale separated by hundreds of feet of sandstone and siltstone. These two thin beds are the wedging edge of the 2,000 feet of continuous oil shale that was deposited in the center of the Piceance Creek lobe of Eocene Lake Uinta about 60 miles to the northwest.

Volcanic stratigraphy in High Plateaus

In the Awapa and Fish Lake Plateaus and adjacent Grass Valley, Sevier and Wayne Counties, Utah, P. L. Williams and R. J. Hackman have established details of volcanic stratigraphy which permit correlation of units between several of the High Plateaus and the Marysvale area to the west. The units are the Bullion Canyon Volcanics of Miocene (?) age, basaltic andesite erupted from three source areas, the Dry Hollow Formation of Pliocene (?) age, and surficial olivine basalt erupted from many vents on the Awapa Plateau. Some of the basalt is faulted and of preglacial age; some is apparently younger than the Bull Lake Glaciation.

Type Cerro Till found to be landslide material

The type Cerro Till is on Cerro Summit about 15 miles east of Montrose, Colo. Study by R. G. Dickinson (p. C147–C151) of the hummocky and bouldery surficial debris composing the deposit indicates that the material was emplaced primarily by landsliding, instead of by a piedmont glacier. The names Cerro Till and Cerro Glaciation are therefore abandoned by the Geological Survey.

Popularization of geology at Capitol Reef

Following publication of the final report of investigations in the Capitol Reef area, in south-central Utah near the west edge of the Colorado Plateau, by J. F. Smith and others,[44] Smith's help was requested by the National Park Service in identifying and describing rocks in the Capitol Reef National Monument. Smith also has served as geologic consultant in preparation of a short movie to be shown at the Monument. The movie, prepared by a private contractor, shows development of the Waterpocket fold and the present scenery. Included were diagrams and sketches by J. D. Stacy, scientific illustrator.

1:250,000-scale geologic map of Moab qradrangle, Colorado-Utah

The geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah (P. L. Williams, I–64), are shown on a new map of an area comprising 2° of longitude and 1° of latitude. Among other features the area includes the uranium deposits of the Uravan mineral belt and of Lisbon Valley, and also the oil field of the Lisbon Valley anticline, the La Sal group of laccolithic mountains, and the salt anticlines of the Paradox basin. The map, in two sheets, was compiled from more than 70 sources and is the second of a series of 10 planned to cover much of the Colorado Plateau.

GEOPHYSICAL STUDIES

Basement structure and salt thickness, Moab-Needles area, Utah

H. R. Joesting, J. E. Case, and Donald Plouff have completed interpretation of gravity and aeromagnetic surveys of the Moab-Needles area, Utah, which covers a large part of the new Canyon Lands National Park. In the northern third of the area, which lies in the deeper part of the Paradox basin, magnetic response is uniform, suggesting uniform Precambrian basement rocks. Pronounced gravity lows are associated with Moab Valley and Salt

[44] J. F. Smith, Jr., L. C. Huff, E. N. Hinrichs, and R. G. Luedke, 1963, Geology of the Capitol Reef area, Wayne and Garfield Counties, Utah: U.S. Geol. Survey Prof. Paper 363, 102 p.

Valley salt anticlines in the northeast corner of the area. From analysis of the gravity anomaly, the amplitude of the salt core of Moab Valley anticline is about 8,000 feet. In the southern third of the area, at the north end of Monument upwarp, the magnetic field is diverse, indicating a corresponding diversity of the basement rocks. In the central part of the area, anomalies are arranged systematically. A zone of steep gravity gradient trends eastward across the area and marks a major lithologic and structural boundary in the basement rocks. Just south of and approximately parallel to this zone are three prominent magnetic highs, each associated with a gravity high. These highs evidently are caused by large intrusive masses in the basement.

BASIN AND RANGE REGION

STRATIGRAPHY AND STRUCTURAL GEOLOGY

NEVADA AND EASTERN CALIFORNIA

Changes in stratigraphy across major faults in southern Great Basin

Stratigraphic studies of upper Precambrian and Lower Cambrian formations in the southern Great Basin by J. H. Stewart indicate abrupt changes in thickness and facies on opposite sides of the Death Valley and Furnace Creek fault complex in Inyo County, Calif., and across the Las Vegas shear zone in Clark County, Nev. The thicknesses of the Stirling Quartzite, Wood Canyon Formation, and Zabriskie Quartzite are approximately doubled across the Death Valley and Furnace Creek fault zone from the Panamint Range on the west side of Death Valley to the Funeral and Grapevine Mountains on the east side. Similar changes in these formations also were observed across the Las Vegas shear zone, although the relations there are less clear. Right-lateral strike-slip movement is suggested by the thickness and facies trends. Offsets may be about 50 miles on the Death Valley and Furnace Creek fault complex and about 30 miles on the Las Vegas shear zone.

Thrust fault in east-central California

A thrust fault which may have considerable regional significance has been recognized by J. H. Stewart, C. A. Nelson, and D. C. Ross in the Last Chance Range, Saline Range, and northern Inyo Mountains of California. The fault emplaced rocks of Precambrian and Early Cambrian age on rocks largely of Mississippian and younger age.

Imbricate thrust faults in Egan Range, Nev.

Mapping by A. L. Brokaw in the Reipetown quadrangle, Nevada, reveals imbricate thrust faults in rocks of Late Devonian to Pennsylvanian age. The rapid thinning of the Joana Limestone in the Robinson (Ely) district, postulated by earlier workers to be a depositional feature, is now believed to be due to tectonic slicing. Moreover, massive limestone considered by earlier workers to be part of the Chainman Shale has been recognized as a thrust segment of the lower part of the Joana Limestone. The structures mapped substantiate earlier conclusions, based on inadequate exposures, that significant faulting occurred in equivalent rocks throughout this part of the Egan Range.

Faults in Ward mining district, eastern Nevada

In the Ward mining district, south of Ely, Nev., mapping by T. L. Heidrick, Jr. and A. L. Brokaw shows that the productive part of the district is related to small monzonitic dikes and mineralized faults and fissures that cut beds in the lower part of the Ely Limestone. The area is a complexly faulted structural block that has been displaced upwards about 1,000 feet, relative to adjacent blocks, along a system of transverse bounding faults. The stratigraphic and structural studies indicate that exploration for deeper potentially favorable host rocks within the displaced block is economically feasible. Exploration targets outside the uplifted block are probably too deep to be economically attractive.

Zonation of Silurian and Devonian rocks by rugose corals

A workable zonation of Silurian and Devonian carbonate rocks in the Great Basin by rugose corals appears practicable, as the collections from areas of detailed geologic mapping are sectioned and studied, according to C. W. Merriam. In central Nevada the Lone Mountain Dolomite of Silurian age contains extensive carbonaceous dolomite bodies in its upper part which bear a coral fauna with bushy *Entellophyllum.* The overlying Devonian Nevada Formation includes seven rugose coral zones which are lettered A to G in ascending order. Zones A, B, and C are Lower Devonian, being characterized by Laccophyllidae, Halliidae, and Streptelasmatidae. Colonial rugose corals do not appear in great abundance until the higher Middle Devonian, as in zone F, which contains such genera as *Hexagonaria, Sociophyllum, Utaratuia,* and *Aphroidophyllum.* Solitary Digonophylloids and Acanthophylloids also occur in these beds which immediately underlie the *Stringocephalus* zone.

Thrusting in northern Nye County, Nev.

Additional mapping of Paleozoic rocks in the Hot Creek Range, central Nevada, by F. J. Kleinhampl, indicates that transitional facies Devonian rocks were thrust over miogeosynclinal carbonate rocks during the Antler orogeny in Late Devonian or earliest Mississippian time. Although rocks of Early Mississippian age are also involved in thrusting, they probably were deposited as an orogenic sediment overlapping autochthonous Devonian rocks and the earlier thrust plate, and subsequently were thrust in late Paleozoic or Mesozoic time.

UTAH

Extension of Mount Raymond thrust near Salt Lake City

M. D. Crittenden, Jr., has completed a reconnaissance study of a possible eastward extension of the Mount Raymond thrust zone east of Salt Lake City, Utah. This fault is a folded thrust which crosses the Wasatch Range from the mouth of Mill Creek near Salt Lake City to a point north of Park City, Utah, where it disappears beneath a cover of alluvium and volcanic rocks. Mapping near Peoa on the Weber River shows that the Crandall Canyon and Dry Canyon faults, previously described as high-angle normal faults, are accompanied by large-scale overturning and by changes in sedimentary facies that are indicative of thrusting. Inasmuch as earlier mapping by students at the University of Utah (N. C. Williams and J. H. Madsen [45]) showed that these faults were overlapped by the Wanship Formation of Williams and Madsen (1959), the movement on the Mount Raymond thrust can be dated as early Late Cretaceous in age.

ARIZONA

Trend of Patagonia Mountains related to Late Cretaceous or early Tertiary faults

In southeastern Arizona, F. S. Simons has found that the northwest trend of the Patagonia Mountains probably was developed in Late Cretaceous or early Tertiary time by large faults that since have been obliterated by igneous intrusion. No sizable faults of this trend are now recognized along the west front of the mountains. Moreover, rocks like the oldest found within the range crop out on the broad alluvial plain as far as 3 miles west of the mountain front. Thus the present topography apparently is not related to basin-range block faulting in late Cenozoic time.

[45] N. C. Williams, and J. H. Madsen, Jr., 1959, Late Cretaceous stratigraphy of the Coalville area, Utah, *in* Intermountain Assoc. Petroleum Geologists Guidebook 10th Ann. Field Conf.: p. 122–125.

Abrigo Formation studied in southeastern Arizona

Stratigraphic studies of the Abrigo Formation in southeastern Arizona by M. H. Krieger reveal that the three members of the Abrigo have widespread distribution and lithologic continuity. The lower member, of late Middle Cambrian age, consists of mudstone, shale, fine-grained sandstone, and variable amounts of limestone and dolomite. The middle member is chiefly sandstone in the Holy Joe Peak and Christmas quadrangles, but to the south it is chiefly limestone or dolomite. The upper member consists of sandy dolomite and dolomitic sandstone in the lower part and thin-bedded dolomite in the upper part. The brachiopod *Billingsella*, which defines a narrow time zone in the middle Late Cambrian, has a widespread occurrence in the thin-bedded dolomite of the upper member.

EMPLACEMENT AND AGE OF INTRUSIVE ROCKS

Age of plutons in Elko County, Nev., and vicinity

In northeastern Nevada and adjacent parts of Idaho and Utah, scattered, relatively small plutons of silicic rocks intrude rocks as young as late Paleozoic, and are overlain by rocks as old as middle Tertiary. R. R. Coats, R. F. Marvin, and T. W. Stern report (p. D11–D15) that K-Ar ages of these rocks fall into three groups: Middle Jurassic, Late Cretaceous, and late Eocene to early Oligocene. Biotite-zircon pairs in samples from nine plutons have been dated by K-Ar and Pb-alpha methods. Results by the two methods are in close agreement in all except two plutons. No petrographic criteria have been found that may be correlated with the age assignments.

Age of intrusive and extrusive rocks in southeastern Arizona

S. C. Creasey reports that about 50 K-Ar ages have been determined from intrusive and extrusive rocks in southeastern Arizona thought to be either of Late Cretaceous to early Tertiary age (Laramide) or Tertiary age. The age determinations show a bimodal distribution in time. The older group, which includes predominantly intrusives but some extrusives, ranges in age from 50 to 75 million years. Most of the stocks associated with the porphyry copper deposits are within this group. The younger group, which is made up mainly of extrusive rocks, ranges in age from 20 to 30 million years. No large ore deposits are known to be associated with rocks of this younger group. Virtually no igneous activity occurred during the period from 30 to 50 million years. These data, although incomplete, tend to confirm the concept that most of the economic copper deposits of southeastern Arizona are associated with stocks that were intruded during a restricted period of time.

Granodiorite stocks in central Yavapai County, Ariz.

In the northern part of the Mount Union quadrangle, Arizona, C. A. Anderson has found three granodiorite stocks of Cretaceous to early Tertiary age. These stocks crop out in an east-trending belt, and are alined with a similar stock in the Copper basin to the west, which is mineralized with copper and molybdenum. Altered facies of the three stocks may be good targets for exploration.

Mesozoic plutons in south-central Mojave Desert, Calif.

In the Ord Mountains and Rodman Mountains quadrangles, California, T. W. Dibblee, Jr. (2–64, 3–64) has found at least two major granitic plutons of Mesozoic age. Both are intrusive into Precambrian gneiss and Paleozoic metasedimentary rocks. The older pluton contains deposits of iron ore along pendant margins of Paleozoic metasedimentary rocks; it is intruded by andesitic porphyry that locally contains deposits of copper, gold, tungsten, and molybdenum. These rocks are invaded by the younger pluton of Cretaceous age, which is unaltered and nearly devoid of metallic mineral deposits.

CENOZOIC VOLCANISM

Source of some exotic blocks in Keetley Volcanics, northern Utah

Mapping by M. D. Crittenden, Jr., near the center of the Keetley volcanic field, between Park City and Kamas, Utah, reveals what appears to be the top of a shallow porphyritic intrusive bounded by rectilinear faults and cutting both basement rocks of Triassic and Jurassic age and bedded andesitic volcanic rocks. The relations suggest that the faulted roof of an igneous mass intruded close to the base of the volcanic rocks, was lifted like a trap door, and then rafted outward in accompanying large-scale volcanic eruptions. Such sites are almost the only possible source for numerous building-size blocks of Nugget Sandstone and quartzite of the Gartra Grit Member of the Ankareh Formation that occur in the Keetley Volcanics between Park City and Wanship. It also suggests that the source of the Keetley Volcanics is in part buried beneath the volcanic field, and not somewhere outside it.

Possible source of rhyolitic lava flows and ash-flow tuffs in west-central Utah

Detailed mapping by H. T. Morris in the northwestern part of the Cherry Creek quadrangle, Utah, has disclosed a vitrophyre dike of rhyolitic composition nearly half a mile wide and more than 2½ miles long that was not recognized prior to the current studies in the area. This dike may be the long-sought eruptive center of extensive flows of rhyolitic lavas and ash-flow tuffs in this part of west-central Utah.

Volcanic units in Esmeralda County, Nev.

Recent studies of Tertiary volcanic rocks in Esmeralda County, Nev., by J. P. Albers show that many of the ash-flow tuffs and flow rocks have the composition of quartz latite, and thus are similar in composition to the plutonic rocks, which are dominantly quartz monzonite. In the Goldfield mining district a number of the volcanic units, including the Vindicator Rhyolite, Kendall Tuff, Morena Rhyolite, dacite vitrophyre, and Meda Rhyolite are now believed to be ash-flow tuffs instead of lava flows. The Meda Rhyolite and the dacite vitrophyre are considered to be parts of the same unit. The Sandstorm Rhyolite, as mapped by Ransome prior to 1909, includes rhyolite flows, ash-flow tuff, and shale.

GEOCHEMICAL EXPLORATION

Geochemical anomalies in northeastern Nevada

R. L. Erickson reports that reconnaissance geochemical sampling in the Pequop Mountains and Wood Hills in northeastern Nevada resulted in discovery of anomalously high metal values in a region generally considered unfavorable for prospecting. Anomalous Pb-Zn-Ag was found along a fault zone in dolomite of Silurian (?) age, and anomalous W-As-Sb probably originated in marble and schist of lower to middle Paleozoic age. Small pods of barite also were discovered at several localities in the range. Mercury, associated with the Pb-Zn-Ag anomaly, appears to increase in concentration vertically. The Guilmette Formation of Devonian age contains more Hg than the underlying base-metal-bearing Silurian dolomite. Thus, strong Hg anomalies with minor amounts of Pb-Zn-Ag in the Guilmette Formation may indicate concealed Pb-Zn-Ag deposits in the underlying Silurian dolomite.

Sampling of bedrock and soil in Stockton district, Utah

R. J. Roberts, E. W. Tooker, and W. J. Moore have collected approximately 1,500 bedrock and soil samples in an area of 4 square miles in the Stockton mining district, Utah. One objective of the study is to establish the distribution of minor elements associated with lead-silver mineralization. The ore bodies of lead and silver are localized at intersections between northwest-trending breccia zones and thin argillaceous limestone units. A compilation of 400 analyses of bedrock from the northern half of the area shows zones of Cu-Mo, Ag-As, and Pb-Zn extending outward from several major fissures. The heavy-metal concentrations of 75 soil samples in the same area are uniformly low, and there is practically no correspondence with the metal zones established from bedrock samples. Both the Stockton deposits and the Bingham copper deposits, 12 miles northeast, occur in the predominantly clastic Bingham sequence of the Oquirrh Formation, as defined by Tooker and Roberts.[46]

GEOPHYSICAL STUDIES

Gravity survey in Carson Sink area, Nevada

Gravity anomalies in the Carson Sink area near Fallon, Nev., indicate that the subsurface bedrock topography is more irregular than the surface topography would suggest, according to R. R. Wahl. Gravity highs in the mountains to the north, west, and southwest of Carson Sink suggest an arcuate structure that could form a transition from northeast-trending anomalies in the northeastern two-thirds of the area to northwest-trending anomalies in the southwestern third of the area. Three gravity lows south of the West Humboldt Range and one gravity low in the Humboldt Sink have closures greater than 15 milligals. The indicated thickness of the valley fill at these localities ranges from 5,000 to 10,000 feet.

Geophysical studies in Safford Valley, Ariz.

Aeromagnetic and gravity studies by G. P. Eaton and G. E. Andreasen in Safford Valley, Ariz. show that the valley fill has a maximum thickness of 3,000 feet, but that the central axis of the valley lies several miles southwest of the present course of the Gila River. The data indicate that the valley is underlain by rocks with properties like those of the Precambrian gneisses and the Upper Cretaceous to lower Tertiary intrusive rocks exposed in the mountains to the southwest. Measurements of bulk density and grain density made on cores from the upper third of the valley fill indicate an average total porosity of 30 percent.

[46] E. W. Tooker, and R. J. Roberts, 1963, Comparison of Oquirrh Formation sections in the northern and central Oquirrh Mountains, Utah: Art. 188 *in* U.S. Geol. Survey Prof. Paper 450-E, p. E32-E36.

COLUMBIA PLATEAU AND SNAKE RIVER PLAIN

OREGON

Basalt extruded along dike swarm

The Picture Gorge Basalt of the Columbia River Group in the Aldrich Mountain quadrangle, Oregon, was extruded along a northwest-trending dike swarm according to T. P. Thayer and C. E. Brown. They have found that the basalt was as much as 6,000 feet thick near the dike swarm, but thinned to 1,500 feet to the west and 2,500 feet to the east. During the extrusion an elongate shield-type domical ridge accumulated to a height of 3,500–4,500 feet above the level of the surrounding plain and was flanked by the accumulating fluvial volcanic debris of the Mascall Formation of late Miocene age. The upper flows of the Picture Gorge Basalt probably intertongued with the sediments of the Mascall Formation, which must have exceeded 4,500 feet in thickness in the Picture Gorge area, about 10 miles to the west.

IDAHO

Buried topographic features interpreted from geophysical data

Evidence for two filled sedimentary depressions and two buried ridges in the eastern Snake River Plain, in the vicinity of the National Reactor Testing Station, Idaho, has been obtained by D. R. Mabey using gravity and aeromagnetic data collected in 1964 in cooperation with the U.S. Atomic Energy Commission. One of these features reported previously (U.S. Geol. Survey, 11–64, p. 109) is a depression filled with a thick sequence of sedimentary and volcanic rocks that is inferred to extend around the east and south sides of the Arco Hills. Another depression extending southwest from Mud Lake is interpreted by G. H. Chase to be a graben. An uplift of pre-Tertiary rocks is inferred to extend east and southeast from Big Southern Butte. A buried extension of the Beaverhead Mountains is suggested in the area of Circular Butte. Although a large amount of relief on the surface of the pre-Tertiary rock beneath the plain is indicated, there is no implication that the basin-range structure in adjoining regions is continuous across the plain.

D. A. Morris reports that the contours of a persistent zone of high permeability that crosses lithologic types appears to reflect the general alinement of the Mud Lake structure, and suggests control by secondary structures such as joint and fracture systems.

PACIFIC COAST REGION

WASHINGTON

Stratigraphy of Anarchist Series of north-central Okanagan Highlands

Four mappable units have been defined by C. D. Rinehart and K. F. Fox in the metamorphic rocks of the Permian Anarchist Series of Daly (1912)[47] in the Loomis area. Although the rocks are metamorphosed in the greenschist facies and are much folded and faulted, they retain enough sedimentary structures to permit determination of order of superposition. From oldest to youngest the units are: (1) interbedded phyllite, slate, and minor limestone; (2) limestone interbedded with substantial amounts of graywacke, slate, and conglomerate, and containing poorly preserved fossils locally near the top; (3) slate and graywacke with prominent and distinctive chert conglomerate; and (4) interbedded greenstone and quartzite. Units 1 and 4 are in general equal to divisions proposed by Waters and Krauskopf.[48] All units are apparently conformable although varied in thickness; aggregate thickness is more than 15,000 feet.

Permian brachiopods in Anarchist Series of northern Washington

A small suite of brachiopods from the Anarchist Series of Daly (1912),[47] Okanogan County, Wash., collected by C. D. Rinehart, includes several Permian forms. Genera identified by J. T. Dutro, Jr., are *Megousia, Yakovlevia* (*Muirwoodia* of earlier usage), *Spiriferina,* and *Rhynchopora.* Poorly preserved pelecypods, gastropods (including *Euphemites*?) and bryozoans complete the fossil assemblage. This collection confirms an earlier tentative Permian assignment by G. H. Girty, based on collections of A. C. Waters.[48] Clearly, Daly's Anarchist Series is at least partly equivalent to the Cache Creek Group of British Columbia.

Upside-down syncline in metamorphic rocks of North Cascades

The discovery of relict graded bedding and flame structure in southwest-dipping schists and gneisses near Holden, by F. W. Cater and C. A. Hopson, has made it possible to show that a large tight antiform on strike to the southeast (Lucerne quadrangle) is really an upside-down syncline.

[47] R. A. Daly, 1912, Geology of the North American Cordillera at the forty-ninth parallel: Canada Geol. Survey Dept. Mines Mem. 38, [1915?], Maps 10–12.

[48] A. C. Waters and K. B. Krauskopf, 1941, Protoclastic border of the Colville batholith: Geol. Soc. America Bull., v. 52, p. 1355–1418.

Age of Vashon Stade and origin of Puget Sound trough in Washington

Two recent papers, one by D. R. Crandell, D. R. Mullineaux, and H. H. Waldron (p. B132–B136) and the other by Mullineaux, Waldron, and Meyer Rubin (4–65) describe results of Pleistocene stratigraphic studies in the Puget Sound lowland, interpreted in the light of radiocarbon age determinations on a variety of materials. A sequence of late interglacial and early Vashon glacial deposits in Seattle indicates that the Puget glacier lobe of Vashon age did not occupy the Seattle area until after 15,000 years ago, several thousand years later than previously believed; the ice retreated from the area by about 13,500 years ago. Distribution of the deposits on both sides of Puget Sound indicates that a deep Puget Sound trough did not exist before the Puget lobe arrived; thus, the trough was eroded wholly by the glacier rather than modified by it from a preexisting valley.

Major tectonic break in northeastern Olympic Mountains

In the Mount Angeles quadrangle, R. W. Tabor and W. C. Cady have found the first evidence of a tectonic break separating lower (?) to middle Eocene mafic volcanic and basaltic clastic sedimentary rocks of the Crescent Formation (which forms the outer volcanic ring of the Olympic Mountains) from the generally slaty core rocks. These core rocks have been referred to, in part, as the Paleocene(?) or lower Eocene Soleduck Formation of Reagan (1909).[49] The Crescent Formation strikes west-northwest, dips steeply north, generally has its top to the north but is locally overturned. The core rocks, characterized by thick-bedded micaceous sandstone, strike more northwesterly and are overturned, chiefly to the northeast, except where involved in a large-scale dextral fold. In the core and converging northwestward with the tectonic break is a marker zone characterized by thin, discontinuous, mafic volcanic rocks and bearing an assemblage of mollusks dated as late Eocene(?) by W. O. Addicott. The tectonic break is marked by sheared-out isoclinal folds and appears to cut out about 12,000 feet of core section; further understanding of relative movement along the break depends on more conclusive dating of the core rocks.

Stratigraphy of Tertiary rocks in southwestern Washington

In the Grays River area, E. W. Wolfe and E. H.

[49] A. B. Reagan, 1909, Some notes on the Olympic Peninsula, Wash.: Kansas Acad. Sci. Trans., v. 22, p. 131–238.

U.S. Geological Survey, 1963, Geological Survey Research 1963, Summary of investigations: U.S. Geol. Survey Prof. Paper 475–A, p. A96.

McKee have mapped a nearly continuous section of marine sedimentary and volcanic rocks ranging in age from middle Eocene to early or middle Miocene and containing possible potential petroleum reservoirs in the upper Eocene and Miocene shallow-water sands. In this section, major volcanic episodes are recorded in the middle Eocene, upper Eocene, and middle(?) Miocene rocks. Heavy-mineral assemblages derived from pre-Tertiary crystalline rocks differ in successive lithologic units and may be useful as stratigraphic markers.

OREGON

Extrusive camptonite in central part of Oregon Coast Range

P. D. Snavely, Jr., has determined that flows and breccias interbedded with upper Eocene marine rocks of the Euchre Mountain quadrangle are of camptonitic composition (barkevikite-augite basalt) and were probably fed by camptonite dikes of the area. Thick sequences of alkalic basalt flows occur in the same stratigraphic position as the camptonite rocks in this part of the Coast Range and suggest that the latter were derived from the same parent magma as the alkalic basalt.

Geology of western Cascade Range

A paper by D. L. Peck and others (2–64) describes Eocene, Oligocene, and Miocene volcanic rocks. The interbedded flows and pyroclastic rocks crop out in an area of about 7,500 square miles, average about 12,000 feet in thickness, and interfinger with marine sedimentary rocks on the west. The volcanic rocks are warped into a series of northeast-trending en echelon folds. Although predominantly basaltic andesite, the rocks range in composition from basalt to rhyodacite, and the origin of sequence can most logically be explained by crystal fractionation of 3 or 4 successive magmas or groups of similar magmas.

CALIFORNIA

KLAMATH MOUNTAINS AND NORTHERN COAST RANGES

Discovery of graptolites in Klamath Mountains

In a recent article, Michael Churkin, Jr. (p. C72–C73), describes graptolites found in shale and siltstone of the Gazelle Formation. These fossils extend the age of the formation downward to include latest Early and Middle Silurian and promise to become a useful stratigraphic tool in this structurally complex area.

Major left-lateral faults in Coast Range in northern California

In the Colyear Springs quadrangle, E. H. Bailey and D. L. Jones have mapped several major faults along the eastern edge of the Klamath Mountain and Coast Range provinces. The northwesterly trending Elder Creek fault marks the northern extent of the Jurassic Knoxville Formation of the Great Valley sequence and has a stratigraphic throw of at least 20,000 feet, probably due to left-lateral movement of even greater magnitude. A parallel fault, 5 miles to the northeast, has similar movement sense and offset of more than a mile. Secondary faults trend northeasterly and have right-lateral separations of comparable magnitude. Renewal of movement on the secondary faults has offset the Pliocene Tehama Formation.

Pennsylvanian metamorphic event in southern Klamath Mountains

As reported in a recent article by M. A. Lanphere and W. P. Irwin (p. D27–D33), potassium-argon ages of hornblende, ranging from 270 to 286, million years, indicate that the Salmon Hornblende Schist was metamorphosed during a hitherto unrecognized Pennsylvanian orogeny rather than during either a pre-Silurian or a Late Jurassic (Nevadan) orogeny. The new age of metamorphism helps explain the paucity of Pennsylvanian sedimentary rocks in the area and indicates that Devonian and Mississippian sedimentary and volcanic rocks to the east, which are chemically similar to the schist, might be the protoliths.

Geologic significance of Franciscan Formation

The Franciscan Formation of the Coast Ranges, long under the scrutiny of California geologists, is described in an exhaustive monograph by E. H. Bailey, W. P. Irwin, and D. L. Jones (3–64). The Franciscan, a eugeosynclinal assemblage of rocks with a known outcrop area of more than 15,000 square miles and an inferred thickness greater than 50,000 feet, is predominantly graywacke with lesser amounts of shale, altered mafic volcanic rocks, chert, minor limestone, and metamorphic rocks; ultramafic rocks are important associates. The age of the Franciscan ranges from Late Jurassic to Late Cretaceous.

The metamorphic rocks are of the zeolite, blueschist, and eclogite facies and crop out both as elongate belts and as isolated tectonic blocks. Pressures for the formation of the blueschists must have exceeded 5 kilobars (greater than 8 kb for the eclogitic rocks), although temperatures were less than 300°C. Local rapid downwarp and accumulations with equally rapid uplift may account for metamorphism in these facies.

The Franciscan rocks are pervasively folded and faulted; structural trends are generally northwest. In the northern Coast Ranges, major faults and serpentine masses separate the Franciscan from its miogeosynclinal equivalent, the Great Valley sequence, to the east; the latter may be thrust westward over the Franciscan rocks. K-feldspar content of the graywackes of the Great Valley sequence increases with a decrease in age, reflecting progressive unroofing of Late Jurassic to mid-Cretaceous Klamath Mountain and Sierra Neveda batholiths. In the southern Coast Ranges, the Franciscan is exposed both to the east of the San Andreas fault, where it occurs chiefly as piercements along the Diablo antiform, and to the west of the Nacimiento fault.

Two types of regional structural terranes are recognized: one has a crystalline basement like the metamorphic and granitoid rocks of the Sierra Nevada; the other, which includes all the Franciscan rocks, has an unknown basement. However, the abundance of ultramafic rocks in the Franciscan plus the lack of sialic crystalline inclusions in the ultramafic rocks indicates that the Franciscan may have been deposited directly on a basaltic crust or on peridotite.

SOUTHERN COAST RANGES

Stratigraphy of Pancho Rico Formation in Salinas Valley

D. L. Durham and W. O. Addicott described the Pliocene Pancho Rico Formation in a recent report.[50] The formation comprises sandy marine strata and interbedded siltstone and shale that generally overlie marine Miocene Monterey Shale and underlie the nonmarine Pliocene and Pleistocene(?) Paso Robles Formation in southern Monterey County. The molluscan fauna, consisting principally of species not previously reported from the area, is correlated with the fauna of the Jacalitos Formation, the traditional lower Pliocene standard of the Pacific coast. The nearshore mollusks of the Pancho Rico include many warm-water types, suggesting a marine climate comparable to that off western Baja California. Faunal distribution suggests that a Pliocene seaway connected the Salinas Valley area with the Santa Maria basin to the southeast.

[50] D. L. Durham, and W. O. Addicott, 1965, Pancho Rico Formation, Salinas Valley, California: U.S. Geol. Survey Prof. Paper 524-A. [In press]

Large fault in southern Salinas Valley

According to D. L. Durham in a recent article (p. D106–D111), the juxtaposition of contrasting units of the upper Miocene and Pliocene Santa Margarita and Pancho Rico Formations brought about by a large fault in the Bradley and Adelaida quadrangles suggests late or post-Pliocene right-lateral displacement of at least 11 miles.

Paleoenvironment of phosphates in Monterey Formation in San Luis Obispo County

Foraminifera of the Monterey Formation at Indian Creek show a marine regression in the middle Miocene (lower and upper Luisian stage of Kleinpell) according to P. J. Smith. The lower 1,000 feet of the formation was deposited at bathyal depths. The water became shallower during deposition of the upper 300 feet at which time an inner continental shelf environment was established, and potentially commercial phosphate was deposited.

New evidence of right-lateral separation along San Andreas fault

According to H. E. Clifton, the distribution, lithologic changes, and structures of basalt flows, and the directional structures of sedimentary rocks, as well as marine-nonmarine facies changes, indicate that there was a west-southwestward regional slope in the vicinity of the southeastern Caliente Range during the middle and late Miocene. The size of granite clasts in a nonmarine pebbly sandstone of probable late Miocene age increases east-northeastward toward the San Andreas fault. Extrapolation of the size increase according to Sternberg's law suggests a source just across the fault in an area now underlain by a thick sequence of middle Miocene deep-water marine sedimentary rocks. The closest granite mass that was exposed during the late Miocene lies 15 miles to the southeast along the fault, indicating at least this amount of right-lateral separation since deposition of the pebbly sandstone.

Décollement structure in Tertiary rocks south of Fox Mountain, Santa Barbara County

Fossil mollusks and corals from graded deep-water marine sedimentary rocks in the Santa Barbara Canyon area indicate that the rocks are middle to late Eocene in age, rather than Cretaceous as hitherto assigned. J. G. Vedder reports that the sequence, which may be more than 15,000 feet thick, forms the north limb of a broad syncline with an axis lying along the north side of Strawberry Peak. South of Fox Mountain and above the homoclinal

Eocene rocks, sedimentary rocks of middle Miocene age chiefly facies within the Monterey Shale are tightly folded. Rocks above and below the contact are jointed, fractured, and contorted, suggesting that the break is a décollement, perhaps related to a low-angle reverse fault dipping northward beneath Fox Mountain.

SIERRA NEVADA

Correlation of aeromagnetic data with major geologic units in central Sierra Nevada

Data from an aeromagnetic survey of a strip across the Sierra Nevada between lat 37° and 37° 15′ N. correlates well with major geologic units according to a preliminary study by H. W. Oliver. Roof pendants of Triassic and Jurassic metavolcanic rocks stand out as magnetic highs of 200–400 gammas, whereas Paleozoic metasedimentary rocks are lows relative to the surrounding granitic rocks. There are a number of examples of association of magnetic anomalies with individual plutons within the batholith, as for example a nearly universal correlation of magnetic lows with various separate plutons of the Cathedral Peak type.

Deformation of Dinkey Creek roof pendant of central Sierra Nevada

Metamorphosed sedimentary rocks in the Dinkey Creek roof pendant exhibit three systems of folds that can be distinguished from one another by their different styles and orientations according to a recent paper by P. C. Bateman and R. W. Kistler. They have shown that minor folds of each system are superimposed on the folds of older sets, indicating that the systems were formed successively and not concurrently. First folds are nearly isoclinal, and before the second deformation their axial surfaces had a strike of about N. 5° E. and a dip of 45° W.; second folds are open and their axial surfaces are vertical and strike N. 15° W.; only locally developed, the third folds also are open, and their axial surfaces are vertical and strike N. 60° W. The folds are continuous across the pendant and are truncated by bounding granitic plutons, indicating that the fold systems were formed before and independently of the emplacement of the plutons. Corresponding fold systems in adjacent pendants and in the south end of the western metamorphic belt suggest that the folds were formed during three periods of regional deformation.

Potassium-argon dating and paleomagnetism of Bishop Tuff

The Bishop Tuff has been redated and studied paleomagnetically, according to a recent paper by G. B. Dalrymple, Allan Cox, and R. R. Doell (6–65). Duplicate potassium-argon analyses on three samples of sanidine, concentrated from primary pumice fragments from widely separated localities, give ages of 0.68, 0.71, and 0.74 million years, respectively. The latter two determinations are on samples from the basal ash fall, and the age of 0.71 m. y. was on a sample from the basal ash where it overlies Sherwin Till. Paleomagnetic studies on 103 oriented samples from 5 widely separated localities suggest that all the sampled outcrops cooled within several centuries or less. All the samples are normally magnetized, and the directions of magnetization from the more consolidated parts of the unit have less scatter than would be produced by geomagnetic secular variation over periods of time ranging from hundreds to thousands of years. Thus the Bishop Tuff probably erupted during a single igneous event about 0.7 m.y. ago, at a time when the earth's magnetic field was normal.

Complex history of Bishop Tuff

M. F. Sheridan, D. F. Crowder, and R. L. Smith have recognized that the Bishop Tuff consists of one ash-flow cooling unit in the west half of the White Mountain Peak quadrangle; they have mapped several lithologies within the tuff. These lithologies represent separate flows, detritus formed during brief erosional intervals, rocks altered by fumaroles, and zones of welding and vapor-phase alteration.

SAN JOAQUIN VALLEY

Stratigraphy of alluvial deposits in southern San Joaquin Valley

The fresh-water-bearing alluvial deposits of Tertiary and Quaternary age in the southern part of the San Joaquin Valley have been divided into three major units by M. G. Croft. Subsurface geologic studies have revealed that the two upper units are comparatively coarser grained than the lowermost unit. The uppermost unit is a veneer, rarely exceeding 60 feet in thickness. Each unit is further subdivided into: (1) oxidized alluvial-fan deposits and (2) reduced flood-plain and deltaic deposits, both of the Sierra Nevada and Coast Range provenances; and (3) flood-basin, lacustrine, and marsh deposits. The two lower units interfinger with eight well-defined lacustrine clay beds. Radiocarbon ages from the middle unit as determined by Meyer Rubin, one from wood collected 3 feet beneath the youngest lacustrine clay bed and one from wood in the upper part of the same clay bed, are 26,780±600 years and 9,040±300 years, respectively. The clay beds probably were deposited in large lakes coeval with glaciation in the Sierra Nevada.

Geophysical studies in San Joaquin Valley

H. W. Oliver suggests that a serpentine body within the granitic basement lies under the Quaternary alluvium near Le Grand; there a magnetic high of about 300 gammas is centered over a gravity low of about 17 milligals. About 10 miles west of Chowchilla, the southern extension of the major magnetic ridge of the Sacramento Valley is expressed with a total relief of about 1,300 gammas and capped with elongate 100–600-gamma anomalies. The extension is coincident with the high gravity axis of the San Joaquin Valley.

Miocene macrofaunal chronology in southeastern San Joaquin Valley

In a recent report, W. O. Addicott (p. C101–C109) described macrofossils representative of the three principal time-stratigraphic divisions of the California Miocene chronology as defined by C. E. Weaver and others.[51] Northeast of Bakersfield, marine mollusks referable to the Vaqueros stage are abundant in the Jewett Silt Member of Diepenbrock (1933)[52] of the Temblor Formation; the Olcese Sand and the Round Mountain Silt, both of Diepenbrock (1933),[52] yield the well-preserved Barker's Ranch fauna, the standard for the Temblor stage. In the northern Tejon Hills near Arvin, the Santa Margarita Formation bears mollusks of the Briones, Cierbo, and Neroly stages.

ALASKA

Figure 4 is an index map of Alaska showing the boundaries of the regions referred to in the following summary of scientific and economic findings of recent geologic and geophysical studies.

NORTHERN ALASKA

Triassic marine ostracodes in Alaska

Triassic marine ostracodes from the Shublik Formation or northeastern Alaska have been identified by I. G. Sohn (1–64). These ostracodes are among the first Triassic marine ostracodes to be recognized on the North American continent. They were collected by E. G. Sable in 1948 and C. L. Whittington in 1952 from a locality on Dodo Creek 2 to 2.3 miles above its junction with the Sadlerochit River. The collections contain the following:

Hungarella sp. or spp.
Paracypris? sp. or spp.
Darwinula? sp.
Steinkerns unident.

Geologic study of Romanzof Mountains

E. G. Sable [53] has made a comprehensive study of the extreme northeastern part of Alaska, between the Jago and Hulahula Rivers. Rocks of sedimentary and of igneous origins are well represented. Sedimentary and metasedimentary bedrock in the area ranges in age from Middle Devonian(?) to Cretaceous. The sedimentary rocks include carbonate rocks, shale, siltstone, sandstone, and conglomerate; and graywacke, phyllite, argillite, and slate make up the metasedimentary rocks. Unconsolidated deposits include glacial drift representing five advances of the ice, and recent alluvial and colluvial deposits.

Intrusive rocks, mostly quartz monzonite to granite in composition, are exposed in a batholith and a stock in the Romanzof Mountains. Contacts with Neruokpuk Formation (Upper(?) Devonian or older) are mostly abrupt, concordant to cross-cutting, and locally adjoin tactite and hornfels. Contacts with Kekiktuk Conglomerate (Upper(?) Devonian or Mississippian) are gradational through a schistose zone. The lead-alpha age of zircon appears to be Late Devonian; the potassium-argon age of biotite, which is Cretaceous, may reflect updating by later reheating. Field age relationships are inconclusive but suggest pre-Kayak(?) (Late Devonian) granite emplacement. A late Paleozoic age is suggested for mafic volcanic(?) rocks and greenstone dikes in the granitic rocks and the Neruokpuk Formation.

The structural grain in the area strikes east-northeast, and south-dipping elements are common. Structures include relatively broad folds, small tight folds, and at least one large-scale overthrust fault. Although Mesozoic and Tertiary deformational features are dominant in northern Alaska, the Romanzof area may have been part of a Late Devonian orogenic belt continuous with one in northern Canada.

The mineral potential of the area is as yet largely unknown. Minor amounts of metallic sulfides and oxides are present in granite and Neruokpuk Formation rocks. Analyses of stream-silt samples suggest

[51] C. E. Weaver and others, 1944, Correlation of the marine Cenozoic formations of western North America: Geol. Soc. America Bull., v. 55, p. 569–598.

[52] Alex Diepenbrock, 1933, Mount Poso oil field: California Oil Fields, Div. Oil and Gas, v. 19, no. 2, p. 4–35.

[53] E. G. Sable, 1965, Geology of the Romanzof Mountains, Brooks Range, northeastern Alaska: U.S. Geol. Survey open-file report, 218 p., 7 pls., 23 figs., Aug. 10, 1965.

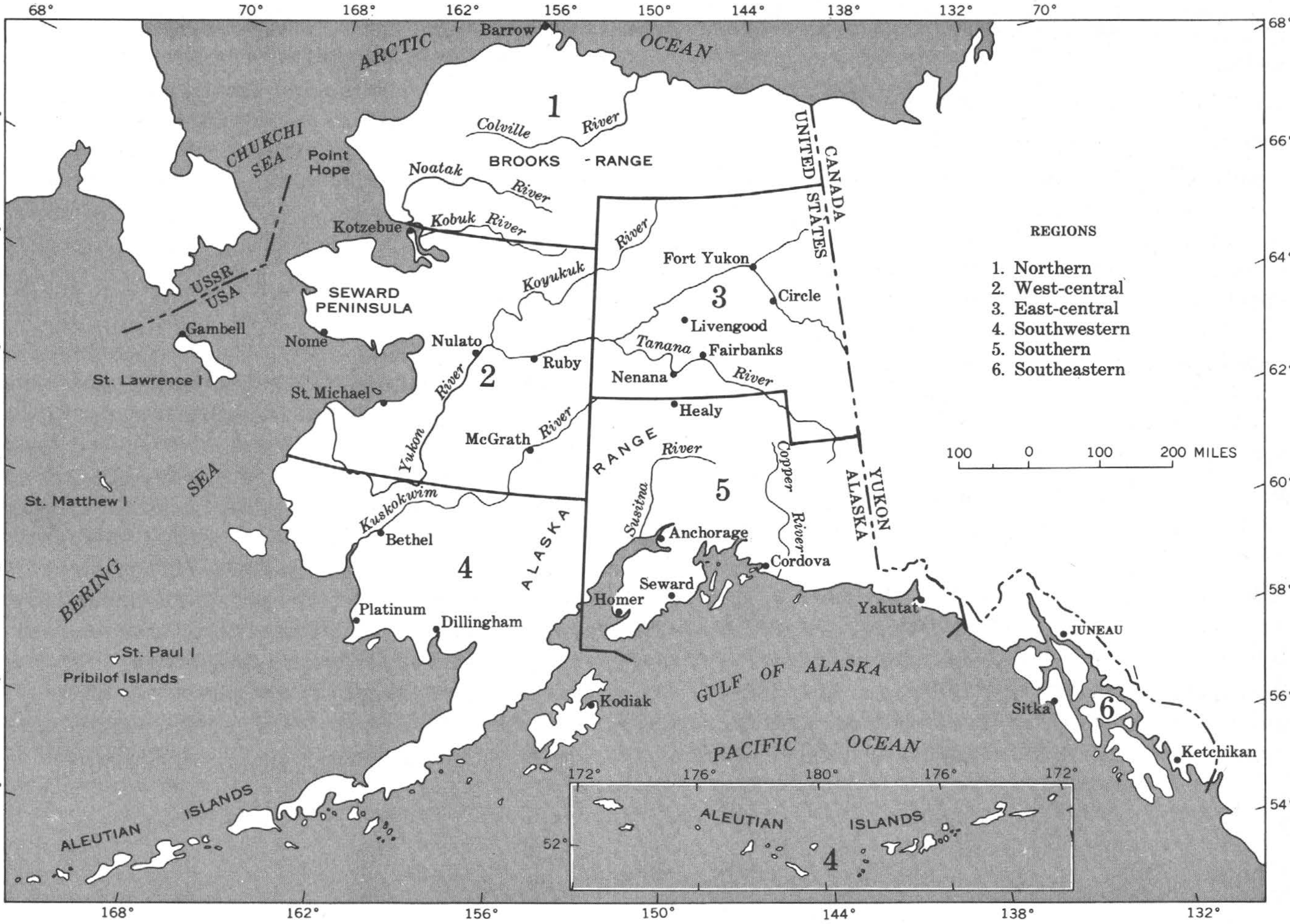

FIGURE 4.—Index map of Alaska, showing boundaries of regions referred to in discussion of Alaska geology.

the possibility of tin and beryllium potential. The Shublik Formation (Lower to Upper Triassic) contains rock phosphate.

New analysis of geologic structure of northern Alaska

E. H. Lathram has compiled a new geologic map of northern Alaska; his interpretation and analysis of the regional geology of this area suggest the following conclusions:

(1) Mid-Early Cretaceous intrabasin thrusting and gravity sliding, and Laramide thrusting, previously proposed in more restricted mapping, seem to have been widespread. The disposition of extensive thrust sheets transported along major thrust zones controls the present distribution of formations and facies throughout the Brooks Range and southern foothills of the range.

(2) Laramide detachment thrusts marked at depth by seismic discontinuities probably underlie the folds of the northern foothills of the Brooks Range. The thrusts appear not to crop out, except perhaps along the faulted axes of northerly asymmetrical anticlines. These folds are the focus of past and current drilling.

(3) The thrusting has displaced the entire Brooks Range northward toward the Barrow high and the Romanzof Mountains.

These factors should be considered in exploration and in evaluation of the petroleum potential of northern Alaska.

Age of Ordovician and Devonian mafic rocks in northern Alaska

A single potassium-argon age of 475 million years, determined by M. A. Lanphere on hornblende from volcanic rocks in the Doonerak Mountain area of the south-central part of the Brooks Range, suggests that these volcanic rocks and associated slate and shale may be Ordovician rather than Devonian as had been previously thought.[54] Another single po-

[54] W. P. Brosgé and H. N. Reiser, 1960, Progress map of the geology of the Wiseman quadrangle, Alaska: U.S. Geol. Survey open-file report, 2 sheets.

tassium-argon age determination by Lanphere, a 373-m.y. age for hornblende from a mafic intrusive in the same area, substantiates the Devonian age of some intrusives in the Brooks Range.

Lisburne Hills largely fault sheets

Geologic mapping by I. L. Tailleur in the Point Hope quadrangle has disclosed that the central and northern Lisburne Hills consist of a number of broad, gently to moderately deformed allochthonous sheets of upper Paleozoic and Mesozoic predominantly marine sedimentary rocks. This structure is similar to that of the southern Lisburne Hills.[55] The apparent lower sheet is tightly crumpled and imbricately faulted along the acruate east front of the hills, a structure analogous to that in the toe of a mud slide. Little stratigraphic order could be made of the graywacke and mudstone that underlie the area east of the Lisburne Hills; rocks probably equivalent to the Fortress Mountain Formation (Lower Cretaceous) predominate. Near the Lisburne Hills the graywacke and mudstone overlie fine-grained rocks of earliest Cretaceous age. To the east, along the upper Ipewik River, similar rocks overlie clay shales of Jurassic and Early Cretaceous age.

New interpretation of Tiglukpuk Formation

Analysis of new paleontologic and field-stratigraphic data by D. L. Jones and Arthur Grantz (2–64) indicates that the Tiglukpuk Formation of northern Alaska is a tectonic assemblage rather than a stratigraphic formation, and that it consists of thrust slices of a Jurassic and Early Cretaceous geosyncline. This interpretation of the Tiglukpuk has major implications for any appraisal of the tectonics or petroleum possibilities of northern Alaska. Reconstruction of the paleogeography of the Tiglukpuk assemblage suggests that: (1) the Jurassic and Early Cretaceous geosyncline of northern Alaska was compound, with a flysch and chert-ophiolite basin to the south, a medial intrabasin high, and a starved, pyritic-shale basin to the north; (2) this compound geosyncline was disrupted by pre-Albian thrusting (gravity sliding?) which produced the Tiglukpuk assemblage; (3) the petroleum possibilities of the newly recognized mid-basin high should be tested, for such highs are a favorable habitat for petroleum. The area underlain by this high is potentially very large.

[55] R. H. Campbell, 1961, Thrust faults in the southern Lisburne Hills, northwest Alaska: Art. 354 *in* U.S. Geol. Survey Prof. Paper 424-D, p. D194–196.

WEST-CENTRAL ALASKA

Newly described marine sediments

Previously undescribed marine sediments in the White Mountain, McGrath area of Alaska have been reported by C. L. Sainsbury (p. C91–C95). Carbonate and clastic rocks about 5,000 feet thick have been dated as Middle(?) Ordovician and Devonian(?). These rocks are in fault contact with 8,100 feet of quartz conglomerate of Cretaceous(?) age. The rocks are unmetamorphosed and may be important in petroleum exploration.

Former warmer climate in Kotzebue Sound area

On the basis of (1) a buried discontinuous wood-rich zone in a now treeless area; (2) fossil beaver habitation beyond their modern range; (3) evidence for a period when ice wedges melted; and (4) buried soils well below the top of permafrost in the Kotzebue Sound-Seward Peninsula area, D. S. McCulloch and D. M. Hopkins postulate a postglacial warm interval of climate in northwestern Alaska. Nine radiocarbon dates suggest that this warm interval started about 10,000 years ago and ended 7,000 years ago.

Two large plutons mapped in Hughes quadrangle

In the Hughes quadrangle in west-central Alaska W. W. Patton, Jr., and T. P. Miller completed 1:250,000-scale mapping of two quartz monzonite-granodiorite plutons whose extent and lithologic character were previously poorly known. One pluton, about 100 square miles in area, is located in the Indian Mountains in the southeastern part of the quadrangle; the other, covering about 150 square miles, forms the core of the Zane Hills along the western margin of the quadrangle. Both plutons are of economic significance as they appear to be genetically related to important gold-placer deposits. Placer deposits within and along the eastern margin of the Indian Mountains pluton have been mined extensively in recent years, although present activity is limited to a small sluicing operation at the head of the Indian River. In the Zane Hills the Fairbanks Exploration Co. currently operates a small dredge on Bear Creek, along the eastern edge of the pluton.

Radiometric dating of deposits of Yarmouth age

The first radiometric ages of deposits of Yarmouth age on the North American continent have been obtained by D. S. McCulloch, D. W. Taylor, and Meyer Rubin (1–65). A fossil marine mollusk fauna containing more than 60 species has been collected from Yarmouth-age sediments of a marine delta which crops out on the Baldwin Peninsula and north shore of Hotham Inlet in the Kotzebue Sound area. These delta sediments are stratigraphically well dated because they lie directly under Illinoian-age till, and have been deformed, presumably by the Illinoian glacier. Thorium-uranium age determinations on these shells indicate ages of 170,000 ± 17,000 years and 175,000 ± 16,000 years.

EAST-CENTRAL ALASKA

Area of Cambrian rocks expanded

Abundant specimens of *Oldhamia,* a fan-shaped trace fossil of probable Cambrian age, were found by Michael Churkin, Jr., and E. E. Brabb (p. D120–D124) in the Charley River quadrangle. The distinctive unit in which *Oldhamia* occurs is correlated with a nearby archaeocyathid-bearing unit of Early Cambrian age, thereby doubling the areal extent of known Cambrian rocks in east-central Alaska. This find, and two other occurrences of *Oldhamia*—in the Mt. Schwatka area [56] and in the Crazy Mountains—about 175 and 100 miles, respectively, west of the Charley River occurrence, suggests that rocks of Cambrian age extend to the central interior of Alaska.

Stratigraphy along Porcupine River

An almost complete section of the stratigraphic sequence from the upper part of the Ordovician through the Lower(?) Permian, on the Porcupine River, is provided by correlation of measured sections and by tentative age assignments of large fossil collections. W. P. Brosgé, H. N. Reiser, Michael Churkin, Jr., and J. T. Dutro, Jr., found that the pre-Permian part of this sequence differs greatly from that in the Brooks Range. It is only about 2,500 to 3,000 feet thick and consists mostly of shallow-water and near-shore shelf deposits. Ordovician, Silurian, and Devonian rocks are mainly fine-grained limestone and dolomite and coral-reef talus; Upper Silurian graptolitic shale a few hundred feet thick is a notable exception. Mississippian rocks are mainly shale (locally plant bearing) and shaly to sandy limestone and sandstone, and are only about 500 feet thick. Unconformities occur at the base of the Devonian and of the Mississippian. The Mississippian rocks in turn are overlain unconformably by 200 to 400 feet of Permian limestone and local basal sandstone, succeeded by a shale unit faunally similar to the Siksikpuk Formation and lithically similar to the southern calcareous Lower(?) Permian facies of the eastern Brooks Range.

[56] J. B. Mertie, Jr., 1937, The Yukon-Tanana region Alaska: U.S. Geol. Survey Bull. 872, 276 p., 15 pls.

Paleozoic stratigraphy of Tatonduk–Nation Rivers area

A sequence of Ordovician, Silurian, and Devonian rocks has been mapped in the vicinity of the Alaska-Yukon Territory border by E. E. Brabb and Michael Churkin, Jr., (1–64, 1–65; Churkin and Brabb, 1–65). The lower half of the sequence, 400 to 900 feet of Ordovician and Silurian graptolitic shale and chert, is considered to be a southwestern extension of the Road River Formation from the Richardson Mountains of the Yukon Territory. The McCann Hill Chert of Middle and Late Devonian age is 200 to 800 feet thick, consists mostly of chert and siliceous shale, and overlies the Road River Formation. In the vicinity of Jones Ridge, only 7 miles north of exposures of Road River Formation, a pure limestone section contains shelly faunas contemporaneous with the Road River Formation and McCann Hill Chert. A rapid change in conditions of sedimentation is suggested. The Tatonduk-Nation Rivers area seems to lie in a transitional zone between an early Paleozoic eugeosynclinal belt south of the Yukon River and a contemporaneous miogeosynclinal belt along the Porcupine River.

SOUTHWESTERN ALASKA

Sedimentary rocks on Nunivak Island

Geologic mapping by J. M. Hoare and W. H. Condon on Nunivak Island, in western Alaska, confirmed the occurrence of sedimentary rocks reported by Dall.[57] Several hundred feet of gently dipping sandstone and siltstone are exposed in cliffs surrounding an unnamed bay 7 miles west of Mikoryuk and underlie an area of about 25 square miles south of the bay. The rocks are largely nonmarine and contain good plant fossils identified by Jack Wolfe as being of Albian and Cenomanian age. Much of the sandstone here and on the west side of Nelson Island is laumontitized and probably forms a southwestern extension of the belt of laumontitized sediments which crops out north of the Yukon River, 150 miles farther northeast (J. M. Hoare, W. H. Condon, and W. W. Patton, Jr., 1–64). A second area of largely fine-grained sedimentary rocks was found on Nunivak Island on the south shore of Nash Harbor.

Jurassic age of Cook Inlet plutonism

R. L. Detterman, B. L. Reed, and M. A. Lanphere (p. D16–D21) have reported on the age of the plutonism in the Cook Inlet region of Alaska. Potassium-argon dates of hornblende and biotite indicate

[57] W. H. Dall and G. D. Harris, 1892, Correlation paper—Neocene: U.S. Geol. Survey Bull. 84, p. 245.

an age of 170 million years for emplacement of the Aleutian Range batholith; geologic mapping suggests emplacement between Early Jurassic and early Middle Jurassic time. The age of this batholith agrees closely with the age of the Kosina batholith in the Talkeetna Mountains about 250 miles to the northeast.

SOUTHERN ALASKA

Jarosite in McCarthy quadrangle

Hydrothermal alteration products, chiefly jarosite not previously reported, were found by E. M. MacKevett, Jr., near the Kennecott copper mines. The principal occurrence of the alteration products lies between the Jumbo and Erie mines in a zone that is several hundred feet long and as much as 10 feet thick. This zone consists mainly of a pulverulent mass of jarosite and clay minerals. It occurs along the contact between Nikolai Greenstone and the Chitistone Limestone in an area that was underlain by some of the large chalcocite lodes and at the approximate stratigraphic horizon of the lodes. Jarosite was also identified from altered limestone collected on the Bonanza mine dump and from altered limestone that was collected about 20 miles southeast of the Kennecott mines. Alteration zones of similar appearance have been noted elsewhere in the southern Wrangell Mountains. This alteration is significant because it should shed some light on the genesis of the Kennecott-type copper lodes, as well as provide target areas for exploration.

Brooks Lake and Naptowne glaciations correlated

R. L. Detterman, B. L. Reed, and Meyer Rubin (p. D34–D36) have established a minimum date of 8,520 ± 350 years B. P., based on radiocarbon analysis, for the second major advance of the Brooks Lake (Wisconsin age) Glaciation in the Iliamna Lake area. Four, or possibly five major advances are recorded by moraines in this area. These probably correspond to the Naptowne (Wisconsin age) Glaciation described by Karlstrom.[58]

Tertiary fossils from Prince William Sound region

Marine megafossils collected by George Plafker from the greenstone unit of the Orca Group (previously considered Late Cretaceous(?) in age) near Galena Bay shed new light on the stratigraphy of the Prince William Sound region. The fossils include two species each of diagnostic crabs and Pelecypoda which, according to F. S. MacNeil, are of middle to late Eocene age. They indicate that at least part of the Orca Group is of early Tertiary age, and that the Yakataga geosyncline, of the Gulf of Alaska Tertiary province, extended into the Prince William Sound region during Eocene time.

Continental Shelf of Alaska

Preliminary synthesis of the Quaternary history of the Gulf of Alaska Continental Shelf by T. N. V. Karlstrom suggests that the topography of the shelf, a series of arcuate ridges and associated deep troughs, represents the effects of deposition and excavation by Pleistocene glaciers. These glaciers repeatedly coalesced to form continuous piedmont ice sheets along the coast. The outermost submerged ridges near the shelf margin adjoining the Aleutian Trench are in line with, or rim, the seaward ends of the troughs that deepen landward to maximum depths between 100 and 400 fathoms. By this interpretation, during both the Knik (pre-classical Wisconsin age) and the Naptowne (classical Wisconsin age) maxima the shelf was virtually covered by ice except for Middleton and Chirikof Islands and a few isolated emergent areas near Kodiak Island. During the earlier, more extensive glaciations—Mount Susitna (Nebraskan? age), Caribou Hills (Kansan? age), and Eklutna (Illinoian? age)—the shelf was probably completely covered by ice that fronted in the ocean throughout the region.

SOUTHEASTERN ALASKA

Igneous activity in Chatham Straight area dated

Interpretation and analysis of more than 30 isotopic ages and of the Tertiary sedimentary and volcanic record in the area comprising eastern Chichagof Island, Baranof Island, and Admiralty Island have been completed by R. A. Loney and D. A. Brew. The results show that at least three post-Paleozoic igneous events have occurred and that probably 10,000 feet of vertical movement has taken place on the Chatham Strait and nearby faults since an Eocene intrusive event. An intrusion of Oligocene age heals a subsidiary fault zone, indicating that some of the vertical and accompanying lateral displacements occurred during the Eocene-Oligocene interval.

Isostatic rebound at Glacier Bay

E. H. Lathram estimates that a load of at least 3,000 feet of ice has been removed from the Glacier Bay area since 1790. Calculations by E. H. Lathram and M. D. Crittenden, Jr., using the time constants derived by Crittenden for unloading of Lake Bonne-

[58] T. N. V. Karlstrom, 1957, Tentative correlation of Alaskan glacial sequence, 1956: Science, v. 125, no. 3237, p. 73–74.

ville, Utah, indicate that this negative load should result in uplift on the order of 5 centimeters per year. Tidal-gauge records of the U.S. Coast and Geodetic Survey are reported (S. D. Hicks, written communication, 1964) to substantiate this result.

PUERTO RICO

Hydrogeologic map of Puerto Rico

A hydrogeologic map of Puerto Rico and adjacent islands was prepared by R. P. Briggs and J. P. Akers for inclusion in a report by D. B. Bogart, Ted Arnow, and J. W. Crooks (1–64) summarizing data and preliminary conclusions resulting from the first years of water resources investigations carried on in cooperation with the Commonwealth of Puerto Rico. The hydrogeologic map, which is also available as a Geological Survey Hydrologic Investigations Atlas (R. P. Briggs and J. P. Akers, 3–65), is a multicolor edition of the previously published provisional geologic map of Puerto Rico and adjacent islands, with surface and ground-water data added.

Variations with time in composition of volcanic rocks

Results of field and chemical studies by A. E. Nelson (1–65) suggests that from Early Cretaceous (Albian) to latest Cretaceous (Maestrichtian) time there was a generally continuous variation from basic to acidic in the chemical composition of volcanic effusions in the north-central part of the volcanic-plutonic core of Puerto Rico. Rocks of basaltic composition were deposited first; these were followed by andesite lavas and finally by pyroclastic rocks ranging in composition from dacite to rhyolite.

Wrench-fault deformation has resulted in large displacements

In the course of geologic mapping of the Aguas Buenas and Naranjito quadrangles and adjacent areas in northeastern Puerto Rico, M. H. Pease, Jr., has found evidence for regional large-scale wrench-fault deformation resulting from northeast-southwest compression. Although the displaced and deformed strata in all but a few instances reflect left-lateral movements, individual faults within the zone record both left-lateral and right-lateral movements. Summation of individual fault displacements shows an overall left-lateral displacement of possibly 20 kilometers. Right-lateral displacement on at least one fault within the zone may be as much as 15 km, and on one left-lateral wrench fault displacement may approach 30 km.

Isla Mona caves and guano deposits

During the late 19th and early 20th centuries, phosphatic guano was mined from caves is Isla Mona, a limestone island located in the Mona Passage, halfway between Puerto Rico and Hispaniola. Conflicting reports on the quantity of guano remaining caused the Puerto Rico Economic Development Administration to request an examination of these deposits and their geological environment by R. P. Briggs and V. M. Seiders. The largest cave systems were found in the base of the gently southwesterly-dipping Lirio Limestone adjacent to the cliffs that form most of the periphery of the island. Although rooms more than 40 meters across are common near the cliffs, large cave development only rarely extends more than 100 meters in from the cliff face; beyond this, passages pinch out. Higher in the Lirio Limestone, smaller ramifying caves occur, but no large rooms were found. No extensive cave systems were found in the dolomitic Isla Mona Limestone that underlies the Lirio. It is apparent that the zone where the lower part of the Lirio Limestone intersects the cliffs was the most favorable cave-forming locale on Isla Mona. On the basis of traverses through all large and many small cave areas, it is estimated that the total of guano originally available probably did not greatly exceed 100,000 short tons, about half of which has been removed in mining. The remaining guano is chiefly in relatively thin deposits in the more remote cave areas, or in isolated thicker pods left unmined for reasons not known.

Thickness of south-coast middle Tertiary basin from gravity studies

A detailed gravity survey of the south-coast middle Tertiary sedimentary basin has been completed by a geophysical party led by Andrew Griscom in cooperation with the Puerto Rico Economic Development Administration. Interpretation of the data indicates that the maximum nearshore thickness of rocks of Oligocene and younger ages probably does not exceed 7,000 feet (about 2,100 meters). Also indicated by the gravity data are major folds and a major fault trending N. 80° W. from Salinas for about 20 kilometers.

Aeromagnetic map of Puerto Rico Trench analyzed

Andrew Griscom, and W. H. Geddes, U.S. Naval Oceanographic Office, have completed analysis of an aeromagnetic map of the Puerto Rico Trench. The data indicate that there is probably no major fault on the north side of the trench. On the south side of the trench a major fault (possibly a thrust fault) with a vertical separation of at least 2 kilometers is buried beneath the middle Tertiary and younger sedimentary rocks which extend north of Puerto Rico.

ANTARCTICA

The U.S. Geological Survey in cooperation with the U.S. Antarctic Research Program (USARP) of the National Science Foundation is continuing reconnaissance geologic mapping and topical studies in several localities in the western half of Antarctica (fig. 5). Topographic and planimetric base maps are compiled by the Topographic Division of the Geological Survey. (See section "Topographic Surveys and Mapping, Mapping in Antarctica.") Logistical support for the Antarctic field projects is provided by the U.S. Navy Operation Deep Freeze; helicopters and their crews for the northeastern Victoria Land study were provided by the U.S. Army.

Reconnaissance of northeastern Victoria Land

A geologic reconnaissance of 20,000 square miles of largely unexplored mountains was carried out by Warren Hamilton, D. F. Crowder, and D. A. Coates. The work was done by helicopter from Hallett Station and extended inland 200 miles, almost to the Rennick Glacier. The mainland consists largely of low-grade but highly deformed metagraywacke and metasiltstone, intruded by discordant plutons of granodiorite. The clastic metasedimentary rocks lie unconformably upon high-grade schist and gneiss, which are exposed in the southwest and are probably products of Cambrian or Early Ordovician metamorphism. The metasedimentary rocks are overlain by little-deformed and unmetamorphosed Beacon Sandstone (Carboniferous? or Permian) intruded by diabase sills (Jurassic?). Deposition, deformation, and metamorphism of the clastic rocks as well as intrusion of the granodiorite thus occurred within the Ordovician to Carboniferous interval. Long high peninsulas along the Ross Sea coast (Adare, Hallett, and Daniell Peninsulas and Coulman Island) consist of Tertiary submarine lavas and breccias capped by Quaternary subaerial lavas. The marine rocks have been raised as high as 6,000 feet above sea level on faults bounding the peninsulas on the east (seaward) side. The Paleozoic rocks of the mainland have also been uplifted by faulting along the coast.

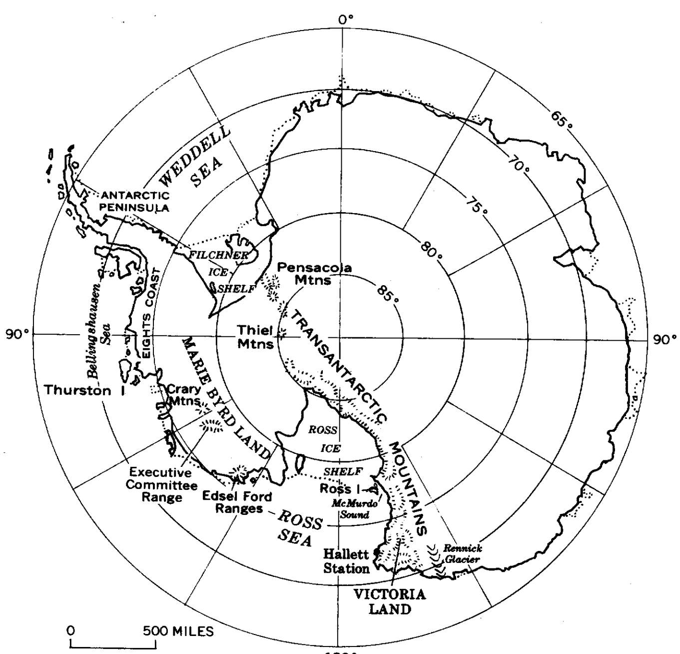

FIGURE 5.—Index map of Antarctica.

Ages of orogeny in the Pensacola Mountains

The stratigraphy and structure of the Pensacola Mountains (D. L. Schmidt, P. L. Williams, W. H. Nelson, and J. R. Ege, p. D112–D119; and 1–64), indicate that they are part of the fold-mountain belt coincident with the modern Transantarctic Mountains. In turn, the tectonic history of the Transantarctic fold-mountain belt is made clearer by the vivid details of geology found in the Pensacola Mountains.

Three major orogenies are recorded in the Pensacola Mountains: (1) During a late Precambrian orogeny, eugeosynclinal slate and graywacke rocks were folded. (2) During a post-Middle Cambrian orogeny (age based on fossils identified by A. R. Palmer), platform sediments consisting of limestone, clastic rocks, and volcanic sedimentary rocks were folded, and granitic magma intruded the Cambrian and older rocks. Granitic plutonic rocks associated with this event are isotopically dated by Rb-Sr whole-rock analysis as 510 ± 30 million years by Z. E. Peterman. (3) During a late Paleozoic orogeny, continental and shallow marine clastic sediments of uncertain age were folded. These clastic sedimentary rocks are younger than the granitic pluton but are probably older than flat-lying sedimentary rocks of Permian age (J. M. Schopf).[59] Biotite from the granitic pluton is dated isotopically by the K-Ar method as 265 ± 13 million years, or latest Carboniferous, by R. F. Marvin. This biotite

[59] J. M. Schopf, 1964, Paleobotanical studies in Antarctica [abs.]: Geol. Soc. America Spec. Paper 76, p. 317.

age presumably dates some part of the late Paleozoic orogeny.

