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B, Descriptive Geology, 65 }

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY

OF THE

TONOPAH MINING DISTRICT, NEVADA

BY

JOSIAH EDWARD SPURR

18

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CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., March 27, 1905.

SIR: I transmit herewith the manuscript of a report on the Geology of the Tonopah Mining District of Nevada, by J. E. Spurr, and recommend its publication as a professional paper.

The geological problem presented in this district is one that could not have been solved except by a trained petrographer, since the igneous rocks that carry the vein deposits have been largely covered by practically barren flows of more recent eruptives; hence the very careful and thorough study of the district made by Mr. Spurr can hardly fail to be of great practical value to the miner, as well as of scientific interest to the student of ore deposits.

Very respectfully,

S. F. EMMONS,
Geologist in Charge of Section of Metalliferous Deposits.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

R. U. Goode, Geographer in charge.
Triangulation by U. S. Coast and Geodetic Survey.
Topography by W. J. Peters.
Surveyed in 1902-1903.

TOPOGRAPHIC MAP OF TONOPAH MINING DISTRICT, NEVADA

A. HOEN & CO. BALTIMORE.

Scale

0 1/8 1/4 1/2 3/4 1 Mile

1000 500 0 1000 2000 3000 5000 Feet

200 100 0 500 1000 Meters

Contour interval 20 feet

Datum is mean sea level

Altitudes based on U. S. C. and G. S. determination of Lone Mountain

1904

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OUTLINE OF PAPER.

Ore deposits were discovered in the Tonopah mining district, Nevada, in April, 1900, by James L. Butler. The town of Tonopah soon had a population of several thousand. The climate is arid and the water supply scanty.

The rocks of the mining district are all of immediate volcanic origin, with the exception of a series of water-laid tuffs, which represent the accumulations of fine volcanic detritus in a Tertiary lake. All the rocks are of Tertiary age, probably Miocene-Pliocene.

The first eruptions of this volcanic epoch, as displayed at Tonopah, were andesite. Two andesites have been distinguished—the younger or earlier andesite and the later andesite, which is slightly more basic than the earlier andesite. Subsequently rhyolite and dacite eruptions occurred at intervals for a long time and produced several of the formations mapped, which include tuffs and flows. The rhyolite and dacites are closely connected in every way. In one of the latest periods of eruption these lavas produced the volcanoes whose necks, left in relief by the erosion of the surrounding softer material, now form the hills around Tonopah.

The water-laid fine tuffs were deposited in this rhyolite-dacite volcanic epoch at a time when the eruptions had ceased temporarily. The lake basin may have been formed by a sinking of the crust consequent upon the long-continued volcanic outpourings. The epoch of the deposition of the lake beds was closed by an uplift accompanied by regional tilting. A little basalt was then thrown out from volcanic vents, and cones of agglomeratic dacitic material were formed, whose once liquid necks are now represented by the isolated hills.

The area occupied by the dacitic volcanic necks is coextensive with the region of observed complicated faulting. Study leads to the conclusion that this faulting was initiated chiefly by the intrusion of these necks. After the intrusion and subsequent eruption there was a collapse, a sinking of the various vents. The still liquid lava in sinking dragged down with it adjacent blocks of the intruded rock.

The silica content of the lavas shows a fairly regular transition between the different types, but there is a marked break in general composition between the andesite-basalts on the one hand and the rhyolite-dacites on the other. In some of the most siliceous rhyolites there appear to be numerous pseudomorphs after hornblende, which consist of fresh rhyolitic groundmass and indicate that the hornblende had been dissolved and replaced by the magma. In the dacitic phases of the rhyolite-dacite fresh hornblende is occasionally found. In the andesites, especially the earlier phase, hornblende is abundant. In the basalt there is abundant hornblende, but it is often pseudomorphosed by magmatic action into aggregates marked by crystals of iron oxide. It is concluded that in both the highly siliceous (rhyolitic) and in the least siliceous (basaltic) magmas, hornblende was developed as a first crystallization, which was unsuited to later conditions. A change of magmatic composition since the first crystallization is inferred, and the original magma is thought to have been intermediate or andesitic. This theory of magmatic segregation is tested by comparison of analyses, and bears the test well. The theory is reached that an original magma of composition similar to that of the earlier andesite has split up by differentiation, first into more basic andesite (later andesite) and siliceous dacite, and later, by a continuation of the process, into siliceous rhyolite and basalt.

The structure is so complicated that no general cross sections have been made. Some interesting information on faulting has, however, been obtained, chiefly from mine workings. The faults are reversed or normal, straight or curved, perpendicular or flat. Many varieties of movement are illustrated by them.

The most important mineral veins occur in the early andesite, and do not extend into the overlying rocks. These veins have been formed, chiefly by replacement, along narrow-sheeted zones, and have all the characteristics of true veins. Transverse fractures have determined the position of cross walls and ore shoots by limiting and concentrating the circulation. The mineralization was probably caused by hot ascending waters immediately after the earlier andesite eruption. The primary ores have a gangue of quartz, adularia, and some sericite and carbonates, and contain silver sulphides—such as argentite, polybasite, and stephanite—silver selenide, gold in a yet undetermined form, chalcopyrite, pyrite, and some galena and blende. The depth of oxidation is irregular. In the ore of the oxidized zone no important changes in the amount of gold or silver, as compared with the primary ore, has been proved to take place. The ore near the surface is not a truly oxidized ore, however, but is an intimate mixture of original sulphides (and selenides), together with secondary sulphides, chlorides, and oxides. Secondary sulphides include argentite and pyrargyrite.

The Tonopah ore deposits, when compared with others, find their closest resemblances in the Comstock in Nevada and in the Pachuca and other districts in Mexico, while the Silver City and De Lamar districts in Idaho are also similar in many respects. These deposits all occur in Tertiary lavas, chiefly andesitic. The writer has previously described the Great Basin region as forming part of a great petrographic province, and later it has been shown that this province extends into Mexico, and may reach much farther northeast and southwest. The similarity of the ore deposits in the district mentioned indicates that there is a metallographic province, which coincides in part at least with the petrographic province.

A series of veins, of small importance commercially within the Tonopah district, was formed after the eruption of one of the members of the rhyolite-dacite series—the Tonopah rhyolite-dacite. These veins may be large, but are usually low grade or barren. They frequently contain a greater proportion of gold than the earlier andesite veins, and have other distinguishing characteristics. In some cases the waters accomplishing this latter mineralization probably attacked and concentrated the ores in the earlier andesite veins.

A series of veins of still less importance was formed after the eruption of one of the later members of the rhyolite-dacite series—a siliceous rhyolite, which makes up some of the hills near Tonopah. One of these, Mount Ararat, a denuded volcanic neck, is traversed by fissure veins, carrying very little values. These veins are restricted to the neck, and the openings they fill were evidently formed by an upward movement of the plug after consolidation.

Part of the earlier andesite is profoundly altered, chiefly to quartz, sericite, and adularia. Other portions are altered chiefly to calcite and chlorite. These alteration phases are transitional into one another, and were evidently caused by the same waters. The maximum effect of these waters was the formation of the mineral veins along their circulation channels. Near the veins they effected the quartz-sericite-adularia alteration, and penetrating farther away they effected the calcite-chlorite alteration. The discussion of these processes is followed by the detailed study of analyses of typical specimens. The conclusion is drawn that the mineralizing waters were charged with an excess of silica, and probably of potash, together with silver, gold, antimony, arsenic, copper, lead, zinc, and selenium; that they also contained carbonic acid and sulphur, with some chlorine and fluorine; but that they were noticeably deficient in iron.

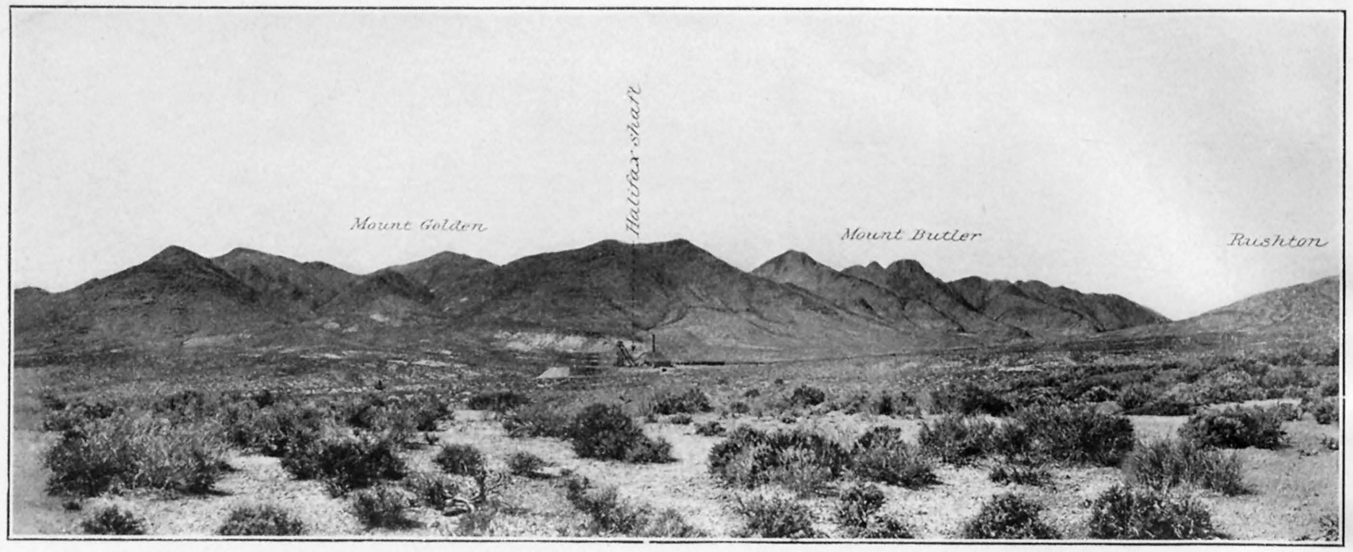
The alteration by thermal waters of the later andesite is also discussed. By comparison of analyses and by microscopic studies it is concluded that the waters which produced the alteration were highly charged with carbonic acid and sulphureted hydrogen, and contained magnesia, iron, and lime. The advent of the waters is believed to have followed the eruption of the white siliceous rhyolite above referred to.

The composition of the mineral waters in the two cases above referred to does not seem to correspond with that of the volcanic rocks whose eruption their advent followed. The eruption of andesite was followed by the advent of siliceous and potassic waters, poor in iron; the eruption of the rhyolite by waters rich in lime, magnesia, and iron. This antithesis may have some bearing on the origin of these waters. There are two theories of the origin of hot springs—atmospheric and magmatic. In the dry Nevada region there are cold springs which give evidence of magmatic origin, while most of the hot springs show no connection with atmospheric precipitation. The meaning of the nature of the metals in the Tonopah veins is also discussed. The conclusion is reached that the waters which produced the veins were largely given off from the congealing lava below.

The temperature in the Tonopah mines shows an abnormally rapid increase with depth, comparable to that in the Comstock.

The water encountered by underground workings is very irregularly distributed. Some of the shafts have reached a depth of over 1,000 feet without encountering any general body of ground water, yet along certain steeply inclined fracture zones water is found sometimes quite near the surface. These water zones are widely spaced and occur only in brittle rocks. They are probably reservoirs bottomed by impervious clay seams. The porous rocks, such as the volcanic breccias, absorb the precipitation like a sponge, and no water has yet been encountered in them.

The relief of the range of hills in which Tonopah lies is primarily due to the volcanic accumulations. These Tertiary volcanic rocks have been eroded and much material has been transported from the hills into the adjoining desert valleys. In arid climates erosion is more general than in moist climates, and as a result the relief is determined to a much greater degree by the relative hardness of the rocks. This feature is beautifully illustrated at Tonopah. The complicated faulting has had very slight effect upon the topography.



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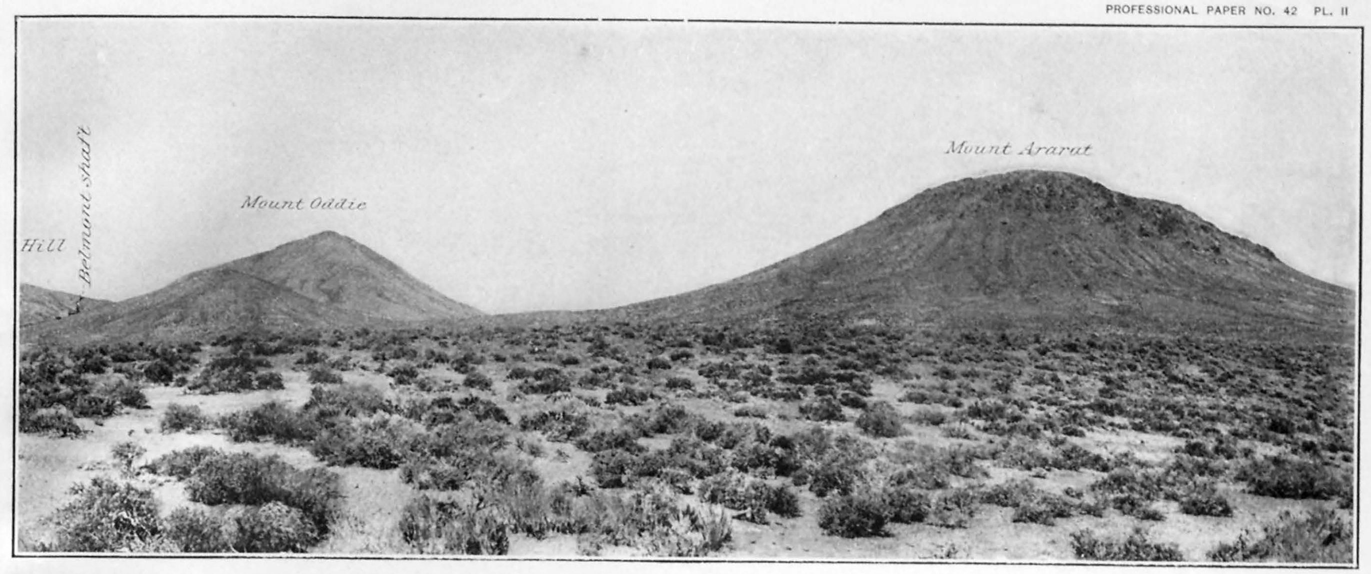

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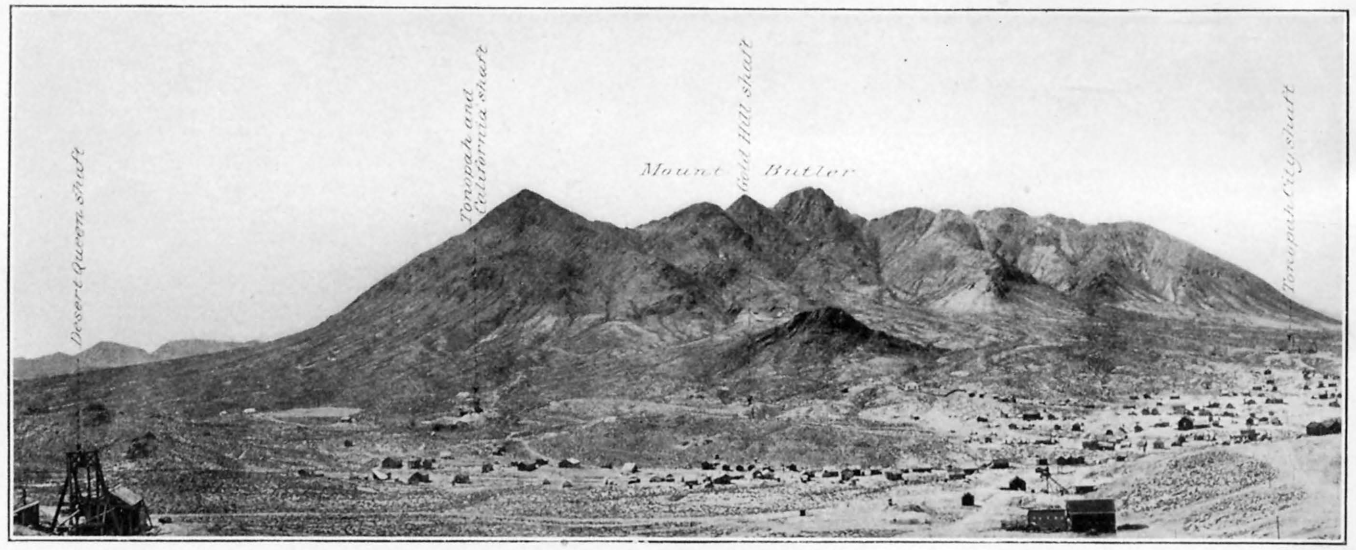
VIEW FROM NEAR EASTERN CORNER OF AREA MAPPED ON PLATE I, LOOKING SOUTHWEST.



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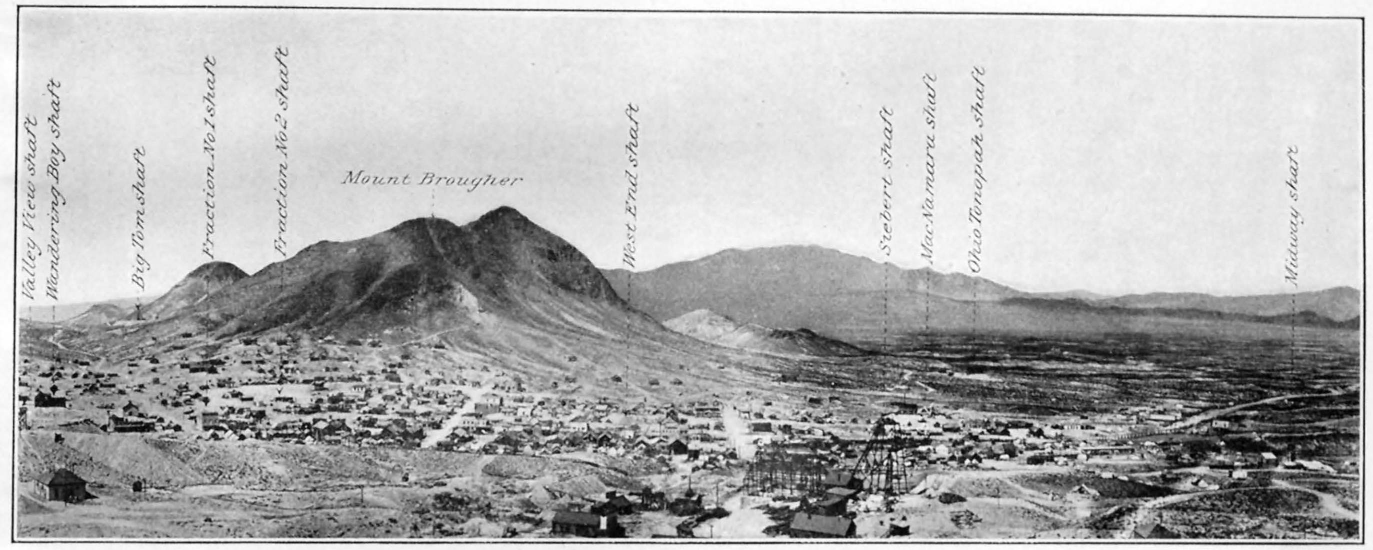
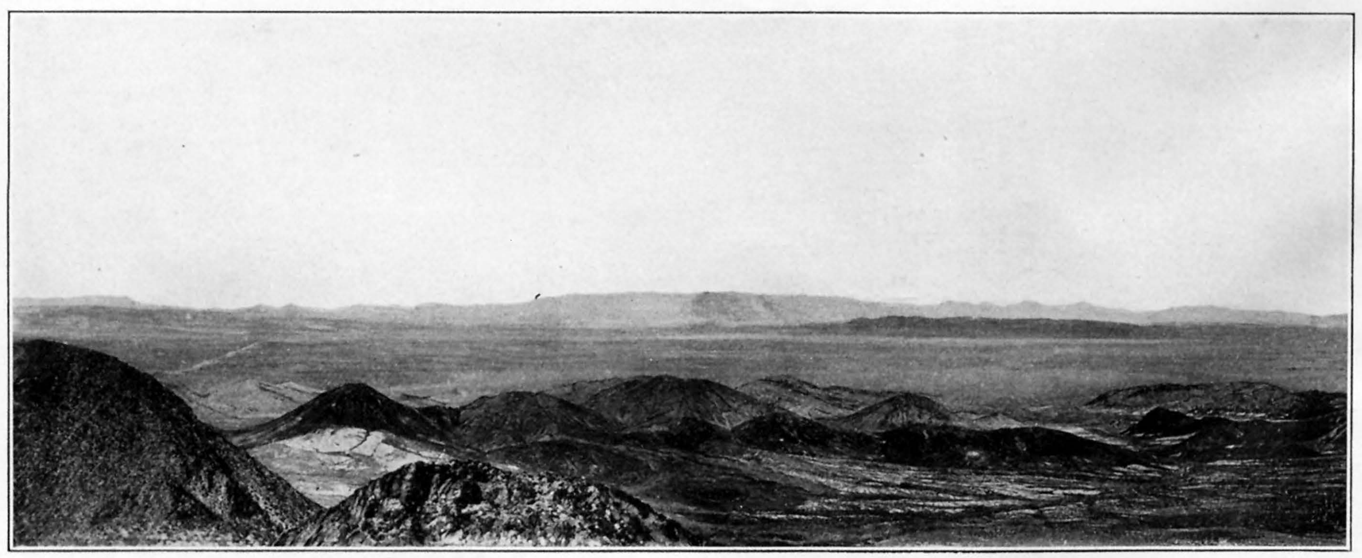


D

TONOPAH AND SURROUNDINGS, LOOKING WEST FROM MOUNT ODDIE.



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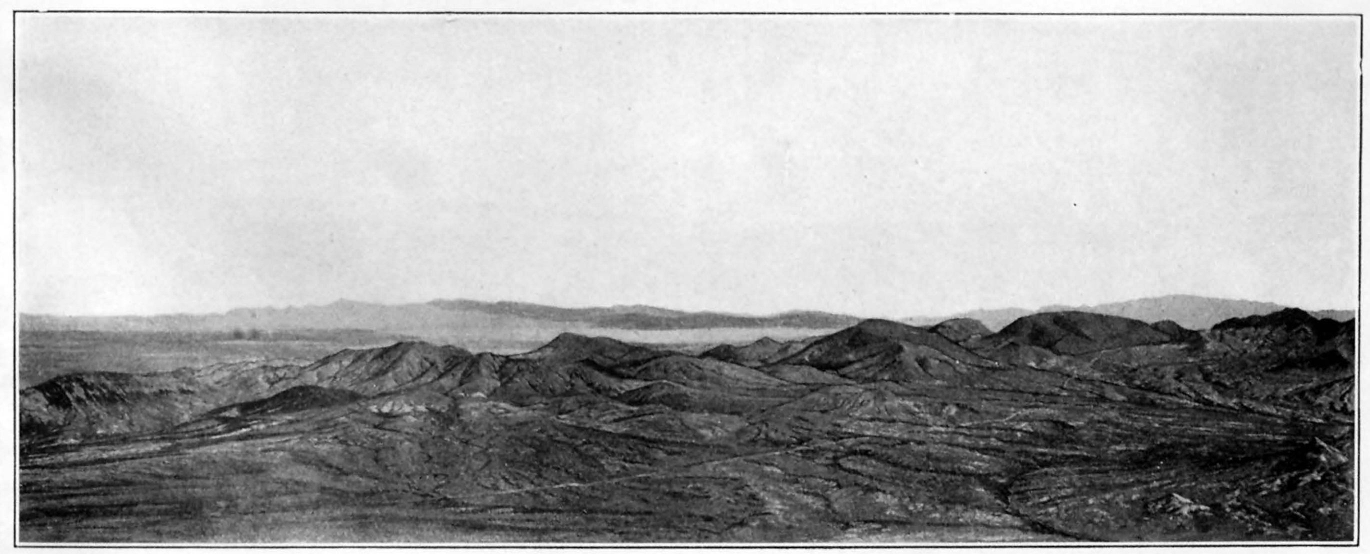

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PANORAMA, LOOKING SOUTH FROM BUTLER MOUNTAIN.

GEOLOGY OF THE TONOPAH MINING DISTRICT, NEVADA.

By Josiah Edward Spurr.

INTRODUCTION.

Location.—Tonopah (see Pl. I) is situated in Nye County, Nev., near the Esmeralda County line. It lies south of Belmont and about 60 miles east of Sodaville, on the Carson and Colorado Railway. During the last year a railroad has been constructed to connect it with the Carson and Colorado Railway at Rhodes, a short distance south of Sodaville.

Topography.—Tonopah is situated in the western part of what has been called the Great Basin region. In this region parallel north-south mountain ranges and low, irregular hills and mesas, having also in general a north-south alignment, alternate with broad, flat, or gently sloping valleys. On account of the aridity of the climate the valleys and low hills are bare, save for scattering desert shrubs, chiefly sagebrush, while higher up, on the mountains, there is a more abundant vegetation.

At Tonopah the topography is typical of volcanic areas. Numerous isolated or connected irregular hills—denuded volcanic necks—rise from a rolling plain. The town lies about 6,000 feet above sea level, and the top of Butler Mountain, the highest point near the town, has an altitude of 7,160 feet (Pl. II).

Discovery.—In April, 1900, James L. Butler, a resident of Belmont, left that place, with a camping outfit packed on burros, to travel toward the mining camp called the "Southern Klondike"[a] and to prospect the neighboring country. The Southern Klondike lies about 10 miles south of the present Tonopah, and Butler's trail lay over the site of the present camp. Observing the ledges of white quartz cropping on Mizpah Hill, he broke off specimens, which he gave to the assayer at the Southern Klondike camp to be examined. So little did these samples indicate the values that the assayer let them lie a while in his shop, and then, not seeing any

[a] A camp which attracted some attention at the time referred to, but which is now practically deserted.

definite prospect of financial benefit from the work, threw them outside into his waste pile.

On his return journey to Belmont, Butler broke off more samples from the same ledge. In Belmont he went to his friend, T. L. Oddie, a young lawyer and miner, and asked him to have them assayed, promising him a share of the claims should they turn out to be worth anything. Mr. Oddie sent the samples to an assayer in Austin, offering him in turn a share in any possible forthcoming results as compensation for the work. After a considerable delay the Austin assayer reported values of from \$50 to \$600 per ton in silver and gold. Mr. Butler did not act promptly on this news, and the report coming to the Southern Klondike camp, a party, including the assayer who had thrown out the ore and who had subsequently fished out the rejected specimens from his waste pile and assayed them with surprising results, started out to locate the veins. They wandered around within half a mile of the locality, but, confused by the similarity of the low isolated mountains, they could not find the veins and were compelled to return. Finally, on August 27, 1900, Mr. Butler, accompanied by his wife, drove out from Belmont, and together they located the ledges in due form.

Mr. Butler gave T. L. Oddie, W. Brougher, and several others interests in the original eight claims which he located, now the property of the Tonopah Mining Company. In doing the location work two tons of ore were sorted out and shipped to Selby's smelting company. This netted about \$600, and from that time the property has paid for its own development, a fact of which the locators, who started in with a joint capital of \$25, are properly proud.

Development.—In order to prove the value of the property, Mr. Butler gave leases, the lessee to pay 25 per cent royalty on the ore extracted. Some leases were given in December, 1900, and over a hundred more in the spring of 1901. Some of them proved enormously remunerative, and it is estimated that, before the end of 1901, the lessees extracted ore to the value of about \$4,000,000. When the leases expired, in January, 1902, the result had been relatively of so little profit to the owners that no more were given. In the meantime the property had been sold to Philadelphia capitalists and reorganized as the Tonopah Mining Company. This company began development work, shipping only enough ore to pay for the expenses of development and the installment of a proper plant until the present season (1904), when much larger shipments have been made.

It is a fact worthy of record that the leases given by Mr. Butler were verbal, not a scrap of paper being used, and that even when such arrangements proved relatively unprofitable to the mine, as above stated, the agreements were observed to the letter by Mr. Butler, who, on selling the control of the mine, expressly

MAP OF MINING CLAIMS, ADAPTED FROM MAP OF BOOKER AND BRADFORD, TONOPAH.

stipulated for the fulfillment of all his promises. A similar spirit, worthy of emulation by all engaged in mining practice, was observed in other respects. The Austin assayer, for example, received $32,000 for the assay which he made.

With the proof that considerable quantities of high-grade ore existed at Tonopah[a] the camp soon filled up with the usual stirring, excited population of a new mining camp. A writer in the Annual Report of the Director of the Mint, on the Production of Precious Metals in 1901, quaintly remarks, speaking of the conditions in 1902:

"Tonopah supports 32 saloons, 6 faro games, 2 dance houses, 2 weekly newspapers, a public school, 2 daily stage lines, 2 churches, and other elements of internal prosperity. It is a very orderly community, and there has been but one stage robbery thus far."

In the center of the town the Fraction shaft, starting in unmineralized soft volcanic rock, sunk down and encountered some rich ore at a depth of several hundred feet. This fired the imaginations of the prospector and the promoter with the idea that ore underlay the surface formations everywhere and was to be had for the sinking. Claims a long distance away from the real discoveries were in demand, though they showed no surface indications. To hold these claims, samples assaying something in gold and silver were diligently sought for, and in some cases it was only an obliging or careless assayer that saved the day. Companies were organized, treasury stock was advertised and sold, and shafts were started in many different places. Four out of five of the shafts or tunnels that were actually begun were desperately forlorn hopes, to speak conservatively, while many companies, especially some who were a considerable distance from the discoveries, may safely be classed as swindles. Others again—and this included most of those near the camp proper—were the honest investments of earnest men (Pl. III).

In the winter of 1902–3 rich ores were discovered in the ground of the Montana Tonopah shaft, which had been sunk several hundred feet through the overlying barren andesite. Later on, other shafts also encountered ore at a considerable depth, notably the Desert Queen shaft, the North Star, and the Tonopah Extension. These, however, are all close to the original discoveries, and no important finds have been made in the outlying territory. On this account, in the summer of 1903, a decided dullness set in. Many of the most important prospecting and exploration workings were closed down on account of lack of funds or too faint encouragement, and the era of reckless and feverish investment and activity was closed, at least for the time being.

[a] The name is Indian, and means water brush, a desert shrub whose presence points to moisture in the soil beneath.

Treatment of ores.—The conditions of mining, reducing, and transportation, which will be of great importance to the future prosperity of the camp, have not yet been finally determined, though progress has been made. Several million dollars' worth of ore has been marketed, but at a great cost, for only ore containing gold and silver to the value of $100 per ton or more was profitable up to the time of the completion of the railroad. This ore had to be hauled 60 miles in wagons, and shipped to smelters in California or Utah. Some of the delay in definitely settling upon more economical ways of reduction has been caused by practical experiments that have been carried on. It seems to have been finally decided, however, that smelting is the best method, since any milling process does not recover the full values. A railroad lately finished from Tonopah to Rhodes, a point south of Sodaville on the Carson and Colorado Railway, has made transportation to the smelters cheaper.

Water supply.—The water problem is an interesting and vital one to any enterprise in this arid region. At first water was brought into camp on the backs of burros, from wells in the valley a number of miles to the east. Subsequently water was developed by wells in the hills about 4 miles north of the camp, and led in by pipes. The supply, however, was not abundant. Borings in the bottom of one of the desert valleys near by, called Rye Patch, have developed a great deal of water. Rather unexpectedly, also, some of the prospecting shafts in the camp have struck an abundant supply of water, though others are quite dry. Altogether, therefore, it appears that there is abundant water for domestic, mining, and milling purposes.

Fuel and power.—The power problem is also important. Coal has not been much used in Tonopah, although since the railroad has been completed the cost is not so great as formerly. For domestic purposes wood has been used. A variety of scrubby pine (pine nut, pinyon) grows in the mountains and is cut and hauled 20 miles or more to Tonopah. Of course this is expensive. Some of the hoists of the mines have been run by steam engines fired with this wood, while others have used gasoline. The balance of favor at present seems to lie with the wood-burning engines in regard both to efficiency and cheapness. In the White Mountain Range, about 60 miles in an air line west from Tonopah, are many mountain streams which have a great fall and on which an abundance of electric power could be generated. The harnessing of this water power and the transmission of the electricity seems feasible if it can be made profitable.

Coal is found about 40 miles west of Tonopah, in the north end of the Silver Peak Range, and also in Tertiary strata in the mountains farther north. It is a lignite, or at best a very light bituminous coal. It has been thus far rejected by those considering the power problem on account of its great content of ash. Not all the seams, however, are of the same character; some coal can be found which is without an extraordinary ash percentage. This is in part a coking coal and might be efficient. The generation of gas from these coals and the use of this gas as a fuel is also a possibility which should be carefully considered. While undoubtedly the material is not high grade, it is worthy of being considered in a region where other sources of power are so costly.

Crude petroleum, chiefly from southern California, has more recently come into favor as a fuel.

CHAPTER I.

GENERAL GEOLOGY.

DESCRIPTION OF THE ROCK FORMATIONS.

PRE-TERTIARY LIMESTONE AND GRANITE.

In the immediate vicinity of Tonopah the rocks are all Tertiary volcanics or tuffs. Eight or 9 miles south of the camp, however, there is limestone, very likely of Cambrian or Silurian age, which is intruded by granitic rock. Limestones and granites occur also several miles north of Tonopah, and at intervals between Tonopah and Belmont. At Belmont the limestone, which is intruded by granite, is known to be Silurian. From 20 to 40 miles west of Tonopah, on Lone Mountain and the Silver Peak Range, both Cambrian and Silurian limestones are cut into by granite.

At Tonopah occasional limestone and quartzite fragments and more abundant blocks of granite (often pegmatitic in structure) occur in the volcanic breccias. Their position shows them to be blocks which were hurled out from volcanoes. Thus it is shown that at an uncertain depth below the present surface the ascending lavas broke through rocks of this character. In every case noted these inclusions were in extremely glassy, generally light-yellow volcanic breccia having the composition of rhyolite-dacite.[a] Three out of four localities are also on the borders of areas of a peculiar dacite, considered probably the oldest dacite of the region (Heller dacite), though whether this fact has any further significance is not clear.

At the northeast base of Heller Butte in this glassy Heller dacite there are inclusions of angular granitic blocks, often several feet in diameter. At the west base of the butte another bowlder of siliceous granitic rock was found in the dacite. A fragment of the same rock was found on the borders of the Heller dacite in the southeast part of the area mapped, southwest of the fork in the road that runs southeastward from Tonopah. A similar fragment was found in glassy rhyolite-dacite at the south base of Ararat Mountain. All these fragments were probably derived from a single underlying granitic mass.

Fragments of altered limestone were noted in dacite breccias, especially in the vicinity of the New York Tonopah shaft.

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[a] These two rocks are intimately allied and associated in the Tonopah district, and in their glassy phases are often not easily distinguishable one from another.

TERTIARY LAVAS.

ANDESITES.

EARLIER ANDESITE (HORNBLENDE-BIOTITE-ANDESITE).

Of the Tertiary volcanics, which occupy all of the Tonopah district proper, andesite appears to be the oldest. The writer has called this andesite the *earlier andesite* to distinguish it from a subsequently erupted rock of very similar composition. In the camp it is often called the "lode porphyry," since in it the most valuable veins lie.

Appearance.—The earlier andesite has never been found in even an approximately fresh state, but is decomposed in varying degrees, sometimes only moderately, often intensely. The freshest specimens are a light colored, dense, finely porphyritic rock, with small glistening feldspar phenocrysts showing on a fresh fracture. They have a greenish tinge, due to the presence of chlorite and similar secondary minerals, if they are from the deeper unoxidized mine levels, and a yellow tinge from iron oxide if they come from nearer the surface. On further alteration the earlier andesite usually has become lighter colored and more siliceous, and at first glance altogether resembles a rhyolite; by another process of alteration, especially when there was a somewhat greater abundance of original ferromagnesian silicates, the rock has become green of various shades.

Original composition.—From microscopic study it appears that the original fresh rock was a hornblende-biotite-andesite, of medium composition. The structure is fine porphyritic, with relatively sparse phenocrysts in a glassy groundmass containing many microlitic crystals and frequently showing original flow structure. The phenocrysts were mostly feldspar, hornblende, and biotite, occasionally quartz. Hornblende and biotite were about equal in amount, sometimes one predominating, sometimes another, and frequently one occurring in a given rock specimen almost to the exclusion of the other. Pyroxene (probably augite) was apparently relatively rare. The ferromagnesian minerals as a whole were not abundant, and the rock had a rather siliceous character. The feldspar was typically andesine-oligoclase (as determined in the fresher rock), though some of the feldspars ranged from orthoclase to labradorite, the basic varieties being more abundant. The feldspar crystals are typically small, slim, and simple (i. e., not compound). Apatite in small crystals is abundant, and zircon is frequent.

Present altered condition.—In the ordinary altered condition these minerals are often completely transformed. No actual biotite or hornblende has been found in these rocks, although several hundred specimens have been studied microscopically. These minerals are represented by their decomposition products—quartz, sericite, pyrite, siderite, and hematite, sometimes chlorite and calcite.

Frequently their former presence is attested only by the greater abundance in certain areas of ferritic minerals, which form a rude pseudomorph after the original crystal. Sometimes only the outline of the original is preserved, and rarely the original lines of cleavage can be traced. Often, on the other hand, the outline has been lost, and the decomposition products are bunched together so rudely that the primary mineral can only be guessed at.

The feldspar also is sometimes so completely altered to a felt of secondary minerals, entirely similar to those resulting from the decomposition of the groundmass, that its former existence can not be determined without careful observation. If viewed by reflected light the outlines of the feldspar crystals can sometimes be seen. Frequently the secondary minerals within the area of the original feldspar are of slightly coarser grain than those without. The feldspar has altered essentially to quartz and sericite. Alteration of the feldspar to adularia or valencianite (a variety of orthoclase) is also widespread and important. The decomposition products not infrequently include kaolin, and occasionally calcite, chlorite, and epidote.

The groundmass undergoes the same decomposition processes as the porphyritic crystals, becoming generally a felty aggregate which is composed of secondary quartz and sericite, but which includes some pyrite, siderite, and limonite, and sometimes a little kaolin. By a rarer process of alteration chlorite and calcite are formed.

As a result of these alteration processes the rock is usually more or less completely altered to an aggregate which is composed of quartz and sericite, and which usually includes some pyrite and siderite, and frequently adularia, kaolin, and the iron oxides. Chlorite and calcite are not so common, but one or both of these minerals may be very abundant. They indicate a process of decomposition different from the ordinary. Chlorite may occur in a rock without calcite, and vice versa. In one specimen studied, quartz and chlorite were the chief products of decomposition; in another, quartz, sericite, and chlorite. As a rule, however, the rocks may be divided according to their processes of decomposition, as follows:

1. Quartz-sericite-adularia-pyrite-siderite rocks; most abundant, and most closely connected with the metalliferous veins.
2. Quartz-sericite-kaolin-iron oxides rock; not infrequent; probably a modification of No. 1. Usually plainly associated with some fault or other underground water channel.
3. Chlorite-calcite rock; not associated with the ores.

Location.—The earlier andesite outcrops in only a limited area, being chiefly confined to Mizpah Hill and Gold Hill. It has been proved to occur extensively, however, underneath later lavas.

LATER ANDESITE (BIOTITE-AUGITE-ANDESITE).

Appearance.—The later andesite is much like the earlier andesite, but is slightly less siliceous. It is often found nearly fresh, and is in other places profoundly decomposed, but the general process of decomposition is usually different from that of the earlier andesite. Typically it is a rock of medium dark color, mottled with crystals of feldspar and biotite, and sometimes with pyroxene. It has generally been more or less altered and has turned dark green. Near the surface the red of the oxidized iron combines with these colors to form a characteristic rich purple. In some places the rock has been thoroughly altered to calcite, chlorite, serpentine, quartz, siderite, and pyrite, and other secondary minerals, and in other places has been so thoroughly leached as to be soft and white.

Composition and alteration.—The porphyritic crystals or phenocrysts are larger than in the earlier andesite, and are also much more abundant. There is usually a graded crystallization, the crystals varying from very large size by easy transitions down to tiny ones, which pass into the microlitic groundmass. These crystals consist chiefly of feldspar, biotite, augite, and hornblende.

The feldspar occurs as stout crystals, which have an irregular form caused by complex twinning or intergrowth. When fresh enough the species may be determined to be predominantly between andesine and labradorite, although there are more calcic and more sodic varieties, varying between oligoclase and bytownite. The feldspar is therefore more calcic than in the earlier andesite, where it is predominatingly oligoclase-andesine. It is usually altered more or less completely to calcite, chlorite, and quartz. Any one or two of these alteration products may be scant or absent, and chlorite, kaolin, and zeolites may be present.

Biotite, which occurs in good-sized crystals, is usually bleached to a light-green or transparent color, or is partly or wholly recrystallized to muscovite, pyrite, calcite, and siderite, and occasionally a chloritic aggregate. Triangular skeletons of rutile (sagenite webs) are included in the biotite, and are left free by its decomposition. The siderite, evidently derived from the breaking up of the iron silicate in the biotite, generally occurs intimately throughout the crystal, along cleavage lines, etc., while the pyrite is usually confined to the outside or the outer edges of the crystals.

The augite is pale green and is usually altered. The alteration products vary considerably, but are generally serpentine, chlorite, siderite, pyrite, calcite, and quartz. Kaolin and the zeolites also sometimes occur.

The hornblende is not abundant, and is almost always entirely altered. The decomposition products are very similar to those of the augite, and include chlorite, quartz, siderite, frequently calcite, and sometimes sericite, kaolin, and zeolites. Small apatite crystals occur, in part as inclusions in the phenocrysts.

Magnetite and specular iron occur as primary minerals, often abundantly. In several cases an isotropic cloudy material of a brilliant green color, suggesting chromium or nickel, was observed in thin sections; and to this some of the rocks owe, in part at least, their peculiarly vivid color. At times this secondary substance seemed to be derived from the augite, but in one section it was plainly derived from the magnetite, for it formed rims around the magnetite crystals. As analysis showed a trace of nickel, it is probable that the magnetite contains some nickel oxide.[a] Siderite also occurs as rims around the magnetite and as pseudomorphs after it.

Siderite and pyrite are more abundant than in the early andesite. They are usually intimately associated, and their relations are interesting. Frequently they seem to have been contemporaneous in origin, and to have formed side by side without inconvenience. As stated above, however, the siderite is more intimately disseminated through the mass of the primary ferruginous mineral (biotite, augite, or hornblende) whence it is derived than is the pyrite. Occasionally the pyrite is altered to siderite along its margins, but in many more cases the siderite has unmistakably altered to pyrite along its borders. A delicate set of changes is thus indicated. The intimate association of the siderite with the primary minerals, its frequent replacement by pyrite along the borders, and the evident alteration of the carbonate to the sulphide show that in general a period of pyritization succeeded one of carbonization, or, if both were contemporaneous, the period of pyritization was longer.

The groundmass when fresh is brown glass, sometimes spherulitic, or it is microlitic with brown glass cement. Feldspar, pyroxene, and magnetite microlites may sometimes be recognized. The groundmass alters, like the phenocrysts, to quartz, chlorite, serpentine, siderite, pyrite, calcite, sericite-like aggregates, and occasional zeolites and epidote.

In general the decomposition products of the rock are typically quartz, chlorite, calcite, pyrite, and siderite, but occasionally portions altered chiefly to quartz and sericite-like aggregates[b] may be found.

Location.—The later andesite outcrops in only the northeastern portion of the area mapped, for in the southwestern portion, as a result of relative subsidence attendant upon faulting, only higher beds are exposed. It occurs in depressions

[a] In magnetite some of the ferrous iron is rarely replaced by nickel; thus a variety from Pregratten, in the Tyrolese Alps, in a schistose serpentine, gave 1.76 per cent nickel oxide (NiO), together with traces of the oxides of manganese, chromium, and titanium.

[b] For some information on the real nature of these sericite-like aggregates see p. 240. It appears probable that hydrargillite and talc form a large part of these masses.

between hills of rhyolite and dacite, because it is less resistant to erosion than these rocks.

Relation to earlier andesite.—The later andesite directly overlies the earlier andesite, and though in many underground workings and probably at every outcrop the contact is a fault contact, caused by movements subsequent to the eruption of the later andesite, yet in several shafts one andesite has been found apparently lying undisturbed in its normal position upon the other. Such was the case in the Midway, the West End, and the Tonopah Extension shafts. In these places the contact was marked by a band of decomposed breccia, or even clay, yet there was no good evidence of faulting. The quartz veins of the earlier andesite extend up to this contact in full strength and then abruptly disappear. Most likely the earlier andesite was deeply eroded and the veins were exposed before the later andesite was poured out, and possibly the decomposed clay or breccia zone represents the result of surface decomposition and disintegration before the later-andesite period.

Distinction from earlier andesite.—The earlier andesite and the later andesite are usually sufficiently distinct in appearance to permit identification in the field. The later andesite is generally darker; on account of the greater amount of iron present it has the characteristic strong coloration mentioned above. The earlier andesite is characteristically finer grained than the later, and contains smaller and less abundant porphyritic crystals. The porphyritic feldspars in the earlier andesite are usually slim, of simple form, and almost rectangular, while those of the later andesite are apt to be stout and complex as a result of twinning. In the later andesite crystals of fresh or bleached biotite can usually be seen; in the earlier andesite they occur more rarely.

Similar characteristics serve, as a rule, for the microscopic determination. The phenocrysts of ferromagnesian silicates—augite, biotite, and hornblende—and their pseudomorphs or decomposition products are usually more abundant in the later andesite. The typical alteration of the earlier andesite is to quartz, sericite, and a little pyrite; that of the later andesite is to chlorite, quartz, calcite, siderite, and pyrite. While the character of the alteration is a valuable help in diagnosis, it is not by any means a sure test, for in some cases the processes of alteration have been apparently almost exchanged.[a]

On account of the similarity in the original composition of the earlier and later andesites it is frequently very difficult, either from field or from microscopic study, to refer a specimen to the proper age. Often this economically important question is decided by tracing the doubtful phase into some decided phase in the same rock body.

[a] It is probable, however, that the sericite-like aggregates in the altered later andesite are composed largely of minerals like hydrargillite, talc, kaolin, etc., rather than of sericite. See pp. 240–241.

RHYOLITES AND DACITES.

INTERRELATION OF RHYOLITES AND DACITES.

The rhyolites and dacites at Tonopah are closely bound together in every way—in chemical and mineralogical composition, in areal distribution, and in manner and time of eruption. In fact, they can be best understood if considered as portions of the same great magma, split up, as the author would like to assume, by internal segregation or magmatic differentiation. These lavas constitute transitions between the two types (rhyolite and dacite) named above, and the dacite itself is a very siliceous[a] one, barely deserving distinction from the rhyolites were it not necessary to emphasize the distinction between it and the still more highly siliceous rhyolite which forms some of the hills of the region, such as Oddie and Ararat. Moreover, although the rocks of Butler, Brougher, Siebert, and Golden mountains are distinctly of the dacitic type, and so fairly classed together and distinguished from the rhyolite, yet different hills (being denuded volcanic necks and so representing separate vents) show different phases. Golden Mountain, for example, is made up of a lava which, both in the field and under the microscope, seems to be more closely allied to the near-by rhyolite than to the dacite of the more distant eminences in the lower or southwestern half of the mapped area, such as Brougher Mountain. Chemical tests bear out this impression in large measure. The fine-grained border facies of this Golden Mountain intrusion, being glassy with sparser feldspar phenocrysts than the normal type, is indistinguishable, without chemical analysis, from similar rhyolite. The glassy dikes which extend from the main mass are of the same character. Many of the small dacite-rhyolite flows, erupted at an earlier period than the volcanic necks, are similarly fine grained, and difficult to classify exactly as dacite or rhyolite without numerous and altogether useless chemical tests. It is practically certain that many of these are transitions between the two extreme but closely related types.

SIMULTANEOUS ERUPTIONS.

The eruption of dacite and rhyolite, which succeeded that of the andesite, extended over a long period and was characterized by many variations in the rhyolite and dacite. The observed phenomena favor the conclusion that different vents were in a state of eruption nearly or quite simultaneously, each one contributing its characteristic rock, and that the notable alternations of different kinds of lava are due rather to the temporary inactivity of some of the vents than to any real change in the character of the magma in the supply basins.

In order to describe better the geologic history and the economic geology a number of subdivisions have been made in the dacite-rhyolite series.

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[a] For the use of the term "dacite" see pp. 58-59.

HELLER DACITE.

Location.—Heller Butte, a small, steep mamelon near the town of Tonopah (Pl. IV), is made up of a dacite containing numerous included fragments. At first it was considered to be of the same class and age as the larger buttes, such as Butler and Brougher mountains, and since the latter are denuded volcanic necks it was thought to represent a smaller contemporaneous vent. Afterward, however, it was recognized that the marked abundance of inclusions, the unusually abundant glassy groundmass, and the fact that the porphyritic crystals are frequently larger than those of the dacite of the larger mountains were characteristic features of this particular rock. Later, other grounds favoring its assignment to a quite different and earlier period were discovered.

Heller Butte has a height of 150 to 200 feet and a steep conical form, elliptical at the base. Its rock is vesicular glassy dacite, which contains inclusions of pumiceous material, frequently of later andesite, and occasionally of coarse siliceous granite. The inclusions of andesite and granite are sometimes large angular bowlders, several feet in diameter. The form of the butte seems to be governed by platy structure. It is steep and slopes away in curves on all sides. On the northeast and southeast sides the lava is cut off from the Fraction dacite breccia and the Siebert tuffs by faults, along which are intruded glassy dikes sent off from the Mount Golden mass of Brougher dacite. On the western side the lava of the butte seems to dip under the nearly horizontal Fraction dacite breccia.

The Tonopah City shaft, 800 feet west of the Heller dacite area last referred to, passed through 300 feet of the partly fragmental, loose Fraction dacite breccia to solid, glassy dacite of the Heller type, which continued for 200 feet more to the bottom. The contact in the shaft could not be seen by the writer on account of the tight lagging, but it seems most likely that the order is normal and that the lower formation is the older. Rounded and subangular inclusions of the later andesite, having the appearance of waterworn pebbles, are frequent in the Heller dacite of this shaft, and are more abundant toward the bottom. There are found, also, smaller rounded quartz pebbles, which are accounted for on the hypothesis that this lava was a flow, which ran over and caught up pebbles from an older surface-gravel deposit.

Near the southeastern edge of the area mapped are other outcrops of lava, which have the same peculiar phases—the abundant glassy groundmass and the numerous inclusions of foreign materials—as the lava at Heller Butte. Here, northeast of the main road that crosses the valley, running between Butler and Golden mountains, is a small, smooth mamelon, or symmetrical cone, about 20 feet high and 80 feet in diameter, that resembles in a general way Heller Butte, and is composed of the same lava. This cone has a concentric, platy structure parallel to its surface, and to this it evidently owes its form. It is adjoined on the west by a long tongue of similar lava, like that surrounding Heller Butte, and the whole is surrounded by the friable Fraction dacite breccia.

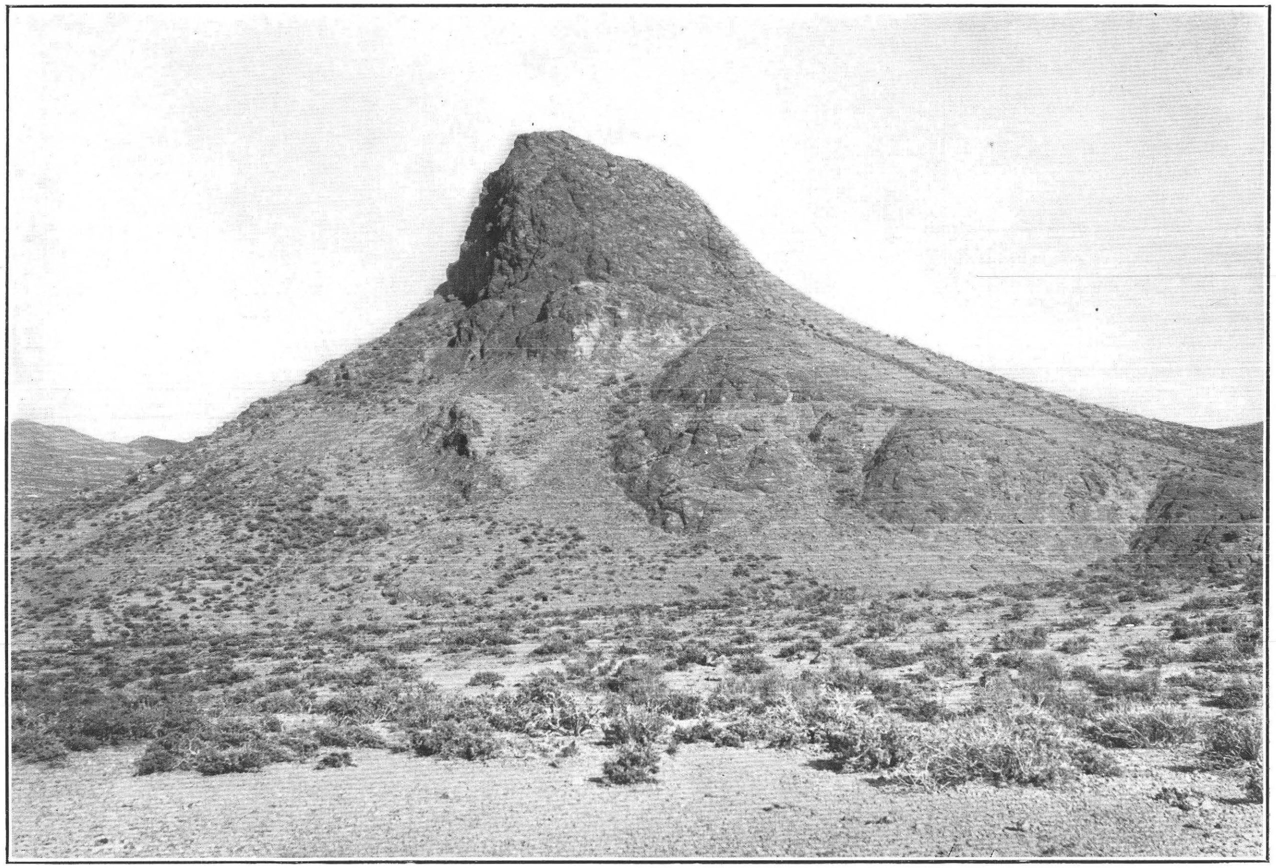
Farther west, just on the west side of the road, is a similar dome-like hill that rises out of a limited irregular area of the same dacite and is surrounded by the Fraction dacite breccia. Still farther west, a short distance, there is a projecting ridge of Heller dacite, capped by a mamelon 5 feet high. The platy structure slopes away from the ridge on all sides.

These three similar cones are aligned in a northeast-southwest direction.

Age of Heller dacite.—The lava of Heller Butte has been faulted. It is thus older than the later intrusive Brougher dacite, which makes up the important hills of the district (see p. 44), and was erupted before the general faulting. It has been found in normal contact only with the Fraction dacite breccia, which circumstance, so far as it goes, favors an age either immediately before or after this formation. On the southeast side of Heller Butte the lava of the butte is separated from the Siebert tuffs by a fault contact. Examination of what is practically the same fault (the California fault) a few hundred feet farther north, where the tuffs are brought into contact with the Fraction dacite and the earlier andesite, both of which are known to be older than the tuff, shows that the tuff block is downthrown, and that the Heller dacite belongs to a lower horizon than the tuff. The fact that nowhere has any of this Heller dacite been found between the Fraction dacite breccia and the overlying formations would further restrict the probabilities; and the fact that the dacite of the butte appears to dip under the Fraction dacite breccia near Heller Butte and reappear beneath the breccia in the Tonopah City shaft favors the final assignment of the Heller dacite to a period preceding the formation of the Fraction dacite breccia. The inclusions of later andesite in the Heller dacite again fixes the dacite as later than the andesite, and the place of the Heller dacite may be held to be between the later andesite and the Fraction dacite breccia.

Nature of Heller dacite.—The glassy groundmass of the Heller dacite indicates cooling at or not far from the surface, and the apparently waterworn pebbles included in the dacite in the Tonopah City shaft suggest that this portion of the lava was a flow. At the same time the presence of inclusions of granitic rocks (sometimes in bowlders several feet in diameter), as well as of the later andesite near Heller Butte, shows that the lava rose directly from depths below the granite and passed through this rock and the already erupted andesites on its way up. A vent or volcanic neck is thus suggested and the topographic forms of Heller Butte and the similar smaller buttes described with platy structure parallel to their surface offer the same suggestion.