Comagmatic igneous suites of Marie Byrd Land

Current petrochemical studies suggest the existence of at least four comagmatic suites in the Eights Coast–Marie Byrd Land region of West Antarctica according to E. L. Boudette and A. A. Drake, Jr. The oldest suite (1) consists of hypersthene-bearing rocks, including leuco-augite norite on the Eights Coast and quartz gabbro in the Executive Committee Range, types formerly known only in East Antarctica. These rocks have not been dated isotopically but are almost certainly pre-Mesozoic. The next younger suite of rocks (2) forms the Eights Coast–Thurston Island composite batholith, the characteristic rock of which is quartz diorite. Rocks of suite 2 have been recognized along the Eights Coast, where they are intrusive into rocks of suite 1. The rocks are at least 150 million years old, as determined by lead-alpha dating of zircon, but contain biotite that is thought to have crystallized during the Late Cretaceous to early Tertiary Andean orogeny, according to A. A. Drake, Jr., T. W. Stern, and H. H. Thomas (p. C50–C53). Suite 3 consists of an extensive series of intrusive and effusive rocks characterized by alkalic granite and rhyolite; a shallow intrusive member of suite 3 intrudes the quartz diorite of suite 2 along the Eights Coast. Members of suite 3 in the Executive Committee Range consist of folded rhyolitic volcanic rocks. Suite 3 is probably contemporaneous with Andean plutonic rocks of the Antarctic Peninsula that have an unknown structural relationship. The youngest suite (4) is volcanic, probably of Quaternary age, and consists of basalt and a distinctive anorthoclase-bearing trachyte. These rocks previously have been considered to form a single effusive suite with the felsic volcanic rocks of suite 3. They are, however, not deformed and are petrochemically quite different. Deformation of the volcanic rocks of suite 3 observed by E. L. Boudette probably antedates the accumulation of the undeformed Quaternary volcanic rocks of suite 4.

Rubidium-strontium age studies by R. F. Marvin, F. G. Walthall, and C. E. Hedge on alkaline biotite granite collected by Boudette in the Clark Mountains of the Edsel Ford Ranges suggests a Late Jurassic or Early Cretaceous age for the granite-rhyolite suite.

Anorthoclase trachyte of Ross Sea–Marie Byrd Land region

Anorthoclase has been identified in trachyte from the Crary Mountains in Marie Bryd Land and on Ross Island by E. L. Boudette and A. B. Ford. Two samples of anorthoclase, $Or_{15.7}Ab_{74.2}An_{10.1}$ and $Or_{16.8}Ab_{64.8}An_{18.4}$, respectively, are homogeneous, transitional in structural state, and triclinic optically negative. The trachyte containing the mineral is the most distinctive rock in the Quaternary alkaline basalt-trachyte suite of the Ross Sea–Marie Byrd Land region. Feldspars of comparable chemical composition and petrographic relations in the Executive Committee Range and on Ross Island that are reported in the literature as plagioclase are probably also anorthoclase. The structural parameters of the anorthoclase from the Crary Mountains and Ross Island were calculated by computer methods in conjunction with work in progress by D. B. Stewart and T. L. Wright. (See the section "Mineralogic Studies and Crystal Chemistry, Physical Properties of the Feldspars.")

GEOLOGIC AND HYDROLOGIC INVESTIGATIONS IN OTHER COUNTRIES

For more than two decades the U.S. Geological Survey has assisted newly developing nations in appraising their natural resources, establishing geologic and hydrologic agencies, and training earth scientists. During this time the Geological Survey has sent 513 members of its staff on investigations and training assignments to 68 countries, and has provided specialized training in the United States for 787 scientists from 70 nations. Under the auspices of the U.S. Agency for International Development and other national and international agencies, this assistance has helped to strengthen earth sciences programs or establish vigorous national geologic and hydrologic organizations in 24 countries.

In fiscal year 1965, the U.S. Geological Survey assigned 128 specialists to 21 countries at the request of other governments, and provided or helped arrange academic or on-the-job training in the United States for 92 geologists and engineers from other countries. The accompanying table summarizes the type of assistance given to each country by the Geological Survey during the year.

Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1965

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity [1]	Number	Field of training
Latin America					
Argentina	None			1	Geology and mining (drilling).
				1	Geochemical research.
Bolivia	1	Chemist	A, C	None	
	3	Geologist			
Brazil	9	do	A, C, D	2	Topographic mapping.
	1	Cartographer		1	Photogeology.
	1	Topographic engineer		1	Laboratory analysis and techniques.
	3	Hydrogeologist		1	Ground-water hydrology.
	3	Hydraulic engineer (SW)		1	Stratigraphy and sedimentology.
				3	General geology.
				1	Vertebrate paleontology.
				1	Mineral exploration.
				1	Ground-water exploration techniques.
British Guiana	None			1	Cartography and map preparation.
Chile	None			1	Engineering geology.
Colombia	5	Geologist	A	None	
Costa Rica	3	do	B		
	5	Geophysicist			
	1	Hydrogeologist			
	1	Chemist			
Panama	1	Hydrogeologist	C	1	Igneous geology.
Venezuela	None			2	Surface-water techniques.
Africa					
Dahomey	2	Geologist	B	None	
Egypt	4	Hydrogeologist	A	4	Ground-water hydrology.
	1	Hydrochemist			
Ghana	None			1	Water development (drilling).
Liberia	5	Geologist	A, C	2	Mineral exploration.
	1	Administrative officer		1	Surface-water techniques.
Libya	1	Hydrogeologist	B	1	Ground-water hydrology.
Morocco	None			1	Mining engineering.
Nigeria	4	Hydrogeologist	A	None	
	2	Hydraulic engineer (SW)			
Sudan	None			1	Ground-water development.
				1	Photogrammetry and cartography.
				1	Rural water development.
				2	Ground-water hydrology.
Tunisia	1	Hydrogeologist	B	None	

Technical assistance to other countries provided by the U.S. Geological Survey during fiscal year 1965—Continued

Country	USGS specialists assigned to other countries			Scientists from other countries trained in the United States	
	Number	Type	Type of activity [1]	Number	Field of training
Near East–South Asia					
Afghanistan	2	Hydraulic engineer (SW)	A	1	Photogrammetry and cartography.
				1	Hydrologic engineering.
				1	Cartography.
				1	Hydrology.
				2	Topography.
				1	Aerial photography and mapping.
				1	Surface-water hydrology.
India	None			3	Exploration and development of uranium ores.
				1	Seismic instrumentation.
Iran	None			1	Spectrography.
Jordan	1	Hydrogeologist	C	1	Well drilling; engineering.
				1	Hydrometry.
				1	Hydrology.
				1	Surface-water hydrology.
Nepal	2	Hydraulic engineer (SW)	B	None	
Pakistan	15	Geologist	A	1	Geochemistry; mineralogy; petrology.
	1	Geophysicist		2	Mineral exploration and development.
	1	Geochemist		7	Hydrology.
	2	Photogrammetrist		2	Geologic administration.
	2	Cartographer		1	Economic geology.
	1	Publications specialist		1	Laboratory techniques and analysis.
	1	Driller		3	Ground-water hydrology.
	2	Program assistant			
	5	Hydrogeologist			
Saudi Arabia	9	Geologist	A	1	Mass spectrometry.
	1	Geochemist			
	5	Geophysicist			
	1	Chemist			
	1	Geodesist			
	1	Photogrammetrist			
	1	Topographic engineer			
	1	Program assistant			
	2	Driller			
	1	Transportation officer			
	1	Cartographer			
Turkey	2	Geologist	C	1	Mapping; photogrammetry.
	2	Hydrogeologist		1	Topography.
				4	Water resources and ground-water engineering.
Far East					
Indonesia	1	Geologist	B	1	General geology; geophysics.
				1	Ground-water investigations (drilling).
				1	General geology.
				1	Mining geology.
Japan	None			1	Geothermal conditions in the United States.
				1	Ash-flow tuffs.
				1	Sedimentary petrology.
Korea	1	Hydrogeologist	C	1	Geophysics; geochemical exploration.
				1	Structural geology.
Philippines	2	Geologist	A	2	Ground-water hydrology.
				1	Engineering geology.
				1	Stratigraphy; sedimentation; petroleum geology.
Thailand	3	Geologist	A, B	1	Hydrometeorology.
				1	Ground-water hydrology.

[1] A, broad program of advisory help in institutional development and direct help in resources appraisal; B, limited program of advisory help, training, and investigation in selected fields; C, advisory help or consultation, with specific training or investigational activity; D, geological education and assistance to universities.

An important result of the U.S. Geological Survey assistance to the newly developing countries has been the publication of maps and reports needed for exploration, development, and use of resources. National geologic maps or summary resources reports have been issued for Ecuador, Indonesia, Libya, Pakistan, Peru, the Philippine Islands, Saudi Arabia, and Thailand. Many hundreds of publications resulting from the work of U.S. Geological Survey specialists and their counterparts have been issued by host-country agencies. In addition, 685 documents, resulting from technical assistance activities, have been published or issued by the Geological Survey. A new bibliography and index of the documents issued by the Geological Survey has been compiled and is now being prepared for publication.

SUMMARY BY COUNTRIES

AFGHANISTAN

Surface-water studies of watersheds expanded

The program of surface-water investigations was markedly expanded to include the Ghazni, Tarnak, Khash, Farah, Adraskand, and Hari Rud watersheds, in addition to existing streamflow, meteorologic, and sediment studies currently in progress in the Helmand River basin. Also, plans were made for an expanded network of snow courses as well as extensive snow surveys in the Helmand basin to improve the accuracy of forecasting for spring runoff. The U.S. Geological Survey team is making a study of recorded data on flood duration, low flow, and flood frequency in the Helmand River basin to assist the Helmand Valley Authority and the Water and Soils Survey Authority in water-management problems.

BOLIVIA

Economic geology

A report titled "The Gold Placer Deposits at the Foot of the Eastern Cordillera of Bolivia," by H. G. Freydanck has been issued by the Bolivian National Department of Geology as a result of the geologic-assistance program sponsored by the U.S. Agency for International Development. The report describes the distribution and extent of gold-bearing gravels in eastern Bolivia, which constitute one of Bolivia's major resources. Geologic exploration necessary to the study was supervised by C. M. Tschanz and J. F. Seitz, of the U.S. Geological Survey. Analyses of samples from mine dumps in the Berenguela district, taken by C. M. Tschanz and analyzed by the Bolivian National Department of Geology, show 3 to 5 percent cadmium. Zinc concentrates produced as a by-product in Comibol's Telamayo mill contain between 0.8 to 1.4 percent cadmium.

BRAZIL

Iron

J. V. N. Dorr 2d (1–64, 2–65) discusses, in two companion papers, the nature, origin, and reserves of the supergene and hypogene iron ores, respectively, in Minas Gerais, Brazil. Each type resulted from enrichment of the original sedimentary iron formation (itabirite). Weathering related to peneplains, the highest and oldest of which may date back to Early Cretaceous time, removed quartz and hydrated some of the iron oxides to form "intermediate" ores averaging about 63 percent iron. Known reserves are estimated at 600 million tons. High-temperature solutions removed quartz and redistributed iron from the itabirite in favorable structural settings, (chiefly in folds, in a few places in thrust-fault zones, and in some localities, where regional linear structures steepen abruptly) to form masses of hard, nearly pure hematite averaging more than 68 percent iron. The ore textures and distribution of the deposits show clearly that enrichment occurred at depth during a severe Precambrian orogeny. Some individual deposits contain more than 400 million tons; in all, 40 ore bodies and closely associated groups of ore bodies are known.

Copper

Geologic and geochemical studies of the Caraiba copper deposit and the surrounding Curaca River basin area by R. W. Lewis, Jr., in cooperation with S. Q. Mattoso, R. J. P. Brim, and A. M. Santos, of the University of Bahia and the Departamento Nacional da Produção Mineral, have indicated the possibility of additional copper deposits near Caraiba in north-central Bahia. Geologic mapping and soil sampling revealed a potential cupriferous belt in highly metamorphosed early Precambrian rocks between Santa Rosa and Carrio Vermelho, 70 kilometers to the north. Copper mineralization is found in ultramafic intrusions, which are localized in small folds of an anticlinal arch. The cupriferous ultramafic masses are marked by well-defined copper anomalies in both soil and vegetation. These anomalies are from 50 to 100 times the background value for copper and are also associated with anomalies indicative of accumulation of copper of possible economic value.

Hydrology

In northeastern Brazil, hydrogeologic work that has been completed indicates favorable ground-water conditions in the alluvial aquifer of the Capibaribe basin, Pernambuco; in the limestone aquifer of the Irecé area; and in alluvial sandstone and limestone aquifers of the Acu Valley, Rio Grande, do Norte.

L. C. Davis reports that measurements to evaluate the flow of the Amazon River during the period July 1963 to August 1964 showed an average rate of flow to the ocean of 7 million cubic feet per second. A maximum rate of flow measured at Obidos, Brazil, was found to be close to 12 million cfs, a figure considerably higher than that previously estimated (8.5 million cfs reported in Professional Paper 501–A).

Geologic-education campaign completed

In December 1964 the Brazilian "Campanha para a Formação de Geologos" (Campaign for the Education of Geologists), begun in 1957, was completed. This project, carried out in cooperation with the Brazilian Ministry of Education and Culture under the sponsorship of the U.S. Agency for International Development, succeeded in firmly establishing or improving modern programs of geologic education at Brazilian universities at São Paulo, Porto Alegre, and Rio de Janeiro. Substantial assistance was also given universities at Ouro Preto, Recife, and Salvador. The U.S. Geological Survey furnished more than 30 man-years of teaching assistance over the 7-year period.

This cooperative effort has culminated in the establishment of six dispersed centers of geologic research. Faculties practicing research, and students working on their senior theses, currently are producing more geologic mapping than Brazil has enjoyed in many years, and the various journals inaugurated by these schools are greatly increasing the production of geologic literature and maps. This information already is being put to use, particularly in the compilation of national maps. Coupling this school effort with the very large absolute increase in geologic manpower, Brazil now is in a good position to staff its research organizations and to begin a significant attack on the enormous problem of studying the geology and resources of the largest nation in Latin America.

D. J. Cederstrom, U.S. Geological Survey, working with the Government of Brazil, has prepared a textbook of ground-water hydrology in the Portuguese language. It is entitled "Aqua Subterranea, Uma Introdução." D. F. Campbell, of the U.S. Geological Survey, and John Milne Albuquerque Forman, of the Brazilian National School of Geology, collaborated on the preparation of a syllabus of economic geology which has been published in Portuguese in two volumes by the National School of Geology at Rio de Janeiro, Brazil.

CHILE

Potassium-argon ages of ash flows in Chile

According to a report by R. J. Dingman (p. C63–C67), of the U.S. Geological Survey, ash-flow sheets that cover many thousands of square kilometers in Chile, Bolivia, Argentina, and southern Peru are also one of the most extensive ash-flow series in the world. On the basis of potassium-argon determinations on biotite from four rock samples, the ash-flow sheets in the San Pedro de Atacama region of northern Chile are of Pliocene age. The ages determined range from 4.7 to 7.6 million years.

Mineralogy of Chilean nitrates

Mineralogic studies of the Chilean nitrate deposits by George Ericksen and Mary Mrose have brought to light the fact that potassium, which is of economic importance, occurs mainly as niter (KNO_3) and as a probably new sulfate mineral, on which further work is being done. Though earlier workers have inferred from chemical data that the potassium is in sylvite, polyhalite, and aphthitalite, these minerals have never been identified in the nitrate ores, and thus probably are rare or absent. Darapskite, $Na_3(NO_3)(SO_4)\cdot H_2O$, is a widespread and relatively abundant constituent of the nitrate ores, including those high in chloride as well as those high in sulfate. Three new minerals, in addition to the potassium-bearing sulfate mineral, have been tentatively identified; two are chromate-bearing salts, and the other is a sulfate.

COLOMBIA

Economic geology

Preliminary investigations on the western side of the large Cretaceous geosyncline show phosphate rock possibilities in grades of 15 to 20 percent phosphate. The favorable geologic environment gives some hope for the possible discovery of higher grade material.

Stratigraphic studies of evaporites in the Cretaceous section near Bogotá indicate a large potential for rock salt and possibly some gypsum-anhydrite, potash, and pyrite.

The Colombian National Geological Service is mapping on a 1:25,000 scale in 4 areas selected for their mineral and metal possibilities. A systematic geologic study of mineral and metal resources of Colombia is being carried out by 22–25 Colombian geologists of the National Geological Service assisted by E. M. Irving, L. V. Blade, Tomas Feininger, and Donald McLaughlin, all of the U.S. Geological Survey.

GHANA

Ground water

H. E. Gill, reporting on a ground-water reconnaissance in the Republic of Ghana, has defined four major geohydrologic provinces. In three of these, known as the Precambrian, Voltaian, and Coastal Block Fault provinces, large or even adequate ground-water supplies are difficult to develop from the prevailing crystalline and consolidated sedimentary rocks. However, small supplies (from a few gallons to 50 gallons per minute) of good quality water can generally be obtained in most parts from carefully located wells. Water supplies ranging from 50 to 200 gpm or more can be obtained from wells tapping sand and soft limestone aquifers of the Coastal Plain province near the Gulf of Guinea.

INDONESIA

Engineering geology

At the close of the year, R. J. Anderson completed manuscripts, in cooperation with counterparts, for publication by the Indonesian Geological Survey on engineering-geology investigations within the Tjimanuk River Project, West Java. A report on recent faulting at the Eretan damsite, West Java, and ground-water studies near Makassar, South Sulawesi are in preparation.

A geologic map of Indonesia, on a scale of 1:2,000,000, is in process of editing, with expectation of publication late in 1965.

NIGERIA

Ground water

William Ogilbee, working in the Sokoto artesian basin in northwestern Nigeria, put down 20 test wells ranging from 300 to 2,000 feet in depth and found high-pressure artesian aquifers in an area of about 2,700 square miles in the western part of the basin. Flowing wells have already markedly contributed to the economy of the region.

In the Chad basin, northeast Nigeria, 200 small-diameter artesian wells drilled in an area covering 13,500 square miles found sufficient water for the requirements of the seminomadic people and their cattle.

PAKISTAN

Geologic map of Pakistan printed

A new geologic map of Pakistan at a scale of 1:2,000,000, compiled by R. O. Jackson, U.S. Geological Survey, and M. Abu Bakr, Geological Survey of Pakistan, was published in December 1964 by the Geological Survey of Pakistan at the Survey of Pakistan press, Rawalpindi. This multicolor, 36- by 45-inch map was prepared as part of the Mineral Exploration and Development Program sponsored by the Government of Pakistan and the U.S. Agency for International Development. Cartographic work was done by the Geological Survey of Pakistan, Quetta, under the overall supervision of J. T. Heare. M. E. Hanes assisted with the final preparation of the map and the supervision of the press run. This map is based on the compilation of all available published and unpublished geologic data as of late 1964, as well as upon results of several special projects undertaken jointly by members of the Geological Survey of Pakistan and the U.S. Geological Survey.

Lithofacies maps of Paleocene rocks in West Pakistan

C. R. Meissner, with Habib-ur-Rahman of the Geological Survey of Pakistan, prepared an isopach map and three lithofacies maps of the Paleocene rocks of West Pakistan. This study reveals the distribution, thickness, and lithology of the Paleocene rocks, economically significant as oil-bearing rocks of the Potwar Plateau in northern West Pakistan. The Paleocene reservoir rocks in the oil fields of the Potwar Plateau have a thickness of 300 to 500 feet or more, a clastic ratio of 1 or less, and a sand-shale ratio of less than 1:4. On the basis of these criteria for finding oil-reservoir rock in Paleocene sediments, the isopach and lithofacies maps show 3 areas where exploration might be concentrated: 2 in the Sulaiman Range and 1 in the northwestern Kirthar Range.

Interpretation of Himalayan structures

The Tertiary mountain system of West Pakistan has a series of four parallel reentrants and intervening festoonlike arcs in the mountain front. Analyses of metamorphic structures in the easternmost reentrant (Hazara-Kashmir), which were mapped by T. W. Offield, J. A. Calkins, and geologists of the Geological Survey of Pakistan, suggest that the structures were formed by large-scale southward movement of rock masses on either side of a zone in which such movement was impeded, probably by a subsurface buttress. Geophysical surveys and deep drilling reveal the presence of basement highs alined with the axial zones of the reentrant. Regional southward thrusts have not yet been identified in Pakistan, but the festoonlike configuration of the ranges and the coincidence of basement highs with at least two of the reentrants lead to the speculation that the whole system formed as a result of regional supracrustal movement southward around deeply buried basement promontories.

Chromite studies in Hindubagh district

Mapping by Roger van Vloten of the ultramafic intrusive at a scale of 1:12,000 is nearing completion in the eastern part of the district. A special study of serpentine diapirs indicated by circular lineaments within the mass was undertaken over the entire extension of the complex. Intensive sampling of the rocks at some diapir structures has shown areas of low-density rocks entirely surrounded by high-density rocks, supporting the idea that the circular lineaments are caused by upward thrust of lighter masses. A contour map showing variation in iron content of chromite samples over the entire complex indicates low-iron anomalies at several diapir sites. Evidence is accumulating that the complex is stratified, but disturbed by faulting and diapirism, especially in the eastern part.

To search the areas of circular lineaments for chromite ore bodies, gravity surveys were completed in 11 areas by Abul Farah, Arif Raza Jafree, and Mohammad Ali Mirza, of the Geological Survey of Pakistan, assisted by W. J. Dempsey. Several gravity anomalies were delineated, and two of them were drilled to a depth of 300 feet. No chromite ore bodies were found. Regional gravity surveys conducted across and around the mass seem to indicate that there is a subsurface extension of the ultramafic rocks to the south and to the east tens of miles beyond the outcrop limit, and that the body or bodies thin to the northwest in conformity with the observed regional stratification.

Mineral investigations in Chagai district

R. H. Nagell, with counterpart geologists of the Geological Survey of Pakistan, completed a study of mineralization in the Chagai district including occurrences of copper, iron, and travertine ornamental-stone deposits in the Chagai Hills. The only deposits of economic importance in this area are those of travertine. Deposits of sulfur and travertine and showings of copper, iron, lead, and zinc in other parts of the Chagai district were also investigated. Of these, the Koh-i-Sultan Volcano sulfur deposit, which produced about 500 tons of sulfur per month, and the Zard Kan, Mashki Chah, and Zeh travertine deposits are the most important economically.

Mineralogic studies of Ziarat laterite

J. J. Matzko, S. A. Stanin, and counterpart geologists of the Geological Survey of Pakistan completed a study on ferruginous "laterite" at the base of the Tertiary sequence near Ziarat, West Pakistan. Detailed mineralogic work was done on samples from 4 stratigraphic sequences of which 3 sections contain intervals 2, 6, and 19 feet thick that are sufficiently high in alumina to justify further investigation for possible bauxite ore. Aluminum in the samples is found in the oxide minerals—boehmite, diaspore, and gibbsite. The laterite has a high iron content which is derived from admixed hematite.

Corrosion and encrustation mechanisms in water supplies of Indus Plain

Preliminary field and laboratory studies of ground water in reclamation projects of the Indus Plain, West Pakistan, by F. E. Clarke and I. K. Barnes, showed that both corrosion and mineral encrustation are contributing to early failure of dewatering wells. Thermodynamic studies showed the waters to be supersaturated in respect to calcite, siderite, and iron hydroxides, so that some encrustation probably is inevitable, even in the absence of pumping. Bacterial sulfate reduction and action of long-line differential-aeration cells appear to be the major corrosion processes, and there is evidence that corrosion is intensifying mineral-encrustation processes. Tentative recommendations for corrective action already are being implemented. New construction materials have been selected to minimize corrosion and bonding of encrustants; design changes are being made to eliminate long-line currents, and sterilization treatments are being applied.

PANAMA

Hydrology

As part of a hydrogeologic training program for the Panamanian Institute de Recursos Hidraulicos y Electrificacion, R. J. Dingman made a brief ground-water reconnaissance of the Azuero Peninsula of south-central Panama. The work points up favorable possibilities for the development of moderate- to large-capacity wells tapping conglomerate or sandstone aquifers near La Flora and Las Flores. In areas favorable for ground-water development, additional detailed geologic mapping and also some seismic surveys are needed because of the complexity of the geologic framework.

PHILIPPINE ISLANDS

Geologic map of Philippine Islands

A new geologic map of the Philippine Islands on a scale of 1:1,000,000 was published as a joint project of the Philippine Government, private petroleum companies, the U.S. Agency for International Development, and the U.S. Geological Survey. Data were assembled and compiled by Oscar Crispin and Froilan Geruasio of the Philippine Bureau of Mines. Twenty-three rock units that represent geologic periods from the pre-Jurassic basement complex to Recent deposits are shown. Among the major features illustrated on the map are the large northwest-trending faults that cut almost every large island except Palawan. Major volcanic activity may be related to the faulting. Flows, tuffs, and ash cover large areas; further structural studies are needed for purposes of correlation. The geologic settings of deposits of copper, chromium, iron, and nickel are shown.

Chromite in Zambales Mountain Range

Detailed mapping by Darwin Rossman and geologists of the Philippine Bureau of Mines in the Zambales Mountain Range covered much of the gabbro-peridotite complex. Five 1:50,000-scale quadrangle sheets show that at least 90 percent of the chromite occurs in 2 dunite zones in peridotite near gabbro contacts in the vicinity of the Acoje and Masinloc mines. Layering in the rocks cannot be used as a reliable guide to prospecting. A report on this work is in preparation.

Santa Inez iron-ore deposit replaces limestone

Geological mapping and exploration by Laurence Andrews and geologists of the Philippine Bureau of Mines show that the Santa Inez iron-ore deposit is a replacement of a limestone member of a roof pendant of Eocene to Miocene sedimentary rocks that are surrounded by intrusive diorite and skarn. To date, 30 to 50 million tons of magnetite, with associated pyrite, pyrrhotite, and chalcopyrite, are indicated. A progress report by Andrews and Leonardo Antonio, Philippine Bureau of Mines, is in preparation.

Mineral-resource maps

Seven mineral-resource maps have been published to show the location of major mineral deposits. No geology is shown.

SAUDI ARABIA

Geochemical prospecting of wadi sediments

Geochemical prospecting for copper, zinc, molybdenum, and tungsten in igneous and metamorphic rocks along the mountains of the Red Sea scarp and the interior plateau of the Precambrian shield in Saudi Arabia by P. K. Theobald, Jr., and C. E. Thompson has disclosed that anomalous concentrations of these metals in wadi; sediments are greatly diluted by wind-transported debris. The mean grain size of the diluting debris is about 100 to 150 mesh. Debris coarser than about 80 mesh does not seem to have travelled far by air. The geochemical effects of dilution of wadi sand by major air transport of fine-grained particles from one drainage area to another can be largely avoided by using coarse fractions of sediment for analysis. Tests for copper in 103 pairs of samples of sand disclosed copper in the range of 20 to 6,000 parts per million in the −30 to +80 mesh used in this study and 20 to 1,500 ppm in the −80 mesh ordinarily used in such investigations. At one locality represented by 91 pairs of samples, the amount of copper in the coarse fraction ranged from <10 to 600 ppm, with 75 ppm being the anomalous threshold; and the zinc ranged from 25 to 800 ppm, with 100 ppm and above considered anomalous. In the fine fraction the copper content ranged from 10 to 225 ppm, with the median at 75 ppm; and zinc ranged from <25 ppm to 300 ppm, with the median at 50 ppm.

Two other metal-bearing media seem useful for reconnaissance sampling: heavy minerals, and magnetite. Heavy minerals from wadi sand show distinctive variations in molybdenum and tungsten content, and magnetite displays strong regional variations in copper, zinc, and molybdenum. Both of these media are present as alluvial trains in the wadis, in contrast to the normal bulk wadi sediment, in which anomalous concentrations of metals are abruptly masked by local sediment.

Mineral discoveries in Arabian Shield

Scheelite and powellite were found for the first time in Saudi Arabia by C. S. Hummel, J. W. Mytton, and J. W. Whitlow, working with Hashim Hakim and A. O. Ankary, of the Directorate General of Mineral Resources, Royal Saudi Arabian Government. Scores of small occurrences, none of which are minable, were discovered in a area 20 to 30 miles wide extending southward about 125 miles from Bishah to Khamis Mushayt. Both minerals occur as disseminated grains in the youngest of the Precambrian granites. They are also disseminated in long, narrow roof pendants of greenstone, chlorite schist, and hornblende schist in the granite, but have not been observed in pendants of marble. Quartz veins and pegmatite dikes of simple mineral composition apparently genetically related to the granite also contain scheelite and powellite.

A possible occurrence of wolframite related to the youngest Precambrian granite has been discovered by Richard Goldsmith, of the U.S. Geological Survey, and Jameel Kouther, counterpart geologist with the Directorate General of Mineral Resources. Heavy-mineral concentrates from the area give no reaction for scheelite by ultraviolet light, but have been found by C. E. Thompson to contain as much as 1,500 parts per million of tungsten. This tungsten is tentatively attributed to wolframite in the concentrates.

Beryl has been discovered in Saudi Arabia by J. W. Whitlow at one locality about 125 miles northeast of Bishah. The beryl is in pegmatite in massive red granite of Precambrian age. The beryl-bearing pegmatite is roughly circular in plan and about 300 feet across. Field estimates indicate less than 0.1 percent beryl in the pegmatite.

Jasperoid in barite veins near Rabagh

An unusual dark-golden-brown jasperoid was found by D. A. Brobst in pods in the thicker parts of barite veins in fractures of the Red Sea rift system about 60 miles north of Jidda, Saudi Arabia. The barite deposits are about 20 miles inland from Rabagh on the Red Sea. The suite of trace elements in the jasperoid includes Be, Pb, Y, B, Mn, Fe, and Cu in anomalous amounts and some Mg and Mo. Field observations and the suite of trace elements detected suggest that the jasperoid is primary. Further investigations of the area containing barite veins may determine if these veins are part of a large zoned ore deposit.

Experimental electromagnetic investigations

Fractures and joint surfaces in zones of alteration and country rock around many of the ancient mines in Saudi Arabia are coated with copper carbonate. The prevalence of this coating in certain places suggests that massive sulfides may be associated with the gold and silver deposits that were formerly worked in these mines. Experimental electromagnetic investigations conducted over five ancient mines by W. E. Davis and R. V. Allen with N. N. Akhrass and R. H. Zeldan, of the Directorate General of Mineral Resources, Royal Saudi Arabian Government, revealed only small anomalies associated with the zones of alteration. This lack of a pronounced electromagnetic response over the zones indicates that the copper minerals are too disseminated to be detected readily by electromagnetic methods, and that the induced-polarization technique, which is generally more successful in searching for disseminated sulfide deposits, should be used in conjunction with other geophysical prospecting methods.

Topographic field operations

Gene Harbert, James Crabtree, and Thomas Taylor began the organization of a Topographic Mapping Section within the Ministry of Petroleum and Mineral Resources for the immediate purpose of furnishing topographic services to the joint minerals-exploration project. The topographic facility thus established is to continue its work after the close of its present duties as a part of the national mapping effort, with strong emphasis on the specific mapping needs of the Ministry.

A photogrammetric and photographic laboratory has been constructed and equipped in Jidda. Tidal observations of the Red Sea have been observed and recorded at Jidda for most of 1 year. Fieldwork to establish a basic geodetic net of vertical and horizontal control for western Arabia has been started.

THAILAND

Economic geology

In the Loei-Chiengkarn area, northeast Thailand, preliminary examinations of 47 iron, base-metal, manganese, gold, barite, and gypsum prospects were completed. Detailed geologic, geochemical, and geophysical studies were conducted at 3 iron and 2 base-metal prospects. Diamond drilling is in progress at two iron deposits. At one of these, approximately 7 million tons of iron ore is indicated.

At Chaiyaphum, northeast Thailand, geologic investigation and diamond drilling of a salt deposit resulted in the development of 600 million tons of halite in a bedded deposit. Additional reserves are inferred.

Three economic-geology reports entitled "The Mae Jong Manganese Deposit of Northwestern Thailand," by L. S. Gardner and R. C. Smith; "Fluorspar Deposits of Thailand," by L. S. Gardner and R. C. Smith; and "Phichit Gypsum Deposits, Central Thailand," by L. S. Gardner were submitted to the Royal Thai Department of Mineral Resources for publication in Thailand.

INTERNATIONAL COOPERATION WITHIN THE REGION OF THE CENTRAL TREATY ORGANIZATION

CENTO symposia on geologic studies

In continuation of activities concerned with coordinating geologic information and geologic investigations within the framework of the CENTO countries, representatives of the U.S. Geological Survey took part in symposia and field trips and were actively engaged in several joint CENTO working groups on various geologic studies and problems common to Pakistan, Iran, and Turkey. A noteworthy contribution of the Second Field Symposium of the CENTO Stratigraphic Working Group resulted in a report entitled "Correlation of the Cretaceous System in Turkey, Iran, and Pakistan." This report describes the five major tectonic zones that extend through these CENTO countries and the Cretaceous System as developed distinctively in each of these zones. Summaries of the historical geology of the Cretaceous System and of the main mineral and mineral-fuel deposits within this system are given for each country. The important mineral and mineral-fuel deposits are copper, chromite, iron, phosphate, and petroleum in Turkey; chromite, lead-zinc, iron, phosphate, and petroleum in Iran; and chromite, laterite, and iron in Pakistan. Attempts are made to relate known mineral deposits to their habitat so that mineral exploration in one country may be aided by the knowledge gained in others.

COOPERATIVE SHORT-TERM TOPICAL INVESTIGATIONS ABROAD

AUSTRALIA

Geomorphology

S. A. Schumm made preliminary studies of modern and ancient river channels located on the Riverine Plains of New South Wales and found that the morphology and sediment characteristics of the Murrumbidgee River differ markedly from those of the ancient aggraded channels still exposed on the surface of the alluvial plain. The modern river has adjusted its gradient for a major decrease in sediment load and changed discharge by a modification of the shape and sinuosity of the channel rather than by incision into the alluvial plain.

GREENLAND

Radiocarbon age determination of turf in Ivar Baardsons Glacier

Turf collected by J. H. Hartshorn and J. P. Schafer that is interbedded with ablation moraine deposits of the large moraine at the end of the Ivar Baardsons Glacier, Schuchert Dal, East Greenland, has a radiocarbon age of 1,490 ± 250 years (W–1378) according to Meyer Rubin. This moraine and similar moraines of nearby glaciers were formed by an ice advance that began much earlier than the advance of the 17th to 19th centuries, to which recent moraines around the North Atlantic have generally been attributed. The turf is from a locality nearly free of vegetation and underlain by dead ice; thus, there is a question as to the conditions under which the formerly continuous cover of vegetation was established. A colder climate presumably would be less favorable for the spread of vegetation; a warmer climate probably would produce accelerated melting of the buried dead ice and severe instability of the ground surface.

Meyer Rubin found the C^{14} age of pelecypod shells from marine deposits 43–50 meters above the present sea level at a nearby locality to be 7,900 ± 350 years (W–1381). This approximately fits Washburn and Stuivers'[60] curve of uplift in Kong Oscars Fjord 80 kilometers to the north.

ICELAND

Ten Pleistocene glaciations recognized in Iceland

Stratigraphic, paleomagnetic, and paleontologic studies in Iceland suggest that the "standard" glacial sequences of the Alps, northwestern Europe, and north-central United States may record half or less of the glacial and interglacial episodes that took place during the Plestocene Epoch. D. M. Hopkins, of the U.S. Geological Survey, and Thorleifur Kinorason, of the University Research Institute of Iceland, demonstrated a record of at least 10 and perhaps 12 distinct glaciations, separated from one another by interglacial episodes, in the course of their study during the summer of 1964 of Tjornes, northern Iceland, and of several other Icelandic localities. The tillites and intervening lavas upon which this record is based all lie above and are younger than marine beds containing an early Pleistocene marine fauna, according to determinations by P. F. MacNeil, paleontologist, U.S. Geological Survey. Paleomagnetic studies by R. R. Doell, of the U.S. Geological Survey, suggest, though, that the oldest glaciation took place at least 1.8 million years ago and more likely on the order of 2.5 to 3.0 million years ago.

JAPAN

Geophysics

Geophysical investigations of calderas in Japan are currently being made by H. R. Blank, Jr., U.S. Geological Survey, in cooperation with Japanese scientists. Airborne-magnetometer surveys of 18 calderas or calderalike structures were carried out during the first half of 1964 by a private company under contract to the U.S. Geological Survey. The data show that many of the calderas are located on discontinuities in the Neogene or pre-Neogene basement complex; in the case of Aso caldera, the discontinuity is interpreted as a west-northwest-trending fault which controls the alinement of post-caldera central cones. A number of volcanic bodies in the target areas produce negative aeromagnetic anomalies, owing to hitherto unsuspected inverse polarization. The polarization is attributed to

[60] A. L. Washburn and Minze Stuiver; 1962. Radiocarbon-dated postglacial delevelling in northeast Greenland: Arctic, v. 15, p. 66–73.

thermal remanant magnetization acquired during the most recent geomagnetic field reversal, thus setting a minimum age for the bodies. Active solfatara fields also produce negative anomalies in some cases. The latter may result from destruction of magnetic minerals by chemical action, together with elevation of temperatures above the Curie point, in zones located within strongly positive regions.

LEEWARD ISLANDS

Paleontology

The first fossil evidence for an Eocene age of deposits on the island of Nevis, Leeward Islands, was obtained from a sample submitted by C. O. Hutton, of Stanford University. The sample, consisting of limestone fragments, contained two species of large Forminifera identified as *Amphistegina* cf. *A. parvula* and *Helicostegina* cf. *H. dimorpha*. Both of these species are common in middle Eocene deposits elsewhere in the Caribbean and Gulf coast regions.

SINO-SOVIET GEOLOGIC STUDIES

Sino-Soviet geologic atlases

The U.S. Geological Survey, on the behalf of Advanced Research Projects Agency, is preparing interpretative geologic atlases of the Sino-Soviet bloc countries that will provide the basic earth-science information needed to discriminate between manmade and natural seismic events in these countries. One atlas, at a scale of 1:5,000,000, will depict the general geologic environment, major tectonic features, thickness of the crust, and regional seismic characteristics of these countries. Final completion is expected by September 1965. Another atlas, at a scale of 1:250,000, is being prepared of the Ulan-Ude quadrangle, a highly seismic area in southeastern Russia that is potentially suitable for underground clandestine nuclear tests. This atlas is the first of a series in which the basic information on the geology, hydrology, soils, vegetation, and cultural features of such areas is being compiled and its potential for nuclear test sites evaluated. The Ulan-Ude quadrangle will be completed by June 1965.

Coal production in China and USSR analyzed

According to a study by Paul Averitt,[61] coal production in Communist China increased very rapidly in the 1957–60 period as a result of technical help from the USSR. As a result, production exceeded that of the United States in 1960. Following 1960, the production dropped markedly, probably as a result of withdrawal of the technical assistance. Coal production in the USSR increased rapidly in the period 1952–58, and was leveled off since then, probably as a result of the increased production and use of petroleum.

[61] Paul Averitt, 1964, Recent trends in coal production in the USSR and Communist China: Econ. Geology, v. 59, no. 2, p. 323–324.

STUDY OF IRAZU VOLCANO, COSTA RICA

Major damage to the economy of Costa Rica was caused by the 1963–65 eruption of Irazú Volcano (figs. 6 and 7). The erupted ash ruined pastures in the heart of the nation's dairy country, destroyed a substantial part of the coffee crop, and contaminated the water supply of major cities. Accelerated runoff of rainwater from the ash-covered slopes of the volcano caused destructive floods, mudflows, and landslides.

In March 1964, a 2-year project for the scientific study of Irazú and other active Costa Rican volcanoes (fig. 8) was started jointly by the Government of Costa Rica and by the Agency for International Development, U.S. Department of State. Two Costa Rican and two U.S. Geological Survey geologists were assigned to the project full time; more than a dozen others provided part-time assistance on different phases of investigation. The work was begun as an emergency project under the direction of K. J. Murata. H. R. Blank, Jr., established gravity stations. H. H. Waldron was

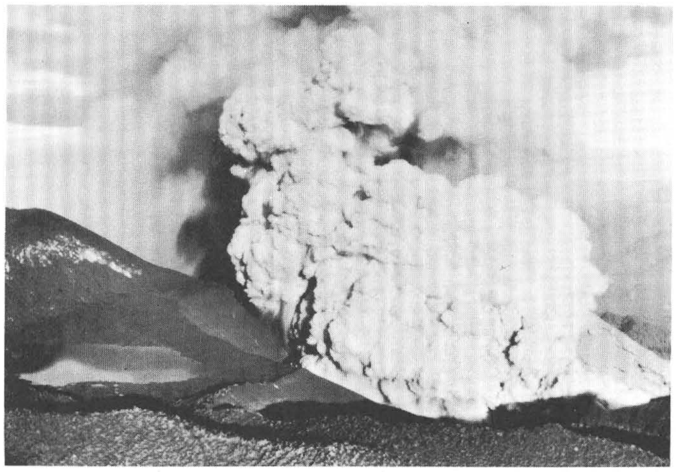

FIGURE 6.—Aerial view from the eastern (windward) side of the Irazú Volcano, which is explosively erupting steam and ash. The highest point (11,260 ft) on the volcano is the somma ridge on the left side of the photo. The ridge is 390 feet above the ephemeral lake of Playa Hermosa.

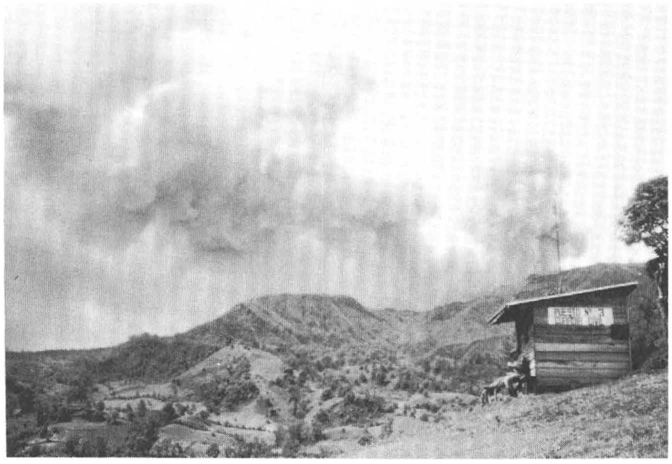

FIGURE 7.—View of erupting Irazú Volcano from the southwest flank, about 3 miles from the summit. A vertically rising column of explosively ejected steam and ash appears on the right skyline. A column erupted a few minutes earlier is being blown westward (left) by the prevailing wind and is dropping out much coarse ash.

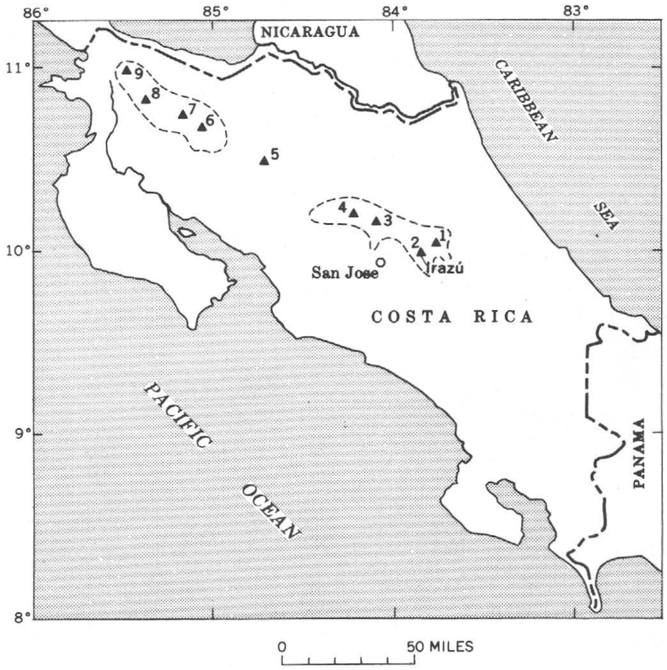

FIGURE 8.—Sketch map of Costa Rica and its volcanoes. 1, Turrialba; 2, Irazú; 3, Barba; 4, Poas; 5, Arenal; 6, Tenorio; 7, Miravalles; 8, Riccn de la Vieja; and 9, Orosi.

responsible for engineering studies, W. D. Cardwell undertook water-resources investigations, and S. J. Gawarecki and R. M. Moxham directed remote-sensing infrared surveys.

Precise geodetic survey

Measurement of upheaval or tilting of ground in the summit region has been used as a means of monitoring the waxing and waning of magmatic pressure in active Hawaiian and Japanese volcanoes. The technique was applied to erupting Irazú through precise determinations of levels on bench marks set along the highway to the summit; the first survey in May 1964 showed that the upper half of the volcano upheaved 11 centimeters above levels determined originally in 1949. A repetition of the survey in September 1964 disclosed a subsidence of the volcano to about the 1949 configuration, indicating a drastic drop in magmatic pressure. Activity declined gradually thereafter, and ash eruption ceased completely in February 1965.

Gravity survey

Gravity observations at 51 monumented stations along the precise level line extending from Cartago to the summit of Irazú Volcano were made in June 1964, September 1964, and February 1965 in an attempt to measure any gravity changes that may have been associated with eruptive activity during these intervals. It had earlier been established in Mihara Volcano, Oshima Island, Japan, that gravity changes of as much as 0.5 milligal during a single eruptive episode could be correlated with inflation and deflation of the volcanic edifice, as reported by I. Hayakawa in 1952. The gravity changes at Irazú were too large to be attributed to the elevation changes alone and were presumably caused by shallow movement of magma. However, no time-dependent changes exceeding the maximum uncertainty in the reduced gravity-station values, or about 0.1 mgal, were detected in surveying the Irazú level line. The absolute accuracy of the gravity measurement must be considerably improved, and the surveys must embrace an entire cycle, before the gravimetric method of monitoring volcanic activity can be fully evaluated for Irazú.

Aerial infrared survey

The method of aerial infrared survey which had been used successfully to locate hot spots at Kilauea Volcano, Hawaii, was applied to Irazú and other volcanoes of the Central Cordillera during May 1964. Infrared imagery obtained using a specially equipped airplane of the University of Michigan clearly delineated thermal anomalies (active and dormant craters and fumerolic areas) on Irazú, Poas, and Turrialba Volcanoes.

Several craters exist at the summit of Irazú; of these, only the younger and currently active crater is marked by thermal activity. Infrared imagery shows the area of this thermal anomaly to be hourglass shaped and elongate to the east. Fumaroles are present approximately 2½ miles east-northeast and 0.8 mile northwest of the summit; those to the east-northeast form three small clusters, those to the northwest are in a northeasterly trending linear array. A large group of hot springs, located approximately 1.3 miles northwest of the summit, form the source of the Rio Sucio. Additional warm springs are present locally along the course of the Rio Sucio for a distance of several miles from its headwaters.

The two southernmost and youngest of the craters on the summit of Turrialba show fumarolic activity, but no thermal anomalies were detected in the other craters. Analysis of the infrared signals reveals that the fumaroles in the southernmost crater have the highest temperature. No other thermal anomalies were detected in the vicinity of Turrialba.

Hot springs south of Cartago, near the villages of Tobosi and Hervidero, were found to be more abundant than previously supposed. A minimum of 27 were located near Tobosi and 7 in the vicinity of Hervidero.

Geochemical studies

The composition of Irazú magma remained remarkably constant at about 55 percent SiO_2 throughout the eruption. Materials of similar composition have been erupted by other volcanoes of the circum-Pacific region, such as Parícutin (Mexico), Crater Lake (Oregon), and certain volcanoes in Hokkaido (Japan). Petrographically, fresh Irazú bombs were porphyritic labradorite pyroxene-olivine-basaltic andesite. Soluble sulfates and chlorides (up to 0.7 percent SO_3 and 0.2 percent Cl) were invariably present in the erupted ash. These substances were formed through solfataric alteration of old rocks of the volcano prior to, or during, the eruption and reflect the abundance of fragments of such altered rocks in the erupted ash.

Engineering geology

The December 1963 flood on the Reventado River, on the southwest slope of Irazú, destroyed several hundred homes, a major highway, and a railroad in the city of Cartago. All through the following rainy season (April-November 1964) flash floods of muddy water and boulders continued to menace the city. Also, large landslides began along the banks of the Reventado and its tributaries.

Engineering-geology studies indicated that main remedial measures should be aimed at controlling the runoff of rainwater from the ash-covered slopes of the volcano. A force of 500 men was put to work on the volcano, ditching to lead water away from the slide areas, installing brush dams in gullies, and planting ash-resistant grasses. A bedrock map of the Reventado Valley was prepared for locating a series of check dams along the river.

Ground-water hydrology

The eruption of Irazú Volcano resulted in considerable damage to the water supplies of San Jose and nearby communities. A reconnaissance program by the U.S. Agency for International Development and U.S. Geological Survey showed possibilities for obtaining ground water from eight types of aquifers or water-bearing zones in the Meseta Central Occidental. These aquifers include three kinds of alluvial deposits and interflow zones between lava flows, as well as scoria, cinders, and ash. Further geohydrologic studies and extensive test drilling will be undertaken before large-scale ground-water development is attempted.

INVESTIGATIONS OF PRINCIPLES AND PROCESSES

A substantial part of the Geological Survey research program is primarily topical and involves the application of principles and analytical techniques largely developed in the laboratory to the elucidation of the evolution, composition, and structure of: (1) the earth as a whole, (2) its rocks and minerals, (3) its constituent elements, (4) its waters, and (5) its past and present living forms. The emphasis is upon quantitative measurements as a means of obtaining basic data having genetic significance. For the past several years the scope of the topical studies has been broadened to include investigations of the Moon and of materials of extra terrestrial origin under sponsorship of the National Aeronautics and Space Agency.

The program of topical studies is, by its nature, long term, but it has produced important current benefits. For example, the program has played an integral part in setting up and operating a nationwide nuclear-blast and earthquake-detection system, together with the volcano eruption warning system for the island of Hawaii. Studies of the stability relations and isotopic compositions of minerals have given insight into the ore-forming processes and have provided new guides for finding ore. Many new analytical techniques and methods of wide application, within the Geological Survey and without, have been developed in the fields of wet chemistry, emission spectroscopy, mineralogy, X-ray spectrometry, and the electron microprobe. Analytical services in these fields and in the fields of paleontology and geochronology are provided for the Geological Survey as a whole.

PALEONTOLOGY

Each paleontologist of the U. S. Geological Survey maintains specialized research interests which are applied to biostratigraphic problems in a number of ways. Systematic and paleoecological studies of particular groups of plants or animals have long-term biostratigraphic implications that often are realized years after the primary work is published. On-the-spot consulting services are accomplished by visits to field mapping projects. These serve to bring the lithostratigraphic and biostratigraphic approaches into harmony by resolving discordant interpretations. Fossils collected by the project geologist, in turn, may lead the paleontologist into peripheral studies that can amplify his own stratigraphic interpretations. Recent paleontologic developments of particular significance, many as yet unpublished, are summarized under the following major taxonomic groups.

FORAMINIFERA

Carboniferous endothyrids from Idaho

Calcareous Foraminifera of Meramec, Chester, and Pennsylvanian ages were identified by B. A. Skipp from samples of the White Knob Limestone collected by W. J. Mapel in the Doublespring quadrangle of central Idaho. One of the forms, *Howchinia* Cushman, 1927, is recognized for the first time in North America. *Howchinia* is associated with the endothyrid foraminifers *Endothyra scitula* Toomey, *Endothyra plectogyra* (E. Zeller), and *Tournayella* spp. which are indicative of Mississippian (Meramec) age. The genus *Howchinia* has previously been reported from the Lower Carboniferous (Viséan) of England and Russia.

Triassic arenaceous forms from Wyoming and Idaho

A small fauna of Lower Triassic arenaceous Foraminifera representing 7 genera and 9 species has been obtained from insoluble residues of the Thaynes Limestone in eastern Idaho and western Wyoming by M. L. Schroeder. Five species of silicified Lower Triassic Foraminifera were previously found in northeastern Nevada by W. W. Schell and D. L. Clark in 1955 and 1956. The microfossils from the Thaynes Limestone were obtained by dissolving more than 2,000 samples of rock from 4 different localities. Several species were found near the top of the Thaynes in the Salt River Range, Lincoln County, Wyo., and relatively abundant Foraminifera were found in the upper part of a 6-foot dark-gray fine-grained carbonaceous limestone bed in the Thaynes in the Caribou Range, Bonneville County, eastern Idaho.

Cretaceous species from Pierre Shale, eastern Wyoming

J. F. Mello's study of samples taken at 50-foot intervals through an approximately 3,300-foot-thick complete section of the Pierre Shale at Red Bird, Wyo., indicates that the foraminifera from almost all the samples are agglutinated forms and are few in number of specimens and species. Because most species occur in many consecutive samples, the fauna has a conservative aspect. The long ranges of many species, and the general similarity of foraminiferal assemblages throughout the section, indicate similarity of environment for the entire Pierre Shale. The predominantly arenaceous nature of the faunas suggests deposition at inner neritic depths.

LOWER INVERTEBRATES

Cambrian archaeocyathid from Alaska

A. R. Palmer reports an Early Cambrian archaeocyathid unlike any previously known form from a collection made by E. E. Brabb along the Tatonduk River, east-central Alaska. The organism has a linear series of barrel-shaped segments ornamented with longitudinal rows of pustules. Near each joint is a collar with a ring of long, slender spines curved parallel to the long axis. In cross section, both the "barrels" and the spines have the double walls and radiating partitions characteristic of archaeocyathids.

Devonian rugose corals, eastern North America

Studies by W. A. Oliver, Jr., of colonial rugose corals of Schoharie and Onondaga age from eastern North America, have shown that most of the genera that are conventionally considered to belong to the Disphyllidae actually comprise ptenophyllid as well as disphyllid species. Species previously assigned to genera on the basis of colony form and gross structure are being revised on the basis of detailed analyses of internal morphology.

Mississippian chaetetid from Kentucky

Material collected by R. D. Trace from the so-called *Chaetetes*—algal horizon near the base of the Kinkaid Limestone in Crittenden, Dixon, and Caldwell Counties, Ky., has been studied by H. M. Duncan who reports that the chaetetid hydrozoan in this faunal zone is a lamellar form named *Chaetetella.* This lamellar chaetetid is particularly characteristic of upper Viséan and lower Namurian rocks in Russia and Great Britain. According to Trace, it is a useful guide fossil inasmuch as it almost invariably occurs within 5 to 10 feet of the base of the Kinkaid.

Echinoderm ecology

P. M. Kier (U. S. National Museum) and R. E. Grant have completed a paper on the distribution and living habits of 17 species of echinoids in the Key Largo Coral Reef Preserve of Florida (a Federal and State undersea wildlife preserve). They report that echinoids live on all kinds of substrates, and that some are highly specialized for the particular kind of environment inhabited. Four species live on dead coral rocks (but two of these also live on sand). Two species live under slabs of rocks; 5 species burrow in sand; 3 species live in grass on sand; and 1 species moves in groups on the surface of grassless sand at relatively great depth. Because many details of distribution and behavior of echinoids are reported for the first time, these results should be useful in interpreting the habits of fossil species.

Bryozoans of Kentucky Upper Ordovician

Study of bryozoans from the Upper Ordovician of Kentucky by O. L. Karklins has resulted in the revisions of the generic assignment of some species, in changes of stratigraphic ranges, and in finding of some new species and, possibly, genera. About 30 genera have been identified from a continuous 240-foot rock sequence in Mason County, Orangeburg and Maysville East quadrangles. Recognizable changes in assemblages suggest that the bryozoans range from late Eden to early Richmond age. Another section, about 210 feet thick, along the Mason–Lewis County line in the same quadrangles, has a bryozoan assemblage of 19 genera, suggesting a Richmond age. An assemblage of 15 genera was found in a 125-foot section in Madison County, Richmond North quadrangle. This bryozoan assemblage resembles bryozoans occurring in the lower half of the section in Mason County. These three sections are invaluable for local and regional correlations of the Upper Ordovician.

Middle Ordovician of Nevada

Physical and paleontologic stratigraphy of the lower Middle Ordovician strata of southern Nevada and adjoining California indicates certain modifications in zonation and correlation, according to R. J. Ross, Jr. (1–64). Only the *Orthidiella* and *Anomalorthis* Zones of the Whiterock Stage appear to have significant time value. The *Palliseria* Zone may be partially controlled by lithic facies and the *Rhysostrophia* Zone is thought to be post Whiterock.

Ordovician brachiopods in Kentucky

Kentucky Ordovician brachiopods are becoming better known through R. B. Neuman's study of silicified specimens, providing firmer bases for correlation than is possible with less well preserved material. For example, *Onniella fertilis* (Bassler) seems to be restricted to the lower part of the Lexington Limestone, where the species is abundant, and the large form *Heterorthina bassleri* (Foerste) is characteristic of the middle part of the Lexington. Higher in the succession, the traditional Richmond guide fossils, *Leptaena richmondensis* (Foerste) and *Platystrophia cypha* (James) are as abundant in some beds traditionally dated as Maysville in age as they are in those dated as Richmond. Studies of the brachiopod *Platystrophia* indicate a clear difference at the species level between collections from Maysville and Richmond beds. Specimens collected by G. C. Simmons from beds of Richmond age in the Palmer quadrangle are specifically distinct from *Platystrophia ponderosa,* which characterizes the Maysville strata in the Richmond North quadrangle.

Mississippian brachiopod zonation in Oklahoma and Missouri

Study by Mackenzie Gordon, Jr., of the Mississippian brachiopods of the Tri-State lead and zinc mining district, in connection with the investigations of E. T. McKnight and R. P. Fisher in the Wyandotte quadrangle, Oklahoma and Missouri, has led to the recognition of six major brachiopod zones in the pre-Chester Mississippian rocks of that region. More than 140 species of brachiopods occur in these rocks, including approximately 35 undescribed species. The major faunal zones can be recognized along the length of the southern flank of the Ozark uplift and permit correlation with the type section in the upper Mississippi River valley.

Evolution of brachiopod superfamily Stenoscismatacea

A study of this conservative group of Paleozoic brachiopods, the Stenoscismatacea, by R. E. Grant (1–65) shows that internal structures of the earliest Middle Devonian species differ but slightly from structures of species that lived near the end of the phyletic line in the Late Permian. On the basis of moderate, but significant, changes in external morphology, the superfamily has been divided into 2 families, 4 subfamilies, 11 genera, and more than 200 species. The group is retained within the Rhynchonelloidea, and stratigraphic implications of phyllogenetic trends are indicated.

MOLLUSCA

Stratigraphic distribution of *Matthevia*

Specimens of *Matthevia,* a genus that has defied precise classification, are widespread in the Western United States, according to E. L. Yochelson, J. F. McAllister, and Anthony Reso (p. B73–B78). Characteristically, specimens are silicified and may be identified on the outcrop by the presence of two narrow deep cavities in a solid pyramidal mass. The genus seems to be confined to rocks of Late Cambrian Trempealeau age. In the Funeral Mountains, Death Valley region, California, and in Pahranagat Range, southern Nevada, extensive fieldwork has demonstrated the stratigraphic utility of *Matthevia* in correlating sections of complexly faulted rocks.

First belemnites from Permian Phosphoria Formation

Examination by Mackenzie Gordon, Jr., of slender rodlike longitudinally striated fossils from the Phosphoria Formation, previously thought to have been spines of fish, shows them to be belemnoid guards of the aulococerid type. They are the hard parts contained within the bodies of a specialized group of squidlike animals, the first Permian ones known in the United States. In fact, only one Permian species has been described previously, from the Upper Permian of Greenland. The Greenland species appears to be represented in the Upper Permian Retort Member of the Phosphoria Formation in western Montana. Another species, in the Lower Permian Meade Peak Member of the Phosphoria in southeastern Idaho, belongs in an undescribed genus and species. It is of considerable interest that in the Upper Permian these free-swimming organisms were common to Greenland and Montana waters.

Triassic bactritid cephalopods found in California

A slender transversely ribbed bactritid cephalopod is under study by Mackenzie Gordon, Jr. It was found by N. J. Silberling in a collection from the Upper Triassic (Karnian) Hosselkus Limestone of California. As the bactritids are supposed to have become extinct at the end of the Paleozoic, this Late Triassic form is of unusual interest from an evolutionary viewpoint because it extends the range of another fossil group into the Mesozoic.

New zonation of Triassic Shublik Formation, Alaska

Study of extensive fossil collections from the Shublik Formation in the Mt. Michelson quadrangle and adjacent areas, northern Alaska, by N. J. Silberling permits recognition of possibly eight different ages based mainly on pelecypods and cephalopods. These faunal subdivisions range from Ladinian through latest Triassic and, apparently, include a full development of Karnian and Norian assemblages.

New Jurassic pelecypod from Alaska

Ralph Imlay has identified the pelecypod *Otapiria* from collections obtained from the topmost part of the Shublik Formation in northern Alaska. The species present is similar to species from the basal Jurassic of New Zealand and of northeastern Siberia. The occurrence of *Otapiria,* plus the presence of *Inoceramus,* which is not known below Jurassic, indicates at least an Early Jurassic age for the top of the Shublik.

Late Tertiary gastropod evolution in Florida

Recent fieldwork by Druid Wilson has established the sequence of evolution in a group of fossils belonging to the gastropod subgenus *Fasciolaria* (*Cinctura*). The group commonly occurs in the upper Tertiary and Pleistocene of Florida. The progressive loss of sculpture of the early whorls from Caloosahatchee time through Fort Thompson time can be used for age determination in the field. A late Miocene species is related, but is not within the evolutionary sequence of the later occurring group.

Fresh-water mollusks from Idaho

In the course of studies of the molluscan fauna of the Pliocene and Pleistocene Glenns Ferry Formation, southern Idaho, D. W. Taylor observed color pattern preserved in some of the shells. Suspecting that color pattern in the calcareous layers of the gastropod shell is a primitive character, Taylor surveyed several families to find out what color patterns exist and how variable they are. Virtual uniformity of pattern exists within groups that can be defined on grounds other than color pattern; and the groups are of useful size, generally at the family or subfamily level. Taylor has identified a Glenns Ferry genus, previously considered extinct, as probably surviving in Yunnan Province, China. The number of related groups of fresh-water mollusks (both Tertiary and Recent) in northeastern Asia and northwestern America is mounting steadily. Faunally, the lake most similar to the Pliocene and Pleistocene lake in which the Glenns Ferry was deposited, is Lake Biwa, Japan. Some of the poorly known lakes in Yunnan also have related molluscan assemblages.

Pacific coast Pleistocene paleoecology

W. O. Addicott has completed a study of late Pleistocene marine mollusks of the central-California–Oregon area and their paleozoogeographic and paleoecologic significance. Assemblages from the lowest marine terrace of the southwestern Santa Cruz Mountains in California (lat 37° N.) show many similarities to mollusks whose modern ranges overlap in southern British Columbia (lat 48° N.) The late Pleistocene assemblages of northern California and Oregon collectively constitute a faunal province that in analogous to the modern Aleutian molluscan province (southern boundary lat 48° N.), and that had its southern boundary between lat 35° N. and 37° N. This suggests a substantially cooler marine hydroclimate from central California to Oregon in the late Pleistocene than at present.

ARTHROPODA

Alaskan Cambrian trilobites

Study of stratigraphically controlled collections from Cambrian rocks of the Alaska-Yukon boundary area shows the presence of at least nine distinct trilobite faunas representing all major parts of the Cambrian Period. More than 100 trilobite species have been identified and described by A. R. Palmer. The oldest fauna is a rich assemblage of trilobites almost entirely of Siberian aspect. A second Early Cambrian fauna has largely North American elements. The Middle Cambrian faunas have affinities with faunas from the southern Cordilleran region, Kazakhstan, eastern Australia, and boulder conglomerates in eastern Canada. The Late Cambrian faunas have affinities to faunas from the same regions and, in addition, some genera previously have been known only from China. Included are the first North American representatives of the widespread Asiatic genus *Proceratopyge,* the Chinese genus *Yupingia,* and other Asiatic forms. These trilobite assemblages are vital links in intercontinental correlations between Asia, Australia, and North America for the middle part of the Upper Cambrian.

Restudy of Silurian ostracode genus

The type specimens of ostracode species assigned to the genus *Beyrichia* by Ulrich and Bassler (1923) have been restudied by Jean Berdan, who finds that they belong to at least 3 genera (2 of which are new) and 2 subfamilies. These genera seem to have fairly restricted ranges and may prove useful in Silurian biostratigraphic studies.

Classification of ostracode superfamily Healdiacea

The shape of carapace, muscle-scar pattern, and inferred nature of soft parts of the fossil superfamily Healdiacea suggest that it should be referred to the order Podocopida, according to I. G. Sohn (p. B69–B72). On the basis of muscle-scar pattern, the genus *Pseudophanasymmetria* is assigned to the

Healdiacea and the generic diagnosis is emended to include dimorphism. *Pseudophanasymmetria? afoveata* is considered to be a dimorphic form of *P. foveata.*

Revision of ostracode families

J. E. Hazel has discovered, by dissection of living representatives, that the ostracode subfamily Campylocytherinae and the *Jugosocythereis-Hermanites* complex of genera, which are normally placed in the Trachyleberididae, are actually representatives of the Hemicytheridae. This has allowed the construction of a more valid phylogenetic classification for the important Hemicytheridae-Trachyleberididae subfamilies.

Oligocene crabs from Alaska

Two fossil crabs, previously known only from the Oligocene or late Eocene, were identified by F. S. MacNeil from beds of the Orca Group, Prince William Sound area, Alaska. These strata are in an area thought previously to consist entirely of upper Mesozoic rocks.

VERTEBRATES

Miocene horses from Panama

Additional collection in the Canal Zone has yielded two horse molars, representing the first Miocene horses to be found in Central America. F. C. Whitmore has identified two genera of forest-living, browsing horses from material collected in Panama in January 1965. *Anchitherium* and *Archaeohippus* are forms related to other Miocene species throughout the world. The species of *Anchitherium* is closest to a species from the lower Miocene of the High Plains. The *Archaeohippus* is most like species found in the late lower Miocene of Texas and late lower to early middle Miocene of Florida. These horses were three-toed, had low-crowned teeth, and probably subsisted for the most part on soft vegetation. Such food was probably also eaten by the other known members of the fauna whose remains are found in the Cucaracha Formation on the banks of the Panama Canal: the rhinoceros *Diceratherium,* an oreodont resembling the North American genus *Brachycrus,* and an unnamed artiodactyl most closely resembling members of the primitive family Protoceratidae. Presence of horses of this type in the Cucaracha fauna reinforces the earlier conclusion that, in the middle and probably in the early Miocene, Panama was connected to North America by a broad land mass and was separated from South America. Apparently, a single continuous fauna lived along the northern and western shores of the Gulf of Mexico during the Miocene.

Locomotion of *Paleoparadoxia* analyzed

C. A. Repenning has made considerable progress in the preparation of the *Paleoparadoxia* specimen from the Stanford Accelerator Site, at Palo Alto, Calif. An analysis of its means of locomotion suggests that, because the heavy hind legs are short and the hind feet are obliquely articulated to the tibia, the animal could not stand erect. *Paleoparadoxia* must have moved on land with flexed legs in a ponderous hopping gait, much as do modern sea lions. In the water, the hind legs were probably used in a froglike kicking motion. Although relatively less shortened, the stout front legs also were modified toward paddling and were ill-adapted to walking.

Big Bone Lick site, Kentucky, dated

Matrix associated with the type skull of the extinct muskox *Bootherium bombifrons* from Big Bone Lick, Ky. was submitted by F. C. Whitmore to Meyer Rubin for age determination by C–14 dating and E. B. Leopold for pollen studies. Rubin reports a date of 17,200 years B. P. (climax of Tazewell ice advance), and Leopold found a preponderance of spruce pollen. The C–14 date is the oldest yet found at Big Bone Lick and indicates the probable existence in the area of a fauna older than those so far collected.

Giant Pleistocene cat found in Alaska

F. C. Whitmore has identified a jaw bone, probably washed out of peat or silt overlying high-level gravels on Lost Chicken Creek near Cathedral Bluffs, central Alaska, as *Felix atrox,* the lion-sized Pleistocene cat especially well-known from the Rancho la Brea tar pits of California. The fossil, collected by H. L. Foster, substantiates reports of large cat bones previously found in Alaska, although there are no published reports of the occurrence of the species this far north. The previous known range included California, Nevada, Idaho, Arizona, Texas, Nebraska, and Maryland.

PALEOBOTANY

Carboniferous iron bacteria identified

The structural remains of fossil Coal Measures bacteria may be resolved clearly by means of the electron microscope, using replicas prepared by delicate oxidation etching of polished pyrite. Two species of iron bacteria closely allied with distinctive modern forms have been identified by J. M. Schopf.

Alliance of the fossil iron bacteria with modern types strongly suggests a similar ecology. Specific microenvironments of Pennsylvanian age must have been similar to those which are widespread at the present time. Additional information is provided on specific deposition of authigenic pyrite and the origin of these common impurities in coal and other sediments. The specific nature of the pyrite also affects the process of Recent weathering that results in an acidic condition in ground water derived from coal-mine refuse areas. The micrographic replica method evidently may be extended with considerable benefit to the microbiology of other types of ancient deposits.

Callipterid reproductive methods studied

S. H. Mamay has completed research describing a new Permian plant genus *Tinsleya,* including the first demonstration of female reproductive parts among the callipterids. These findings have direct bearing on the question of pteridospermous reproduction and may be significant in problems of cycad and angiosperm evolution.

Early Tertiary wood from Atlantic Continental Shelf

A specimen of dicotyledonous wood dredged up by a fishing boat in the Georges Bank area of the Continental Shelf off New England has been identified by R. A. Scott. The specimen, submitted by J. C. Hathaway, represents the extant genus *Euptelea,* now growing in Japan, China, and parts of India. The only previous fossil record of the genus in North America is from the early Tertiary of Oregon. The Atlantic occurrence is evidence for widespread distribution of *Euptelea* on this continent during early Tertiary, or possibly Late Cretaceous time.

Cenomanian floras in southwest Alaska

Large collections of fossil leaves, made by J. M. Hoare during the summer of 1964, indicate the presence of Albian rocks on Nunivak Island and probable Cenomanian rocks on Nelson Island. According to Jack Wolfe's analysis, the collections from Nelson Island represent the first probable Cenomanian floras south of the Brooks Range; they are dominated by flowering plants and have some similarities to Cenomanian floras of the Atlantic Coastal Plain.

Pierre Shale palynomorphs from Wyoming studied

The pollen and spore flora of the Pierre Shale at Red Bird, Wyo., has been the subject of a study by E. B. Leopold and Bernadine Tschudy. The sequence has been dated by W. A. Cobban and J. R. Gill as late Campanian to early Maestrichtian in age, according to baculite evidence. Though these marine sediments are poor in plant microfossils, a total of 191 forms were found. These include: 68 spore, 15 gymnosperm, 5 probable monocot and 45 dicot types, and 14 dinoflagellate algal, 18 hystrich, and 26 miscellaneous plantonic species. The seed plants include several groups whose modern relatives live in Australasia in the warm temperate and subtropical zones. Among the dicotyledons, 14 forms are assigned to the genus *Aquilapollenites* Rouse which, as far as is known, represents an extinct group. The fern types include several with living counterparts in the New World tropics. The flora seems to show little qualitative change through the late Campanian and early Maestrichtian; the primary changes are in pollen abundance in the sediments. The land-based flora of the marine Red Bird section corresponds to the pollen and spore flora described by K. R. Newman [62] from the continental deposits of the Mesaverde Group near Craig, Colo.

Cretaceous pollen in Appalachian Mountains

Samples of a black sandy clay from the Appalachian Mountains near Chambersburg, Pa., have yielded a suite of Late Cretaceous pollen and spores, according to R. H. Tschudy (p. B64–B68). Evidence from known stratigraphic ranges of some forms, and from the number and percentage of triporate pollen, indicates an extreme possible age range from early Turonian through middle Campanian. A probable age range for the deposit is late Turonian through early Campanian. This locality is about 80 miles west of the nearest known Upper Cretaceous outcrops.

Megaspores from Tuscaloosa Group

R. H. Tschudy reports the identification of the megaspore genus *Ariadnaesporites* in a sample from the Tuscaloosa Group from Alabama. Structurally similar, but much smaller, spores were found tangled in the long hairlike processes of the megaspores. Tschudy believes them to be microspores of *Ariadnaesporites* and the tangling to be an adaptation to promote fertilization of the megagamete. This genus was reported previously only from an Upper Cretaceous coal in Greenland.

Mummified microfossils from Green River Formation

Continued study of the fresh-water microorganisms found in the rich oil shales of the Eocene Green River Formation of Wyoming by W. H. Bradley has revealed the presence of several genera of micro-

[62] K. R. Newman, 1964, Palynologic correlations of Late Cretaceous and Paleocene formations, northwestern Colorado: Soc. Econ. Paleontologists and Mineralogists Spec. Publ. 11, p. 169–180.

scopic aquatic fungi. Several of these are specifically indistinguishable from those living today in the lakes of the Lake District of England. Others are specifically unlike any known living aquatic or terrestrial fungi, yet the genus is fixed beyond doubt. More remarkable as microfossils are the well-preserved remains of one rotifer, *Cephalodella* sp., and two midge larvae that must have just emerged from their eggs at the time they died. All these microfossils are unmineralized and, in reality, are mummified. This sort of preservation for the rotifer and the two midge larvae is remarkable because such delicate animal tissue ordinarily decays within hours of death.

Reclassification of diatoms

In connection with the preparation of the section of Diatomacea for the *Treatise on Invertebrate Paleontology,* K. E. Lohman has devised a new classification of the diatoms, consisting of 1 class, 4 orders, 11 suborders, 23 families, 54 subfamilies, and 320 genera. This reclassification includes all of the diatoms, living and fossil, marine and nonmarine.

Miocene diatoms from Washington

An extensive study by K. E. Lohman of diatoms from the Latah Formation near Spokane, Wash., has pointed up correlations with other middle and late Miocene deposits in the West. The material, collected by J. W. Hosterman, contains a number of species in common with the Latah Formation near Mica, Wash.; the Virgin Valley Beds of Humboldt County, Nev.; and the Mascall Formation of Central Oregon. The diatoms suggest that the Latah near Spokane was deposited in a temperate, fresh-water lake having a pH ranging from 6 to 8.

MARINE GEOLOGY AND HYDROLOGY

The marine program and related activities of the U.S. Geological Survey emphasize: (1) mapping and evaluation of the geologic environment and resources of the sea floor adjacent to the United States, (2) topical studies of geologic and hydrologic processes and environmental factors both near the coasts and in deep-sea areas, and (3) detailed investigations of oceanic islands under the jurisdiction of the United States. The major effort has continued to be concentrated on regional studies of the Atlantic Continental Shelf and Slope. Following the Alaska Earthquake of 1964, investigations of earthquake-triggered submarine slides and their effects were undertaken as part of the Geological Survey's contribution to the disaster program. (See the section "Alaska Earthquake 1964.")

ATLANTIC CONTINENTAL SHELF AND SLOPE

During 1964, the 5-year reconnaissance studies of the east-coast continental margin by the Geological Survey entered their third year. These investigations, directed by K. O. Emery, of the Woods Hole Oceanographic Institution, are carried on in collaboration with the institution and with the U.S. Bureau of Commercial Fisheries. Nearly continuous spring, summer, and fall cruises were undertaken to collect systematically surficial sediments and rocks from all parts of the shelf and slope and to obtain sub-bottom structural profiles of the Gulf of Maine and adjacent portions of the shelf and slope. Complementary laboratory and office studies have continued to emphasize the compilation and evaluation of existing geologic and hydrologic data for the entire shelf and the analysis and interpretation of new samples and data from the Gulf of Maine and adjacent shelf.

Potential for new oil discoveries increases seaward

Chiefly on the basis of records and samples obtained from State geological surveys and from oil companies, J. C. Maher has prepared a longitudinal cross section and a series of transverse cross sections of the Atlantic Coastal Plain from Key West, Fla., to Long Island, N.Y., showing correlations of the subsurface stratigraphy. The sections clearly illustrate the seaward thickening of the formations and the progressive lithologic changes from nearshore to offshore marine facies. They provide a basis for correlation of rocks beneath the continental shelf with those beneath adjacent land and support the suggestion that the potential for discovery of new petroleum reserves improves seaward along the Atlantic coast.

Contour of floor of Gulf of Maine reflects basement rocks

On the basis of preliminary results of continuous sub-bottom profiling (sparker) surveys in the Gulf of Maine, Richard Tagg and Elazar Uchupi have concluded that unconsolidated sediments are generally less than 100 meters thick and that major topographic irregularities of the gulf are related to corrugations within the basement rocks. Triassic rocks, which form the basement in the northeastern part of the gulf, extend 120 kilometers westward from the Bay of Fundy and have been eroded, partly by glacial scour, to depths of 300 m and more below present sea level. Where the Triassic rocks are deeply eroded, glacial and Recent sediments exceed 100 m in thickness.

Reworking of glacial sediments greatest north of Cape Cod

J. C. Hathaway, Jobst Hulsemann, J. S. Schlee, and J. V. A. Trumbull report that the amount of apparent reworking of unconsolidated glacial sediments differs in areas of similar topography in various parts of the Gulf of Maine and is greatest in and near the Wilkinson and Murray Basins, north of Cape Cod, Mass. R. M. Pratt has found that nearshore gravels consist chiefly of rocks from adjacent shores, whereas gravels of the central and southern gulf area have a more diversified lithology, probably caused by ice rafting from several source areas.

Oyster shells from shelf are 8,000–11,000 years old, according to C–14 dating

In the course of sediment sampling on the shelf and of dredging by the U.S. Bureau of Commercial Fisheries, shells of shallow-water (less than 40 meters) oysters have been recovered from depths of 145–165 m at 71 localities between North Carolina and Cape Cod. Radiocarbon measurements on 4 shells indicate ages of 8,000–11,000 years. A. S. Merrill, K. O. Emery, and Meyer Rubin have concluded that the oysters lived in lagoons or estuaries that were submerged when sea level rose at the end of the latest glacial epoch.

Gravels off New Jersey are potential construction material

J. S. Schlee (1–64), on the basis of textural analyses of sediment samples off the coast of New Jersey, has outlined an extensive area of Pleistocene sandy gravels and pebbly sands at depths of less than 40 meters. The sands and gravels provide a potential source of construction material for adjacent coastal areas. Iron staining of the grains suggests that the deposits are relict.

Salinity and temperature variations in Maine estuaries

R. H. Meade has collected hydrologic data in several areas where the existing data were scarce. Salinity and temperature profiles of the Penobscot and Kennebec River estuaries were made in July. One 12-hour anchor station on the Penobscot River at Winterport recorded a tidal range in surface salinity of 4.3 to 15.1‰. Two 12-hour stations in September near Georges Bank, one in Great South Channel and the other in Northeast Channel, also recorded tidal variations in salinity and temperature. In Northeast Channel, salinity ranged from 31.8 to 34.7‰ during one tidal cycle; the temperature of the bottom water during this time remained nearly constant at 7.1°C.

MARINE GEOLOGIC ENVIRONMENT AND PROCESSES

Cores from experimental Mohole relate fossils and vulcanism

A study of the composition and mineralogy of late Tertiary sediments, recovered from the experimental deep-sea Mohole drill hole (Guadalupe site), allowed quantitative interpretation of the relations between biogenic opal, biogenic calcite, and lithogenic matter. Large amounts of trachytic ash, rhyolitic ash, or decomposition products of basalt in a few samples record eruptions of nearby oceanic and continental volcanoes. Volcanic activity seems to influence organic productivity as suggested by the tendency of sediments rich in remains of siliceous and calcareous organisms to have above-average proportions of basaltic materials (K. J. Murata and R. C. Erd, 1–65).

Eocene Radiolaria from Puerto Rico Trench

K. N. Sachs, Jr., has identified Eocene Radiolaria from a dredge sample recovered from the north slope of the Puerto Rico Trench at a depth of 3,650 to 3,150 fathoms. The radiolarian fauna contained in one of four samples submitted by R. L. Chase, of Woods Hole Oceanographic Institution, has many elements in common with that from the Eocene of Saipan, described by W. R. Riedel.[63]

Organic content of deep-sea sediments in North Pacific

J. G. Palacas and V. E. Swanson have analysed the organic matter from segments of three cores from the North Pacific Ocean, provided by G. W. Moore and collected during the 1963 cruise of the USCGS ship *Pioneer*. The clayey sediment contains 250–3,000 parts per million humic acids, 55–200 ppm amino acids, and 30–40 ppm bitumens. These 3 fractions account for more than 50 percent of the organic matter in gray clay from a depth of 6,800 meters in the Aleutian Trench, but for less than 25 percent in tan siliceous clay from a depth of 5,400 m in the central North Pacific.

FRESH-WATER–SALT-WATER MIXING

Sporadic low-oxygen concentrations, Delaware River estuary

In summarizing 14½ years of monthly measurements of a 44-mile tidal reach of the Delaware River

[63] W. R. Riedel, 1957, Eocene Radiolaria *in* Geology of Saipan, Marianna Islands, pt. 3, Paleontology: U.S. Geol. Survey Prof. Paper 280-G, p. 257–263, pls. 62, 63.

estuary W. B. Keighton has noted occasional low dissolved-oxygen concentrations, especially in that reach of the river adjacent to Philadelphia, Pa. At the Benjamin Franklin Bridge, Philadelphia, a third of the samples were less than 30 percent saturated with oxygen.

Biota zones due to offshore ground-water discharge, Florida

In studies of fresh ground-water discharge to the sea, F. A. Kohout and M. C. Kolipinske demonstrated that biological zonation in Biscayne Bay is related to ground-water discharge. Fresh ground water flowing seaward through the upper part of the Biscayne aquifer discharges through the bottom sediments of the bay in a littoral zone that extends about 400 feet seaward from the shoreline. Brackish-water species of both plants and animals predominate near shore and are progressively replaced seaward by typical marine species. The zonation of different sea grasses is recognizable by color differentiation on aerial photographs.

WATER MOVEMENT IN ESTUARIES

Theoretical analysis of flow in estuaries

Using the nonlinear hyperbolic partial-differential equations representing one-dimensional homogeneously dense unsteady flow in open channels, R. A. Baltzer and Chintu Lai have found it possible to model analytically the transient streamflow observed in rivers and some estuaries. Numerical solution techniques premised on power-series methods, characteristic methods, and implicit methods provide both accurate and economical means for determining transient-flow information when evaluation is carried out using a high-speed digital computer.

BIOHYDROLOGIC STUDIES OF ESTUARIES

Phytoplankton and tides, Duwamish River estuary, Washington

The diurnal variability of phytoplankton population (as indicated by diatom and chlorophyll concentrations) in the Duwamish River estuary adjacent to Puget Sound is inversely related to tidal stage, according to E. B. Welch and J. F. Santos. The relation is less clear at high than at low river discharges. High plankton concentrations at low tide (2 to 3 times the high-tide concentrations) appear to be a result of high velocities near the river bottom that carry benthic diatoms into suspension. This theory is supported by the improvement of the relation between tidal stage and plankton population as sampling depth increases.

Variation in attachment organisms, Patuxent River estuary, Maryland

In a 2-year study of attached marine organisms in the Patuxent River, R. L. Cory has observed that generally the attachment sequence is the same but that numbers of individuals and total biomass vary from station to station and year to year. At six of the sites, ash-free dry weight (organic carbon), a measure of the productivity of attached organisms, was significantly higher in 1964 than in 1963. At one site it was almost the same as in 1963, and two sites, both in the vicinity of a new powerplant, showed nearly a 50-percent reduction in biomass.

Cory believes that the higher biomass production over the entire estuary, with the exception of a 1-mile stretch in the vicinity of the powerplant, is probably due to the decrease in rainfall in 1964 which resulted in slightly higher salinities and a decrease in nutrient flushing time. The decrease in production at the plant site was probably due to higher turbidities observed during most of the summer while the intake and effluent channels were being dredged.

OCEANIC ISLANDS

Marine geologic studies, Palau to Guam

At the invitation of the U.S. Coast and Geodetic Survey, Gilbert Corwin and J. I. Tracey, Jr., participated in marine geological studies near the Palau Islands and Guam aboard the USCGS ship *Pioneer* on her return from the Indian Ocean. The studies included bottom sampling and geophysical measurements while underway across and along the arcuate ridges from which the islands rise and across and along the associated trenches. Preliminary analysis of sparker-probe measurements adjacent to the Palau Islands appears to confirm the importance of northwest-southeast faulting in development of the islands, and suggests the presence of at least three major longitudinal faults on the west side of the Palau trench. The identification of westward-dipping sediments on the east side of the trench and of their termination within the trench presents problems that merit further investigation.

Moderately indurated calcareous silt dredged from the west slope of the Palau Islands and poorly indurated limestone with volcanic pebbles from the east slope appear to be deposits of Pleistocene age that lack counterparts on the islands. If Pleistocene, these samples represent a potential source of information on intervals of otherwise unrecorded local geologic history when sea level was lower than at present.

Samples of andesitic pumice, which included one piece with a 20-mm glomerocryst of calcic plagioclase and olivine, was dredged from the crest of a submarine volcano 20 miles northwest of Guam. The lack of appreciable alteration and the nature of the pumice suggest that it is the product of a Recent eruption and that the source magma was of the northern Mariana (high-alumina) type rather than southern Mariana (tholeiitic) type. Late Quaternary ash eruptions of the volcano may explain the presence of volcanic detritus in limestone of the northern plateau of Guam and the origin of the overlying thin lateritic soils.

On Guam, Corwin and Tracey discovered a deeply weathered volcanic plug near the center of the southern volcanic area of the island. The plug appears to be one of several probable sources of the patchy uppermost lava flows of Guam (Dandan flows of Miocene age).

ASTROGEOLOGY

The U.S. Geological Survey investigations in support of the space exploration program of the National Aeronautics and Space Administration include: (1) earth-based lunar investigations, (2) studies of terrestrial and experimental impact and cratering phenomena, (3) cosmochemistry and petrology, (4) unmanned lunar exploration studies, and (5) manned lunar exploration studies.

EARTH-BASED LUNAR INVESTIGATIONS

Lunar geologic mapping

Geologic mapping of the Moon at a scale of 1:1,000,000 forms the base for the lunar investigations of the U.S. Geological Survey. Figure 9 shows the status of this mapping program. Maps completed to date cover about 3 million square miles.

Major structure of Mare Vaporum region interpreted

A preliminary geologic map of the Mare Vaporum region, which lies within the peripheral belt of

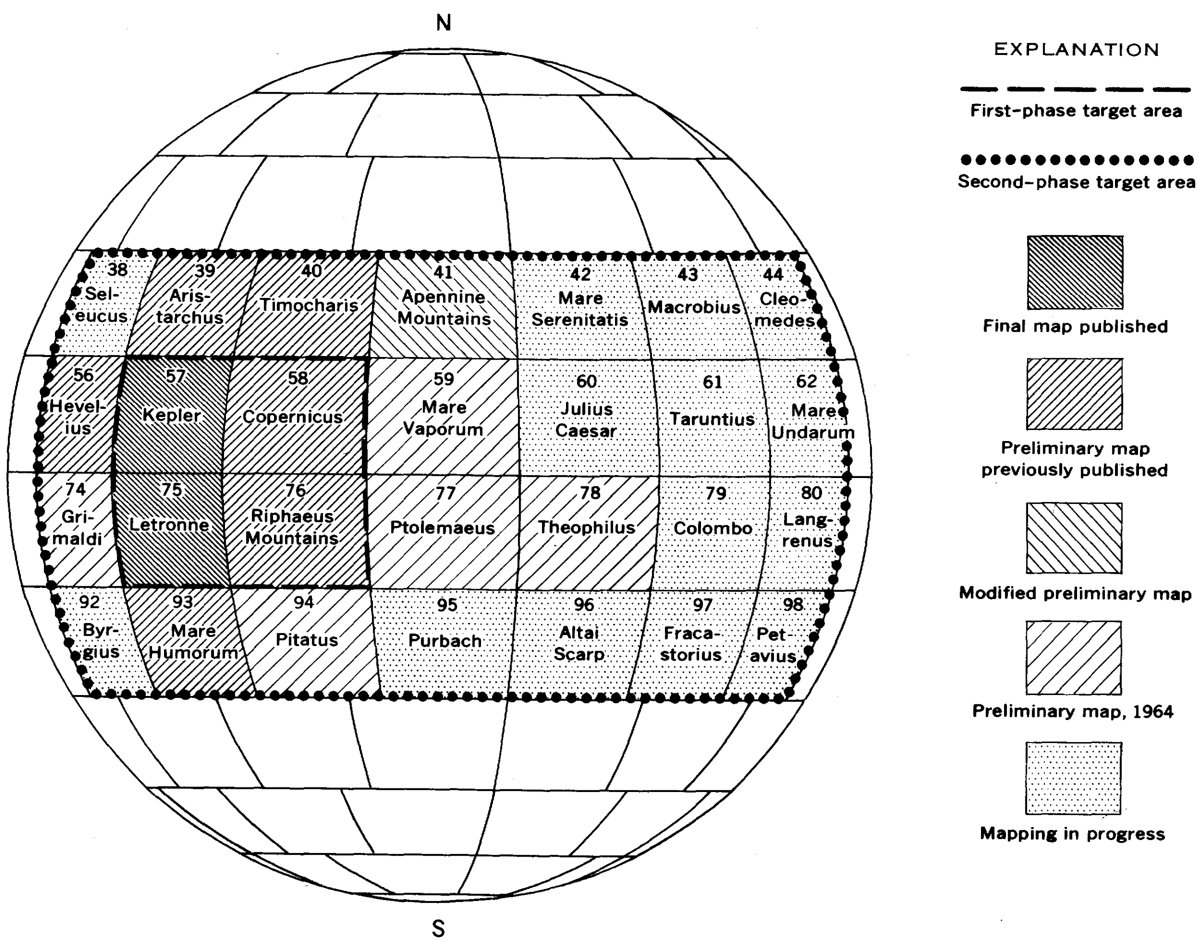

FIGURE 9.—Index map of the Moon, showing status of geologic mapping at a scale of 1 : 1,000,000. ACIC number and name are given in each region.

structures related to the Mare Imbrium basin, has been completed by D. E. Wilhelms (U.S. Geol. Survey, 1–65, pt. A). Major structural elements within the region, mare depressions and terra high, are interpreted as synclines and anticlines, which are roughly concentric with the Mare Imbrium basin and in places are modified by faults. Most of the terra in the region is deformed by troughs and ridges of the "Imbrian sculpture" radial to the basin and is covered by the Fra Mauro Formation, which is interpreted as ejecta from the Mare Imbrium basin. Some of the structure may have been produced by interaction of deforming forces at the time the Mare Imbrium basin was formed on older structures related to the basin of Mare Serenitatis. Still other structures not obviously related to the Mare Imbrium basin, such as the Triesnecker rille system, may have been formed by isostatic readjustment of the lunar crust subsequent to the Imbrian event. Part of the Hyginus rille is alined with Imbrian sculpture.

Stratigraphy of western Theophilus area unravelled

A complex stratigraphic sequence has been mapped in the terra of the western Theophilus region by D. J. Milton (U.S. Geol. Survey, 1–65, pt. A). Crater rims and other terrain cut by prominent scarps (Imbrian sculpture) trending northwest-southeast are believed to be pre-Imbrian. Terrain with a much finer texture of small rounded hills and valleys elongated in the same direction is correlated with the Fra Mauro Formation of Apenninian age. This is overlain by a smooth-surfaced plains-forming unit that partially fills basins. Adjacent higher areas with subdued relief are probably underlain by a thinner deposit of the same material. This material is tentatively considered to be of Apenninian age; it may, however, be Archimedian. A plateau-forming unit has a broadly rolling smooth surface with some steep-walled irregular depressions. This unit, in contrast to the plains-forming unit, does not tend to occupy basins but forms broad plateaus with the underlying relief completely concealed. The age of the plateau-forming unit is uncertain; it may be an age equivalent of the plains-forming unit.

Stratigraphic relations in Grimaldi region

Preliminary geologic mapping of the Grimaldi region by J. F. McCauley (U.S. Geol. Survey, 1–65, pt. A) establishes the stratigraphic relations among the regional materials surrounding the Mare Orientale and Mare Humorum basins. North of the crater Fontana, smooth-textured high-albedo material of the Cordillera Group (associated with the Orientale basin) overlies darker, rougher textured material of the Humorum Group, which clearly is younger than the Humorum basin. Very dark mare material, extensive within the area, is characterized by a low spatial density of craters and a general lack of superimposed rays, suggesting that it may be younger than the mare material typical of the Procellarum Group.

Complex sequence of events recorded in Pitatus region

S. R. Titley (U.S. Geol. Survey, 1–65, pt. A) has mapped the stratigraphic and structural relations in the Pitatus region and adjacent areas. A complex sequence of events in this region includes basin formation, regional deposition, and tectonic activity. Certain critical structural and stratigraphic relations permit tentative interpretations of relative ages of the Mare Humorum, Mare Nubium, and Mare Imbrium basins. Ejecta(?) from Mare Humorum basin make up most of the old upland exposures around the west edge of Mare Nubium and, in the northwest part of the quadrangle, may underlie the Fra Mauro Formation, which consists of ejecta from the Mare Imbrium basin. Structural relations on the west edge of the quadrangle suggest that the circumferential structures about Mare Humorum are older than those about Mare Nubium.

Possible volcanic complex near Harbinger Mountains

A possible volcanic complex near the Harbinger Mountains of the Moon has been investigated by H. J. Moore (U.S. Geol. Survey, 1–65, pt. A). Abundant hills, craters, and rilles are present just west of the Harbinger Mountains. The close association of the craters and rilles suggest that the area is a volcanic complex. These lunar craters resemble terrestrial maars and rampart craters, and one is like a caldera. Lunar craters that are similar to maars and rampart craters are larger than their suggested terrestrial counterparts. Some of the sinuous rilles are crater chains; not all can be the result of erosion by nuées ardentes as suggested by other workers.

Hummocky deposit about Mare Humorum basin interpreted

S. R. Titley and R. E. Eggleton (U.S. Geol. Survey, 1–65, pt. A) have described an extensive hummocky deposit around the Mare Humorum basin. This material, which is uniform in its subdued topographic characteristics and normal albedo, is distributed about Mare Humorum. It occurs now as isolated patches and tongues but is believed to have surrounded Mare Humorum at one time as a nearly continuous blanket. In many respects it is similar to hummocky Fra Mauro Formation. The extent and distribution of the hummocky material about Mare Humorum is comparable with those of the Fra Mauro Formation, when the relative sizes of the Humorum and Imbrium basins are considered. The material has all the characteristics of an extensive ejecta blanket and appears to be derived from the Mare Humorum basin.

THEORETICAL ANALYSES OF LUNAR PHENOMENA

Trajectories for Copernicus ray material calculated

Trajectories of objects producing Copernicus ray material on the crater Eratosthenes have been studied by M. H. Carr (U.S. Geol. Survey, 1–65, pt. A). In the region of Eratosthenes, areas lacking ray material are principally on slopes facing away from Copernicus. On the assumption that the absence of ray material in these areas is due mainly to topographic shielding, trajectories were computed for objects ejected from Copernicus to produce secondary craters and rays in Eratosthenes. Mean values of 7° for the ejection angle 1.1 kilometers per second for the ejection velocity were found.

Isostatic rebound of lunar craters interpreted

Harold Masursky (U.S. Geol. Survey, 1–65, pt. A) has reported on the isostatic rebound of lunar craters and a reinterpretation of Ptolemaeus. The rebound of lunar craters similar in size to Ptolemaeus indicates that the cover on the floor of the crater may be very thin; that is, only thick enough to have buried the central peaks. The present shallow depth of the crater is attributed chiefly to respringing of the crater floor.

Impact temperatures around Timocharis calculated

The history of the temperature regime around the crater Timocharis was computed by M. H. Carr (U.S. Geol. Survey, 1–65, pt. A), assuming an impact origin for the crater and shock equations of state similar to basalt for the target and projectile. For impact velocities greater than 8 kilometers per second, temperatures sufficiently high for melting extend a distance of 6 km below the crater. At lower impact velocities, melting temperatures are not reached. The transient high temperature source at the surface, immediately after impact, has an insulating effect, so that lunar internal heat cannot escape to the surface. This raises temperature at depths far below the impact-induced temperature anomaly. Lowering of the thermal conductivity near the surface by impact brecciation also has an insulating effect. The temperature rise at depth may be great enough to produce melting and volcanism long after the impact event.

INSTRUMENTATION AND TECHNIQUES FOR LAND-BASED LUNAR STUDY

Excess infrared emission at lunar limb studied

Infrared emission from the illuminated Moon is being investigated by Kenneth Watson (U.S. Geol. Survey, 1–65, pt. A). Edison Pettit and S. B. Nicholson [64] observed that the infrared emission of the Moon near zero phase angle at the limb along the lunar equator exceeds the emission to be expected from a Lambert emitter. Pettit and Nicholson suggested that this excess emission at the limb is due entirely to the lack of shadows at full Moon; only illuminated surfaces contribute to the emission. This cannot be valid at the scale of lunar mountains and valleys, however. The average slopes at this scale are much too low to produce appreciable departure from Lambert emission in the infrared. At the other extreme or scale, reradiation between inclined surfaces less than a few centimeters apart also tends to produce uniform emission that follows the Lambert law. The observed excess emission of the limb may be caused by either (1) roughness on a scale between a centimeter and meter, and (2) non-Lambert emission for individual surface elements. In the first case, roughness may possibly be related to the high spatial density of secondary craters on the lunar surface.

Study of lunar polarimetry begun

D. E. Wilhelms (U.S. Geol. Survey, 1–65, pt. A) has initiated a program of lunar polarimetry with a Lyot visual polarimeter mounted on the 12-inch refractor of Lick Observatory. Preliminary results indicate that polarization of areas on the lunar surface 8 kilometers in diameter can be measured with these instruments under conditions of good viewing.

New high-speed camera reduces shutter errors

Existing high-speed photographic systems employed in lunar photographic photometry have, for the most part, contained large inherent errors. These errors can be traced to (1) shutters with variable speeds and (2) processing systems that employ nonuniform agitation of developing solutions. H. A. Pohn (U.S. Geol. Survey, 1–65, pt. A) has designed a high-speed photometric camera that largely overcomes shutter errors by adjustable slits that are pulled along mated Teflon ways. This system is coupled with a plate-processing system that holds the

[64] Edison Pettit and S. B. Nicholson, 1930, Lunar radiation and temperatures: Astrophys. Jour., v. 71, p. 102–135.

internal variations in plate response to about 3 percent of mean plate density. A camera with the new design features will be used on the Geological Survey's 30-inch telescope to make photographs for a photoelectrically calibrated photographic atlas of the Moon.

TERRESTRIAL AND EXPERIMENTAL IMPACT AND CRATERING PHENOMENA

The U.S. Geological Survey program of study of natural and manmade terrestrial craters throws light on the origin of their structure, stratigraphy, and mineral composition and, what is perhaps more important, also provides clues to the makeup and origin of lunar craters.

FIELD STUDIES OF IMPACT STRUCTURES

Ray crater in Australia mapped and interpreted

D. J. Milton and F. C. Michel (p. C5–C11) have mapped the only terrestrial meteorite impact crater known to have rays of ejecta similar to those around lunar craters. Crater 3 of the Henbury crater field, Northern Territory, Australia, is a roughly circular crater about 200 feet in diameter with a relief of 15 feet from floor to rim crest and 5 feet from the surrounding surface to the crest. It is formed in alternating beds of well-cemented sandstone and weak shale dipping about 35° and overlain by a varying thickness of pediment gravel. Beds striking into the walls of the crater are deformed, predominantly by folding about almost vertical axes.

Specific types of ejecta when traced to specific outcrops of source beds in the crater permitted the directions and distances of throw-out to be measured. From these data the distribution of impact energy was calculated. The results showed that the effective energy decreased as a function of the radius of the shock-wave front at a greater rate than would be predicted from a simple shock-propagation model probably because the finite strength of the bedrock is not considered in such a model.

Rim of Flynn Creek cryptovolcanic structure studied

D. J. Roddy (U.S. Geol. Survey, 1–65, pt. B) found that the southeastern rim of the Flynn Creek structure, Tennessee, a feature of suspected impact origin, consists of a structurally complex sequence of Upper Ordovician rocks and contains what appears to be a part of a land surface that existed immediately before the deformation. A large mass of breccia covers the ancient land surface and is preserved in a downfaulted block. Field and laboratory studies of the rocks underlying this surface strongly suggest that they are Late Ordovician in age and can probably be assigned to the Richmond Group. Calculations of the stratigraphic thicknesses in the southeastern rim suggest that not more than 60 meters of Late Ordovician strata was removed by erosion after the structure was formed and before later sediments of Late Devonian age were deposited. The maximum age of the Flynn Creek structure is therefore Late Ordovician. The minimum age is early Late Devonian.

A preliminary search did not reveal the high-pressure silica polymorphs coesite and stishovite that have been found in some known meteorite impact structures. Geophysical studies by Shawn Biehler and D. J. Roddy indicate that there is no large magnetic anomaly, as might be expected if an igneous plug were present below the structure.

LABORATORY STUDIES OF IMPACT-RELATED PHENOMENA

Stishovite synthesized by experimental shock metamorphism

P. S. DeCarli (U.S. Geol. Survey, 1–65, pt. B), Stanford Research Institute, and D. J. Milton separated small amounts of stishovite from explosively shocked sandstones, novaculite, and single-crystal quartz. Estimated peak pressures for the syntheses ranged from 150 to 280 kilobars and shock temperatures from 150° to 300° C. Coesite was not detected in any sample. This suggests that quartz can invert during shock to a short-range-order phase with sixfold coordination, a small part of which may develop the long-range order of stishovite. Part of the short-range-order phase may invert to coesite during the more protracted decay of the pressure pulse through the stability field of coesite accompanying meteorite-crater formation.

High-index plagioclase glass from meteorite described

M. B. Duke (U.S. Geol. Survey, 1–65, pt. B) found the average composition of maskelynite (natural plagioclase glass) from the Shergotty meteorite to be about An_{49}. Its density varies within a range near 2.57 grams per cubic centimeter. The refractive index ranges from 1.539 to 1.554 and is distinctly higher than the indices of synthetic plagioclase glass in the same compositional range. Experiments show that the refractive index can be markedly reduced by heating for a few minutes at temperatures as low as 450°C. The glass is believed to have been formed by solid-state transformation under shock pressure.

Argon loss from shocked granite, Ries crater

P. Signer (U.S. Geol. Survey, 1–65, pt. B) compared the argon content of unshocked and strongly shocked granite from the Ries crater, Germany, and found that the shocked granite contains far less radiogenic argon than the unshocked. New amorphous phases formed by shock absorb much greater quantities of atmospheric argon than their parent crystalline phases.

Two types of "shock" minerals from natural craters noted

E. C. T. Chao (U.S. Geol. Survey, 1–65, pt. B) described selective shock transformation of minerals in rocks from known and probable meteorite craters and showed that their special characteristics may be used as evidence of meteorite impact. The transformations are of two types: (1) from a crystalline phase of complex chemical composition to glass of the same composition and (2) from a crystalline phase of simple chemical composition to its high-pressure and high-density polymorph. Transformations of the first type, formed at high pressure and probably low temperatures, occurred in impact-metamorphosed sandstones from the Henbury craters of Australia and in biotite granite, gneiss, and schist in suevite from the Ries crater. Transformations from a low-density to a high-density polymorph, such as from quartz to coesite or stishovite, occurred (1) in impact-metamorphosed sandstones of Meteor crater, Ariz., and the Wabar crater, Saudi Arabia; (2) in biotite granite gneiss of the Ries crater; and in (3) metamorphic rocks of the Lake Bosumtwi crater, Ghana.

Experimental impact studies using high-energy missiles

A study by H. J. Moore, Reuben Kachadoorian, and H. G. Wilshire (U.S. Geol. Survey, 1–65, pt. B) of craters produced by the impact of missiles provides data on cratering by projectiles with large kinetic energies (2.3×10^{15} ergs). The amount of material displaced during crater formation by projectile impact is nearly the same as the amount of material displaced during crater formation by chemical explosives with shallow depths of burial when the kinetic energy of the projectile (corrected for the angle of impact) is equal to the equivalent energy of TNT of the chemical explosive.

Strain gages measure shock-wave speeds in sandstone

M. H. Carr (U.S. Geol. Survey, 1–65, pt. B) used strain gages to measure shock pressures and shock-wave speeds in sandstone. The Hugoniot curve of Coconino Sandstone for pressures from 0 to 150 kilobars shows shock-wave speeds from 3.0 to 4.0 kilometers per second. For similar shock energies in sandstone from the Moenkopi Formation, an elastic precursor with a speed of 3.1 km/sec and a shock wave with speeds from 2.5 to 2.9 km/sec are generated.

Crater shapes reflect porosity and cohesion of target

H. J. Moore, D. E. Gault, E. D. Heitowit, and R. V. Lugn (U.S. Geol. Survey, 1–65, pt. B) found that the shapes of craters produced by hypervelocity impacts differ according to the porosity and cohesion of the target. Depth-to-diameter ratios increase from 1 : 5 for nonporous targets (basalt) to about 1 : 1 for porous targets (pumice). Craters in weakly bonded sand targets are larger than those in sandstone and basalt, and craters in fine-grained weakly bonded sand targets are smaller than those in coarse-grained sand. Application of a defect theory of strength explains the differences between crater size and shape in sandstone and those in weekly bonded sand targets. The shapes of recent small lunar craters may be used to estimate cohesion of lunar surface materials.

Significant parts of the ejecta from craters in pumice are complex aggregates of crushed pumice and glass fibers. The aggregates resemble volcanic ash. It is postulated that, as the result of micrometeoroid bombardment, the uppermost part of the lunar surface could be similar to volcanic ash.

COSMOCHEMISTRY AND PETROLOGY

Studies in cosmochemistry and petrology include (1) geological distribution and physical and chemical properties of tektites, (2) investigations of microanalytical techniques for analyzing milligram and submilligram quantities of tektites, meteorites and, eventually, returned lunar samples, and (3) petrology and chemistry of meteorites.

Aerodynamically modified moldavite described

E. C. T. Chao [65] found indirect evidence of aerodynamic heating and ablation on a moldavite from Slavice, Czechoslovakia. No evidence for heating or ablation of moldavites had previously been recognized. The indirect evidence consists of the keel left by spallation of the heated and strained glass of the leading surface of a teardrop-shaped tektite. The keel is identical to those of australite indicators (partially spalled tektites). This is the first evidence of the probable entry velocity of moldavites into

[65] E. C. T. Chao, 1964, Spalled, aerodynamically modified moldavite from Slavice, Moravia, Czechoslovakia: Science, v. 146, No. 3645, p. 790–791.

Earth's atmosphere which must have been greater than about 5 kilometers/second to cause ablation.

Age and abundance of Australasian tektites

Field geologic studies of Australasian tektite occurences by E. C. T. Chao (U.S. Geol. Survey, 1–65, pt. C) indicate that they formed since middle Pleistocene. The tektites are found primarily in laterite soils, where transportation probably has been minimal, and in gravel deposits, where reworking and transportation are probable. The maximum number of tektites in the Australasian strewn field is estimated to be about 2×10^{13} on the basis of their areal density in places where reworking is improbable. From estimates of the number of tektites concentrated by fluvial transportation in the Manila Bay area of the Philippine Islands, the minimum number of tektites is estimated to be about 4×10^{9} for the entire strewn field. No terrestrial impact crater capable of producing the Australasian tektites has been discovered.

Analyses of small tektite samples by two spectrographic methods

C. S. Annell (U.S. Geol. Survey, 1–65, pt. C) analyzed 1–2-milligram samples of tektites for A1, Ca, Fe, Mg, and Ti by emission spectrography with both the rotating-disk–high-voltage-spark method and the gas-controlled-arc methods. The two solution methods give similar precision and accuracy, but the rotating-disk method is 3 to 5 times more sensitive and has wider application to the study of small quantities of silicate minerals. Working curves for the spectrographic determination of Na and K by the rotating-disk–high-voltage-spark method were also obtained. As little as 0.1 percent Na and 0.3 percent K now can be determined in silicate samples weighing 1 to 2 mg.

Mo, As, and Ir in tektite spherules imply meteoritic origin

Preliminary applications of the laser microprobe for emission spectrographic analysis and neutron-activation analysis of spherules from Philippine tektites by Frank Cuttitta, E. C. T. Chao, and C. S. Annell (U.S. Geol. Survey, 1–65, pt. C) indicate the presence of siderophile and chalcophile elements such as Mo, As, and Ir. These minor elements are generally much more abundant in iron meteorites than in most silica-rich rocks. The qualitative neutron-activation analysis gives further indication of the meteoritic origin of metallic spherules in tektites.

Older analyses for alkalies and TiO_2 of tektites in error

D. B. Tatlock (U.S. Geol. Survey, 1–65, pt. C) compared 55 older analyses of Australasian tektites with 110 modern, precisely monitored analyses and found that more than half of the older alkali and titania determinations are decidedly inaccurate and misleading. Deviations of the older analyses from the restricted values of the modern analyses are comparable to the imprecisions shown by early analyses of G–1 granite and W–1 diabase. This suggests that a high percentage of older alkali and titania analyses, such as those of Washington's tables, are of questionable quality.

Luminescence of achondritic forsterite and synthetic diopside

A mineral that luminesces red under ultraviolet radiation in the Norton County, Kans., enstatite achondrite meteorite has been identified as forsterite by M. B. Duke and B. A. Tryba (U.S. Geol. Survey, 1–65, pt. C). Low forsterite content in the meteorite means that the luminescent efficiency of the total meteorite is very low. This appears to eliminate ultraviolet-excited enstatite achondrite as a possible lunar red fluorescent material. Electron-excited luminescence of synthetic diopside shows the major role played by minor-element content of the mineral. Pure diopside luminesces blue; Mn-bearing diopside, red; Ti-bearing, orange; and Ni-bearing, green.

Thermomagnetic studies of tektites

In continuation of studies of the magnetic properties of tektites, F. E. Senftle, A. N. Thorpe, and S. R. White (A. N. Thorpe and F. E. Senftle, 1–64) have made thermomagnetic experiments on tektites to establish the state of the iron in the glass. Metallic iron spherules can be formed from the dissolved iron in any tektite heated under strong reducing conditions to temperatures above 1,530°C (melting point of iron). If the tektite is heated to lower temperatures under reducing conditions for several days, subsequent magnetic measurements show that the iron in solution, mainly as Fe^{+2}, is not reduced by this treatment. However, the magnetism of the surface regions of the tektite changes from paramagnetic to ferromagnetic after heating. The only reasonable explanation of this phenomenon is that a small amount of particulate iron present before heating, aggregates by a diffusion process to form ferromagnetic centers during heating. Further work is being done to see if the particulate matter is submicroscopic metallic spherules or an iron compound, as this is germane to the origin of tektites.

Electrical resistivity and viscosity of tektite glass

A. F. Hoyte, F. E. Senftle, and P. W. Wirtz (1–65) measured the electrical resistivity of 25 tektites from 7 different strewn fields as a function of temperature over the interval 330–450°K, using a time-of-discharge technique. From these data they determined activation energy for each specimen, and constructed a viscosity curve for the temperature region between 1,370° and 1,770°K. The calculated curve agrees within the limits of error with the experimental curves for several examples. The method can be used to calculate the viscosity within half an order of magnitude of the correct value. Mean viscosity curves have been constructed from the experimental data for tektites from the seven known strewn fields (A. F. Hoyte, F. E. Senftle, and P. W. Wirtz, 1–65).

UNMANNED LUNAR EXPLORATION STUDIES

The unmanned lunar exploration studies are concerned primarily with the scientific exploitation of the imagery received from the unmanned spaceflight projects of the National Aeronautics and Space Administration. The work includes the development of flight-operations procedures for spacecraft television systems and techniques by which the data received can be reduced to provide detailed topographic information, terrain maps, and large-scale geologic maps of the lunar surface.

RANGER TELEVISION INVESTIGATIONS

Rangers VII, VIII, and IX have contributed much important new information on the fine structure of the lunar surface. The wealth of photographic data acquired (over 17,000 pictures) will require several years of systematic analysis. Craters are the dominant small relief features; small positive relief features on the lunar surface, other than crater rims, are relatively rare. Ranger–VII pictures contributed to a better understanding of the nature of the lunar rays. The ray areas have a high density of irregularly shaped, shallow secondary craters probably formed by the low-velocity impact of materials thrown out of larger primary craters. The bright walls of these telescopically unresolvable craters contribute to the high albedo of the rays and, in addition, the rim materials of the secondary craters have a higher albedo than the adjacent parts of the maria.

Craters less abundant than impact origin predicts

On the basis of the observed crater distribution on the lunar maria, the present rate of meteorite infall on the earth, and information on the distribution and age of ancient impact craters and eroded structures of possible impact origin on the earth, E. M. Shoemaker has constructed a detailed model for the fine structure of the maria. The present number of small primary craters on the Moon is considerably lower than the number expected to have been formed by meteorite impact. The expected number of primary craters of a few meters in diameter and larger is more than two orders of magnitude greater than the observed number. A similar deficiency exists for small secondary craters.

It is impossible to observe the number of small craters of both primary and secondary impact origin expected to have been formed on the lunar maria. The total area of expected craters larger than 1 meter across is more than 10 times the total area of the mare surface. Small craters are lost by superposition of other craters of the same size or larger. In addition, the repeated formation of small craters obliterates larger ones. This interaction of craters produces a layer of shattered and pulverized rock that covers most of the mare. The layer is of varying thickness and rests with an irregular contact on the underlying mare material. Fragments in this layer have been derived for the most part by ejection of material from nearby craters, but some of the material has been derived from great distances. The grain size of the debris layer tends to decrease from bottom to top, because the fragments in the upper part have been shocked and broken a greater number of times during the formation of the more numerous smaller craters. The porosity of the debris layer may be as much as 90 percent at the surface, but it probably decreases rapidly at depth because of compaction by repeated impact events.

Ranger photograph permits detailed slope measurements

H. A. Pohn and L. C. Rowan made detailed slope measurements of the last Ranger-VII P3 frame using a modification of photoclinometric techniques employed in lunar terrain analysis. The calibrated transfer characteristics of the Ranger camera system were used, along with an adopted photometric function, to determine slopes from the density of the Ranger photographs. Topographic profiles were then constructed from the slope measurements, and the profiles were adjusted to a common datum plane to prepare a contour map. The final map shows an area approximately 30 by 25 meters at an approximate scale of 1:80 with a contour interval of 10 centimeters. It represents the most detailed information available on the distribution of lunar slopes and has been used to study problems of the landing dynamics of both manned and unmanned spacecraft.

SURVEYOR TELEVISION INVESTIGATIONS

The Surveyor television investigations by E. C. Morris, H. E. Holt, and R. M. Batson have been concerned with the development of test and calibration procedures for the Surveyor cameras and the development of techniques for extracting photogrammetric, photometric, and geologic information from the television pictures to be received from the system on the lunar surface. This work is required to insure that the television system on the Surveyor spacecraft will function as an effective geologic tool and that the maximum amount of information about the surface of the Moon will be acquired from each successful flight.

Prototype of Surveyor television camera tested

A field test of a prototype Surveyor television camera was conducted during the summer of 1964 on the Bonito lava flow in Sunset Crater National Monument, 15 miles northeast of Flagstaff, Ariz. Experience gained in this test led to the development of an efficient command sequence for mission operations. The pictures obtained have been used to develop specialized cartographic techniques for handling, processing, and mosaicking the imagery. Photogrammetric analysis of the imagery obtained indicates that distance measurements can be made to an accuracy of ±3 percent at a distance of 20 meters from the spacecraft; this figure may be exceeded by later flight-configurated cameras.[66]

Specialized instruments have been designed to aid in the geologic analysis and photogrammetric reduction of the Surveyor television imagery. These include a specialized stereoscope to view spherical mosaics prepared from large numbers of narrow-angle pictures taken by the Surveyor cameras and a special stereoranging instrument to be used as a focus analyzer or as a stereoplotter during mission operations.

LUNAR ORBITER INVESTIGATIONS

Kenneth Watson has solved the general equations for photoclinometric mapping of the Moon's surface from spacecraft imagery, and a computer program that will permit automatic digital production of topographic maps is being written. With these results and appropriate instrumentation, it will be possible to produce base maps very rapidly for terrain and geologic analysis from lunar Orbiter imagery.

LUNAR TERRAIN ANALYSIS

Slope measurements lead to classification of lunar surface

Lunar terrain analysis by J. F. McCauley and L. C. Rowan has led to a quantitative morphologic classification of the lunar surface.[67] An automated photometric measuring technique developed by the Geological Survey was used to measure some 40,000 slope components in the east-west direction from the best available earth-based photographs. Slopes of 1 kilometer base length are measured. These measurements have been used as the basis for classifying the lunar surface within the equatorial belt (±10° latitude, ±60° longitude). The primary terrain characteristics used for classification purposes have been the average or median slope and the 10th-percentile and the 90th-percentile slopes. The lunar equatorial belt was divided into 6 terrain units at a scale of 1:2,000,000. The smoothest of these units comprises relatively featureless parts of the maria that have a median slope of about 1.5° or less. The roughest terrain unit is in the lunar highlands and has a median slope of about 6°. This terrain is comparable to very rough terrestrial mountain areas such as the Sierra Nevada, in California. The terrain map has been used to help select the target areas for Rangers VII and VIII and for Surveyor test flights.

Extrapolation techniques have been used for the purpose of predicting the average slope of lunar terrain units over a broad range of slope lengths. The predicted median slope of the smooth mare terrain unit for slopes with a base length of 1 meter was within 1° of the median slopes measured with photoclinometric techniques from the last photograph obtained from Ranger VII.

STUDIES RELATED TO MANNED LUNAR EXPLORATION

Studies are being carried out to prepare for geological exploration of the lunar surface by manned space flight. The work includes geological training of the astronauts and investigation of methods of geological and geophysical exploration to be used by the astronauts on the lunar surface.

ASTRONAUT TRAINING

Program of instruction: first year

In July 1963, the U.S. Geological Survey, in cooperation with the Manned Spacecraft Center of the National Aeronautics and Space Administration, began a program to train astronauts in geology. The purpose of the program is to teach the astronauts to carry out geological studies on APOLLO missions. In the first year 13 classroom lectures were

[66] U.S. Geological Survey, 1964, Surveyor television investigations, Surveyor television experiment, field test no. 2, December 1964, Final report.

[67] U.S. Geological Survey, 1964, Terrain analysis of the lunar equatorial belt, July 1, 1964: Preliminary report.

given under the direction of E. D. Jackson on terrestrial and lunar aspects of the following subjects: geologic processes, geologic principles, stratified rocks, geologic structure and landforms, geologic mapping, and geophysics. Four field trips were held under the direction of A. H. Chidester.

At the Grand Canyon, in Arizona, training was concerned principally with field techniques and with the fundamentals of geology, such as the law of superposition, and laws of truncation and intersection. A field trip to west Texas provided training in observing and measuring stratigraphic sections and in mapping complexly folded and faulted rocks; the astronauts were also introduced to a variety of volcanic rocks. In the Sunset crater area, near Flagstaff, Ariz., the astronauts received training in hand-specimen petrology, morphology, stratigraphy, and structure of basaltic cinder cones and associated lava flows. A night at Kitt Peak Observatory, near Tucson, Ariz., was spent in lunar observations and mapping. At Philmont Ranch, New Mexico, the earlier training was applied in mapping exercises in three areas of varied geologic character, and an introduction was given in field geophysical techniques.

Program of instruction: second year

In the second year of the training program, classroom lectures were given by visiting experts in volcanic geology, impact structures, shock metamorphism, and lunar mapping. Field trips were oriented chiefly toward providing experience in a wide variety of volcanic geology and in crater geology, with emphasis on petrologic and stratigraphic relations, structural features, constructional forms, and genetic history. At Newberry crater, Oregon, under A. C. Waters, the astronauts studied (1) a basaltic shield volcano with a summit caldera in which the final stage of eruption was rhyolitic; and (2) the flanking fields of cinder cones on the shield, which are structurally controlled. At Valles caldera, New Mexico, under R. A. Bailey, they studied geologic and geophysical features of a caldera with a resurgent structural dome associated with rhyolite ash-flow tuffs. H. A. Powers conducted the astronaut group in a study of the shield volcanoes of Hawaii, and in the geological and geophysical research activities of the Hawaii Volcano Observatory. At the Nevada Test Site, W. J. Carr and R. L. Christiansen led a trip to Timber Mountain caldera, which had a complex history of ash-flow eruption after resurgence of the dome; and to Black Mountain caldera, which has no resurgent dome, but has instead centrally located constructional volcanic forms. The astronauts studied nuclear craters that are structurally analogous to impact craters, and followed this with a study of Meteor crater, Arizona, all under the leadership of E. M. Shoemaker.

INVESTIGATIONS IN SUPPORT OF MANNED LUNAR EXPLORATION

A manned lunar-exploration investigations group has been organized under D. P. Elston to advise the National Aeronautics and Space Administration on the requirements for geologic exploration of the Moon, to help develop and test operations and instruments of potential use during lunar exploration, and to provide the scientific and technical capability to simulate specific types of lunar surface missions.

Instrument testing in the field

Field tests were directed by H. H. Schmitt and G. A. Swann on the Bonito lava flow and at Meteor crater, in Arizona, to evaluate several possible instrument systems. The following instrument systems were shown to have useful geologic applications in Project APOLLO and possible following stages of lunar exploration: (1) a hand-held surveying staff on which are mounted imaging, tracking, and orientation subsystems; (2) an exploration periscope capable of range, azimuth and vertical-angle determination from the lunar excursion module of the APOLLO spacecraft; (3) a surveillance television system with both automatic and manual tracking of an astronaut on the surface from the lunar excursion module; (4) a staff-mounted television camera capable of transmitting continuous high-resolution images of surface materials; and (5) an instrument and sample carrier for use on the lunar surface.

Field experiments by Yukio Yamamoto with a prototype ranging laser have confirmed the applicability of this instrument for surveying from a lunar roving vehicle.

Testing of survey procedures in the field

During the field tests carried out on the Bonito lava flow and at Meteor crater, data have been obtained that permit both subjective and statistical evaluations of the relation between time required for given geological and surveying operations and the quality and quantity of the data obtained. Motion picture films of these operations have been compiled by H. G. Stephens so that further time and motion studies can be made by interested agencies. Time and information studies conducted to date have led to the following observations and recommendations: (1) Pre-flight planning of sample sites, in the absence of an automatic tracking system, is not feasible in heterogeneous terrain because the large amount of time required to locate sample sites would eliminate other high-priority scientific tasks during early APOLLO landings. (2) If samples and photographs of lunar material are returned to earth, geologic description on the Moon should be limited to (a) features too subtle, large, or complex to be illustrated by a sample or photograph, (b) items necessary to place the sample, photograph, or experiment in the context of its environment, and (c) lunar surface features which identify a structural unit for future reference during the lunar mission. (3) Operational flexibility rather than operational programming should be emphasized in the geological training program for the astronauts, as the time and efficiency of description, sampling, and photography largely depend on the nature of the geologic features and will not be completely predictable.

The manned lunar exploration investigations group has assisted the field geology planning team for Project APOLLO in preparing the functional specifications for an APOLLO field-exploration system. This system will provide automatic imaging, tracking orientation, physical-properties sensing, and telemetry subsystems. Such a system will permit the astronauts to use their time on the lunar surface for description of the Moon's fine structure and for the selection of pertinent samples, photographs, and physical-properties measurements, rather than for many routine acts of mapping and data collection.

Development of geophysical instruments and techniques

Investigations under the direction of J. S. Watkins are concerned with devising geophysical instruments and techniques for use by man on the lunar surface and for developing guides for interpreting the data. Field investigations have been conducted at Mono craters, California; the Pisgah crater area near Barstow, Calif.; the S. P. crater flow and the Kana-a flow in the San Franciscan volcanic field near Flagstaff, Ariz.; Meteor crater, Arizona; and in the Hopi Buttes area of the Navajo Reservation, Ariz. Work to date has resulted in the development of a shallow seismic-refraction technique for use in Project APOLLO to determine the thickness and character of the uppermost layer of fragmental material on the lunar surface. Field investigations also have shown that seismic techniques can be used to detect shallow subsurface cavities.

GEOPHYSICAL INVESTIGATIONS

STUDIES OF THE CRUST AND UPPER MANTLE

Continuing interpretation and synthesis of seismic-refraction data from throughout the United States are expanding our knowledge of the variations of crustal and upper mantle structure within and among the various physiographic provinces, and are increasing our understanding of the nature of regional isostatic compensation. It is now possible to publish reasonably reliable maps of crustal and upper-mantle velocity structure in the continental United States (L. C. Pakiser and J. S. Steinhart, 3–64). Large-scale differences extending deep into the earth that are associated with major physiographic features at the earth's surface have been discovered. For example, studies of the rate of attenuation of P-waves that have penetrated the upper mantle support previous conclusions, derived from traveltime data alone, as to differences in the properties of the upper mantle beneath the Central and Western States.

The accumulated evidence shows that the difference between continents and oceanic basins, as well as the difference between active areas and stable areas on continents, clearly is related to the observed seismic characteristics of the crust and upper mantle. Recent analysis of surface-wave data, which has been one of the principal sources of information on mantle structure, indicates that the mantle low-velocity zone for shear waves varies significantly between continents and ocean basins. The evidence available from such studies suggests that the lateral variations in upper-mantle velocity reported by the U.S. Geological Survey in recent years extend to considerable depth, at least several hundred kilometers, and thus are indicative of the deep structure of the planet rather than simply indicating minor near-surface differences.

REGIONAL SEISMIC-REFRACTION STUDIES

Differences in mantle between Eastern and Western United States

A detailed seismic-refraction profile extending more than 1400 kilometers was made from Lake Superior to the vicinity of Denver, Colo., as a part of the international cooperative Lake Superior experiment. This profile contains some of the highest-quality seismic data ever recorded in this distance range. The data show an unusually low attenuation of P-waves that have traveled in the upper mantle, and give no indication of a shadow zone which is usually taken as evidence of a low-velocity zone in the upper mantle. In fact, the low attenuation with distance implies an increase in velocity with depth sufficient to hold a large fraction of the seismic energy in shallow propagation paths.

By contrast, analysis of data from nuclear and chemical explosions in the Western United States (J. C. Roller, 2–65; Ronald Willden, p. C44–C50) shows a high attenuation of P-waves in the upper mantle and indicates that the mantle in the tectonically active Western United States is distinctly different from the mantle in the stable areas of the east. This difference had been predicted earlier from the traveltimes of P-waves, but the noted amplitude attenuation with distance is an important additional clue to the nature of the rocks composing the upper mantle.

Basalt-filled rift under Lake Superior suggested

Continuing analysis of data collected in the Lake Superior experiment shows that the crustal structure under Lake Superior is probably a continuation of the crustal structure associated with the midcontinent gravity high. This segment of the crust apparently was formed by the intrusion of great masses of basalt into a crustal rift which extended from Lake Superior to the southern limits of the midcontinent gravity high. In addition to the local geologic interest and associated economic implications of this structure, its existence illustrates that anomalous zones can persist in the crust for hundreds of millions of years and has an important bearing on the strength and stability of crustal rocks over long periods of time.

No marked crustal root under Southern Rockies

Two underground mining blasts detonated at Climax, Colo., in May 1964, have led to increased understanding of the nature of isostatic compensation in the Western United States. Interpretation of seismograms recorded at 17 locations in the Front Range uplift of the Southern Rocky Mountains suggests a crustal thickness north of Climax of approximately 54 kilometers, thinning abruptly by about 15 km in the area directly east of the Uinta Mountains (W. H. Jackson and L. C. Pakiser, p. D85–D92). Comparison of these results with those previously reported for the Basin and Range, Colorado Plateaus, Middle Rocky Mountains, and Great Plains provinces reveals that there is no pronounced crustal root under the Southern Rocky Mountains (as might be expected because of their high average elevations) and that isostatic compensation is related primarily to density variations in the upper mantle and only secondarily to variations in crustal thickness.

Crust under Basin and Range province and Snake River Plain

D. P. Hill and L. C. Pakiser have completed a study of crustal structure along a line that extends northward from the Nevada Test Site across the Basin and Range province and the Snake River Plain to Boise, Idaho. Seismic waves generated by chemical explosions along profiles about 300 kilometers long and by nuclear explosions at the Nevada Test Site along the entire 1700-km-long profile were analyzed. The study indicates that the M-discontinuity is very irregular, with abrupt (possible vertical) changes in depth of several kilometers at several places along the profile. These abrupt changes in depth could be due to faults that extend downward into the upper mantle. Crustal thickness in the Basin and Range province ranges from 25 to 36 km. Crustal thickness in the Snake River Plain ranges from 42 to 49 km. An intermediate crustal layer, probably of basaltic composition, rises from a depth of about 20 km in the Basin and Range province to less than 10 km in the Snake River Plain. Amplitudes of seismic waves generated by the nuclear explosions fall off approximately as the inverse cube of distance, but are scattered through a factor of five. This extreme scatter in amplitudes may be caused by the irregular shape of the M-discontinuity and by complexities in crustal structure.

Crust thickens near Mogollon Rim

Analysis of a set of seismic recordings made at the Tonto Forest Seismological Observatory, Payson, Ariz., shows an abrupt thickening of the crust in the vicinity of the Mogollon Rim (J. C. Roller and D. H. Warren, written communication). The Mogollon Rim is generally considered to be the transition between the Basin and Range province and the Colorado Plateaus province and formerly was generally thought to be an erosional feature. The new seismic evidence suggests that the boundary represents a fundamental lateral change in the crust of the earth.

Break in crustal structure at Walker Lane indicated

An analysis of a seismic profile recorded between Lake Mead, Nev., and Mono Lake, Calif., clearly shows the thickening of the crust from the Basin and Range province to the Sierra Nevada, and suggests a break in crustal structure as the profile crosses the surface feature known as the Walker Lane, according to Lane Johnson.[67a]

[67a] Lane Johnson, 1965, Crustal structure between Lake Mead, Nevada, and Mono Lake, California: Jour. Geophys. Research. [In press]

High crustal velocities typical of rift zones on Hawaii

During August 1964 seismic-refraction profiles were recorded along the northeast, southeast, and west coasts of the triangular-shaped island of Hawaii. Shots were fired at 10-kilometer intervals from the U. S. Coast Guard cutter *Cape Small*, and were recorded along each coast by 5 refraction units spaced at approximately 25-km intervals. Interpretation of the seismograms by D. P. Hill indicates that the crust is 16 to 18 km thick under the west flanks of Mauna Loa and Hualalai, and 11 to 12 km thick under the northeast and southeast flanks of Kilauea. The crust has an intermediate thickness along the northeast flanks of Mauna Kea and the Kohala Mountains. The velocity of P waves in the upper crust increases with depth from 2.0 to as much as 6.0 km/sec; velocities in the upper crust are generally lower on the flanks of Kilauea than on the flanks of the other volcanoes. Clearly recorded arrivals indicate that a layer with velocities from 6.9 to 7.4 km/sec forms the lowermost 4–8 km of the crust under each of the coasts. The velocity of P_n under each of the coasts is about 8.2 km/sec. Anomalously high crustal velocities are associated with the major rift zones extending from the five volcanoes that form the island. This interpretation of the refraction data is consistent with gravity data on the island of Hawaii.

Seismic network at site of Hebgen Lake earthquake

The Yellowstone Park, Wyo.–Hebgen Lake, Mont. region–site of the major Hebgen Lake earthquake of August, 1959–provides a natural laboratory in which to study the relationships between volcanic activity, recent earthquakes, and surface geology. In the fall of 1963, J. P. Eaton of the U. S. Geological Survey, in cooperation with the National Park Service, initiated a detailed study of earthquakes in and near Yellowstone National Park. Since that time, equipment and operational procedures have been developed that permit continuous recording at remote stations throughout the year, and a network of 3 vertical-component seismometers and 2 three-component seismometers has been established.

Highlights of a preliminary study of earthquakes recorded from December 1964 to March 1965 are: (1) a swarm of about 70 earthquakes originating in the Upper Geyser Basin area near Old Faithful was recorded December 15, 1964; (2) a swarm of about 150 earthquakes originating along the eastern margin of West Yellowstone Basin was recorded February 19–20, 1965; (3) other earthquakes recorded during this period outline a zone of activity trending roughly east-west from Hebgen Lake to Norris Junction.

Important earthquake zone northeast of Denver indicated

Seismic activity is continuing northeast of Denver, Colo. Geophysicists of the U. S. Geological Survey and the Colorado School of Mines are cooperating in a study of these earthquakes. To supplement the sparse network of seismic stations, the U. S. Geological Survey operated three additional portable seismic systems on a temporary basis during February and March, 1965. A study by Y. Wang of the Colorado School of Mines indicates that the most important earthquake zone is in the Commerce City area northeast of Denver. Hypocenters determined for approximately 150 earthquakes in this area range in depth from 5 to 40 kilometers.

COOPERATIVE EXPERIMENTS IN SEISMOLOGY

USGS takes part in Canadian study of crust in Alberta

In July 1964, a 500-ton charge of TNT was detonated on the surface of the Watching Hill Range, Suffield Experimental Station, Alberta, Canada, for the Canadian Defense Research Board. The shot was recorded by seven U. S. Geological Survey low-frequency seismic-refraction systems along a line extending from High River, Alberta, in the Great Plains, westward into the Canadian Rocky Mountains at radial distances ranging from 220 to 300 kilometers from the shot. Other Geological Survey units that recorded the explosion were a conventional exploration reflection-refraction system located near Brooks, Alberta, about 100 km west of the shot point, and a prototype slow-speed tape system located about 350 km from the shot point in the Rocky Mountains north of Canal Flats, British Columbia. All seismic systems recorded air arrivals in addition to seismic arrivals. The work was conducted in cooperation with Dr. G. L. Cumming, associate professor of geophysics, University of Alberta, to assist in his study of the earth's crust in the Great Plains and Rocky Mountains of Alberta.

Crustal structure in Oklahoma under cooperative study

U.S. Geological Survey personnel also participated in a cooperative seismic study of the earth's crust and upper mantle in central Oklahoma as a joint Geological Survey–Advanced Research Projects Agency (ARPA) contribution to the transcontinental geophysical survey of the upper mantle project. The study was organized and directed by Dr. Eysteinn Tryggvason, Assistant Professor of Geophysics, University of Tulsa. Other participants were University of Wisconsin, Jersey Production

Research Co., and Seismograph Service Corp. A total of 10 shots, ranging in size from 1,000 to 10,000 pounds, were fired with shot-point communications and timing equipment operated by Geological Survey crews. Five Geological Survey seismic crews occupied presurveyed locations along the recording line, moving with each successive shot.

REGIONAL GRAVITY STUDIES

San Luis Valley believed to be a rift broken by horsts and grabens

A regional gravity survey in the San Luis Valley area of South Central Colorado has been completed by J. R. Gaca. Interpretation of the data indicates that the San Luis Valley is a large rift valley internally broken by horsts and grabens. Depths to Precambrian rock underlying a filled graben along the eastern edge of the valley range from a minimum of 16,000 feet near Villa Grove to more than 30,000 feet north of Mount Blanca. The Sangre de Cristo mountains are interpreted as being locally uncompensated, indicating that these mountains are an excess mass being supported by the strength of the earth's crust.

Similar crust under Mount Shasta and Lassen Peak noted

Gravity measurements in the Mount Shasta–Lassen Peak areas of northern California suggest certain similarities in the upper part of the earth's crust in these two regions (La Fehr, written communication; L. C. Pakiser, 1–64). Interpretation of the Bouguer anomaly field suggests that both regions are characterized by large volumes of low-density rocks at relatively shallow depths. Limiting depth estimates indicate that the anomalous masses cannot lie entirely below depths of 4 to 10 kilometers. Application of Gauss' theorem [68] to the residual gravity anomalies in these areas indicates that the amount of mass deficiency so obtained corresponds well with the topographic mass excess. This indicates that the topographic mass excess of the Mount Shasta–Lassen Peak area is in approximate isostatic equilibrium with the shallow, low-density rocks. Thus, the compensation of Mount Shasta may be entirely a local phenomenon. In the classic sense of Airy or Pratt there may be no compensation necessary for Mount Shasta or the rest of the high Cascades. A vertical column taken through the crust at Mount Shasta may have no net excess mass below the relatively shallow depth of 6 to 10 km (La Fehr, written communication).

[68] T. R. La Fehr, 1965, The estimation of the total amount of anomalous mass by Gauss' theorem: Jour. Geophys. Research, v. 70, no. 8, p. 1911–1919.

GEOTHERMAL INVESTIGATIONS

Studies of terrestrial heat flow in the Appalachian Mountain system, in active orogenic regions such as Puerto Rico and Chile, in the Western United States, and in the Arctic Ocean basin are continuing.

Heat flow in Appalachian Mountains measured

W. H. Diment reports that measurements of terrestrial heat flow at six localities in the central and southern part of the Appalachian Mountain system range from 0.7 to 1.4 microcalories per square centimeter per second. If a regional pattern exists, these measurements would suggest that heat flow is low in the eastern part of the Valley and Ridge province, higher in the metamorphic terrain adjacent to the east, and possibly highest in the intruded core of the Appalachian Mountain system (W. H. Diment, R. Raspet, M. A. Mayhew, and R. W. Werre, 4–65).

Low heat flow found in two active orogenic regions

Terrestrial heat flow was found to be low at two localities in active orogenic regions. A value of 0.6 microcalorie per square centimeter per second was found near Mayaguez, Puerto Rico (W. H. Diment and J. D. Weaver, 2–64; W. H. Diment, 1–64), and a preliminary value of 0.7–1.0 microcalorie per square centimeter per second was found near Vallenor, Chile. These low values are not entirely unexpected, and when compared with values in Japan and California, suggest that high lateral gradients of heat flow may be typical of active orogenic regions.

Average heat flow in the western conterminous United States and Alaska

A few generalized preliminary results are available for the thermal gradient and thermal conductivity measurements being carried out in the western conterminous United States and Alaska by A. H. Lachenbruch. If heat flow is defined as "average" if its value is between 1.2 and 1.6 microcalories per square centimeter per second, and "low" or "high" if it is respectively below or above this range, then the heat flows determined at the western edge and the eastern edge of the Basin and Range province are high. Heat flow at the southern margin of the Basin and Range province varies locally from low to high. One determination in the eastern Mojave region of California, suggests average heat flow, and average values are being obtained in other parts of the State, in the Los Angeles Basin and western San Joaquin Valley. A high value was obtained in the Coeur d'Alene district of Idaho, and evidently average values were obtained in arctic Alaska. The significance of results such as these cannot be studied profitably until more data become available.