Summarizing the evidence and inferences, it appears that the eruption of the later andesites was followed by an interval of rest and erosion; and that the



HELLER BUTTE.

beginning of the dacite-rhyolite eruptions was signalized by the appearance of the Heller dacite, which formed numerous small cones along lines of weakness and was poured forth in relatively limited quantities.

Microscopic characters.—Under the microscope the Heller dacite shows a brown glass groundmass, which is sometimes spherulitic and which contains numerous porphyritic crystals, nearly always broken, of quartz, feldspar, and biotite. It resembles the Brougher dacite. Striated and unstriated feldspars are about equally represented. The latter are probably in large part orthoclase, while in one slide examined striated feldspars proved to be andesine.

FRACTION DACITE BRECCIA.

Location.—A considerable part of the southern half of the area mapped is covered with a soft brownish or greenish rock of volcanic origin. This rock is sometimes solid, is occasionally dimly horizontally layered or packed, is at times definitely stratified, and even contains well-bedded tuffs. The material is dacitic, essentially like the Heller and the Brougher dacite. It does not occur in the relatively elevated northwestern half of the area mapped but in the southeastern half it spreads far beyond the map limits and occupies large portions of the low areas between the hills.

Thickness.—This formation varies in volume, but is frequently several hundred feet thick. Perhaps the greatest thickness actually demonstrated is at the New York Tonopah shaft, which is 745 feet deep and is entirely in this formation, except for intrusive bodies of the Tonopah rhyolite-dacite or included fragments of earlier rocks.

Conditions of eruption.—In places the dacite belonging to this formation is nonfragmental and of the nature of a flow. But it is invariably soft and friable. It grades into a common type where it is often difficult to decide whether or not the rocks are of fragmental character. They often consist of broken, close-packed, medium-sized fragments of more or less pumiceous dacite, but under the microscope show no signs of fragmental origin. An explanation of their origin that accounts for their different features is that these rocks were partly or entirely volcanic mud flows, in which the highly pumiceous and aqueous lava was mingled with such an excess of heated waters that it was partly broken and ground up in the course of the flowing. Rock of this nature grades with no sharp line into thick, unstratified accumulations of brownish or greenish pumice fragments, which are of considerable size, and which grade into similar masses of smaller pieces. In some parts of such deposits a rude stratification or layering may be observed, and occasionally there are thin layers of well-stratified tuff (fig. 1). These pumice accumulations point to explosive eruptions. In them are found fragments, some of which are several feet in diameter, of the earlier andesite, of the later andesite, and of andesite and dacite tuff, which were probably hurled out of the volcanoes in blocks during these eruptions.

We may therefore reason that the period of the formation of the Fraction dacite breccia was one of considerable volcanic activity, though not necessarily prolonged. The volcanoes exploded repeatedly, producing showers of pumice and ash and rapid subaerial accumulations of these materials on and near the slopes, while the flows were scanty and so mixed with water as to be often nearly or quite mud flows. The upper part of the formation, as seen in the New York Tonopah shaft, in the northwest side of Siebert Mountain, and elsewhere, is more fragmental than the lower portion. Some solid lava flows appear interstratified with these upper fragmental deposits, but they belong rather to the Tonopah glassy rhyolite-dacite than to the Fraction dacite breccia.

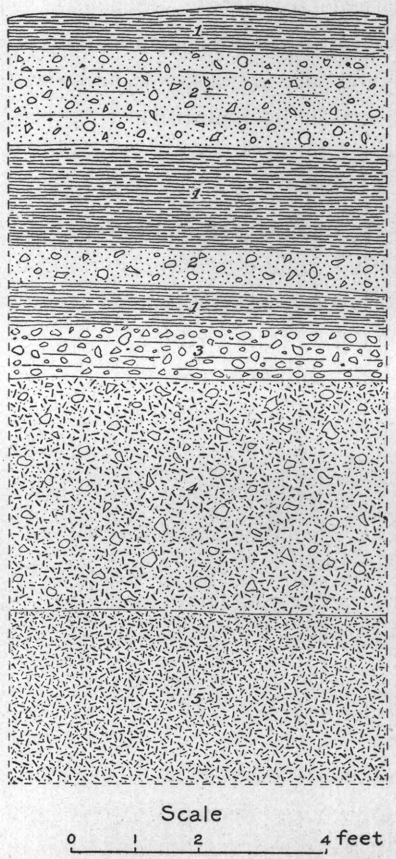


FIG. 1.—Vertical section of shaft about 1,600 feet east of Tonopah and California shaft, showing Fraction dacite breccia and interbreccia tuffs. (1) Finely stratified tuff; (2) sandstone composed of angular and rounded fragments of dacite glass; (3) stratified rock, largely made up of pumice fragments; (4) soft dacite, broken and containing pumice fragments, probably a mud flow; (5) like 4, but containing little pumice.

Relative age.—A number of data are of value in the determination of the relative age of this formation. It is clearly younger than the later andesite, for it sometimes rests upon this formation and typically contains abundant inclusions of it. On the other hand, it is frequently cut by dikes of the Tonopah rhyolite-dacite (fig. 2). As already stated, it overlies the Heller dacite in the Tonopah City shaft, and is most likely younger than it. Therefore it is probably immediately between the Heller dacite and the Tonopah rhyolite-dacite.

Microscopic characters.—Microscopically the rock of the Fraction dacite breccia is a biotite-dacite, substantially of the same composition as the Heller dacite and the Brougher dacite. The groundmass is brown glass, often felty, and frequently very vesicular. As porphyritic crystals (usually broken) it contains quartz, relatively sparse biotite, and feldspar, both striated and unstriated. The striated crystals are relatively considerably more abundant than in the Tonopah rhyolite-dacite. One determination showed andesine-oligoclase.

TONOPAH RHYOLITE-DACITE.

The Tonopah rhyolite-dacite occupies a large part of the area mapped. It occurs in large unbroken areas in the northern corner and in numerous broken and separated areas, bounded by faults, in the western corner.

Appearance.—The rock has many different aspects in the field, gray, bright red, black, and white being among the colors represented. Fine brecciation is frequently observable, while in many cases the rock is glassy, dense, and characterless, especially near the contacts of the intrusive masses, or in the thin sheets. Under the microscope, however, the characters are much more uniform.

Microscopic characters.—Characteristically sparse and small phenocrysts occur in a glassy, sometimes partly microcrystalline brown, gray-brown, or yellowish groundmass. The rock often possesses flow structure, is rarely pumiceous or slaggy, and frequently shows autobrecciation. Angular fragments of broken glass, included in a cement of similar glass, and other phenomena indicate that the lava moved while stiffening.

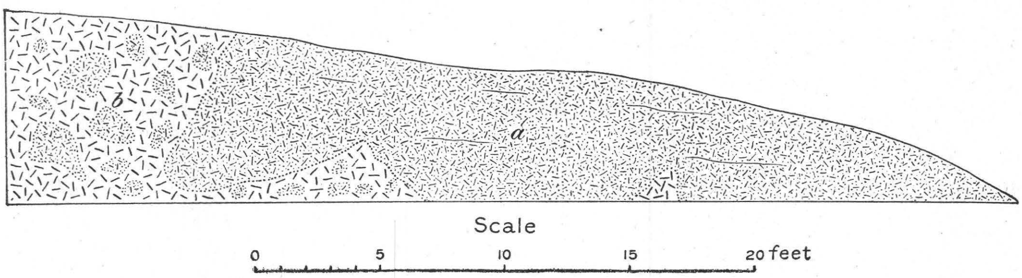


FIG. 2.—Vertical sketched section of trench just west of Brougher Mountain, showing Tonopah rhyolite-dacite (*b*), intrusive into Fraction dacite breccia (*a*).

The porphyritic crystals consist of feldspar, biotite, and quartz, which occur in the order named. Small unstriated blunt crystals of orthoclase are always predominant among the feldspars, though striated and more elongated crystals are frequent. Optical determination of these shows that they range from andesine to albite, andesine-oligoclase being the most frequent phase. Quartz crystals are abundant in some phases, in others rare, and in many are wanting, especially in the more glassy phases. Fresh biotite crystals are frequently present though rarely abundant. They are usually small in size.

A pseudomorph of iron oxide (specular iron?) after hornblende was observed in one case, the original hornblende having been resorbed by the dacitic magma. A single small crystal of augite was found in one of the slides, out of several hundred examined. Small original crystals of specular iron are often observed.

Alteration near contacts.—Silicification and the production of secondary minerals is widespread, especially near contacts where the rhyolite is intrusive into older rocks, in which places the alteration has been accomplished mainly by hot-spring action succeeding the intrusion. Secondary quartz, pyrite, and sometimes siderite are the chief results, with exceptionally epidote and adularia and very rarely a little calcite. The quartz may form veinlets in the rock as viewed under the microscope, and these silicifications may increase in importance till they form large quartz veins. Vesicles lined with chalcedony were noted in one instance.

Some of the Tonopah rhyolite-dacite presents, when altered by the processes above referred to, a close resemblance to certain highly altered and silicified phases of the earlier andesite. Field work, however, seems to leave little doubt as to the nature of such types, as they can be traced into unequivocal rhyolite-dacites.

These altered and silicified rhyolite-dacites, especially those which contain no quartz phenocrysts, differ from the similarly altered earlier andesites in the scarcity and smallness of the phenocrysts, in the predominating stout, blunt form of the feldspars, which indicates orthoclase where the alteration is so great that no determination can be made, and in the absence or scarcity of apatite.

Distinction between the northern and the southern areas.—The general character and relations of the Tonopah rhyolite-dacite differ considerably north and south of an east-west line across the middle of the area mapped. This line, probably a fault line (see Pl. XI), runs up the main gulch along which the road to town passes and into the town. To the north the dacite is always intrusive, as its contacts prove. To the south the petrographic characters are in general the same as to the north, but the geologic relations are more complicated. In many cases the dacite is evidently intrusive, while in other places it occurs in sheets that alternate with pumiceous tuffs and have all the appearance of flows. Under the microscope also new features present themselves and indicate that many of these rocks are probably fragmental. In thin sections of such rocks the autoclastic glassy dacite has been finely broken mechanically and the fragments are intersected by dense kaolinic matter into which iron has infiltrated. The material seems to be an unassorted accumulation of angular fragments, which resulted from a shower of dacitic ash and lava fragments during and after explosive eruptions.

The southern part of the area mapped has in general been depressed below the northern half by faulting, and here internal faulting has been much more active than in the other part (see p. 47). This depressed tract exactly corresponds with the area of intermingled Tonopah rhyolite-dacite dikes, flows, and tuffs. In the relatively elevated northern portion of the area mapped the surficial formations have been largely worn away, and only the intrusive portions of the Tonopah rhyolite-dacite are left, while in the southern portion the corresponding flows and tuffs, as well as the feeding dikes, remain.

Age and origin.—There is a great deal of evidence concerning the age of the Tonopah rhyolite-dacite. In the northern part of the area mapped this formation is intrusive into the earlier andesite, and in many places into the later andesite. In the southern half of the area it contains numerous inclusions of later andesites, as well as probable earlier andesites, vein quartz, and granitic fragments. It is often intrusive into or overlies the Fraction dacite breccia, which therefore in general seems to be older (fig. 3).

Above the Fraction dacite breccia proper is a series of coarse, pumiceous tuffs which are rudely layered and rarely well stratified, and in which Tonopah rhyolite-dacite sheets are often interbedded, with no sign of intrusion. This shows that the flows were poured out intermittently and alternated with explosive eruptions, which caused the great intervening accumulation of pumice and the yellow ash derived from its disintegration. Occasionally also, but not commonly, thin sheets of the same rhyolite-dacite are found in the lower part of the waterlaid Siebert tuffs, which overlie the pumiceous unassorted tuffs and breccias and their intercalated Tonopah rhyolite-dacite flows.

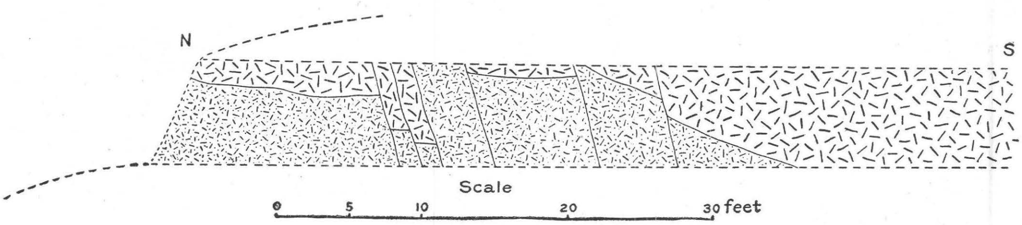


FIG. 3.—Vertical section of part of tunnel north of Brougher Mountain and southeast of Ohio Tonopah shaft, showing (1) Tonopah glassy rhyolite-dacite overlying Fraction dacite breccia; (2) faulting subsequent to both; (3) contact dipping down and in general faulted down toward the volcanic neck of Brougher Mountain (mouth of the tunnel is about 800 feet distant from the border of this neck).

The geologic position of the Tonopah rhyolite-dacite is, then, pretty clearly fixed. The eruptions of Fraction dacite breccia were soon followed by those of the Tonopah rhyolite-dacite, which mingled with the Fraction dacite, as indicated by numerous observations where these rocks are intimately associated. The eruptions of Fraction dacite became subordinate to those of the Tonopah rhyolite-dacite and were probably chiefly explosive, contributing material to the brown pumice beds, which are often several hundred feet thick and which alternate with the Tonopah rhyolite-dacite flows. At this period the Tonopah rhyolite-dacite eruption was at its height, though for some time subsequently, after the formation of the Tertiary lake and the accumulation of the Siebert tuffs therein, scanty flows were occasionally and locally emitted. Near Rushton Hill, however, pebbles of glassy Tonopah rhyolite-dacite in a conglomerate at the base of the Siebert tuffs indicate that the older Tonopah rhyolite-dacite flows contributed by erosion their material to the upbuilding of the tuffs, at the same time that the last tardy flows of the same lava were being brought forth.

BROUGHER DACITE.

Location.—This rock forms most of the important hills, the others being composed mainly of rhyolite of the same age and origin as the dacite. The dacite hills are Butler, Brougher, Siebert, and Golden (Pls. V and VI).

Volcanic necks.—These eminences represent the necks of former volcanoes or the columns of lava which rose from the abyssal regions to the surface. The Brougher Mountain neck (as mapped) is roughly circular, though slightly elongated. Butler Mountain is elliptical, Siebert Mountain is irregular, while Golden Mountain is elongated and irregular. Butler, Brougher, and Golden are all elongated in an east-west direction.

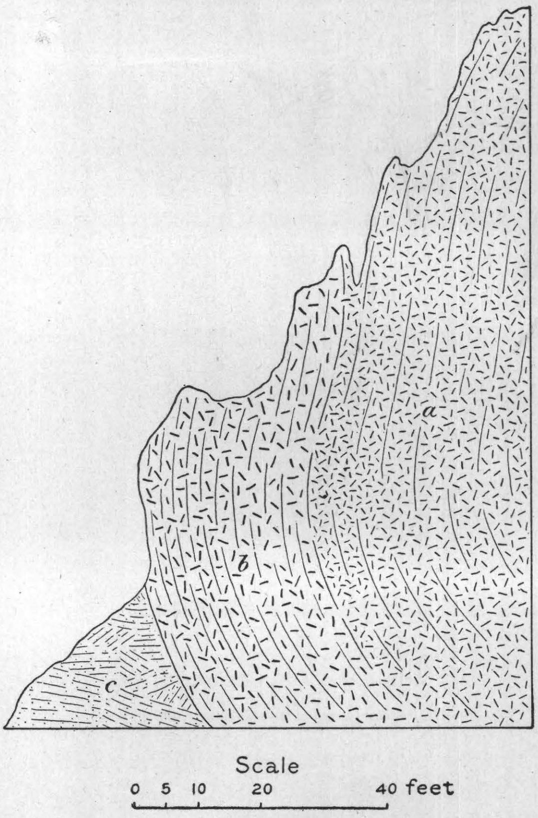
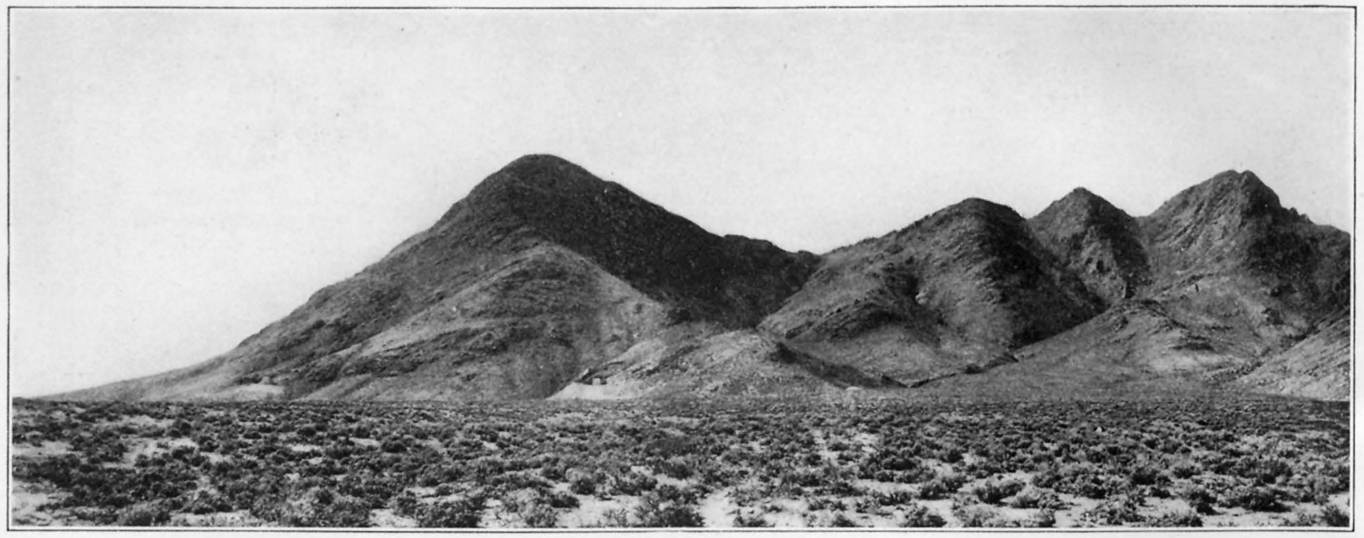


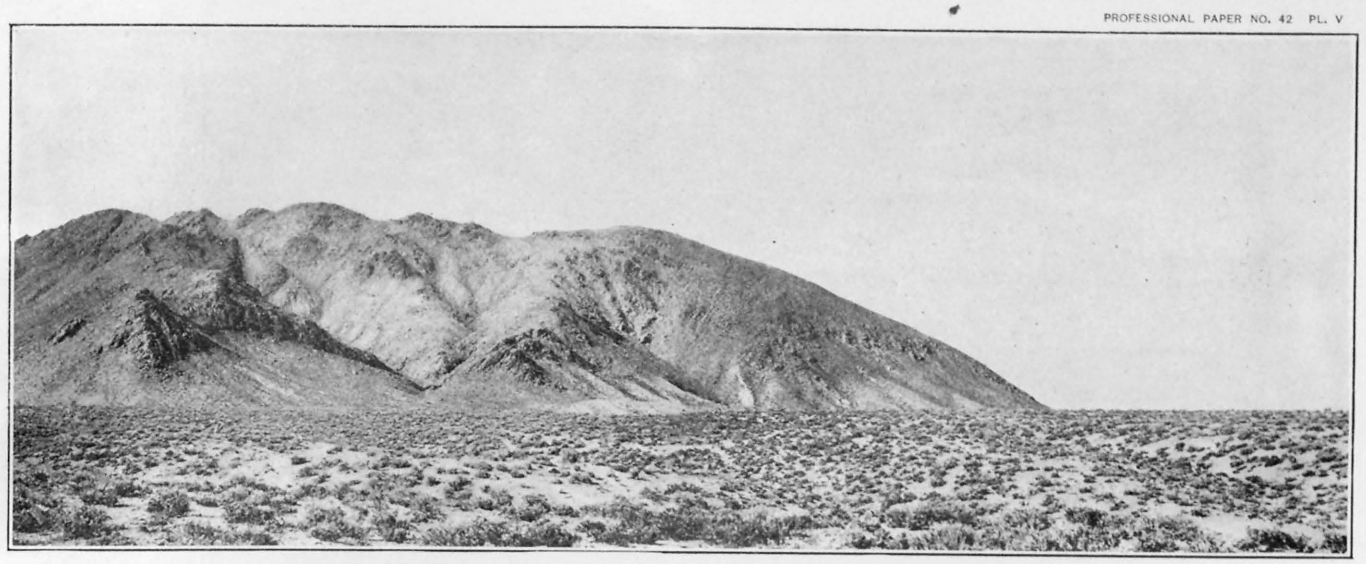
FIG. 4.—Vertical sketch section showing contact of intrusive dacite with tuff, southwest base of Butler Mountain. *a*, Dacite; *b*, dacite glass, contact face; *c*, tuff, broken at contact.

Contact phenomena.—The proof of their origin is found chiefly in their contact phenomena. The contacts are usually marked by a belt of dacite, which appears in the hand specimen as a black glass and which is shown by the microscope to be a glassy phase of the dacite. This band is generally several feet thick, and locally as much as a hundred feet. Powerful flow lines, parallel to the contact, are usually observed, and not infrequently the actual contact with the intruded rock can be seen. The contacts are typically vertical, but they are by no means regular. They frequently dip out from the mountains, and perhaps more frequently into them, and are often wavy (figs. 4 and 5). The earlier andesite, the Fraction dacite breccia, the Tonopah rhyolite-dacite, the Siebert tuffs, and the basalt are at various places intruded along the contact of these dacite necks, and thus the age of the dacite is established. The intruded rocks are usually hardened and silicified near the contact, and contraction cracks in them are coated with chalcedony.

Dikes from main masses.—The contacts are irregular in detailed horizontal plan, and tongues are frequently sent out into the intruded mass. Along faults

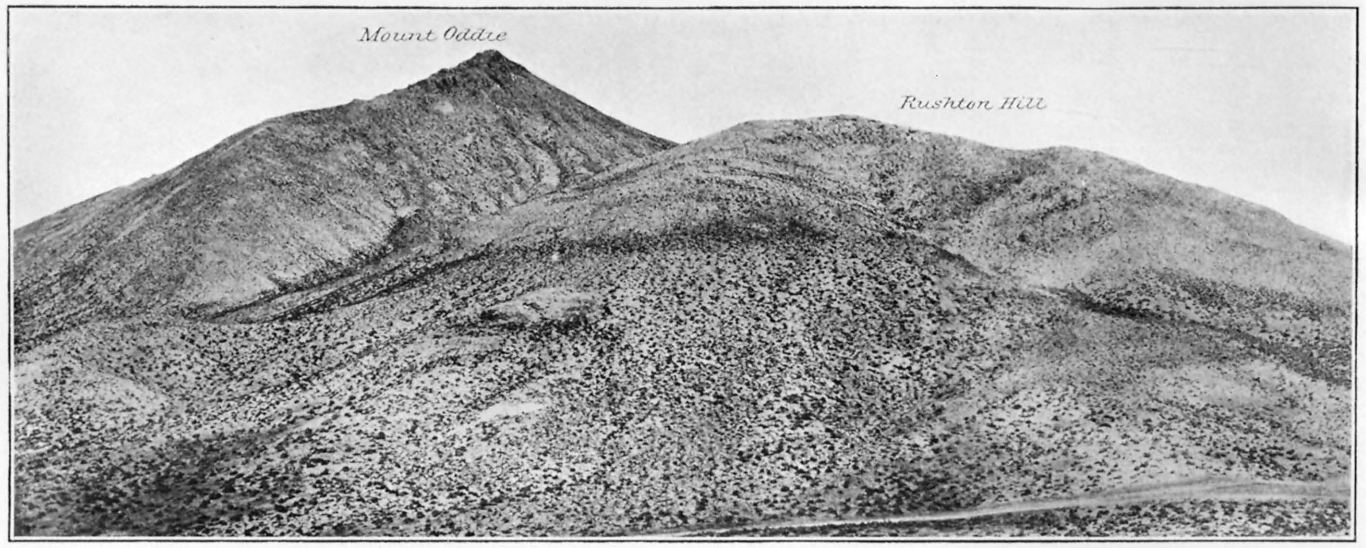


A



B

BUTLER MOUNTAIN.



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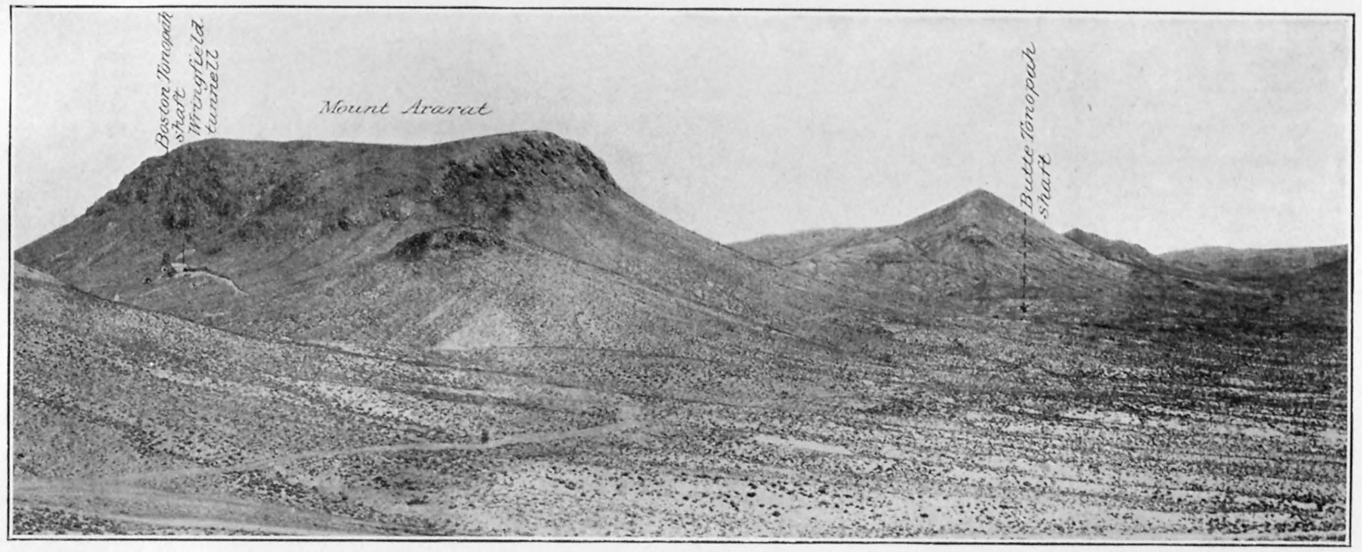
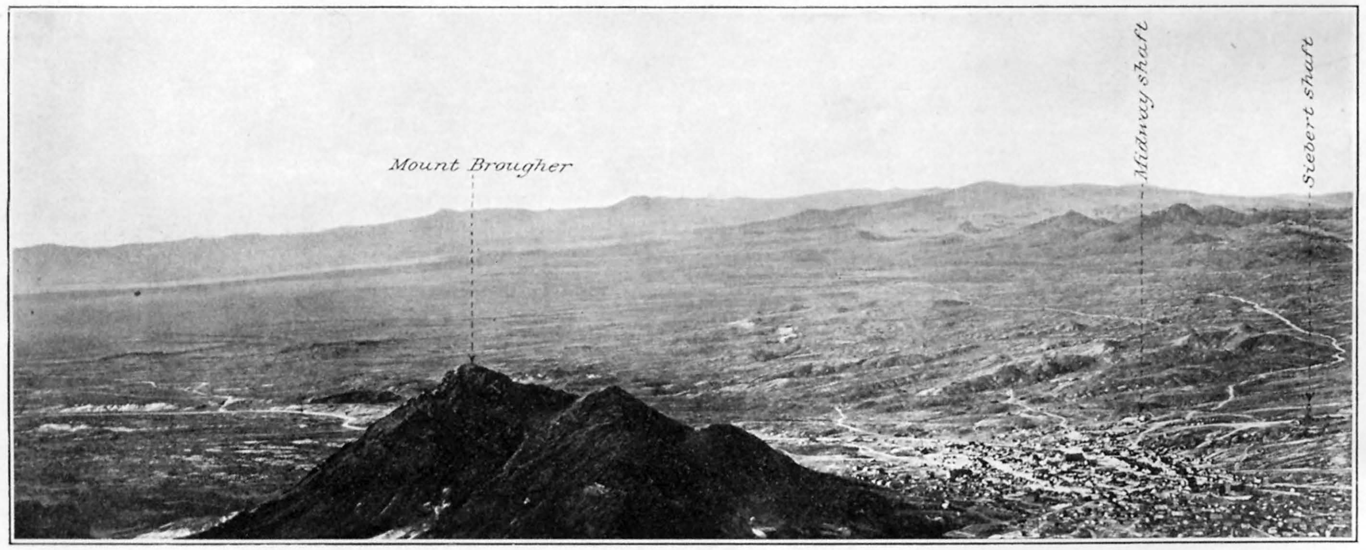


D

VIEW LOOKING NORTHWEST FROM A POINT BETWEEN RUSHTON HILL AND GOLDEN MOUNTAIN.