Heat flow in the Arctic Ocean

The Arctic Ocean lies in the center of what was formerly one of the largest geothermally uncharted regions on earth. Studies by A. H. Lachenbruch show that the heat flow throughout much of the Canada Basin is about 1.40 microcalories per square centimeter per second, and that at its northern limit (at the flank of the Alpha Rise) heat flow drops abruptly to less than 0.8 microcalorie per square centimeter per second. The anomaly has no simple explanation in terms of bottom topography, oceanic circulation, or inhomogeneity in source distributions or thermal properties of the crust or upper mantle.

Theoretical and experimental studies by A. H. Lachenbruch show that the formulas in general use for finding the thermal conductivity of oceanic sediments yield results on the order of 10 percent too low for material from the Arctic Ocean. This was determined from a series of 300 thermal conductivity tests of sediment from the Arctic Ocean. In addition, mathematical results have been obtained for the effect of a surface slope on surface heat flow. These results provide a means of making approximate topographic corrections to ocean-bottom heat-flow data.

THEORETICAL AND EXPERIMENTAL GEOPHYSICS

ROCK MAGNETISM

Time scale for geomagnetic-polarity epochs

The time scale, shown in the accompanying table, for reversals of the geomagnetic field has been developed by Allan Cox, R. R. Doell, and G. B. Dalrymple.[69] Ages, given in millions of years, were determined by the potassium-argon method.

Reversed geomagnetic polarity	Age (millions of years)	Normal geomagnetic polarity
	0.0	
		Brunhes epoch
	0.85 ± 0.15	
Matuyama epoch		(Olduvai event, 1.8–1.9 m.y.)
	2.4 ± 0.1	
(Mammoth event, 3.0–3.1 m.y.)		Gauss epoch
	3.35 ± 0.1	
Gilbert epoch		

Geomagnetic polarity epochs are time intervals during which the magnetic field of the earth was predominantly or entirely of one polarity. These are interrupted by brief fluctuations in polarity termed "polarity events," as indicated in the accompanying table. During the past year several gaps in the time scale have been filled with information from additional paleomagnetic-geochronometric studies of rocks from the Sierra Nevada, the Pribilof Islands of Alaska, the Galapagos Islands, and New Mexico.

One of the more important new results has been confirmation of the Olduvai normal event occurring 1.8–1.9 million years ago. Previously this event was based on a single determination from Africa. Allan Cox, D. M. Hopkins, and G. B. Dalrymple have found four additional normally magnetized flows with the same age in the Pribilof Islands. These flows are bracketed in radiometric age and in stratigraphic position by reversely magnetized flows, leaving little room for questioning that the Olduvai event represents a brief worldwide fluctuation in the polarity of the earth's field.

A close correlation of polarity epochs with geomorphology has been established in the Hawaiian Islands, in Alaska, and in the Galapagos Islands. In all these areas, primary volcanic features are still recognizable in volcanic terrain formed during the Brunhes normal-polarity epoch. In terrain formed during the Matuyama or earlier polarity epochs, there is much more erosion and faulting. One of the more important contributions of paleomagnetism to geology may, in fact, be to provide in the Matuyama-Brunhes boundary an easily recognizable time horizon from which variations in rates of erosion may be determined as a function of environment.

The polarity time scale has also been linked to other methods for geologically inferring age. The relation of polarity epochs to the Pliocene-Pleistocene boundary, as defined by the type section in Italy, is being reviewed. Most probably the Pliocene-Pleistocene boundary lies within the Gauss normal-polarity epoch, although this is subject to considerable uncertainty because of a paucity of paleomagnetic and geochronometric results from the type section. Despite the uncertainty of the link with the Pliocene-Pleistocene boundary, polarity epochs are already proving very useful in providing stratigraphic links between Alaska, Idaho, California, New Mexico, Hawaii, Iceland, France, and the U.S.S.R.

Geomagnetic secular variation linked to earth's mantle

At the present time magnetic north deviates from true north by an angle which, while highly variable,

[69] Allan Cox, R. R. Doell, and G. B. Dalrymple, 1964, Reversals of the earth's magnetic field: Science, v. 144, p. 1537–1543.

is typically several tens of degrees. Only a small part of this secular variation is due to iron-bearing minerals in the earth's crust; the greater part of such variation is caused by a system of currents in the earth's liquid core. The irregular field produced at the earth's surface today by these currents varies from place to place. In the South Atlantic Ocean, Indian Ocean, and Siberia, it is pronounced; in the central Pacific it is almost absent. The question arises, have these geographical differences persisted over long periods of time? If the answer is yes, the highly significant geophysical conclusion may be drawn that some process or condition in the mantle exerts control on the system of currents in the core which produces the secular variation, giving us one of our first indications of lateral inhomogeneities in the earth's lower mantle. Allan Cox and R. R. Doell (2–64) have found from paleomagnetic studies in Alaska, the western conterminous United States, Hawaii, and the Galapagos Islands that many of the geographic controls apparent in the present pattern of geomagnetic secular variation have persisted for the past million years. The present dependence on latitude is even more pronounced. Moreover, the low value of secular variation in the central Pacific has persisted during this time. An explanation that was previously offered is that this represents inductive shielding by layers with high electrical conductivity in the mantle. Cox and Doell (2–64) have examined this quantitatively and found that it fails by a wide margin to explain all of the observations. They advance the alternative explanation that lateral temperature difference in the lower mantle may exert control on the pattern of fluid convection in the core.

Paleomagnetism of Mesozoic rocks

Consistent paleomagnetic directions have been obtained by Andrew Griscom for each of the following Mesozoic intrusions in Maine, New Hampshire, and Vermont: Cuttingsville, Ascutney, Merrymeeting, Pawtuckaway, Ossipee, Alfred, Tatnic, Cape Neddick, Sanford, and Agamenticus. The directions differ somewhat but are all consistent with the Mesozoic ages. Some are normally, and others reversely, magnetized.

Geophysical investigations in the Gettysburg-Newark basin, Pennsylvania, by M. E. Beck, Jr., have suggested a correlation between lithology and variations in the degree of instability of remanent magnetic moments in the diabase of that area. Results to date show a marked correlation of magnetic instability with samples having a higher than average concentration of late magmatic material, especially interstitial micropegmatite. These observations apply to comparisons between separate samples from the same locality as well as to contrasts between localities. Grain-size differences, variations in degree of oxidation, or the existence of a range of titanium substitution in magnetite, all may contribute to the observed differences in magnetic properties.

Computer technique for magnetic analysis as applied to seamounts

In the conventional method used at present the direction of internal magnetization is determined by a laboratory examination of hand specimens of rock. On the other hand, the computer method developed by B. F. Grossling permits a determination to be made even for large geologic bodies. As an example, he determined the internal magnetization for three seamounts off the coast of California, finding that the directions of magnetization are markedly different from that of the earth's present magnetic field.

The determination of the internal magnetization of seamounts can be a valuable tool in the study of the relative movements of segments of the earth's crust, and of the crust as a whole with respect to the earth's magnetic field. Because seamounts are numerous (their number has been estimated at about 10,000) and scattered throughout most of the oceans, they may be expected to yield, ultimately, a wealth of information.

Changes in position of a seamount, since the time of its cooling below the Curie point, with respect to the dipole field, will result in a discrepancy between the directions of the remanent and induced magnetizations. The fact that some seamounts are found to be magnetized uniformly throughout may indicate that the earth's dipole field has been relatively stable during the length of time required for the formation and sufficient cooling of the seamount. Seamounts might have formed at quite different times. Meanwhile, many crustal movements have taken place.

An area of particular interest for an investigation of crustal movements, using the magnetization of seamounts, is the area of the Pacific Ocean west of the United States. Vacquier and others believe that very large displacements, even larger than 1,000 kilometers, have taken place along certain linear fractures in the oceanic crust. Such large displacements near the continental block may require other secondary displacements, such as rotation of crustal blocks, or an entirely new genetic conception about the formation of the oceanic and continental crusts.

New method for gravity and magnetic interpretation

R. G. Henderson's work on depth calculation by downward continuation has led to development of the depth functional, a new and powerful concept in quantitative magnetic and gravity interpretation. With the aid of the functional, explicit formulas for depth and depth extent have been obtained for some configurations for the first time. The depth for more complex configurations can be found from a plot of the functional versus depth. An analytical method has been devised for locating contacts between contrasting magnetic rocks despite shifts in the anomaly, with respect to the body, due to horizontal components of magnetization. It is now possible to compute susceptibility without recourse to a model for size.

Some success has been achieved in computing bottom configurations for two- and three-dimensional gravity distributions by downward continuation and an improved version of Tsubois' condensation method.

PHYSICAL PROPERTIES OF MINERALS AND ROCKS

New method for calculation of elastic constants

Previous methods of calculating the average elastic constants of single crystal aggregates invoked unrealistic assumptions regarding the stress (or strain) distribution in the aggregate. These assumptions led to dissimilar values for the calculated averages, especially when the anisotropy of the single crystal was large.

Louis Peselnick and Robert Meister have devised a variational method for calculating the average elastic constants, based on an energy extremum, and not using the assumptions on stress or strain. The method was extended to aggregates having hexagonal single crystals and to aggregates of trigonal single crystals. The bounds of the effective moduli obtained in this way show a considerable improvement over the bounds found by using the conventional stress-strain assumptions.

Experimental compaction of carbonate sediments

The pressure required to compact carbonate sediments during diagenesis is estimated with difficulty from such evidence as absence of crushing of fossils. Even delicate aragonite needles, 1 micron long, do not begin to crush until the pressure exceeds 100 bars. Most fossil shells, moreover, retain integrity to 1 kilobar of pressure because the wet sediment flows into and around the shell and supports it. Studies by E. C. Robertson show that compaction, measured by the ratio of grain volume to bulk volume, varies linearly with log pressure from 0.7 to 1 kb, but compaction increases more rapidly at higher pressure, approaching 1.0 (zero porosity) at about 20 kb. In the linear range, other variables affecting compaction are initial water content, grain size, and rate of loading; in the high range, permeability and cohesive grain friction become more important.

Dielectric constant of moist rocks

An old controversy regarding the dielectric constant of moist rock has been settled, according to J. H. Scott, by the development of a new laboratory method which avoids errors inherent in previous methods. Past attempts to determine the dielectric constant of moist rock have been hampered by electrode-polarization errors which caused measured values to be too high. Some critics believed that values of dielectric constant measured at low frequencies (100 cycles per second), which have been reported in the order of 10^6 for porous, saturated rocks, were entirely erroneous, and that the true value was probably closer to 10 or 20, as it is for dry rock. The new laboratory method uses electrochemically reversible electrodes made of platinized platinum plates and blotter-paper discs that are saturated with a suspension of silver and silver chloride. Preliminary results indicate that measurements by previous investigators are in error by no more than an order of magnitude, and that the dielectric constant of moist rock at low frequencies is, indeed, quite high.

Seismic-wave attenuation in various rocks

The amplitudes of the P head wave have been measured by J. S. Watkins, J. C. DeBremaecker, and R. H. Godson on an aa lava flow, on cinders, and on limestone. The results can be treated by assuming a complex shear modulus μ, but a real second Lame constant λ. The data are satisfied by an equation of the type $A = Nd^{-2} \exp (-\Pi\ d\ Q\alpha^{-1} \upsilon\alpha\ -1)$, where A is the amplitude, N an arbitrary constant, d the distance, $Q\alpha$ the attenuation coefficient for P waves, υ the frequency, and α the P-wave velocity. The ratio of the attenuation coefficient for P waves and the attenuation coefficient for shear waves $(Q\alpha/Q\beta)$ derived from the assumption of a complex shear modulus equals half the ratio of the squares of the P- and S-wave velocities $(0.5\ \alpha^2/\beta^2)$. This relationship is in reasonable agreement with published results of investigations of P- and S-wave attenuation.

Field versus laboratory measurements of wave velocities

C. R. Tuttle and E. J. Monk measured a mean longitudinal wave velocity along the strike of 16,290 feet per second for 6 selected NX core samples of quartz-albite-feldspar schist from Dartmouth, Mass. The velocity for the same rock type measured in the field under shallow overburden in a direction bearing an unknown relation to structure was 14,900 feet per second. The mean longitudinal wave velocity measured on 16 cores from 5 boreholes compared to the velocity measured in the field was in the ratio of 1:0.9.

AERIAL INFRARED SURVEYS

Temperature distribution at summit of Mount Rainier

Aerial infrared surveys of Mount Rainier, Wash., by R. M. Moxham, D. R. Crandell, and W. E. Marlatt (p. D93–D100) showed that the highest temperature fumeroles are associated with the youngest, east summit crater. Temperatures are lower around the periphery of the west crater; a reticulated pattern extends down the northwest flank of the present summit cone and is bounded by an arcuate pattern of isolated anomalies that perhaps coincides with a third, older crater that has not been previously recognized. The summit craters are offset to the southeast of the central axis of the volcano and inferred central plug. The maximum temperatures associated with each of the craters are found consistently on their northwest quadrant, coinciding with the nearest approach to the central plug.

Results of infrared survey of Irazú Volcano, Costa Rica, are summarized in the section "Investigations in Other Countries."

SOLID-STATE STUDIES

FIELD STUDIES OF THERMOLUMINESCENCE

Contact metamorphic effects near Marble, Colo.

C. R. Roach and G. R. Johnson have studied the thermoluminescence characteristics of two formations in an attempt to trace their thermal histories. Detailed studies have been made on the Yule marble (contact metamorphosed Leadville Limestone) and the Niobrara Limestone near the Treasure Mountain stock, in the vicinity of Marble, Colo. The marble samples near the granite-marble contact and the nonrecrystallized limestone farthest removed from the stock had the greatest thermoluminescence. Heat from the stock probably destroyed some of the natural thermoluminescence of the Niobrara Limestone near the intrusive. The cause of the higher thermoluminescence in the marble near the contact is not clear.

Characteristics of granite near a ring dike in Colorado

In a study of Precambrian granite near a ring-dike complex in the vicinity of Virginia Dale, Colo., C. R. Roach and G. R. Johnson found that samples of the granite adjacent to the outer ring of the complex do not show natural thermoluminescence initially. However, after irradiation with gamma rays, they exhibit the thermoluminescence characteristic of this granite elsewhere. These relations suggest that the natural thermoluminescence of the Precambrian granite near the outer ring was destroyed by a relatively recent thermal event.

LABORATORY STUDIES OF THERMOLUMINESCENCE

Emission of cesium iodide measured by fast-scan monochrometer

Using a fast-scan monochrometer developed and built in laboratories of the U.S. Geological Survey, Prudencio Martinez and F. E. Senftle have been able to make spectral-emission measurements of thermoluminescence peaks in the ultraviolet and visible regions in a matter of a few seconds. X-ray fluorescence measurements of cesium iodide show 3 emission bands—at 290 millimicrons, 325 mμ, and a broad band centered at 400 mμ. The decay times of the 290-mμ and 325-mμ bands are temperature dependent with maximum values at 100 nanoseconds and 500 nsec, respectively. The decay time of the 400-mμ emission is about 15 microseconds. The 290-mμ and 325-mμ emission is ascribed to the production of V_k centers by the X-rays. Due to an absorption band at 299 mμ, the 290-mμ emission is strongly absorbed in thick crystals. The cause of the 400-mμ band has not yet been determined.

Background thermoluminescence reduced by water lapping

In a study of low-temperature thermoluminescence of halite, C. R. Roach and G. R. Johnson have found that low-temperature autoluminographs of halite wafers indicate that water-lapped wafers of halite have less background thermoluminescence than do emery-lapped wafers of halite. Low-temperature glow curves obtained on these wafers indicate that the intensity of background thermoluminescence of the water-lapped halite is, on the average, about 250 percent lower than that of emery-lapped halite. These studies indicate that the best way to prepare samples of halite for low-temperature thermoluminescence studies is to prepare the wafers first by emery-lapping techniques and then to finish the specimens by water lapping.

MAGNETIC-SUSCEPTIBILITY MEASUREMENTS

Magnetic properties of zircon due to iron oxide coatings

In magnetic susceptibility and magnetization measurements on more than 100 granitic zircon samples, A. N. Thorpe, F. E. Senftle, and Sherman White found that all but one sample showed weak ferromagnetic properties. Leaching, reduction, and oxidation experiments along with magnetization studies on some of these specimens indicate that the crystal grains are coated with one or more iron oxides and (or) iron oxide hydrates and that the ferromagnetism is due to either or both Fe_3O_4 and γ-Fe_2O_3. The Fe_3O_4 or γ-Fe_2O_3 are not contamination brought in from outside the zircon crystals, but are formed by oxidation of natural-impurity iron exposed to the atmosphere on the grain surface.

Magnetic susceptibility of palladium

A. N. Thorpe has measured the magnetic susceptibility of palladium over the temperature interval between 4°K and 300°K. Previous measurements did not cover the 4°K to 20°K region. His measurements confirm the previous work and show that the susceptibility is almost temperature independent in the 4°K to 20°K range. The palladium-hydrogen and palladium-deuterium measurements confirm Mott's hypothesis that the addition of hydrogen or deuterium to palladium fills the D band of the electronic energy configuration. However, the measurements also show that the systems palladium-hydrogen and palladium-deuterium are not completely two-phased at intermediate concentrations of hydrogen and deuterium.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

FIELD STUDIES IN PETROLOGY AND GEOCHEMISTRY

SILICIC PLUTONIC ROCKS

Allanite and monazite from Mount Wheeler area, Nevada

D. E. Lee and Harry Bastron have studied the rare-earth elements in 20 samples of allanite and 13 samples of monazite separated from granitic and xenolithic rocks of the Mount Wheeler area, eastern Nevada. The degree of fractionation of the rare earths, as measured by the sum of the atomic percentages of La, Ce, and Pr, varies directly with the CaO content of the whole rock, which itself depends largely on proximity of limestone. Comparisons of CaO and rare-earth data between xenoliths and respective closely associated intrusive phases indicate that the degree of fractionation of rare earths responds to whole-rock composition over distances of a few yards or more. Assimilation of limestone rather than magmatic differentiation must be the dominant process that produced the observed chemical gradients in these granitic rocks. Allanites from the most calcium-rich rocks show a degree of concentration of the most "basic" rare earths usually found only in minerals from alkalic rocks and carbonatites, and whole-rock concentrations of such rare constituents as total rare earths, Zr, Ti, P, Ba, and Sr increase sympathetically with whole-rock calcium. These observations suggest that the chemical processes that produced these intrusive rocks may be similar to processes that form alkalic rocks and their associated carbonatites.

Allanite in Boulder Creek batholith, Colorado

N. L. Hickling has made a chemical, optical, and X-ray study of the accessory allanite in the Boulder Creek batholith, Colorado, as part of a continuing investigation of the rocks and minerals in this complex Precambrian intrusion. Allanite was separated from 20 representative rocks ranging from mafic granodiorite to leuco-quartz monzonite.

Consistent with an inferred late (deuteric?) origin for the allanite based upon field and microevidence, specific rare earths and other constituents of the allanite when plotted against the same, or other, oxides in the containing rocks showed little or no systematic relationship. In certain of the variation diagrams, however, the field of allanite from rocks of relatively low apparent age (as dated by T. W. Stern using the lead-alpha method applied to zircon) was clearly separable from that of allanite from relatively high-age rocks, indicating a loss of constituents during some later event. The variation in indices of refraction of the allanite was found to be strongly dependent upon its thorium and uranium content, and only slightly related, if at all, to other major constituents. The main variation in indices, therefore, is attributed to metamictization. The resulting radiation damage is evident in X-ray powder patterns as a broadening of lines.

Distribution of tantalum in southern California batholith

The distribution of tantalum in comagmatic rocks and in coexisting minerals of the southern California batholith has been studied by David Gottfried and J. I. Dinnin (p. B96–B100). The study is based on low-level tantalum analyses by J. Thompson of the Imperial College of Science and Technology, University of London, using neutron-activation methods and by Dinnin, using chemical methods. The tantalum content of the batholith is estimated at 0.4 parts per million, ranging from 0.13–0.24 ppm in gabbro to 0.38–0.45 ppm in granodiorite and quartz monzonite. About 80 percent of the tantalum in the rocks is contained in hornblende and biotite. In the more siliceous rocks the tantalum content of these minerals is greater, but the abundance of the minerals is reduced.

Microperthite in Boulder batholith, Montana

R. I. Tilling, during the course of a petrologic study of the Boulder batholith, Montana, has found that the potassic phase of microperthite within 2 to 3 miles of the margin of the Rader Creek granodiorite is monoclinic, whereas the potassic phase near the core of this granodiorite body exhibits simultaneous monoclinic and triclinic symmetry. These dual-symmetry feldspars appear to record an intermediate state in the discontinuous inversion of orthoclase to microcline.

Use of refractive index of glass beads to estimate silica content

Use of the index of refraction of glass beads fused from samples of volcanic rocks has been suggested for estimating the silica content of the rock. N. K. Huber and C. D. Rinehart have now demonstrated that maximum accuracy can only be obtained when separate curves are established for individual rock suites.

MAFIC AND ULTRAMAFIC ROCKS

Alkali content of alpine-type ultramafic rocks

A study of the sodium and potassium contents of alpine-type ultramafic rocks from 6 regions in the United States and 1 in Australia was made by Warren Hamilton and Wayne Mountjoy. A dilution-addition modification of the flame-spectrophotometric method was used to measure the very small quantities of alkalies present in these rocks. The median value found for Na_2O is only 0.004 percent, and that for K_2O is 0.003 percent. Derivation of basalt magma from upper-mantle material similar to such ultramafic rocks, as has been postulated, is precluded by the relative amounts of sodium and potassium, which are 200 to 600 times more abundant in basalt than in these ultramafic rocks. The ultramafic rocks might have originated either as magmatic crystal precipitates or as mantle residues left after melting and removal of basaltic magma.

Composition and origin of oceanic tholeiites

A. E. J. Engel and C. G. Engel have determined that the oceanic tholeiites that form many submerged volcanic features in the oceans are characterized by extremely low amounts of Ba, K, P, Pb, Rb, Sr, Th, U, and Zr, as well as $Fe_2O_3/FeO < 0.2$ and $Na/K > 10$ in unaltered samples. The oceanic tholeiites also have rare-earth distribution patterns, and K/Rb (1,300) and Sr^{87}/Sr^{86} (0.702) ratios that are similar to those of calcium-rich (basaltic) achondritic meteorites. In contrast, the alkali-rich basalts that cap submarine and island volcanoes are relatively enriched in Ba, K, La, Nb, P, Pb, Rb, Sr, Ti, Th, U, and Zr, and in ferric iron. The analytical data and field relations indicate that the alkali-rich basalts are derived from oceanic tholeiites via processes of magmatic differentiation, and that the oceanic tholeiites are the principal, or only primary magma generated in the upper mantle. The close compositional kinship between the oceanic tholeiites and calcium-rich achondrites is further evidence of the relatively primitive nature of the oceanic tholeiites. The chemical properties of oceanic tholeiites suggest that the upper mantle probably contains less than the following amounts (in parts per million): Ba, 10; K, 1,000; Pb, 0.4; Rb, 10; Th, 0.2; and U, 0.1. The Sr^{87}/Sr^{86} ratio must be less than 0.7015, Th/U about 2, K/Rb about 1,500–2,000, and Fe_2O_3/FeO less than 0.1.

Origin of aluminous basalt versus tholeiitic basalt

Warren B. Hamilton (4–64) proposed that basaltic magmas of the high-alumina association are generated by partial melting of the basaltic component of mantle rock at levels above transformation of mantle to eclogite or pyroxenite. The broad compositional spectrum within high-alumina basalts reflects varying degrees of partial melting over a broad temperature range. Tholeiite magmas, on the other hand, are thought to be generated beneath the level of transformation to eclogite or pyroxenite, and the narrow spectrum of their compositions reflect more complete melting of mantle material over a narrow temperature range.

Undevitrified Late Triassic glass from Alaska

Petrographic and X-ray study by D. A. Brew and L. J. P. Muffler (p. C38–C43) of glass-bearing aquagene tuff of Late Triassic (Norian) age from the Keku Strait area has shown that the basaltic glass is undevitrified and that it occurs together with other volcanic fragments as angular clasts in a matrix of sparry calcite. Glass fragments separated from the rock were analyzed by J. D. Obradovich and found to give a K-Ar age of 126 million years, indicating that some radiogenic argon has been lost from the glass. This glass is apparently one of the oldest undevitrified volcanic glasses ever reported.

X-ray curves give composition of Hawaiian olivine

K. J. Murata, Harry Bastron, and W. W. Brannock (p. C35–C37) have established an X-ray curve for the determination of the composition of Hawaiian olivine. The curve deviates from that previously established by E. D. Jackson [70] for plutonic olivine. This deviation is related to the larger cell size of the Hawaiian olivine, which in turn is caused by the presence of calcium, a cation of large radius relative to other cations of olivine. The Hawaiian olivine contains 0.2–0.5 percent calcium, compared to a few hundredths of a percent in plutonic olivine.

SILICIC VOLCANIC ROCKS

Chemical characteristics of pantellerite glass, Nevada

D. C. Noble (p. B85–B90) has separated and described a pantellerite glass from the basal vitrophyre of a middle Pliocene ash-flow tuff in southern Nevada. Content of sodium, iron, zirconium, and halogens of the glass is extremely high for a silicic rock, and content of aluminum, magnesium, and calcium is abnormally low. Analyses of devitrified rocks of the same ash-flow tuff are low in sodium and halogens; these elements probably were leached from the pantellerite by ground water after devitrification. This pantellerite is tentatively believed to have been generated by the direct fractionation of a mafic or low-silica intermediate alkalic magma without the existence of trachyte as an intermediate magma.

Scapolite related to chlorine release in Bandelier Tuff, New Mexico

R. L. Smith and K. O. Dickson, during the course of a continuing study of the mineralogy of ash flows of the Bandelier Tuff, Jemez Mountains, N. Mex., have discovered that scapolite is a common and apparently characteristic mineral of the vapor-phase zone. The mineral is associated with cristobalite, tridymite, and alkali feldspar in pumice vesicles and is apparently precipitated from chlorine-rich gases during cooling of the tuff. X-ray studies show that the cell dimensions of the scapolite change systematically with degree of welding of the tuff, and may reflect differences in Si-Al ordering related to rate of cooling of the tuff or may reflect variable chemistry. The discovery provides clues to problems of chlorine release during crystallization of rhyolitic ash flows.

Nb, Th, and U decrease upward in Bandelier Tuff

David Gottfried has studied the variation in amount of Nb, Th, and U in several sections of the Bandelier Tuff in the Jemez Mountains, N. Mex. The vitric zone at the base of a typical section of genetically related multiple-flow units contains the highest amounts of Nb (130 parts per million), Th (30 ppm), and U (10 ppm). There is a progressive decrease in the amounts of these elements in the flow units higher in each section. The uppermost units contain approximately 60 ppm Nb, 15 ppm Th, and 5 ppm U. These data support the concepts of R. L. Smith and R. A. Bailey that the Bandelier ash-flow sheets represent the inverted contents of zoned or layered magma chambers.

Three different niobium trends in volcanic rocks noted

In a general study of niobium in volcanic rocks, David Gottfried has isolated three fairly distinct trends of variation of niobium during magmatic differentiation: (1) an increase in niobium throughout differentiation (alkalic and alkalic-calcic volcanic suites from Augusta County, Va., and from the Big Bend area, Texas), (2) a decrease in niobium throughout differentiation (high calcic volcanic suites from Saipan, the Mount Garibaldi area of British Columbia, and the Strawberry Mountains, Oreg.), and (3) a slight increase in niobium in mafic rocks and a relatively constant amount in the intermediate and siliceous rocks (calc-alkalic suite from the Medicine Lake Highland, Calif.). The volcanic rocks of a low-lime alkalic suite show a 10- to 50-fold enrichment in niobium over the amounts found in corresponding rock types in a highly calcic suite.

METAMORPHIC ROCKS

New iron silicates reported from Cazadero area, California

R. G. Coleman, R. C. Erd, and D. E. Lee have identified two recently discovered[71] iron silicates, deerite and howieite, in the Franciscan Formation of the Cazadero area, California, and suspect the presence of zussmanite also at this locality. These minerals appear to be restricted to iron-rich metasedimentary rocks of intermediate metamorphic grade within the glaucophane schist facies. The bulk composition of the metasedimentary rocks is similar to that of the Precambrian iron formations, except for high sodium values. Stilpnomelane, crossite-riebeckite, and spessartine-almandine garnet are the commonly associated minerals in the Cazadero area. Deerite is found in both quartz-rich and quartz-poor rocks. In contrast, howieite (and zussmanite?) is usually restricted to quartz-poor iron-

[70] E. D. Jackson, 1960. X-ray determinative curve for natural olivine of composition Fo_{80-90}: Art. 197 *in* U.S. Geol. Survey Prof. Paper 400–B, p. B432–B434.

[71] S. O. Agrell, M. G. Gown, and D. McKie, 1965, Deerite, howieite, and zussmanite, three new minerals from the Franciscan of the Laytonville district, Mendocino Co., California [abs.]: Am. Mineralogist, v. 50, no. 1–2, p. 278.

stones. The apparent restriction of these new minerals to the glaucophane schist facies indicates that they may be the high-pressure analogs of greenalite, minnasotaite, and grunerite.

Composition of jadeite throws light on its genesis

R. C. Coleman (p. C25–C34) has found that the pyroxene from the metagraywackes of the Franciscan Formation in California is not a pure jadeite. The presence of significant amounts of pyroxene components other than jadeite in these jadeitic pyroxenes suggest formation at lower pressures and temperatures than those found experimentally for the conversion of albite to pure jadeite + quartz. Petrologic and chemical evidence indicates that the conversion of graywacke to the assemblage quartz-jadeitic pyroxene-lawsonite-muscovite-glaucophane takes place without the introduction of alkalies. The reaction 8 albite + chlorite + $CaCO_3 \rightarrow$ 5 jadeitic pyroxene + 2 glaucophane + quartz + $2H_2O$ + CO_2 may be important in relating greenschist to glaucophane schist facies metamorphism.

Geothermal well data record present-day metamorphism

Petrologic and chemical data from the Salton Sea geothermal area have enabled D. E. White and L. J. P. Muffler (1–65) to conclude that upper Cenozoic sediments of the Colorado River delta are being metamorphosed in the present thermal environment to mineral assemblages of the greenschist facies. In the I.I.D. No. 1 geothermal well, the following generalized reaction occurs in the zone from 1,200 to 2,300 feet and in the general temperature range of 120°C to 200°C:

$$\text{Dolomite} + \text{kaolinite} + \text{quartz} + \text{water} + Fe^{+2} + O^{-2} \rightarrow \text{chlorite} + \text{calcite} + \text{carbon dioxide}$$

In the zone from 2,700 to 4,000 feet and at temperatures in the range from 200°C to more than 300°C, calcite breaks down and epidote is formed. This second relationship involves considerable cation exchange with the saline geothermal brine found in the geothermal field.

THERMAL WATER

Large magma chamber at Steamboat Springs, Nev., indicated

D. E. White, G. A. Thompson, and C. H. Sandberg, (2–64), in an exhaustive documentation of the detailed late Tertiary and Quaternary history of the Steamboat Springs thermal area, Washoe County, Nev., conclude that a magma chamber of at least 50 cubic kilometers at 6 to 9 km depth has evolved heat, water, and mineral matter for at least 100,000 years. Structural control for most of the thermal activity of the area was provided by old north-trending east-dipping normal faults. Extensive deposits of siliceous sinter are localized around structurally favorable outlets.

Three patterns of alteration found in drill holes at Steamboat Springs, Nev.

Robert Schoen and D. E. White have recognized three patterns of alteration in two drill holes at Steamboat Springs, Nev.:

1. Near-surface acid leaching where H_2S oxidizes to form H_2SO_4 above the water table; opal, kaolinite, and alunite are characteristic products.
2. Near-surface alteration below the chloride-water table; hydrothermal K-feldspar is an especially abundant replacement of plagioclase of the volcanic rocks but also replaces plagioclase of granodiorite.
3. Zoned alteration adjacent to fractures at depths greater than 200 feet. In the outer zone, hornblende is replaced by illite-montmorillonite and chlorite, biotite by chlorite, and plagioclase by albite and calcite and (or) illite-montmorillonite. In the most intensely altered rocks next to fractures, all earlier formed hydrothermal silicates and plutonic K-feldspar are replaced by illite ($<$ 10 percent interlayered montmorillonite), quartz, and pyrite.

DIAGENETIC ROCKS

Lazurite, talc, and chlorite in Green River Formation, Wyoming

W. H. Bradley (2–64) has identified authigenic lazurite, talc, and chlorite in a salt bed of the Green River Formation, Wyoming. Talc and chlorite as authigenic minerals in lacustrine salt beds had not previously been reported. The presence of these silicates instead of the usual magnesium silicates of greater hydration, such as stevensite or saponite, suggests that the assemblage formed at a late stage of diagenesis, and may have replaced previously formed saponite or stevensite.

Alteration of rhyolitic glass related to topography

R. A. Sheppard and A. J. Gude 3rd (p. D44–D47) in a study of the diagenetic alteration of a gently dipping bedded tuff in the Pliocene Ricardo Formation of southeastern California, have documented a correlation between topographic elevation and stage of replacement of fresh rhyolitic glass by clinoptilolite, opal and (or) montmorillonite. The tuff above an elevation of 3,000 feet generally is fresh, but the same tuff below 3,000 feet is altered. This suggests that alteration was accomplished by subsurface water after the formation had been tilted. Solution and hydrolysis of rhyolitic glass by downward-moving water would increase the pH and salinity of the water, thereby providing a chemical environment more favorable for the formation of zeolites.

MINERALOGIC STUDIES AND CRYSTAL CHEMISTRY

Crystal structure of scapolites

The crystal structure of mizzonite, a calcium and carbonate-rich scapolite, has been refined by J. J. Papike. The results of this refinement together with a previous analysis of the crystal structure of a sodium and chlorine-rich scapolite (J. J. Papike and T. Zoltai, 1–65) provide the following new crystal chemical information concerning the variation of the structure with composition:

The basic structure is the same throughout the solid-solution series, although there are some significant distortions in the tetrahedral framework.

Ordered marialite-rich scapolites have aluminum in only 1 of the 2 types of 4-membered rings of tetrahedra present in the structure, whereas meionite-rich scapolites have aluminum distributed in both types of rings. The aluminum distribution varies with the overall composition and can be associated with the variation of unit-cell dimensions in the isomorphous series.

The electron-density distribution indicates disorder of the CO_3^{-2} groups in the structure. The disorder does not appear to be rotational, but instead, the result of averaging among four distinct positions for each group.

Mineralogy of djurleite

D. E. Appleman and E. H. Roseboom have found that the new copper sulfide mineral djurleite, is orthorhombic with $a = 15.752$, $b = 26.895$, and $c = 13.554$ Å. The composition of synthetic djurleite lies between $Cu_{1.963}S$ and $Cu_{1.972}S$; the density is 5.747 ± 0.007 as measured on 2 large natural crystals. Previous workers had concluded incorrectly that djurleite was probably two phases. From Roseboom's work on the system Cu–S, it is clear that djurleite is a single phase. The most probable formula for djurleite is $128[Cu_{1.969}S]$, corresponding to a unit-cell content of $Cu_{252}S_{128}$. This represents a loss of four Cu atoms per unit cell over chalcocite, Cu_2S.

Aluminous enstatites

B. J. Skinner and F. R. Boyd (2–64) have calculated unit-cell volumes and densities for a series of aluminous enstatites at regular intervals up to 15 weight percent Al_2O_3. The extensive coupled substitution of (AlAl) for (SiMg) in orthorhombic enstatite ($MgSiO_3$) had been demonstrated earlier by F. R. Boyd and J. L. England[72] in their high-pressure studies. They proposed that a pyroxene having a composition equivalent to pyrope garnet ($Mg_3Al_2Si_3O_{12}$) with 25 percent Al_2O_3 substitution might be prepared at high pressure. However, projecting the density-versus-composition relation determined for aluminous enstatites to the composition $Mg_3Al_2Si_3O_{12}$, a density of 3.28 ± 0.01 gram/cubic centimeter is predicted. When this is compared to the high measured density of 3.58 g/cm³ for pyrope it suggests that increasing pressure will favor the assemblage pyrope plus enstatite over aluminous enstatites, a conclusion now verified by F. R. Boyd and J. L. England.[73]

Relation of reedmergnerite to feldspar structures

Following the completion of least-squares refinement of 3,000 observed X-ray intensity measurements of reedmergnerite, $NaBSi_3O_8$, D. E. Appleman and J. R. Clark compared the refined structure to the related low albite, maximum microcline, and anorthite crystal structures. Strikingly similar Si-O distances between like atoms in reedmergnerite and low albite confirm the assumption of completely ordered tetrahedral cations in both mineral structures. The sodium cations in reedmergnerite, unlike those in low albite, exhibit no apparent anisotropy. Also, the AlO_4 tetrahedra are found to be less regular than either the SiO_4 or BO_4 tetrahedra.

Polytypism in micas

Malcolm Ross, D. R. Wones, and Hiroshi Takeda have completed a systematic description of all possible 1-, 2-, 3-, and 4-layer mica polytypes, as well as all 5- and 6-layer forms which have 0° and ± 120° stacking sequences. Unit-cell parameters, vector stacking symbols, space groups, and "structure presence criteria" have been derived for all of the above 62 possible crystal structures. With these data it is possible to predict the crystal structure of a large number of these polytypes merely by inspecting the single-crystal X-ray photographs. The accompanying table lists the various crystallographic parameters of all possible 1-, 2-, and 3-layer forms.

The $3Tc_2[02\bar{2}]$ and $4M_2[2220]$ forms, as well as many other more complex polytypes such as 8-, 11-, and 20-layer monoclinic and 8-, 14-, and 25-layer

[72] F. R. Boyd and J. L. England, 1960, Aluminous enstatite, *in* Minerals of the mantle: Carnegie Inst. Washington Year Book, 1959–1960, p. 49–52.

[73] F. R. Boyd and J. L. England, 1964, The system enstatite-pyrope: Carnegie Inst. Washington Year Book 1963–1964, p. 157–161.

Information for systematic identification of all possible 1–, 2–, and 3–layer mica polytypes

Polytype vector symbol	a(Å)	b(Å)	d_{001}(Å)	α (degrees)	β (degrees)	γ (degrees)	Space group	Structure presence criteria
1M[0]	5.3	9.2	10.0	90	100.0	90	$C2/m$	--
$2M_1[2\bar{2}]$	5.3	9.2	20.0	90	95.1	90	$C2/c$	$h3hl:l=2n+h$
$2M_2[1\bar{1}]$	9.2	5.3	20.0	90	98.7	90	$C2/c$	--
2O[33]	5.3	9.2	20.0	90	90	90	$Ccmm$	--
3T[222]	5.3	--	30.0	90	90	120	$P3_112$	$hh2\bar{h}l:l=3n$
$3M_1[033]$	5.3	9.2	30.0	90	93.4	90	$C2/m$	$0kl:l=3n$
$3M_2[11\bar{2}]$	5.3	9.2	30.0	90	93.4	90	$C2$	--
$3Tc_1[01\bar{1}]$	5.3	9.2	30.0	98.7	91.7	90	$C\bar{1}$	$0kl:l=3n$
$3Tc_2[02\bar{2}]$	5.3	9.2	30.0	92.9	95.1	90	$C\bar{1}$	$h0l:l=3n$
$3Tc_3[123]$	5.3	9.2	30.0	90	93.4	90	$C\bar{1}$	--

triclinic forms have been found by Malcolm Ross and D. R. Wones (2–65). Examination of more than 150 biotite crystals by Ross indicates that (1) most biotite samples consist of mixtures of many complex polytypes, and (2) all biotite structures consist of only 0° and ± 120° stacking sequences. At the present time the following distribution of polytypes in micas is indicated: biotites, mixture of many polytypes and also $1M_r$-120 forms (random ± 120° layer rotations); phlogopites, 1M, rarely $2M_1$, 3T; lithium micas, 1M, $2M_1$, $2M_2$, 3T, rarely more complex forms; muscovite and paragonite, $2M_1$, rarely 1M, 3T; authigenic micas, 1M, $2M_1$, plus possible disordered $1M_r$-60, $1M_r$-120, $1M_r$-180, and two-dimensional forms.

Crystal structure of ulexite

The crystal structure of the Na-Ca borate mineral ulexite has been found by J. R. Clark and D. E. Appleman (3–64) to contain three structural groups: isolated borate polyanions, $[B_5O_6(OH)_6]^{-3}$; Ca-coordination polyhedra; and Na-coordination octahedra that share edges to form continuous chains parallel to the *c* direction. These three groups are joined by hydrogen bonds into a three-dimensional network. The structural formula for ulexite is $NaCaB_5O_6(OH)_6 \cdot 5H_2O$. The isolated polyanions, according to C. L. Christ's fourth rule [74], may polymerize into chains by linking and splitting out water. Such chains have been found by H. M. Kurbanov and others [75] in the crystal structure of the related mineral, probertite, $CaNaB_5O_7(OH)_4 \cdot 3H_2O$.

Crystal structure of zinc analog of hummerite

H. T. Evans, Jr. (1–65) has solved the crystal structure of a complex potassium-zinc vanadate, $K_2Zn_2V_{10}O_{28} \cdot 16H_2O$, the zinc analog of hummerite. The structure was solved from a three-dimensional, sharpened Patterson map. The decavanadate group $(V_{10}O_{28})^{-6}$ consists of a cluster of 10 condensed VO_6 octahedra: 6 are arranged in a 2×3 rectangle by sharing horizontal edges, and 2 pairs of octahedra are inserted above and below the rectangle by sharing sloping edges. The $(V_{10}O_{28})^{-6}$ ion is known to exist in solutions although until the present X-ray study was completed the structure was not understood.

Coordination of uranyl ion in uranium (VI) oxide hydrates

C. L. Christ (1–65) has explained the spontaneous transformation of schoepite I ($UO_3 \cdot nH_2O$), with loss of water, to schoepite II or schoepite III, as due to a change from an unstable near-hexagonal coordination of the uranyl ion in schoepite I, to a pentagonal coordination of the uranyl ion in the less hydrous phases. A plan is proposed for determining the kind and extent of thermodynamic stability among these hydrates of UO_3, and for relating the thermodynamic stability to the observed type of uranyl ion coordination (6-, 5- or 4-fold).

Crystallography of ganophyllite

Two polytypes of ganophyllite, a manganese aluminosilicate, have been recognized by M. L. Lindberg. Ganophyllite samples from Franklin Furnace, N. J. contain two forms with the following unit-cell data: (phase A) $a = 50.36$, $b = 27.08$, $c = 16.59$Å, $\beta = 94°10'$, space group Cc or $C2/c$; and (phase B) $a = 24.70$, $b = 16.32$, $c = 22.20$ Å., $\beta = 94° 20'$, space group Cc or $C2/c$. Phase A was also found in samples from the Harstig mine, Sweden. The following unit-cell parameters were measured from this specimen: $a = 50.34$, $b = 27.04$, $c = 16.60$ Å, $\beta = 94°10'$,

[74] C. L. Christ, 1960, Crystal chemistry and systematic classification of hydrated borate minerals: Am. Mineralogist, v. 45, p. 334–340.

[75] H. M. Kurbanov, I. M. Rumanova, and N. V. Belov, 1963, Crystal structure of probertite, $CaNa[B_5O_7(OH)_4] \cdot 3H_2O$: Dokl. Akad. Nauk SSSR, v. 152, p. 1100–1103. [in Russian]

space group *Cc* or *C2/c*. Both phases have subcells similar in projection on (010) to an "expanded" $2M_1$ mica. A relationship to the allevardite structure is indicated.

Physical properties of feldspars

Refinement of X-ray powder diffraction data of the feldspar phases in perthites with sodic bulk compositions by D. B. Stewart, T. L. Wright, and Dora von Limbach yielded the unit-cell dimensions and structural states of the exsolved phases. Before exsolution takes place, the lattice becomes considerably distorted, particularly along the *a* axis. The distortion is relieved by a simultaneous change of composition and structural state as exsolution takes place. The low temperature assemblage ultimately consists of low albite of nearly pure $NaAlSi_3O_8$ composition, and maximum microcline of nearly pure $KAlSi_3O_8$ composition. Intermediate compositions and structural states do occur, but they are rare and characteristically show cell dimensions that are strongly distorted with reference to the standard curves for known series of intermediate structural states. The refined dimensions gave values for the reciprocal cell angles that were consistently different from those reported by W. S. MacKenzie and J. V. Smith [76] for the same samples. Their results were obtained by another X-ray method (J. V. Smith and W. S. MacKenzie [77]) that apparently does not always yield correct values.

The unit-cell parameters of a number of natural ternary feldspars of high structural state (anorthoclases) were determined and compared with the determinative curves for the high albite-high sanidine series to determine how closely the cell parameters indicate the Or content and structural state. The very satisfactory agreement suggests that the determinative curves prepared for the pure alkali feldspars may be applicable to An-bearing ternary solid solutions as well.

Examination by D. B. Stewart, T. L. Wright, and Dora von Limbach of the relationship between the volume of calcic labradorite (An 67.2) and temperature indicates the possible existence of a reversible high-order transformation between 650° and 1050°C. The transformation may be the change from a body-centered lattice to a C-centered lattice. If verified by X-ray single-crystal measurements in this temperature range, the possibility of establishing an equilibrium phase diagram for calcic plagioclase by high-temperature X-ray measurements is indicated.

D. B. Stewart resolved a mineralogical mystery by showing that the physical properties reported for "analbite" and "monalbite," supposedly polymorphs of $NaAlSi_3O_8$ feldspar, were actually those for the potassium-bearing sodic feldspars, anorthoclase and sanidine. This result considerably simplifies the phase diagram for alkali feldspars, and makes our understanding of feldspar order-disorder relations more complete.

[76] W. S. MacKenzie and J. V. Smith, 1962, Single crystal X-ray studies of crypto- and micro-perthites: Norsk Geologisk Tidsskrift, v. 42, p. 72–103.

[77] J. V. Smith and W. S. MacKenzie, 1955, The alkali feldspars: II. A simple X-ray technique for the study of alkali feldspars: Am. Mineralogist, v. 40, p. 773–747.

EXPERIMENTAL GEOCHEMISTRY

BASIC STABILITY RELATIONSHIPS

Theory and applications of phase diagrams

E-an Zen has found in systems of $n + 3$ phases that a definite relationship exists between the permissible configurations of invariant points and univariant curves and the relative compositions of the phases, and that for some cases, a unique relationship exists. Zen also found that the possible "grids" may be derived from the projection of primitive polyhedra without body diagonals.

Heats of solution of alkali feldspars

Heats of solution of low albite, microcline, and 10 intermediate compositions on the $NaAlSi_3O_8$-$KAlSi_3O_8$ binary, in 20 percent HF, have been measured by D. R. Waldbaum and R. A. Robie. The excess enthalpy of mixing is nearly symmetric and has a maximum value of 1,800 ± 200 calories. Refined unit-cell parameters provide information on the volume of mixing, and permit a thermodynamic analysis of the alkali feldspar solid-solution series.

STUDIES OF MAGMATIC PROCESSES

Crystal settling and convection in granitic magma

H. R. Shaw (1–65), in an examination of the conditions for natural and forced convection and crystal settling in magma of granitic composition, found that the behavior of such a magma cannot be treated as a static condition. Crystallization, differentiation, and heat flow must take account of mass and heat transfer by natural convection. Although more fundamental data are required concerning the mechanical behavior of the crust in which a magma is contained, dike propagation and eruption rates of rhyolite magma require the flow sequence: Incompressible homogeneous flow → compressible two-phase flow (liquid-gas) → particulate flow.

Absorption of H_2O by obsidian at high temperature and pressure

The rate of absorption of H_2O in obsidian at

850°C and at fluid pressures between 100 and 2,000 bars has been determined by H. R. Shaw. The sorption curves at 850°C and 700 bars are complicated by sharp changes in slope, although the initial slopes of all the curves at a variety of conditions of pressure and temperature are similar. The data indicate that the average diffusion coefficients range from 1 to 7×10^{-8} cm^2/sec^{-1}, that the Stokes-Einstein relationship is not applicable to the diffusion of H_2O in silicate melts, and that the gain or loss of H_2O by a diffusion mechanism in granitic magma is exceedingly slow. A driving potential of 2,000 bars H_2O pressure would move the hydration front in a dry granitic melt less than 50 meters in 1 million years.

Reactions of phlogopite and quartz

D. R. Wones and F. C. Dodge have demonstrated that the assemblage phlogopite + quartz reacts to form the two assemblages, sanidine + enstatite + gas, and melt + enstatite + gas. The univariant curves that represent the two reactions intersect at an univariant point at 840° ±10°C and 400 ±100 bars H_2O pressure. The fluorobiotite component may increase the thermal stability of the biotite phase, but the data indicate temperatures and H_2O pressures at which biotite and quartz may crystallize contemporaneously from a silicate melt. The data also prove that charnockitic metamorphic rocks result from low H_2O pressures during metamorphism, and probably represent either metamorphosed igneous rocks, or a metamorphic terrane dominated by decarbonation reactions.

The univariant reaction phlogopite + sanidine + quartz + $H_2O \rightleftarrows$ melt is less than 10°C below the sanidine + quartz + H_2O curve and indicates that high MgO contents of granitic magmas are due either to superheating during fusion or to contamination of a melt of "granite minimum" composition.

Pyrrhotite-biotite, a promising geothermometer

Compositions of coexisting pyrrhotite and biotite in the Mount Antero Granite, Chaffee County, Colo., are consistent with calculated values for magmatic temperatures, according to Priestley Toulmin III. Toulmin and D. R. Wones are undertaking a laboratory investigation to calibrate this promising geothermometer.

STUDIES OF METAMORPHIC PROCESSES

Low H_2O pressures calculated for metamorphism of marble

D. R. Wones calculated the H_2O pressures implied by biotite-potassium feldspar-magnetite assemblages described by A. E. J. Engel and C. G. Engel [78] in gneiss and interbedded marble from the northwest Adirondacks of New York. The calculated pressures range between 0.1 and 10 bars, and agree with comparable calculations based on the amphibolite + clinopyroxene + orthopyroxene + quartz assemblages. The low H_2O pressures are consistent with a metamorphism in which the decarbonation of the marble was the dominant reaction. The CO_2 pressures, calculated from graphite equilibria, range from 500 to 5,000 bars and are consistent with the proposed model of the metamorphism.

Sedimentary–zeolitic–greenschist facies

A combination of pressure-temperature (P–T) diagrams and activity-activity diagrams may provide a sound basis for the interpretation of coexisting mineral parageneses. E–an Zen has shown that plots of the activity of H_2O, a_{H_2O}, and activity of metal oxides, a_{MO}, explain some relationships between the zeolite facies (high a_{H_2O} –high a_{MO}), sedimentary facies (high a_{H_2O} –low a_{MO}), and greenschist facies (low a_{H_2O} –high a_{MO}). As a consequence, the zeolite facies is not a necessary intermediate step between the sedimentary and greenschist facies.

SOLUBILITIES AND EXCHANGE REACTIONS

Flocculation of kaolinite suspensions

The flocculation of fine kaolinite suspensions in aqueous ionic solutions was found by J. B. Robertson and C. H. Wayman to occur over a range of pH values in weak ($10^{-1}N$) sodium, calcium, or aluminous chloride solutions. Maximum flocculation occurred at pH 4.0–2.0 for sodium and calcium ion-saturated kaolinite and at pH 5.0–2.5 for aluminum ion-saturated kaolinite. The flocculation was determined by measuring dispersion settling rates by a light-beam transmittance principle.

Solubility of silica glass at elevated temperature and pressure

R. O. Fournier and J. J. Rowe have determined the solubility of silica glass in H_2O at 200°C–380°C and at pressures of 15–1,000 bars. Logarithmic plots of H_2O fugacity and the concentration of dissolved silica suggest the presence of three different hydration states of the dissolved silica. The number of H_2O molecules associated with an SiO_2 group varies inversely with the density of the solution. Similar types of dissolved species coexist with quartz and silica glass at any given temperature and pressure.

[78] A. E. J. Engel and C. G. Engel, 1958, 1960, Progressive metamorphism and granitization of the major paragneiss, northwest Adirondack Mountains, New York; pt. I. Total rock; pt. 2. Mineralogy: Geol. Soc. America Bull., v. 69, p. 1369–1413, 1958; v. 71, p. 1–58, 1960.

Exchange constants for natural and synthetic glasses

Exchange constants for natural and synthetic glasses which involve the ions H^+, Na^+, K^+, Ca^{+2}, and Mg^{+2} have been determined by A. H. Truesdell using an electrode method[79]. The aluminosilicate glasses vary in content of Fe_2O_3, FeO, MgO, CaO, Na_2O and K_2O, and these variations affect the exchange constants in a manner that may be explained by a model of ion-exchange selectivity.

Sulfate equilibria

G. W. Morey, J. J. Rowe, and C. C. Silber have shown, in their studies of the system K_2SO_4–$CaSO_4$–$MgSO_4$, that a high-temperature form of $MgSO_4$ exists and that a new compound, $CaSO_4 \cdot 3MgSO_4$ exists between 800° and 850°C. The latter compound extends to the field between langbeinite–calcium langbeinite.

Euhedral anhydrite, $CaSO_4$, has been synthesized in unseeded artificial sea water at 70°C by E-an Zen. The crystals exhibit skeletal growth and pinacoidal facies.

Activity-activity diagrams explain borate parageneses

C. L. Christ, A. H. Truesdell, and R. C. Erd have explained mineral parageneses in borate deposits of California and Nevada by representing the system Na_2O–MgO–CaO–B_2O_3–H_2O in terms of activity-activity diagrams and the three ternary systems: (1) $4CaO \cdot 5B_2O_3 \cdot 7H_2O$ (priceite)–$B_2O_3 \cdot H_2O$–H_2O; (2) $Na_2B_4O_7 \cdot 4H_2O$ (kernite)–$2CaO \cdot 3B_2O_3 \cdot 5H_2O$ (colemanite)–H_2O; and (3) $2CaO \cdot 3B_2O_3 \cdot 5H_2O$–$2MgO \cdot 3B_2O_3 \cdot 7H_2O$–$H_2O$.

Stability fields in systems K_2O- and Na_2O-Al_2O_3-SiO_2-H_2O

J. J. Hemley has found, in the system K_2O– and Na_2O–Al_2O_3–SiO_2 H_2O, that relations between kaolinite, muscovite, and K-feldspar are quite different in the aqueous chloride and aqueous sulfate environments. The muscovite field is both shifted to higher total acidities and reduced in size in the aqueous sulfate environment. The effect of silica activity on the weathering of kaolinite and muscovite to form bauxite; the analcite-albite relationships; and the coexistence of K-feldspar and kaolinite in alteration assemblages are all problems in which the silica activity plays an important part. Hemley has found that high silica activities cause kaolinite to react to form pyrophyllite or montmorillonite at temperatures above 200°C.

[79] A. H. Truesdell, 1962, Study of natural glasses through their behavior as membrane electrodes: Nature, v. 194, p. 77–79.

Clays as osmotic membranes may "float" overthrusts

Osmotic pressures of 500 bars can be obtained in clayey sediments by filtration of NaCl-saturated solutions through clays which act as osmotic membranes. E-an Zen and B. B. Hanshaw (2–65) has suggested that such situations (1) may exist in sections containing thick shale beds and evaporite deposits, and (2) could "float" sheets of unconsolidated sediments as much as 4 kilometers thick. Such mechanisms may be important in the mechanism of near-surface thrusting as suggested by M. K. Hubbert and W. W. Rubey.[80]

STUDIES OF FLUID INCLUSIONS IN MINERALS

Salinity of fluid in inclusions found to increase with ore stage

Edwin Roedder and A. V. Heyl made a field and laboratory study of the conditions of ore deposition at the Mex-Tex mine, Hansonburg district, New Mexico. The ore is similar in some respects to the "coontail" ore of the southern Illinois lead-zinc-fluorite deposits. The salinity of the fluid in primary fluid inclusions progressively increased (hence freezing temperatures of the fluid decreased) throughout the first 6 of the 7 stages of ore deposition recognized. The salinity changed from about 9.5 percent NaCl equivalent brines in the inclusions in the earliest fluorite to about 17.5 percent in the 6th stage as represented by inclusions in the cores of late amethyst crystals. The 7th and last stage comprising inclusions in the outer rims of the late amethyst crystals contained only 12 percent NaCl equivalent brines. Numerous planes of secondary inclusions cutting these samples contained fluids equivalent to primary inclusions in later zones. Such a systematic increase in salinity with stage in ore deposition has never been reported before in ore deposits of any kind.

Evidence for separation of an immiscible water-rich fluid phase

A missing link in the chain of reasoning that connects hydrothermal fluids and granitic melts has long been an ignorance as to whether or not a sudden break takes place in the line of descent involving the separation of an immiscible water-rich fluid phase from a silicate-rich, fluid melt. Edwin Roedder, in cooperation with D. S. Coombs of the University of Otago, New Zealand, has found concrete evidence of such a break in the course of a study of the fluid

[80] M. K. Hubbert and W. W. Rubey, 1959, Role of fluid pressure in mechanics of overthrust faulting. I. Mechanics of fluid filled porous solids and its application to overthrust faulting: Geol. Soc. America Bull., v. 90, p. 115–166.

inclusions in the minerals of ejected granitic blocks in volcanic breccias from Ascension Island, in the south Atlantic Ocean. Primary inclusions in these rocks have a phase assemblage indicating that immiscible globules of highly saline (about 50 percent NaCl) aqueous fluids with some CO_2 occurred in the rhyolitic silicate melt, and were trapped in the inclusions.

"Fetid" odor of calcite due to liquid H_2S in inclusions

Although mineral samples have been found that give off the "fetid" odor of H_2S on crushing, they are rare, and nothing unusual has ever been seen in their inclusions. It has been presumed that the odor was from exceedingly minute amounts of H_2S dissolved in the water-rich fluid inclusions. A sample of strongly fetid calcite from the U.S. Section (Lark mine, Lark, Utah) has been found by Edwin Roedder to contain inclusions with four mutually immiscible fluids, plus a crystal of NaCl. One of the fluids is believed to be liquid H_2S, on the basis of its index of refraction and phase relationships; it might easily be mistaken for water in a cursory examination. Although the evidence from fluid inclusions indicates H_2S to be a relatively minor constituent, and seldom found in hydrothermal fluids, these particular fluids had a very high concentration of H_2S.

GEOCHEMICAL DATA

Collection and synthesis of geochemical data are important parts of the program of the U.S. Geological Survey. Some types of collections, such as the "Data of Geochemistry," are of immediate value as reference works, not only to geologists but to workers in other scientific fields as well. Other collections, commonly those resulting from fieldwork, provide background for studies of geologic processes and environmental effects on animal and human health, or for programs in economic geology such as geochemical prospecting. (See also the sections "Distribution of Elements as Related to Public Health, Minor Elements," "Field Geochemistry and Petrology," "Experimental Geochemistry," "Geochemical Prospecting," and "Geochemistry of Water.")

Lithium in plants and soils of Nevada basins

Unusual amounts of lithium have been found in plants and soils from several basins in Nevada. H. L. Cannon reports that spectrographic analyses of samples of 20 species of plants from 27 sites in 9 basins has shown a content of lithium ranging from 300 to 1,500 parts per million in plant ash and as much as 3,000 ppm in soil. Concentrations of lithium occur in springs, the salts of closed basin playas, and old lake beds. The most probable source is volcanic tuff, which is abundant in the study area. Further studies will be made of the source of the lithium and its secondary enrichment in plants and soils of both hydrologically "closed" and "open" basins.

Metal content of black shales

J. D. Vine reports that a comparison of the abundance and distribution of elements in shelf and eugeosynclinal black shales indicates that vanadium, zinc, chromium, nickel, copper, and silver are locally concentrated in both environments. Eugeosynclinal sediments were represented by analyses of samples of Ordovician and Silurian black siliceous shales from the western conterminous United States, and the shelf environment by analyses of several sets of transgressive marine black-shale samples associated with cyclothemic coal sequences. Shales of the shelf environment are especially characterized by local concentrations of molybdenum, and those of the eugeosynclinal environment by concentrations of barium. Copper and nickel show a consistent positive correlation with the organic carbon content of samples. Vanadium and chromium show a consistently strong positive correlation with each other, but the highest concentrations of these metals do not necessarily correlate with the highest concentration of organic carbon.

Extractable organic material in Cretaceous shales

H. A. Tourtelot and I. C. Frost (p. D73–D81) have extracted organic material from 5 samples of nonmarine carbonaceous shale, 10 samples of marine black shale, and 3 samples of marlstone, all from the Pierre Shale and equavalent stratigraphic units of Late Cretaceous age. The organic material was separated with activated silica and solvents into fractions interpreted as saturated hydrocarbons, aromatic hydrocarbons, and "nonhydrocarbons." Organic carbon content of the samples extracted ranges from 0.53 to 17.3 percent, but only 1 sample contained less than 2 percent. Extractable organic material content of the samples ranged from 0.008 to 0.354 percent and was roughly proportional to the organic carbon content. The ratio between saturated and aromatic hydrocarbon fractions is more than 1 except for 1 sample, and tends to be inversely proportional to the organic carbon content. The data on extractable material do not permit distinction between shales and marlstones of marine or nonmarine origins.

Comparison of the data on these samples with published data of samples with a wide range of ages and geologic histories suggests that post-depositional reactions increase the proportion of saturated and aromatic hydrocarbons compared to nonhydrocarbons.

Composition of magnetite as related to type of occurrence

Compilation by Michael Fleischer of analyses of magnetite from veins in basaltic trap rocks shows that such magnetite has a high content of MgO. Its bulk composition covers the greater part of the isomorphous series, magnetite-magnesioferrite (p. D82–D84). It is also characterized by having a much lower content of TiO_2 than magnetite from diabases or basalts.

Magnetite from alkalic rocks and carbonatites usually has a high MgO, Al_2O_3 and MnO content; its composition is such that it would be expected to contain exsolved hercynite or spinel.

Tin content of silicate rocks

Claude Huffman, Jr., analyzed 111 plutonic, volcanic, and sedimentary rocks for tin, using the ion-exchange separation technique described in Professional Paper 501–A, p. A196, with results as follows:

Rock	Number of samples	Range of tin (ppm)	Average tin (ppm)
1. Pikes Peak Granite, Taryall lobe, Colorado	39	11–32	16
2. Beryliferous rhyolitic tuff, Utah	13	22–270	75
3. Pierre Shale, South Dakota and Montana	53	$<$ 1–4	1
4. Porphyritic biotitic granite, Alaska	6	7–54	27

Sources of error in field geochemical data analyzed

A. T. Miesch has defined sampling and analytical error in field geochemical data, classified the types of error present, and described the effects of various error types in data interpretation by statistical and nonstatistical methods. The most serious error types are overall bias in the data, bias or precision that is variable from one sampling locality to another, and nonnormal error frequency distributions. The error effects are the same whether the error is due to sampling or analysis, or whether the method of interpretation is statistical or nonstatistical.

GEOCHEMISTRY OF WATER

Investigations of the geochemistry of water by the U.S. Geological Survey are directed mainly toward understanding the interrelations of the chemical character of water with the geologic and hydrologic environment. Some of the topics under study include the source of dissolved constituents in precipitation, the chemical content of stream water, the relation of the chemistry of ground water to the mineralogy of aquifer materials, the effects of local hydrology on the chemistry of lake sediments, and the use of isotopes in hydrologic investigations.

STUDIES OF ATMOSPHERIC PRECIPITATION

Dissolved solids in snow

R. J. Archer, A. M. LaSala, Jr., and W. E. Harding found concentrations of dissolved solids as high as 327 parts per million and of sulfate as high as 222 ppm in samples of a single snowfall occurring on February 16, 1964, in an area of 2,000 square miles in western New York, bordering Lake Erie and the Niagara River. The highest concentrations found were in samples collected downwind (east and northeast) of Buffalo.

Dissolved solids in rain

Studies by A. W. Gambell and D. W. Fisher have shown that over a 7,000-square-mile drainage area in North Carolina, for a 1-year period, rainfall contributed an amount of dissolved solids equal to one-third to two-thirds of the total dissolved solids carried by the streams. The amount of SO_4^{-2} and NO_3^{-1} brought down in rainfall exceeded that carried by the streams. The "excess" of SO_4^{-2} and NO_3^{-1} appears to be a normal occurrence for the area studied; it is thought that these constituents are taken up by plants, and that when the plants die and decay some sulfur and nitrogen are lost to the atmosphere in gaseous form.

Comparison of composition of dissolved solids in rain and in ground water

R. L. Laney (p. C187–C189) compared the chemical composition of dissolved solids in rain and in ground water in western North Carolina. The outstanding features he found are (1) an apparent lack of gradational members between typical analyses of rain water and of ground water, (2) a change from a calcium sulfate and calcium bicarbonate composition (rain) to a mixed-cation bicarbonate composition, and (3) a marked increase of silica in the ground water.

Tritium in precipitation and stream water

Concentrations of tritium in precipitation in the United States, observed by G. L. Stewart, T. A. Wyerman, and C. M. Hoffman, were in general lower than those in 1963 but were still considerably higher than 1962 levels. Exceptions were found at Albuquerque, N. Mex., and at Lincoln, Nebr., where 1964 peaks were slightly higher than those in 1963. The highest concentrations were observed at Denver, Colo. (12,950 tritium units in 1963 and 9,700 T.U. in 1964); the lowest were at San Juan, P.R. (440 T.U. in 1963 and 290 T.U. in 1964). A spring rise and a peak in late spring and early summer were observed in 1964, as in previous years. The concentration of tritium in streams can be correlated with tritium rainout and with stream discharge and other stream characteristics. Concentrations in streams follow patterns in time similar to those in precipitation; those in 1964 were in general slightly lower than those in 1963.

STUDIES OF STREAMS AND LAKES

Saline lakes in Oregon

Studies by A. S. Van Denburgh have shown that Abert and Summer Lakes, two saline, closed-basin lakes in south-central Oregon, contain about 13 million and 0.6 million tons, respectively, of dissolved solids—mostly sodium, carbonate bicarbonate, and chloride. Salts stored within the top 5 feet of peripheral and lake-bottom sediments total about 60 million tons at Abert Lake (total area 75 square miles) and about 20 million tons at Summer Lake (85 sq mi).

Mineralogy of sediments exposed to brine

Extensive mineralogical examination by B. F. Jones of clay and fine-silt fractions from alluvial-fan materials, older lacustrine sediments, and modern playa deposits of the Deep Springs Valley, Calif., suggests that limited reaction takes place when the clay minerals are exposed for long periods to alkaline brine with a content of as much as 2½ percent K^{+1}. The apparent correlation of clay suites with sediment source materials suggests that original mica structures, after weathering, are rejuvenated by K^{+1} uptake, but that there is little effect of the brine on expandable clays originally derived from sources other than sheet-silicate minerals.

GROUND-WATER STUDIES

Exhaustion of cation-exchange capacity of glauconitic sand

Investigations by H. B. Wilder, in the Atlantic Coastal Plain in North Carolina, indicate that the cation-exchange capacity of glauconitic sands in some geologic formations has been exhausted by hard ground water flowing through the formations. A test well in Craven County, N.C., which penetrated glauconitic Cretaceous sands of unusually high permeability, yielded water with a hardness of more than 200 parts per million (as $CaCO_3$). Normally, in this area, ground water in this sand would have less than 50 ppm hardness. Laboratory tests with samples of the glauconitic sands produced no softening of natural hard-water samples.

Estimation of dissolved-solids content of ground water

Using the many available electrical logs and chemical analyses, A. N. Turcan, Jr., developed an empirical field method for estimating the content of dissolved solids in potable water in most of the major aquifers in Louisiana. The method is based upon the averaged relation of the resistivity reading from the long normal curve on the electrical log to the laboratory resistivity reading for water from the aquifer. Results indicate that this relation, which is termed the field-formation resistivity factor, can be used for an aquifer over a large area. The factor varies with changes in the sand-clay ratio and in the basic type of water.

Uranium in ground water, Arkansas River valley, Colorado

Collection and analysis of 200 samples of ground water from the Arkansas River valley in Colorado by R. C. Scott and J. E. Moore showed that the ground water contains as much as 180 micrograms of uranium per liter, whereas water in the Arkansas River contains 2–3 micrograms per liter—the background amount of uranium for the area. Uranium concentrations in ground water from the valley-fill aquifer generally increase downstream. The uranium in the ground water is thought to have been introduced in phosphate fertilizers which have widespread use throughout the valley. Isolated anomalous highs are in areas where agricultural activity is or has been most intense and where well density is greatest. Anomalous lows are along the southern edge of the valley where ground water in the alluvium is diluted by recharge from adjacent dune sands. The downstream increase in uranium concentrations may be attributed to continuous reuse of irrigation water by successive farmers.

Velocity of ground-water flow determined from radiocarbon studies

Radiocarbon determinations on water from a series of wells in west-central Florida, made by R. N. Cherry, Meyer Rubin, B. B. Hanshaw, and William

Back, show lower concentrations (younger water) in recharge areas than in areas downgradient from the recharge areas. The calculated velocity of ground-water movement, 7 meters per year for 140 kilometers of travel, is in agreement with a velocity of 7 m per yr calculated independently from hydrologic equations.

CHEMICAL EQUILIBRIUM STUDIES

Behavior of manganese in water

J. D. Hem[81] found a stability constant of $10^{4.24}$ for a 1:1 complex of divalent manganese with tannic acid. This type of metal-organic complex may influence the behavior of manganese and other metals in natural water. A similar but weaker complexing action occurs between gallic acid and manganese.