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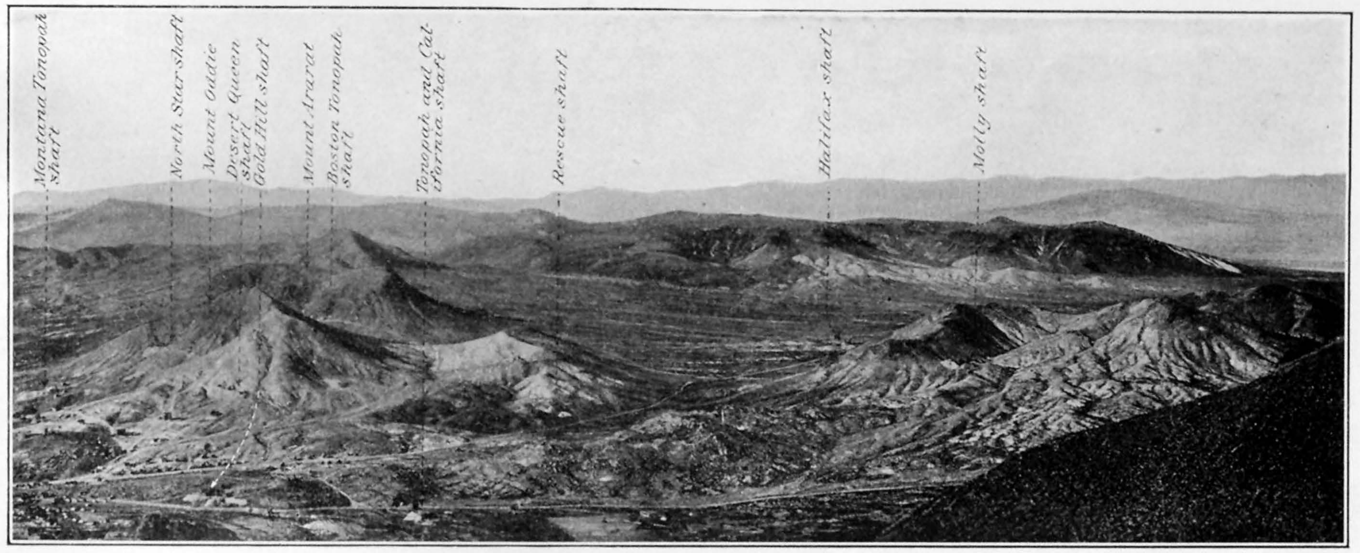


F

VIEW NORTH FROM BUTLER MOUNTAIN.

these tongues have sometimes penetrated a considerable distance, and there the lava forms dikes, sometimes thinning to a very great degree or showing only in occasional outcrops as "intermittent" dikes. The lava in these dikes is glassy, like the contact phase of the main mass.

Included basalt.—Inclusions of basalt were found in the Brougher dacite in several places. In two places dikes sent off from the Golden Mountain neck along fault planes contain augite-hornblende-basalt, like that in place on Siebert Mountain. Besides augite and hornblende, anorthite and labradorite-bytownite feldspar were recognized in these inclusions. At the north base of Butler Mountain, within the conspicuous hollow there, the dacite is packed full of inclusions of similar basalt.

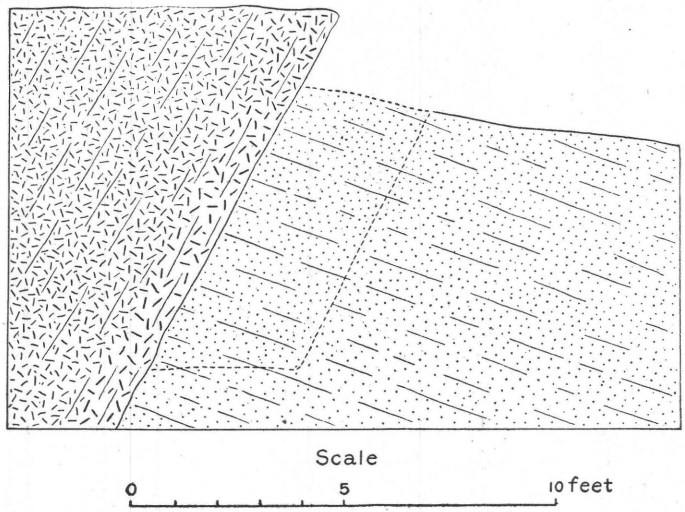


FIG. 5.—Vertical section showing contact of the Golden Mountain dacite, glassy along the margin, with Siebert tuff (lake beds). Location due east of Golden Peak. Dotted outlines indicate a prospecting pit sunk in the tuff at the contact.

Vestiges of cinder cones.—At various points around the base of Butler Mountain, close to the intrusive neck, is a coarse volcanic agglomerate of a kind not seen at any greater distance from the mountain. It consists of large angular blocks of volcanic rocks, alternating with finer breccia and ash. On the south side of Butler Mountain this material has a thickness of about 200 feet, and contains bowlders up to 5 feet in diameter. These bowlders consist of lava resembling the Tonopah rhyolite-dacite. Immediately adjacent to the intrusive Brougher dacite contact on this side of the mountain there was noted a bowlder of similar Tonopah rhyolite-dacite that was 30 feet in diameter and lay in the Siebert tuffs, as if it had dropped into them when they were soft mud. On the north side of the mountain similar agglomerates were observed, and here the blocks were chiefly of glassy dacite. This indicates an accumulation of volcanic cinders and bombs, and their localization around the base of Butler Mountain shows that this was the site of a cinder and bomb cone, which was built up as a result of the resumption of volcanic activity at the close of the tuff period and perhaps following the slight basaltic eruptions (manifested within the area mapped only on Siebert Mountain). On the southwest slope of Brougher Mountain, also, a coarse agglomerate was observed in one place; and it is very likely that this and other of the mountains of this group have had a similar history.

Formation of the present Brougher dacite.—After these explosions a column of lava rose and filled the vent. It is not likely that this lava ever overflowed, for no traces of flows have been found, and from such important vents the lava, if poured out, would be sufficient in quantity not to have been wholly swept away by erosion.

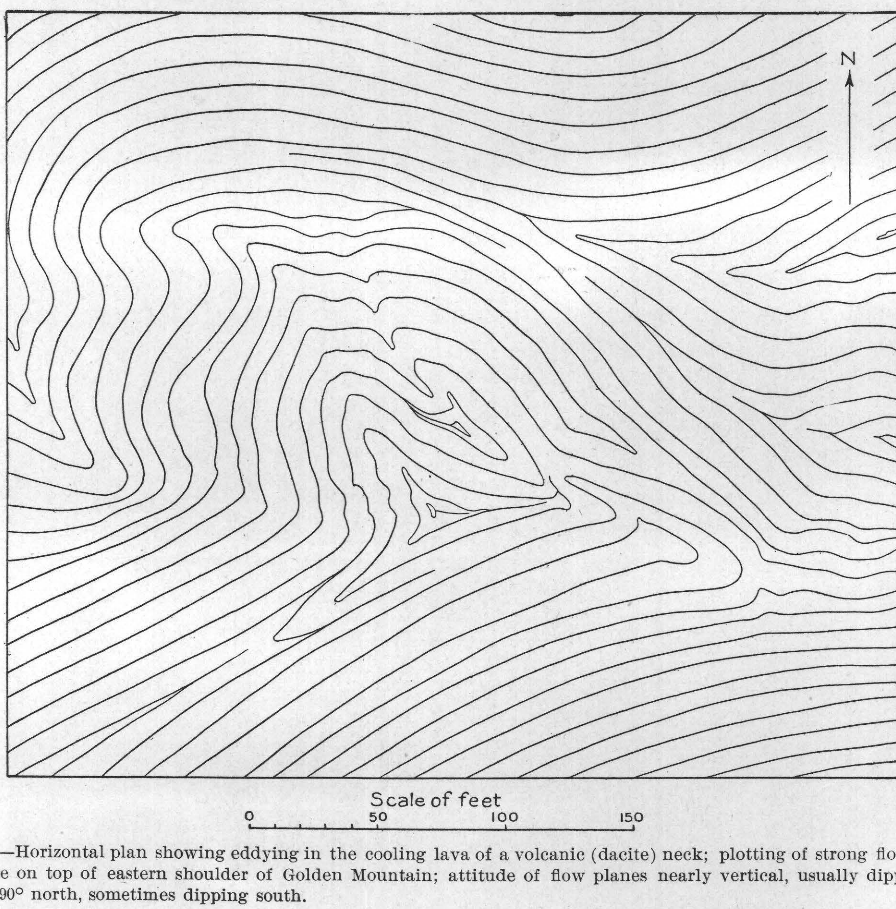
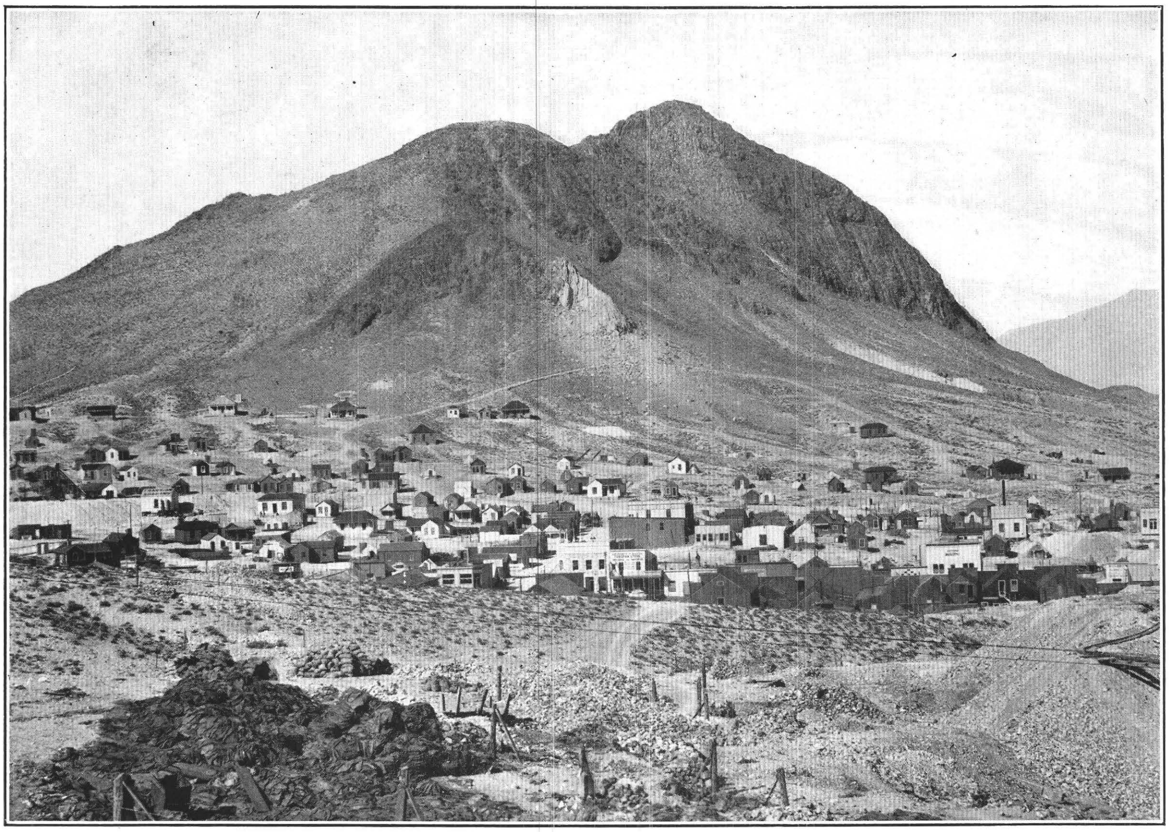
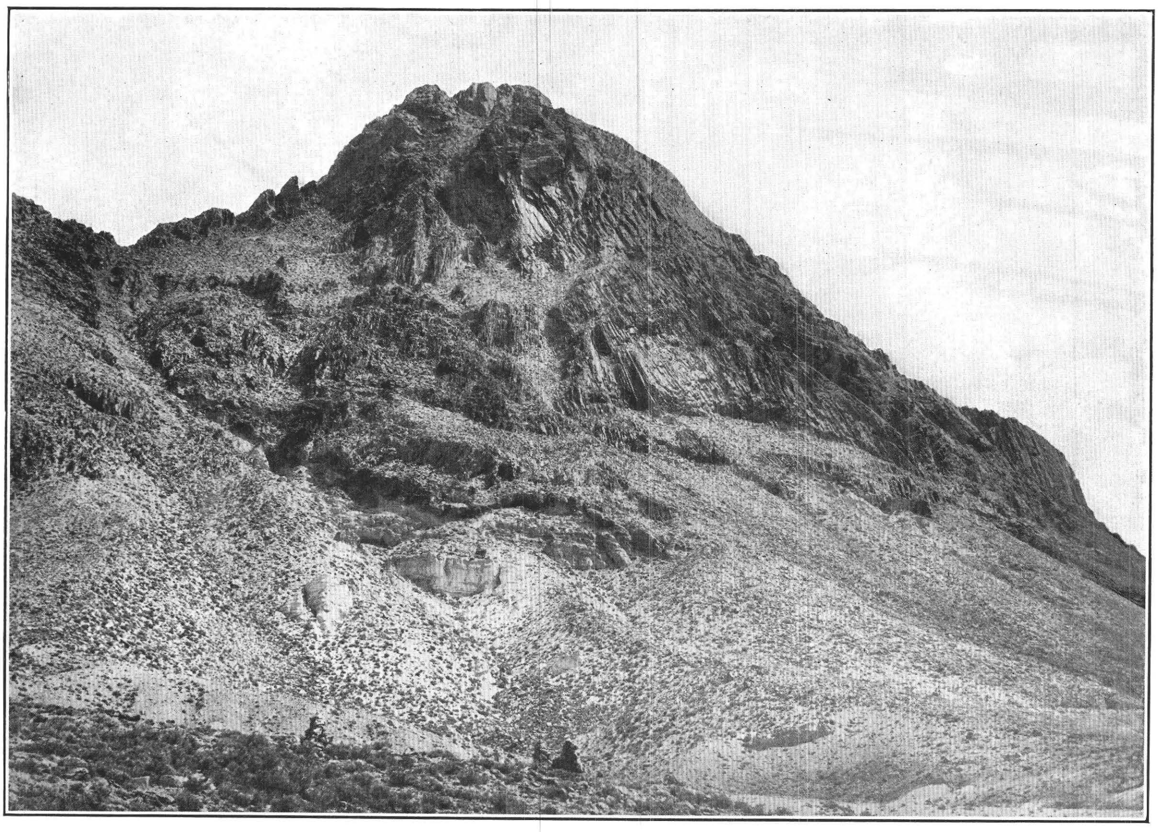


FIG. 6.—Horizontal plan showing eddying in the cooling lava of a volcanic (dacite) neck; plotting of strong flow structure on top of eastern shoulder of Golden Mountain; attitude of flow planes nearly vertical, usually dipping 70° to 90° north, sometimes dipping south.

Flow structure and other phenomena.—The flow structure in these necks was carefully observed, and the conclusion was reached that only at the contact do the flow lines indicate the direction of the original flow. Away from the contact the lines follow all imaginable curves (fig. 6). It is plain that after the rapid cooling of the glassy lava near the contacts the liquid material standing in the neck circulated and eddied extensively before cooling. There may be seen in



A. BROUGHER MOUNTAIN AND TONOPAH, SEEN FROM MIZPAH HILL.



B BUTLER MOUNTAIN FROM EAST BASE, SHOWING COLUMNAR DACITE ABOVE AND STRATIFIED SIEBERT TUFFS BELOW.

these mountains columnar jointing, small gaping cracks caused by the stretching of the nearly cooled lava, caves formed by the collapse of highly vesicular lava, platy structure or parting parallel to the contacts, and other interesting volcanic phenomena.

Faulting due to Brougher dacite eruptions.—The Brougher dacite is confined to the southern half of the area mapped. This general dacite area is also coextensive with the region of observed complicated faulting, and a connection between the dacite intrusion and the faulting is suggested. The faulting occurred subsequent to the eruption of all the rocks older than this dacite, while the dacite is unaffected by it. This complexly faulted southern half of the area is also downsunken in comparison with the little-faulted northern portion. Near the dacite necks the observed faults are rather more numerous than elsewhere, and in many instances the blocks adjacent to the dacite have been downsunken in reference to blocks farther away (Pl. VII). From these intrusive necks the faults run in a roughly radiating fashion and seem to follow no regular system of trend (Pl. VIII). Detailed study of the contact phenomena of the dacite shows that the minute faults in the tuffs at these points generally have their downthrown side next the dacite.

From these facts the following conclusions have been reached. The faulting was chiefly initiated by the intrusion of the massive dacite necks (the rhyolite necks were probably not so bulky).[a] After this intrusion and subsequent eruption there was a collapse and a sinking at the vents. As the still liquid lava sank it dragged downward the adjacent blocks of the intruded rock, accentuating the faults and causing the described phenomena of downfaulting in the vicinity of the dacite.

In reference to this phenomenon of subsidence around volcanic vents Scrope[b] wrote:

"It would appear, however, that in some cases the eruption of volcanic matter is accompanied by the subsidence not only of the column of lava which had risen within the vent, but also of the neighboring surface rocks themselves. Several of the cinder cones of New Zealand, as described by Mr. Heaphy, have been thrown up on a line of fault in the Tertiary strata whose upcast forms the sea cliff, and show a clear synclinal depression of the elsewhere horizontal beds, on either side toward the eruptive vent."

Tuff dikes near contacts.—At some points along the contact of the Butler Mountain neck with the Siebert tuffs, particularly on the south and east sides, sand and tuff dikes are observed. They are composed of yellow tuff and included frag-

[a] In the North Star and Desert Queen mine workings, along the southeastern part of Mount Oddie, for example, the dip of the lower contact of the rhyolite into the mountain is very flat.

[b] Volcanoes, p. 225.

ments of the glassy contact phase of the dacite, and are intrusive into the Siebert tuffs. Sometimes these dikes are composed mainly of glassy dacite fragments, sometimes of clear sand. They often follow the exact intrusive contact and are never far from it (fig. 7). Detailed study shows that these breccias are truly dikes that have been injected in a plastic condition (fig. 8). This injection followed the intrusion, and the intrusive material was probably a mixture of ascending hot waters, consequent upon the eruption, with tuff and dacite fragments.

Mineral composition.—Microscopically the Brougher dacite shows a brown, glassy groundmass, which is sometimes finely crystalline and contains frequently

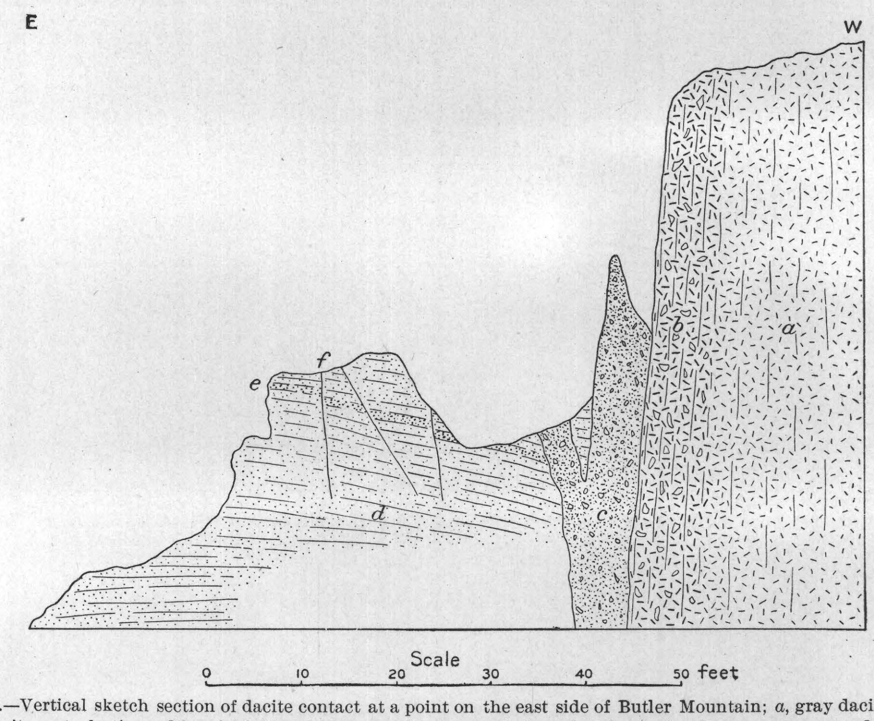


FIG. 7.—Vertical sketch section of dacite contact at a point on the east side of Butler Mountain; *a*, gray dacite; *b*, glassy dacite, autoclastic; *c*, dike of friable, partly consolidated detrital sand and angular fragments composed of material derived from the tuff and from dacite glass; *d*, finely stratified Siebert tuffs (lake beds); *e*, coarser layer of tuffs; *f*, faults. The sketch shows clastic dikes consequent upon marginal fissuring around the dacite, and downfaulting toward the contact.

broken porphyritic crystals of quartz, orthoclase, andesine or andesine-oligoclase, biotite, and occasionally hornblende and augite. Magnetite and specular iron occur.

In the field the Golden Mountain dacite was judged to be more siliceous than that of the other mountains, and this observation has been borne out by microscopic and chemical analysis. It shows, indeed, a close relation to the Oddie rhyolite. However, the Golden Mountain rock is distinguished as dacitic by the greater abundance of porphyritic crystals, the frequent presence of elongated plagioclase feldspars, the greater amount of biotite, the characteristic brown, glassy groundmass, and the occurrence of occasional augite.

R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by W.J. Peters.
Surveyed in 1902-1903.

A. HOEN & CO. BALTIMORE.

DIAGRAM SHOWING RELATIVE DISPLACEMENT OF FAULT BLOCKS AND THEIR RELATION TO THE DACITE NECKS

By J. E. Spurr

1904

Scale

0 1/8 1/4 1/2 3/4 1 Mile

1000 500 0 1000 2000 3000 4000 Feet

200 100 0 500 1000 Meters

Contour interval 20 feet

Datum is mean sea level

Altitudes based on U.S.C. and G.S. determination of Lone Mountain

ODDIE RHYOLITE.

Location.—A white siliceous rhyolite makes up Mount Oddie (Pl. IX, *B*) and Rushton Hill, and extends irregularly in spurs and lobes away from their bases. A similar rhyolite occurs on the summit in an irregular area at the northwest base, but not on the slopes of Ararat Mountain, and in small patches around the north base of Brougher Mountain.

Contact phenomena of Oddie-Rushton neck.—By the same method of reasoning applied to the Brougher dacite necks, the conclusion is reached that Mount Oddie and Rushton Hill are also the necks of ancient volcanoes. On Mount Oddie and Rushton Hill the rhyolite is intrusive. At many points along the contact there is a vertical flow structure in the rhyolite and a platy structure parallel to it. The rhyolite of Rushton Hill, at its contact with the later andesite near the Rescue shaft, dips at an angle of 45° to 60° away from the hill. The Rescue shaft passed into this rhyolite and has continued in it several hundred feet up to the time of latest information.

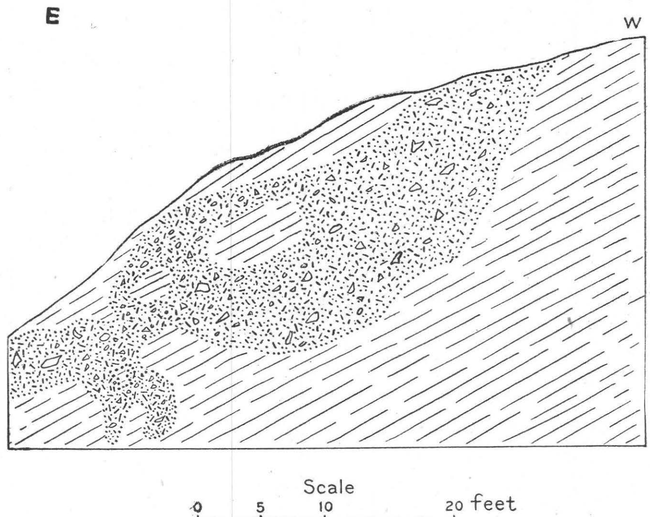


FIG. 8.—Vertical sketch section taken at a point on the east side of Butler Mountain, 100 feet below the contact of Butler dacite and tuff, showing dike of light-brown, semi-consolidated sand, of volcanic origin, containing angular fragments of dacite glass, intrusive into Siebert tuffs (lake beds).

Near the contact the rhyolite is frequently glassy and resembles the Tonopah rhyolite-dacite; it has also been silicified in many places subsequent to its eruption.

The rhyolite of Oddie and Rushton hills sends out irregular lobes into the surrounding rocks, which by reason of their superior hardness, as compared with the intruded later andesite, form ridges. These also are characterized by vertical flow lines and platy structure. As a whole the intrusion is elongated in an east-west direction, parallel to the previously noted elongation of the dacite necks.

Contact phenomena of Ararat neck.—The slopes of Ararat Mountain are formed by the Tonopah glassy rhyolite-dacite, which has already been described. The top, however, is of rhyolite like that of Mount Oddie, and the contact between the two is sharp. The white rhyolite at the top of the mountain has a roughly circular outline. At its margin it is brecciated, sometimes profoundly, and contains large veins, filled chiefly with calcite, which do not extend into the Tonopah rhyolite-dacite. That this brecciated and veined white rhyolite is intrusive is shown by the fact that it includes large blocks of the later andesite, where it comes in contact with that rock on the southwest side of the mountain. The brecciation of the white rhyolite near its contact with the Tonopah rhyolite-dacite is of a nature between a flow breccia and a friction breccia. It indicates clearly that movement continued in this uprising column of lava after hardening and stiffening had begun, so that the cooled portions were broken and dragged onward in a jumbled mass by the still viscous upward-flowing lava. The upward strain, continued after further hardening, resulted in marked sheeting, and even in gaping fissures, which were filled with calcite and other minerals by the waters which circulated through them after the eruption.

Smaller necks.—The small areas of this rhyolite near the base of Brougher Mountain are also probably necks. They are circular or roughly elliptical and of relatively small size. One just northeast of Brougher Mountain is about 400 feet by 150 feet in dimensions, and a shaft has been sunk 200 feet in it without encountering any change in the character of rock.

Relative age of Oddie rhyolite.—The later rhyolite is intrusive into the later andesite at many points—into the Fraction dacite breccia near Brougher Mountain, into the Tonopah glassy rhyolite-dacite breccia at Ararat Mountain and Brougher Mountain, and into the Siebert tuffs on the east side of Rushton Hill.

The faults near Mount Oddie and Rushton Hill, which sometimes show great displacement, seem to cease on reaching the rhyolite, like the faults that reach the dacite necks. At the West End shaft a column of this rhyolite has apparently ascended the fault plane which runs through the shaft. Therefore the rhyolite is younger than all the other formations excepting the Brougher dacite, and is also younger than the faulting. It is of apparently about the same age as the Brougher dacite, and, as has been explained, is of the same nature and origin. It is probable that the rhyolite and the siliceous Brougher dacite volcanoes were contemporaneous, and that adjacent vents gave outlet to slightly differing lavas. The petrologic relationship of the rhyolites to the dacites will presently be pointed out.

Mineral composition.—Examined microscopically, the rhyolite shows scattered porphyritic crystals in a generally fine-grained microgranular groundmass consisting mainly of quartz and feldspar. The porphyritic crystals consist of quartz, orthoclase, and occasional plagioclase, one determination of which shows andesine. Biotite is a sparse accessory. Original magnetite and sphene have been noted. On decomposition the rocks yield as secondary minerals quartz and sericite, sometimes kaolin.