Chemical equilibria in Florida ground water

In a continuing study of chemical equilibrium between solid phases and water in the aquifer system of central Florida, William Back and B. B. Hanshaw have shown that ground water in areas of recharge in the limestone aquifer is undersaturated with respect to calcium, aragonite, dolomite, gypsum, and anhydrite; away from the recharge areas it may maintain a state of supersaturation with respect to calcite and dolomite.

Chemical equilibria in prairie potholes in North Dakota

During a study of two prairie potholes in North Dakota, H. T. Mitten (p. C176–C180) found that concentrations of dissolved oxygen and CO_3^{-2} and the ratio of the ion-activity product to the equilibrium constant for calcite varied diurnally in the water. Peak values for these three variables correlated with the peak (maximum or minimum) values of temperature. The water in both potholes was supersaturated with respect to calcite at all times.

THERMAL WATERS

Types of thermal waters in Yellowstone Park

C. L. Christ, R. M. Garrels (Harvard University), and K. L. Temple (Montana State College) analyzed samples of eight thermal waters from bubblers and pools in the area of the Artists Paint Pot, in Yellowstone National Park, Wyo. The samples were analyzed for sodium and potassium, by the electrode method in the field and by the flame-photometer method in the laboratory. Results obtained are shown in the accompanying table.

Sample	Method					
	Electrode			Flame		
	Na	K	Na/K	Na	K	Na/K
1	17.0	0.78	21.8	17.6	0.56	31.5
2	18.2	.77	23.6	18.4	.58	31.7
3	17.4	.72	24.2	17.5	.56	31.3
4	17.5	.74	23.6	18.0	.56	32.2
5	1.02	.79	1.29	[1](2.42)	.58	4.17
6	1.50	1.42	1.06	1.32	.96	1.38
7	.77	.85	.90	.77	.62	1.24
8	[2](0.91)	.83	1.09	.77	.56	1.38

Results are in milliequivalents. 1–4, alkaline waters, pH≈9; 5–8, very acid waters, pH≈2.7.

[1] Flame photometer value not accurate.

[2] Electrode value not accurate.

The agreement between results by these two methods is better for sodium than for potassium. The values obtained by the electrode method are in closer agreement with values found by E. T. Allen and A. L. Day[82] than are those by the flame-photometer method.

Samples analyzed are representative of the waters throughout Yellowstone Park. There are two types of waters, an alkaline type and an acid type, each of which is remarkably consistent in terms of composition. This consistency suggests one common mechanism for the origin of the alkaline waters and one common mechanism for the origin of the acid waters. The alkaline waters are thought to result from the travel of solution through the rock and equilibration with it, probably at the three-phase point where montmorillonite, kaolinite, and muscovite exist at equilibrium; this would yield the Na:K:H ratio found. On the other hand, the acid waters can be explained by assuming an original solution of H_2S, which is not very corrosive toward rock, becoming oxidized to aqueous H_2SO_4 as the solution nears the surface, when it will then largely dissolve the rock except for quartz. At the surface, kaolinite will be precipitated.

INVESTIGATIONS AT THE HAWAIIAN VOLCANO OBSERVATORY

Eruption of Kilauea, March 1965

Kilauea erupted more than 30 million cubic yards of lava from fissures along nearly 8 miles of the upper east rift zone between March 5 and March 15, 1965. This adds another rift eruption to the series of 1962 and 1963 that broke from the rift without a preliminary summit eruption in the

[81] J. D. Hem, 1965, Reduction and complexing of manganese by gallic acids: U.S. Geol. Survey Water-Supply Paper 1667-D. [In press]

[82] E. T. Allen and A. L. Day, 1935, Hot springs of the Yellowstone National Park: Carnegie Inst. Washington Pub. 466, p. 453.

caldera. Each rift outbreak, however, has been associated with a short, abrupt collapse of the summit as evidenced by tilt and level observations, further substantiated this year by surface-distance measurement. The distance between two points across the summit caldera, somewhat more than 3 kilometers, was shortened during the summit collapse by 25–30 centimeters as determined by a series of tellurometer and geodimeter measurements.

This eruption filled Napau Crater to a depth of 40 feet in a few hours, but about half this drained back immediately into the vents. A lake more than 330 feet deep formed during 9 days of eruption in the west pit of Makaopuhi Crater; after draining back it still contains over 6 million cubic yards of lava in its 270-foot depth. Documentation of the cooling history of this new lake was started at once, with the benefit of previous experience on Kilauea Iki and Alae lakes.

Crystallization of Alae lava lake

The 50-foot-thick Alae lava lake, formed in the August 1963 eruption of Kilauea Volcano (D. L. Peck and others [83]), solidified in August 1964, and its last interstitial melt crystallized in late September. Most aspects of the cooling history were watched closely by recurrent surveying, surface mapping, and core drilling in a total of 12 holes. Repeated leveling showed, unexpectedly, that the lake surface constantly rose over those parts of the lake still partly molten and subsided only over the solidified part during the year required for complete solidification. The rise was greatest (as much as 0.81 feet uplift) in a doughnut-shaped area that ringed the lake about halfway from center to shore. Uplift of the lake surface apparently was caused by continued exsolution of gas from lava undergoing crystallization; vesicles formed by the gas and trapped in the solidifying lava reduced the bulk density of the crust to less than that of the molten lava. Preliminary estimates based on the leveling data, density of drill core and a bulk thermal contraction rate of 0.001 percent per degree from leveling and temperature measurements near the margin of the lake, suggest that the melt in the lake in September 1963 had a density of about 2.76. The average density of the drill core used in the calculations, excluding the upper 7 feet, was 2.665 grams per cubic centimeter.

[83] D. L. Peck, J. G. Moore, and George Kojima, 1964, Temperatures in the crust and melt of Alae lava lake, Hawaii, after the August 1963 eruption of Kilauea Volcano — a preliminary report, *in* Geological Survey Research 1964: U.S. Geol. Survey Prof. Paper 501-D, p. D1–D7.

Petrographic study of more than two dozen core and probe samples from the zone of crystallization at the base of the crust of the lake indicates a solidus temperature of 980±10°C. All core that was cooler than 980°C before drilling (disregarding that from the chilled surface of the lake) is completely crystalline except for 5 to 10 percent colorless interstitial glass with refractive index of 1.49. Core that was hotter than 980°C contains brown glass quenched from the melt, the volume percent and refractive index of the glass increasing proportionately with temperature; at 1030°C the lava contains 40 percent glass with index of 1.57, and at 1070°C, 65 percent glass with index of 1.61. The great change in refractive index may result from the late crystallization of opaque material, largely ilmenite.

All samples studied, whether pumice quenched at the point of eruption or wholly or partly crystallized core at all different depths, show inhomogeneous distribution of 1–5 percent olivine crystals. Chemical analyses of 16 samples spanning initially quenched pumice to core samples (partly crystallized and partly molten) from depths as great as 31 feet in the lava lake show no change in composition associated with position in the lake or with time of existence as a liquid after extrusion (see accompanying table). Apparently there was no detectable differential movement of plagioclase, pyroxene, or olivine crystals during the year of crystallizing. Five samples of the interstitial liquid that was filter pressed into the drill holes from the partly molten crystal mesh at the base of the crust show large changes in composition, particularly depletion of magnesia and lime and increase of silica, alkali, and titania.

Chemical composition of material from Alae lava lake
[In weight percent]

Constituent	Maximum	Minimum	Average of 16 samples	Partly crystalline core drilled Sept. 1964, at 31-ft depth	Ooze from 19–20-ft depth, Dec. 30, 1963
SiO_2	50.51	50.32	50.44	50.47	53.30
Al_2O_3	13.82	13.41	13.64	13.69	12.37
TiO_2	2.85	2.63	2.73	2.71	3.36
$FeO + 0.9 Fe_2O_3$	11.11	10.75	10.94	10.88	14.28
MgO	7.68	7.32	7.55	7.58	3.10
CaO	11.20	11.00	11.12	11.17	7.28
Na_2O	2.48	2.33	2.40	2.41	3.26
K_2O	.59	.53	.55	.54	1.57

Submarine pillow basalt from Mauna Kea rift zone

The U.S. Coast and Geodetic Survey hosted James G. Moore and Dallas I. Peck, U.S. Geological Survey, in a dredging program from the research vessel *Surveyor*. Samples collected from the submarine part of the east rift zone of Mauna Kea volcano (to a depth of 3,200 meters) are fresh olivine-rich tholeiitic pillow basalt. In contrast is the cap of lava and cinder cones of alkalic basalt and hawaiite that covers, and may be restricted to, the upper exposed flanks and summit of Mauna Kea.

The vesicularity of the submarine samples from Mauna Kea is greater than the vesicularity of similar samples collected from the same depth on the submarine rift zones of the currently active Mauna Loa and Kilauea. This suggests that Mauna Kea has sunk about 1,000 meters relative to sea level since these vesicular submarine lavas erupted.

Seismic-refraction profiles yield crustal thicknesses at Hawaii

Three seismic-refraction profiles were investigated along the northeast, southeast, and west coasts of the triangular-shaped island of Hawaii. Two hundred twenty five seismograms were recorded by 5 refraction units spaced at about 25 kilometer intervals along each coast from 300-pound shots fired at 10-km intervals from the U.S. Coast Guard cutter *Cape Small.* Preliminary interpretation, by David P. Hill of the Hawaiian Volcano Observatory, indicates that the crust is about 16 km thick under the west flanks of Mauna Loa and Hualalai, is 11 km thick under the northeast and southeast flanks of Kilauea, and has an intermediate thickness along the northeast flanks of Mauna Kea and the Kohala Mountains. The velocity of P waves in the upper crust increases with depth from 2.0 to as much as 6.0 km/sec; velocities in the upper crust are generally lower on the flanks of Kilauea than on the flanks of the other volcanoes. Clearly recorded arrivals indicate that a layer with velocities from 6.9 to 7.3 km/sec forms the lowermost 4–8 km of the crust under each of the coasts. The velocity of P_n under each of the coasts is about 8.2 km/sec. Anomalously high crustal velocities are associated with the major rift zones extending from the five volcanoes that form the island. This interpretation of the refraction data is consistent with gravity data on the island of Hawaii.

ISOTOPE AND NUCLEAR STUDIES

GEOCHRONOLOGY

An interlaboratory standard muscovite for K-Ar analyses

Approximately 1,100 grams of an 81-million-year-old muscovite, P–207, has been prepared by M. A. Lanphere and G. B. Dalrymple (1–65) as an interlaboratory standard for argon and potassium analyses. Twelve argon analyses and 10 potassium analyses made in the U.S. Geological Survey laboratory give mean values of 1.253×10^{-9} moles $Ar^{40}{}_{rad}$/gram ($\sigma_{\bar{x}} = 0.002$) and 10.19 percent K_2O ($\sigma_{\bar{x}} = 0.03$).

This standard sample has been distributed to 21 age determination laboratories in Australia, Canada, England, Japan, Switzerland, and the United States. To date, 11 laboratories have reported the results of their analyses. The mean values of potassium and argon analyses in 11 laboratories and of rubidium and strontium analyses in 3 laboratories are: $Ar^{40}{}_{rad} = 1.267 \times 10^{-9}$ moles/g ($\sigma_{\bar{x}} = 0.009$); $K_2O = 10.34$ percent ($\sigma_{\bar{x}} = 0.05$); $Rb = 9.37 \times 10^{-6}$ moles/g; $Sr^{87}{}_{rad} = 3.17 \times 10^{-9}$ moles/g; and common $Sr = 0.113 \times 10^{-6}$ moles/g.

Effect of weathering upon U-Th-Pb system in zircon

In an investigation of the possible effects of weathering on the U-Th-Pb system in zircon, T. W. Stern, S. S. Goldich, and M. F. Newell analyzed 3 samples of zircon from residual clay formed by weathering of the granite gneiss in the vicinity of Morton, Minn., and 5 samples of zircon from the fresh gneiss. The latter are somewhat discordant but define a chord intersecting the concordia curve at 3,600 million years and 1,900 m.y. The zircon samples from the residual clay all show lead loss of 50 percent or more, with the greatest loss for samples with the greatest content of uranium and thorium. A plot of these data on a concordia diagram clearly shows the superimposed effect of weathering on this zircon population. Geologic evidence shows that the loss of lead from zircon at Morton, Minn., came about only after prolonged weathering; nevertheless, the results emphasize that this factor should not be ignored, especially in studying zircon from metasedimentary rocks which may have gone through one or more sedimentary cycles.

Variations in U^{238}/U^{234} and U^{235}/U^{234} ratios of zircon

Ziron concentrates representing 13 distinct occurrences were analyzed for isotopic abundance of U^{238}, U^{235}, and U^{234} by Bruce Doe and M. F. Newell. Twenty determinations by mass spectrometric techniques and 5 cross checks on U^{238}/U^{234} by alpha spectrometry show that the U^{238}/U^{235} ratios do not vary more than 0.5 percent and that the U^{235}/U^{234} ratio variation is 9 percent. Variations of U^{235}/U^{234}

cannot be correlated with age, grain size, percent discordance in isotopic ages, type of discordance (positive or negative), uranium content, or radiation damage. Sample inhomogeneity or chemical procedures may account for the nonreproducibility of U^{235}/U^{234} ratios in several of the samples. The range in U^{235}/U^{234} is not great enough to account for discordant U-Pb ages in zircons resulting from disequilibrium decay of U^{234}. Since most zircon concentrates are obtained from rock samples near the earth's surface, the weathering effect could be estimated by the U^{235}/U^{234} ratio; however, our observations suggest that near-surface incipient weathering has little or no effect on zircon.

Old age of Morton and Montevideo gneisses confirmed

An extensive dating study by C. E. Hedge of the granitic gneiss and associated plutonic rocks at Morton, Minn., has indicated a geologic history both long and complex. Whole-rock Rb-Sr ages of the Morton and Montevideo granite gneisses form a spectrum ranging from 2.5 billion years to 3.5 b.y. The older age limit is in agreement with earlier zircon age determinations by E. J. Catanzaro [84] and T. W. Stern,[85] and the 2.5-b.y. age represents a time of major metamorphism and plutonism as indicated by both K-Ar and Rb-Sr mineral ages. The Sacred Heart Granite yields concordant Rb-Sr, K-Ar, and U-Pb zircon ages of 2.5 b. y. Late granite is dated at 1.7 b.y. by all methods.

Rb-Sr dating of argillaceous metasedimentary rocks

Whole-rock Rb-Sr dating studies of Precambrian argillaceous metasedimentary rocks being conducted by Z. E. Peterman strongly suggest that such rock types do not remain closed systems after deposition and lithification. Those sedimentary rocks which have been metamorphosed in the upper greenschist facies or higher facies give ages which can reasonably be attributed to the time of metamorphism. Other sedimentary rocks which have not been appreciably metamorphosed yield ages which are significantly too young both for an age of deposition and an age of metamorphism.

Age of alkalic intrusive rocks from eastern and midcontinent States

R. E. Zartman and R. F. Marvin in cooperation with A. V. Heyl and Maurice Brock are continuing a geochronologic study of mica peridotites and related alkaline intrusive rocks from the eastern and midcontinent states. Biotites and phlogopites were dated by both the K-Ar and Rb-Sr methods with the following results:

(1) The syenitic bodies which intrude Ordovician rocks near Beemerville, N. J., yield a Late Ordovician age of 440 ± 20 million years.

(2) Diatremes of mica peridotite which cut Cambrian rocks in southeastern Missouri give an Early Devonian age of 385±20 m.y.

(3) Dikes, sills, and explosion breccia in Mississippian carbonate rocks from the Rosiclare fluorite district of Illinois and Kentucky have an Early Permian age of 265±15 m.y.

(4) Isolated mica peridotites, nepheline syenites, and alkalic lamprophyres occurring in various areas of Paleozoic rocks give Jurassic to Cretaceous ages. Included in this latter group are intrusions having an age of approximately 140±10 m.y. along the western side of the Appalachian Mountains in Vermont, New York, Pennsylvania, and Virginia, and also distinctly younger alkalic rocks of Magnet Cove, Ark., and Silver City, Kans., where ages of 95±5 m.y. are obtained.

Ground waters increase in age toward Great Salt Lake

Ground water along the line of flow from the Stansbury Mountains recharge area toward the southern end of Great Salt Lake, Tooele County, Utah, has been sampled by A. B. Tanner, and the radiocarbon content of the bicarbonate in seven of the water samples has been determined by Meyer Rubin. The results when plotted on a map show a progressive increase in apparent age down the alluvial fan toward Great Salt Lake. The rate of ground-water movement along the flow line averages 4.5 feet per year in the region of low salinity (<100 parts per million of dissolved solids) but decreases abruptly at the contact with highly saline waters here considered remnant from glacial Lake Bonneville. The apparent age of the water ranges from 2,000 years in the recharge area to more than 30,000 years in the highly saline area.

List of additional age determinations

A considerable part of the work of the geochronology laboratory of the U.S. Geological Survey is carried on in cooperation with Survey field geologists. Results of such service investigations throw light on local geologic problems and are reported under appropriate headings elsewhere in this chapter. A tabulation of these determinations for use in cross reference follows:

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[84] E. J. Catanzaro, 1963, Zircon ages in southwestern Minnesota: Jour. Geophys. Research, v. 68, p. 2041–2048.

[85] T. W. Stern, 1964, Isotopic ages of zircon and allanite from the Minnesota River valley and La Sal Mountains, Utah [abs.]: Am. Geophys. Union Trans., v. 45, no. 1, p. 116.

Samples dated	Method	State or area (from east to west by regions shown in table of contents)	Subdivision shown in table of contents
Oyster shells	C–14	Atlantic shelf	Marine Geology and Hydrology.
Metamorphic and igneous rocks	Rb–Sr K–Ar U–Th–Pb Pb–α	Connecticut	New England and Eastern New York.
Matrix, muskox skull	C–14	Kentucky	Paleontology.
Spruce wood	C–14	Wisconsin	Shield Area and Upper Mississippi Valley.
Vitrophyre	K–Ar	Colorado	Southern Rocky Mountains and Plains.
Syenite	U–Th–Pb K–Ar	Idaho	Northern Rocky Mountains and Plains.
Silicic intrusives	K–Ar	Nevada	Basin and Range Region.
Intrusives and extrusives	K–Ar	Arizona	Do.
Variety of materials	C–14	Washington	Pacific Coast Region.
Salmon and Abrams Schists	K–Ar	California	Do.
Bishop Tuff	K–Ar	do	Do.
Wood	C–14	do	Do.
Hornblende, igneous	K–Ar	Alaska	Alaska (northern).
Hornblende, biotite, igneous	K–Ar	do	Alaska (southwestern).
Organic material	C–14	do	Alaska (southern).
Mollusk shells	Th–U disequilibrium	do	Alaska (west-central).
Whole rock, granitic	Rb–Sr	Antarctica	Antarctica.
Biotite from granite	K–Ar	do	Do.
Zircon from quartz diotite	Pb–α	do	Do.
Ash flows	K–Ar	Chile	Geologic and Hydrologic Investigations in Other Countries.
Turf in glacial moraine	C–14	Greenland	Do.
Pelecypod shells	C–14	do	Do.

RADIOACTIVE DISEQUILIBRIUM

Fractionation of uranium isotopes in sandstone

Isotopic ratios of U^{234}/U^{238} for 14 samples representing a sandstone-type uranium deposit that formed at, and just above, the present level of standing water in the Wentz mine, Natrona County, Wyo., show that the deposit has a relatively consistent U^{234} deficiency ranging from 7 to 29 percent (J. N. Rosholt, Jr., and C. P. Ferriera, p. C58–C62). Th^{230}/U^{234} and Pa^{231}/U^{235} ratios indicate that the mean time interval since uranium emplacement near the level of standing water occurred about 80,000 years ago and that the time interval generally is greater with increasing distance above standing water. The source uranium also appears to be deficient in U^{234}; this deficiency was maintained by a relatively continuous preferential leaching of U^{234}.

Isotopic composition of uranium in surface water

Determinations of uranium isotopes in surface water that drained diverse terranes on opposite sides of the Shirley Basin, Wyo. indicated differences in the isotopic composition of uranium derived from different sources. R. C. Scott and K. W. Edwards found a considerable enrichment of U^{234} with respect to U^{238} in water from granitic terranes, two samples of which had an average U^{234} excess of 50 percent above the radioactive equilibrium composition, whereas water that drained sedimentary terranes was characterized by only a slight excess of the U^{234} isotope.

Migration of uranium in soil profiles

Data collected on the isotopic composition of uranium and thorium in soil profiles provided information for interpreting the causes of uranium migration in soils and for constructing a tentative model to explain the isotopic evolution of uranium and thorium in this environment. The model proposed by J. N. Rosholt, Jr., and J. R. Dooley, Jr., indicates that (1) uranium was leached at depth in the profile, (2) preferential leaching of U^{234} continued with time in the subsoil, and (3) upward capillary migration of a fraction of the uranium with a higher than normal U^{234}/U^{238} ratio tended to make uranium of high U^{234} ratio available for isotopic exchange in upper soil horizons and for assimilation in organic complexes in surface soils which are rich in organic matter. Thus some of the organic-rich surface soils, which have had considerable time to develop, contain uranium with excess U^{234} compared to U^{238}. Interpretations from this model suggest that remixing of radioisotopes by geochemical processes can play a significant part, in addition to the usual physical processes of radioactive growth and decay, in the production of an isotopic composition near radioactive equilibrium.

STABLE-ISOTOPE INVESTIGATIONS

LEAD

Isotopic composition of lead in basalt

The systematic study of the isotopic composition of lead in basalt by Mitsunobu Tatsumoto has included oceanic tholeiites from the Mid-Atlantic ridge and East Pacific rise, and basalt flows from the marine Tertiary sediments of the Newport Embayment, Oregon. The isotope composition of lead from these various samples is nonuniform, giving the following ranges in ratios:

Pb^{206}/Pb^{204}	17.8 –18.8
Pb^{206}/Pb^{207}	1.15– 1.20
Pb^{208}/Pb^{204}	36.6 –38.4
U^{238}/Pb^{204}	5 –13
Th^{232}/U^{238}	0.9 – 2.9

One of the tholeiite samples dredged from near Ascension Island, in the Atlantic Ocean, contains the least radiogenic lead among those basalts so far studied. The lead from tholetites within the Miocene sediments of Oregon has an isotopic composition similar to basalt of the Columbia River Group, but the alkali basalt from this Oregon section shows large radiogenic lead aberrations similar to those of the Iwo-Jima volcanic rocks.[86]

Lead isotopes in feldspar from Boulder batholith

Recent work by Bruce Doe, R. I. Tilling, and M. R. Klepper has been completed on the isotopic composition of lead in feldspar from the major intrusive units of the Boulder batholith, Montana. The ratios of lead isotopes (given in the following order: (a) Pb^{206}/Pb^{204}, (b) Pb^{206}/Pb^{207}, (c) Pb^{208}/Pb^{204}) from these units range widely [(a) 17.0 to 18.4, (b) 1.095 to 1.171, and (c) 38.0 to 39.0] and show unusual relationships between separate intrusive units. These units are internally uniform isotopically and contain B-type lead anomalies. Lead-isotope ratios characteristic of the oldest major intrusive granodiorite to the south [(a) 16.99, (b) 1.0948 and, (c) 38.04] are drastically different from those typical of the Unionville Granodiorite [(a) 18.08, (b) 1.150, and (c) 38.51] (Adolph Knopf[87]), the oldest intrusive unit some 80 kilometers to the north. These two units, though similar in appearance and intrusive sequence, appear to be distinct in their genesis as testified by the lead-isotope ratios. Either these geographically separate intrusives were generated by different magmas having distinct ratios, or the magmas came from the same source and subsequently acquired distinct ratios. The Butte Quartz Monzonite and its contained ores, younger associated granites, and the Clancy Granodiorite (Adolph Knopf[87]) make up a uniform isotopic unit that includes 75 percent of the exposed batholith. This uniform unit gives the following average ratios: (a) 18.00, (b) 1.46, and (c) 38.54. Further interpretation of the lead-isotope data confirms the geologic observations that similar isotopic intrusive units were derived from a common source by differentiation.

Isotopic variation of ore lead in Colorado Rockies

Collaborative studies of A. P. Pierce, R. S. Cannon, Jr., and J. C. Antweiler on the isotopic nature of lead from the Colorado mineral belt have revealed an extremely complicated and yet unresolved geologic relationship that produces lead-isotope variations. Isotopic composition of these ore leads differs systematically in an unusual manner from those of ordinary ore-leads. The principal ores are low in uranium derived lead. Pb^{206}/Pb^{204} and Pb^{207}/Pb^{204} ratios are 18.37 to 17.57 and 15.71 to 15.58, respectively. Low content of uranium-derived lead gives the Laramide ores "model" age values that range continuously from 0 to as much as 750 million years. This distinctive isotopic variation has been named "Colorado mineral belt type" ore lead. Such unusual isotopic variations are believed to result from partial remobilization of lead from Precambrian rocks; however, other alternate hypotheses require testing.

One episode of Precambrian mineralization in the Rocky Mountains of Colorado is characterized by "Grenville"-type ore lead with a model age of about 1,650 m.y. Ore lead of this same approximate composition has been found abundantly in major ore deposits in other States in the Rocky Mountains region and elsewhere in the world. This statistical correlation may be considered encouraging to future search for a major deposit of this type even though other kinds of geologic evidence have not heretofore stimulated much exploration for such deposits in Colorado and Wyoming.

OXYGEN AND TRITIUM

Oxygen isotopes in carbonates from Pierre Shale

Shells of many specimens of cephalopods collected by H. A. Tourtelot (baculites, ammonites, nautiloids) from the Pierre Shale still consist of original arago-

[86] M. Tatsumoto, 1964, Isotopic composition of lead in volcanic rocks from Japan, Iwo-Jima, and Hawaii [abs.]: Am. Geophys. Union Trans., v. 45, p. 109.

[87] Adolph Knopf, 1957, The Boulder bathylith of Montana: Am. Jour. Sci., v. 255, p. 81–103.

nite. The inner nacreous layer of many specimens of *Inoceramus* also consists of original aragonite, and the outer prismatic layer is calcite. Preservation of aragonite from Late Cretaceous time seems to depend on the specimens having been sealed in early diagenetic concretions or buried in claystone. Oxygen-isotope analyses by R. O. Rye of aragonite from baculites give temperatures of 15°–27°C, which bracket the temperatures determined on two specimens of Pierre belemnites (17°–22°C). Aragonite and calcite from individual *Inoceramus* valves have the same isotopic composition, but indicate temperatures of 29°–37°C. The temperatures indicated by nektonic baculites and other cephalopods are considerably lower than those indicated by benthonic pelecypods even where the cephalopods and pelecypods come from the same locality. This contrast between nekton (belemnites) and benthos has been reported before in material from widely scattered localities (mostly European). It has been attributed to a temperature control whereby the benthos grew shell only within the warmer part of the local temperature range while the nekton grew shell in other regions of the Cretaceous seas where the temperatures were markedly lower. Such an explanation is not satisfying for the Pierre material because it implies that present-day equatorial temperatures north of lat 40° N. existed in Cretaceous time, and there are no unknown parts of the Pierre sea basin in which temperatures as low as 15°C can be postulated.

Tritium fractionation

Fractionation of tritium occurs as a result of many physical and chemical processes. Such isotopic fractionation varies from only a few percent, as in liquid-vapor equilibria systems, up to a factor of 30 percent or more as in the electrolysis of tritiated water. G. L. Stewart has observed that isotopic fractionation occurs during the diffusion of water through porous materials. Laboratory investigations have shown that the degree of fractionation depends upon the tenacity with which water is held to mineral surfaces. Preliminary results show that tritiated water held at low tensions has a greater tritium concentration than water held at higher tensions. It has also been observed that fractionation occurs in different degrees depending upon the temperature at which water is removed from clay systems. Tritiated water extracted at various pressures and temperatures from sand and glass beads showed considerably less fractionation than tritated water extracted from the clays kaolinite, illite, and montmorillonite.

HYDRAULIC AND HYDROLOGIC STUDIES

SURFACE WATER

Hydraulic studies of open-channel flow have helped define relationships among velocity, depth, slope, and roughness in straight and meandering channels, and have shed new light on the mechanics of transport and dispersal of solutes and solids in the flow.

Hydrologic studies have helped show how annual runoff, storm runoff, and peak flow are affected by natural and manmade features in the drainage basins.

Flow in open channels

Jacob Davidian found that an expression containing depth of flow (D), median grain size (d_{50}), and Froude number (F) gives some insight into scale effects in alluvial channels ranging in size from laboratory flumes to large rivers. The expression, which is $F^4(D/d_{50})^{3/2}$, has been used to predict regimes of flow (type of bed configuration) and to explain the inverse relation known to exist between Froude number and channel size in meandering streams.

Dispersion in open-channel flow

Although previous work by Nobuhiro Yotsukura showed that in flume experiments the longitudinal dispersion coefficient was a function of the Reynolds number, he has found the relation to be of little use in predicting the longitudinal-dispersion coefficient in natural channels, because the nonuniformity of the flow makes it nearly impossible to evaluate the convective effect. The lateral dispersion coefficient, on the other hand, is relatively free from the convective effect, and the formula $L = W^2/\beta D\ \sqrt{8f}$, which he developed from flume data, allows the prediction of the lateral dispersal length with reasonable accuracy. In this formula L represents the downstream distance necessary for complete lateral dispersal, and W, D, and f are the width, depth, and friction factors, respectively; β is a coefficient which ranges from 0.3 to 1.0 in natural streams.

Discharge coefficients for flow in open channels

Resistance to flow in alluvial channels is intimately related to the bed configurations that form there. Using laboratory and field data, D. B. Simons and E. V. Richardson (2–65) have defined the Chezy discharge coefficient, C, for plane bed conditions as $C/\sqrt{g} = 7.4 \log (D/d_{85})$; in this formula g is the force of gravity, D is the depth of flow, and d_{85} is the grain diameter which is coarser than 85 percent of the grains on the bed. To determine the Chezy coefficient for ripple, dune, or antidune bed configuration, they applied a factor to the plane bed equation to compensate for the energy dissipation resulting from form roughness and from wave acceleration and deceleration. The correction factor was defined, on the basis of laboratory and field data, as a function of bed material size, slope, depth, and bed configuration.

Flow in curved channels

C. H. Hannum computed discharge for a concrete-lined flume by using the superelevation of the water surface in a bend as a measure of the velocity head. His results differed from discharge measured with a current meter by an average of only 6 percent. The flume was 40 feet wide, with vertical walls and an 8½-foot trapezoidal center section, and thus is comparable to a main channel with flood plains on each side. The bends were 36°, 47°, and 62°. Fifteen of the 18 determinations agreed with the measured discharge within 10 percent.

On the basis of a study of flow in seven bends of a trapezoidal concrete-lined canal, D. B. Simons and E. V. Richardson found that the usual method for designing sinuous canals based on the energy-loss concept is inadequate. A design method was developed which considers the effect of each bend on backwater and superelevation as well as on possible wave height.

Flow under ice cover

K. L. Carey found the configuration of the underside of the ice on the Saint Croix River near Danbury, Wis. to resemble the ripples and dunes found in streams with sandy bottoms. The dunes and ripples are oriented generally transverse to the flow and extend for half a foot to at least 4 feet before merging into similar forms that are out of phase with their neighbors. The ice dunes have an average wave length of 0.65 foot and an average amplitude of 0.07 foot. The configuration, which varies slowly with time, is assumed to be due to the turbulent, thermal, and hydraulic characteristics of the flow, because the suspended-sediment load is virtually nil.

Backwater in open channels

Although the pool elevation at a dam 29 miles downstream now submerges the low-water control at a bridge on the Neosho River in northeastern Oklahoma by 3 feet, L. L. Laine has found that the stage-discharge relation for high discharges is the same as before the dam was built; and that the dam causes no decrease in the net operating head on the turbines at Pensacola Dam, half a mile upstream from the bridge, when the turbine discharge exceeds 7,000 cubic feet per second. From this he concludes that backwater in the tailrace of a power plant at low flow does not necessarily indicate a decrease in the net head on the turbines under operating conditions. The conveyance of the channel downstream from the bridge is obviously such that backwater from the downstream dam does not extend this far upstream at high discharges.

Rate of movement and dispersion of solutes in streams

Measurements of the time of travel of soluble contaminants were made in many stream reaches. A tracer, Rhodamine-B dye, is introduced into the stream and is detected with a fluorometer as it is carried successively farther downstream. The distribution of concentration in the dye cloud as it passes a monitored cross section is obtained from readings of the fluorometer repeated at short intervals or from a record of continuous monitoring. Time of travel in a reach, which is usually taken as the elapsed time between peak concentrations at the ends of the reach, varies with the discharge of the stream. For example, P. W. Anderson and G. M. Horwitz measured traveltimes of 5 days and 12 days at moderate and extremely low discharges, respectively, through a 31-mile reach of the Passaic River, N.J. Average velocities of peak concentrations of dye ranging from 0.3 feet per second to 0.5 feet per second were reported by J. D. Shell in 2 reaches of Big Black River, Miss.

Dye was introduced near one bank of the Missouri River at Jefferson City, Mo., when the discharge of the river was 37,000 cubic feet per second, which is the normal flow for the navigation season. Samples were taken at 5 lateral points at each of 4 sampling sites in a 76-mile reach. M. S. Petersen reported that lateral dispersion of the dye progressed slowly. The first sampling site to show dye throughout the cross section was 26 miles downstream from Jefferson City. Velocities in the subreaches ranged from 2.9 to 3.6 feet per second.

J. R. Williams injected dye into a tide-affected reach of the Duwamish River, Wash., and measured dye concentration continuously for 67 hours. Four peaks of concentration were recorded at one site, each peak concentration being appreciably less than the preceding one.

J. F. Wilson and W. E. Forrest measured the time of travel of the Potomac River in the 192-mile reach from Cumberland, Md., to Washington, D. C.

Discharge ranged from 400 cfs at Cumberland to 5,000 cfs at Washington. The time of travel was 15.6 days.

W. W. Evett compared measured time of travel through a 26-mile reach of the Catawba River, S. C., with that computed from velocities at 34 surveyed cross sections. Agreement between the two was good for the total reach, but variations of about 15 percent were found for subreaches.

Analysis of data obtained by W. W. Sayre and D. W. Hubbell in a Colorado canal demonstrated convincingly that the longitudinal dispersion of low concentrations (less than 500 parts per million) of colloidally suspended bentonite particles did not differ significantly from the longitudinal dispersion of dye in the same flow.

In a series of flume experiments W. W. Sayre and F. M. Chang showed that the longitudinal dispersion coefficients for dye and suspended silt-size particles in open-channel flow were on the order of 10 times as large as the longitudinal dispersion coefficients for small polyethylene particles floating on the surface.

Effect of reservoirs on time of travel

Also using Rhodamine-B dye as a tracer, D. F. Farrell found that 10 low dams in a 50-mile reach of the Housatonic River in western Massachusetts so slowed the velocity of water that 12 days were required for the dye to travel through the 50-mile reach. River discharge ranged from 25 cubic feet per second at the injection point to 145 cfs at the sampling point farthest downstream.

T. J. Buchanan and J. E. McCall found that pools above the dams on the South Branch of the Raritan River downstream from Stanton, N.J., tend to speed the velocity of the flood wave and to slow the movement of water particles, so that the flood wave traveled 2.0 to 2.7 times as fast as the water as compared with 1.1 to 1.6 times as fast in the natural stream channel above Stanton. These figures confirm the expected effect of reservoirs, and provide factual data for use in studying the movement of contaminants in stream channels and for scheduling the release of water from upstream reservoirs for water supply 30 miles downstream.

Effect of reservoir release on stream temperature

P. W. Anderson and G. M. Horwitz found that following the release of water in July 1964 from Pepacton Reservoir, N.Y., on the East Branch of the Delaware River, the temperature of the river water 30 miles downstream decreased by about 20°F. A simultaneous drop in air temperature accounts for only about 5°F of this decrease in stream temperature. At a point 58 miles downstream the water temperature decreased 10°F 3 days later.

Time-of-travel characteristics

Using field measurements of the time of travel of water in White Oak Creek in Tennessee, and relating the results to mean velocity, discharge, and the flow-duration curve, W. M. McMaster found in 4 out of 5 trials that the time required for water to travel through a 1.6-mile reach of the creek is between 2.5 and 5 hours. The median travel time in this creek, which drains from the Oak Ridge National Laboratory area, is 3.7 hours for the 1.6-mile reach.

Effect of urbanization on peak flow

In analysis of how change in land use affects peak discharge, the effect on the time distribution of storm runoff is usually more important than the effect on the percentage of the precipitation that becomes runoff. J. R. Crippen (p. D196–D198) studied discharge hydrographs of Sharon Creek, near Menlo Park, Calif., for storms in 1959, 1960, and 1963. Urbanization of the 0.38-square-mile basin between 1960 and 1963 brought the change from natural ground cover to suburban residences, light commercial facilities, and a golf course. Change in the distribution of runoff, as a result of this change in land use, increased the peak discharge by about 40 percent, and decreased by a similar amount the time required for nine-tenths of the storm runoff to leave the basin.

L. A. Martens found that a formula previously developed for streams near Washington, D.C., for relating mean annual flood to basin characteristics, is applicable to streams in the Piedmont region near Charlotte, N.C. The formula, by R. W. Carter,[88] is

$$Q_{MAF} = 223A^{0.85}T^{-0.45}K,$$

in which Q_{MAF} is the mean annual flood in cubic feet per second, A is the area of the drainage basin in square miles, T is the basin lag time in hours, and K represents relative imperviousness. Martens used a second formula, developed by D. G. Anderson, to determine T without the use of rainfall records. This formula is

$$T = 4.18(L/\sqrt{S})^{0.52},$$

where L is stream length and S is channel slope. The relation between mean annual floods and drainage area determined with Carter's formula agreed closely with a similar relation defined by gaging-station records. Because the difference was only 10 percent at 1 square mile and zero at 285 square miles,

[88] R. W. Carter, 1961, Magnitude and frequency of floods in suburban areas: Art. 5 *in* U.S. Geol. Survey Prof. Paper 424–B, p. B9–B11.

Martens concludes that the formula can be used to estimate the effect of urbanization on peak near Charlotte by substituting empirically determined values for T and K.

Effect of saltcedar on channel characteristics of Pecos River

Physical effects of increase in the area covered by the phreatophyte saltcedar (*Tamarix gallica*), in and along the Pecos River in Texas near the New Mexico boundary, described by R. U. Grozier (p. B175–B176), include a 35-percent reduction in channel conveyance, observed in the records of floods in August 1916 and June 1937, and a 15-percent reduction in channel cross section between December 1932 and March 1963.

Rainfall-runoff relations

E. E. Schroeder found that storm runoff from a 75-square-mile basin in northeastern Texas can be graphically related to storm rainfall, with good results, by using as factors (1) duration and amount of the rainfall, (2) season of the year, and (3) an index of soil-moisture conditions. The index of soil moisture was computed from antecedent precipitation adjusted by a factor of 0.9^t in which t is the number of days since the precipitation.

Effect of storage on runoff

F. W. Kennon and C. T. Welborn found that 11 floodwater-retarding structures in Texas reduce streamflow by an average of 34 percent during years of average precipitation (32 inches) and by about 10 percent when the annual rainfall is 40 inches. For years in which the annual precipitation is less than 20 inches all the runoff is usually retained in the structures. Evaporation losses account for about half of the reduction, and seepage and evapotranspiration losses for the other half.

Reservoir storage for flood reduction

Data on the volume and frequency of flood runoff at stream-gaging stations are used to determine the size of storage reservoirs required to control the amount of flow. By analyzing annual flood volumes at stream-gaging stations in Kansas, L. W. Furness, C. V. Burns, and M. W. Busby (1–64) found that for a 4-percent chance of inadequacy, a reservoir with a capacity of a 1-inch depth of runoff from the basin could hold the release rate to 0.05 cubic feet per second per square mile in western Kansas, as compared with 30 to 80 cfs per sq mi for small streams in eastern Kansas. By using the relations they developed, similar computation of reservoir capacity, flood outflow, and chance of inadequacy can be made on any stream in Kansas that drains more than 100 square miles.

Relation of flow variability to geology

For drainage areas of 25 to 100 square miles in New Jersey, E. G. Miller found that an index of the slope of the duration curves of daily discharge could be used to classify the variability of the streamflow in different types of terrain. For the Coastal Plain he found the ratio of the discharge at the 20- and 80-percent flow-duration points to vary only from 2.2 to 3.6, as compared with much higher and more variable ratios in other parts of the State. Ratios of 15 to 20 for areas underlain by Triassic formations, in southern Hunterdon and northern Mercer Counties in northwestern New Jersey, were the highest in the State.

Estimation of mean runoff from ungaged mountain basins

H. C. Riggs and D. O. Moore (p. D199–D202) used a relation between surface runoff and basin area, for mountain basins in northern Nevada and southern Idaho, to estimate mean runoff from ungaged basins nearby. Because the magnitudes of both precipitation and evaporation in this mountainous region are related to altitude, runoff data used in the runoff-area relationship were for zones of altitude within each basin.

Time of low flow

Although some of the heaviest storm rainfall in Hawaii occurs during the cooler months of November to April, G. T. Hirashima found that for streams whose basins have little surface or ground-water storage the lowest flows of the year often occur during these months. He attributes this phenomenon to the fact that many periods of consecutive days with little or no rain occur in these months of decreased trade-wind activity.

Base-flow relations

In relating the base flow of small streams near Oak Ridge, Tenn., to that at nearby stream-gaging stations, W. M. McMaster found that satisfactory correlation could be made using the flow on concurrent days which were preceded by at least 10 days without rises. In 4 years of record he found more than 20 recessions for which this limitation was satisfied, and that the resulting correlation coefficient for 4 pairs of stations ranged from 0.91 to 0.97.

GROUND WATER

Research on ground water continued across a broad front, the range in subject matter being illustrated, on the one hand, by experiments on water movement in clay involving flows of as little as a few cubic centimeters per day, and on the other hand by studies of the influence on ground-water flow and chemistry of structures in lava rocks covering tens or hundreds of square miles. Temperature was recognized as a property having greater hydrologic significance than has been generally thought. There was renewed effort to correlate ground-water availability with topographic criteria as a method of prospecting. Seismic and other fluctuations of water levels in wells were scrutinized for their hydrologic significance. Substantial efforts continued in laboratory and field research on permeability and specific yield of porous media and on the usefulness of radioactive tracers. Carbonate rocks continued to receive attention as aquifers of both great economic importance and great hydrologic complexity. Both research on, and routine application of, electric-analog modeling of ground-water systems continued. Research on possible applications of "remote sensing" of hydrologic phenomena from the air was accelerated during the year. Techniques were developed for handling several types of problems involving recovery of fresh water in areas where salt-water encroachment is a threat.

Relation of permeability to particle size in a glacial-outwash aquifer

S. E. Norris and R. E. Fidler (p. D203–D206) investigated the relation between particle size and permeability in a glacial-outwash aquifer at Piketon, in southern Ohio. The aquifer contains two types of material, (1) medium to coarse sand, and (2) coarse sand to coarse gravel, which are characterized by different kinds of particle-size graphs. The first type of material, which is relatively less permeable, has an average uniformity coefficient of 6; the second type, more permeable, has an average uniformity coefficient of 13.9.

Darcy's law and water movement in kaolinite

H. W. Olsen (1–65) measured the flow of water through rigidly confined samples of kaolinite, as a followup of work that partially explained apparent deviations from Darcy's law in clays as due to atmospheric contamination of capillary tubes.[88a] The new experiments, using a system in which the contamination problem is avoided, confirmed the validity of Darcy's law at hydraulic gradients of 0.2–40 in samples consolidated under loads of 0.5–350 kilograms per square centimeter.

[88a] H. W. Olsen, 1965, Deviations from Darcy's law in saturated clays: Soil Sci. Soc. America. [In press]

Structural control of ground water in basalt

Studies by R. C. Newcomb of the effects on ground water of tectonic structures in basalt of the Columbia River Group in Washington, Oregon, and Idaho have confirmed preliminary conclusions that flow tends to be concentrated in synclines. Plateau areas lacking pronounced structures are characterized by widespread but meager supplies of high-level water in relatively unfractured basalt. Although the largest supplies are found in synclines, there are several disadvantages of using water from these areas: (1) water of poor quality may rise along faults or tensional joints along synclinal axes; and (2) the synclinal aquifers tend to be isolated from one another and limited in natural recharge potentiality. Artificial recharge is a promising means of increasing natural supplies.

Temperature as a geohydrologic tool

R. W. Stallman (1–65), R. A. McCullough, and E. E. Parshall, using temperature profiles as a measure of ground-water velocity, have found that (1) infiltration rates as low as 0.05 foot of water per day can be measured by analysis of the diurnal temperature wave originating at the land surface; (2) downdip flows as small as a few tenths of a foot per day in artesian aquifers can be calculated from temperature profiles in wells if the dip of the strata is known; and (3) steady vertical flow in an aquifer, or vertical leakage from one aquifer to another, as small as 10^{-3} foot per day can be detected by analysis of temperature profiles. Present equipment measures temperature reliably to 0.005°C, and improvement to 0.001°C is in prospect.

J. D. Bredehoeft and I. S. Papadopulos (1–65) have developed a technique of estimating from the earth's thermal profile, vertical ground-water flow through semiconfining beds.

F. C. Koopman and W. D. Purtyman, in studies related to disposal of heat from radioactive materials stored underground, discovered that holes ending above the water table tend to gain heat energy from the atmosphere, whereas holes extending into the zone of saturation tend to lose heat to the atmosphere.

J. M. Weigle made the interesting temperature-related observation that, in southern New Hampshire, winter thaws following summer and fall droughts resulted in ground-water recharge through dry and therefore porous and permeable soil. Brief thaws following periods of normal precipitation found the soil pores filled with frozen water and resulted in direct runoff rather than ground-water recharge.

Topographic and other criteria for predicting ground-water conditions

Topographic criteria recognized in previous years as valuable in predicting well yields in crystalline rocks of the southern Piedmont (in general, wells in valleys yield more than wells on hills) are being extended to other areas and types of rocks. Other criteria, such as fracture patterns visible at the land surface, are being studied also.

C. W. Poth found that wells in crystalline rocks in upland areas of Chester and Delaware Counties, in southeastern Pennsylvania, were drilled deeper and reached water at greater depth, penetrated a thinner mantle of weathered rock, and had lower yields than wells in draws; wells on slopes were intermediate. L. D. Carswell found similar conditions in Triassic rocks in southernmost New York and adjacent New Jersey and made the additional observation that headwater valleys of high stream gradient tended to have a thicker and more permeable zone of fresh-water circulation than valleys farther downstream. Harold Meisler and A. E. Becher found wells in carbonate rocks in the Lancaster quadrangle, in southeastern Pennsylvania, to be both shallower and more productive in valleys than on ridges.

F. W. Trainer and R. L. Ellison, the latter of the University of Virginia, found that fracture traces seen on aerial photographs are more abundant in carbonate rocks in the Shenandoah Valley in western Virginia than in shale; in both types of rock the dip of the strata is an important control on both orientation and abundance of fractures, and hence probably on the occurrence of ground water.

J. J. Musser, in the Roaring Creek district of east-central West Virginia, has correlated depths of overburden above coal mines with ground-water conditions. Thick overburden is characterized by little fracturing and perched ground water; thin overburden tends to be fractured and drained of ground water.

Interpretation of water-level fluctuations in wells

Interest in seismically induced fluctuations of water levels in wells, stimulated by the Alaska earthquake of 1964, continued during the year. R. C. Vorhis (2–65) devised a technique of estimating the magnitude of earthquakes from the fluctuation of the water level and the location of the well with respect to the epicenter of the quake. H. H. Cooper, Jr., J. D. Bredehoeft, I. S. Papadopulos, and R. R. Bennett developed an equation relating seismic fluctuations to the type and frequency of the seismic wave, the geometry of the well (diameter of well and depth of water), and hydraulic characteristics of the aquifer (transmissibility and storage coefficients). (See also the section "Alaska Earthquake, 1964".)

K. D. Wahl observed "reverse" water-level fluctuations in a well in Pickens County, Ala. The water level in the well, in a confined aquifer 235 feet deep, rises when nearby wells tapping an aquifer 113 feet deep are pumped. The cause is not certain but may be the unloading effect on the deeper aquifer of removal of water from the shallower one. Explanation of the phenomenon might contribute to understanding of the hydraulic characteristics of the aquifers.

Permeability and specific yield

Following up research by Benjamin Reyes and A. I. Johnson on relation of permeability to particle size, Johnson, R. C. Prill, and D. A. Morris evaluated methods of determining unsaturated permeability. As an outgrowth of this study, A. H. Ludwig is developing a centrifuge method of measuring unsaturated permeability, and Ludwig and R. P. Moston are evaluating gas-permeability methods.

A report by Prill, and Morris Johnson [89] shows that time of drainage is an important factor in determining the specific yield of materials packed in long vertical columns, even rather permeable materials that might be expected to drain quickly. Centrifuge techniques for evaluating the effect of variation in time of drainage have been developed by Prill, Johnson, and Ludwig.

The concepts of material transport in ground water systems were evaluated by H. E. Skibitzke (1–64), who pointed out that the tensor characteristic of the permeability coefficient and its correlation with the dispersion coefficient provide a possible means of defining the flow regime with a given aquifer. Because of the large-scale changes in magnitude and direction of the tensor component of permeability, the concept of a mean line of dispersion may produce a more significant statement on the characteristics of flow than does the present concept of hydraulic potential and the streamline.

Use of radioactive substances as tracers in geohydrology

J. M. Cahill tested radiophosphorus (P–32) and an organic dye in a glycerin base against a weak sodium chloride solution for effectiveness as tracers of water movement. The tests were made in columns of silica sand. The tests show both P–32 and the dye to be well suited for laboratory use in studies of mass transport of liquids through porous media.

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[89] R. C. Prill, A. I. Johnson, and D. A. Morris, 1965, Specific yield—laboratory experiments showing the effect of time on column drainage: U.S. Geol. Survey Water-Supply Paper 1662–B, 55 p.

C. W. Carlston reviewed the usability of tritium in geohydrologic research. Its short half life (12.26 years) limits its usefulness as a tracer of ground-water movement to small and perhaps unrepresentative sections of aquifers. Its usefulness for dating recharge is similarly limited because of mixing of waters of different ages. The presence of tritium is meaningless as an indication of ground-water availability because in a humid area it may be present in a shallow aquifer of small yield. Carbon-14 is more useful because its time span of dating, a few tens of thousands of years, appears to include the periods during which most of our ground-water resources accumulated.

Carbonate-rock hydrology

W. J. Powell, and D. B. Knowles, and P. E. LaMoreaux of the Geological Survey of Alabama, found a close correlation among water chemistry, thickness of residuum, and productivity of underlying limestone aquifers in northern Alabama. Where the residuum is thick and gravelly the water in it and in the underlying limestone tends to be softer and the limestone to be more permeable and productive than where the residuum is thin.

From the results of 25 pumping tests of wells in limestone in Tennessee, G. K. Moore developed a type curve that is useful in predicting well yield from "step" drawdown tests of a new well (pumping the well at several successively greater rates and measuring the water-level drawdown). (See also the section, "Water Resources, Pacific Coast Area, Nevada".)

Use of electrical analog models in water-table studies

N. D. White and W. F. Hardt analyzed an electrical-analog model of the San Simon Basin, Ariz., and predicted water-level declines that will occur by 1980—120 feet near Bowie and 160 feet near San Simon. The analysis was based on hypothetical amounts and areal distribution of pumping in the basin which are believed reasonable on the basis of present trends in the use of ground water in the basin.

Geochemical data used in outlining geohydrology of Sparta Sand

J. N. Payne, as a phase of his study of the hydrologic system formed by the Sparta Sand in Louisiana and adjacent States, found geochemical data useful in outlining subsurface geology and water movement. For example, channel sands oriented parallel to the direction of regional flow contain fresher water than interchannel sediments or channel sands oriented across the flow.

Remote sensing of hydrologic phenomena

H. E. Skibitzke and associates, expanding work already begun on a small scale, studied the design, construction, and testing of infrared sensors and the use of conventional film photography (including that on infrared film) as a means of gathering information on water. Color aerial photographs of the Everglades, in southern Florida, and of adjacent coastal waters show paths of surface flow and points of underwater discharge of ground water more effectively than other techniques tried to date. Film photography and infrared imagery of parts of Puerto Rico and the Virgin Islands are being analyzed for signs of offshore discharge of ground water.

Recovery of fresh water in saline-water areas

G. G. Wyrick and H. B. Wilder developed an interesting and effective method of pumping from a thin fresh-water lens at a campground in the Cape Hatteras National Seashore Recreational Area, N. C. The lens is only 3 feet thick, and fresh water is skimmed from the upper part of it by means of an infiltration gallery. The gallery is pumped at a sufficiently low rate to prevent the rise of the underlying salt water to the bottom of the gallery bottom for at least 12 hours. Twice a day, when the tide goes out, the adjacent salt water retreats shoreward and the fresh water, following behind it, sweeps away the cone of salt water that has been rising beneath the gallery.

R. A. Long tested a "seavenger-well" system in Ascension Parish in southern Louisiana. The well is screened in a fresh-water aquifer above and a saline aquifer below. A packer separates the two parts of the well; through it passes a pump extending into the lower part. Pumping the two parts of the well at the same time lowers the head in the salt-water aquifer. This lowering prevents the upward movement of saline water, through the confining bed separating the aquifers, that normally occurs here when the fresh-water level is lowered by pumping. It was concluded, however, that separate wells would be more effective than the dual-purpose well.

Rejuvenation of waste-disposal well

A deep waste-disposal well at the National Reactor Testing Station, Idaho, was rehabilitated by selective perforation of the casing, guided by study of geophysical logs, by releasing and following a radioactive tracer in the well, and by injection tests. According to D. A. Morris, the capacity of the well to absorb wastes was increased from less than 200 to more than 1,000 gallons per minute, at modest cost. Similar techniques could be used to increase the yield of production wells where the proper conditions exist.

Geochemistry of glacial and fluvial sediments

Waters from four glacial and fluvial rock units on the Kitsap Peninsula and adjacent islands in the Puget Sound, Wash., studied by A. S. Van Denburgh (p. D219–D221), differ sufficiently in average content of potassium, orthophosphate, and dissolved solids, and in ratios of these constituents to each other, to enable identifying sources of ground water and to help in working out patterns of movement.

RELATIONS BETWEEN GROUND WATER AND SURFACE WATER

Because the principles governing the movement and occurrence of surface water and ground water differ in many respects, the methods by which they are investigated likewise differ. For this reason they are commonly studied separately. In many areas, however, water in streams and lakes and water underground are closely related and interdependent. Included in U.S. Geological Survey hydrologic investigations, therefore, are studies of (1) the magnitude and source of ground-water contributions to streamflow, (2) methods of forecasting the low flow of streams by use of ground-water levels and aquifer characteristics, (3) the effects of changes in the stage of streams and surface impoundments on ground-water levels, and (4) other subjects concerning the relations of water in the two environments.

Forecasts of ground-water storage and inflow to streams of Columbia River basin

A method has been developed by M. I. Rorabaugh for forecasting the ground-water inflow to the Spokane River between Post Falls, Idaho, and Spokane, Wash. The forecasts include: (1) ground-water outflow from Rathdrum Prairie, indexed by an observation well; (2) reduction in outflow as the water level declines seasonally; (3) bank storage caused by rises in stage of the Spokane River; and (4) return flow associated with lowering stages of the river. Verification of monthly forecasts for the period August through March for 33 years shows that observed flows exceed the forecast 95 percent of the time. The portion of the outflow associated with the water level in the Prairie has had a range of 300 cubic feet per second during the period 1929–64.

A study of forecasts of assured flow for the October-March period in the Bitterroot Basin, Mont., by W. D. Simons, indicates that the record minimum runoff during the power season from October 1936 through March 1937, did not stem from a deficiency of water in the basin, but probably from unusually large ice storage. Analysis of date on the temperatures in western Montana indicates that in January 1937 both the minimum monthly temperature and the duration of days below freezing reached record or near-record values.

Separation of streamflow into components

Using a method devised by G. R. Kunkle[90], L. E. Bidwell and R. D. Cotter have separated the flow of the Pomme de Terre River in Minnesota during a 6-year period into base flow, basin-storage discharge, and overland runoff. A plot of these components along with total flow provides a meaningful summary of the flow characteristics.

L. G. Toler (p. C206–C208) has used the specific conductance of water to separate the base flow of Econfina Creek, Fla., into components from the Floridan aquifer (cavernous limestone) and from the overlying sand aquifer. The components from the Floridan aquifer was correlated with the stages of lakes that recharge the aquifer.

G. R. Kunkle (p. D207–D210) used measurements of specific conductance and of discharge in a study of two streams in east-central Iowa. He separated the hydrograph of one stream into surface-runoff and ground-water components, and he computed the ground-water discharge from an aquifer to a particular reach of the other stream.

Ground-water inflow, bank and channel storage, and streamflow pickup

W. E. Clark (p. D211–D213) studied streamflow in an 8-mile reach of the Santa Fe River in north-central Florida. The pickup in flow in this reach is provided, entirely or nearly so, by ground-water runoff. After floods, part of the ground-water runoff from within the 8-mile reach is provided by water which drains back into the stream from bank storage.

Increase in base flow due to removal of vegetation

H. C. Riggs (p. C196–C198) has related the base flows of small streams in the Hazel River basin, Virginia, to the percentage of the stream valley that is cleared of trees and brush. His analysis, based on 8 sets of measurements on 9 streams, indicates that

[90] G. R. Kunkle, 1962, The baseflow-duration curve, a technique for the study of ground-water discharge from a drainage basin: Jour. Geophys. Research, v. 67, no. 4, p. 1543–1554.

clearing increases the yield considerably during droughts but only slightly when the base flow is high.

Runoff altered by coal mining

Coal mining in Randolph County, W.Va., has caused a part of the flow of Roaring Creek to be diverted into Grassy Run. According to J. J. Musser, some of the water from the Roaring Creek basin moves down the dip of a synclinal limb through abandoned mines into streams of the Grassy Run basin. The augmented base flow of Grassy Run, per square mile, is 20 to 30 times that of Roaring Creek.

New tunnel in Hawaii will decrease yield of Waihee tunnel

G. T. Hirashima reports that the Waihee tunnel reservoir in the Waihee Valley, Oahu, Hawaii, receives as much as half a million gallons of water a day from ground-water discharge whenever the stage in the tunnel is lowered sufficiently. A proposed new tunnel will capture this discharge of ground water, thereby decreasing the yield of the Waihee tunnel.

Estimating aquifer characteristics from changes in ground-water levels near clogged streambeds

A pumping test from a stream in the Little Plover River basin, in Portage County, in central Wisconsin, indicated that the stream was not freely connected to the contiguous aquifer. Treating the perimeter of the stream and the aquifer as a two-permeability system, A. G. Law has developed an analytical procedure to estimate the hydraulic characteristics of the aquifer and the effect of the clogged streambed on the response of ground-water levels to changes in stream stage. The procedure employs a type-curve technique.

Streamflow computed from ground-water recharge data

According to E. P. Weeks, D. W. Ericson, and C. L. R. Holt, Jr., the monthly mean streamflow of the Little Plover River in Portage County, Wis., can be computed from recharge data. The basin was divided into rectangular areas based on the drainage pattern, the location of the ground-water divides, and the geology of the basin. Average values for the coefficients of transmissibility and storage were then determined for each of the rectangular areas, and these values were used to compute the rates at which given volumes of recharge were discharged to the stream. The computed mean monthly streamflow for a 20-month period agreed with the measured streamflow within a few percent in all but 2 months, in which recharge and runoff were abnormally high.

SOIL MOISTURE AND EVAPOTRANSPIRATION

Permeability of soil to water determined from movement of water vapor

In a study near Cuba, in north-central New Mexico, R. W. Stallman, G. E. Ghering, and R. A. McCullough determined the vertical permeability of soils to water by measuring gas pressures at different depths below the surface in the unsaturated zone. The conductivity of the soil to gas is related to its conductivity to water, and moisture flow was estimated from the results of the measurements.

Storage of soil moisture in flood-plain deposits

A. O. Waananen measured an increase in soil-moisture content in Humboldt River sediments near Winnemucca, in north- central Nevada, after periods of high flow. This moisture was retained in storage during 2 years of near-normal rainfall and runoff but surely will become depleted during a very dry spell.

Magnitude of rise of soil moisture computed

R. W. Stallman and J. E. Reed described steady capillary conduction of moisture from the water table in a homogeneous medium, by equations which can be solved by different methods that use digital computers, analog computers, or graphical techniques. Applying the graphical methods for computing the steady flow of liquid between water table and land surface they found that the magnitude of rise through silts can attain as much as 100 feet, at a rate exceeding the demand on moisture made by the vegetation. Thus the assumption that a deep water table is isolated from evaporation may be subject to doubt.

Formula for soil-moisture change with time

M. R. Collings and R. M. Myrick, studying soil moisture changes in the Cibeque Ridge basin in east-central Arizona, constructed an empirical equation describing the decrease in soil moisture with time, with which they can predict soil-moisture content at future dates with a satisfactory degree of confidence, for use in precipitation-runoff studies.

Infiltration in fine-textured soils favorable for forage grass

R. F. Miller, F. A. Branson, J. S. McQueen, and William Buller report that soil-moisture conditions favorable for the growth of good forage grasses on fine-textured soils on basin spreaders can be attained, provided that ponding is prevented. Coarse-textured soils have rates of infiltration and percolation too high for water to remain available for edible plants, although at some places sediment deposits may, after a time, lower the infiltration and percolation rates.

Projected effect of dams on evapotranspiration rates

J. E. Reed, M. S. Bedinger, and H. H. Tanaka have found that construction of navigation dams along the Arkansas River will result in a change in evapotranspiration rates, with the effect that the water levels in the alluvium along the river will not rise as much as the stream stage. They used analog models to arrive at their conclusion.

Use of soil moisture by riparian vegetation

It is often assumed that destroying the riparian vegetation will result in an increase in ground-water supply because of the diminished use of ground water resulting from the destruction. R. C. Zimmerman reports that along the tributaries of the San Pedro River, in south-eastern Arizona, vegetation commonly depends not on ground water but on water retained in the alluvium along the stream following floods. Destruction of such vegetation would result in reduced river-channel stability and would deprive livestock of emergency browse.

J. S. McQueen and R. F. Miller, studying vegetation along the Gila River in Arizona, found indications that saltcedar may not use soil moisture at all but may live on ground water exclusively. However, cottonwood, mesquite, and willow seem to draw upon both sources.

Effect of Great Swamp, N. J., on streamflow

During periods of high evapotranspiration, streamflow from Great Swamp, N.J., is considerably less than inflow to the swamp. E. G. Miller (p. B177–B179) believes that evapotranspiration causes a significant reduction in outflow during the period from June to September.

Evapotranspiration studies

T. E. A. van Hylckama found, near Buckeye in southwestern Arizona, that saltcedar grown in tanks (evapotranspirometers) containing water of low salinity used more water than saltcedar grown in those with high-salinity water. This observation is surprising in view of the well-known tolerance of these plants for salt. The rate of water loss from tanks during hot days can be assigned to transpiration and evaporation factors by the use of harmonic analysis. Water-level records on bare and vegetated tanks both show daily fluctuations which are suggestive of transpiration curves but which apparently are due to daily barometric-pressure changes. Such curves cannot be used to estimate evapotranspiration.

T. W. Robinson and D. E. Donaldson, working with evapotranspirometers at Winnemucca, Nev., showed that a fluorescent dye, Pontacyl Brilliant Pink B, can be used to trace the path of water from the ground water to the leaves. Dye was detected (1) in the soil moisture, (2) in the leaves, and (3) in transpired water collected from the leaves in plastic bags.

T. W. Robinson also reports from Winnemucca that a clear-cut effect of air temperature and length of frost-free season was found on the use of water by four species of woody plants. Water use by greasewood, rabbitbrush, willows, and wildrose was 25 to 40 percent less in 1964 than in 1963. The growing season was both shorter and cooler in 1964 than in 1963: there were 102 frost-free days in 1964, as compared with 135 in 1963, and the average temperature for the period April 1 to November 1 was 1.7°F lower in 1964 than in 1963.

Computation of evapotranspiration

J. S. Meyers and A. M. Sturrock, Jr., compared use of the energy-budget and mass-transfer methods of computing evapotranspiration on two large reservoirs: Garrison Reservoir in North Dakota and Pomme de Terre Reservoir in Missouri. Using the energy-budget techniques developed for Lakes Hefner and Mead,[91] they found good agreement for an entire season but not for short periods. The relationship of energy budget versus mass transfer, so well defined for Lakes Hefner and Mead, did not agree for the two reservoirs.

W. S. Eisenlohr, Jr., in a study of the hydrology of prairie potholes, found that the mass-transfer coefficient *N*, described by Harbeck,[92] changes with change in vegetation. This effect provides a means of separating the water losses due to evaporation from those due to transpiration. The mass-transfer coefficient for evaporation is a constant; the one for transpiration has a curvilinear relation to the emerged height of the vegetation.

O. E. Leppanen reports that analysis of data describing the thermal-energy exchange over 12-foot-tall saltcedar thickets indicates that the energy-budget approach to evaluate evapotranspiration is workable. Computation of energy available for evapotranspiration at Buckeye, in southwestern Arizona, shows that evapotranspiration can be

[91] U.S. Geological Survey, 1954, Water-loss investigations—Lake Hefner studies: U.S. Geol. Survey Prof. Paper 269, 158 p.

G. E. Harbeck, M. A. Kohler, G. E. Koberg, and others, 1958, Water-loss investigation—Lake Mead studies: U.S. Geol. Survey Prof. Paper 298, 100 p.

[92] G. E. Harbeck, Jr., 1962, A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory: U.S. Geol. Survey Prof. Paper 272–E, p. 101–105.

estimated within 20 percent of that measured by evapotranspirometers. Further refinement appears to be possible.

SEDIMENTATION

The scope of investigation termed "sedimentation" includes the sequence of events which begins with the separation of particles from parent rock and concludes with their consolidation into another rock. Sedimentation, therefore, involves consideration of sediment sources; of the weathering, erosion, transportation and deposition of sediments; and of environments of deposition and sedimentary deposits.

EROSION

Erosion near mouth of Rio Puerco

The general balance between erosional and depositional processes in a channel may be altered by the formation of a head cut and its movement upstream. Observations by C. F. Nordin, Jr. (4–64), indicated that aggradation and armoring of the bed of the Rio Puerco, in New Mexico, followed aggradation in the main stream, the Rio Grande. Local scour in the Rio Grande at the mouth of the Rio Puerco formed a head cut and a plunge pool, by erosion of the armored layer and an underlying layer of sand. In 1 year the head cut moved upstream in the Rio Puerco a distance of 1 mile. The depth of the plunge pool reached a maximum of 8 feet during this period.

Scour and fill in sand-bed streams

B. R. Colby (3–64) concluded from a review of general principals of scour and fill and a study of the behavior of a few types of natural streams that:

1. At any instant, the quantity of moving sand, even in deep and swift flows, is usually equivalent to an average depth of deposit of only a few hundredths of a foot on the streambed.

2. In a straight sand-bed channel that has uniform cross section, slope, roughness, and bed material, the streambed neither scours nor fills appreciably during the passage of a flood.

3. In a straight channel having uniform cross section but varying slope or roughness along the channel, fill during a rising stage is usually followed by fill on the falling stage, and scour during a rising stage is usually followed by scour on the falling stage.

4. If a change in roughness or in streamflow requires a change in the depth of flow, the depth generally adjusts through a change in elevation of the water surface and not through a change in elevation of the streambed.

Rate of slope denudation in San Gabriel Mountains

V. C. LaMarche, Jr. (1–64) found, in the San Gabriel Mountains in southern California, that the exposed root system of a 1,400-year-old pine indicates a slope-denudation rate of about 4 acre-feet of sediment per square mile per year during the lifetime of the tree. Modern sediment yields computed from 40 years of reservoir-sedimentation records approach this rate.

Piping and collapse structures in near-surface deposits

In studies of basic processes of erosion, G. G. Parker[93] has shown that piping and collapse structures occur commonly in semiarid parts of the United States and under certain conditions in humid climates. Piping is the natural development of subsurface drainage tubes in relatively insoluble clastic materials. Collapse structures attack several kinds of low-density detrital materials, chiefly deposits of silt, loess, and volcanic ash having a very loose initial packing. Acting alone or together, piping and collapse structures often produce pseudokarst features.

TRANSPORTATION

Predicting sediment loads of rivers

In streams such as the Rio Puerco, in New Mexico, C. F. Nordin, Jr., (4–64) found that the concentrations of suspended sediment are so great that the properties of the fluid, per se, cannot be neglected and that both the flow and concentration change so rapidly with time that the usual assumptions of uniform flow and equilibrium transport are not applicable.

D. W. Hubbell and W. W. Sayre (2–64) concluded from a study of the transport and longitudinal dispersion of bed-material particles in the North Loup River in Nebraska that the discharge of bed-material particles can be computed by using data collected by the radioactive-tracer technique in conjunction with a continuity equation.

In a study of the fluvial characteristics of the Middle Rio Grande, in New Mexico, J. K. Culbertson and D. R. Dawdy (1–64) computed total sand transport using both the modified Einstein and the

[93] G. C. Parker, 1963, Piping, a geomorphic agent in landform development of the drylands: Internat. Assoc. Sci. Hydrology Pub. 65, Berkeley, Calif., p. 103–113, 3 figs.