R. U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by W. J. Peters.
Surveyed in 1902-1903.

A. HOEN & CO., BALTIMORE.

DIAGRAM SHOWING RELATIVE PROVINCES OCCUPIED BY THE BROUGHER DACITE AND THE ODDIE RHYOLITE NECKS, AND THE RELATION OF THE FAULT LINES TO THE FORMER

By J. E. Spurr
1904

Scale

0 1/8 1/4 1/2 3/4 1 Mile

1000 500 0 1000 2000 3000 4000 Feet

200 100 0 500 1000 Meters

Contour interval 20 feet
Datum is mean sea level
Altitudes based on U.S.C. and G.S. determination of Lone Mountain

LATEST RHYOLITE OR DACITE.

Location.—A few thin sheets of glassy rhyolite-dacite, which are of very little importance, do not clearly seem to be correlatable with the other volcanic formations described. One of the small areas of this lies on the south side of Mount Oddie. This rock is a black, very glassy, thin flow, overlying a coarse stratified tuff made up of small fragments of glass. It also overlies the later andesite in such a way as to indicate that the tuffs may have been eroded in places from the andesites before the glassy sheet was poured out.

Similar lava occurs around the base of Brougher Mountain. On the north side, immediately overlying the tuff, is a thin bed of such lava. There seems to be a slight unconformity between the two. Near by, the glassy lava seems to rest on the Tonopah glassy rhyolite-dacite, which normally underlies the Siebert tuffs, suggesting again that the tuff was eroded before the advent of the lava.

Age and origin.—These flows may have been emitted from the volcanoes of Butler, Brougher, and Oddie mountains during their earlier history, while the cinder cones were being built up, or as the writer is inclined to believe, mainly during their later history and so subsequent to the eruption of the Brougher dacite. They are not observed to be more than a few feet thick. In places small amounts of similar lava seem to have ascended as dikes, especially along faults. Where it occurs as dikes, however, it may be difficult to distinguish it from some of the glassy rhyolite-dacite lavas of other periods.

Mineral composition.—Microscopically the lava resembles closely the Tonopah rhyolite-dacite. In a groundmass of brown glass there are porphyritic crystals of quartz, orthoclase, striated feldspar, and biotite.

SIEBERT TUFF (LAKE BEDS).

LACUSTRINE ORIGIN.

The white stratified tuffs form a conspicuous feature of the geology near Tonopah. As a rule they are beautifully and uniformly bedded, and composed of well-assorted material. Where beds of conglomerate occur the pebbles are perfectly rounded. Since these sediments do not vary in character for thicknesses of several hundred feet, it is plain that they were laid down in a large body of standing water that lasted for a considerable length of time. That this body was a lake is indicated by numerous general considerations derived from the study of the geology of the surrounding region and by the presence of numerous fresh-water infusoria in some of the strata. In contrast to the general regular stratification, cross-bedded strata may occasionally be found, and at one place markings like those made by rills on a sandy shore were noted. These are probably shore and delta features.

Size of the lake.—The quantity of sediment which accumulated in this lake shows that it was deep, and if it had a proportionate areal extent it must have been a very important geographic feature, of which only a very small part was included in the area mapped.

Origin of lake basin.—The lake came into existence at the close of the most active period of the Tonopah rhyolite-dacite eruptions. These lavas, as well as those of the preceding Fraction dacite-breccia eruptions, were poured out on a land surface. The formation of the lake was due to a depression of the crust, forming an inclosed basin, or to a climatic change with increased rainfall, or to both combined. It is at least certain that there was such an inclosed basin, and while it may have been due to unknown causes, a hypothesis to account for it is suggested.

The extensive, active, and long-continued dacitic eruptions, which are attested by the Heller dacite, the Fraction dacite breccia, and the Tonopah glassy rhyolite-dacite not only poured out or showered upon the surface a great bulk of lava, but emitted an enormous volume of gas and steam, which mingled with the atmosphere. At the close of the active eruptions there ensued a period of comparative rest, as is indicated by the presence of fine-grained and undisturbed white tuffs, which were deposited for the most part slowly. As the incompletely occupied spaces left by the violent eruptions were filled the crust subsided of its own weight and the basin was formed. That such collapse occurs around centers of volcanism, consequent on the relief obtained by outbreaks, has been proved by European geologists.

Sir Archibald Geikie, in his study of the ancient volcanic rocks of Great Britain, refers to the plateau of Antrim in the north of Ireland, as follows:

> . . . Hence the original area over which the iron ore and its accompanying tuffs and clays were laid down can hardly have been less than 1,000 square miles. This extensive tract was evidently the site of a lake during the volcanic period, formed by a subsidence of the floor of the lower basalts. . . . For a long time quiet sedimentation went on in this lake, the only sign of volcanic energy during that time being the dust and stones that were thrown out and fell over the water basin or were washed into it by rains from the cones of the lava slopes around.
>
> It may here be remarked that the tendency to subsidence in the Antrim plateau seems to have characterized this region since an early part of the volcanic period. The lake in which the deposits now described accumulated was entirely effaced and overspread by the thick group of upper basalts. But long after the eruptions had ceased a renewed sinking of the ground gave rise to the sheet of water which now forms Lough Neagh.[a]

Lough Neagh, which occupies the deepest part of this hollow and covers about one-eighth of the whole area of subsidence, is the largest sheet of fresh water in the British Isles.[b]

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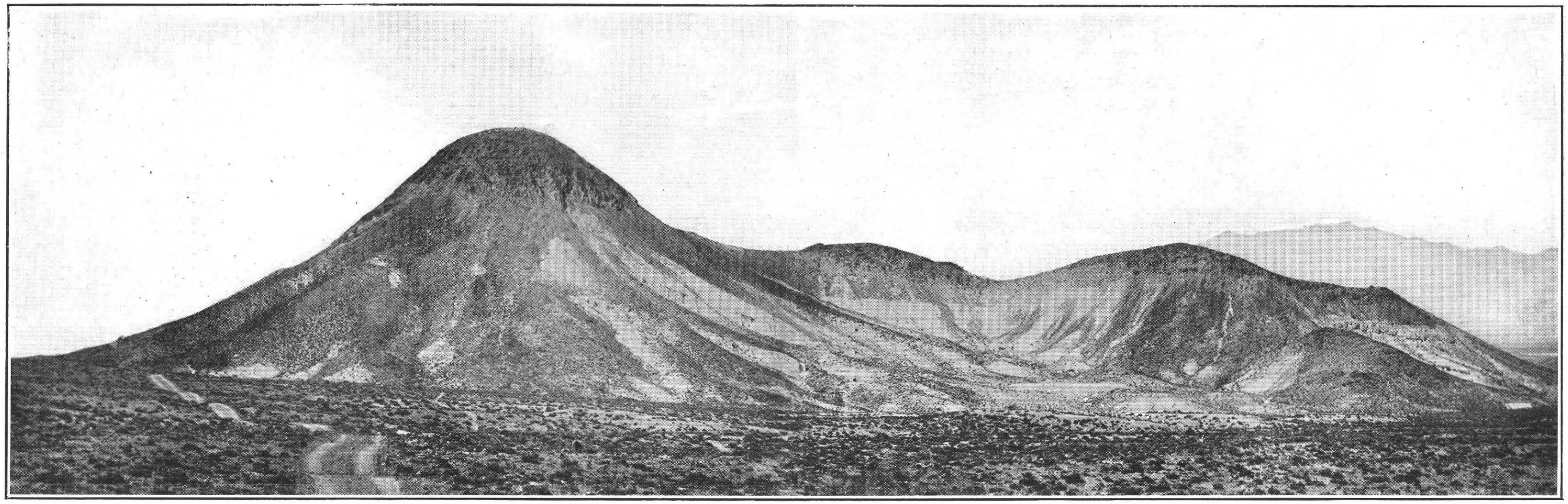
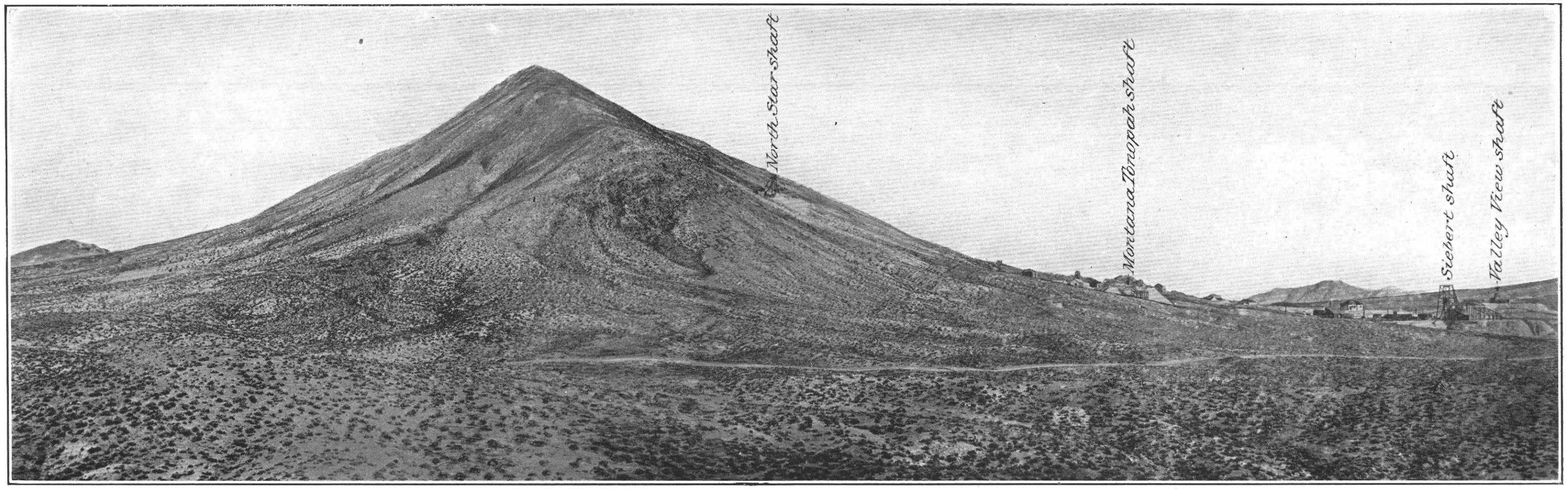
[a] Ancient Volcanoes of Great Britain, vol. 2, p. 205.

[b] Op. cit., p. 448.



A. SIEBERT MOUNTAIN FROM THE NORTHEAST.



B. MOUNT ODDIE FROM THE NORTHWEST.

We may conceive that after the cessation of the outflows of basalt the territory overlying the lava reservoir that had been emptied would tend to subside, partly by ruptures of the crust, producing faults, and partly by a downward movement of a more general kind. [a]

The same writer remarks, in his summary of observations: [b]

There seems to have been commonly a contraction and subsidence of the material in the vents, with a consequent dragging down or sagging of the rocks immediately outside, which are thus made to plunge steeply toward the necks.

Within the area shown on the Tonopah map a similar subsidence, due beyond question to the causes mentioned, has been proved by the writer to have followed the dacite outbreak which brought the formation of the tuff and the lake period to a close (p. 47).

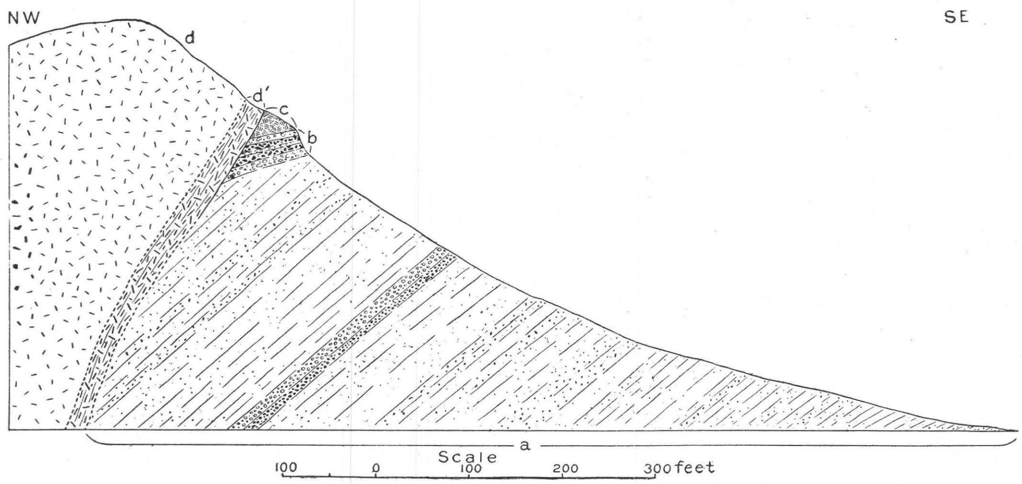


FIG. 9.—Vertical cross section of southeast side of Siebert Mountain, showing relations of Siebert tuffs (lake beds), basaltic flow and agglomerates, and Brougher dacite. a, finely stratified Siebert tuffs with occasional layers of rounded pumice fragments or waterworn lava; b, basaltic agglomerate with bombs, capped by solid basalt; c, basalt; d, Brougher dacite, intrusive neck; d′, glassy marginal facies of dacite.

THICKNESS OF SEDIMENTS.

On account of the complex faulting of the district the maximum thickness of the Siebert tuffs can not be given. On the east slope of Siebert Mountain (Pl. IX, *A*), however, an unbroken section about 600 feet in thickness is exposed (fig. 9). As neither the bottom nor the top was seen, it is likely the maximum is much more than 600 feet.

CONDITIONS DURING DEPOSITION.

The Siebert tuffs rest sometimes on the earlier andesite, as in the Tonopah and California shaft; on the later andesite, as southwest of Mount Oddie; or more often on the closely connected Fraction dacite breccia and the Tonopah rhyolite-dacite,

[a] Ancient Volcanoes of Great Britain, vol. 2, p. 450.

[b] Op. cit., p. 473.

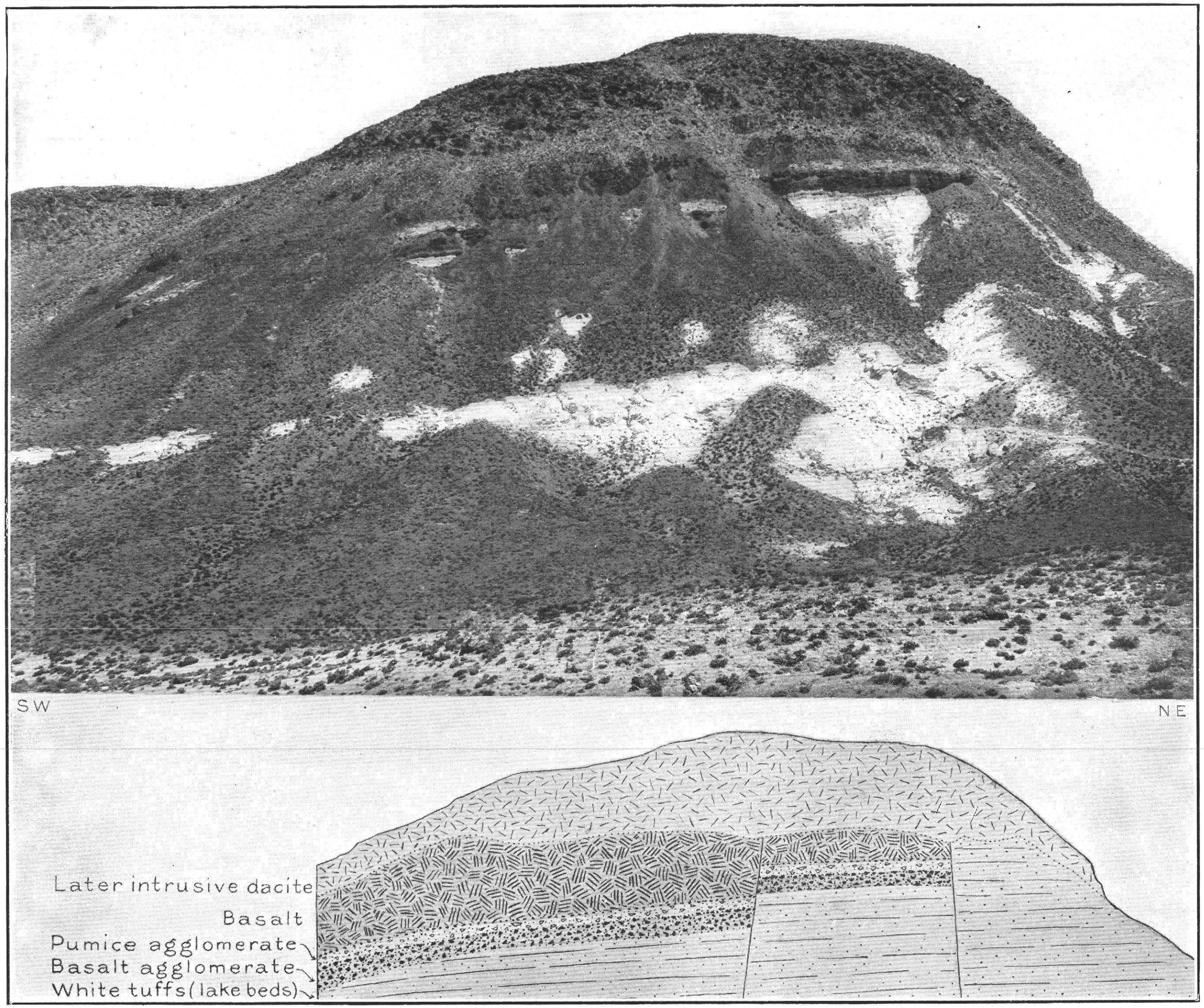
as is usually the case in the southern half of the area mapped. These facts show that before the deposition of the sediments considerable active erosion stripped off the débris of the earlier dacite-rhyolite eruptions and bared the underlying andesites. It is not unlikely, however, that the land which adjoined the lake and which contributed the sediment was vigorously worn away, and that the sediments were extended over this eroded region as a result of a rise in the lake or of a shifting of its boundaries due to crustal movements. This idea is strengthened by the fact that a careful macroscopic and microscopic study of the materials in the tuffs proves that they were derived mainly from the erosion of the glassy dacites and rhyolites. Pebbles in the tuffs, besides those of the rocks just mentioned, are frequently of the later andesite, well rounded.

EXPLOSIVE ERUPTIONS OF THE LAKE PERIOD.

It is probable that the quiet of the lake's existence was occasionally slightly disturbed by small local eruptions of rhyolitic or dacitic material. Stratified beds composed of rounded waterworn pumice fragments are sometimes found between fine-grained strata. The imperfect bedding shows that they were deposited more hastily than most of the strata, and each bed probably represents an explosive eruption. Sometimes angular fragments of obsidian occur in the pumice. Moreover, thin sheets of Tonopah rhyolite-dacite, similar to the main masses, are sometimes found within the tuff series.

UPLIFT TERMINATING LAKE PERIOD.

At one point on the northeast side of Siebert Mountain the tuff at its contact with the Siebert dacite body, which is here intrusive, contains a conglomerate from which may be made significant inferences as to the conditions prevailing at the time of its formation. This conglomerate is made up of rounded pebbles up to 4 inches in diameter, most of which are composed of the Tonopah rhyolite-dacite, but some are of later andesite. In it was found a fragment of silicified wood over a foot long. This conglomerate is exposed for only about 50 yards. It dips with the inclined tuffs, but is not continuous; in fact, it occupies a channel in the tuffs. The change between the tuff and the conglomerate is abrupt and complete, indicating a sudden change of conditions. All this suggests that these pebbles are old river gravels. If this is true, the tuffs were uplifted at the close of the lake period and became land. Immediately thereafter important outbreaks of lava occurred, and the hypothesis may be formulated that the accumulation of the lava beneath the future vents produced the uplift. A river, probably flowing from the north (where the later andesite is now and was then exposed), brought down the pebbles to this bed. That the banks of the stream were wooded is shown by the now silicified fragment.



FACE OF SIEBERT MOUNTAIN, FROM THE SOUTHEAST.

BASALTIC ERUPTIONS.

The conditions thus suggested could not have lasted for a long time, for at a short distance from the conglomerate, at about the same horizon (on the east side of Siebert Mountain near the summit), the white tuffs are overlain by beds of yellow pumice breccia, full of fragments of black, slaggy basalt, a rock not known to have been previously erupted. Small hollow spheres of pumice (lava bubbles) are present. Some layers are made up entirely of large, angular fragments of scoriaceous basalt. Over this lies a bed of black basalt 40 or 50 feet thick. This rude accumulation of pumice and scoriæ appears to lie unconformably on the tuffs, for it is nearly horizontal, while the tuffs have a decided dip to the west; and the same breccia appears at several other points on the mountain in contact with different horizons of the tuffs. The uplifted tuffs of the same age as the river conglomerate were probably tilted bodily to the west by a continuation of the disturbing uplift, and after this tilting new volcanic vents were opened and there occurred a violent explosion which scattered a relatively slight amount of basaltic material. This explosion was followed in the neighborhood of Siebert Mountain by the welling out of a thin sheet of slaggy basalt. On Brougher Mountain also a volcanic breccia overlies the tuffs, but here no basalt is exposed.

REGIONAL TILTING ACCOMPANYING UPLIFT.

The uplift which preceded the explosions was not local. The westward dip of the tuffs on Siebert Mountain is not essentially different from their general attitude wherever found in the area mapped. There is a notably persistent north-south strike, and a westward dip averaging perhaps 20°, independent of local phenomena These local phenomena bring about variations in the attitude; for example, near the great Butler Mountain neck, where, as will be presently explained, the rocks have been faulted and dragged down at the contact, there are places where the tuff is locally folded so that it dips toward the mountain.

BASALT.

LOCATION.

Basalt in place occurs in only one small area within the district mapped—near the top of Siebert Mountain (Pl. XI), although it was observed in three other places, close to the area. Near Tonopah, on the road from Sodaville, low hills of vesicular lava stand on the edge of the wash-covered desert valley. This lava is an augite-olivine-basalt, containing augite and reddish altered olivine in a microlitic groundmass consisting of feldspar, augite, olivine, and magnetite.

The top of a broad, black mountain just north of Ararat Mountain is alos covered with basalt of the kind just mentioned. A determination of one of the feldspars here showed anorthite. Similar lava forms the hill east of Golden Mountain and overlies the Fraction dacite breccia.

RELATIONS AND COMPOSITION OF BASALT OF SIEBERT MOUNTAIN.

Particulars concerning the age of these two occurrences can not be given, but the basalt on Siebert Mountain has been more carefully studied than that north of Ararat Mountain. The white tuffs which make up the bulk of the mountain are overlain by a breccia of yellow pumice containing fragments of scoriaceous basalt. This breccia probably rests unconformably on the tuffs, which are tilted, and is overlain by a flow of vesicular basalt 40 or 50 feet thick. This flow extends southwest of the mountain, beyond the limits of the area mapped. Basalt inclusions occur also in the Brougher dacites (see p. 45).

Under the microscope this basalt shows small porphyritic crystals in a fine holocrystalline groundmass consisting chiefly of feldspar and augite. The porphyritic crystals are predominating pale-green augite, brown hornblende partly or wholly altered to iron oxide by magmatic reactions, and feldspar.

AGE.

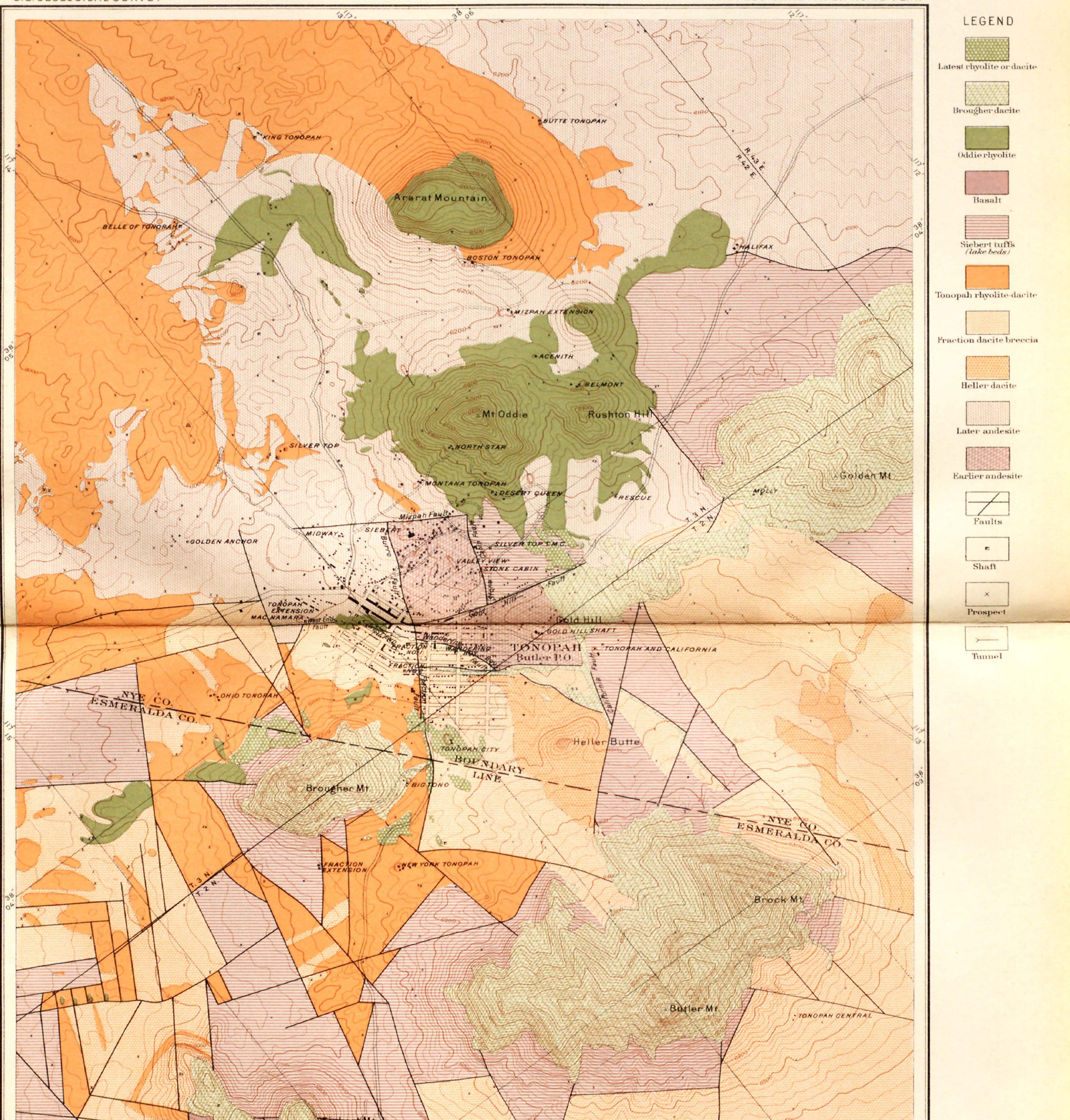
This basalt overlies the tuffs unconformably, so it must have been erupted subsequent to the tilting. It and the tuff are intruded by the neck of dacite which outcrops all over the summit, and which by its resistance to erosion has created the mountain. On the east side of the mountain a fault has displaced the basalt flow and the tuff, but has not affected the dacite (Pls. X, XI).

CHEMICAL COMPOSITION OF LAVAS.

For the purpose of comparison the analyses of the fresh rocks of the district have been assembled in the accompanying table. To represent the earlier andesite, since no fresh specimen is available, an ideal type of hornblende-mica-andesite (p. 217) has been substituted, practically identical with the analyses of the least altered earlier andesite except as to the amount of silica. The knowledge obtained by these analyses, though valuable, is only fragmentary, and more investigation would certainly show a greater variation.

TRANSITIONS IN SILICA CONTENT.

The analyses have been arranged according to their silica content, which shows the following differences: Between the basalt and the later andesite about 3 per cent; between the earlier and the later andesites approximately 6 per cent; between the earlier andesite and the least siliceous dacite about 6 per cent; and between this dacite and the siliceous rhyolite about 5 per cent. This transition of silica content is, then, fairly equable, but considering the analyses as a whole there is a marked break between 4 and 5—that is, between the andesite-basalts on the one hand and the dacite-rhyolites on the other. The same break is shown, even more plainly, in the iron and magnesia content, and, to a less degree, in the lime percentage.



R.U. Goode, Geographer in charge
Triangulation by U.S. Coast and Geodetic Survey
Topography by W.J. Peters
Surveyed in 1902-1903

GEOLOGIC MAP OF TONOPAH MINING DISTRICT, NEVADA

By J.E. Spurr

1904

Scale

0 1/8 1/4 1/2 3/4 1 Mile

1000 500 0 1000 2000 3000 5000 Feet

200 100 0 500 1000 Meters

Contour interval 20 feet

Datum is mean sea level

Altitudes based on U.S.C. and G.S. determination of Lone Mountain

A rather characteristic difference between the dacites and the rhyolites is the predominance of potash over soda in the latter; and in this particular the intermediate character of the Tonopah rhyolite-dacite is also seen.

Analyses of Tonopah lavas. [a]

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
SiO_2	53.94	56.26	57.51	62.16	71.71	72.31	73.00	75.56	75.66	76.57
Al_2O_3	....	16.18	16.55	16.45	14.00	13.79	....	....	....	....
Fe_2O_3	....	5.56	3.20	3.27	1.06	1.54	....	....	....	....
FeO	....	1.17	2.02	2.71	.51	.26	....	....	....	....
MgO	....	2.78	2.30	2.20	.43	.56	....	....	....	....
CaO	7.32	5.07	6.06	4.13	2.25	1.08	1.55	1.16	.47	....
Na_2O	3.89	3.25	2.76	4.07	3.21	2.56	3.50	4.20	1.70	.96
K_2O	2.09	3.43	2.81	3.45	4.41	4.66	4.71	4.50	4.94	5.81
H_2O-	....	2.07	1.45	....	.44	....	....	....	....	....
H_2O+	....	2.61	2.56	1.15	1.38	....	....	....	....	....
TiO_2	....	.73	.80	....	.28	.27	....	....	....	....
P_2O_5	....	.32	.30	....	.07	.07	....	....	....	....
	....	99.43	98.32	99.59	99.75	97.10	....	....	....	....

[a] Analyses 1, 7, 8, 9, and 10 are by Dr. E. T. Allen; analysis 2 by Dr. W. F. Hillebrand; analyses 3, 5, and 6 by Mr. George Steiger.

1. Basalt, Siebert Mountain (specimen 168). This basalt is not typical chemically, containing only 2.37 less silica than the andesite, analysis No. 2. It appears to fall, more accurately considered, into the group intermediate between the basalts and the andesites, for which the writer has proposed the name *aleutite*. For the same reasons that are given later for not using the term *latite*, however, the name basalt will be retained.
2. Augite-biotite-andesite (later andesite), Halifax shaft (specimen 349).
3. Augite-biotite-andesite (later andesite), Mizpah Extension shaft (specimen 225).
4. Hornblende-biotite-andesite (earlier andesite). (See p. 217.)
5. Mountain dacite, Brougher Mountain (specimen 359).
6. Glassy Tonopah rhyolite-dacite, 2,700 feet north of King Tonopah shaft (specimen 661).
7. Mountain dacite, Butler Mountain (specimen 368).
8. Mountain dacite, Golden Mountain (specimen 388).
9. Rhyolite, Belmont shaft, Rushton Hill (specimen 376).
10. Rhyolite, G. & H. tunnel, Mount Oddie (specimen 337).

CHEMICAL COMPOSITION OF THE DACITE-RHYOLITE SERIES.

Differences and relations.—The volcanic rocks which have been described as dacites and rhyolites often differ markedly in composition as well as in age. For example, the rock of Brougher and Butler mountains is quite different from that of Mount Oddie, as is evident to every one, be he geologist or not. Yet the two rocks are closely related and there are transitions between them, as represented, for example, in the rock in parts of Golden Mountain.

Comparison with Eureka and Washoe dacites and rhyolites.—It is important to ascertain the position of the Tonopah rocks with reference to (1) dacites and rhyolites which have been described by Becker and by Hague and Iddings from the neighboring and closely related districts of Washoe and Eureka (for these districts and their rocks will often be compared with Tonopah in the present report), and (2) to the system of igneous rocks as a whole. The comparison with the Washoe and Eureka rocks is shown by the following analyses,[a] which are arranged according to silica content.

Analyses of dacite and rhyolite from Tonopah and other districts in Nevada.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
SiO_2	67.03	69.96	71.71	72.31	73.00	73.07	73.09	73.91	75.56	75.66	75.69	76.57
Al_2O_3	16.27	15.79	14.00	13.79	......	11.18	14.47	15.29	......	......	12.26	......
Fe_2O_3	......	2.50	1.06	1.54	......	2.30	......	......	......	......	......	......
FeO	3.97	......	.51	.26	......	......	2.99	.89	......	......	2.93	......
MgO	1.19	.64	.43	.56	......	.39	......	......	......	......	......	......
CaO	3.42	1.73	2.25	1.08	1.55	2.02	1.13	.77	1.16	.47	1.13	......
Na_2O	2.93	3.80	3.21	2.56	3.50	1.19	2.77	3.62	4.20	1.70	3.01	.96
K_2O	3.96	4.12	4.41	4.66	4.71	6.84	5.07	4.79	4.50	4.94	4.74	5.81
TiO_2	.58	......	.28	.27	......	......	......	......	......	......	......	......
P_2O_5	.23	......	.07	.07	......	......	......	.07	......	......	.06	......
SO_3	......	......	.54	......	......	......	......	......	......	......	......	......

1. Dacite, Eureka, Nev.
2. Dacite, Washoe, Nev.
3. Brougher dacite, Brougher Mountain, Tonopah (specimen 359).
4. Tonopah rhyolite-dacite, Tonopah (specimen 661).
5. Brougher dacite, Butler Mountain, Tonopah (specimen 368).
6. Rhyolite, Washoe, Nev.
7. Rhyolite, Eureka, Nev.
8. Rhyolite, Eureka, Nev.
9. Brougher dacite, Golden Mountain, Tonopah (specimen 388).
10. Rhyolite, Rushton Hill, Tonopah (specimen 376).
11. Rhyolite, Eureka, Nev.
12. Rhyolite, Mount Oddie, Tonopah (specimen 337).

There is a close relation between Nos. 2 and 3, dacites from Washoe and Tonopah (Brougher Mountain). These rocks are plainly almost identical, and suggest the general correlation of the dacites of the two districts, although the high silica content of No. 9, dacite from Tonopah (Golden Mountain), has caused it to be placed in the table between a Eureka rhyolite and a Tonopah rhyolite.

Retention of the term dacite.—The analyses represent a series of closely related rocks which show a transition from No. 1, which has nearly the composition of an

[a] The Eureka and Washoe analyses are taken from Mon. U. S. Geol. Survey, vol. 20, pp. 264, 282.

andesite, to No. 12, an extremely siliceous and potassic rhyolite.[a] Separation of this series into dacites and rhyolites is evidently largely arbitrary; but the dacites and rhyolites of Tonopah appear to be roughly comparable to those of Eureka and Washoe, and as they are on the whole distinct rocks (in spite of the transitions) it is desirable to have separate field names for them. For this reason it seems advisable to the writer to retain the field name dacite for the less siliceous and alkalic of the dacite-rhyolite rocks at Tonopah.[b]

Rhyolitic nature of both dacites and rhyolites.—To determine the position of the Tonopah dacite-rhyolites in the system of igneous rocks the writer has compared their analyses with similar analyses. As almost all comparable rocks have been classed as rhyolites, this designation would apply to these rocks, and there would be no distinction between the white siliceous rock of Mount Oddie and the darker rock of Brougher Mountain. If the region had been mapped without strict accuracy and detail, therefore all these phases would probably have been included together and mapped collectively as rhyolites, and the significance of their relations would have been lost sight of.

Determination according to a quantitative classification.—The word rhyolite is part of the old-established classification, and its meaning is indefinite and inexact. Undoubtedly the most notable attempt at an exact classification of igneous rocks is that recently made by Cross, Iddings, Pirsson, and Washington.[c] Their own characterization of the system is as follows:

"This system is a chemico-mineralogical one. All igneous rocks are classified on the basis of their chemical composition, and all rocks of like chemical composition are grouped together. The definition of the chemical composition of a rock is expressed in terms of certain minerals capable of crystallizing from a magma of the given chemical composition, and the expression is quantitative."[d]

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[a] Such rocks have been called tordrillite by the writer. Am. Geologist, vol. 25, p. 230.

[b] Since the classic work done in Nevada by Zirkel, Hague and Iddings, Becker, and others, some further division in petrographic nomenclature has been made in rocks similar to those which they studied. Brögger has given the name monzonite to granular rocks occupying an intermediate chemical position between granites and diorites. This group therefore is made up of rocks which previously were classified either as granites or diorites. Dr. F. L. Ransome has followed out this idea and assigned a special name—latite—to extrusive rocks having a monzonitic composition. This new division is made up of rocks previously classified as rhyolites, dacites, and andesites. The Sierra Nevada volcanic province whose latites were described by Dr Ransome is probably part of the same petrographic province as that in which Nevada lies (Spurr, J. E., Jour. Geol., vol. 8, No. 7, p. 638). Latites, indeed, are abundant in Nevada, and have there been described by the writer; and monzonites are also present (Spurr, J. E., Bull. U. S. Geol. Survey No. 208, pp. 53, 59, 73, 92, 108, 118, 122, 126, 141, 186). The latites correspond to a part of the dacites and andesites described by the earlier investigators in the region, as previously pointed out by the writer (Spurr, J. E., Jour. Geol., vol. 8, no. 7, p. 643). Thus a number of the dacite and andesite analyses given for the Washoe and Eureka rocks would to-day be doubtless classified as latite by most petrographers.

Under the newer nomenclature and subdivision, therefore, the rhyolitic series at Tonopah would pass with decreasing silica, increasing lime, and attendant changes to a *latite* rather than a *dacite*, and this is the classification which the writer would use were the Tonopah district an independent problem. Actually, however, the correlation of these Tonopah lavas with those already described at Washoe and Eureka, as well as other parts of Nevada (Spurr, J. E., Jour. Geol., vol. 8, no. 7, pp. 621–646), is a highly important feature of the investigation; and most of the previous work on this region has been stated simply in terms of basalt, andesite, dacite, and rhyolite. Thus the writer would be compelled to reorganize completely the literature of the province in order not to introduce more confusion than illumination, and this task he does not at present feel able or anxious to undertake.

[c] Quantitative Classification of Igneous Rocks, 1903.

[d] Washington, H. S., Chemical analyses of igneous rocks: Prof. Paper U. S. Geol. Survey, No. 14, p. 47.

Rocks of different mineralogical but similar chemical composition are not distinguished, therefore the classification is one of magmas, and is especially valuable in discussions of the relation of magmas.

The Tonopah dacite and rhyolite analyses (the last six in the table on p. 57) were classified according to this system. The results are as follows:

Position of Tonopah rhyolites and dacites in the quantitative classification.

No. anal. in table on p. 57.	Specimen No.	Field name.	Locality.	Class.	Order.	Rang.	Subrang.	Name.
5	359	Dacite	Brougher Mountain.	Persalane.	Quardofelic.	Domalkalic.	Sodipotassic.	Toscanose.
7	368	Brougher dacite.	Butler Mountain	do	do	do	do	Do.
8	388	do	Golden Mountain	do	do	do	do	Do.
6	661	Tonopah rhyolite-dacite.	½ mile N. of King Tonopah shaft.	do	Quarfelic	do	do	Tehamose.
9	376	Rhyolite	Belmont shaft	do	do	do	Dopotassic	Magdeburgose.
10	337	do	G. and H. tunnel, Mount Oddie.	do	do	do	do	Do.

Thus it is seen that all the Brougher dacite falls under one subrang, toscanose; the rhyolite falls under a quite distinct order, rang, and subrang, magdeburgose; while the Tonopah rhyolite-dacite is in the same order as the rhyolite (though nearly in the same order as the Brougher dacite) and otherwise like the Brougher dacite; so that it falls into the subrang tehamose.

These divisions correspond to the natural divisions; and the classification is evidently in this case a suitable one.

It may be added that the dacite from Washoe, Nev. (analysis No. 2 in table on page 58), is classified by Washington[a] as toscanose, like the Tonopah dacites, and rhyolite from Eureka, Nev. (analysis No. 7, p. 58), as mihalose (near dellenose).[b] It is of the same order and rang as the Tonopah rhyolite-dacite of Tonopah, but of a dopotassic subrang, like the Tonopah rhyolite, and is, therefore, intermediate between these two Tonopah rocks.

Varying composition of lavas in different vents.—The transition phases of the dacite-rhyolite are not limited to small areas, but are represented by large masses; so that there is no fixed point, either theoretically or in the field, where one can be separated from the other. Each vent, now represented by a more or less separated and isolated volcanic plug, seems to have ejected nearly homogeneous lavas that differed slightly in composition from the lavas from neighboring vents. Thus the silica content in the dacite-rhyolite series was least in the Brougher Mountain vent, and increased successively in Butler Mountain, Golden Mountain, Rushton Hill, and Mount Oddie. The difference between the lava of Brougher Mountain and that of Mount Oddie is very considerable. When compared with the Brougher Mountain

[a] Op. cit., p. 167. [b] Op. cit., p. 131.

lava, the lava of Mount Oddie shows an increase of 4.86 per cent silica and of 1.41 per cent potash; and a decrease of 2.25 per cent soda, and probably 2 per cent lime. The course followed by this gradual change from Brougher Mountain to Mount Oddie by way of Butler Mountain, Golden Mountain, and Rushton Hill, is almost circular; and while more extended knowledge is desirable, it has probably a significance, for, as already explained, all these vents belonged to the same period, though they were not necessarily absolutely contemporaneous. They may well have been successive centers of outbreak in the order given.

THEORY OF DIFFERENTIATION OF TONOPAH LAVAS FROM A UNIFORM TYPE.

PSEUDOMORPHS IN RHYOLITE.

Character of pseudomorphs.—The description of the first specimen of rhyolite analyzed, as seen under the microscope (column 10 in table on p. 58), is as follows:

Specimen 376, from Belmont shaft, 50 feet down. This rock shows to the naked eye small fresh crystals of orthoclase (sanidine), quartz, and biotite in a pinkish-white groundmass. Abundant small, dull-white spots often have crystalline form, and seem to play the part of phenocrysts.

Under the microscope the rock is seen to be fresh. The sanidine shows sometimes Carlsbad twinning; it is often broken, and may be partly resorbed by the magma. The quartz is frequently in dihexahedral crystals, rounded and invaded by the resorbing magma. The biotite is fresh, in small crystals, and in very small amount. The groundmass is a fine microgranular aggregate of quartz and feldspar.

Some of the dull-white spots noticed in the hand specimen are without crystal outlines, while others have sharp outlines. Inspection of a number of longitudinal and cross sections leads to the conclusion that the forms are probably those of hornblende. The material, however, is evidently pseudomorphous, for it is a fine transparent aggregate of low single and double refraction, which under high powers is seen to be spherulitic. It separates itself from the rest of the groundmass chiefly by its greater fineness. In several cases small biotite crystals were observed in this aggregate, as large as many in the rest of the rock, and these were clustered together with a tendency to a diverging or radial arrangement.

The description of the second specimen of rhyolite analyzed is as follows:

Specimen 337, from face of G. and H. Tunnel, Mount Oddie, contains larger phenocrysts than usual of quartz, orthoclase, and a little biotite in a fine microgranular groundmass of quartz and orthoclase. The feldspar is glassy and fresh sanidine. The biotite contains apatite crystals, which are clear, not smoky like those of the andesites.

After the observations made on the areas apparently pseudomorphous after hornblende in No. 376, similar areas were looked for in this rock. They were at first not evident, but some definite though irregular areas of a fine aggregate similar to the pseudomorphs referred to were found. On close observation, however, faint but distinct crystal forms shaped like those of No. 337 were distinguished. The area occupied by these forms is surrounded by a border of similar fine aggregate, running irregularly off into the rest of the rock, which so obscures the crystal-like outline that it would not have been detected save for the observations made on No. 337. This aggregate is somewhat coarser than in No. 337, and its nature can be determined. It is semispherulitic and semigranular, and differs from the rest of the groundmass only in being slightly finer grained and containing a little more biotite. It is a fine mixture of quartz, orthoclase (sanidine), and biotite. Very small idiomorphic crystals, or phenocrysts, of sanidine form part of the aggregate. It thus appears that the original hornblende (in part pyroxene?) substance has been replaced by rhyolitic material.

Magmatic origin of pseudomorphs.—Since these pseudomorphs in No. 337 are often in direct contact with perfectly glassy sanidine, they must be of magmatic origin and must have been formed before or during the consolidation of the rhyolite. It is probable that they represent hornblende, which was an early mineral to crystallize and was afterwards decomposed by the siliceous magma and pseudomorphosed to biotite and the fine aggregate. The process was plainly a partial replacement of some material by others, for no mineral containing lime in any quantity resulted. Indeed, it is somewhat difficult to determine where the lime went to, for the analysis of the rock shows only so much lime as is commonly contained in orthoclase. It seems difficult to explain such a process as this without supposing a chemical change in the magma.

HORNBLENDE IN TONOPAH LAVAS.

No hornblende or augite has been found in the white Tonopah rhyolites. In the Tonopah rhyolite-dacite no fresh hornblende was seen, but there was found in it one pseudomorph after hornblende, marked by crystals of specular iron, the hornblende having been resorbed by the magma (p. 41). In the glassy Tonopah rhyolite-dacite also only one small crystal of augite was seen out of very many thin sections examined. In the Brougher dacite hornblende is rare, but has been occasionally found. A specimen of dacite from Golden Mountain, at a point south of the top of Mount Oddie, showed a single fresh hornblende crystal. This Golden Mountain dacite is, as shown by the analyses (p. 58), closely related to the near-by Oddie rhyolite, so that, as has already been mentioned, the two must be considered as variations of a single magma. Augite is rare in the Brougher dacite, but is occasionally met, more often than hornblende. In all the dacites and rhyolites, the dark mineral is almost exclusively biotite. The earlier andesite, on the other hand, contains abundantly both hornblende and biotite, with some augite, while the later andesite contains much augite and biotite, with some hornblende. The basalt, again, contains abundantly both augite and hornblende, the latter often partly or wholly resorbed by magmatic action and pseudomorphosed into aggregates of iron-oxide crystals. No biotite is present. The presence, or evidence of the former presence, of hornblende is thus shown in nearly all the Tonopah volcanics, from the very siliceous to the very basic, and emphasizes their consanguinity. But the number of hornblende crystals (it is possible that some of these pseudomorphs were also after augite) indicated by the pseudomorphs above described as having been originally present in the unconsolidated rhyolitic magma is large, being equaled only in the earlier andesites and the basalts.

DERIVATION OF RHYOLITE AND BASALT FROM INTERMEDIATE MAGMA.

Statement of theory.—The Oddie rhyolite is considerably separated from the earlier andesites in age, while it was nearly contemporaneous with the basalt of Siebert Mountain. In this basalt the partly corroded and pseudomorphosed hornblende crystals indicate that the hornblende was an earlier crystallization, not entirely stable under the later conditions of the magma, which produced naturally augite. That is to say, both the highly siliceous rhyolitic magma and the basic basaltic magma developed, as first mineral, hornblende, which in each case was unsuited to later conditions; the magma of the rhyolite became more siliceous and alkaline, so that biotite was formed as the dark mineral, and that only sparingly; the magma of the basalt became more basic and calcareous, so that abundant augite was formed. If this is so, then these two magmas at the time of the first hornblende crystallization must have been more nearly intermediate in nature and approached each other more closely; and as they were erupted at nearly the same locality they may possibly have been nearly or quite the same. Such a common intermediate magma might have a composition like that, for example, of an andesite. These considerations would harmonize with the hypothesis that the writer adopted several years ago, that the contemporaneous "complementary" rhyolites and basalts of the Great Basin region were the results of the splitting up of a magma of intermediate composition.[a]

Rhyolite-basalt differentiation theory tested by analyses.—Complete analyses of the basalt and of the Oddie rhyolite were, unfortunately, not made; one partial analysis of each shows the relative amounts of silica, lime, and the alkalies. These analyses may be compared in considering the theory that the basalt and the rhyolite are the

[a] Succession and relation of the lavas of the Great Basin: Jour. Geol., vol. 8, pp. 621-646.

two parts of an original andesitic magma. The average of the analyses of these rocks resembles the analysis of the type of hornblende-mica-andesite, taken as a standard in default of any fresh andesite of this kind in Tonopah (p. 217).

Comparison of the means of the analyses of rhyolitic and basaltic rocks of Tonopah with those of andesitic rocks.

	1 (376).	2 (168).	3.	4.	5.	6.
SiO_2	75.66	53.94	64.80	62.16	65.13	65.68
CaO	.47	7.32	3.89	4.13	3.62	3.50
Na_2O	1.70	3.89	2.79	4.07	2.93	3.20
K_2O	4.94	2.09	3.51	3.45	3.96	3.37

1. Siliceous rhyolite, Belmont shaft.
2. Basalt, Mount Siebert.
3. Average of 1 and 2.
4. Average type of andesite.
5. Andesitic pearlite, Eureka.[a]
6. Mica-andesite, Washoe.[b]

COMPLEMENTARY NATURE OF DACITES AND LATER ANDESITES.

The fact that the rhyolite and basalt of the district were nearly contemporaneous and probably complementary, and were perhaps derived from an original magma like that of the earlier andesite, suggests that the later andesites and dacites, whose eruptions in a general way intervened[c] between those of the earlier andesite and of the rhyolite-basalt, may also be complementary and represent an earlier stage in the differentiation.

There is available a single complete analysis of the dacite made from a typical specimen of the Brougher dacite[d] of Brougher Mountain (No. 359). There are, as before stated, two complete analyses of the fresh later andesites (Nos. 225 and 349, p. 57). To determine how far the dacite and later andesite may be complementary, these analyses have been added together and halved.

The average of No. 349, perhaps the freshest specimen of later andesite, and of No. 359 (dacite) is given in column 1 of the following table. The average of two analyses of fresh later andesite (Nos. 349 and 225) was averaged with the dacite analysis. The result is given in column 2.

[a] Mon. U. S. Geol. Survey, vol. 20, p. 264.

[b] Ibid., p. 282.

[c] This applies to the Heller dacite, the Fraction dacite breccia, and the Tonopah glassy rhyolite-dacite. The Brougher dacite is an exception, immediately succeeding the basalt eruption of Mount Siebert, and being probably nearly contemporaneous with the Oddie rhyolite.

[d] Since this part of the report was written, an analysis was made of the glassy Tonopah rhyolite-dacite (No. 661) north of the King Tonopah shaft, as given on p. 57. This analysis has not been introduced into these calculations, since it offers no new but only corroboratory evidence concerning conclusions here set forth. This will appear from the following average of the glassy Tonopah rhyolite-dacite (No. 661) with fresh later andesite (No. 349).

SiO_2, 64.28; Al_2O_3, 14.98; Fe_2O_3, 3.55; FeO, 0.71; MgO, 1.67; CaO, 3.07; Na_2O, 2.95; K_2O, 4.04.

Mean composition of Tonopah dacites and later andesites compared with composition of early andesite.

	1.	2.	3.	4.
SiO_2	63.98	64.29	65.68	65.13
Al_2O_3	15.09	15.18	15.87	15.73
Fe_2O_3	3.31	2.72	1.78	2.24
FeO	.84	1.05	1.25	1.86
MgO	1.60	1.48	1.79	1.49
CaO	3.66	3.90	3.50	3.62
Na_2O	3.15	3.08	3.20	2.93
K_2O	3.92	3.76	3.37	3.96

To compare these results with known rocks, the nearest analyses of Washoe and Eureka rocks are also given above. No. 3 is mica-andesite from Washoe,[a] already twice referred to; No. 4 is andesitic pearlite from Eureka. These two rocks from Eureka and Washoe are among those which are regarded (p. 219) as closely similar to the earlier andesite of Tonopah.

By comparison of the different analyses it is seen that the dacite and the later andesite of Tonopah added together produce an andesite of intermediate composition, such as is usually a hornblende-andesite or a hornblende-mica-andesite. Moreover, the amounts of silica, lime, soda, and potash in this average are strikingly like those in the average of the partial analyses of basalt and rhyolite, as is shown by the following table:

Analyses of siliceous andesite compared with mean analysis of rhyolite and basalt and mean analysis of dacite and later andesite.

	1.	2.		3.	4.
		a.	b.		
SiO_2	64.80	63.98	64.29	....	65.68
CaO	3.89	3.66	3.90	4.27	3.50
Na_2O	2.79	3.15	3.08	4.08	3.20
K_2O	3.51	3.92	3.76	3.17	3.37

1. Average of rhyolite and basalt (Nos. 376 and 168, p. 64).
2. Averages of later andesite and dacite (see table above).
3. Earlier andesite, Tonopah (p. 216).
4. Mica-andesite, Washoe.

Further averages of the silica, lime, soda, and potash of the dacite and later andesite may be had by combining with the andesite analyses the partial analyses of the dacite (No. 368) from the east end of Butler Mountain and of the dacite

[a] Mon. U. S. Geol. Survey, vol. 20, p. 282.

(No. 388) from the south side of Golden Mountain. If each of these is combined separately with the later andesite analysis, No. 349, the result is as follows:

Comparison of mean analyses of dacites and andesites.

	1 (349 and 368).	2 (349 and 388).	3.
SiO_2	64.63	65.91	65.15
CaO	3.31	3.11	3.60
Na_2O	3.37	3.62	3.29
K_2O	4.07	3.96	3.83

1, 2. Averages of later andesite and dacite.

3. The average of the fresh later andesite specimens 349 and 225 is averaged with the average of the three dacite analyses, 359, 368, and 388.

STATEMENT OF DIFFERENTIATION THEORY.

These considerations suggest that an original magma of composition similar to that of the earlier andesite has split up by differentiation, first into a more basic andesite (later andesite) and a siliceous dacite, and later, by continuation of the process, into a siliceous rhyolite and a basalt, as follows:[a]

Intermediate andesite.
Basic andesite. Siliceous dacite.
Basalt. Siliceous rhyolite.

SUMMARY OF GEOLOGICAL HISTORY.

Previous to the Tertiary period, Paleozoic limestone, intruded by granitic rocks, occupied this region. With the Tertiary began a period of volcanism, attended by the accumulation of lake sediments and subaerial deposits in inclosed basins. These deposits began in the Eocene, and beds belonging to this epoch are found near Tonopah, though not within the area mapped.

About 8 miles north of Tonopah and 1 mile west of the little mining camp of Ray the writer found a series of folded gravels, tuffs, lavas, and some white, thin limestones carrying numerous Eocene fossils. These were sent to Dr. W. H. Dall for determination, who remarks:

"According to the literature the fresh-water beds from which these fossils came have been referred by Doctor White and Meek to the Wasatch, or Bear River Laramie, Eocene, which is believed to be nearly the equivalent of the lower Eocene or Chickasawan marine Eocene (Lignitic of old authors) of our southeastern coastal plain. The species are:

[a] This corresponds with the scheme for the general succession of lavas in the Great Basin, as outlined by the writer (Jour. Geol., vol. 8, p. 643), and reaches the same conclusion that is already arrived at from independent considerations. It coincides, as the writer has previously pointed out, with the law previously deduced by Iddings from study of the volcanics of the Great Basin and other regions (Bull. Phil. Soc. Wash., vol. 12, p. 145).

"*Vivipara*, close to if not *V. couesi; Planorbis utahensis* Meek; *Ancylus* ? sp.; and a small bivalve, probably a *Corbicula*, but which I suspect to be the same as *Sphærium idahoënse* Meek. The specimens are merely internal casts, but if they are really *Corbicula* may prove to be *C. occidentalis* Meek. Their condition is too imperfect to be certain even of the genus, but the form closely approaches that of the figures of *S. idahoënse*."

These overlie the Paleozoic limestones near Ray. Similar beds were noted at several places between Ray and Sodaville. They are probably continuous with a part of the Tertiary deposits of the Silver Peak and Monte Cristo mountains.[a]

The oldest of the Tertiary rocks within the area of the Tonopah map are probably early Miocene, and so far as known the volcanic manifestation began with an eruption of andesite. In this andesite were formed fracture zones, along which heated waters ascended and deposited the valuable veins of the region. Another extensive eruption of similar but slightly more basic andesite followed, and then there was probably a period of volcanic rest and of denudation. Eruption was resumed by the outbreak of volcanoes, which alternately ejected siliceous dacite and poured out volcanic mud and frequently pumiceous lava. Some of the material may have been accumulated in water; most of it was probably deposited upon the land. Later, more glassy dacite of a slightly different composition ascended from below in irregular channels and poured out on the surface as thin sheets, or exploded and formed tuffs. Heated ascending waters followed the intrusive contacts of this lava and formed a group of quartz veins which contain gold and silver, but which are less important as regards strength and values than the veins formed after the eruption of the earlier andesite.