G. G. Parker, L. M. Shown, and K. W. Ratzlaff, 1964, Officer's Cave, a pseudokarst feature in altered tuff and volcanic ash of the John Day Formation in eastern Oregon: Geol. Soc. America Bull., v. 75, no. 5, p. 393–402, 2 pls., 3 figs.

Bagnold methods. For the data available, the modified Einstein method gave consistent results, whereas the Bagnold method did not appear to be suitable for the field conditions met in the study.

A means of determining the bed-material discharge per foot of stream was presented by B. R. Colby (4–64) in terms of four dominant measures: total shear, shear velocity, mean velocity, and stream power. The graphical average relationship of bed-material discharge to mean velocity is the most convenient to apply. The effects of water temperature and of high concentration of fine sediment on the relationship were determined approximately.

VARIABILITY OF SEDIMENT LOADS IN RIVERS

Very high concentrations of suspended sediment

The highest observed suspended-sediment concentrations occur in streams that drain semiarid regions. J. P. Beverage and J. K. Culbertson (1–64) present data from the basins of the Rio Grande and the Colorado River for samples in which streamflow was more than 40 percent sediment by weight. They found no relation between stream discharge and the occurrence of these very high concentrations of sediment. The proportion of sand increases with increasing concentrations of suspended sediment, and the minimum concentration of the clay fraction, when there is more than 5 percent sand, appears to be about 15 percent. Increase in clay content decreases the fall velocity of the finer sand fractions[94] and thus facilitates the transport of sand.

Snowmelt and sediment loads

Studies by B. L. Jones of sediment loads in streams in small drainage basins in central and northern Pennsylvania indicate that a third to a half of the suspended-sediment discharge for the year occurs during periods of snowmelt runoff.

Flood runoff and sediment load

S. E. Rantz and A. M. Moore (2–65) report that floods in the far western States in December 1964 were outstanding for record-breaking peak discharges and accompanying maximum suspended-sediment concentrations. In tributary streams of the lower Snake and Columbia Rivers the maximum observed sediment concentrations ranged from 188,000 to 309,000 parts per million.

[94] C. F. Nordin, Jr., 1963, Sediment transport in alluvial channels, a preliminary study of sediment transport parameters, Rio Puerco near Bernardo, New Mexico: U.S. Geol. Survey Prof. Paper 462–C.

D. B. Simons, E. V. Richardson, and W. L. Haushild, 1963, Studies of flow in alluvial channels, some effects of fine sediment on flow phenomena: U.S. Geol. Survey Water-Supply Paper 1498–G.

Urbanization and sediment load

D. H. Carpenter reports that accelerating urban development has increased the sediment load in the Northwest Branch of the Anacostia River, Md., near Washington, D.C. The average annual sediment yield has increased from 470 tons per square mile in 1962 to 1,800 tons per square mile in 1964.

DEPOSITION

Effect of confining banks and channel encroachment by saltcedar

R. C. Culler and R. M. Myrick found spectacular sediment deposition and channel plugging in the Gila River in the upper part of the San Carlos Reservoir area, in Arizona. A dense cover of saltcedar on the riverbanks and flood plain had held the channel to the same location for a period of 20 years. Deposition on natural levees and in the channel caused the river bed to aggrade to a level above the adjacent flood plain. Beginning in 1962 the debris carried by summer floods jammed and became buried in sediment in the channel, and water flowed in rivulets over the natural levees. The channel plugging progressed upstream half a mile in 1963 and 2 miles in 1964.

Storage in reservoirs

Trap-efficiency investigations at K-79 Reservoir, Kiowa Creek basin, Colorado, indicate that the sediment discharge from the reservoir is limited to short periods of time. Robert Brennan reports that during the 8-year period, 1956–63, about 85 percent of the sediment discharge from the reservoir occurred during about 0.1 percent of the time. Sediment deposition in the reservoir has been reduced by deposition above upstream structures which were built in 1960.

George Porterfield and C. A. Dunnam (1–64) reported that the loss of original storage capacity in Lake Pillsbury, Calif., during the period 1921–59, due to accumulation of sediment, was 8.1 percent of the original total storage capacity. The elevation of the outlet sill of the dam is 1,740.7 feet above mean sea level. Fifty percent of the sediment, 3,810 acre feet, was deposited above the 1,794-foot contour.

Sedimentary structures formed by flow in stream channels

Results from laboratory and field studies of the mechanics of flow and sediment transport in alluvial channels have been used by D. B. Simons, E. V. Richardson, and C. F. Nordin, Jr., to establish flow regimes and channel-bed configurations; sizes and shapes of ripples, dunes and antidunes; and sediment-transport rates associated with the various bed forms. Because sedimentary deposits contain ripple marks and crossbedding from the initiation and migration of configurations generated at a fluid-sediment interface by a current, the relations developed from flume and field studies have applications in interpreting the hydraulic environment of such deposits. Bed configuration is related to stream power and particle size, and the ratio of wavelength to amplitude of dunes is related to shear stress and particle size. If ripple marks or cross stratification in a sedimentary deposit permit identification of bed configuration, the range in velocity, depth, and unit water discharge associated with a particular sedimentary unit can be determined.

Sedimentary structures in streambed deposits

E. D. McKee determined through experiments on ripple lamination that such lamination is typically formed and preserved in river flood-plain deposits but is not preserved in tidal-flat deposits. Thus the abundance of ripple lamination constitutes a useful criterion for distinguishing between sediments of two environments that in general are similar.

Orientation of axes in sediments

A. E. Scheidegger (p. C164–C167) shows that the mean of a series of axes in space (normals to bedding planes, long axes of sand grains, and so forth) is not given by the vector mean of the individual axes, but should be calculated as the eigenvector of a certain symetric matrix.

LIMNOLOGY

Studies of Pretty Lake, Ind.

J. F. Ficke and R. G. Lipscomb have studied stratification of water in Pretty Lake, LaGrange County, in northeastern Indiana. Chemical stratification of the water in winter, when the water density is near its maximum throughout the lake, is attributed to the action of algae. The algae remove nutrients from the upper part of the water; after death the algae settle to the bottom and decompose, enriching the bottom water.

During summer, Ficke and Lipscomb found diurnal changes in pH and dissolved-oxygen content. The greatest changes were in a shallow embayment where little mixing with water from the rest of the lake occurred. The changes are due to photosynthetic release of oxygen by aquatic plants during the day and to their consumption of oxygen at night.

Ficke described (p. C199–C202) the course of seasonal erasure of thermal stratification on the basis of changes in the temperature and dissolved-oxygen content of the water during late summer and autumn.

Hydrology of Great Salt Lake

In a summary of the physical and chemical hydrology of Great Salt Lake, Utah, D. C. Hahl, M. T. Wilson, and R. H. Langford (p. C181–C186) describe two recent significant discoveries: (1) the two-directional flow of brine through a causeway which separates the lake into two arms, and (2) the formation of a temporary fresh-water layer at the surface of part of the lake as a result of inflow from streams and of precipitation on the lake.

Effect of emergent vegetation on stratification of water in a prairie pothole

Study of a shallow 15-acre pothole in Dickey County, in southeastern North Dakota, showed the influence of emergent vegetation on water properties. During a windy day, H. T. Mitten found in areas of emergent plants a stratification of specific conductance, temperature, and dissolved oxygen between the surface and the bottom in water about 2 feet deep. Where the pothole was without emergent vegetation the water was mixed by wind action, and in this open area there was no significant difference in the properties of water between surface and bottom.

GEOMORPHOLOGY

Erosion rates and processes

Six years of observations of erosion pins, painted rocks, and erosion plots by L. B. Leopold, W. W. Emmett, and R. M. Myrick near Santa Fe, N. Mex., show that about 95 percent of the sediment produced from woodland hillslopes of low relief results from unconcentrated sheet erosion. Processes of mass movement and gully extension contribute a small percentage of the total sediment load under present conditions. Of the total sediment eroded, only about a third is caught in small reservoirs or contributed to aggrading channels.

In his investigations of the effect of exposure on slope erosion in three areas in Colorado and New Mexico, R. F. Hadley has found that the rate of removal of surficial material by sheet erosion is 50 to 75 percent greater on slopes that have southerly and southeasterly exposures than on slopes that have other exposures.

S. A. Schumm and R. J. Chorley (2–64), in a study of cliff recession and rock weathering, reported some interesting observations at Pueblo Bonito, Chaco Canyon, N. Mex. In 1941 a huge monolith of Cliff House Sandstone toppled and damaged a portion of the ruins. Measurements of the movement of the rock prior to its fall demonstrate that the movement of the sandstone block over the underlying shale is an exponential function of total precipitation and that the rate of movement was seasonal, being relatively faster during the winter. It is estimated that the rock began moving slowly away from the cliff about 550 B.C.

Circular patterns caused by exfoliation

In a study of aerial photographs of the Grandfather Mountain area on the Blue Ridge escarpment, in western North Carolina, J. T. Hack found numerous circular patterns from a quarter of a mile to more than a mile in diameter. They are marked by curving ravines, ridges, and streams. Generally circular basins and domical hills of similar diameter are also common. It is believed that the circular features are formed as a result of exfoliation. The tectonic joints in the area open when the stress on the rock, due to deep burial, is relieved by dilation and spalling along large and deep exfoliation fractures or sheets. The fracturing produces roughly circular sheets of rock of varying permeability. This process may help explain the irregular distribution of saprolite and the occurrence of shallow groundwater supplies in massive crystalline rocks.

Geometry of free meanders

C. W. Carlston has completed a study of the geometry of free stream meanders. The relation of free-meander wavelength to stream discharge is most closely approximated (S. E. = 11.8 percent) by the equation $L_m = 106.1\overline{Q}^{\,0.46}$, where L_m is meander wavelength, $\overline{Q}$ is mean annual discharge, and S.E. is the standard error. For bankfull discharge (Q_b), $L_m = 8.2Q_b^{\,0.62}$ and S. E. = 25 percent; for mean discharge of the month of maximum discharge ($\overline{Q}_{mm}$), $L_m = 80.0\overline{Q}_{mm}^{\,0.46}$ and S. E. = 15 percent. For meander width (W_m), $W_m = 65.8\overline{Q}^{\,0.47}$ and S. E. = 23 percent; for stream width (W) $W = 7\overline{Q}^{\,0.46}$ (approximately). Carlston concludes that the dominant discharge which controls meander wavelength is in a range of flows, possibly on falling stages, between $\overline{Q}_{mm}$ and $\overline{Q}$; and that meander migration takes place during these stages. Some field evidence indicates that slope also influences meander wavelength. Whatever the hydrodynamic cause of the wave form of meanders, the effect of the tortuosity of meandering streams is to produce a low-gradient channel for average flows, while the higher-gradient flood plain is an efficient transit channel for large-scale floods.

Paleohydrologic studies along upper San Joaquin River, Calif.

Studies by R. J. Janda indicate that during periods of aggradation, in Pleistocene time, the San Joaquin River near Friant, Calif., carried approximately 2½ times more sediment than the modern river. Channel alluvium deposited during periods of aggradation contains a greater percentage of coarse sand than the modern alluvium.

Paleohydrologic studies at Thorne Cave, Utah

The relationship of alluvial deposits to artifacts of early man has been studied by H. E. Malde at Thorne Cave, near Jensen, Utah. Valley alluvium which accumulated to a depth of 48 feet along Cliff Creek continued to build up another 13 feet while man occupied the cave, and then reached 30 feet higher, sealing in the signs of man. The cave was subsequently exposed by erosion that carved a deep arroyo in the valley. Radiocarbon dates indicate that the cave debris is about 4,000 years old, and they suggest that the valley alluvium was deposited during the period from 5,000 to 3,000 years B.P. The link of the alluvium with early man is archeologically important because the deposit implies a relatively wet environment.

PLANT ECOLOGY

Plants and their hydrologic and physical environment are intimately interrelated. The kinds of plants, their establishment and survival, and their growth rates are strongly affected by, and in turn affect, surficial deposits, geomorphic processes, and land use. Study of these complex interrelations is necessary to provide a better understanding of man's environment.

Historic changes in vegetation in southwestern States

The saguaro *(Carnegiea gigantea)* has failed to reproduce in some habitats where it formerly maintained dense stands. Previous studies have shown that most saguaros in the Saguaro National Monument, in southeastern Arizona, may be gone by the year 2000 because of the sparseness of seedlings in the population and the inevitable death of each remaining old cactus. According to recent studies by R. M. Turner, S. M. Alcorn, George Olin, and J. A. Booth, the pattern of mortality among the seedlings indicates that most deaths may be attributed to (1) lack of shade, (2) small herbivores, and (3) insects. Lack of shade appears to be the most important of these three factors. Presumably, the amount of shade is affected by the volume of associated plants and may be altered by fluctuations in climate or by changes in man's use of the land.

Growth of trees related to local climatic variables

Growth studies of eastern deciduous trees by R. L. Phipps have shown that annual ring growth probably occurs first in the top of a tree and then, at an increasingly later time, down the trunk. Growth at any level is consequently a function of previous growth at higher levels and of environmental conditious at the time growth occurs at that level. Thus, an understanding of annual ring growth of trees in relation to environment necessitates growth determinations from several heights in the trunk. Better correlations with environmental variables have been obtained using ring data from trees that grew under relatively optimum conditions than from suppressed trees containing discontinuous or missing rings. A high degree of correlation has been obtained between ring-area increment and evapotranspiration deficit, a single parameter of environmental water and energy. Growth of an individual tree was found to reflect strongly the particular microclimate in which it grows.

Tree growth and precipitation

In studies of tree rings from Arizona, New Mexico, and Colorado, Lee Horner, Deric O'Bryan, and N. C. Matalas have found, in correlation of precipitation and ring width, that a match to within 60 percent of perfect correlation can be attained. The best results were obtained by use of three measures: (1) precipitation for the 12-month period November through October, (2) total annual precipitation, and (3) winter (November-April) precipitation. The use of ring area (especially where based on 4 radii instead of 1 radius) improved correlation of tree growth with November-October annual precipitation by an additional 10 percent over use of ring width. The yield of corn grown by Indians in nonirrigated fields also showed high correlation with the November-October annual precipitation.

Effects of coal strip mining on upland forests

Acid water from coal strip mines in Kentucky seems to cause trees irrigated by it to grow rapidly in radius. Studies by R. S. Sigafoos (*in* C. R. Collier and others, 2–64, p. B73–B74) show that irrigated trees grew more rapidly during the 5 years following cessation of mining than they had done previously. Preliminary analysis of data collected in 1964 from the same and additional trees after a second 5-year period shows continued rapid growth. Naturally seeded shortleaf, pitch, and Virginia pine saplings on mine tailings have grown rapidly, and abundant fruiting bodies of fungi among the pine trees suggest that mycorrhizae have developed in the tree roots. Eight-year-old pine saplings are producing viable seed, and second-generation seedlings are becoming established on the tailings.

Relation of flood-plain forests to land use and flooding

Past use of flood-plain land by man along the Potomac River in Maryland, near Washington, D.C., was found by R. S. Sigafoos to have had little effect upon vegetation that has grown since abandonment of the activity. The present forest, at a site where a mill was operated until about 1900 and where the March 1936 flood later destroyed all summer cottages, is similar in species content and in form and appearance of the trees to forests on sites that were not used by man but are otherwise similar. Forests on sites of Chesapeake and Ohio Canal lock-keepers' gardens are like those on relatively undisturbed sites, even though most gardens were not abandoned until the 1920's. Floods that occur about once every 2 years or at greater intervals disturb the surface and tend to maintain an unstable environment in which erosion, deposition, and the development of vegetation are in dynamic equilibrium (R. S. Sigafoos, 1–64, p. A31–A32). The most recent events—floods—seem to be the most effective agent in the life and death of the flood-plain forests.

Effects of soil moisture and land treatment upon establishment of grasslands

L. M. Shown, R. S. Aro, R. F. Miller, and F. A. Branson have studied the conversion of sagebrush land to grassland, a change which results in a more beneficial use of the water resource of some of the arid and semiarid regions of the intermountain west. They found that the establishment of grass is mostly a function of precipitation-soil relationships. The most productive seedlings, which signify efficient use of soil moisture, are found on areas receiving 10 to 15 inches of average annual precipitation, and on soils which have medium moisture-holding capacities per soil unit. The soil texture is usually sandy loam, silt loam, or loam. Seedlings either do not become established or soon die on coarser or finer soils, on thin rock, or in rocky soils, all of which do not hold enough water or are poorly permeable. Seedling establishment is poor where growth of big sagebrush *(Artemisia tridentata)* is poor and where greasewood *(Sarcobatus vermiculatus)* and shadscale *(Atriplex confertifolia)* are predominant.

In a study of conversion of pinyon-juniper woodlands to grassland in semiarid areas of the West, R. S. Aro has found that the percentage of trees killed is directly proportional to the intensity of woodland treatment. Uprooting trees by chain and tractor was least effective, whereas chaining and bulldozing trees into windrows and burning the woodlands was the most effective treatment. Preliminary analyses suggest that benefits derived from increased grass in the more intensively treated areas exceed the higher cost.

Relationship between chemistry of bedrock and chemistry of plants

Vegetation and soil analyses of 17 sedimentary formations in Wyoming and Montana by F. A. Branson and R. F. Miller show that variation in chemical characteristics between formations is smaller than between different plant species. Potassium percentages in formations including the Eagle Sandstone, Wasatch Formation, Niobrara Formation, and Bearpaw Shale varied about 1 percent, but shrubs growing on these formations contained an average of more than 6 percent more potassium than did grasses. Causative factors, more important than chemical characteristics of geologic materials in determining kinds of plants present, are (1) soil textures, which affect infiltration and runoff rates; and (2) the quantities of water available for plant use. The great differences in uptake of certain elements by different species growing on the same soil indicates that upland vegetation may have significant effects on quality of surface water.

Effects of geomorphic process on desert vegetation

Investigation of winterfat *(Eurotia lanata)* and big sagebrush *(Artemisia tridentata)* along their contact zone in eastern Nevada by R. S. Aro has shown that soil, water, and forage are being lost by death of winterfat, which is valuable for livestock grazing. Erosion of the surface at the downslope boundary of winterfat is changing the slope from a concave to a convex one and resulting in the replacement of winterfat by sagebrush. Understanding of the nature and rate of this process should suggest appropriate corrective action to provide optimum utilization of the scarce water resource in this area and to help stabilize the soil.

GLACIOLOGY

Glaciology is an interdisciplinary field bearing on several aspects of earth science. Glaciers are important as winter resources in some Western States, such as Washington, where about 40 million acre-feet of water is currently stored in the form of glacier ice. The marked growth and decline of glaciers in response to slight changes in climate is, therefore, an important factor in water-resources planning. Conversely, the study of changes in the glaciers produces insight into the nature of climatic changes; traditionally this has been one of the most important reasons for the study of glaciers. The net mass budget, the crucial link between glaciers and climate, has received much recent scientific attention.

Net mass budget of South Cascade Glacier, Wash.

Ice-storage changes for South Cascade Glacier were determined by W. V. Tangborn for the 1957–64 period using basin runoff and precipitation measurements. Evaporation and condensation are shown to have negligible effect. Runoff, measured by a stream discharge station, averaged 4.05 meters per year; precipitation, determined by snow-accumulation measurements on the glacier and in storage gages, averaged 3.82 m/yr, resulting in a basin net loss of about 0.23 m/yr. During the same period, South Cascade Glacier net mass budgets were determined each year by conventional glaciological studies. The glaciological and hydrometeorological results are consistent both as to long-term averages and as continuous functions of time.

Data on relations between ice velocity, net mass budget, and changes in surface elevations, collected from 1957 to 1964, have been analyzed by M. F. Meier and W. V. Tangborn. Ice velocities range up to about 20 m/yr, net mass budgets averaged over the glacier surface range between −3.3 m of water equivalent (1957–58) and +1.2 m (1963–64), and the glacier became thinner (during the period 1958–61) at a rate averaging 0.93 m/yr. The algebraic sum of emergence velocity, net budget, and change of surface elevation was examined at four points on the glacier surface and as functions of distance along the length of the glacier. Ice discharge and thickness were calculated from these data. A steady-state distribution of net budget was used to calculate a steady-state discharge, which was found to be 2.2 times larger than the present discharge.

Studies by M. F. Meier indicate that an advance of South Cascade Glacier 4,700 years ago produced a massive moraine 880 m beyond the 1963 location of the terminus. One subsequent advance in the 16th century and two in the 19th century produced small moraines 1,360, 1,250, and 1,130 m beyond the 1963 terminus. Since 1900 the glacier has receded. Approximate longitudinal profiles corresponding to these moraines were constructed and used with the present-day vertical variation of net mass budget to estimate steady-state net budgets at the times of moraine construction. A long-continued net budget only 90 centimeters more positive than the 1957–64 average would be sufficient to reproduce the greatest advance of this glacier since the Pleistocene.

Influence of 1964 Alaska earthquake on glaciers in State

The severe 1964 Alaska earthquake provided an ideal opportunity to test the theory that earthquake-induced avalanching of snow and ice can cause catastrophic glacier advances. An extensive aerial photographic study was made by A. S. Post in August 1964, when snow cover was at a minimum, and the results were compared with similar studies made in earlier years. Observed changes in the several thousand glaciers examined were largely those expected in a normal year. The only exceptions were 6 widely scattered glaciers that appeared to have begun very rapid movements; however, 4 other glaciers showed similar characteristics in 1963. One tributary of the Martin River Glacier may be responding to earthquake-induced avalanching, but the evidence is inconclusive. Thus there appears to be very little evidence of dynamic glacier response 5 months after an earthquake of unusual severity.

Movement and thickness of Teton Glacier, Wyo.

Resurvey of markers near the snowline on Teton Glacier, Grand Teton National Park, Wyo., by J. C. Reed, Jr. (p. B137–B141), showed that there the ice advanced as much as 37 feet between August 1963 and September 1964 while the terminus of the glacier remained in the same position. The ice is thought to have moved mostly as a rigid mass. It may be as thin as 50 feet near the snowline.

PERMAFROST

Permafrost map of Alaska

O. J. Ferrians, Jr.,[95] has prepared a map, at a scale of 1:2,500,000, showing the distribution and character of permafrost in Alaska. Because 85 percent of Alaska is within the permafrost region, the potential deleterious effects of building on permafrost pose serious engineering problems. This is the first such Statewide map produced in sufficient detail to be useful in the selection of sites, the determination of road alinements, and the design of engineering structures.

Inventory of pingos in part of central Alaska

Pingos, mounds or hills formed by updoming by hydrostatic pressure in areas underlain by perennially frozen ground, have received considerable attention in Alaska. More than 250 known pingos in the Yukon-Tanana Upland, central Alaska, were inventoried and described by G. W. Holmes, D. M. Hopkins, and H. L. Foster. These pingos, which occur in a zone of discontinuous permafrost, are evidence that pingos are not confined to areas of continuous permafrost, as was previously believed. All the pingos of the Yukon-Tanana Upland are of the open-system type (that is, the hydrostatic pressure results from hydraulic head related to an adjacent slope). Many show several stages of development, suggesting that sequences of growth, decay, and rejuvenation are common. The ages of the pingos are deduced to range from a few decades to several thousand years. Because the maximum age, based on radiocarbon dating of contained organic sediments, is about 7,000 years old, growth of the pingos is believed to be a product of recent climate.

Birch Creek pingo, Alaska

Studies by D. B. Krinsley (p. C133–C136) of sediments contained in a pingo along Birch Creek west of Circle, Alaska, indicate that permafrost was present during the period 6,950 ± 400 years B.P. to 5,720 ± 65 years B.P., which coincides with the postglacial thermal maximum (altithermal) episode. In the upper sediments of the pingo, lacustrine silt that was deposited in an oxbow of Birch Creek after 5,720 ± 65 years B.P. is now as much as 5 feet higher than the present level of Birch Creek. On the basis of this evidence the local base level is believed to have been reduced at least 5 feet in the last 5,720 ± 65 years, and the now-tilted sediments of the pingo are believed to have been updomed during this time.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Atomic absorption flame spectrophotometry

An extensive research program has been underway in the U.S. Geological Survey on testing the

[95] O. J. Ferrians, Jr., 1965, Permafrost map of Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–445. [In press]

applicability of atomic-absorption flame spectrophotometry to the analysis of geologic samples. This method is of considerable interest because of the reported high sensitivities for many elements. It is also less subject to interferences than ordinary emission flame photometry so that direct determinations with no separations are more often possible. Those elements for which high sensitivities have been reported and which are of geochemical interest are being studied systematically.

Edward Fennelly and Claude Huffman, Jr., were able to determine Pb ranging from 30 to 1,200 parts per million, and Zn from 50 to 500 ppm by atomic-aborption flame spectrophotometry in highly mineralized soil samples from Alaska. No preliminary separations were found necessary, the elements being directly determinable after dissolution of the samples in mineral acids.

The applicability of the method to the determination of Na, Ca, K, Mg, and Zn was demonstrated by Claude Hoffman, Jr., and Joseph Haffty. A few tenths of a part per million of Mg and Zn were found, concentrations too low to be determinable by emission flame spectrophotometry.

Claude Huffman, Jr., and J. D. Mensik have shown that silver can be determined quickly and reliably on a 1-gram sample to a threshold of about 1 ppm by the technique of atomic-absorption flame spectrophotometry. No difficulties were experienced on mineralized samples previously fire assayed and known to contain silver, or on selected ores and minerals known to contain many elements that interfere when other methods are used.

Ammonium ion in silicates

Robert Meyrowitz has developed a spectrophotometric procedure employing Nessler's reagent for the determination of ammoniacal nitrogen in small samples of silicate minerals. About 100 parts per million of ammonium oxide are determinable on a 50-milligram sample. The method as applied to illite, potassium feldspar, and celadonite separated from hydrothermally altered drill core from Steamboat Springs, Nev., yielded 950, 170, and 320 ppm of $(NH_4)_2O$, respectively. Muscovite from San Diego County, Calif., was found to contain 200 ppm of $(NH_4)_2O$.

Spectrophotometric determination of magnesium in phosphates

Spectrophotometric procedures based on Clayton Yellow which require no separations were developed by Robert Meyrowitz for rapid determination of magnesium in phosphate rocks, and for the microdetermination of magnesium in phosphate minerals such as apatite, crandallite, whitlockite, morinite, and lewistonite. Interferences are masked by ethylenebis (2-oxyethylenenitrilo) tetracetic acid (EGTA) allowing 1 part of MgO to be determinable in the presence of up to 500 parts each of CaO and P_2O_5.

Determination of silica after decomposition with HF

Irving May and J. J. Rowe have developed a method for determining silica in rocks and minerals after decomposition with hydrofluoric acid. The method avoids the loss of SiO_2 as volatile SiF_4 which customarily results when hydrofluoric decompositions are used. The samples are decomposed in a platinum-lined bomb (p. B165–B166), and the silica content of the sample solution is determined by a molybdenum-blue procedure using aluminum ion to complex interfering fluoride. Because no fluxes are introduced, both silica and alkalies can be determined on the same sample solution.

Detection of bismuth by fire assay

The routine fire assay for silver and gold has long been known to furnish indications of bismuth if this element is present in more than "trace" quantities. A series of cupellations with known amounts of bismuth made by O. M. Parker and L. B. Riley suggests that bismuth in concentrations as low as 0.1 percent may be detected during routine assaying. Furthermore, approximate bismuth percentages may be estimated by comparison with "standard" cupels having bismuth contents spaced geometrically in steps similar to the "6-step" spectrographic series, up to at least 7 percent bismuth (93 percent lead) in the lead assay button. Recognition of bismuth in samples during assaying is important as its presence may affect the silver values unless special precautions are taken.

Determination of fixed water in minerals by infrared absorption

A method was developed by I. A. Breger for the quantitative determination of fixed water (H_2O^{+1}) in rocks and minerals by infrared absorption analysis. Infrared absorption was also found useful in distinguishing between hydroxyl groups and water in minerals. Only 2 milligrams of sample is necessary for either of the infrared techniques, thus making it possible to reduce greatly the length of time spent in tedious handpicking of samples for analysis.

Removal of polonium from standard radium solutions

Polonium impurities in standard radium solutions can be easily removed by spontaneous electrochemical deposition on gold alloys. K. W. Edwards (p. D184–D188) found that when a gold-alloy disk is added to radium solutions which are 0.11–0.21 molar in hydrogen ion, 80–90 percent of the polonium is deposited within 48 hours. The deposition of polonium occurs with very slight contamination of the solution by gold, silver, and copper. No radium is deposited, and the solutions are therefore improved radium standards.

Bromine in brines and rocks

F. O. Simon and Irving May combined and refined several published procedures into a method for determining bromide in brines. Iodide is first oxidized to iodine with nitrite, and removed by boiling. Bromide is oxidized to bromate with hypochlorite, and the excess hypochlorite is destroyed by formate. Bromine is then generated by adding potassium bromide, which reacts with bromate. The bromine is determined spectrophotometrically by its bleaching effect on methyl orange. As little as 1 microgram of bromine can be determined reliably. The applicability of the method to the determination of bromine in rocks is being studied.

Confirmation of formula of langite

B. L. Ingram's determination of water in a small sample of langite confirms crystallographic evidence by Mary Mrose that the formula of langite is $Cu_4(SO_4)(OH)_6.2H_2O$. There has been uncertainty in the literature regarding the water content. The seventh edition of Dana lists langite as a monohydrate, although the original analysis by Maskelyne in 1865 and a subsequent one by Pierrot and Sainfield in 1958 lead to a dihydrate formula. Ingram's analysis also provides further evidence that posnjakite, $Cu_4(SO_4)_4(OH)_6.1H_2O$ is not the monoclinic dimorph of langite but a new mineral.

Trivalent vanadium in a chromian tourmaline

John Marinenko analyzed a chromian tourmaline from Mariposa County, Calif. Seventeen constituents were determined including ferrous iron, and vanadium in two valence states. Of interest is the finding that nearly all of the vanadium (about 5 percent vanadium in the original sample) is trivalent. The determination of valence states was a particularly difficult problem because the refractory nature of tourmaline required that the decomposition be made by fusing with powerful fluxes, without altering the valence states of the constituents.

OPTICAL SPECTROSCOPY

New device used to measure widths of intense lines

P. R. Barnett has designed and put into operation a device for use with certain types of densitometers that permits the spectroscopist to measure the widths of spectral lines recorded on plates or films. This measurement makes possible the use of lines for analytical purposes that could not otherwise be used because of their high density and broadened image. The inability to use these lines in the past has sometimes necessitated re-arcing the sample at a reduced exposure or after dilution. The measurements are precise and the analytical results are as accurate as those obtained by conventional densitometric methods.

Atmosphere control improves detectability of zinc

It is of special interest to the astrogeology program to be able to determine zinc in the concentration range of 1–100 parts per million. About 200 ppm is the limit normally attained in quantitative spectrochemical procedures. Using (1) a jet developed in the U.S. Geological Survey laboratory together with argo-arc atmosphere control,[96] (2) an undercut carbon sample-bearing electrode, (3) an auxiliary lens ahead of the slit, and (4) a higher current than normally used for the d-c arc, C. S. Annell and A. W. Helz have increased the detectability by several orders of magnitude so that zinc is determinable in concentrations as low as 1 ppm. The change from air to argon atmosphere control accounts for an improvement of about 10-fold in the detection limit; the use of carbon in place of graphite —2-fold; the introduction of the auxiliary lens to increase the light-gathering power of the instrument —4-fold; and the increase of the current from 15 to 25 amperes—1½-fold. Argon maintains a relatively cool steady arc; the volatization of matrix material is minimized (lowering background), and the rate of volatilization of zinc is decreased (increasing efficiency of excitation).

X-RAY FLUORESCENCE ANALYSIS

Rock analysis by X-ray quantometer automated

Conversion to full automation of the X-ray quantometer for simultaneous determination of common rock-forming elements was completed by Leonard

[96] A. W. Helz, 1964, A gas jet for d-c arc spectroscopy: Art. 159 *in* U.S. Geol. Survey Prof. Paper 475-D, p. D176–D178.

Shapiro and Camillo Massoni (p. D178–D183). Steps automated include (1) positioning of a sample under the X-ray tube, (2) X-ray irradiation and X-ray fluorescence integration for a preset period of time, (3) termination of X-ray excitation and sequential read-out of integrated voltages, (4) printing of results, (5) positioning of a new sample, (6) repetition of the cycle, and (7) cutoff of instrument after a preset time. The unattended instrument can analyze 32 samples during the day and another 32 samples at night. In addition to virtually doubling productivity, the automated system yields more precise results as a result of a steady-state operation in which vacuum is maintained at a uniformly high level unattainable in manual operation.

X-ray fluorescence analysis of small samples

A combined X-ray fluorescence and chemical procedure has proved to be very useful for the total analysis of very small samples of minerals. In developing the method H. J. Rose and Frank Cuttitta sought to minimize the sample size required and to stress analyses that are otherwise unusually difficult and time consuming by chemical methods. In the procedure one milliliter of the sample solution is absorbed on powdered filter paper which is then pressed into a pellet for X-ray excitation. The method requires no more than 10 milligrams of sample and can detect microgram amounts of many elements. Applications include the determination of the zirconium-hafnium ratio in zircon and the determination of major elements in tektites, minerals, and alloys.

Rapid method for barium analyses of rocks and soils

Using an X-ray fluorescence method D. A. Brobst was able to run 200 barium analyses per day in the concentration range of 250 parts per million to 10 percent on rock and soil samples. The dry powdered samples were held for X-ray excitation in a disk 1 inch in diameter and having a suitably shaped plastic holder and cover. The X-ray fluorescence results obtained on 600 samples of Arkansas rocks when compared with barium results on the same samples obtained by spectrographic and (or) turbidimetric methods gave excellent agreement once allowance is made for the varying limits of sensitivity of the different methods.

Determination of chlorine and sulfur in fluid inclusions

X-ray fluorescence was used by P. J. Dunton for determining chlorine and sulfur in fluid inclusions. In 8 fluid inclusions in samples from Zacatacas, Mexico, chlorine concentrations ranged from 1 to 100 parts per million and SO_4 from <1 to 10 ppm. Half a milliliter of the sample solutions was evaporated on aluminum planchettes for X-ray excitation.

Combined X-ray and chemical procedure used to measure magnesium

By first precipitating magnesium as the arsenate, then using X-ray fluorescence analysis to measure arsenic in the precipitate, W. W. Brannock and A. C. Bettiga were able to determine magnesium quantitatively. This new combined chemical and X-ray procedure promises to extend the range of X-ray fluorescence analysis to other elements that have a low atomic number and are, as a result, not now determinable.

ANALYSIS OF WATER

Atomic-absorption spectrophotometry

S. C. Downs is investigating atomic-absorption spectrophotometric techniques for the routine determination of several heavy metals. He has found that as little as 0.005 parts per million of zinc, 0.01 ppm of manganese, and 0.01 ppm of copper can be detected without enrichment techniques. Measurements of zinc are accurate and reproducible to within ± 0.01 ppm for concentrations from zero to 1 ppm and within ± 0.05 ppm for concentrations from 1 to 7.5 ppm. Measurements of manganese and copper are accurate and reproducible within ± 0.03 and ± 0.02 ppm, respectively, for concentrations from zero to 1 ppm, and within ± 0.15 and ± 0.10 ppm for concentrations from 1 to about 35 ppm. Analyses by atomic-absorption techniques require about a fourth as much time as analyses by standard chemical methods.

M. J. Fishman and K. A. Gardner have prepared tentative procedures for the determination of a number of major and minor cations in both fresh and brackish waters by atomic-absorption spectrophotometry. In general, atomic-absorption procedures are as accurate as conventional flame-photometric or titrimetric methods; in many cases they offer greater ease and simplicity of operation. As little as 5 parts per billion of magnesium can be determined directly; samples containing 10 ppm, or less, of calcium and magnesium can be analyzed much more quickly and accurately by atomic absorption than by titrimetric or colorimetric methods. The determination of strontium in both fresh water and in brines is greatly simplified, requiring neither separation nor preconcentration in order to achieve a sensitivity and accuracy of the order of 0.01 ppm.

Measurement of pesticides and herbicides by gas chromatography

W. L. Lamar, D. F. Goerlitz, and L. M. Law (1–64) have reported a convenient and extremely sensitive method (in the parts-per-trillion range) for the detection and measurement of chlorinated organic pesticides by electron-capture gas chromatography. A 4-liter sample of water is extracted with three 25-milliliter portions of purified hexane. The extracts are combined, and most of the hexane is removed by heating on a fluidized sand bath at 100°C. The extract is then transferred to a 10.00-ml volumetric flask, brought to volume with hexane, and about 50 milligrams of anhydrous sodium sulfate added. Five-microliter aliquots are then injected into an electron-capture gas chromatograph, using both Dow–11 and QF–1 columns to facilitate identification through the different partitioning effects of the two liquid substrates. Quantitative and qualitative pesticide standards are injected on the same day as the samples to aid identification and to provide corrections as necessary. The pesticides are usually identified by comparing retention times relative to aldrin on two columns. High purity of reagents and distilled water is essential; contamination of glassware is avoided by heating at 300°C overnight.

Identification and analysis of insecticides in water

A method for identifying and measuring chlorinated hydrocarbon insecticides in water was developed by Garland Stratton. The insecticides, with other organic compounds, are extracted from a 1–2-gallon sample with chloroform. The residue from evaporation of the chloroform extract is placed on a silica-gel column and eluted with hexane. The eluate is also dried. The resulting residue, dissolved in two drops of acetone, is spotted on silical-gel-loaded chromatograph paper and developed in hexane containing 1 percent acetone. The resulting chromatogram is cut into 4 sections, each of which is added to 1 milliliter of benzene to make sample concentrates for gas chromatographic analysis. This separates the insecticides into groups to facilitate analytical determination and enables detection and measurement of chlorinated hydrocarbon insecticides at very low concentrations.

D. F. Goerlitz and W. L. Lamar (1–65) also reported details of methods and techniques used to determine 5 to 10 nanograms (about 10 parts per trillion, using a 4-liter sample) of selected herbicides, including 2,4-D, 2,4,5-T, and Silvex. In tests made on 4-liter samples of distilled water containing 1.00 to 1.90 parts per billion of these herbicides, the recoveries generally ranged from 73 to 95 percent. The analysis of samples from several canals in a National Wildlife Refuge gave values for Silvex which ranged from 0.13 to 51.5 ppb; for 2,4–D, from 0.10 to 0.25 ppb; and for 2,4,5-T, from 0.01 to 0.09 ppb.

Sodium-sensitive glass electrodes

B. F. Jones, A. H. Truesdell, and A. S. Van Denburgh (1–65) described a method using a glass electrode for the determination of sodium in closed basin waters of highly variable composition. In analyzing samples which ranged from 10 to 130,000 parts per million of sodium and from 102 to 332,000 ppm of total dissolved solids, they found in all cases that the electrode values compared favorably with conventional sodium determinations for both natural waters and stock solutions. They found no relation between differences in values obtained by glass-electrode and conventional methods and the contents of dissolved solids or of sodium. The electrode method offers good accuracy and the advantage of simplicity.

X-ray-fluorescence methods of analysis

Two X-ray-fluorescence methods have been developed and applied by P. J. Dunton to the quantitative and semiquantitative analysis of water samples for elements of atomic number 92 (U) through atomic number 14 (Si). The more sensitive methods consist of evaporating 0.5 milliliter of the sample onto aluminum foil or a filter-paper disk, which is then placed directly in the spectrograph. The sensitivity is 0.5 parts per million through atomic number 16 (S), and from 1 to 5 ppm for the lighter elements.

An alternate method must be used when the content of dissolved solids in the sample exceeds 1,000 ppm, because of the tendency for the dried residue to flake off the foil or paper disk. In this method a 4-ml sample aliquot is transferred to a sample cell fitted with a ¼-mil Mylar film, and then is placed directly in the X-ray spectrograph. The sensitivity is 1 ppm for elements through atomic number 19 (K), and 5–10 ppm for elements lighter than potassium.

Determination of lead-210

A method for the determination of trace amounts of lead–210 has been developed by J. O. Johnson and K. W. Edwards. The lead is concentrated by coprecipitation with barium sulfate, purified by ion exchange, and finally reprecipitated as the chromate. The final precipitate is aged to allow ingrowth of 5-day bismuth-210; the beta activity of this daughter nuclide is determined on a low-background counter. The detection limit (based on 95-percent confidence level) is 2 picocuries per liter for a 500-ml sample.

Method for determination of phosphate in water

M. J. Fishman and M. W. Skougstad (p. B167–B169) simplified an existing method to make it suitable for the rapid field and laboratory determination of phosphate in natural water. Replicate determinations are reproducible to ±0.01 parts per million, and results agree to ±0.01 ppm with those determined by the standard method in use in the U.S. Geological Survey.

Changes in composition of stored water samples

K. V. Slack and D. W. Fisher reported (p. C190–C192) changes in composition observed when water samples were stored in sealed bottles for periods as long as 5 months. Three different types of polyethylene containers were used. Following exposure for 3 months to alternating 12-hour light and dark periods, the pH of replicate samples ranged from 9.27 to 10.17, HCO_3 was not detected in most samples, CO_3 concentrations ranged from 7 to 13 parts per million, and free CO_2 and NO_3 were below detection. After an additional 2 months of dark storage, pH decreased 2 units relative to the illuminated condition, free CO_2 and HCO_3 concentrations increased greatly, and CO_3 was below detection. The changes were attributed to photosynthesis by algae during illumination and to re-solution of substances following decay of the algae in the dark.

Carbonate brines

S. L. Rettig and B. F. Jones (1–64) analyzed samples of carbonate brines having a CO_2 content in the range of 0.5–9 percent by potentiometric titration and by manometric measurement of the total CO_2 evolved upon acidification. The potentiometric data show that the actual end points may differ significantly from the pH values of 8.2 and 4.5 commonly used as end points in such titrations. Some of the errors in the potentiometric method can be evaluated by comparison with the manometric method.

HYDROLOGIC MEASUREMENTS AND INSTRUMENTATION

Multiple-channel digital recording systems

R. N. Cherry (p. D222–D224) and G. F. Smoot have developed instruments which automatically record several hydrologic variables on punched tape for automatic data processing. These systems are battery powered for unattended operation over periods of several months at remote locations. Each employs a digital recorder. Cherry's system records in sequence 2 values of water temperature and 2 values of the specific conductance of the water. Smoot has developed sensors to measure temperature, rainfall, water stage, specific conductance, and soil moisture, and is developing sensors for wind direction and velocity, and for water turbidity. A wide range of sensors and of time intervals for measurements can be used in a single system.

Instruments for measuring velocity of flow of water

A miniature current meter has been developed by G. F. Smoot for the measurement of longitudinal velocities and velocity fluctuations. This meter, utilizing a 30-mm-diameter Ott Minor propeller, has an increased sensitivity response provided by an improved bearing design and a drag-free electronic revolution-sensing system. The output from the sensing system is a series of pulses. Within the response range of the meter, minute rotational variations which are recorded as instantaneous frequency fluctuations in the sequence of pulses are proportional to the encountered turbulence. Initial field tests of the meter produced reasonable results.

Instruments which measure flow velocities by means of strain gages have been developed for use in surface streams by H. P. Guy, D. B. Simons, and J. B. Bole, and for use in deep water wells by J. E. Eddy. In these instruments the strain gages are components of wheatstone bridge circuits; the strain, expressed as electrical output, is proportional to the deforming force of the current and hence to the velocity. The instrument for surface streams, which has a drag-wire velocity probe, has been tested in flume studies to within 0.005 inch of the flume floor. The well instrument, in which the strain gage is mounted on a vane normal to the direction of flow, has been tested in wells at depths as great as 1,000 feet.

G. F. Smoot reports development of a continuous-tone sonar device utilizing the Doppler effect. A beam of ultrasonic energy projected into an inhomogeneous liquid is scattered by the suspended particulate matter in the liquid. Part of the energy, reflected to a receiver, shifts in frequency if there is a net movement of the inhomogeneities with respect to the transmitter or receiver. If the scatterers are stationary with respect to the liquid, the observed Doppler shift is proportional to the velocity of the liquid.

H. O. Wires and W. Smith have tested an acoustic-velocity meter which sends a cycled pulse diagonally back and forth across a stream. The difference in transit time of the upstream and downstream pulses is related to water velocity. In the tests, on a canal and on the Snake River in Washington, measured discharges were within 5 percent and 2 percent, respectively, of known values.

Automatic data processing

Discharge in channels having flat and variable water-surface gradients can be computed from the water-surface stage and an index of the velocity provided by the deflection of a vane in the current. S. D. Leach reports that use of digital-punch equipment for recording stage and deflection at Florida stream-gaging stations has permitted rapid computation, by digital computer, of discharge at stations using deflection meters.

Measurement of stream flow by dilution method

A concentrated solution of radioactive gold was injected at a constant and known rate into an operating turbine penstock 15 feet in diameter, and the rate of water flow in the penstock was computed from observations of the time of passage of the tracer to a section 220 feet downstream from the injection point. B. J. Frederick reported that computed flow rates for 7 tests in the 1,100–1,650 cubic-feet-per-second range were within an average of about 2½ percent of the discharge obtained from the powerplant integrator, which had been calibrated by the Gibson method.

J. F. Bailey and E. D. Cobb made 12 dye-dilution discharge measurements on 4 small streams in Maryland and Virginia. The average error for the 12 discharges, relative to discharge measured by current meter, was 5 percent. The dye was injected at a constant rate into discharges which ranged from 10 to 50 cfs. The reaches of channel used were from 200 to 1,800 feet long.

F. A. Kilpatrick reports favorable results from the dye-dilution method of measuring flows in open channels for discharges up to 3,000 cfs. The excessive channel length required in some instances for complete mixing, when using a point source of dye injection, suggests the desirability of using a line source.

Fluorometer correction curves

Temperature of sample and temperature of fluorometer compartment influence readings on the Turner-111 fluorometer. Bernard Dunn and D. E. Vaupel (p. D225–D227) have prepared correction curves for use when sample and compartment temperatures cannot be controlled.

Portable deep-well sampler

R. N. Cherry (p. C214–C216) has developed a portable deep-well sampler which isolates a section of well between two inflatable boots. The water sample is pumped from the isolated section by a submersible pump mounted between the boots. Auxiliary instruments can be used to measure temperature, specific conductance, or other characteristics of the water in the isolated interval during pumping.

Data storage, retrieval, and compilation

A system for the storage and retrieval of groundwater data has been devised by a committee of hydrologists under the chairmanship of S. M. Lang. The basic elements of the system are: (1) a well-schedule form for use in the field to record the data obtained during an inventory of wells, and (2) punch cards that are used for the actual storage and retrieval of the data. The schedule form is keyed to the punch cards in such a manner that a punch operator can transfer data conveniently from the schedule form to the cards. The system is being used on a trial basis in the States of Florida, Iowa, and Wyoming.

M. D. Edwards and T. H. Woodward have developed programs for compiling and tabulating water-quality data, and for computing such parameters as ionic strength of solution, activity coefficient, and activity of each component of the dissolved solids, from the analytical data.

J. M. McNellis and C. O. Morgan have developed digital-computer programs which compile tables of well records and well logs from data cards, and prepare maps of the thickness, saturated thickness, and other characteristics of geologic or geohydrologic units.

Concentration of water samples

One of the problems encountered in the study of trace elements and organic materials in natural waters is that of rapidly concentrating a sample to a residue without contamination or appreciable alteration of the dissolved solids. V. C. Kennedy has developed a successful technique for rapid concentration, using a combination of a commercial evaporator and a commercial freeze-dryer.

Measurement of dissolved oxygen

A low-cost small kit for measuring dissolved oxygen has been designed by K. V. Slack for use in water-quality studies. Oxygen determinations can be made more rapidly and safely, and with less chance of contamination, than is possible with the usual method. All necessary equipment and supplies for performing the Alsterberg modification of the Winkler method can be packed into an index-card file box measuring 3 × 5 × 2¾ inches. The cost of the kit, exclusive of reagents, is about $15.00. An oxygen determination for a 10-milliliter sample takes less than 10 minutes; precision is better than 0.5 ppm.

Measurement of cation-exchange rates

A method of measuring rates of cation exchange, developed by V. C. Kennedy and T. E. Brown, involves the use of specific-ion electrodes to monitor the rate at which monovalent cations are released into solution when a monovalent, monionic, solid exchanger is added to a solution of a divalent cation. As the monovalent cation is released from the solid by exchange with the dissolved divalent cation, the electromotive force of the specific-ion electrode reflects changes in the concentration of monovalent cation in solution. The emf of the specific-ion electrode forms the input to a pH meter whose output is plotted on a potentiometric strip recorder. When calcium is used to exchange for sodium, about 90-percent exchange occurs in 1–2 seconds for kaolinite, montmorillonite, or illite in particles smaller than 2 microns. Exchange on sand-size stream sediment containing fine-grained rock fragments may take 10 minutes or more before 90-percent completion is attained.

R. L. Malcolm and V. C. Kennedy have used the exchange of barium for potassium in an attempt to distinguish various clay minerals on the basis of differences in rates of exchange. Results indicate that the rate-of-exchange curve for vermiculite differs significantly from that of kaolinite, montmorillonite, and illite. Thus, rate-of-exchange studies appear to be another tool which can be used in the characterization of clay minerals.

TOPOGRAPHIC SURVEYS AND MAPPING

MAPPING ACCOMPLISHMENTS

Objectives of National Topographic program

The major function of the Topographic Division of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic Map Series covering the United States and other areas under the sovereignty of the United States of America. The individual series, at various scales, constitute a fundamental part of the background information needed to inventory, develop, and manage the natural resources of the country. Other Division functions include the production of special maps and research and development in techniques and instrumentation.

In addition to the maps described below, the Topographic Division prepares shaded-relief maps, United States base maps, special maps, and also a few planimetric maps.

Procedures for obtaining copies of the maps and map products of the Survey are given in the section "How To Order Geological Survey Publications."

Series and scales

All topographic surveys, except those in Alaska, conform to standards of accuracy and content required for publication at the scale of 1:24,000. Initial publication scale may be either 1:24,000 or 1:62,500, depending on the need. If 1:62,500-scale maps are published initially, the 1:24,000-scale surveys, in the form of photogrammetric compilation sheets, are available as advance prints and for future publication at the larger scale. For Alaskan maps, the publication scale is 1:63,360 or "inch-to-the-mile."

Coverage of the Nation

Approximately 63 percent of the total area of the 50 States, Puerto Rico, and the Virginia Islands (fig. 10) is covered by published standard quadrangle maps at scales of 1:20,000 (Puerto Rico only), 1:24,000, 1:62,500, and 1:63,360 (Alaska only). An additional 8 percent of the total area is covered by topographic surveys which are available as advance prints at these scales.

During fiscal year 1965, 1,078 maps were published covering previously unmapped areas equivalent to 3 percent of the total area referred to above. In addition, 392 new maps at the scale of 1:24,000, equivalent to approximately 1 percent of the total area, were published to replace 15-minute quadrangle maps (scale 1:62,500) not meeting present needs. For the extent and location of map coverage, see figure 11.

Map revision and maintenance

During fiscal 1965, about 42,000 square miles of 7½-minute mapping was added to the growing backlog of maps needing revision. Concurrently, the backlog was diminshed by revising about 11,000 square miles of mapping, leaving about 403,000 square miles of 7½-minute mapping needing revision at the end of the year (fig. 12).

1:250,000-scale series

The 48 conterminous States and Hawaii are 99 percent covered by 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service. As these maps are completed, certain changes and additions are incorporated to make them more suitable for civil use. This series of maps is being revised and maintained by the Topographic Division. Maps of Alaska at this scale are prepared and published by the U.S. Geological Survey. Coverage of the 50 States, Puerto Rico, and the Virgin Islands by 1:250,000-scale maps and the work in progress are shown on figure 13.

State maps

State maps are published at scales of 1:500,000 and 1:1,000,000, except for Alaska, which is covered by base maps published at scales of 1:1,584,000 and 1:2,500,000, and Hawaii, which is not yet covered by any of these types of maps.

Thirty-one maps covering 35 States and the District of Columbia, compiled to modern standards, have been published in a new series comprising as many as four editions: base; base and highways; base, highways, and contours; and shaded relief on a modified base. As shown on figure 14, other conterminous States are covered by an earlier series.

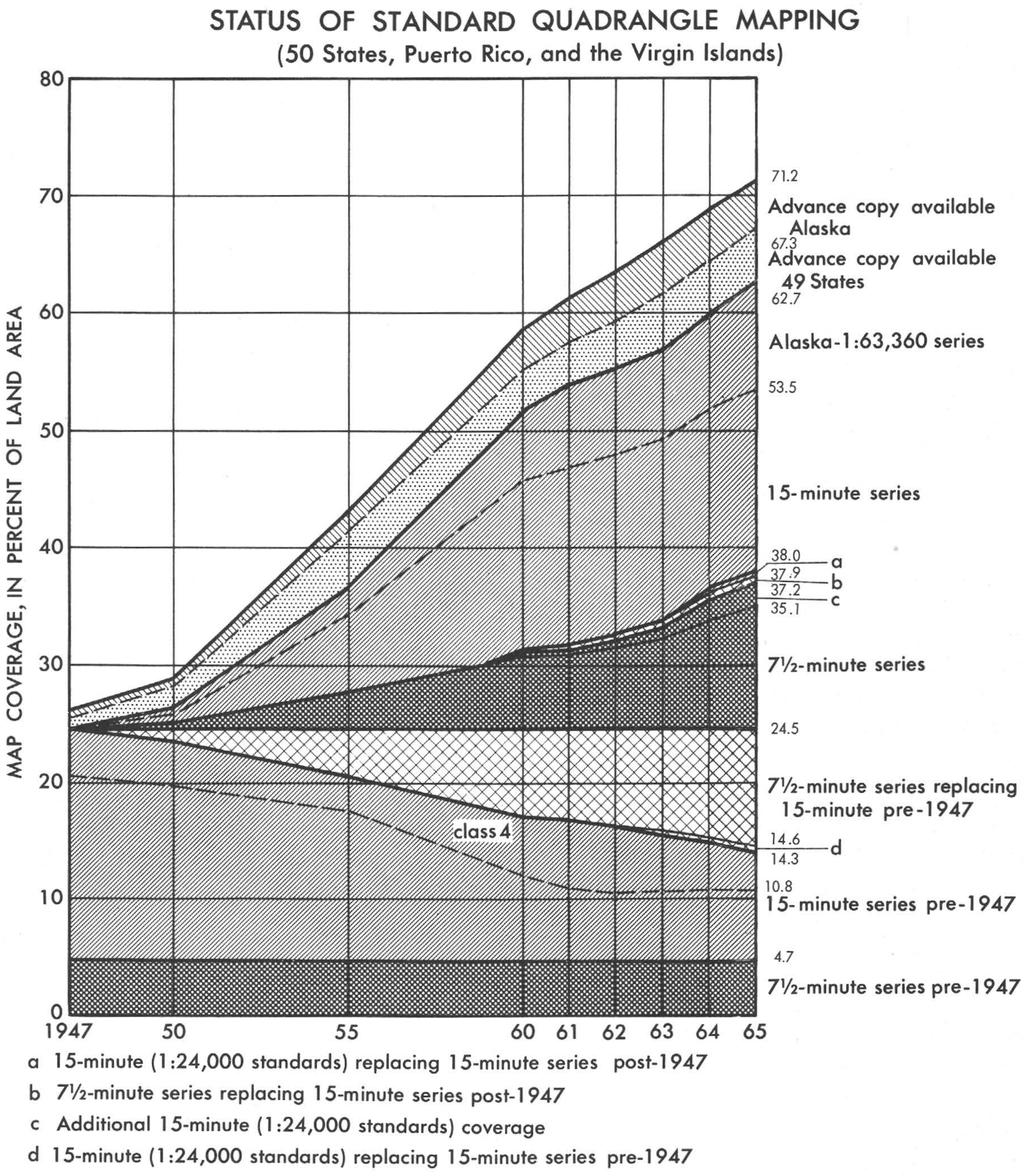


FIGURE 10.—Progress of 7½- and 15-minute quadrangle topographic mapping in the 50 States, Puerto Rico, and the Virgin Islands.

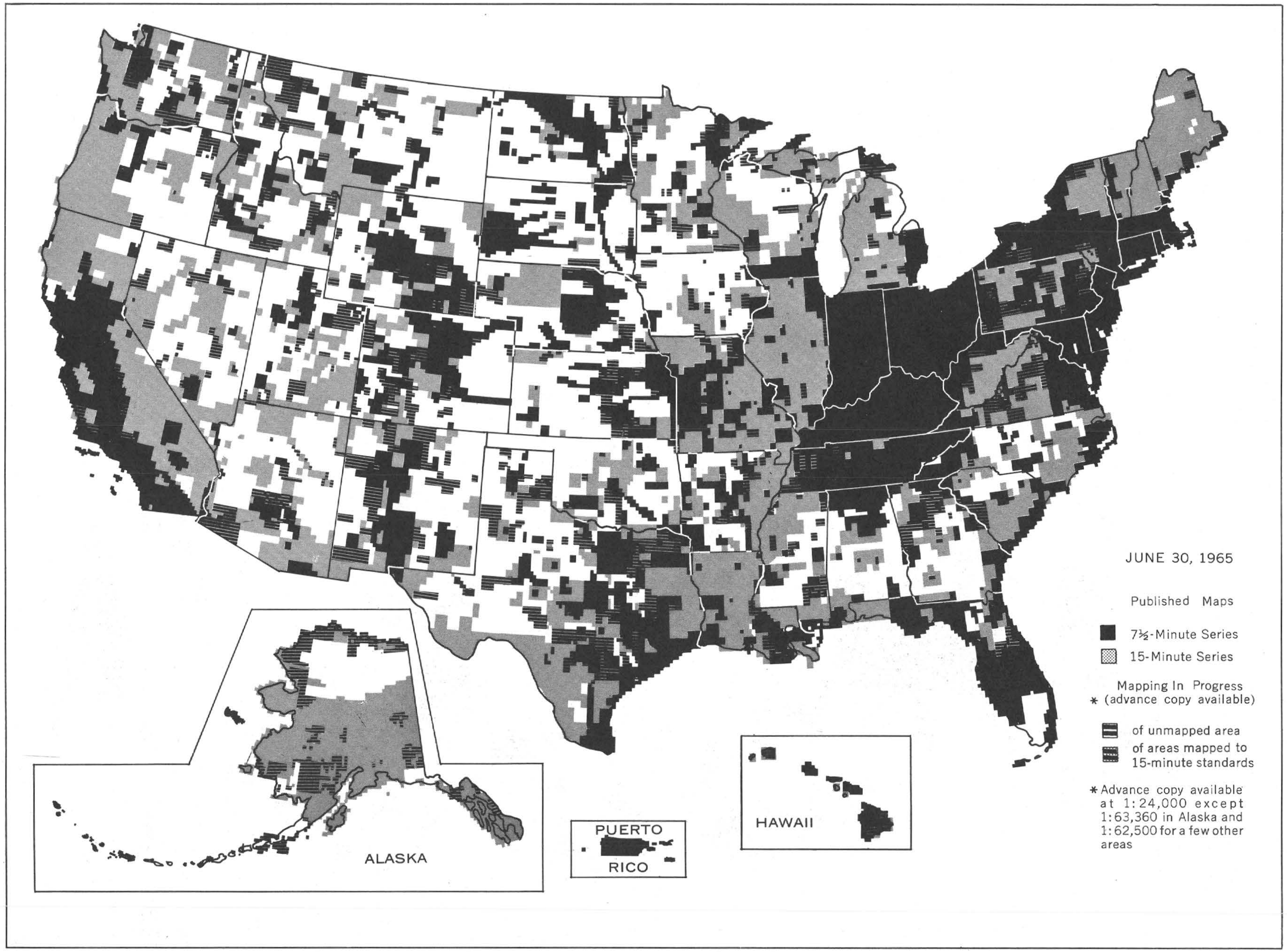


FIGURE 11.—Status of 7½- and 15-minute quadrangle topographic mapping.

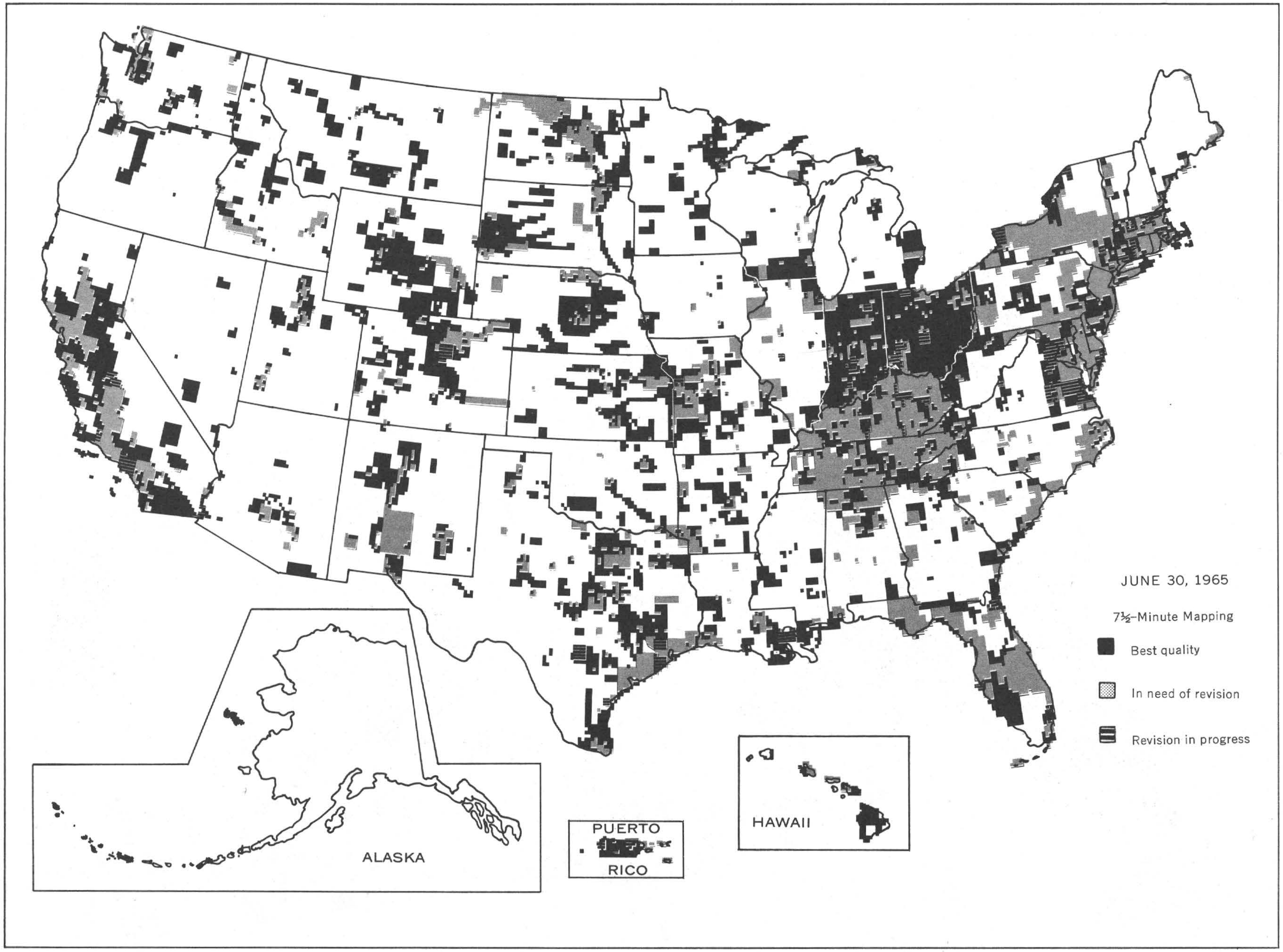


FIGURE 12.—Status of revision of large-scale mapping.

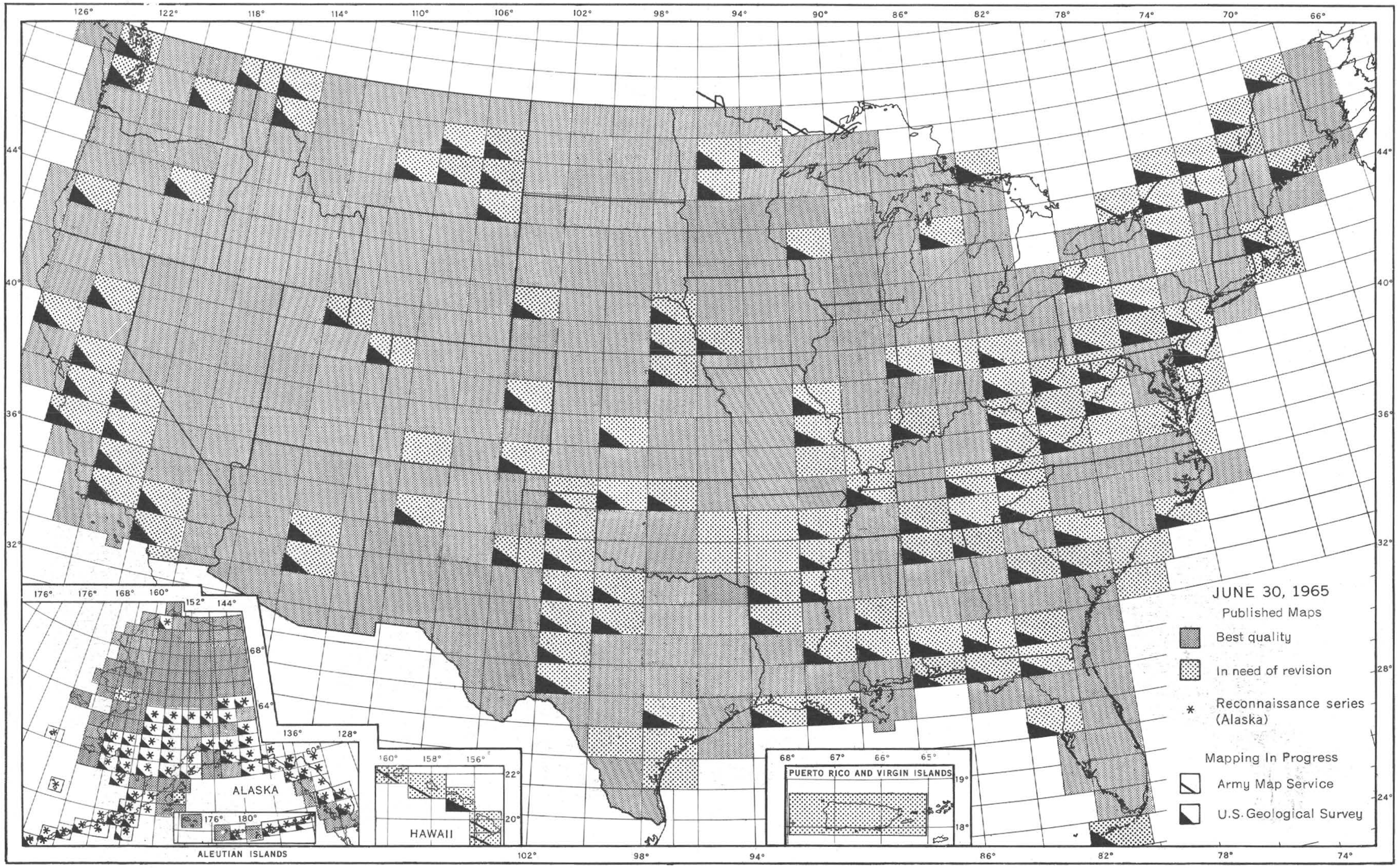
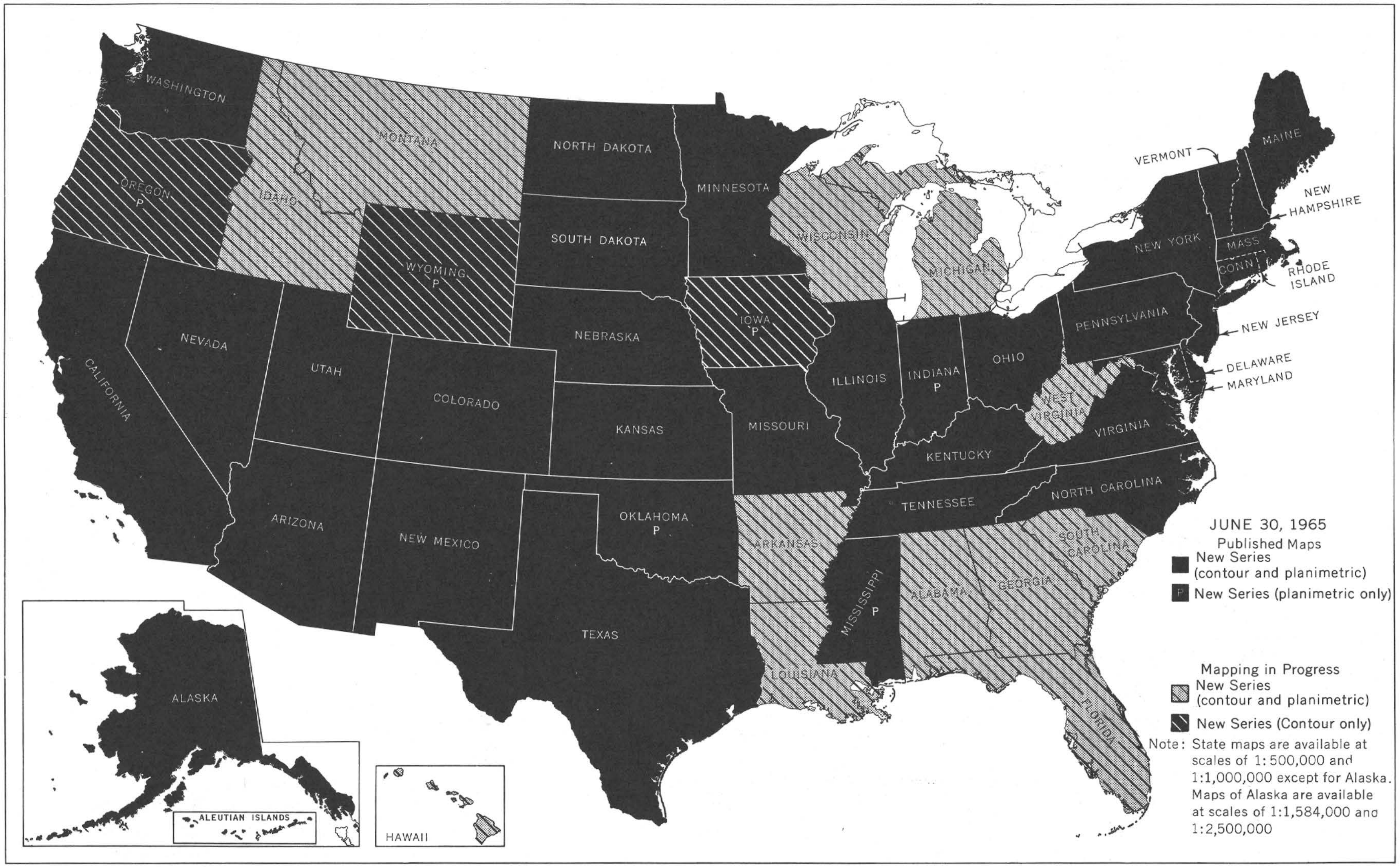


FIGURE 13.—Status of 1:250,000-scale mapping.