As these dacite-rhyolite eruptions quieted down a lake was formed in a basin, which may have been due to a depression of the crust consequent upon the previous copious eruptions. In this lake there accumulated quietly several hundred feet of sediments, with occasional light showers of ash from volcanoes, and, in the lower portions, some thin flows of dacite lava. Then the beds were lifted and became dry land. This uplift may have been due to the accumulation of additional volcanic material beneath this portion of the crust. Streams began to cut into the lake beds, the uplift was continued, and the whole district was tilted bodily to the west at an average angle of 20°. After this there were renewed outbursts, from probably new vents, which doubtless, corresponded, in part at least, to the present mountains. On Brougher and Butler mountains explosive eruptions occurred, the material being dacitic, like that immediately preceding the lake deposits. Cones of ash, cinders, and bombs were built up, and there were occasional very thin and scanty glassy flows. On Siebert

[a] Turner, H. W., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 192-244; Spurr, J. E., Bull. U. S. Geol. Survey No. 208, Pl. I, and pp. 105-106, 185.

Mountain there was an explosive outburst of basaltic material, followed by a thin basalt flow. Subsequently columns of liquid lava welled up and stood in the vents of the volcanoes, but did not outflow. Some of these were composed of dacite, some of rhyolite. As these columns cooled, heated waters rose along their contacts and deposited chalcedony and other minerals, and mud dikes were injected into the soft intruded rocks. The explosive outbreaks and the intrusion of these large necks must have broken the rocks into blocks and displaced the blocks, for at this time many faults were formed.

On the cessation of this dacite-rhyolite period of volcanic activity there was a collapse or depression around the vents. This sinking took place largely along the fault planes, and was especially prominent around the volcanic necks, which as they sagged dragged down blocks of the intruded older rocks with them.

Since this time, which was probably somewhere in the Pliocene, erosion has been active, stripping away the débris covering from the dacite-rhyolite necks, and leaving them as hills, and in general removing the surface layers from the hills to the desert valleys.

AGE OF THE ROCKS AT TONOPAH.

It is known that all these volcanic rocks are of Tertiary age. They belong to a series of lavas which occupy a large part of the Great Basin and whose Tertiary age has been established.

Place of Tonopah lavas in Great Basin volcanic history.—Some years ago[a] the writer attempted to classify the known facts concerning the nature and succession of the lavas in this region. He found that in many places the same lavas occur in much the same relative quantity, have nearly the same mineralogical composition, and give evidence of about the same relative age. Moreover, where two or more of these lavas are found close together, their order of succession is in general much the same, although at any given place certain members of the series may be lacking. In no one locality has the complete succession, as indicated by the correlation of all the sections, been observed; but in order to find it, gaps in one place may be filled from observations in another.

The result of this comparison was the separation of the Tertiary lavas into five successively erupted groups, as follows:

1. Rhyolites.
2. Hornblende-biotite-pyroxene-andesites, followed by dacites.
3. Rhyolites, sometimes accompanied by basalts.
4. Pyroxene-andesites.
5. Basalts, sometimes accompanied by rhyolites.

[a] Succession and relation of lavas in the Great Basin region: Jour. Geol., vol. 8, No. 7, pp. 621-646.

At Tonopah the succession of lavas, as above worked out, may be expressed as follows:

(a) Hornblende-biotite-andesite.
Biotite-augite-andesite.
(b) Dacites and rhyolites, with a little basalt.

These may be assumed to coincide with 2 and 3 of the above general grouping.

Probable Neocene age.—In the comparative study above referred to[a] available data were accumulated for determining roughly the age of the different groups with reference to the standard divisions of geologic time and to the different periods of Tertiary lakes as defined by King in his summary of the results of the Fortieth Parallel Survey. The eruption of group No. 2 (the hornblende-biotite-pyroxene-andesites, followed by the dacites) occurred between the end of the Eocene and the latter part of the Miocene, and was contemporaneous with the Miocene lakes, while that of No. 3 (rhyolites, sometimes accompanied by basalts) extended from the latter part of the Miocene well into the Pliocene, to the time of the beginning of the Pliocene Shoshone Lake. On the assumption that the correlation of the Tonopah lavas above given is correct, the andesites, both earlier and later, would belong to the first half of the Miocene and to the Miocene lake period; while the dacites, rhyolites, and basalts would extend from near the middle of the Miocene into the Pliocene, and would be partly contemporaneous with the latter part of the Miocene lake.

INFUSORIA IN THE SIEBERT TUFFS.

In the white tuffs at the east base of Siebert Mountain a stratum, not distinguished in the field from the more ordinary white rhyolitic or dacitic tuff, was shown by the microscope to be entirely made up of minute diatoms or infusoria. These were recognized by the writer as probably similar to species described by Mr. King as occurring in the deposits of the Miocene lakes of Nevada. At the time the recognized succession of lavas did not seem compatible with this idea, and the thin section was referred to Dr. Rufus M. Bagg, jr., for examination. Subsequently, it is proper to add, new discoveries as to the lava succession removed the difficulties in the way of considering the deposits Miocene.

Doctor Bagg's report follows:

"The material submitted me from Tonopah, Nev., for examination consists of innumerable diatoms which belong almost exclusively to two species, *Melosira granulata*, L. W. Bailey, and *Melosira varians*, Ag., the latter being considerably less abundant than the former.

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[a] Jour. Geol., vol. 8, No. 7, p. 637.

"This species, *Melosira granulata*, is synonymous with Ehrenberg's *Gallionella granulata*, and other synonyms for the species are *Melosira punctata*, *Gallionella marchica*, *G. procera*, and *G. tenerrima*.

"I can discover no species in the material sent me which would limit the deposit to the Miocene age, for the most abundant form, *M. granulata*, is living to-day in the Para River, South America, and elsewhere, as well as occurring fossil in Tertiary deposits.

"There is nothing to prevent this deposit from being regarded as Pliocene if stratigraphical evidence warrants this view, but the deposit was laid down in fresh water. In addition to the two species above given there are a few forms of *Coscinodiscus radiatus*."

COMPARISON OF SIEBERT TUFFS WITH MIOCENE PAH-UTE LAKE DEPOSITS.

Miocene deposits have been described by King in western Nevada[a] between the one hundred and seventeenth meridian and the Sierra Nevada. These deposits are always upturned, dipping from 10° to 25°, and they are frequently cut through and overflowed by basalt. They are usually made up of volcanic materials, and are several thousand feet thick. They contain beds of white and yellow infusorial silica, and on the northeast point of the Kawsoh Mountains, where the strata are tilted, eroded, and covered by caps of basaltic rock (as on Siebert Mountain in Tonapah), the following species were most abundant:

Gallionella granulata.
Gallionella sculpta.
Spongolithis acicularis.

These also were recognized:

Pinnubaria inæqualis, and
Coscinodiscus radiatus.

The age of these beds is determined more especially by molluscan and mammalian fossils, found elsewhere.

These beds, therefore, are of the same character as the Siebert tuff at Tonopah, which was deposited in the rhyolite-dacite period, and suggest that the lake in which the tuffs were deposited is identical with the Miocene Pah-Ute Lake of King.[b] The tilting and amount of erosion of the Tonopah white tuffs prevents any correlation with the Pliocene lake (Lake Shoshone)[c] beds, whose distribution frequently bears a close relation to the present topographic basins, and which are little disturbed.

[a] U. S. Geol. Expl. Fortieth Par., vol. 1, p. 412 et seq. [b] Op. cit., p. 454. [c] Op. cit., p. 456.

CONCLUSION.

It may be provisionally concluded that the volcanic rocks at Tonopah, from the earlier andesites to the Brougher dacites and the rhyolites, were erupted between the early Miocene and some time in the first half of the Pliocene.

The following, then, is the sequence of events as deciphered for the vicinity of Tonopah (fig. 10):

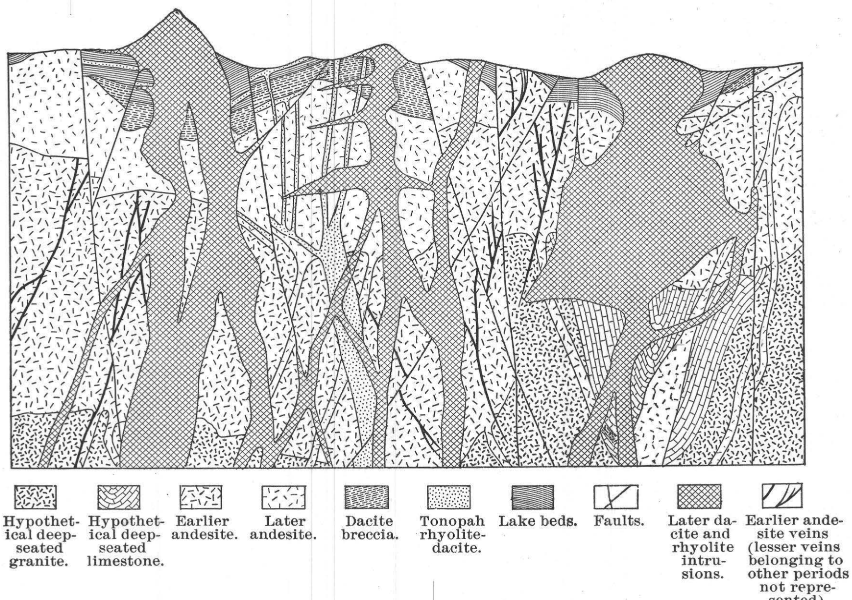


FIG. 10.—Ideal cross section of Tonopah rocks. (This section does not represent any particular place, and is simply intended to illustrate the geologic conditions as described in the text.)

Sequence of formations and events in the vicinity of Tonopah.

Earlier andesite.

Fracturing.

Vein formation. Primary minerals, quartz, adularia (valencianite), carbonates of lime, magnesium, and manganese, stephanite, polybasite, argentite, silver selenide, galena, pyrite, chalcopyrite, etc. Values good; gold and silver, silver predominant.

Erosion.

Later andesite.

Probable erosion.

Heller dacite.

Fraction dacite breccia.

Tonopah, rhyolite-dacite breccias, flows, and dikes, intermingled with slightly stratified or unstratified pumiceous or tuffaceous fragmental material.

Vein formation. Primary minerals, quartz, pyrite, barite. Values usually relatively low; gold and silver, gold apt to predominate.

Erosion.

Siebert tuffs (lake beds) deposited, with an occasional thin dacite flow.

Elevation of tuffs.

Tilting.

Basalt.

Chief faulting. Affects everything preceding.

Rhyolite intrusion (Ararat, Oddie, Rushton hills).

Vein formation. Primary minerals, quartz, chalcedony, calcite, siderite, pyrite, etc. Values low; gold and silver, gold apt to predominate.

Brougher dacite intrusion (Butler, Brougher, Golden, Siebert mountains).

Mineralization (chalcedony, manganese). Values slight to insignificant. Mud veins.

Contemporaneous,

Erosion.

Latest rhyolite-dacite flow (slopes of Oddie and Brougher).

Erosion.

PRINCIPLES OF FAULTING.

The chief recognized faulting of the district has already been described (p. 47) as attendant and consequent upon the Brougher dacite intrusion. The writer deems it unnecessary to attempt to describe separately the evidence and effect of each fault. Their locations and the general nature of their displacement are shown on the areal geology map. Their underground courses and intersections are doubtless complicated, and their study would constitute a geometrical problem in three dimensions for the solution of which there are in most cases no sufficient data. On account of the irregular thickness and extent of each of the volcanic formations at Tonopah, projection far beyond actual observation can not safely be made; so no general cross sections have been constructed.

Valuable observations on faulting have been made underground, however, in some of the mines, especially where veins have afforded measures of displacement. It has been found impracticable to separate the account of such faulting from the discussion of the veins which they affect, so the reader is referred to such discussions, particularly to those concerning the Fraction, Wandering Boy, Valley View, Mizpah, and Montana Tonopah workings (pp. 115–176).

CRITERIA OF FAULTING.

It is worth while to record the manner in which the structure has been worked out in this complicated region. Although the region mapped embraces only about 6 square miles, and outcrops are very nearly continuous, several months of study were necessary to reach an approximately satisfactory solution of the areal geology. Ideas concerning the structure were successively exchanged for newer ones as fact after fact was brought to light. The existence of faulting was strongly suspected, from topographic evidence, from the time of arrival in the field, but the final results proved that in every case the faults assumed from such evidence were not faults, while the ultimate discovery of numerous and important faults was due to careful study of the rocks.

When by close examination and correlation of facts the complicated and often closely related rocks were satisfactorily separated into stratigraphic units, after numerous unsatisfactory attempts, the most important step toward the elucidation of the geologic history and structure had been taken. But still the most extreme caution was necessary, for while the local geologic column was probably historically correct for the whole district, there were many local gaps and irregularities. As there were several periods of apparently active but irregular erosion between volcanic outbursts and as the distribution of many of the members of the series was limited and irregular it seemed that any member might rest directly upon any older one, the intervening ones being unrepresented, while a few hundred yards away the represented succession would be different. For similar reasons it was not possible to reckon upon any constant thickness for any formation; in one place it might be a few feet thick, in others hundreds. So the ordinary stratigraphic criteria of faulting were very inconclusive.

SIEBERT TUFF BOUNDARIES.

The key to the problem undoubtedly was the determination of the geologic position of the Siebert tuff, which consists of characteristic finely stratified thick beds. In working out the structure the first thing done was to carefully follow the limits of these Siebert tuff areas. It was found that in most cases these were separate; they reappear in different parts of the area mapped and are bounded on several sides by straight lines. This fact immediately suggested the existence of numerous intersecting faults.

Where a rectilinear boundary of a Siebert tuff area ran transversely to the strike of the beds, a fault was evident, in case the contiguous rock was not intrusive. In the case of a surface formation, like the Fraction dacite breccia, this evidence was conclusive, and parts of the majority of detected faults were followed in this way. Similarly, if a fault was parallel with the strike, and the dip of the tuff would carry it below a contiguous rock (as the Fraction dacite breccia, for example) which was known to be lower in the geologic column than the tuff, the nature of the contact, as due to dislocation, was evident.

DIKES ALONG FAULT ZONES.

Another criterion, perhaps not so important, was developed by the discovery that the Brougher dacite sent out dikes along some of the faults, as along the California fault. (See map, Pl. XVI.) This showed at once that the dacite reached its present position essentially subsequent to the faulting (a conclusion which was otherwise abundantly verified), and that the dikes running out from the volcanic centers occupied at times fault zones. These dikes were then traced, and when they were conspicuously straight and narrow their course was critically examined to determine whether it could possibly be a fault plane. Often such dikes are intermittent, appearing only in small outcrops here and there along the line, with no visible connection. Such a condition was still more strongly suggestive of a fracture zone. Frequently the examination of the rocks on both sides of such a line confirmed the suspicion of faulting, and important faults were discovered in this way.

BOUNDARIES OF LAVAS.

As the knowledge of the different formations increased it became possible to draw their boundaries with frequently great accuracy. Where these were rectilinear, as in the case of the tuffs, and could not reasonably be interpreted as normal contacts caused by the outcropping of inclined formations, and one formation could not have been intruded into the other, faults were considered to be indicated. Even in the case of two volcanic rocks, like the earlier and later andesite on Mizpah Hill, the boundaries, though obscure and traceable with difficulty on the surface, could finally be determined to be rectilinear, intersecting, and probably due to faulting. In this case the veins afforded valuable evidence, for their outcrops were cut clean off along the fault planes.

EROSION FAULT SCARPS.

As the perception of the real connection between the stratigraphy and structure and the topography grew, the latter often became an efficient guide. The underlying rocks have exercised a remarkably efficient control over the surface forms. Where two rocks of unequal hardness are brought together by faults, the harder rock will rise above the softer in a more or less perceptible scarp. With the exception of the rhyolites and the Brougher dacite, and to a less degree of the silicified earlier andesite, however, the difference in resistance of the rocks is not great. The Fraction dacite breccia and the glassy Tonopah rhyolite-dacite in the southern part of the area mapped are chiefly friable fragmental surface deposits, while the later andesite disintegrates rapidly. The Siebert tuff is softer than the others, and when sufficiently removed from the influence of a protecting harder rock, forms flat, smooth areas, on whose boundaries fault contacts are apt to be marked by slight but pronounced scarps, usually only a few feet high, since the adjacent rock is apt to be very little harder. These slight scarps afford strong preliminary evidence, and invite the closest searching after stratigraphic corroboration.

Nearly every topographic feature in the Tonopah district, however small, is due to the nature of the underlying rock; thus many straight depressions or slight valleys are probably due to the easier erosion of a fractured or faulted zone, as compared with the less fractured rock on each side. Such is probably the case with the northeast depression at the southeast base of Brougher Mountain, and with other creases in the surface.

SCARP PHENOMENA WEST OF BROUGHER MOUNTAIN.

Some especially interesting observations on the surface configuration as an indication of faulting were made in the comparatively flat area in the west part of the district mapped, west and northwest of Brougher and Siebert mountains, respectively. Here rhyolitic-dacitic breccias, chiefly detrital, are intermingled with tuffs, so that they sometimes can be distinguished only with difficulty from the main overlying Siebert tuff. Where the Siebert tuff is certainly distinguishable the rectilinear intersecting boundaries show that complicated faulting has taken place, but the mass of rhyolite-dacite breccias offered at first little suggestion as to structural relations.

When this area is viewed from an eminence, as from Brougher Mountain or from the hill west of Siebert Mountain, just beyond the area mapped, there is seen a significant series of parallel ridges which were at once surmised to indicate the presence of faults. From the hill last referred to, these slight scarps are seen to bound areas which have rectilinear outlines, and which are plainly distinguished in tint from one another, one being purplish, another reddish, and so on. A minute study strengthened the conjecture that in this region there are complicated and numerous intersecting faults. It was concluded that these faults brought into juxtaposition the Tonopah rhyolite-dacite breccia, the Fraction dacite breccia, the Siebert tuff, or different parts of any one of these, and that the resulting erosion brought out the harder blocks, which were thus bounded by straight scarps, usually of slight relief. The Tonopah rhyolite-dacite breccia, being harder, nearly always occupies the relatively elevated portions, while the soft Fraction dacitic breccia and the Siebert tuff lie in the depressions. These depressions are covered with a slight thickness of detritus, but prospect holes show in almost every case that they are floored with the softer breccias. The straight boundary lines are strongly contrasted with the irregular unfaulted contact of the glassy Tonopah rhyolite-dacite in the north corner of the area mapped.

DESCRIPTION OF ZIGZAG SCARPS.

One or two of the most interesting occurrences of these slight scarps were made the subjects of especial study. Between Siebert and Brougher mountains the flat area floored by the dacitic breccias and by the Siebert tuffs reveals to the close observer certain straight lines, which are apparently slight ridges and depressions in the detritus, but which are really closely underlain by the soft bed rocks, though these outcrop only occasionally. In this area the occurrence of a number of faults was proved by stratigraphic evidence, chiefly by the rectilinear boundaries of the Siebert tuffs. The position of one such fault, marked A on the accompanying diagram (Pl. XII), was determined by stratigraphic evidence for a part of its course, as will be noted by consulting the geologic map (Pl. XI). Eastward of this part, however, it is bordered apparently on both sides by the tuff, yet along the continuation of the line established by stratigraphic evidence there is on its north side a slight scarp about 10 feet high. Just north of this scarp a similar scarp, of about the same height, and, like the former one, facing to the south, runs in a straight line, but in a direction more nearly east and west than the one first mentioned. Toward the east the foot of this scarp is in the bottom of a narrow depression; toward the west, where the depression broadens, the scarp lies on the north side. In this broader portion, however, the other side of the depression has little or no scarp, is at a maximum of 3 or 4 feet in height, varying from that to nothing, and has no straight or rectilinear course (fig. 11). This first-mentioned scarp is continued

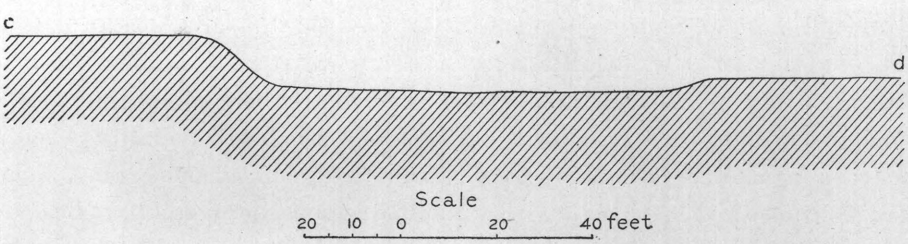
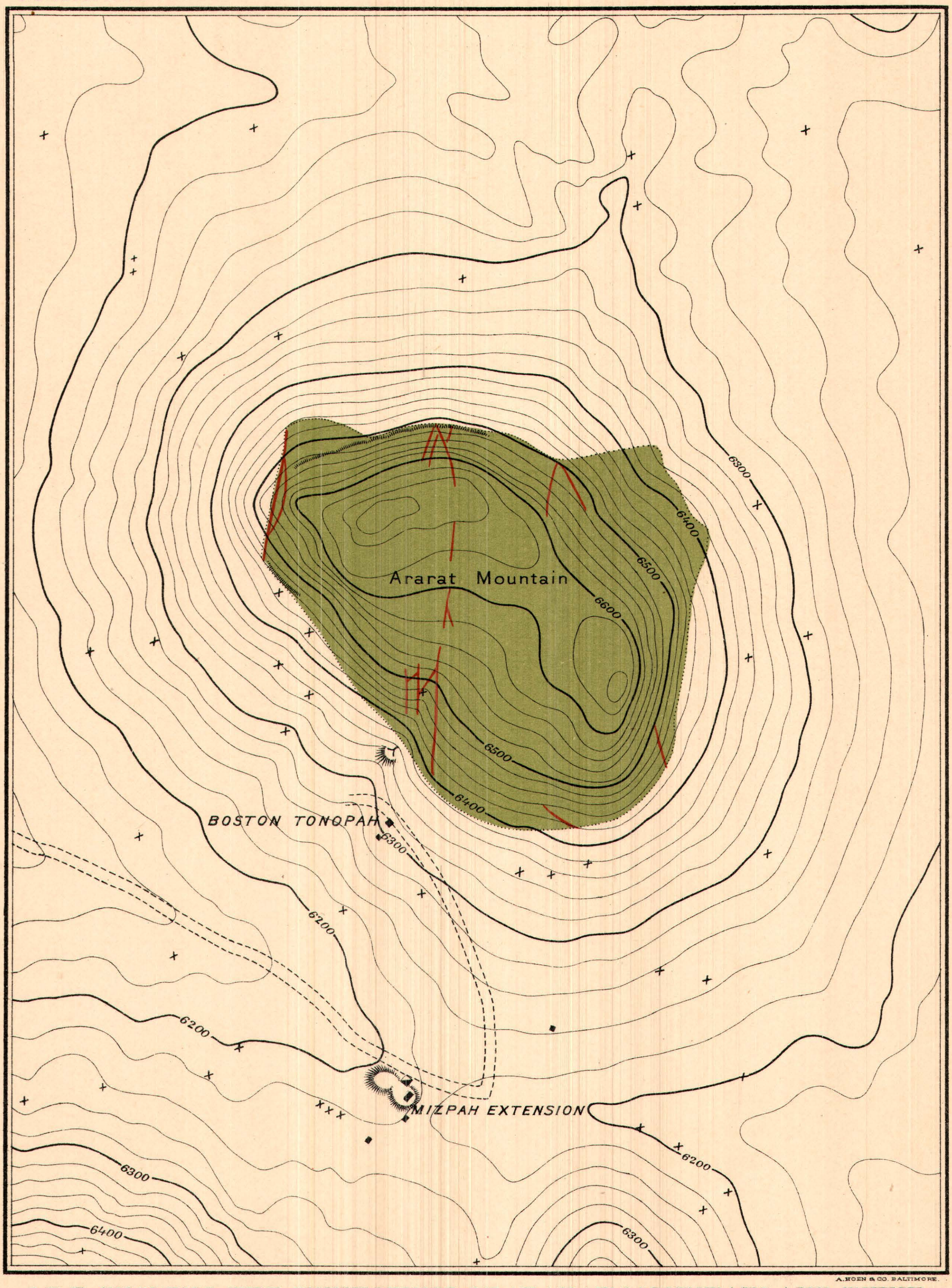


FIG. 11.—Cross section of water runway, usually dry (*c-d* of Pl. XII), showing bold, straight scarp on left, believed to be consequent on faulting, and low, curved bank on right, believed to be due to occasional drainage.

farther west, but is set off en échelon, although the corners are slightly rounded; the set-offs are always in a northerly direction and the main trend corresponds to that of the straight scarp farther east. With a slight interruption, caused by the incoming of a depression which is probably due to an unusually soft fault block, this scarp continues northwestward beyond the area mapped, and can be followed with the eye a considerable distance farther, toward the little eminence called Table Mountain. A sighted line along the scarp near the western limit of the map has a general direction of N. 65° W. On examination, however, the front of the scarp, which has a uniform height of 10 or 15 feet, and which always faces the south, is found to be continuously set off en échelon in the same sense and fashion as the portion farther east. The conditions are indicated in Pl. XII. The two chief alternating directions of the scarp faces are, (1) *chief*, N. 85° E., (2) *minor* (set-offs), N. 45° W. Along the whole of its course the relative depression to the south of the scarp is used as a runway for the occasional surface waters, and can easily be mistaken for a depression due simply to erosion. However, the south side of this depression does not partake at any point of the peculiarities of the north side, being low and irregular in course, and without



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MAP SHOWING THE CHIEF VEINS OF ARARAT MOUNTAIN AND THEIR RESTRICTION TO THE ODDIE RHYOLITE PLUG

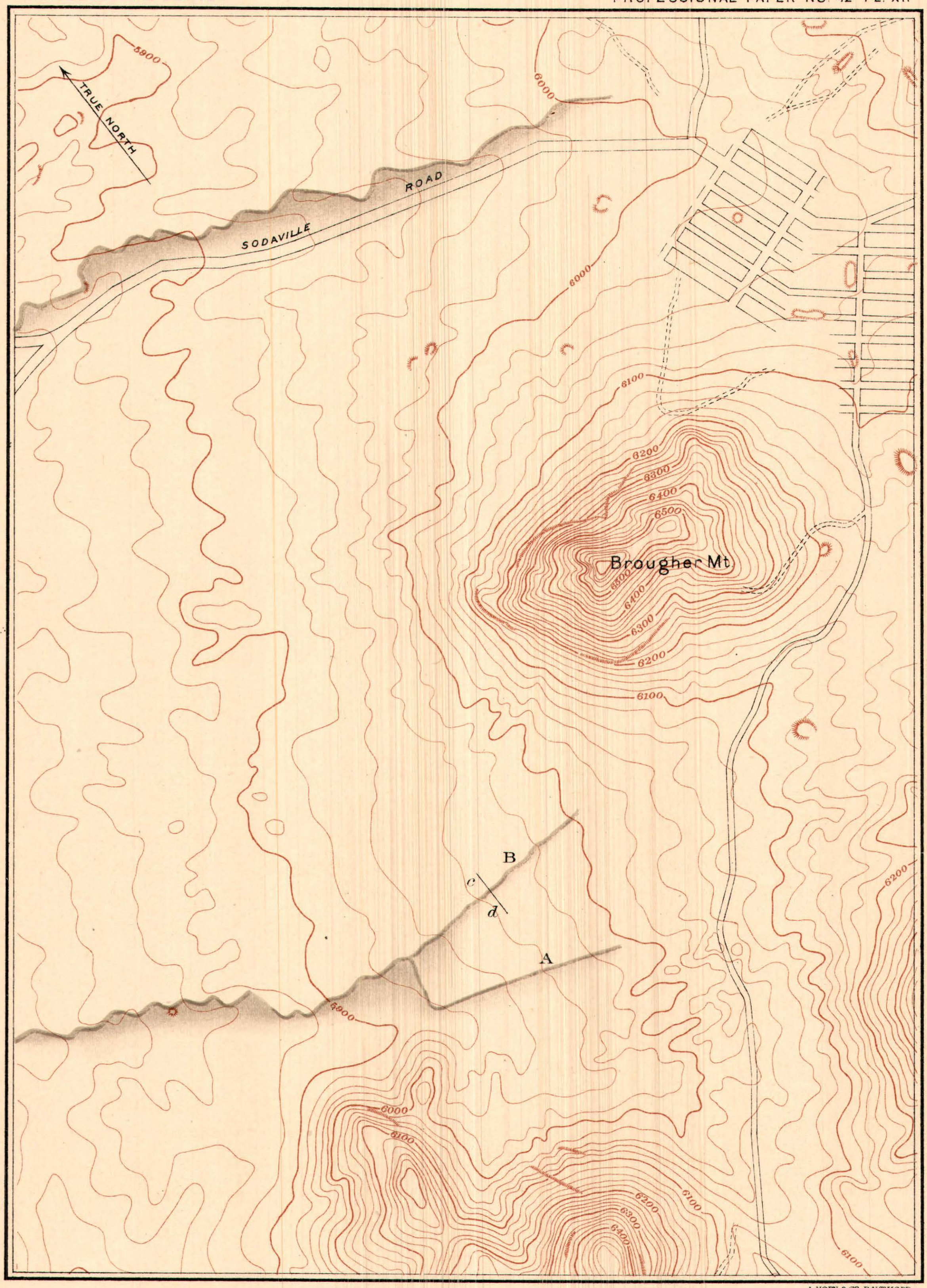
By J. E. Spurr

1904

Scale

500 0 500 1000 1500 feet

Oddie rhyolite shown in green; veins in red.