NOTE: The letter "P" on the pattern for "mapping in progress, new series (contour only)" in Oregon, Wyoming, and Iowa indicates that planimetric maps of these States have already been published.

FIGURE 14.—Status of State maps.

Metropolitan areas

Metropolitan-area maps are prepared by combining on one or more sheets the 7½-minute quadrangles that cover a metropolitan area. Maps of 59 metropolitan areas have been published, including 1 new map completed during fiscal year 1965. Work in progress includes the revision of 8 others. Maps in the metropolitan-area series include:

PUBLISHED

Albuquerque, N. Mex.
Anchorage, Alaska
Atlanta, Ga.
Austin, Tex.
Baton Rouge, La.
Boston, Mass.
Bridgeport, Conn.
Buffalo, N.Y.
Champaign–Urbana, Ill.
Chattanooga, Tenn.
Chicago, Ill. (3 sheets)
Cincinnati, Ohio
Cleveland, Ohio
Columbus, Ohio
Davenport–Rock Island–Moline, Iowa–Ill.
Dayton, Ohio
Denver, Colo.
Detroit, Mich. (2 sheets)
Duluth-Superior, Minn.–Wis.
Fort Worth, Tex.
Gary, Ind.
Hartford–New Britain, Conn.
Honolulu, Hawaii
Houston, Tex.
Indianapolis, Ind.
Juneau, Alaska
Knoxville, Tenn.
Little Rock, Ark.
Long Beach, Calif.
Los Angeles, Calif. (2 sheets)
Louisville, Ky.
Madison, Wis.
Wilwaukee, Wis.
Minneapolis–St. Paul, Minn.
New Haven, Conn.
New Orleans, La.
New York, N.Y. (8 sheets)
Norfolk–Portsmouth–Newport News, Va.
Oakland, Calif.
Peoria, Ill.
Philadelphia, Pa. (2 sheets)
Pittsburgh, Pa.
Portland–Vancouver, Oreg.–Wash.
Rochester, N.Y.
Salt Lake City, Utah
San Diego, Calif.
San Francisco, Calif.
San Juan, P.R.
Seattle, Wash.
Shreveport, La.
Spokane, Wash.
Tacoma, Wash.
Toledo, Ohio
Washington, D.C.
Wichita, Kans.
Wilkes-Barre–Pittston, Pa.
Wilmington, Del.
Worcester, Mass.
Youngstown, Ohio

IN REVISION

Baton Rouge, La.
Cincinnati, Ohio
Cleveland, Ohio
Little Rock, Ark.
Salt Lake City, Utah
San Juan, P.R.
Spokane, Wash.
Washington, D.C.

National park maps

Maps of 40 of the 201 national parks, monuments, historic sites, and other areas administered by the National Park Service have been published and are available for distribution. These usually are made by combining all existing quadrangle maps of the area into one map sheet, but occasionally surveys are made covering only the park area. Most of the other parks, monuments, and historic sites are shown on maps of the standard quadrangle series. Published maps in the National Park series include:

Acadia National Park, Maine
Bandelier National Monument, N. Mex.
Black Canyon of the Gunnison National Monument, Colo.
Bryce Canyon National Park, Utah
Canyon de Chelly National Monument, Ariz.
Carlsbad Caverns National Park, N. Mex.
Cedar Breaks National Monument, Utah
Colonial National Historical Park (Yorktown), Va.
Colorado National Monument, Colo.
Crater Lake National Park, Oreg.
Craters of the Moon National Monument, Idaho
Custer Battlefield, Mont.
Devils Tower National Monument, Wyo.
Dinosaur National Monument, Colo.–Utah
Franklin D. Roosevelt National Historic Site, N.Y.
Glacier National Park, Mont.
Grand Canyon National Monument, Ariz.
Grand Canyon National Park, Ariz. (2 sheets)
Grand Teton National Park, Wyo.
Great Sand Dunes National Monument, Colo.
Great Smoky Mountains National Park, N.C.–Tenn. (2 sheets)
Isle Royale National Park, Mich.
Lassen Volcanic National Park, Calif.
Mammoth Cave National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
Olympic National Park, Wash.
Petrified Forest National Monument, Ariz.
Rocky Mountain National Park, Colo.
Scotts Bluff National Monument, Nebr.
Sequoia and Kings Canyon National Parks, Calif.
Shenandoah National Park, Va. (2 sheets)
Vanderbilt Mansion National Historic Site, N.Y.
Vicksburg National Military Park, Miss.
Wind Cave National Park, S. Dak.
Yellowstone National Park, Wyo.–Mont.–Idaho
Yosemite National Park, Calif.
Yosemite Valley, Calif.
Zion National Park (Kolob section), Utah
Zion National Park (Zion Canyon section), Utah

Million-scale maps

The worldwide million-scale series of topographic quadrangle maps was originally sponsored by the International Geographical Union and designated the International Map of the World on the Millionth Scale (IMW). The conterminous United States will be covered by 53 maps, 17 of which were produced before 1955. At that time the U.S. Army Map Service began a military series at 1:1,000,000 scale. Eventually this military series will be modified slightly and published in the IMW series (fig. 15).

Three of the maps, Hudson River, Mississippi Delta, and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Both the IMW and military series are available for Boston, Chesapeake Bay, Hatteras, Mount Shasta, and Point Conception. In addition, the American Geographical Society has

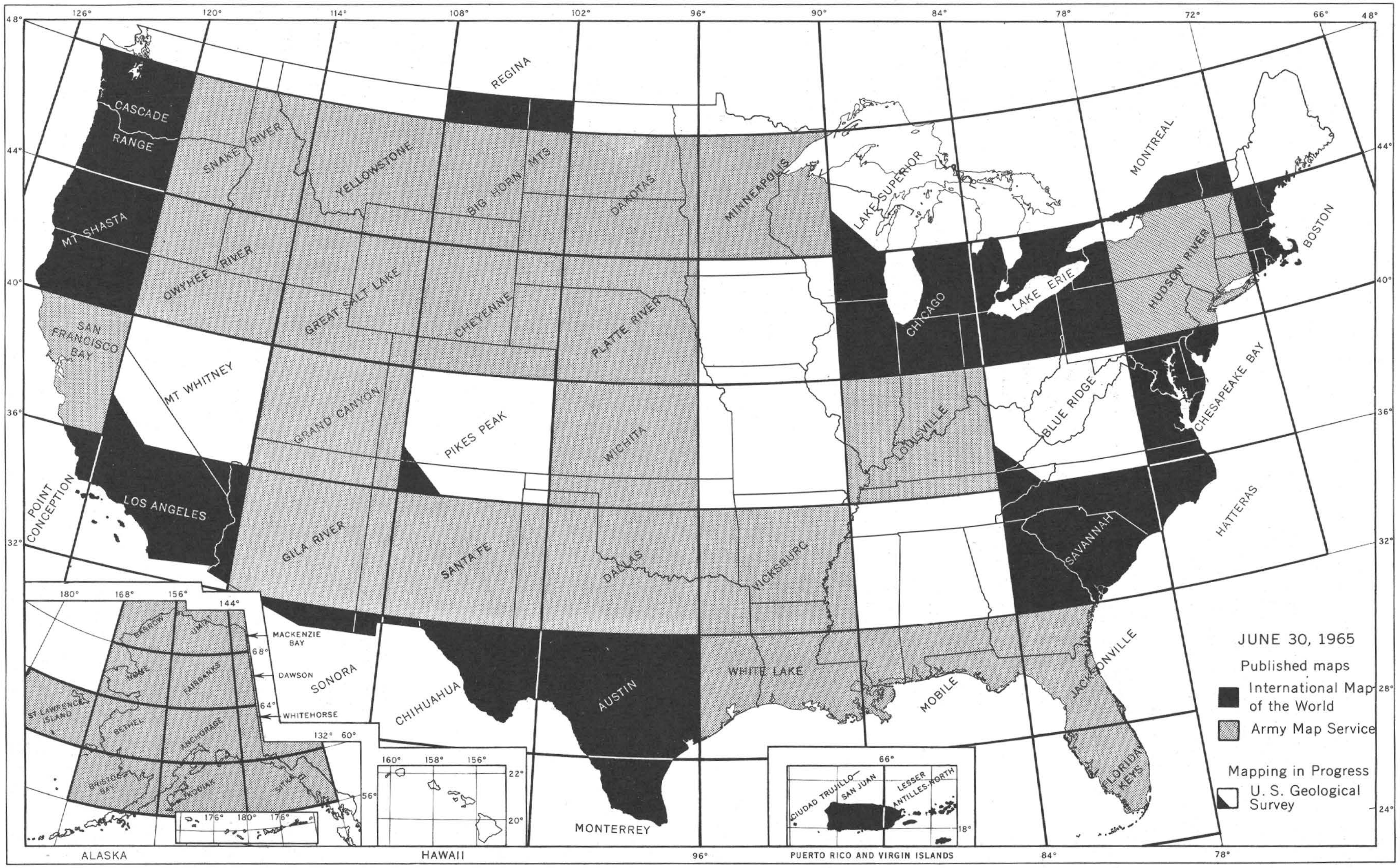


FIGURE 15.—Status of 1:1,000,000-scale topographic mapping.

published the Sonora, Chihuahua, and Monterrey maps; and Canada, the Regina and Montreal maps. Puerto Rico is covered by two maps, compiled by the American Geographical Society and published by both the Society and the Army Map Service.

Some maps of the military series have been modified for broader civil use by changing them to conform to the IMW sheet lines and sheet numbering system, but they do not meet IMW specifications in all respects. These maps are recognized by the United Nations Cartographic Office as provisional editions in the IMW series.

Work in progress includes four new maps: Blue Ridge, Lake Superior, Mt. Whitney, and Pikes Peak.

Official United States wall map

A revised edition of the official United States wall map, prepared at the direction of the 88th Congress, was published in January 1965. This 42- by 65-inch, 12-color map, at the scale of 1:3,168,000 (1 inch equals 50 miles), shows national parks and monuments, national forests, Indian reservations, wildlife refuges, public lands, historical boundaries, and 7,500 selected cities, towns, rivers, and lakes. Insets at smaller scales show Alaska, Hawaii, the Canal Zone, and Puerto Rico and the Virgin Islands. (Copies of this map are available only from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, at $2 each.)

MAPPING IN ANTARCTICA

The topographic mapping of Antarctica, conducted as a part of the U.S. Antarctic Research Program (USARP) of the National Science Foundation, was continued during fiscal year 1965. Four topographic engineers went to Antarctica during the austral summer of 1964–65 to obtain geodetic control for the topographic mapping program and to execute surveys in support of other scientific disciplines. Also, a specialist in aerial photography was again assigned to Christchurch, New Zealand, for photographic liaison duty with the U.S. Navy.

Topographic field operations

E. R. Soza, Alfred Zavis, C. E. Morrison, and D. E. Reed made two helicopter-supported electronic-distance traverses in the David Glacier and Northern Victoria Land areas (fig. 17) to establish control for topographic mapping and to establish geodetic ties between previously established control nets. This party also completed the precise Byrd Station glaciological strain net initiated in the 1963–64 austral season, so that this net now extends eastward from New Byrd Station to the divide between the Filchner Ice Shelf and the Ross Ice Shelf. Snow accumulation markers were set along the new traverse, and accumulation measurements were made on the markers and poles established the previous year. The total traverse is a 106-mile-long chain of 52 quadrilaterals. To obtain the required survey accuracy of 1 part in 60,000, the engineers used theodolites for measuring angles and electronic equipment for measuring distances. This party also established glaciological strain nets at mileposts 60 and 120 of Army-Navy Drive (the sledge trail between Little America and Byrd Station) and determined new geographic positions for these two mileposts. In addition, positions were determined for four ice holes in McMurdo Sound for University of Arizona biologists using scuba diving techniques to investigate polar adaptation of the Weddell seal.

Supported by a U.S. Army helicopter detachment, E. R. Soza and C. E. Morrison established control by electronic-distance traverse from McMurdo Station around the perimeter of Ross Island. They also completed an electronic-distance traverse near Byrd Station to determine the position of the University of Washington's VLF (very low frequency) long-wire antenna facility, established to study the properties of the earth's magnetic field.

Alfred Zavis and D. E. Reed obtained 5 stellar observations and 8 sets of solar observations at the previously established New Byrd Astronomic Station. Also at Byrd Station, the geographic position of Stanford University's readout center of the NASA POGO (polar orbiting geophysical observatory) satellite was determined. In addition, these engineers extended a second-order triangulation net at McMurdo for detailed mapping in anticipation of new construction at the main United States base.

Aerial photography

U.S. Navy Air Development Squadron 6 (VX–6) obtained aerial photographs for mapping in accordance with U.S. Geological Survey specifications. W. R. MacDonald was assigned to the U.S. Navy Photographic Laboratory at Christchurch, New Zealand, to advise on the quality of developed photographs, to assist with further planning, and to recommend reflights when necessary. MacDonald also served as visual navigator on flights over troublesome and high-priority areas.

This season's aerial photography program was the most successful in the history of Antarctic photographic operations (fig. 16). This is attributed to the fact that, in addition to the C–121J Super Con-

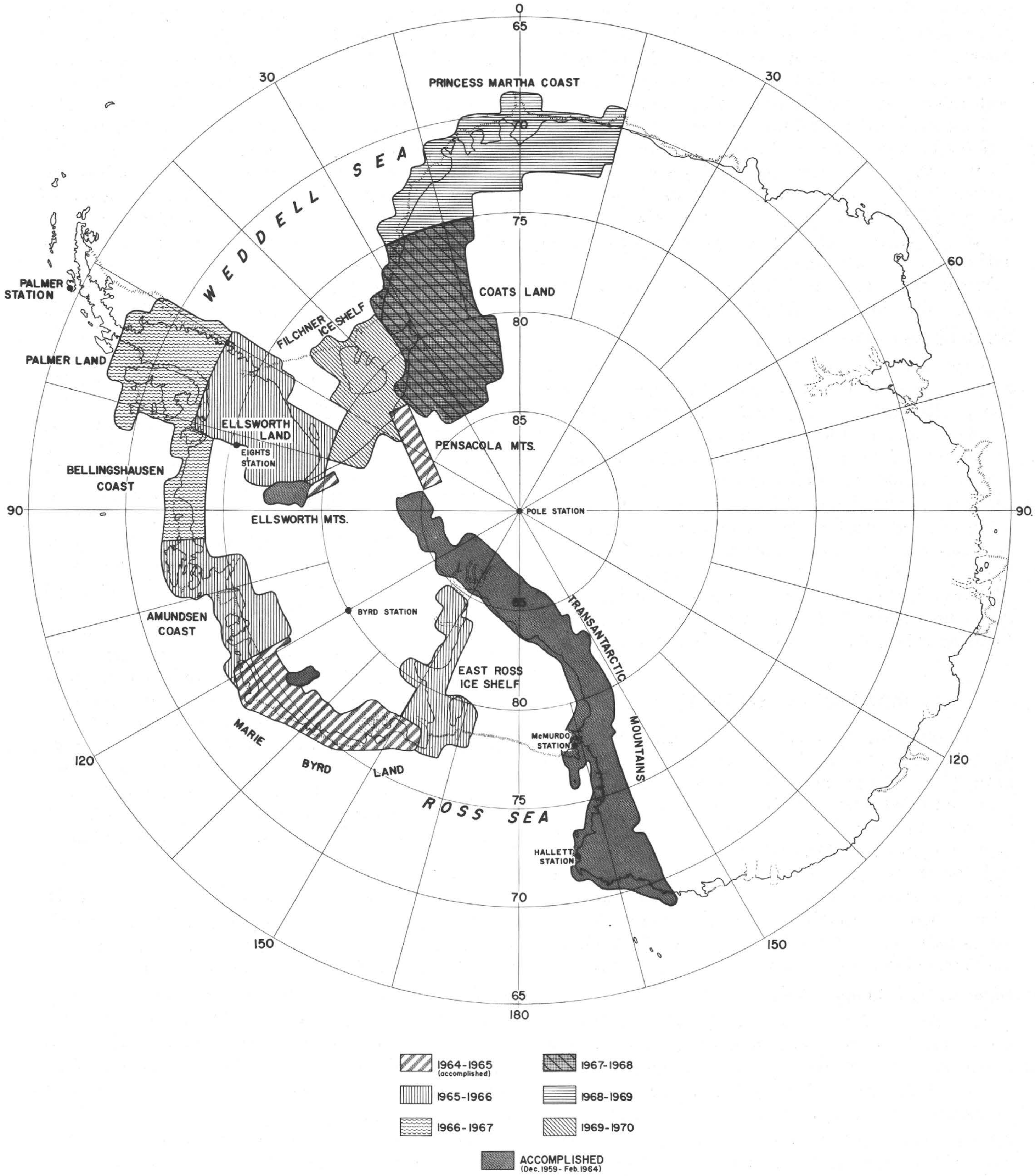


FIGURE 16.—Plan for optical aerial mapping photography of Antarctica, prepared by the National Science Foundation and the Geological Survey, May 1965.

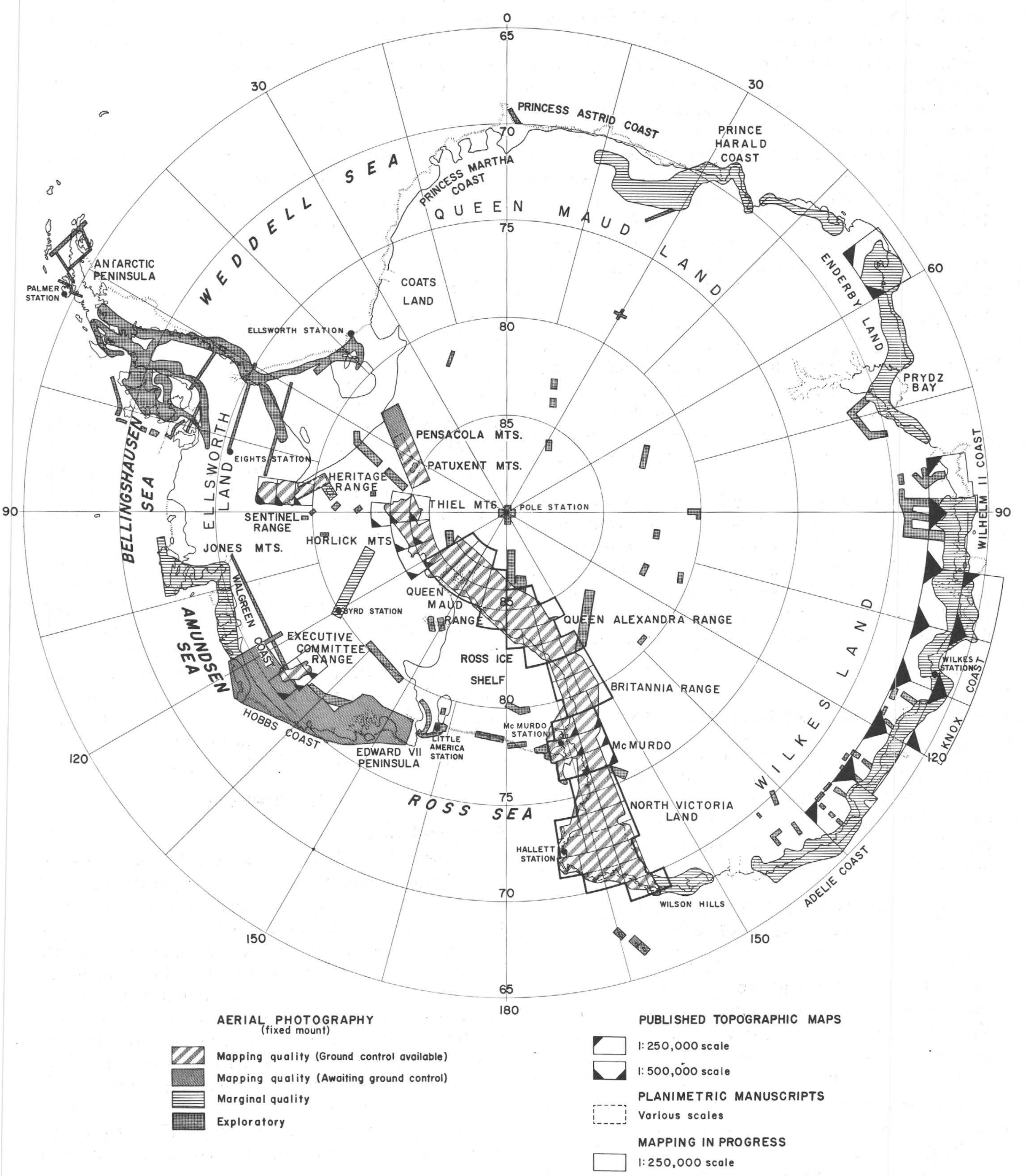


FIGURE 17.—Index map of Antarctica, showing status of topographic mapping by the U.S. Geological Survey as of June 30, 1965.

stellation aircraft previously used in Antarctica photographic missions, an LC–130F Hercules aircraft, specially designed for aerial photographic work, was also used. The LC–130F is ski equipped, permitting the aircraft to make emergency landings on unprepared snow and ice surfaces. Also, it accommodates a removable 3,600-gallon internal gas tank which increase its flight time by approximately 5 hours. As a result, a final analysis of the season's photography indicates that areas totaling about 182,500 square miles were photographed acceptably for use in the Geological Survey mapping program (as compared to a net total of 244,500 square miles obtained between 1959 and 1964).

Cartographic activities

Six 1:250,000-scale topographic maps of the McMurdo area were published in shaded-relief editions, making a total of 19 sheets at this scale now available (fig. 17). Mapping at the same scale is in progress for 8 sheets in the Queen Maud Range, 6 in the Britannia Range, 9 in the Queen Alexandra Range, and 18 in Victoria Land.

A 1:500,000-scale shaded-relief planimetric sketch map was published of Northern Victoria Land, showing an area of 50,000 square miles north of lat 73° S., and between long 158° and 171° E. A 1:40,000-scale planimetric manuscript was compiled of the Neptune Range and used in revising the 1:500,000-scale planimetric sketch map of the Pensacola Mountains.

RESEARCH AND DEVELOPMENT

To support the National Topographic Program, continuing research and development are needed to improve techniques, instruments, and materials. The chief objectives are to improve the quality and usability of the maps and to reduce the cost of producing them.

ESTABLISHMENT OF TEST SITE FOR MAPPING RESEARCH

Many research projects in topographic surveying and mapping require a group effort by engineers and cartographers with different backgrounds and talents to achieve useful and meaningful results. A project of this type, completed in 1965 by the combined effort of field and photogrammetric engineers, was the establishment of a test site near Phoenix, Ariz., with a high density of control points. Within the test area, a 16-mile square, 31 points had been established and marked with permanent targets by the U.S. Army Map Service. Many more points, however, were needed to provide adequate source data for testing and evaluating photogrammetric techniques and instrumentation.

Additional elevations were established at quarter-mile intervals within a 2- by 3-mile area, at half-mile intervals within a 3- by 5-mile area, and at mile intervals within an 8- by 8-mile area. Within the 8- by 8-mile area, additional horizontal points were established at mile intervals. Half of the total 16- by 16-mile area contains control points at intervals of 2 miles or less, and the rest contains control points at 4-mile intervals.

Each of the 223 new points was marked with a permanent monument for future recovery and also was temporarily marked with polyethylene sheeting to provide square target images on aerial photographs. Three sizes of targets were used: 6 by 6 feet, 9 by 9 feet, and 12 by 12 feet. Including the 31 Army Map Service points, the test area contains a total of 254 control points.

Horizontal positions were extended by second-order triangulation and electronic-distance traverse. Elevations were extended by fourth-order fly leveling, with closure errors held to 0.1 foot or less.

After the points had been surveyed and marked with targets, aerial photographs were taken at several flight heights, ranging from 3,000 to 24,000 feet. The photographs were taken with wide-angle (90°) and super-wide-angle (120°) cameras, on film and glass plates, with panchromatic and infrared emulsions. The photographs and survey data are now being used in an evaluation of super-wide-angle photogrammetric instrumentation and in a test of analytical aerotriangulation techniques.

FIELD SURVEYS

Bench-mark stability tests

A research project was started in July 1964 to investigate the stability and the comparative cost of various methods of setting bench marks in different types of soil. A test course about 3,000 feet long was established, containing 41 points marked in 5 different ways: by tablets embedded (1) in boulders and (2) in concrete posts, by tablets crimped (3) on special copper-coated rods and (4) on ordinary reinforcing steel, and (5) by copper nails in tree roots. The stability of the marks was determined by repeated leveling of super-first-order accuracy at 1- to 2-month intervals.

Although the tests are not completed, the preliminary results indicate that the copper-coated steel rods provide the most stable setting for the tablets.

Compared to conventional concrete posts, they cost only 50 percent as much and are much easier to transport and to set. They are obtained in 5-foot sections which can be joined by crimping with special tools, and can be driven with a gasoline-powered hammer. The tablets are fastened to the rods by crimping. Arrangements have been made to use this type of bench-mark setting in all topographic fieldwork.

A yearly cycle of variation in elevations has been observed. All marks showed upheaval in spring and summer and settling in fall and winter, in some cases as much as 5 millimeters. The tests are being continued to learn more about the long-range effects of this cyclic variation.

Military evaluation of ABC system

The U.S. Geological Survey supplied equipment components and engineer advisers for a military evaluation of the Survey-developed AirBorne Control System near Fort Sill, Okla., in September and October 1964. The U.S. Army Artillery Board was responsible for the evaluation, assisted by the Armor Board, the 30th Engineers, and Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA).

Summary conclusions of the evaluation are that the ABC System is suitable for establishing control for topographic mapping but that it is not an alternative to either of the military systems with which it was compared, the Visual Airborne Target Locator System and the Long Range Survey System. GIMRADA is now studying the adaptability of ABC System components to military design and the possible use of available military components.

Level-rod graduation strips

The evaluation of photographically prepared invar graduation strips for precise level rods, begun last year, is continuing. Several prototype strips have been calibrated. Sections of some of them have exceeded the specified accuracy. The reasons for failure of the prototype strips to meet specifications fully are being investigated, and improved testing and installation methods have been developed.

Commercially printed self-reading facing strips and check scales have been laboratory tested. These strips have withstood temperatures ranging from −65°F to +155°F, and relative humidities from 16 percent to 100 percent. Strips of this material will be installed on rods to be used in the field as soon as possible.

An investigation of the possibility of using similar strips for stadia rods is underway, with a good chance that a more scale-stable material can be found. Prospective savings over the cost of rebuilding and maintaining present silk-screen printing equipment will probably save several hundred dollars annually and will produce superior graduations.

PHOTOGRAMMETRY

Analytical aerotriangulation

The availability of high-speed electronic computers has led to the development of analytical systems of aerotriangulation for establishing the control needed to orient and position stereomodels for map compilation. The U.S. Geological Survey direct geodetic constraint method has been developed to solve the entire photogrammetric aerotriangulation problem mathematically. Input data for the solution consist of x and y photocoordinates measured on glass plates by means of a Mann monoscopic comparator.

To facilitate the measuring and recording of the great number of precise coordinates required for aerotriangulation, the Mann comparator has been recalibrated and modified by the addition of electric motor drives for the x and y motions, an analog-to-digital converter, an automatic electric typewriter, and an automatic card punch. These refinements have increased the speed and precision of operation and have virtually eliminated the possibility of gross errors in recording photocoordinates.

In an early test of the direct geodetic constraint method, a strip of 7 photographs taken at a flight height of 10,000 feet with a 6-inch camera was aerotriangulated with control limited to 2 horizontal points and 6 vertical points. The root-mean-square error (RMSE) for 13 vertical test points was 0.5 foot, and for 17 horizontal test points the RMSE was 1.2 feet.

Operational tests of the method are now in progress for the Middleburg and Arcola, Va., 7½-minute quadrangles. All the constraining ground-control points and all the test points for the project were marked with specially designed targets before the area was photographed on film and glass-plate negatives. Preliminary results indicate a high order of horizontal and vertical accuracy.

Super-wide-angle photogrammetric systems

The introduction of super-wide-angle cameras and stereoplotters has provided a potential for increased economy in photogrammetric mapping. Photographs taken with the new cameras (angular field, 120°; focal length, 3.5 inches) cover 3 times the area of those taken at the same flight height with wide-angle cameras (angular field, 90°; focal length, 6 inches).

Comparative studies and production tests of available super-wide-angle stereoplotters continued during 1965, to determine the type most suitable for and adaptable to Geological Survey mapping operations. The accuracy and economy of super-wide-angle systems as compared with wide-angle systems for analytical aerotriangulation are also being investigated. Stereoplotters under test include the Wild Aviograph B8, the Kelsh K8, the Kern PG–2, the Bausch and Lomb Super Balplex (ER–32), and the Wild WH–6.

Automatic mapping instrumentation

As a means of investigating the possibilities and applications of automation in mapping, the U.S. Geological Survey in 1965 acquired a Stereomat III on indefinite loan from the U.S. Army Map Service. This instrument, designed for automatic stereocompilation, contains electronic image-correlating circuits that sense x and y parallax in the stereomodel. The error signals due to y parallax control servomotors attached to the optical projectors and automatically bring the projectors into proper orientation relative to each other. The x-parallax signals control servomotors which move the scanning head in the x, y, and z directions according to the selected mode of operation—contouring, profiling (in either x or y direction), or drainage compilation. It is expected that the profiling output of the Stereomat, in digital form, can be used to control the Orthophotoscope for automatic production of orthophotographs.

Multiband aerial photography

Simultaneous multiband photographs taken with a special six-unit camera were evaluated for potential utility in photogrammetric mapping. Four types of 70-mm film were used: standard color, false color (camouflage detection), infrared, and standard panchromatic (exposed through red, green, and blue filters). Coverage was obtained over typical areas of urban development, dense timber cover, and intricate hydrographic detail at flight heights of 6,000, 18,000, and 30,000 feet. The photographs were compared visually to assess their relative quality for photointerpretation of ground detail at the three flight heights.

The false color film was considered to have the greatest photointerpretive value, and the standard color film was rated a close second. The infrared film gave the best differentiation of ground detail in dense timber. Little falloff in photointerpretive quality was noted in the photographs taken at 30,000 feet as compared with those taken at 18,000 feet.

Orthophotomap research

The availability of instruments and practical techniques for preparing orthophotographs (that is, photographs corrected for image displacements due to tilt and relief) has led to the experimental development of a new map product, the orthophotomap. This new type of map presentation consists of a precise assembly of orthophotographs in standard quadrangle format, to which limited cartographic treatment in the form of symbols, names, boundaries, and marginal information is applied. The orthophotomap may be printed in multicolor form and is considered to have wide potential application in engineering and other scientific disciplines.

An orthophotomap of the Cave Creek 2 SE, Ariz., 7½-minute quadrangle has been prepared to demonstrate the additional map information provided by photographic imagery of natural terrain features in areas of sparse cultural detail. The color tones used in printing were adjusted to match very closely the natural colors of the terrain. (The original orthophotographs were prepared from normal black-and-white aerial photographs.) The orthophotomosaic was overprinted with contours, elevations, and selected cartographic symbols to augment the portrayal. The resultant presentation, which meets the National Map Accuracy Standards, contains much more detailed information about the terrain than can be expected of a conventional line-drawn map.

Color photomaps of large swamps

Two projects are underway to provide color photomaps of large swamp areas, the Everglades in Florida and the Okefenokee Swamp in southeastern Georgia. These projects differ from the orthophotomap project described above in that the range of topographic relief is too small to require the use of orthophotographs, and color aerial photographs are being used as part of the source data.

The shortcomings of line-drawn map representation of large swamps have long been recognized. Therefore, the new approach consists in preparing a precisely controlled photomosaic, adding cartographic delineation and accentuation where appropriate, and color-coding features of major interest. Some of the terrain features to be differentiated are pine keys, bay heads, mangrove, and sawgrass. Other features to be shown include conspicuous airboat trails, saline-water boundaries, and survival water holes, as well as standard planimetric features, such as roads, buildings, canals, and levees. Ground elevations will also be shown.

Three types of aerial photographs will be used in preparing the photomaps—color, infrared, and standard panchromatic. It is expected that the color photographs will be particularly useful in interpreting and delineating the various types of terrain.

NATIONAL ATLAS

Work on the National Atlas during 1965 consisted in compiling general reference maps and in preparing proof prints of the physical and thematic maps of the climatic and water sections. Parts of the historical section were started, and proofs of some of these pages are expected early in fiscal year 1966.

In addition, experimental printings were made in cooperation with the Publications Division of the U.S. Geological Survey to determine suitable procedures, colors, and type of paper for the Atlas. Other investigations will lead to a final selection of type of binding, cover fabric, and type of plastic overlay sheets for the bound volumes.

During the year, the Bureau of the Budget issued a revision of Exhibit B to Circular A-16 which requires all interested Federal agencies to appoint liaison officers for the National Atlas Project. On February 16, 1965, a meeting of all the liaison officers was held. As a result of this initial meeting, activity on the atlas was increased significantly, and much planning of content and format was completed during the second half of the year.

For geologic subjects covered see "National Atlas," a subheading under "MAPS OF LARGE REGIONS" in the section "REGIONAL GEOLOGY."

COOPERATING AGENCIES FOR FISCAL YEAR 1965

FEDERAL AGENCIES

Agency for International Development
Air Force:
- Cambridge Research Center
- Technical Application Center

Army:
- Corps of Engineers, Waterways Experiment Station
- U.S. Army—Europe

Atomic Energy Commission:
- Division of Raw Materials
- Division of Reactor Development
- Idaho Operations Office
- Nevada Operations Office
- Research Division
- San Francisco Operations Office
- Savannah River Operations Office

Department of Agriculture:
- Forest Service
- Soil Conservation Service

Department of Commerce:
- Weather Bureau

Department of Defense:
- Advanced Research Projects Agency
- Defense Atomic Support Agency
- Defense Intelligence Agency
- Office of Scientific Research

Department of Health, Education and Welfare:
- Public Health Service

Department of the Interior:
- Bonneville Power Administration
- Bureau of Commercial Fisheries
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Bureau of Sport Fisheries and Wildlife
- National Park Service
- Office of Minerals Exploration
- Office of Saline Water
- The Alaska Railroad

Department of State
District of Columbia
Executive Office of the President—Office of Emergency Planning
Federal Aviation Agency
Federal Power Commission
General Services Administration
National Aeronautics and Space Administration
National Science Foundation
Navy:
- Office of Naval Research

Navy—Continued
- Petroleum and Oil Shale Reserve
- Radiological Defense Laboratory

Tennessee Valley Authority

STATE, COUNTY, AND MUNICIPAL AGENCIES

Alabama:
- Alabama Highway Department
- City of Huntsville
- City of Mobile
- Department of Conservation
- Geological Survey of Alabama
- Water Improvement Commission

Alaska:
- City of Anchorage
- State Highway Department

Arizona:
- Arizona Highway Department
- Buckeye Irrigation Company
- City of Flagstaff
- City of Tucson
- City of Williams
- County of Apache, Superior Court
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Navajo Tribal Council
- Salt River Valley Water Users Association
- San Carlos Irrigation and Drainage District
- State Land Department

Arkansas:
- Arkansas Geological Commission
- Arkansas State Highway Commission
- University of Arkansas—Agricultural Experiment Station

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Calaveras County Water District
- City of San Diego
- City of Santa Barbara
- Contra Costa County Flood Control and Water Conservation District
- County of Los Angeles Department of County Engineers
- Department of Conservation, Division of Mines and Geology
- East Bay Municipal Utility District
- East Kern Water Agency—Antelope Valley
- Georgetown Divide Public Utility District

California—Continued
- Imperial Irrigation District
- Lake County Flood Control and Water Conservation District
- Metropolitan Water District of Southern California
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Orange County Flood Control District
- Orange County Water District
- Palo Verde Irrigation District
- Placer County Water Agency
- Sacramento Municipal Utility District
- San Bernardino County Flood Control District
- San Bernardino Valley Water Conservation District
- San Francisco City and County Public Utilities Commission
- San Francisco Water Department
- San Luis Obispo County Flood Control and Water Conservation District
- San Mateo County
- Santa Barbara County Water Agency
- Santa Clara County Flood Control and Water Conservation District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Maria Valley Water Conservation District
- State Department of Fish and Game
- State Department of Water Resources
- State Water Pollution Control Board
- Ventura River Municipal Water District

Colorado:
- Arkansas River Compact Administration
- City of Westminster
- Colorado River Water Conservation Board
- Colorado State Metal Mining Fund Board
- Colorado State University Agricultural Experiment Station
- Colorado Water Conservation Board
- Costilla Creek Compact Commission
- Denver Board of Water Commissioners
- Inter-county Regional Planning Commission
- Office of State Engineer, Division of Water Resources
- Rio Grande Compact Commission
- Southeastern Colorado Water Conservancy District

Connecticut:
- City of Torrington—Engineering Department
- Connecticut Geologic and Natural History Survey
- Greater Hartford Flood Commission
- Hartford Department of Public Works
- Highway Department
- New Britain Board of Water Commissioners
- State Water Resources Commission

Delaware:
- Delaware Geological Survey
- State Highway Department

District of Columbia:
- District of Columbia Department of Sanitary Engineering

Florida:
- Broward County—Board of County Commissioners
- Central and Southern Florida Flood Control District
- City of Boca Raton

Florida—Continued
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Jacksonville:
  - City Commission
  - Office of the City Engineer
- City of Miami—Department of Water and Sewers
- City of Miami Beach
- City of Naples
- City of Perry
- City of Pompano Beach
- City of Tallahassee
- Collier County—Board of County Commissioners
- Dade County—Board of County Commissioners
- Florida Geological Survey
- Hillsborough County—Board of County Commissioners
- Orange County—Board of County Commissioners
- Pinellas County—Board of County Commissioners
- Polk County—Board of County Commissioners
- State Board of Parks and Historic Memorials
- State Road Department
- Trustees of Internal Improvement Fund

Georgia:
- Department of Mines, Mining and Geology, Division of Conservation
- State Highway Department

Hawaii:
- City and County of Honolulu
- State Department of Land and Natural Resources

Idaho:
- Idaho Department of Fish and Game
- Idaho Department of Highways
- Idaho Department of Reclamation

Illinois:
- Division of Highways
- Division of Waterways
- Fountain Head Drainage District
- Metropolitan Sanitary District of Greater Chicago
- Northeastern Illinois Metropolitan Area Planning Commission
- Sanitary District of Bloom Township (Cook County)
- State Department of Public Works and Buildings
- State Department of Registration and Education

Indiana:
- Department of Conservation
- Department of Natural Resources
- Flood Control and Water Resources Commission
- State Board of Health
- State Highway Commission

Iowa:
- Agricultural Experiment Station, Iowa State University of Science and Technology
- City of Cedar Rapids
- City of Fort Dodge—Department of Utilities
- City of Iowa City
- City of Muscatine
- Iowa Geological Survey
- Iowa Institute of Hydraulic Research
- Iowa State Conservation Commission
- Iowa State Highway Commission
- Iowa State University
- Linn County—Board of Supervisors

Kansas:
- Board of Agriculture, Division of Water Resources

Kansas—Continued
- City of Wichita—Department of Public works
- Kansas State Geological Survey
- State Department of Health—Environment Health Services
- State Highway Commission
- State Water Resources Board

Kentucky:
- Kentucky Geological Survey
- University of Kentucky

Louisiana:
- Sabine River Compact Commission
- State Department of Conservation
- State Department of Highways
- State Department of Public Works

Maine:
- Maine Public Utilities Commission
- State Highway Commission

Maryland:
- Baltimore County—Department of Public Works
- Charles County
- City of Baltimore
- City of Cambridge
- City of Easton
- City of Salisbury
- Dorchester County—Board of County Commissioners
- Maryland Geological Survey
- State Board of Health
- State Planning Department
- State Roads Commission
- Talbot County—Board of County Commissioners
- Washington Suburban Sanitary Commission

Massachusetts:
- Boston Metropolitan District Commission
- Massachusetts Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Massachusetts Water Resources Commission

Michigan:
- State Department of Conservation:
  - Engineering and Architecture Section
  - Fish Section
  - Game Section
  - Geological Survey Section
  - Parks and Recreation Section
- State Highway Department
- State Water Resources Commission

Minnesota:
- Board of County Commissioners of Hennepin County
- Department of Administration
- Department of Iron Range Resources and Rehabilitation
- State Department of Conservation, Division of Waters
- State Department of Highways

Mississippi:
- City of Jackson
- Harrison County—Board of Supervisors and Development Commission
- Jackson County—Port Authority
- Mississippi Board of Water Commissioners
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pearl River Valley Water Supply District

Missouri:
- Curators of the University of Missouri

Missouri—Continued
- Division of Geological Survey and Water Resources
- State Department of Conservation:
  - Conservation Commission
  - Fisheries Division
- State Highway Commission
- Water Pollution Board

Montana:
- Montana Bureau of Mines and Geology
- Montana State College—Endowment and Research Foundation
- State Engineer
- State Fish and Game Commission
- State Highway Commission
- State Water Conservation Board

Nebraska:
- Department of Roads
- Department of Water Resources
- Nebraska Mid-State Reclamation District
- University of Nebraska—Conservation and Survey Division

Nevada:
- Department of Conservation and Natural Resources
- Department of Highways
- Nevada Bureau of Mines

New Hampshire:
- New Hampshire Water Resources Board

New Jersey:
- Camden County Planning Board
- County of Bergen
- Delaware River Basin Commission
- Department of Agriculture
- Department of Conservation and Economic Development:
  - Division of Fish and Game
  - Division of Water Policy and Supply
- Department of Health
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission
- Rutgers University, The State University of New Jersey

New Mexico:
- Carlsbad Irrigation District
- Costilla Creek Compact Commission
- Interstate Stream Commission
- New Mexico Institute of Mining and Technology
- Pecos River Commission
- Pecos Valley Artesian Conservancy District
- Rio Grande Compact Commission
- State Engineer and School of Mines
- State Highway Department
- State Game and Fish Commission
- University of New Mexico

New York:
- Board of Hudson River—Black River Regulating District
- Brighton Sewer District No. 2
- City of Albany—Department of Water and Water Supply
- City of Auburn—Water Department
- Dutchess County Board Supervisors
- Nassau County Department of Public Works
- New York City Board of Water Supply
- Office of Atomic and Space Development
- Onondaga County Department of Public Works
- Onondaga County Water Authority
- Oswegatchie River—Cranberry Reservoir Commission

New York—Continued
- State Conservation Department:
  - Division of Lands and Forests
  - Division of Water Resources
- State Department of Commerce
- State Department of Health, Water Pollution Control Board
- State Department of Public Works
- Suffolk County Board of Supervisors
- Suffolk County Department of Public Works
- Suffolk County Water Authority
- Village of Nyack—Board of Water Commissioners
- Westchester County Department of Public Works

North Carolina:
- City of Asheville
- City of Burlington
- City of Charlotte
- City of Durham
- City of Greensboro
- City of Winston-Salem
- North Carolina Department of Conservation and Development, Division of Mineral Resources
- Pitt County Board of Commissioners
- State Department of Water Resources
- State Highway Commission
- Town of Waynesville

North Dakota:
- North Dakota Geological Survey
- Oliver County
- State Highway Department
- State Water Conservation Commission

Ohio:
- City of Columbus—Department of Public Service
- Miami Conservancy District
- Ohio Department of Health
- Ohio Department of Highways
- Ohio Department of Natural Resources—Division of Water
- Ohio River Valley Water Sanitation Commission
- Scioto Conservancy District

Oklahoma:
- City of Oklahoma City Water Department
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma State Department of Health
- Oklahoma Water Resource Board

Oregon:
- Board of Higher Education
- Burnt River Irrigation District
- City of Dallas
- City of Dalles City
- City of Eugene—Water and Electric Board
- City of McMinnville—Water and Light Department
- City of Portland—Bureau of Water Works
- City of Toledo
- Coos Bay—North Bed Water Board
- County Court of Douglas County
- County Court of Lane County
- County Court of Morrow County
- County of Coos—Board of Commissioners
- Mosier Irrigation District
- State Engineer, Water Resources Department
- State Game Commission
- State Highway Commission

Oregon—Continued
- Vale Irrigation District
- Talent Irrigation District

Pennsylvania:
- Chester County Soil and Water Conservation District
- City of Bethlehem
- City of Harrisburg
- City of Philadelphia
- Conestoga Valley Association, Inc.
- Department of Internal Affairs, Bureau of Topographic and Geologic Survey
- Pennsylvania Department of Agriculture
- Pennsylvania Department of Forests and Waters
- Pennsylvania Department of Health

Rhode Island:
- Department of Public Works
- Rhode Island Water Resources Coordinating Board

South Carolina:
- City of Spartanburg—Commissioners of Public Works
- State Development Board
- State Highway Department
- State Public Service Authority
- State Water Pollution Control Authority

South Dakota:
- South Dakota Department of Highways
- South Dakota Geological Survey
- South Dakota Water Resources Commission

Tennessee:
- City of Chattanooga
- City of Murfreesboro—Water and Sewer Department
- City of Oak Ridge
- Memphis Board of Light, Gas, and Water Commissioners—Water Division
- Metropolitan Government of Nashville and Davidson County—Department of Public Works
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Highways
- Tennessee Department of Public Health
- Tennessee Game and Fish Commission

Texas:
- City of Dallas
- City of Houston
- Highway Department
- Pecos River Commission
- Rio Grande Compact Commission
- Sabina River Compact Administration
- Texas Water Commission

Utah:
- Bear River Compact Commission
- Salt Lake County
- State Road Commission of Utah
- Utah Geological and Mineralogical Survey
- Utah State Engineer
- Utah Water and Power Board

Vermont:
- Department of Highways
- State Water Resources Board
- Vermont Geological Survey

Virginia:
- City of Alexandria
- City of Charlottesville
- City of Newport News—Department of Public Utilities

Virginia—Continued
- City of Norfolk—Division of Water Supply
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Department of Conservation and Development—Division of Mineral Resources
- Department of Highways

Washington:
- City of Seattle
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- King County Board of Commissioners
- Municipality of Metropolitan Seattle
- State Department of Conservation, Division of Mines and Geology
- State Department of Fisheries
- State Department of Game
- State Department of Highways
- State Pollution Control Commission
- Stevens County

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- State Department of Natural Resources
- State Geological and Economic Survey

West Virginia—Continued
- State Road Commission

Wisconsin:
- Madison Metropolitan Sewerage District
- Public Service Commission of Wisconsin
- Southeastern Wisconsin Regional Planning Commission
- State Committee on Water Pollution
- State Highway Commission
- University of Wisconsin—Geological and Natural History Survey

Wyoming:
- City of Cheyenne—Board of Public Utilities
- Geological Survey of Wyoming
- State Engineer
- Wyoming Highway Department
- Wyoming Natural Resource Board

Commonwealth of Puerto Rico:
- Aqueduct and Sewer Authority
- Department of Agriculture
- Department of Public Works
- Economic Development Administration
- Water Resources Authority

American Samoa:
- Government of American Samoa

Guam:
- Government of Guam

Virgin Islands:
- Government of the Virgin Islands

U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

Main Office: General Services Building, 18th and F Streets NW., Washington, D.C. 20242; 343-1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; BElmont 3-3611
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; DAvenport 5-6761

PUBLIC INQUIRIES OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage, 99501	Margaret I. Erwin (277-0577)	108 Skyline Bldg., 508 2d Ave.
California, Los Angeles, 90012	Lucy E. Birdsall (688-2850)	7638 Federal Bldg., 300 N. Los Angeles St.
San Francisco, 94111	Jean V. Molleskog (556-5627)	504 Custom House, 555 Battery St.
Colorado, Denver, 80202	Lorene C. Young (297-4169)	15426 Federal Bldg., 1961 Stout St.
Texas, Dallas, 75202	Mary E. Reid (RIverside 9-3230, ext. 3230).	602 Thomas Bldg., 1314 Wood St.
Utah, Salt Lake City, 84111	Maurine Clifford (524-5652)	8102 Federal Bldg., 125 South State St.
Washington, Spokane, 99204	Eva M. Raymond (TEmple 8-3361, ext. 121).	South 157 Howard St.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices not included; list current as of September 1, 1965. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

CONSERVATION DIVISION

Location	*Official in charge* and telephone number*	*Address*
Alaska, Anchorage, 99501	Leo H. Saarela (m) (277-0578), Alexander A. Wanek (c) (277-0570), W. J. Linton (o) (277-0570).	P.O. Box 259; Skyline Bldg., 218 E. St.
California, Los Angeles, 90012	Russell G. Wayland (c) (688-2846), D. W. Solanas (o) (688-2846).	7744 Federal Bldg., 300 N. Los Angeles St.
Sacramento, 95814	Richard N. Doolittle (w) (449-2203)	8030 Federal Bldg., 650 Capitol Ave.
Bakersfield, 93301	Harry Lee Wolf (o) (327-7274), E. E. Richardson (c) (327-7274).	309 Federal Bldg., 800 Truxtun Ave.
Colorado, Denver, 80202	G. G. Frazier (o) (297-3211), H. B. Lindeman (m) (297-4038).	15428 and 15444 Federal Bldg.
Denver, 80225	George H. Horn (c) (233-3611, ext. 8168)	Building 25, Federal Center.
Denver, 80202	W. C. Senkpiel (w) (297-3316)	15407 Federal Bldg., 1961 Stout St.
Durango, 81302	Jerry W. Long (o) (247-5144)	P.O. Box 1809; Jarvis Bldg., 125 W. 10th St.
Louisiana, New Orleans, 70113	Admiral D. Acuff (o) (527-6543)	T-6009 Federal Bldg., 701 Loyola Ave.
Lafayette, 70504	George Kinsel (o) (232-0239)	301 Federal Bldg.
Montana, Billings, 59103	Ray M. Bottomley (m) (245-6711, ext. 6368), Hillary A. Oden (o) (245-6711).	P.O. Boxes 1435 and 2550; 223 and 327 Federal Bldg.
Great Falls, 59401	Andrew F. Bateman (c) (454-3314), John A. Fraher (o) (454-3336).	P.O. Boxes 1215 and 2265; 510 First Ave.
New Mexico, Artesia, 88210	James A. Knauf (o) (746-4841)	Drawer U; 210 Carper Bldg., 105 S. 4th St.
Carlsbad, 88220	Robert S. Fulton (m) and Bruno R. Alto (c) (885-6454).	P.O. Box 1716; Federal Bldg., Fox and Haleguena St.
Farmington, 87401	Phillip T. McGrath (o) and J. E. Fassett (c) (325-4572).	P.O. Box 959; 409 Petroleum Club Plaza, 3535 East 30th St.

* The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: b—Branch of Connally Act Compliance, c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification.

Location	Official in charge* and telephone number	Address
New Mexico—Continued		
Hobbs, 88240	Arthur R. Brown (o) (393–3612)	Box 1157; 205 N. Linam St.
Roswell, 88201	J. A. Anderson (o) and T. F. Stipp (c) (622–1332).	Drawer 1857; Farnsworth Bldg., 120 W. 2nd St.
Oklahoma, Holdenville, 74848	Gerhardt H. W. Schuster (o) (379–3840)	P.O. Box 789; 5 Federal Bldg.
McAlester, 74502	A. M. Dinsmore (m) (423–5030)	509 South 3rd St.
Miami, 74354	Andrew V. Bailey (m) (542–9481)	P.O. Box 509; 205 Federal Bldg.
Oklahoma City, 73102	Charley W. Nease (o) (236–2311)	4321 Federal Court House and Office Bldg., 220 N.W. 4th St.
Tulsa, 74103	Edward L. Johnson (c) and N. Orvis Frederick (o) (584–7161, ext. 638 and 632).	521 Wright Bldg., 115 W. 3rd St.
Oregon, Portland, 97208	Loyd L. Young (w) (226–3252)	P.O. Box 3087; 319 Post Office Bldg.
Texas, Kilgore, 75662	Warren W. Mankin (b) (5564)	P.O. Box 1230, Rader Bldg., 901–903 Broadway Blvd.
Midland, 79701	Everett H. Patterson (b) (684–6741)	P.O. Box 1830; 132 Western American Bldg., 305 N. Big Spring St.
Utah, Salt Lake City, 84111	Ernest Blessing (m) (524–5646), Harry McAndrews (c) (524–5643), Rodney A. Smith (o) (524–5650).	8402, 8422, and 8416 Federal Bldg.; 125 S. State St.
Washington, Tacoma, 98401	Gordon C. Giles (w) (383–5380)	P.O. Box 1152; 244 Federal Bldg.
Wyoming, Casper, 82602	J. R. Schwabrow (o) and Donald M. Van Sickle (c) (265–4310).	P.O. Box 400; 305 Federal Bldg.
Newcastle, 82701	Glenn E. Worden (o) (746–4554)	P.O. Box 219; 611 S. Summit St.
Rock Springs, 82901	John Duletsky (o) (362–6422), Arne A. Mattila (m) (362–7350).	P.O. Box 1170; 201 and 204 First Security Bank Bldg., 502 S. Front St.
Thermopolis, 82443	Charles P. Clifford (o) (864–3477)	P.O. Box 590; 202 Federal Bldg.

* See footnote, p. A211.

GEOLOGIC DIVISION

Location	Geologist in charge and telephone number	Address
Alaska, College, 99735	Robert M. Chapman (479–6725)	P.O. Box 580; Brooks Memorial Bldg.
Arizona, Flagstaff, 86002	Eugene M. Shoemaker (774–5081)	601 East Cedar Ave.
California, Los Angeles, 90424	Robert O. Castle (GRanite 3–0971, ext. 9881).	Geology Bldg., Univ. of California.
Hawaii, Hawaii National Park, 96718	Howard A. Powers (678–485)	Hawaiian Volcano Observatory.
Kansas, Lawrence, 66044	Windsor L. Adkison (VIking 3–2700)	c/o State Geological Survey, Lindley Hall, Univ. of Kansas.
Kentucky, Lexington, 40503	Paul W. Richards (4–2473)	496 Southland Drive.
Maryland, Beltsville, 20705	James C. Wright (GRanite 4–4800, ext. 470).	U.S. Geological Survey Bldg., Dept. of Agriculture Research Center.
Massachusetts, Boston, 02116	Lincoln R. Page (KEnmore 6–1444)	Room 1, 270 Dartmouth St.
Michigan, Marquette, 49855	Jacob E. Gair (226–2110)	Industrial Lane.
New Mexico, Albuquerque, 87100	Charles B. Read (CHapel 7–0311, ext. 483).	P.O. Box 4083, Station A; Geology Bldg., Univ. of New Mexico.
Ohio, Columbus, 43200	James M. Schopf (AXminster 4–1810)	Orton Hall, Ohio State Univ., 155 Oval Drive.
Puerto Rico, Roosevelt, 00927	Watson H. Monroe (San Juan 6–5340)	P.O. Box 803.
Tennessee, Knoxville, 37906	Robert A. Laurence (2–7787)	13 Post Office Bldg.
Texas, Austin, 78701	D. Hoye Eargle (HObart 5–6501)	801 Federal Bldg.
Utah, Salt Lake City, 84111	Lowell S. Hilpert (524–5640)	8426 Federal Bldg.
Washington, Spokane, 99204	Albert E. Weissenborn (TEmple 8–2084)	South 157 Howard St.
Wisconsin, Madison, 53706	Carl E. Dutton (262–1854)	222 Science Hall, Univ. of Wisconsin.
Wyoming, Laramie, 82070	J. David Love (FRanklin 5–4495)	Geology Hall, Univ. of Wyoming.

TOPOGRAPHIC DIVISION

Location	Engineer in charge and telephone number	Address
California, Menlo Park, 94025	Robert O. Davis (415 325–6761, ext. 411)	345 Middlefield Rd.
Colorado, Denver, 80225	Roland H. Moore (303 233–3611, ext. 8551)	Federal Center, Bldg. 25.
Missouri, Rolla, 65401	Daniel Kennedy (314 364–3680)	P.O. Box 133; 9th and Elm Sts.
Virginia, Arlington, 22201	Charles F. Fuechsel (703 JAckson 5–7550)	1109 N. Highland St.

WATER RESOURCES DIVISION

AREA OFFICES

Location	*Official in charge* and telephone number*	*Address*
Atlantic Coast Area:		
Arlington, Virginia, 20242	George E. Ferguson, Area Hydrologist (202 343-4840).	George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
Mid-Continent Area:		
St. Louis, Missouri, 63103	Harry D. Wilson, Jr., Area Hydrologist (314 622-4361).	1252 Federal Bldg., 1520 Market St.
Rocky Mountain Area:		
Denver, Colorado, 80225	Sherman K. Jackson, Area Hydrologist (303 233-3611).	Federal Center, Bldg. 25.
Pacific Coast Area:		
Menlo Park, California, 94025	Warren. W. Hastings, Area Hydrologist (415 325-6761).	345 Middlefield Road.

DISTRICT OFFICES

Alabama, University, 35486	William L. Broadhurst (w) (205 752-8105).	P.O. Box V; Oil and Gas Board Bldg., Univ. of Alabama.
Alaska, Anchorage, 99501	Harry Hulsing (w) (907 277-5526, 5527)	P.O. Box 2480; 218 "E" St., Skyline Bldg.
Arizona, Tucson, 85717	Horace M. Babcock (w) (602 623-7731) (ext. 5791).	P.O. Box 4070; Geology Bldg., Univ. of Arizona Campus.
Arkansas, Little Rock, 72201	Richard T. Sniegocki (w) (501 372-5246)	2301 Federal Office Bldg., 700 West Capitol Ave.
California, Menlo Park, 94025	Walter Hofmann (w) (415 325-6761)	345 Middlefield Road.
Colorado, Denver, 80215	John W. Odell (s) (303 233-3611, ext. 644).	Rm. 22, 1455 Ammons St.
Denver, 80225	Leonard A. Wood (g) (303 233-3611, ext. 8546).	Federal Center, Bldg. 25.
Connecticut, Hartford, 06101	John Horton (s) (203 244-2528)	P.O. Box 715; 203 Federal Bldg.
Middletown, 06458	John A. Baker (g) (203 346-5542)	204 Post Office Bldg.
Delaware, Dover, 19901	Philip Pfannebecker (s) (302 734-2506)	604 Fairview Ave.
Florida, Tallahassee, 32304	Clyde S. Conover (w) (305 377-4231)	P.O. Box 2315; Gunter Bldg. (Tennessee and Woodward Sts.)
Georgia, Atlanta, 30323	Albert N. Cameron (w) (404 876-3311)	Rm. 164, Peachtree Seventh Bldg.
Hawaii, Honolulu, 96814	Dan A. Davis (g) and Mearle M. Miller (s) (588-111, ext. 692, 693, 694).	332 and 330 First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise, 83702	Wayne I. Travis (s) (208 342-2711, ext. 531), Herbert A. Waite (g) (208 342-2711, ext. 539).	Rms. 215 and 205, 914 Jefferson St.
Illinois, Champaign, 61820	William D. Mitchell (s) (217 356-5221)	605 South Neil St.
Indiana, Indianapolis, 46204	Malcom D. Hale (w) (317 633-7398)	Rm. 516, 611 North Park Ave.
Iowa, Iowa City, 52241	Sulo W. Wiitala (s) (319 338-0581, ext. 475).	508 Hydraulic Laboratory
Iowa City, 52240	Walter L. Steinhilber (g) (319 338-1173)	Geological Survey Bldg.
Kansas, Lawrence, 66045	Robert J. Dingman (g) (913 864-3001)	c/o Univ. of Kansas.
Topeka, 66601	Edward J. Kennedy (s) (913 234-8661, ext. 201).	P.O. Box 856; 403 Federal Bldg.
Kentucky, Louisville, 40202	Robert V. Cushman (g) and Floyd F. Schrader (s) (502 582-5241, 5242, 5243).	310 Center Bldg. 522 West Jefferson St.
Louisiana, Baton Rouge, 70806	Mack R. Stewart (s) and Russell M. McAvoy (q) (504 348-7181, ext. 281).	215 and 201 Prudential Bldg., 6554 Florida Blvd.
Baton Rouge, 70803	Rex R. Meyer (g) (504 348-7181, ext. 224).	P.O. Box GS, University Station; Rm. 223, Field House, Louisiana State Univ.
Maine, Augusta, 04330	Gordon S. Hayes (s) and Glenn C. Prescott (g) (207 623-4511, ext. 708).	Vickery Hill Bldg., Court St.
Maryland, Towson, 21204	John W. Wark (w) (301 828-7460)	724 York Road.

* The small letter in parentheses following each official's name signifies his affiliation in the Water Resources Division, as follows: g—Ground Water Branch; q—Quality of Water Branch; s—Surface Water Branch; w—Water Resources Division.

DISTRICT OFFICES—Continued

Location	*Official in charge* and telephone number*	*Address*
Massachusetts, Boston, 02110	Charles E. Knox (w) (617 223–2824)	Rm. 205, 211 Congress St.
Michigan, Lansing, 48933	Arlington D. Ash (w) (517 372–1910, ext. 561 and 564).	700 Capitol Savings and Loan Bldg.
Minnesota, St. Paul, 55101	David B. Anderson (s) and Richmond F. Brown (g) (612 228–7842).	1610 and 1002 New Post Office Bldg.
Mississippi, Jackson, 39205	William H. Robinson (w) (601 354–2326, 2327).	P.O. Box 2052, 302 U.S. Post Office Bldg.
Missouri, Rolla, 65401	Anthony Homyk, Jr. (s) (314 364–1599) Edward J. Harvey (g) (314 364–1599).	P.O. Box 340; 103 W. 10th St.
Montana, Billings, 59601	Charles W. Lane (g) (406 259–2412)	P.O. Box 1818; Bell Bldg., 2 South 7th St., West.
Helena, 59601	Frank Stermitz (s) (406 442–9040, ext. 3263).	P.O. Box 1696; 409 Federal Bldg.
Nebraska, Lincoln, 68501	Kenneth A. MacKichan (w) (402 475–3326).	P.O. Box 591; 125 Nebraska Hall, 901 N. 17th St.
Nevada, Carson City, 89701	George F. Worts, Jr. (w) (702 882–1388)	222 E. Washington St.
New Jersey, Trenton, 08605	John E. McCall (s) (609 599–3511, ext. 214).	P.O. Box 967; 433 Federal Bldg.
Trenton, 08607	Allen Sinnott (g) (609 599–3511, ext. 213).	P.O. Box 1238; 432 Federal Bldg.
New Mexico, Albuquerque, 87106	Samuel W. West (g) and Jay M. Stow (q) (505 247–0311, ext. 2248 and 2249).	P.O. Box 4217; Geology Bldg., Univ. of New Mexico.
Santa Fe, 87501	Wilbur L. Heckler (s) (505 982–3801, ext. 3307).	P.O. Box 1750; Federal Bldg., Cathedral Place.
New York, Albany, 12201	Ralph C. Heath (w) (518 472–3107)	P.O. Box 948; 342 Federal Bldg.
North Carolina, Raleigh, 27602	Edward B. Rice (w) (919 828–9031, ext. 156).	P.O. Box 2857; 4th Floor, Federal Bldg.
North Dakota, Bismarck, 58502	Harlan M. Erskine (s) (701 255–4011, ext. 227), Delbert W. Brown (g) (701 255–4011, ext. 228).	P.O. Box 778; 348 New Federal Bldg., 3rd St. and Rosser Ave.
Ohio, Columbus, 43212	John J. Molloy (w) (614 221–6411, ext. 113).	85 Marconi Blvd.
Oklahoma, Oklahoma City, 73102	Alvin R. Leonard (g) (405 236–2412), Alexander A. Fischback, Jr. (s) (405 236–2257, 2258).	4011 and 4301 Federal Bldg., 200 Northwest 4th St.
Oklahoma City, 73109	Richard P. Orth (q) (405 677–5022)	P.O. Box 95205; 2800 S. Eastern.
Oregon, Portland, 97208	Roy B. Sanderson (s) and Eugene R. Hampton (g) (503 226–3361, ext. 1248 and 1246).	P.O. Box 3418; 419 and 415 Federal Bldg., 701 NW. Glisan St.
	Lawrence Bodhaine (q) (503 234–3361, ext. 241).	P.O. Box 3202; 830 NE. Holladay.
Pennsylvania, Harrisburg, 17104	Joseph E. Barclay (g) (717 787–3420)	100 North Cameron St.
	Robert E. Steacy (s) (717 787–3917)	1224 Mulberry St.
Philadelphia, 19106	Norman H. Beamer (q) (215 597–4420)	1302 U.S. Custom House, 2d and Chestnut Streets.
Puerto Rico, Hato Rey, 00918	Dean B. Bogart (w) (809 766–3310)	12 Arroyo St.
Rhode Island, Providence, 02903	Joseph C. Rosenshein (g) (401 331–9312)	401–2 Federal Bldg. and U.S. Post Office.
South Carolina, Columbia, 29201	Albert E. Johnson (s) (803 253–8371, ext. 401).	121 Veterans Administration Regional Office Bldg., 1801 Assembly St.
Columbia, 29205	George E. Siple (g) (803 253–3405)	P.O. Box 5314; 627 Bull St.
South Dakota, Huron, 57350	John E. Powell (g) (605 352–8651, ext. 293).	P.O. Box 1412; 231 Federal Bldg.
Pierre, 57501	John E. Wagar (s) (605 224–7856)	P.O. Box 216; 207 Federal Bldg.
Tennessee, Nashville, 37203	Joseph S. Cragwall, Jr. (w) (615 242–8321, ext. 5924).	144 Federal Office Bldg.
Texas, Austin, 78701	Trigg Twichell (w) (512 476–6411)	Federal Bldg., 300 E. 8th Ave.
Utah, Salt Lake City, 84111	Milton T. Wilson (w) (801 524–5663)	8002 Federal Bldg., 125 S. State St.
Virginia, Charlottesville, 22903	James W. Gambrell (s) (703 296–5191 ext. 321).	P.O. Box 3327, University Station; Natural Resources Bldg., McCormick Road.
Washington, Tacoma, 98402	Leslie B. Laird (w) (206 383–2861, ext. 384).	Rm. 300, 1305 Tacoma Ave., So.

* See footnote, p. A213.

DISTRICT OFFICES—Continued

Location	Official in charge* and telephone number	Address
West Virginia, Charleston, 25301	William C. Griffin (s) (304 343-6181, ext. 311).	3303 New Federal Office Bldg. and U.S. Court House; 500 Quarrier St. East.
Morgantown, 26506	Porter E. Ward (g) (304 296-3338)	405 Mineral Industries Bldg., Univ. of West Virginia.
Wisconsin, Madison, 53706	Charles L. R. Holt, Jr. (g) (608 262-2488).	175 Science Hall, Univ. of Wisconsin.
Madison, 53705	Kenneth B. Young (s) (608 233-0195)	5001 University Ave.
Wyoming, Cheyenne, 82002	Ellis D. Gordon (g) (307 634-5920, ext. 2331), Leon A. Wiard (s) (307 634-5920, ext. 2317).	P.O. Box 2087; 2129 E. 8th Ave.
Worland, 82401	Thomas F. Hanley, (q) (307 347-2181)	1214 Big Horn Ave.

* See footnote, p. A213.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	Official in charge	Address
Bolivia, La Paz	James F. Seitz	U.S. Geological Survey, U.S. AID/Bolivia, c/o American Embassy, La Paz, Bolivia.
Brazil, Recife	John J. Matzko	U.S. AID/Recife, U.S. Department of State, Washington, D.C. 20521. STOP 27.
Rio de Janeiro	Alfred J. Bodenlos	U.S. Geological Survey, U.S. AID/RIO, c/o American Embassy, APO New York 09676.
Colombia, Barranquilla	Charles M. Tschanz	U.S. Geological Survey, c/o American Consul, American Consulate, Barranquilla, Colombia.
Bogotá	Earl M. Irving	U.S. Geological Survey, U.S. AID/UID, c/o American Embassy, Bogotá, Columbia.
Medellin	Lawrence V. Blade	U.S. Geological Survey, c/o American Consulate, Medellin, Colombia.
Costa Rica, San José	Frank D. Spencer	U.S. Geological Survey, c/o American Embassy, San José, Costa Rica.
Dahomey, Cotonou	Jules A. MacKallor	U.S. Geological Survey, U.S. AID/Cotonou, U.S. Department of State, Washington, D.C. 20521, STOP 27.
Liberia, Monrovia	Darwin L. Rossman	U.S. Geological Survey, U.S. AID/Monrovia, U.S. Department of State, Washington, D.C. 20521, STOP 27.
Pakistan, Quetta	Max G. White	U.S. Geological Survey, U.S. AID, c/o American Embassy, APO New York 09271.
Philippines, Manila	Laurence E. Andrews, Jr.	U.S. Geological Survey, U.S. AID, c/o American Embassy, APO San Francisco 96528.
Saudi Arabia, Jidda	Glen F. Brown	U.S. Geological Survey, c/o American Embassy, APO New York 09697.
Thailand, Bangkok	Charles T. Pierson	U.S. Geological Survey, USOM, c/o American Embassy, APO San Francisco 96346.

WATER RESOURCES DIVISION

Location	Official in charge	Address
Afghanistan, Bost	Vito J. Latkovich	U.S. Geological Survey, U.S. AID/Bost, c/o American Embassy, APO New York 09668.
Kabul	Arthur O. Westfall	U.S. Geological Survey, U.S. AID/Kabul, c/o American Embassy, APO New York 09668.

Location	*Official in charge*	*Address*
Brazil, Recife	Stuart L. Schoff	U.S. AID/Recife, U.S. Department of State, Washington, D.C. 20521, STOP 27.
Egypt, Cairo	Robert L. Cushman	U.S. Geological Survey, U.S. AID/Cairo, U.S. Department of State, Washington, D.C. 20521, STOP 27.
Nepal, Katmandu	Woodrow W. Evett	U.S. Geological Survey, U.S. AID, c/o American Embassy, APO New York 09674.
Nigeria, Kaduna	David A. Phoenix	U.S. Geological Survey, c/o Geological Survey of Nigeria, Kaduna South, Northern Nigeria.
Kano	Billy E. Colson	U.S. Geological Survey, U.S. AID Mission to Nigeria, c/o American Embassy, Lagos, Nigeria.
Maiduguri	G. C. Tibbitts	U.S. Geological Survey, c/o Geological Survey of Nigeria, Maiduguri, Northern Region, Nigeria.
Sokoto	Henry R. Anderson	U.S. Geological Survey, U.S. AID/GSN, P.O. Box 93, Sokoto, Northern Nigeria.
Pakistan, Lahore	Maurice J. Mundorff	U.S. Geological Survey, U.S. AID/L, c/o American Embassy, APO New York 09271.

INVESTIGATIONS IN PROGRESS IN THE GEOLOGIC, WATER RESOURCES, AND CONSERVATION DIVISIONS

Investigations in progress at the end of fiscal year 1965 are listed below, together with the names and headquarters of the individuals in charge of each. Headquarters at main centers are indicated by (W) for Washington, D.C., (D) for Denver, Colo., and (M) for Menlo Park, Calif.; headquarters in other cities are indicated by name (see list of offices, p. A211 for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Washington, D.C. 20242. The lowercase letter following the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division (g, Ground Water Branch; s, Surface Water Branch; q, Quality of Water Branch; h, General Hydrology Branch); no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic of commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or large (for example, 1:62,500; 1:24,000).

Abstracts. See Bibliographies and abstracts.

Analytical chemistry:
- Analytical methods—water chemistry (M. W. Skougstad, q, D)
- Analytical services and research (I. May, W; L. F. Rader, Jr., D; R. E. Stevens, M)
- Electron probe (R. H. Heidel, M)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organic substances—pesticides—in water (W. L. Lamar, w, M)
- Physical chemistry of radioelements (K. W. Edwards, q, D)
- Radioactivation and radiochemistry (F. E. Senftle, W; H. T. Millard, D)
- Rock and mineral chemical analysis (J. J. Fahey, W)
- Rock chemical analysis:
  - General (L. C. Peck, D)
  - Rapid (L. Shapiro, W)
- Trace analysis methods:
  - Development (H. W. Lakin, D)
  - Research (F. N. Ward, D)
- Trace analysis service (F. N. Ward, D)
- See also Spectroscopy.

Artificial recharge:
- Basalt aquifers, Oregon, Salem Heights and The Dalles (B. L. Foxworthy, g, Portland)
- Blended industrial waste, Arizona, Tucson area (W. G. Weist, w, Tucson)
- Treated sewage through an injection well, New York, Bay Park, Long Island (P. Cohen, w, Albany)
- Arkansas, Grand Prairie region (R. T. Sniegocki, w, Little Rock)

Asbestos:
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)
- Arizona, Blue House and McFadden Peak quadrangles (A. F. Shride, D)
- Vermont, north-central (W. M. Cady, D)

Barite:
- Arkansas (D. A. Brobst, D)

Base metals:
- Colorado:
  - Kokomo and Tenmile Range mining district (M. H. Bergendahl, D)
  - Wet Mountains (M. R. Brock, D)
- Montana, Philipsburg area (W. C. Prinz, W)
- Nevada, Antler Peak quadrangle (R. J. Roberts, M)
- Utah, San Francisco Mountains (D. M. Lemmon, M)
- See also base-metal names.

Bauxite:
- Southeastern United States (E. F. Overstreet, W)
- Hawaii, Kauai (S. H. Patterson, W)

Beryllium:
- Western United States, volcanic and associated rocks (D. R. Shawe, D)
- Alaska, Lost River mining district (C. L. Sainsbury, D)
- Colorado:
  - Lake George district (C. C. Hawley, D)
  - Mt. Antero (W. N. Sharp, D)
- Nevada, Mt. Wheeler mine area (D. E. Lee, D)

Bibliographies and abstracts:
- Alaskan geology, index of literature (E. H. Cobb, M)
- Geochemical exploration abstracts (C. B. Davidson, D)
- Hydrology, bibliography (J. R. Randolph, w, W)
- North American geology, bibliography (M. Cooper, W)

Geochemical distribution of the elements--Continued
- Minor elements in volcanic rocks (R. R. Coats, M)
- Organometallic complexes, geochemistry (I. A. Breger, W)
- Sedimentary rocks, chemical composition (H. A. Tourtelot, D)
- Synthesis of ore-mineral data (D. F. Davidson, D)
- California, Sierra Nevada batholith, geochemical study (F. Dodge, M)
- Colorado, Mount Princeton area (P. Toulmin III, W)
- Georgia, biogeochemical reconnaissance (H. T. Shacklette, D)
- Montana, Boulder batholith, petrochemistry (R. I. Tilling, W)
- Nevada, Mt. Wheeler mine area, beryllium distribution (D. E. Lee, M)
- Wisconsin, Driftless area, geochemical survey (H. T. Shacklette, D)

Geochemical prospecting methods:
- Botanical exploration and research (H. L. Cannon, D)
- Dispersion pattern of minor elements related to igneous intrusions (W. R. Griffitts, D)
- Geochemical exploration abstracts (C. Davidson, D)
- Instrument-development laboratory (W. W. Vaughn, D)
- Mineral exploration methods (G. B. Gott, D)
- Mobile spectrographic laboratory (F. N. Ward, D)
- Plant-analysis laboratory (F. N. Ward, D)
- Sulfides, accessory in igneous rocks (G. J. Neuerberg, D)
- Alaska, geochemical prospecting techniques (R. M. Chapman, College)
- Arizona, geochemical halos of mineral deposits (L. C. Huff, Manila, P.I.)
- Maine:
  - Geochemical mapping (E. V. Post, D)
  - The Forks quadrangle (F. C. Canney, E. V. Post, D)
- Michigan, Marquette County (K. Segerstrom, D)
- Nevada, geochemical halos of mineral deposits (R. L. Erickson, D)
- New Mexico, geochemical halos of mineral deposits (L. C. Huff, P.I.)
- Utah, geochemical halos of mineral deposits (R. L. Erickson, D)

Geochemistry, experimental:
- Alkali and alkaline-earth salt systems (E-an Zen, W)
- Environment of ore deposition (P. Toulmin III, W)
- Fluid inclusions in minerals (E. W. Roedder, W)
- Geologic thermometry (E. H. Roseboom, Jr., W)
- Hydrothermal silicate systems (P. Toulmin III, W)
- Hydrothermal solubility (G. W. Morey, W)
- Kinetics of igneous processes (I. Shaw, W)
- Late-stage magmatic processes (G. T. Faust, W)
- Metallic sulfides and sulfosalt systems (P. Toulmin III, W)
- Mineral equilibria, low-temperature (E-an Zen, W)
- Mineral fractionation and trace-element content of fine-grained sedimentary rocks (T. D. Botinelly, D)
- Organic geochemistry (J. G. Palacas, D)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organometallic complexes, geochemistry (I. A. Breger, W)
- Oxygen geothermometry (H. L. James, St. Paul, Minn.)
- Rock weathering and alteration (J. J. Hemley, M)
- Solubility of minerals in aqueous fluids (R. O. Fournier, P. Toulmin III, W)

Geochemistry, experimental--Continued
- Solution-mineral equilibria (C. L. Christ, W)
- Thermodynamic properties of minerals (E. H. Roseboom, Jr., W)

Geochemistry, water:
- Chemistry of atmospheric precipitation (A. W. Gambell, Jr., w, W)
- Geochemical controls of water quality (I. Barnes, w, M)
- Hydrology and geochemistry of the Atlantic Coast Continental Shelf and Slope (R. H. Meade, Jr., F. T. Manheim, w, Woods Hole, Mass.)
- Hydrosolic metals in natural water (J. D. Hem, w, M)
- Mineralogic controls of the chemistry of ground water (B. B. Hanshaw, w, W)
- Minor elements in fresh and saline waters of California, occurrence and distribution (W. D. Silvey, w, Sacramento)
- Radiochemical surveillance (V. J. Janzer, q, D)
- Radioelements, occurrence and distribution in water (R. C. Scott, q, D)
- Solute composition and minor-element distribution in lacustrine closed basins (B. F. Jones, w, W)
- Solute-solid relations in lacustrine closed basins of the alkali-carbonate type (B. F. Jones, w, W)
- Spatial distribution of chemical constituents in ground water (W. Back, w, W)

Geochemistry and petrology, field studies:
- Geochemical sampling and statistical analysis of data (A. T. Miesch, D)
- Geochemistry of minor elements (G. Phair, W)
- Gold, geochemistry and occurrence (J. C. Antweiler, D)
- Green River Formation, mineralogy and geochemistry (C. Milton, W)
- Humates, geology and geochemistry (V. E. Swanson, D)
- Igneous rocks of Southeastern United States (C. Milton, W)
- Inclusions in basaltic rocks (E. D. Jackson, M)
- Jasperoids (T. G. Lovering, D)
- Manganese, geology and geochemistry (D. F. Hewett, M)
- Mercury, geochemistry and occurrence (A. P. Pierce, D)
- Metamorphic rocks and ore deposits (R. C. Erd, M)
- Oceanic volcanics (A. E. J. Engel, La Jolla, Calif.)
- Ore lead, geochemistry and origins (R. S. Cannon, D)
- Pacific Coast basalts, geochemistry (K. J. Murata, M)
- Pierre Shale, chemical and physical properties, Montana, North Dakota, Nebraska, South Dakota, and Wyoming (H. A. Tourtelot, D)
- Rare-earth elements, resources and geochemistry (J. W. Adams, D)
- Sedimentary petrology laboratory (H. A. Tourtelot, D)
- Selenium, resources and geochemistry (D. F. Davidson, D)
- Thermal waters, origin and characteristics (D. E. White, M)
- Titanium, geochemistry and occurrence (N. Herz, W)
- Volcanoes, infrared studies (R. W. Moxham, W)
- Alaska, Katmai National Monument, petrology and volcanism (G. H. Curtis, M)
- California:
  - Burney area (G. A. MacDonald, Honolulu, Hawaii)
  - Coast Range ultramafic rocks (R. A. Loney, M)
  - Franciscan Formation, glaucophane schist (R. G. Coleman, M)
  - Kings Canyon National Park (J. G. Moore, M)
  - Ritter Range, metavolcanic rocks (R. S. Fiske, W)
  - Sierra Nevada batholith, geochemical study (F. Dodge, M)

Geologic mapping--Continued
Map scale smaller than 1 inch to 1 mile--Continued
Nevada--Continued
Nevada Test Site, reconnaissance (F. N. Houser, D)
Nye County:
Northern part (F. J. Kleinhampl, M)
Southern part (H. R. Cornwall, M)
Ormsby County (J. G. Moore, M)
Pershing County (D. B. Tatlock, M)
Ruby Mountains (C. R. Willden, D)
White Pine County (R. K. Hose, M)
New Mexico, geologic map (C. H. Dane, W)
North Carolina:
Knoxville 2-degree quadrangle (J. B. Hadley, W)
Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)
Oregon, geologic map (G. W. Walker, M)
South Carolina, Knoxville 2-degree quadrangle (J. B. Hadley, W)
Tennessee, Knoxville 2-degree quadrangle (J. B. Hadley, W)
Utah, Grand Junction 2-degree quadrangle (W. B. Cashion, D)
Virginia, Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)
Washington:
Grays Harbor basin, regional compilation (H. M. Beikman, M)
Spokane-Wallace region (A. B. Griggs, M)
Wyoming, Preston 2-degree quadrangle (S. S. Oriel, D)
Map scale 1 inch to 1 mile, and larger:
Alabama, Warrior quadrangle (W. C. Culbertson, D)
Alaska:
Project CHARIOT (harbor construction) (G. D. Eberlein, M)
Gulf of Alaska, Tertiary province (G. Plafker, M)
Northeastern part, coastal plain and foothills (C. R. Lewis, W)
Aleutian Islands:
Eastern part (R. E. Wilcox, D)
Western part (R. E. Wilcox, D)
Aleutian Trench – Trinity Island (G. W. Moore, M)
Anchorage – Matanuska Glacier area, surficial geology (T. N. V. Karlstrom, W)
Annette Island (H. C. Berg, M)
Beluga-Yentna area (F. F. Barnes, M)
Bering River coal field (A. A. Wanek, c, Anchorage)
Chitina Valley, lower part, surficial geology (L. A. Yehle, W)
Copper River basin:
Northeastern part, surficial geology (O. J. Ferrians, Jr., W)
Southeastern part, surficial geology (D. R. Nichols, W)
Southwestern part, surficial geology (J. R. Williams, W)
Denali Highway, eastern part, surficial geology (D. R. Nichols, W)
Heceta-Tuxekan area (G. D. Eberlein, M)
Iniskin-Tuxedni region (R. L. Detterman, M)
Johnson River district, surficial geology (H. L. Foster, W)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Alaska--Continued
Katmai National Monument, petrology and volcanism (G. H. Curtis, M)
Lost River mining district (C. L. Sainsbury, D)
Mt. Chamberlain area, surficial geology (C. R. Lewis, W)
Mt. Hayes D-3 and D-4 quadrangles (T. L. Péwé, College)
Mt. Michelson area (E. G. Sable, Elizabethtown, Ky.)
Nenana coal investigations (C. Wahrhaftig, M)
Nome C-1 and D-1 quadrangles (C. L. Hummel, Bangkok, Thailand)
Seward-Portage Railroad, surficial geology (T. N. V. Karlstrom, W)
Slana-Tok area, surficial geology (H. R. Schmoll, W)
Steese Highway area, surficial geology (W. E. Davies, W)
Tanana River, upper part, surficial geology (A. T. Fernald, W)
Taylor Highway area, surficial geology (H. L. Foster, W)
Tofty placer district (D. M. Hopkins, M)
Valdez-Tiekel belt, surficial geology (H. W. Coulter, W)
Windy-Curry area (R. Kachadoorian, M)
Antarctica:
Horlick Mountains (A. B. Ford, W)
Pensacola Mountains (D. L. Schmidt, W)
Arizona:
Benson quadrangle (S. C. Creasey, M)
Blue Horse Mountain quadrangle (A. F. Shride, D)
Bradshaw Mountains (C. A. Anderson, M)
Carrizo Mountains area (J. D. Strobell, D)
Cibecue-Grasshopper area (T. L. Finnell, D)
Cochise County, southern part (P. T. Hayes, D)
Elgin quadrangle (R. B. Raup, D)
Empire Mountains (T. L. Finnell, D)
Gila River basin, upper part (R. B. Morrison, D)
Globe-Miami area (D. W. Peterson, M)
Heber quadrangle (E. J. McKay, D)
Holy Joe Peak quadrangle (M. H. Krieger, M)
Lochiel quadrangle (F. S. Simons, D)
McFadden Peak quadrangle (A. F. Shride, D)
Mammoth quadrangle (S. C. Creasey, M)
Mt. Wrightson quadrangle (H. Drewes, D)
Mustang Mountains (R. B. Raup, D)
Navajo Reservation, fuels potential (R. B. O'Sullivan, D)
Nogales quadrangle (F. S. Simons, D)
Prescott-Paulden area (M. H. Krieger, M)
Ray district, porphyry copper (S. C. Creasey, M)
Show Low quadrangle (E. J. McKay, D)
Twin Buttes area (J. R. Cooper, D)
Winkelman quadrangle (M. H. Krieger, M)
Arkansas:
Northern part, oil and gas investigations (E. E. Glick, D)
Arkansas Basin, coal investigations (B. R. Haley, D)
Ft. Smith district (T. A. Hendricks, D)
California:
Big Maria Mountains (W. B. Hamilton, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Colorado--Continued
Thornburg area (J. R. Dyni, c, D)
Trinidad coal field (R. B. Johnson, D)
Tungsten quadrangle (D. J. Gable, D)
Wet Mountains (M. R. Brock, D)
Woody Creek quadrangle (V. L. Freeman, D)
Connecticut:
Ashaway quadrangle:
Bedrock geology (T. G. Feininger, Boston, Mass.)
Surficial geology (J. P. Schafer, Boston, Mass.)
Ashley Falls quadrangle, construction materials (G. W. Holmes, M)
Bristol quadrangle, bedrock geology (H. E. Simpson, D)
Broad Brook quadrangle (R. B. Colton, W)
Columbia quadrangle, bedrock geology (G. L. Snyder, D)
Danielson quadrangle, bedrock geology (H. R. Dixon, Boston, Mass.)
Durham quadrangle (H. E. Simpson, D)
Fitchville quadrangle, bedrock geology (G. L. Snyder, D)
Hampton quadrangle, bedrock geology (H. R. Dixon, Boston, Mass.)
Manchester quadrangle (R. B. Colton, W)
Marlborough quadrangle, bedrock geology (G. L. Snyder, D)
Meriden quadrangle, bedrock geology (P. M. Hanshaw, Boston, Mass.)
Montville quadrangle, bedrock geology (R. Goldsmith, Boston, Mass.)
Mystic quadrangle, bedrock geology (R. Goldsmith, Boston, Mass.)
New Britain quadrangle, bedrock geology (H. E. Simpson, D)
New Hartford quadrangle (R. W. Schnabel, D)
New London quadrangle (R. Goldsmith, D)
Niantic quadrangle (R. Goldsmith, D)
Old Mystic quadrangle (R. Goldsmith, D)
Plainfield quadrangle, bedrock geology (H. R. Dixon, Boston, Mass.)
Scotland quadrangle, bedrock geology (H. R. Dixon, Boston, Mass.)
Southwick quadrangle (R. W. Schnabel, D)
Springfield South quadrangle (J. H. Hartshorn, C. Koteff, Boston, Mass.)
Tariffville quadrangle:
Bedrock geology (R. W. Schnabel, D)
Surficial geology (A. D. Randall, g, Middletown)
Thompson quadrangle (P. M. Hanshaw, H. R. Dixon, Boston, Mass.)
Tolland Center quadrangle, construction materials (G. W. Holmes, M)
Uncasville quadrangle, bedrock geology (R. Goldsmith, Boston, Mass.)
Voluntown quadrangle, bedrock geology (T. G. Feininger, Boston, Mass.)
Watch Hill quadrangle:
Bedrock geology (G. E. Moore, Jr., Columbus, Ohio)
Surficial geology (J. P. Schafer, Boston, Mass.)
West Springfield quadrangle (R. B. Colton, J. H. Hartshorn, Boston, Mass.)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Connecticut--Continued
Windsor Locks quadrangle, bedrock geology (R. W. Schnabel, D)
District of Columbia, Washington metropolitan area (H. W. Coulter, C. F. Withington, W)
Florida:
Land-pebble phosphate deposits (J. B. Cathcart, D)
Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, W)
Georgia:
Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, W)
Brevard Belt, crystalline rocks (M. Higgins, Atlanta)
Greenland, Schuchert Dal, East Greenland, glacial geology (J. S. Hartshorn, Boston, Mass.)
Idaho:
Central part, radioactive placer deposits (D. L. Schmidt, W)
American Falls region (D. E. Trimble, D)
Aspen Range–Dry Ridge area (V. E. McKelvey, W)
Bancroft quadrangle (S. S. Oriel, D)
Bayhorse area (S. W. Hobbs, D)
Big Creek quadrangle (B. F. Leonard, D)
Clarks Fork quadrangle (J. E. Harrison, W)
Coeur d'Alene mining district (S. W. Hobbs, D)
Doublesprings quadrangle (W. J. Mapel, D)
Driggs NE, SE, and SW quadrangles (M. L. Schroeder, c, D)
Elmira quadrangle (J. E. Harrison, W)
Garns Mountain NW and SW quadrangles (M. H. Staatz, c, D)
Greenacres quadrangle (P. L. Weis, Spokane, Wash.)
Hawley Mountain quadrangle (W. J. Mapel, D)
Leadore quadrangle (E. T. Ruppel, D)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
Mountain City quadrangle (R. R. Coats, M)
Orofino area (A. Hietanen-Makela, M)
Owyhee quadrangle (R. R. Coats, M)
Packsaddle Mountain quadrangle (J. E. Harrison, W)
Palisades Peak quadrangle (D. A. Jobin, c, D)
Palisades Reservoir quadrangle (H. F. Albee, c, D)
Patterson quadrangle (E. T. Ruppel, D)
Pocatello quadrangle (D. E. Trimble, D)
Poker Peak quadrangle (H. F. Albee, c, D)
Riggins quadrangle (W. B. Hamilton, D)
Soda Springs quadrangle (F. C. Armstrong, D)
Upper Valley quadrangle (R. L. Rioux, c, W)
Yellow Pine quadrangle (B. F. Leonard, D)
Indiana, Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Kansas:
Shawnee County (W. D. Johnson, Jr., Owensboro, Ky.)
Wilson County (H. C. Wagner, M)
Kentucky:
Note: The entire State of Kentucky is being mapped geologically by 7½-minute quarangles under a cooperative program with the Kentucky Geological Survey. 141 quadrangles have been published and 208 more are currently in progress. Project is

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Kentucky--Continued
under the supervision of P. W. Richards, Lexington, Ky. The following investigations are separate from the cooperative mapping program:

Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
Eastern part, coal investigations (K. J. Englund, W)
Jellico West quadrangle (K. J. Englund, W)
Ketchen quadrangle (K. J. Englund, W)
Owensboro quadrangle, Quaternary geology (L. L. Ray, W)
Maine:
Paleozoic stratigraphy, regional (R. B. Neuman, W)
Aroostook County, southern (L. Pavlides, W)
Attean quadrangle (A. L. Albee, Pasadena, Calif.)
Big Lake area (D. M. Larrabee, W)
Greenville quadrangle (G. H. Espenshade, W)
Kennebago Lake quadrangle (E. L. Boudette, W)
Moosehead gabbro (G. H. Espenshade, W)
Rangeley quadrangle (R. H. Moench, D)
Rumford quadrangle (R. H. Moench, D)
Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
The Forks quadrangle (F. C. Canney, E. V. Post, D)
Maryland:
Chesapeake Bay area, upper part (J. P. Minard, W)
Washington, D. C., metropolitan area (H. W. Coulter, C. F. Withington, W)
Harford County (D. Southwick, W)
Massachusetts:
Assawompsett Pond quadrangle (C. Koteff, Boston)
Athol quadrangle (D. F. Eschman, Ann Arbor, Mich.)
Billerica quadrangle (R. H. Jahns, University Park, Pa.)
Blue Hills quadrangle (N. E. Chute, Syracuse, N. Y.)
Boston and vicinity (C. A. Kaye, Boston)
Clinton quadrangle, bedrock geology (R. F. Novotny, Boston)
Concord quadrangle (N. P. Cuppels, C. Koteff, Boston)
Duxbury quadrangle (N. E. Chute, Syracuse, N.Y.)
Georgetown quadrangle (N. P. Cuppels, Boston)
Heath quadrangle (A. H. Chidester, D; J. H. Hartshorn, Boston)
Lawrence quadrangle, bedrock geology (R. O. Castle, Los Angeles, Calif.)
Lowell quadrangle (R. H. Jahns, University Park, Pa.)
Norwood quadrangle (N. E. Chute, Syracuse, N.Y.)
Plainfield quadrangle, bedrock geology (P. H. Osberg, Orono, Maine)
Reading quadrangle:
Bedrock geology (R. O. Castle, Los Angeles, Calif.)
Surficial geology (R. N. Oldale, Boston)
Rowe quadrangle (A. H. Chidester, D; J. H. Hartshorn, Boston)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Massachusetts--Continued
Salem quadrangle:
Bedrock geology (P. Toulmin III, W)
Surficial geology (R. N. Oldale, Boston)
Scituate quadrangle (N. E. Chute, Syracuse, N.Y.)
Shrewsbury quadrangle, bedrock geology (R. F. Novotny, Boston)
South Groveland quadrangle, bedrock geology (R. O. Castle, Los Angeles, Calif.)
Southwick quadrangle (R. W. Schnabel, D)
Springfield South quadrangle (J. H. Hartshorn, C. Koteff, Boston)
Taunton quadrangle (J. H. Hartshorn, Boston)
Tyngsboro quadrangle (R. H. Jahns, University Park, Pa.)
West Springfield quadrangle (R. B. Colton, D; J. H. Hartshorn, Boston)
Westford quadrangle (R. H. Jahns, University Park, Pa.)
Wilmington quadrangle, bedrock geology (R. O. Castle, Los Angeles, Calif.)
Michigan:
Dickinson County, southern (R. W. Bayley, M)
Gogebic Range, eastern (W. C. Prinz, W)
Iron County, eastern (K. L. Wier, D)
Iron River–Crystal Falls district (H. L. James, Minneapolis, Minn.)
Lake Algonquin drainage (J. T. Hack, W)
Marenisco - Watersmeet area, iron deposits (C. E. Fritts, D)
Marquette district, eastern (J. E. Gair, D)
Michigan copper district (W. S. White, W)
Negaunee quadrangle (J. E. Gair, D)
Palmer quadrangle (J. E. Gair, D)
Mississippi:
Homochitto National Forest (E. L. Johnson, c, Tulsa, Okla.)
Tatum salt dome (W. S. Twenhofel, D)
Missouri, Lesterville quadrangle (T. H. Kiilsgaard, W)
Montana:
Southwestern part, ore deposits (K. L. Wier, D)
Alberton quadrangle (J. D. Wells, W)
Anaconda NW quadrangle (A. A. Wanek, c, Anchorage, Alaska)
Bearpaw Mountains, petrology (W. T. Pecora, W)
Black Butte quadrangle (A. F. Bateman, Jr., c, Great Falls)
Boulder batholith area (M. R. Klepper, W)
Browning area, Quaternary geology (G. M. Richmond, D)
Cameron quadrangle (J. B. Hadley, W)
Clarks Fork quadrangle (J. E. Harrison, W)
Crazy Mountains Basin (B. A. Skipp, D)
Gardiner SW quadrangle (G. D. Fraser, c, D)
Girard coal field (G. E. Prichard, D)
Great Falls area (R. W. Lemke, D)
Hardy quadrangle (K. S. Soward, c, Great Falls)
Hedstrom area (A. F. Bateman, Jr., c, Great Falls)
Holter Lake quadrangle (G. D. Robinson, D)
Hughesville quadrangle (I. J. Witkind, D)
Jordan (30-minute) quadrangle (G. D. Mowat, c, Great Falls)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Montana--Continued
Livingston-Trail Creek area (A. E. Roberts, D)
Maudlow quadrangle (B. A. Skipp, D)
Montaqua quadrangle (E. D. Patterson, c, W)
Neihart 1 quadrangle (W. R. Keefer, D)
Packsaddle Mountain quadrangle (J. E. Harrison, W)
Philipsburg area, manganese deposits (W. C. Prinz, W)
Powder River coal fields (N. W. Bass, D)
Rocky Reef quadrangle (K. S. Soward, c, Great Falls)
Sun River Canyon area (M. R. Mudge, D)
Tepee Creek quadrangle (I. J. Witkind, D)
Toston quadrangle (G. D. Robinson, D)
Varney quadrangle (J. B. Hadley, W)
Wise River quadrangle (G. D. Fraser, c, D)
Wolf Creek area, petrology (R. G. Schmidt, W)
Wolf Point area (R. B. Colton, D)
Nebraska:
Omaha-Council Bluffs and vicinity (R. D. Miller, D)
Valley County (R. D. Miller, D)
Nevada:
Antler Peak quadrangle (R. J. Roberts, M)
Ash Meadows quadrangle (C. S. Denny, W)
Beatty area (H. R. Cornwall, M)
Bellevue Peak quadrangle (T. B. Nolan, W)
Buffalo Mountain quadrangle (R. E. Wallace, M)
Coaldale area (R. G. Wayland, c, Los Angeles, Calif.)
Cortez quadrangle (J. Gilluly, D)
Crescent Valley quadrangle (J. Gilluly, D)
Ely district (A. L. Brokaw, D)
Eureka quadrangle (T. B. Nolan, W)
Garrison quadrangle (D. H. Whitebread, M)
Horse Creek Valley quadrangle (H. Masursky, M)
Humboldt Range, Unionville and Buffalo Mountain quadrangles (R. E. Wallace, M)
Jiggs quadrangle (C. R. Willden, D)
Kobeh Valley (T. B. Nolan, W; C. W. Merriam, M)
Las Vegas-Lake Mead area (C. R. Longwell, M)
Montello area (R. G. Wayland, c, Los Angeles, Calif.)
Mt. Lewis quwdrangle (J. Gilluly, D)
Mountain City quadrangle (R. R. Coats, M)
Nevada Test Site:
Geologic studies (F. A. McKeown, D)
Pahute Mesa (F. N. Houser, D)
Site studies (R. E. Davis, D)
Owyhee quadrangle (R. R. Coats, M)
Pinto Summit quadrangle (T. B. Nolan, W)
Pioche district (C. M. Tschanz, La Paz, Bolivia)
Railroad district (J. F. Smith, Jr., D)
Schell Creek Range (H. D. Drewes, D)
Snake Range quadrangle (D. H. Whitebread, M)
Sonoma Range, northern, orogenic processes (J. Gilluly, D)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
Unionville quadrangle (R. E. Wallace, M)
Wheeler Peak quadrangle (D. H. Whitebread, M)
New Jersey:
Delaware River basin:
Lower part (J. P. Owens, W)
Middle part (A. A. Drake, Jr., W)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
New Mexico:
Animas River area (H. Barnes, D)
Carrizo Mountains area (J. D. Strobell, D)
Franklin Mountains (R. L. Harbour, D)
Gila River basin, upper part (R. B. Morrison, D)
Grants area (R. E. Thaden, Columbia, Ky.)
Johnson Trading Post quadrangle (J. S. Hinds, c, Farmington)
Laguna district (R. H. Moench, D)
Las Vegas quadrangle, western half (E. H. Baltz, g, Albuquerque)
Manzano Mountains (D. A. Myers, D)
Mesa Portales quadrangle (J. E. Fassett, c, Farmington)
Nash Draw quadrangle (L. M. Gard, D)
Oscura Mountains, southern part (G. O. Brachman, D)
Raton coal basin:
Eastern part (G. H. Dixon, D)
Western part (C. L. Pillmore, D)
San Andres Mountains, northern part (G. O. Bachman, D)
San Juan Basin, east side (C. H. Dane W)
Silver City area (W. R. Jones, D)
Valles Mountains, petrology (R. L. Smith, W)
New York:
Dannemora quadrangle, surficial geology (C. S. Denny, W)
Gouverneur area, metamorphism and origin of mineral deposits (A. E. J. Engel, La Jolla, Calif.)
Mooers quadrangle (A. W. Postel, W)
Ohio quadrangle (A. W. Postel, W)
Plattsburgh quadrangle, surficial geology (C. S. Denny, W)
Richville quadrangle (H. M. Bannerman, W)
North Carolina:
Central Piedmont (H. Sundelius, W)
Franklin quadrangle (F. G. Lesure, W)
Grandfather Mountain (B. H. Bryant, D)
Great Smoky Mountains (J. B. Hadley, W)
Morganton area, geomorphic studies (J. T. Hack, W)
Mount Rogers area (D. W. Rankin, W)
Volcanic Slate series (A. A. Stromquist, D)
North Dakota:
Clark Butte and Clark Butte NE quadrangles (G. D. Mowat, c, Great Falls, Mont.)
Clark Butte NW and SW quadrangles (E. H. Gilmour, c, Great Falls, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, D)
New Salem quadrangle (H. L. Smith, c, D)
North Almont quadrangle (H. L. Smith, c, D)
Oklahoma, Ft. Smith district (T. A. Hendricks, D)
Oregon:
Bandon SE quadrangle (R. G. Wayland, c, Los Angeles, Calif.)
Coquille SW quadrangle (R. G. Wayland, c, Los Angeles, Calif.)
John Day area (T. P. Thayer, W)
Monument quadrangle (R. E. Wilcox, D)
Newport Embayment (P. D. Snavely, Jr., M)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Utah--Continued
Ogden 4 NE quadrangle (T. E. Mullens, c, D)
Ogden 4 NW quadrangle (R. J. Hite, c, D)
Orange Cliffs area (F. A. McKeown, D)
Park City area (M. D. Crittenden, Jr., M)
Park City district (C. S. Bromfield, D)
Phil Pico Mountain quadrangle (J. R. Dyni, c, D)
Promontory Point (R. B. Morrison, D)
Sage Plain area (L. C. Huff, Manila, P.I.)
Salt Lake City and vicinity (R. Van Horn, D)
San Francisco Mountains (D. M. Lemmon, M)
San Rafael Swell (C. C. Hawley, D)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Snake Range, Wheeler Peak and Garrison quadrangles (D. H. Whitebread, M)
Strawberry Valley (A. A. Baker, W)
Tintic lead-zinc district, eastern (H. T. Morris, M)
Uinta Basin, oil shale (W. B. Cashion, D)
Wasatch Mountains (A. A. Baker, W)
Wheeler Peak quadrangle (D. H. Whitebread, M)
Vermont:
North-central part (W. M. Cady, D)
Rowe and Heath quadrangles (A. H. Chidester, D; J. H. Hartshorn, Boston, Mass.)
Virginia:
Appalachian folded belt, southern part (L. D. Harris, W)
Washington, D. C., metropolitan area (H. W. Coulter, C. F. Withington, W)
Big Stone Gap district (R. L. Miller, W)
Herndon quadrangle (R. E. Eggleton, Flagstaff, Ariz.)
Mount Rogers area (D. W. Rankin, W)
Washington:
Bodie Mountain quadrangle (R. C. Pearson, D)
Chewelah 1 quadrangle (L. D. Clark, M)
Cumberland quadrangle (J. D. Vine, M)
Glacier Peak quadrangle (D. F. Crowder, M)
Grays Harbor basin, western part (H. C. Wagner, M)
Grays River quadrangle (E. W. Wolfe, M)
Hobart quadrangle (J. D. Vine, M)
Holden quadrangle (F. W. Cater, D)
Hunters quadrangle (A. B. Campbell, D)
Inchelium quadrangle (A. B. Campbell, D)
Loomis quadrangle (C. D. Rinehart, M)
Lucerne quadrangle (F. W. Cater, D)
Maple Valley, Hobart and Cumberland quadrangles (J. D. Vine, M)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)
Olympic Peninsula:
Eastern part (W. M. Cady, D)
Northern part (R. D. Brown, Jr., W)
Puget Sound Basin (D. R. Crandell, D)
Republic-Curlew area (R. L. Parker, D)
Seattle and vicinity (D. R. Mullineaux, D)
Stevens County (R. G. Yates, M)
Togo Mountain quadrangle (R. C. Pearson, D)
Twin Lakes quadrangle (G. E. Becraft, D)
Wilmot Creek quadrangle (G. E. Becraft, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Wisconsin, Florence County (C. E. Dutton, Madison)
Wyoming:
Arlington quadrangle (H. J. Hyden, c, D)
Atlantic City district (R. W. Bayley, M)
Baggs area (G. E. Prichard, D)
Beartooth Butte quadrangle (W. G. Pierce, M)
Bengough Hill quadrangle (H. J. Hyden, c, D)
Bosler quadrangle (H. McAndrews, c, Salt Lake City, Utah)
Bradley Peak quadrangle (R. W. Bayley, M)
Clark quadrangle (W. G. Pierce, M)
Cokeville quadrangle (W. W. Rubey, Los Angeles, Calif.)
Crowheart Butte area (J. F. Murphy, D)
Deep Lake quadrangle (W. G. Pierce, M)
Devil Slide quadrangle (E. K. Maughan, D)
Devils Tooth quadrangle (W. G. Pierce, M)
Ferris quadrangle (R. L. Rioux, c, W)
Fish Lake quadrangle (W. L. Rohrer, c, D)
Fossil basin (J. I. Tracey, Jr., W)
Four Corners quadrangle (J. A. Van Lieu, Laramie)
Gas Hills district (H. D. Zeller, D)
Grand Teton National Park (J. D. Love, Laramie)
Jackson (30-minute) quadrangle (D. A. Jobin, c, D)
Kisinger Lakes quadrangle (W. L. Rohrer, c, D)
LaBarge 1 SW and 2 SE quadrangles (R. L. Rioux, c, W)
Lake Ione quadrangle (H. McAndrews, c, Salt Lake City, Utah)
Lamont-Baroil area (M. W. Reynolds, D)
McFadden quadrangle (H. J. Hyden, c, D)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Pat O'Hara quadrangle (W. G. Pierce, M)
Pierce Reservoir quadrangle (H. J. Hyden, c, D)
Pilot Knob quadrangle (W. L. Rohrer, c, D)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
Reid Canyon quadrangle (W. H. Laraway, c, Casper)
Rock River quadrangle (H. J. Hyden, c, D)
Shirley Basin area (E. N. Harshman, D)
Spence-Kane area (R. L. Rioux, c, W)
Square Top Butte quadrangle (W. H. Laraway c, Casper)
Sweetwater County, Green River Formation (W. C. Culbertson, D)
T-L Ranch quadrangle (H. J. Hyden, c, D)
Taylor Mountain quadrangle (M. L. Schroeder, c, D)
Tepee Creek quadrangle (I. J. Witkind, D)
Wapiti quadrangle (W. G. Pierce, M)
Wedding of Waters quadrangle (E. K. Maughan, D)
Whalen-Wheatland area (L. W. McGrew, Laramie)
White Rock Canyon quadrangle (H. J. Hyden, c, D)
Wind River Basin, regional stratigraphy (W. R. Keefer, Laramie)
Wind River Mountains, Quaternary geology (G. M. Richmond, D)
Subsurface:
Alabama, hydrogeologic study (W. J. Powell, w, Tuscaloosa)

Geophysics, regional--Continued
- California--Continued
  - Los Angeles basin, gravity study (T. H. McCulloh, Riverside)
  - San Francisco Bay area, geophysical studies (G. D. Bath, M)
  - Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Colorado:
  - Arkansas Valley, geophysical study (J. E. Case, D)
  - Cheyenne Mountain, electrical properties (J. H. Scott, D)
  - Middle Park - North Park basins, geophysical studies (J. C. Behrendt, D)
  - Uncompahgre uplift, northwest portion, geophysical studies and geologic mapping (J. E. Case, D)
- District of Columbia, Eastern Piedmont, geophysical studies (S. K. Neuschel, W)
- Idaho, Snake River Plain, geophysical studies (D. R. Mabey, D)
- Iowa, central, aeromagnetic survey (J. R. Henderson, W)
- Maine:
  - Island Falls quadrangle, electromagnetic mapping (F. C. Frischknecht, W)
  - Stratton quadrangle, geophysical and geologic mapping (A. Griscom, W)
- Maryland, Montgomery County, geophysical studies (A. Griscom, W)
- Massachusetts:
  - Application of geology and seismology to public-works planning (C. R. Tuttle, R. N. Oldale, Boston)
  - Geophysical studies (R. W. Bromery, W)
- Michigan:
  - Gogebic district, aeromagnetic study (J. E. Case, D)
  - Marquette district, aeromagnetic study (J. E. Case, D)
- Minnesota, southern, aeromagnetic survey (I. Zietz, W)
- Mississippi, Tatum salt dome (W. S. Twenhofel, D)
- Missouri, southeast, aeromagnetic study (J. W. Allingham, W)
- Montana:
  - Bearpaw Mountains, aeromagnetic study (K. G. Books, W)
  - Boulder batholith, aeromagnetic and gravity studies (W. E. Davis, M)
- Nevada:
  - Central part, geophysical studies (D. R. Mabey, D)
  - Armagosa Desert, gravity surveys (R. G. Bates, D)
  - Clark County, gravity investigations (M. F. Kane, W)
  - Nevada Test Site, aeromagnetic surveys (J. W. Allingham, W)
- New Jersey:
  - Gettysburg–Newark Basin, geophysical investigations (M. E. Beck, W)
  - New York–New Jersey Highlands, aeromagnetic studies (A. Jespersen, W)
- New Mexico, Valles caldera, geophysical study (H. R. Joesting, W)
- New York:
  - Adirondacks area, aeromagnetic studies (J. R. Balsley, Middletown, Conn.)
  - New York–New Jersey Highlands, aeromagnetic studies (A. Jespersen, W)
- North Carolina, Concord quadrangle, geophysical studies (R. G. Bates, W)
- Ohio, seismic survey for buried valleys (J. S. Watkins, Flagstaff, Ariz.)

Geophysics, regional--Continued
- Oregon Cascades, geophysical study (H. R. Blank, M)
- Pennsylvania:
  - Gettysburg–Newark Basin, geophysical investigations (M. E. Beck, W)
  - Gravity survey (R. W. Bromery, W)
  - Triassic area, aeromagnetic study (R. W. Bromery, W)
- Puerto Rico, geophysical studies (A. Griscom, W)
- South Dakota, Hills area, regional gravity studies (R. M. Hazelwood, D)
- Texas, coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
- Utah:
  - Iron Springs, aeromagnetic survey (H. R. Blank, M)
  - Sheeprock Mountains, West Tintic district (D. R. Mabey, D)
  - Uncompahgre uplift, northwest portion, geophysical studies and geologic mapping (J. E. Case, D)
- Washington:
  - Northeastern part, geophysical studies (W. T. Kinoshita, M)
  - Western part, gravity survey (D. J. Stuart, D)
- Wisconsin, Florence County, aeromagnetic study (E. R. King, W)
- Wyoming:
  - Anchor Reservoir, gravity survey (G. P. Eaton, D)
  - Black Hills area, regional gravity studies (R. A. Black, W)
  - Bradley Peak area (D. R. Mabey, D)
  - Jackson Hole region, geophysical studies (D. R. Mabey, D)
  - Mowry Shale and Frontier Formation, geophysical studies (G. P. Eaton, D)

Geophysics, theoretical and experimental:
- Borehole geophysics as applied to geohydrology (W. S. Keys, h, D)
- Earthquake - explosion effects (V. R. Wilmarth, W)
- Earthquakes, local seismic studies (J. P. Eaton, D)
- Elastic and inelastic properties of earth materials (L. Peselnick, W)
- Electric and magnetic properties of minerals (A. N. Thorpe, W)
- Electrical methods, development (C. J. Zablocki, D)
- Electrical properties of rocks (G. V. Keller, D)
- Electromagnetic radiation studies (W. A. Fischer, W)
- Geophysical data, interpretation using electronic computers (R. G. Henderson, W)
- Geothermal studies (A. H. Lachenbruch, M)
- Gravity and magnetic anomalies, analysis (W. H. Diment, W)
- Heat flow in the Appalachian Mountains (W. H. Diment, W)
- Heat transfer in salt (E. C. Robertson, W)
- Infrared and ultraviolet radiation studies (R. M. Moxham, W)
- Magnetic and luminescent properties (F. E. Senftle, W)
- Magnetic model studies (G. E. Andreasen, W)
- Magnetic properties of crystals (A. N. Thorpe, W)
- Magnetic properties of rocks (A. Griscom, W)
- Radon, geologic behavior (A. B. Tanner, W)
- Remanent magnetization of rocks (R. R. Doell, M)
- Rock behavior at high temperature and pressure (E. C. Robertson, W)
- Tension fractures and thermal investigation (A. H. Lachenbruch, M)

Radioactive-waste disposal--Continued
Hydrogeologic studies:
National Reactor Testing Station, Idaho (D. A. Morris, g, Boise)
Oak Ridge Reservation, Tenn. (W. M. McMaster, w, Chattanooga)
Savannah River Plant, S. C. (I. W. Marine, G. E. Siple, g, Columbia)
Laboratory investigations (C. R. Naeser, W)
Nuclear-irradiation studies (C. M. Bunker, D)
Waste-contamination studies, Los Alamos, N. Mex. — ground water (W. D. Purtyman, g, Albuquerque)
Rare-earth metals. See Minor elements.
Regional studies and compilations, large areas of the United States:
Basement-rock map of the United States (R. W. Bayley, M)
Geologic map of the United States (P. B. King, M)
Geologic map of the United States between lats 35° N and 39° N, scale 1:1,000,000 (C. R. Willden, D)
Gravity map of the United States (H. R. Joesting, W)
Military intelligence studies (M. M. Elias, W)
National Atlas, water-resources section (H. E. Thomas, g, M)
Paleotectonic-map folios:
Mississippian System (L. C. Craig, D)
Pennsylvanian System (E. D. McKee, D)
Permian System (E. D. McKee, D)
Sino-Soviet terrain atlas (M. M. Elias, W)
Rhenium. See Minor elements and Ferro-alloy metals.
Saline minerals:
Colorado and Utah, Paradox basin (O. B. Raup, D)
New Mexico, Carlsbad potash and other saline deposits (C. L. Jones, M)
Wyoming, Sweetwater County, Green River Formation (W. C. Culbertson, D)
Sea-water intrusion:
Salt-water intrusion in coastal streams (T. H. Woodard, w, Raleigh, N. C.)
Connecticut and New York, recognition of late glacial substages in coastal areas (J. E. Upson, w, W)
Delaware River basin, lower part (D. McCartney, q, Philadelphia, Pa.)
Florida:
Dade County and city of Miami (H. Klein, w, Tallahassee)
Everglades National Park, estuaries (K. A. MacKichan, w, Ocala)
Miami River (S. D. Leach, w, Ocala)
Georgia:
Brunswick area (R. L. Wait, w, Atlanta)
Savannah area (H. B. Counts, w, Atlanta)
Sedimentation:
Effect of sedimentation on the propagation of trout in small streams, Montana (A. R. Gustafson, q, Worland, Wyo.)
Evaluation of dependent and independent variables with respect to sediment transport and resistance to flow in alluvial channels (H. P. Guy, h, Fort Collins, Colo.)
Fall velocity of fluvial sediment particles as affected by size, shape, density, concentration, and turbulence (H. P. Guy, h, Fort Collins, Colo.)
General studies of erosion and sedimentation and evaluation of erosion-control practices (N. J. King, w, D)

Sedimentation--Continued
Some sedimentation characteristics of a sand-bed stream (D. M. Culbertson, w, Lincoln, Nebr.)
Sources, movement, and distribution of sediment in a small watershed (M. G. Wolman, w, Baltimore, Md.)
Statistical analysis of ripples, dunes, and antidunes (C. F. Nordin, Jr., h, Fort Collins, Colo.)
Transport properties of natural clays (R. G. Wolff, w, W)
California, Eel and Mad River basins, sediment transport (G. Porterfield, w, Sacramento)
Colorado, Kiowa Creek, fluvial sedimentation and runoff (R. Brennan, q, D)
Indiana, reconnaissance of sediment yields in streams (R. F. Flint, w, Columbus, Ohio)
Kansas, Little Blue River basin, fluvial sediment and quality of water (J. C. Mundorff, w, Lincoln, Nebr.)
Missouri, St. Louis, special sediment investigations at Mississippi River (C. H. Scott, w, Lincoln, Nebr.)
Nebraska:
Little Blue River basin, fluvial sediment and quality of water (J. C. Mundorff, w, Lincoln)
Medicine Creek basin, erosion and deposition (J. C. Brice, w, Lincoln)
New Jersey:
Sediment reconnaissance, coastal plain streams (D. W. Moody, w, Philadelphia, Pa.)
Stony Brook watershed, fluvial sedimentation (J. R. George, q, Harrisburg, Pa.)
North Carolina, upper Yadkin River basin, sediment yield (H. E. Reeder, q, Raleigh)
Oregon:
Alsea River basin, sedimentation in forested drainage areas (R. C. Williams, q, Portland)
Fluvial sediment transport (R. C. Williams, q, Portland)
Sediment-transport characteristics of certain streams (R. C. Williams, q, Portland)
Pennsylvania:
Statewide studies (J. R. George, q, Harrisburg)
Bixler Run watershed, hydrology and sedimentation (B. L. Jones, q, Harrisburg)
Corey Creek and Elk Run watershed (B. L. Jones, q, Harrisburg)
Susquehanna River basin, fluvial sediment reconnaissance (J. R. George, q, Harrisburg)
Texas:
Reconnaissance sediment investigations (C. T. Welborn, w, Austin)
Upper Trinity River basin, sedimentation (C. H. Hembree, w, Austin)
Washington:
Chehalis River basin, sedimentation (P. A. Glancy, w, Tacoma)
Palouse River basin, fluvial sediment transport (P. R. Boucher, w, Pasco)
Walla Walla River basin, fluvial sediment transport (B. E. Mapes, w, Pasco)
Wisconsin, reconnaissance sediment investigations (C. R. Collier, w, Columbus, Ohio)
Wyoming, Wind River Basin, sediment transport (D. C. Dial, q, Worland)
See also Geomorphology and Quality of water.

Water resources--Continued
Kansas (Lawrence)--Continued
Ground water--Continued
Finney County (W. R. Meyer, g)
Hamilton County (W. R. Meyer, g)
Jefferson County (J. D. Winslow, g)
Johnson County (H. G. O'Connor, g)
Kearny County (W. R. Meyer, g)
Labette County (W. L. Jungmann, g)
Linn County (W. J. Seevers, g)
Montgomery County (H. G. O'Connor, g)
Neosho County (W. L. Jungmann, g)
Pratt County (D. W. Layton, g)
Republican River valley (S. W. Fader, g)
Rush County (J. McNellis, g)
Walnut River basin (J. M. McNellis, g)
Kentucky (Louisville):
Ground water:
Jackson Purchase area (R. W. Davis, g)
Louisville area (E. A. Bell, g)
Ohio River, alluvial terraces (W. E. Price, J. T. Gallaher, g)
Quality of surface and ground water — statewide inventory (R. J. Pickering, q, Columbus, Ohio)
Water resources:
Bell County, upper Yellow Creek basin (D. S. Mull, g)
Mammoth Cave area (R. V. Cushman, g)
Louisiana (Baton Rouge):
Floods, southeastern Louisiana — rainfall-runoff relations (A. J. Calandro, s)
Ground water:
Avoyelles Parish (J. R. Marie, g)
Gramercy area (D. G. Moore, Jr., g)
Greater New Orleans area (J. R. Rollo, g)
Lower Red River valley (M. S. Bedinger, w, Little Rock, Ark.)
Norco area (P. B. Bieber, g)
Surface water:
Southeastern Louisiana, unit-hydrograph studies (V. B. Sauer, s)
Southwestern Louisiana, unit-hydrograph studies (V. B. Sauer, s)
Water resources:
Southwestern part (A. H. Harder, g; S. M. Rogers, q)
Lake Pontchartrain study (G. T. Cardwell, g)
Ouachita Parish (J. E. Rogers, g)
Plaquemine–White Castle area (C. D. Whiteman, Jr., g)
Pointe Coupee Parish (M. D. Winner, Jr., g)
Maine (Augusta):
Ground water:
Coastal area of southwestern Maine (G. C. Prescott, g)
Lower Androscoggin basin (G. C. Prescott, g)
Lower Penobscot basin (G. C. Prescott, g)
Maryland (w, Baltimore):
Ground water:
Baltimore County, use of ground water (C. P. Laughlin)
Chesapeake and Ohio Canal (E. G. Otton)
Susquehanna River basin (P. R. Seaber, g, Harrisburg, Pa.)

Water resources--Continued
Maryland (w, Baltimore)--Continued
Water resources:
Dorchester and Talbot Counties (F. K. Mack)
Georges Creek basin, a corner of Appalachia (D. O'Bryan, J. W. Crooks, W)
Patuxent River basin (J. W. Crooks, D. O'Bryan, w, W)
Salisbury area (D. H. Boggess)
Massachusetts (w, Boston):
Ground water:
Highway salt, ground-water contamination from (R. G. Petersen)
Assabet River basin (S. J. Pollock)
Boston, central area (W. N. Palmquist)
Cape Cod National Seashore (R. G. Petersen)
Lower Merrimack valley (J. E. Cotton)
Parker and Rowley Rivers drainage basins (E. A. Sammel)
Ten Mile–North Taunton Rivers basin (J. R. Williams)
Water resources:
Connecticut River basin (D. J. Cederstrom)
Housatonic River basin (R. F. Norvitch)
Millers River basin (M. R. Collings)
Michigan (w, Lansing):
Ground water:
Dickinson County (G. E. Hendrickson)
Kalamazoo County (J. B. Miller)
Tri-County area (K. E. Vanlier)
Surface water, North Branch Clinton River basin (R. G. Knutilla)
Water resources:
Branch County (L. E. Stoimenoff)
Grand River basin (K. E. Vanlier)
Marquette Iron Range (S. W. Wiitala)
Minnesota (St. Paul):
Ground water:
Grand Rapids area (E. L. Oakes, g)
Kittson, Marshall, and Roseau Counties (G. R. Schiner, g)
Hydrology, Twin Cities metropolitan area, Anoka, Carver, Dakota, Goodhue, Hennepin, Ramsey, Scott, and Washington Counties (H. O. Reeder, g)
Water-resources reconnaissance of watershed units:
Chippewa River Unit, Chippewa, Douglas, Grant, Kandiyohi, Otter Tail, Stearns, and Stevens Counties (R. D. Cotter, g)
Lac qui Parle River unit, Lac qui Parle, Lincoln, and Yellow Medicine Counties (R. D. Cotter, g)
Mississippi Headwaters unit, Aitkin, Becker, Beltrami, Carlton, Cass, Clearwater, Crow Wing, Hubbard, Itasca, and St. Louis Counties (E. L. Oakes, g)
Pomme de Terre River unit, Big Stone, Chippewa, Douglas, Grant, Otter Tail, Stevens, and Swift Counties (R. D. Cotter, g)
Roseau River unit, Beltrami, Kittson, Lake of the Woods, Marshall, and Roseau Counties (T. C. Winter, g)
Two Rivers unit, Kittson, Marshall, and Roseau Counties (R. W. Maclay, g)

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  - Mississippi (w, Jackson):
    - Geology and ground water:
      - Big Black River basin (B. E. Wasson)
      - Pascagoula River basin (R. Newcome, Jr.)
      - Pearl River basin (J. W. Lang)
    - Ground water:
      - Hancock County, National Aeronautics and Space Administration Test Facility (R. Newcome, Jr.)
      - Pearl River basin, middle part (R. E. Taylor)
    - Water resources:
      - Clay, Lowndes, Monroe, and Oktibbeha Counties (B. E. Wasson)
      - Forrest, Green, Jones, Perry, and Wayne Counties (B. E. Wasson)
      - Harrison and Stone Counties (R. Newcome, Jr.)
  - Missouri (Rolla):
    - Joplin area (E. J. Harvey, g)
    - White River basin (G. M. Hogenson, w, Little Rock, Ark.)
  - Montana (Billings):
    - Ground water:
      - Cedar Creek anticline, west flank (O. J. Taylor, g)
      - Deer Lodge Valley (R. L. Konizeski, g)
      - Glacier and Toole Counties, Cut Bank area (E. A. Zimmerman, g)
      - Lower Bighorn River valley, Hardin Unit (L. J. Hamilton, g)
      - Missouri River bottoms, northeast Montana (W. B. Hopkins, g)
      - Ravalli County, Bitterroot Valley (R. G. McMurtrey, g)
    - Hydrology, Hungry Horse Reservoir (M. I. Rorabaugh, W. D. Simons, w, Tacoma, Wash.)
  - Nebraska (w, Lincoln):
    - Geology and hydrology, Saline County (P. A. Emery)
    - Ground water:
      - Adams County (C. F. Keech)
      - Box Butte County, water-level fluctuations (C. F. Keech)
      - Fillmore County (C. F. Keech)
      - York County (C. F. Keech)
  - Nevada (w, Carson City):
    - Humboldt River valley, reconnaissance (T. E. Eakin, R. D. Lemke)
    - Ground water:
      - Antelope Valley (F. E. Rush)
      - Carico Lake valley (D. E. Everett)
      - Eagle Valley (G. F. Worts, Jr.)
      - Eldorado Valley (F. E. Rush)
      - Grass Valley (P. Cohen)
      - Huntington Valley (F. E. Rush, D. O. Moore)
      - Kings River valley (G. T. Malmberg)
      - Kobeh Valley (F. E. Rush)
      - Lovelock area (D. E. Everett, F. E. Rush)
      - Monitor Valley (F. E. Rush)
      - Pahrump Valley (G. T. Malmberg)
      - Piute Valley (F. E. Rush)
      - Quinn River valley (C. J. Huxel, Jr.)
      - Reese River balley, upper part (F. E. Rush)
      - Spring Valley (F. E. Rush)
      - Snake Valley (J. W. Hood, F. E. Rush)
      - Steptoe Valley (T. E. Eakin, D. O. Moore, D. E. Everett)

- Water resources--Continued
  - Nevada (w, Carson City)--Continued
    - Ground water--Continued
      - Washoe Valley (G. F. Worts, Jr.)
      - White River valley system (T. E. Eakin)
    - Surface-water resources, statewide (R. D. Lamke, D. O. Moore)
  - New Hampshire (w, Boston, Mass.):
    - Ground water:
      - Ashuelot River basin (J. M. Weigle)
      - Lower Merrimack River basin (J. M. Weigle)
    - Water resources, Connecticut River basin (D. J. Cederstrom)
  - New Jersey (Trenton):
    - Drought in the Delaware River basin (J. E. McCall, s)
    - Geohydrology, Raritan-Magothy aquifer system (H. E. Gill, D. Langmuir, g)
    - Ground water:
      - Water-level fluctuations, 1963-67 (C. R. Austin, g)
      - Camden County (E. Donsky, g)
      - Cumberland County (J. G. Rooney, g)
      - Essex County (W. D. Nichols, g)
      - Hackensack River basin (L. D. Carswell, g)
      - Ocean County (H. R. Anderson, g)
      - Pine Barrens (E. C. Rhodehamel, g)
      - Wharton Tract (E. C. Rhodehamel, g)
  - New Mexico (Albuquerque):
    - Miscellaneous activities under the New Mexico State Engineer program (L. V. Davis, g)
    - State Planning Office Report (g):
      - Pt. 1 – Arkansas River basin (W. C. Ballance)
      - Pt. 2 – Southern High Plains (W. C. Ballance)
      - Pt. 3 – Pecos River basin (W. A. Mourant)
      - Pt. 4 – Central closed basins (F. B. Titus, Jr.)
      - Pt. 5 – Rio Grande basin (G. A. Dinwiddie)
      - Pt. 6 – Western closed basins (J. B. Cooper)
      - Pt. 7 – San Juan River basin (J. B. Cooper, F. D. Trauger)
      - Pt. 8 – Lower Colorado River basin (F. D. Trauger)
      - Pt. 9 – Southwestern closed basins (G. C. Doty)
    - Ground water:
      - Water levels and artesian pressure in observation wells in New Mexico (F. E. Busch, g)
      - Eddy County:
        - Major Johnson Springs aquifer, evaluation of hydraulic characteristics (R. L. Cushman, g)
        - Malaga Bend area, evaluation of pumping effects (E. R. Cox, g)
      - Grant County (F. D. Trauger, g)
      - Guadalupe County (A. Clebsch, Jr., G. A. Dinwiddie, g)
      - Luna County, southern (G. C. Doty, g)
      - McMillan delta area (J. S. Havens, g)
      - Manzano Mountains area (F. B. Titus, g)
      - Quay County (W. A. Mourant, g)
      - Roswell basin:
        - Chaves County, well drilling and testing (G. E. Maddox, g)
        - Chaves and Eddy Counties, quantitative analysis of the ground-water system (G. E. Maddox, g)
      - Sandia Mountains area (F. B. Titus, g)
      - White Sands Missile Range, reconnaissance, ground-water resources at selected sites (G. C. Doty, g)

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- New Mexico (Albuquerque)--Continued
  - Ground water--Continued
    - White Sands Missile Range Headquarters well field, reappraisal (W. C. Ballance, g)
  - Water resources, Los Alamos (E. C. John, g)
- New York (w, Albany):
  - Ground water:
    - Nassau County (J. Isbister)
    - Orange County (M. H. Frimpter)
    - Queens County (J. Soren)
    - Rensselaer County, Schodack terrace (H. Stewart)
    - Suffolk County, mid-island area (J. Soren)
    - Susquehanna River basin (P. R. Seaber, g, Harrisburg, Pa.)
    - Syracuse area (I. H. Kantrowitz)
    - Ulster County (M. H. Frimpter)
  - Surface water:
    - Gazetteer of streams (F. L. Robison)
    - Statewide resources (J. C. Kammerer)
    - Susquehanna River basin, fluvial sediment (A. D. Randall)
  - Water resources:
    - Genesee River basin (B. K. Gilbert)
    - Lake Erie–Niagara area (A. L. LaSala)
    - Western Oswego River basin (W. J. Shampine)
- North Carolina (w, Raleigh):
  - Stream sanitation and water supply of State (G. C. Goddard)
  - Ground water:
    - Cape Hatteras National Park, quality of ground water (H. B. Wilder)
    - Chowan County (O. B. Lloyd, Jr.)
    - Craven County (E. O. Floyd)
    - New Hanover County (G. Bain)
    - Pitt County (C. T. Sumsion)
  - Surface water:
    - Interpretation of surface-water data (G. C. Goddard)
    - Neuse River headwaters, surface-water resources (G. C. Goddard, J. F. Turner, Jr.)
- North Dakota (Grand Forks):
  - Flood characteristics of streams at selected sites (O. A. Crosby, s, Bismarck)
  - Ground water:
    - Barnes County (T. E. Kelly, g)
    - Burleigh County (P. G. Randich, g)
    - Cass County (R. L. Klausing, g)
    - Divide County (C. A. Armstrong, g)
    - Eddy and Foster Counties (H. Trapp, g)
    - Grand Forks County (T. E. Kelly, g)
    - Minot area, artificial recharge (D. L. Hills, g)
    - Renville County (W. A. Pettyjohn, g)
    - Richland County (C. H. Baker, Jr., g)
    - Stutsman County (C. J. Huxel, g)
    - Ward County (W. A. Pettyjohn, q)
    - Wells County (P. G. Randich, g)
    - Williams County (E. A. Ackroyd, g)
- Ohio (w, Columbus):
  - Flood characteristics of streams at selected sites (E. E. Webber)
  - Ground water:
    - Northeastern part, principal aquifers (J. L. Rau)
    - Lower Miami River basin (A. M. Spieker)
    - Lancaster municipal well field (S. E. Norris)

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- Oklahoma (Oklahoma City):
  - Special investigations and reports (P. R. Wood, g)
  - Ground water:
    - Fresh ground-water zone, thickness (D. L. Hart, Jr., g)
    - Arkansas River valley, eastern part of State (M. S. Bedinger, w, Little Rock, Ark.)
    - Arkansas and Verdigris River valleys (H. H. Tanaka, g)
    - Cleveland and Oklahoma Counties, Garber Sandstone and Wellington Formation (P. R. Wood, g)
    - Lower Red River valley (M. S. Bedinger, w, Little Rock, Ark.)
    - Woodward County (P. R. Wood, g)
  - Quality of water, upper Arkansas River basin (R. P. Orth, q)
- Oregon (Portland):
  - Abert Lake and other closed-basin lakes, hydrology and geochemistry (A. S. Van Denburgh, q)
  - Ground water:
    - Eola–Amity Hills area (D. Price, g)
    - French Prairie area (D. Price, g)
    - Molalla–Salem slope area (E. R. Hampton, g)
- Pennsylvania (g, Harrisburg; q, s, Philadelphia):
  - Ground water:
    - Chester County, metamorphic and igneous rocks (C. W. Poth, g)
    - Lancaster County, carbonate rocks (H. Meisler, g)
    - Loysville quadrangle (H. E. Johnston, g)
    - Luzerne County, Wyoming Valley (J. R. Hollowell, g)
    - Mifflintown quadrangle (H. E. Johnston, g)
    - Monogahela River basin (B. M. Wilmoth, g)
    - New Oxford Formation (H. E. Johnston, g)
    - Susquehanna River basin (P. R. Seaber, g)
  - Quality of water:
    - Brandywine Creek basin, water-quality reconnaissance (A. N. Ott, q, Harrisburg)
    - Lehigh River basin, chemical quality (S. D. Faust, q)
    - Neshaminy Creek basin, chemical quality of surface waters (B. A. Malo, q)
  - Surface water, Philadelphia area, hydrology of streams (E. L. Smith, s)
  - Water resources, Schuylkill River basin (J. E. Biesecker, q)
- Puerto Rico (w, San Juan):
  - Salinity reconnaissance and monitoring system, south coast (J. R. Díaz)
  - Water resources, Ponce area (N. E. McClymonds)
- Rhode Island (w, Providence):
  - Ground water, Potowomut-Wickford area (J. Rosenshein)
- South Carolina (Columbia):
  - Ground water:
    - Coastal plain:
      - Northeastern part, geology and ground-water resources (G. E. Siple, g)
      - Subsurface geology and hydrology (G. E. Siple, g)
    - Greenville County, geology and ground-water resources (N. C. Koch, g)
    - Leesville area, potential sand aquifers (G. E. Siple, W. D. Paradeses, g)

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Indexes to topographic-map coverage of the various States and Guam and American Samoa are released periodically and are free on application. The release of revised indexes is announced in the monthly list of new publications of the Geological Survey. Each State index shows the areas mapped, with listings of special and United States maps, and gives lists of Geological Surveys offices from which maps may be purchased and also of local agents who sell the maps.

Advance material available from current topographic mapping is indicated on quarterly releases of State index maps. This material, including such items as aerial photography, geodetic-control data, and preliminary maps in various stages of preparation and editing, is available for purchase. Information concerning the ordering of these items is given on the quarterly issues. Requests for indexes or inquiries concerning availability of advance materials should be directed to the MAP INFORMATION OFFICE, GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Surface-water records of [State]

Pending publication of surface-water records at 5-year intervals in the Water-Supply Paper series on the basis of drainage basins, streamflow records and related data are being released in annual reports on the basis of State boundaries. Distribution of these basic-data reports, which are free on request, is limited and primarily for local needs. Those interested should write to the GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242, specifying the State or States for which records are needed.

State water-resources investigations folders

A series of 8- by 10½-inch folders entitled "Water Resources Investigations in [State]" is a project of the Water Resources Division to inform the public about its current program in the 50 States and Puerto Rico, and Guam and American Samoa. As the State programs change, the folders are revised. Folders for all 50 States and Puerto Rico are available free on request to the GEOLOGICAL SURVEY, WASHINGTON, D.C. 20242.

Open-file reports

Open-file reports include unpublished manuscript reports, maps, and other material made available for public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date and places of availability for consultation by the public are given in press releases or other forms of public announcement. In general, open-file reports are placed in one or more of the three Geological Survey libraries: ROOM 1033, GENERAL SERVICES BLDG., WASHINGTON, D.C.; BLDG. 25, FEDERAL CENTER, DENVER, COLO.; and 345 MIDDLEFIELD ROAD, MENLO PARK, CALIF. Other depositories may include one or more of the Geological Survey offices listed on pages A211 to A215, or interested State agencies. Many open-file reports are replaced later by formally printed publications.

CONTENTS OF GEOLOGICAL SURVEY RESEARCH 1965, CHAPTERS B, C, AND D

Listed below are the contents of Professional Papers 525–B, –C, and –D, comprising 128 articles, many of which are cited in the preceding pages. References to chapters B, C, and D are given in the test in the following form: Pakiser (p. B1–B8); the chapter is identified by the letter preceding the page number.

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CHAPTER D

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CHAPTER D

PUBLICATIONS IN FISCAL YEAR 1965

A complete list of abstracts, papers, reports, and maps (exclusive of topographic maps) by U.S. Geological Survey authors published or otherwise released to the public during fiscal year 1965 (July 1, 1964–June 30, 1965) is given below. Publications are listed alphabetically by senior author. Each citation is identified by a number: for example, 1–64, which indicates the first entry for that author for 1964. The number is followed by the names of coauthors and the citation itself. References to this list are identified in the preceding text by author and serial number: for example, Adams and Boggess (1–64).

The list also includes some publications that were not listed in either Professional Papers 475–A or 501–A.

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