A. HOEN & CO. BALTIMORE

DIAGRAMMATIC MAP SHOWING TWO PARALLEL ZIGZAG SOUTH-FACING SCARPS

THE SOUTHERN ONE ABOUT 10 FEET HIGH, THE NORTHERN ONE 25 FEET HIGH

By J. E. Spurr

Scale

1000 500 0 1000 2000 3000 feet

Contour interval 20 feet

any definite continuous scarp. Moreover, the jogs in the scarp under consideration can not be explained by stream erosion, for they are not at the entrance of auxiliary gullies, the angle of the jog forming practically an unbroken wall.

ZIGZAG SCARPS EXPLAINED BY FAULTING.

The phenomenon described can hardly be explained except as controlled by faulting, and two intersecting systems are indicated. Corroborative evidence of this conclusion is present. Along the western portion of the scarp where examined there occur at different points isolated outcrops of light-colored dike rhyolite that has the characteristics of the Oddie rhyolite, and is distinct from the glassy Tonopah rhyolite-dacite with which it is in contact. These dikes are intermittent rather than continuous, but form distinct jogs parallel with the set-offs of the scarp. It is known that this rhyolite sometimes forms dikes along faults in this district and is later than the main faulting.

CONSEQUENCES OF EXPLANATION.

The chief or longer scarp faces are parallel to the straight scarp into which the jogged scarp runs farther east (*B*, in Pl. XII), while the shorter or minor faces are parallel with the slight scarps lying a short distance farther north, limiting probable fault blocks, as already described. It appears, then, that the jogged scarp is the result of two sets of intersecting faults, and from the figure it is evident that when the dimensions of the jogs are diminished the course of the resultant will approach a straight line, and indeed may do so to such a degree as to be practically indistinguishable from such a line. By the predominance of one set of faulting over the other set the resultant line may lie in any given direction and may be straight or curved. The line made by joining the points of the sharp spurs along the scarp, indicating the general resultant of the two systems of jogs, is parallel with the scarp first mentioned, which lies farther east (*A*, in Pl. XII). It is possible, therefore, that this last named straight scarp may actually be a resultant of two intersecting systems, such as have been described.

ZIGZAG FAULT SCARP ON TONOPAH-SODAVILLE ROAD.

On the north side of the main road which leads from Tonopah toward Sodaville, in the western part of the area mapped, a similar phenomenon was noted. The road lies in a depression, on the south side of which there is an irregular, undecided embankment consisting mostly of fragmental material and having a height of about 10 feet. On the north side there is a sharp scarp about 25 feet high, consisting of a continuous outcrop of solid, glassy Tonopah rhyolite-dacite. On inspection this scarp shows well-marked rectilinear courses, forming steps or jogs, although the detail is somewhat rounded by erosion. It runs chiefly in two directions—N. 60°–70° E. and N. 30°–40° W. This zigzag course, and the absence of the scarp on the south side of the depression, as in the case of the occurrence previously described, seem to indicate a complex fault fracture, and the directions of the rectilinear components in each case are similar. In this case also the indentations are not due to gulches, for there is usually not the slightest depression at the top of the scarp, at the angles. The scarp continues beyond the area mapped. The general trend (being the resultant of the two directions noted) is almost exactly parallel to the similar scarp previously described.

ORIGIN OF ZIGZAG FAULT SCARPS.

From the general sum of knowledge concerning the relation of faulting to topography in this district (see p. 114), it is inferred that probably these slight scarps are due to differential erosion and mark the limits of fault blocks which are slightly harder than those contiguous. Their invariable slight relief strengthens this idea. Similar scarps, which have been proved to have originated in this manner, are characteristic of fault contacts in other portions of the area mapped. The other possible hypothesis is that the faults are recent, and that the scarps have formed as a result of direct displacement of the surface. In spite of the fact that the probabilities seem to favor the first explanation, certain features support the second. One of these is that scarps of this sort, like those just described, sometimes have on each side material belonging to the same formation, as the scarp marked B in Pl. XII, which has tuff on both sides, or, as the scarp last described, on the Tonopah-Sodaville road, which has the glassy Tonopah rhyolite-dacite on both sides. If these surface features are due to erosion, the higher block must be slightly harder than the lower and must represent a slightly more resistant part of the formation. This indeed is true in the place last mentioned, where the glassy Tonopah rhyolite-dacite in the area north of the road is the solid intrusive lava, while the formation included under the same head in the region south of the road is surface material, breccias and tuffs, and therefore more fragile and more easily eroded. Another circumstance which also favors the idea of direct displacement is that the two chief compound scarps just described both face the south. It is known from independent evidence that the southern part of the area mapped has been downthrown in respect to the northern part, so that a slight continuation of the general movement into very recent times might result in these south-facing scarps.

ORIGIN OF ZIGZAG FAULTS.

Zigzag fault courses like those described may originate in two ways: (1) By the intersection of independent fault systems which produce a zigzag line of equal dislocation oblique to both the intersecting systems, as explained in the consideration of the Wandering Boy fault (pp. 157–161); and, (2) by a simple fault whose initial movement follows a zigzag course along previously existing fractures.

INTRUSIONS CONTROLLED BY INTERSECTING FRACTURES.

Rectilinear boundaries or rectilinear boundary scarps do not always indicate faulting in the sense above described, where one of the rocks is intrusive. A case is furnished by the outline of the Golden Mountain intrusion. As shown on the map, the contact of the Golden Mountain dacite with the earlier andesite, on the east side of Gold Hill, is so straight as to suggest the possibility of faulting. Moreover, east of Gold Hill the long south contact of the same intrusion follows alternating straight northwest-southeast and northeast-southwest courses, strongly suggesting the resultant of two intersecting systems of faults, similar to the scarps already described. But excellent evidence that the contact has not been faulted is present in the band of dacite glass which represents the quickly chilled lava along the margin of the intrusion, and which was found to follow the contact along its different courses.

It appears that the straight western limit of the intrusive Brougher dacite along Gold Hill, above referred to, has been determined by a *preexisting* fault, for the continuation of this fault is evident near the California-Tonopah (California fault), where a dike from the main dacite mass follows the fault zone. In this light, also, it seems probable that the rectilinear courses and the set-offs regularly in the same direction on the south side of the Golden Mountain indicate that the intrusive contact was here also determined by a system of preexisting intersecting faults or fractures.

CORROBORATION OF CONCLUSIONS.

A number of faults that were located on the surface by the methods above given were subsequently found in mine workings and observed more closely and satisfactorily. The Mizpah fault was recognized at an early stage in the investigation, both on the surface and underground. The Burro fault, distinguished and followed with great difficulty at the surface, was subsequently developed underground. The Wandering Boy and Fraction faults, first distinguished on the surface, were subsequently found to be well exhibited in the mine workings.

ACCURACY OF FAULT MAPPING.

In this volcanic region faults can very often not be distinguished at all. This is the case if similar rocks lie on both sides of a fault and other signs fail. Therefore on the map some faults have been projected a reasonable distance and probable connections made across spaces intervening between different fragments of what is probably a single fault line. While the structure as finally depicted is undoubtedly not strictly accurate in many details, the general features are well shown, and the error, were a closer study possible, would undoubtedly be found to be not that too many faults are represented, but that many have escaped detection.

FAULTING DUE TO VOLCANIC ACTION.

The faulting in this district is of extraordinary interest, for the origin, time, and cause are clearly understood. It is rare that any explanation other than a general unsubstantiated hypothesis can be applied to any particular case of faulting. Here, however, it is plain that the faulting was the result of adjustments of the crust to suit violent migrations of volcanic rock; that it originated with the swelling up of the crust and its forcible thrusting up and aside to make way for the numerous columns of escaping lava; and that after the cessation of the eruptions it was continued by the irregular sinking of the crust into the unsolid depths from which the lavas had been ejected. It can readily be seen that all sorts of pressure (from below upward, lateral, and downward, by virtue of gravity) must have been concerned in such movements, and that the first faults were due rather to upward and lateral irregular thrusts, while the later ones (in many cases along the same planes as the first) were due to gravity. So reversed and normal faults are equally natural, and both occur frequently.

APPLICATION OF PRINCIPLES TO REGIONS LYING BEYOND AREA MAPPED.

These observations are probably not of slight and local significance. The faulting is intense, and the faults have frequently very great displacements, amounting to many hundred feet at least. Moreover, considerable areas are affected by subsidence or elevation connected with and in part, at least, accomplished by faulting, as, for instance, the relative depression of the southern part of the area mapped (near the dacite necks), as compared with the northern portion. The cause of these larger movements is plainly the same as that of the individual faults. Evidently such phenomena are not confined to the area mapped, but extend indefinitely beyond it. The writer at first looked upon the faulting at Tonopah as exceptional and local, and not to be connected with ordinary faulting in the Great Basin; but there now appears no reason for doubting that the phenomena within this small, carefully studied area are typical of the unstudied similar volcanic region beyond the limits of the map.

The individual faults have been shown to have been minor, irregular movements attending broader elevations or depressions; and the hypothesis has been presented that at an earlier period the lake basin in which the Siebert tuffs were laid down was formed by general subsidence of an area that was occupied by earlier eruptive rocks (the earlier dacitic eruptions) and that this basin was destroyed by a broad uplift which preceded the later dacitic outbursts. There is little doubt that these earlier movements were attended by some faulting, although such faults would be difficult of detection, especially in the presence of the subsequent complicated faulting of the period of the later dacitic intrusions.

SUGGESTED EXPLANATION OF GREAT BASIN TERTIARY DEFORMATIONS.

The recognition (pp. 52, 70) of the facts that the lake in which the white tuffs were laid down was a very large one, and that it very likely corresponds to the great Miocene Pah-Ute Lake of King, gives a broader interest to this hypothesis of its origin; and the hypothesis naturally extends itself to the other Tertiary lake basins which preceded and followed the Pah-Ute.

In the great interior province in which Tonopah is situated, and which lies between the Wasatch and the Colorado Plateau on the east and the Sierra Nevada on the west, a number of successive lake basins of varying extent formed during the Tertiary, as was first shown by King. These changing basins, of varying shape and extent, were due to uneasy continual warpings (elevations and depressions) which continued through the Tertiary period down to the present day. This warping has been contemporaneous with folding and faulting, and all of this crustal disturbance has been accompanied by volcanism.

"In general the period of deformation which lasted from the Mesozoic to the present has been contemporaneous with volcanic activity. By far the most energetic vulcanism, so far as we know, occurred in the Tertiary, beginning probably in late Cretaceous or early Eocene and extending into the Pleistocene. Vulcanism and deformation were, therefore, allied phenomena."[a]

In the earlier recognition of this coextension of the two phenomena of deformation and volcanism the writer's conception was that they were both the result of a single unknown cause. In the light of the Tonopah studies, however, it seems fair to admit that the former may have been the result of the latter, the effect of the repeated accumulation and eruption of vast bodies of molten material, and the subsequent subsidences and local adjustments.

[a] Spurr, J. E., Origin and structure of the Basin ranges: Bull. Geol. Soc. America, vol. 12, p. 248.

CONTINUANCE OF VOLCANIC EPOCH.

Viewed in this or in other lights, there is small reason for believing that the period of volcanism in this province is past. It rather appears that we are still in it. The occurrence of recent almost undefaced basaltic craters at various points, such as at Silver Peak (Pl. XV, *A*), at Lake Mono, and in central Oregon, show that the last eruptions occurred only a few hundred years ago, while the evidence of enormous Pleistocene and recent elevation and subsidence, especially in the western part of the region, near the Sierra Nevada,[a] suggests the migrations of the molten tide beneath the present crust.

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[a] Spurr, J. E., op. cit., p. 247, 248; also Bull. U. S. Geol. Survey No. 208, pp. 110, 129, 209, 210, etc.

CHAPTER II.

MINERAL VEINS.

VEINS OF THE EARLIER ANDESITE.

PERIOD OF MINERALIZATION.

The most important veins of the Tonopah district occur in the earlier andesite and do not extend into the overlying rocks; hence, where the earlier andesite is not exposed at the surface the later rocks form a capping to the veins, and this capping must be passed through before anything can be learned of the presence or the nature of the veins beneath. This fact shows pretty plainly that the veins were deposited before the eruption of the later andesite and immediately after that of the earlier andesite, for the period of erosion between the two andesites seems to have exposed the veins at the surface, indicating that they were formed before this period or early in it. Indeed, there is every evidence that the veins were formed by ascending hot waters succeeding and connected with the earlier andesite intrusion, and that these waters had become inactive by the time of the later andesites.

NATURE OF CIRCULATION CHANNELS.

The openings which afforded channels for these ascending waters were of the nature of sheeted zones. The rock was complexly fractured, apparently soon after cooling, and probably as a result of the stresses exerted by the still active volcanic energy below. A major set of fractures extended in an east-west direction and zones of close-set parallel fractures attained a maximum thickness of several feet. These became the chief channels of circulation. In places the circulating waters divided into separate channels, which diverged and frequently reunited, and many lateral channels were favorable to egress of the waters. These channels, however, were apt to get poorer as the distance from the main fracture zone increased.

The conditions above stated are clearly shown by a study of the veins of Mizpah Hill and vicinity (fig. 12). The circulation channel now occupied by the Mizpah vein may be taken as a type of the main fracture zones, and the diverging Burro veins, dwindling as they increase their distance from the master veins, represent the lateral channels. The splitting and reuniting is shown by the structure of the veins at many points.

VEINS DUE CHIEFLY TO REPLACEMENT.

That the circulation channel was in practically every case a fracture zone and not an open fissure is shown by the study of the veins, which reveals all stages in the change from a fracture zone in porphyry to a solid quartz vein. In many cases the vein consists simply of a zone of more or less altered andesite, not essentially different, except, perhaps, for a somewhat greater silicification, from

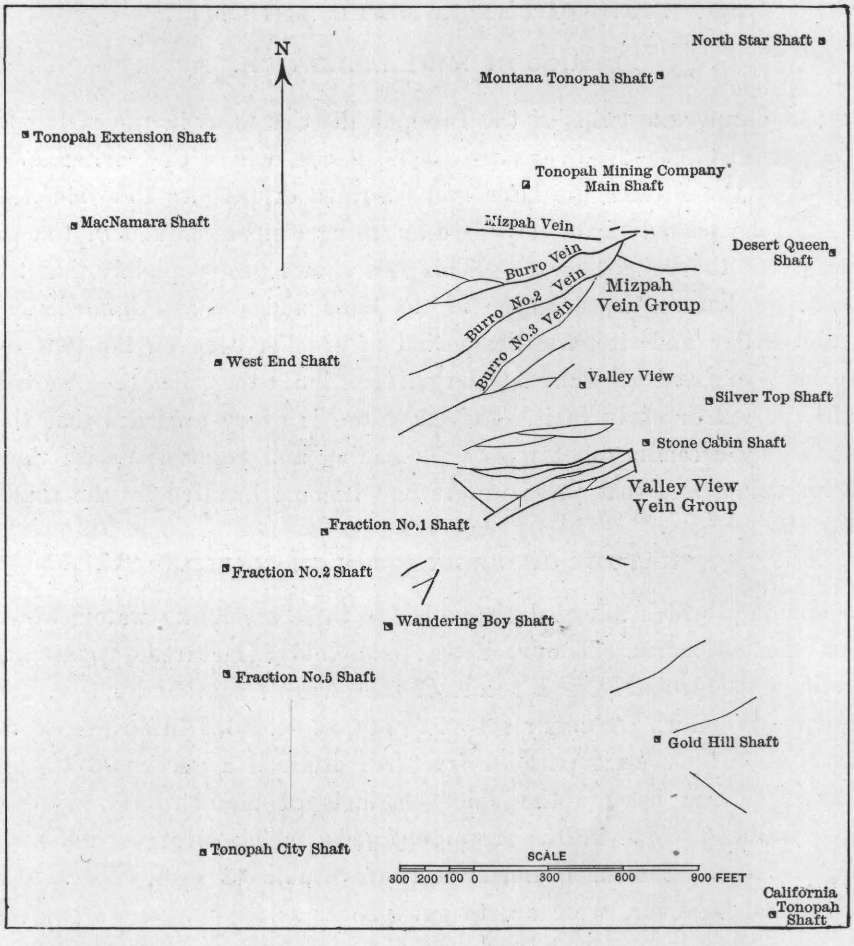
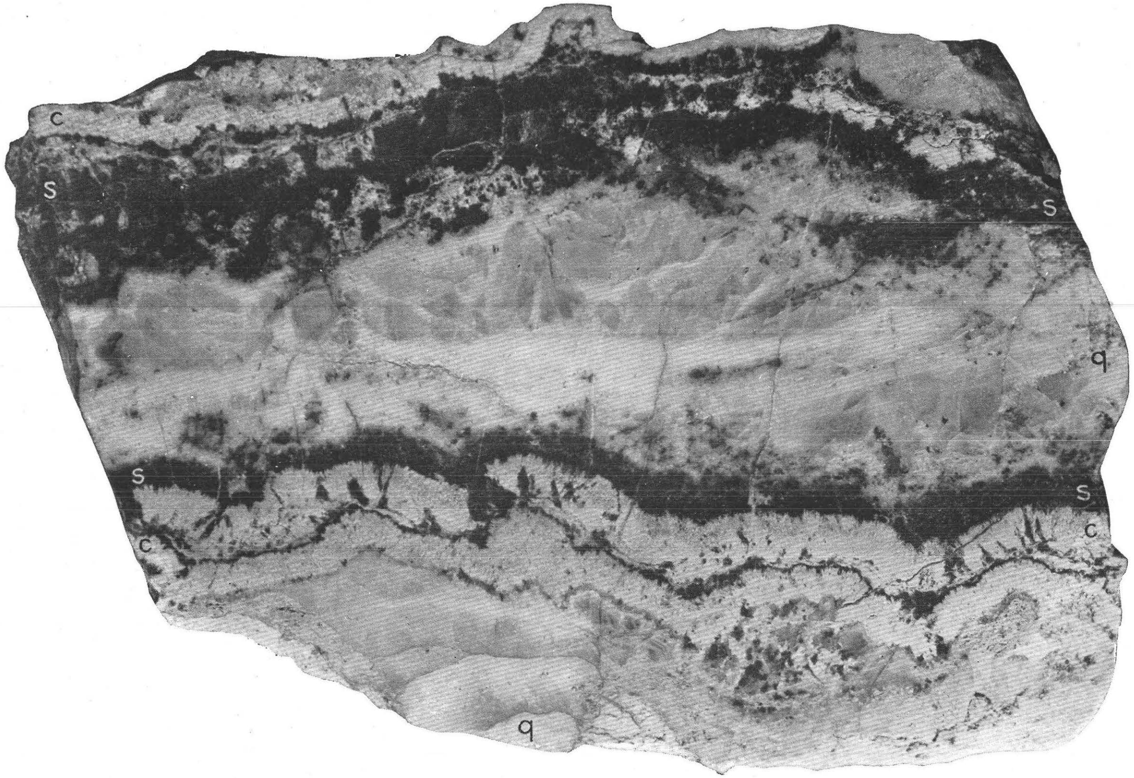


FIG. 12.—Map showing outcropping veins of Tonopah.

the andesite which forms the walls. This zone is cut by parallel fractures having the same strike and dip as the walls, and the walls themselves are nothing more than stronger fractures of the same kind. In the next stage, where part of this fractured zone becomes altered to quartz, the main wall fractures have been the most favorable for water circulation, so that sometimes a hanging-wall streak of quartz and a foot-wall streak are found with only altered andesite between.



FRAGMENT OF MONTANA VEIN, ACTUAL SIZE, SHOWING CRUSTIFICATION.

q=quartz, c=carbonates, s=rich black sulphides.

Sometimes, also, either the hanging-wall or the foot-wall streak may be wanting. Next, streaks of quartz parallel with the walls may be found, or the quartz may form a network in the andesite. Thus the process may be traced to the stage where the whole of the andesite is replaced by quartz, forming a solid vein several feet in width. As a rule, however, more or less decomposed andesite forms part of the vein.

PORTIONS OF VEINS DUE TO CAVITY FILLING.

As exceptions there are found streaks of quartz, usually small, within the vein, which show crustification and comb structure and thus bear evidence of having been formed in cavities. These cavities, however, were often of irregular shape and were not fissures, properly speaking, but spaces of dissolution, and were the effect of the mineralizing waters themselves.

The largest example of a crustified vein is found in certain parts of the Montana Tonopah workings, where the cavities were sometimes 2 or 3 feet in diameter and gave rise to well-banded ores (Pl. XIII).

CROSS WALLS AND ORE SHOOTS.

The fractures transverse to the main system had a not inconsiderable effect in determining the course of the ore solutions. Along important transverse fractures it has been found that the vein frequently widens or narrows abruptly, the cross fractures playing the same part as the lateral wall fractures, even if not to such an extent, and so earning the name of cross walls which has been given them. To these cross walls, more or less pronounced, the division of the water circulation along the main zone into columns of unequal importance was due, and hence the mineralization accomplished by these waters was correspondingly localized. It is probable that the recognized ore shoots or bonanzas had their origin in this way.

NATURE OF MINERALIZING AGENTS.

That the mineralizing agent was water is evident from the character of the vein and from the nature of the alteration of the wall rock. That its action was probably connected with the earlier andesite eruption is shown by the fact that it followed this and, at least so far as mineralizing activity was concerned, was of limited duration, for its effects have not been determined in the succeeding later andesite. It appears probable, therefore, that the mineralizing agents were volcanic waters, such as are usually among the after effects of volcanic outbursts, and that they were hot and ascending. A consideration of their effects, as displayed both in the veins and in the country rock, will throw further light on their nature.

PRIMARY ORES.

LOCALITY.

The contents of veins lying near the surface have been transformed more or less into new minerals—minerals that are more stable under surface conditions; the materials originally deposited from the mineralizing solutions must therefore be sought in the unoxidized lower region. The Montana Tonopah veins carry solid sulphide ores, primary and contemporaneous with the original quartz gangue and very slightly altered, presenting strong contrast with the oxidized ores of the Mizpah mine. Similar sulphide ores have been found in the North Star, the Tonopah Extension, the Midway, and the Tonopah and California.

COMPOSITION.

MINERALS.

Quartz.—In these veins the chief gangue mineral is quartz, frequently well crystallized and translucent, but more usually rather fine-grained and dense, and mixed with more or less aluminous material. This material, which will be described later on, is a residue of the least soluble material of the earlier andesite. Under the microscope the quartz has a characteristic structure, distinct from that of ordinary crystalline vein quartz. Instead of the coarse interlocking grains commonly displayed by vein quartz, these veins usually show a mosaic in which the grain varies enormously in size, ranging from very fine cryptocrystalline to very coarse. Under the microscope the aluminous material proves to be very fine muscovite (sericite). The quartz holds numerous fluid inclusions, which contain bubbles, showing that the included material was in a state of vaporous tension at the time of its inclusion or at the time of the vein formation, and that it has contracted so as to fill only part of its original chamber upon the lowering of the temperature. The inclusions are frequently densely packed and curiously arranged. In some cases the interior of the crystals is clear, while the marginal zone is packed with inclusions. Frequently the quartz has the rough retiform structure which is due to the intergrowth of idiomorphic crystals starting from independent crystallization centers, and which is often characteristic of quartz formed by replacement.[a] There are also coarser veinlets of quartz, later than the bulk of the vein, which were introduced along cracks, and these in places show comb structure.

Adularia.—The nearly pure potash feldspar, adularia, a purer variety of orthoclase, is a common gangue mineral. It is frequently very abundant, usually in more or less idiomorphic crystals that show the characteristic rhombic cross-section. It is intercrystallized with the quartz, which often incloses isolated

[a] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, p. 218.

idiomorphic crystals of it, showing the nearly contemporaneous deposition of the two minerals. Its condition is fresh and glassy, and only when it has been locally strained does it show cleavage cracks. That it has been deposited from solution in the same way as the quartz and the metallic minerals of the veins is evident. Where the adularia and quartz crystallize together the sharply idiomorphic feldspar, included in the xenomorphic quartz, shows the former to have first crystallized, the order being the same as in igneous rocks. The adularia, like the quartz, is sometimes closely packed with liquid and gaseous inclusions.

For chemical determination a specimen (No. 254) from the Fraction vein, which is made up of this mineral and quartz, finely intercrystallized, was ground. The quartz was then removed, as far as possible, by the use of the Thoulet solution. The best material thus obtained was analyzed by Dr. W. F. Hillebrand of the United States Geological Survey.

Analysis of adularia and quartz.

SiO_2	75.28
Al_2O_3[a]	13.19
Na_2O	.32
K_2O	10.95
	99.74

Inspection of this analysis shows that the material is a nearly pure silicate of aluminum and potassium, which, from its optical properties, can be only orthoclase or adularia. The silica, however, is considerably too high, showing a mixture of quartz. By calculating the amount of silica needed for orthoclase it is found that about 28.8 per cent of it is present as free quartz, leaving as components of the adularia—

SiO_2	46.48
Al_2O_3	13.19
Na_2O	.32
K_2O	10.95
	70.94

Recalculating this on a basis of 100 we have—

SiO_2	65.52
Al_2O_3	18.59
Na_2O	.45
K_2O	15.44
	100.00

Sericite.—Muscovite occurs in the veins only as a fine aggregate (sericite). It usually is scattered through the vein, or is irregularly bunched in certain areas. It has been found included in adularia.

[a] May contain traces of Fe_2O_3, etc.

Carbonates.—A carbonate is sometimes found microscopically mingled with the quartz as a gangue material, and has also been noted macroscopically. Doctor Hillebrand has determined that this is composed of the carbonates of lime, iron, magnesia, and manganese, in the proportions stated later on.

Silver sulphides.—The principal metallic mineral of the ores is a black sulphide, usually dense, fine grained, and intimately intermingled with quartz. As seen under the microscope, this black sulphide has a typical blue-black color, and often shows cleavage, but almost always lacks crystal outlines. In tiny cavities, however, crystals form. These are usually the six-sided, tabular, striated crystals characteristic of polybasite and stephanite. Partial analysis by W. T. Schaller of such crystals from the Montana Tonopah—crystals which may possibly be secondary (see p. 95)—showed appreciable amounts of antimony and copper, the latter ingredients indicating that the mineral is polybasite rather than stephanite. In such cavities argentite crystals also occur.

Silver chloride.—What is apparently silver chloride (cerargyrite) is found in some of the primary ores, interwoven with the primary sulphides in such a way as to seem to denote contemporaneous crystallization. In thin sections of such ores the chloride is apt to be more or less bunched, as is the sulphide, but the two are occasionally intergrown, with clear-cut lines of demarcation, seeming to denote independent and contemporaneous origin.

Chalcopyrite.—Chalcopyrite in occasional small grains is often noted in the primary ores, and is frequently so intergrown with the primary silver sulphide and with the gangue minerals as to indicate its primary character. In quantity, however, it is relatively unimportant.

Pyrite.—Pyrite in the veins is comparatively scanty, much more so than in the wall rock. In many thin sections of the ores it is not found at all; in others it occurs in considerable amount. In the primary ores it is frequently intergrown with the silver sulphide, with which it is evidently contemporaneous, though usually less in quantity.

Galena.—Galena has been noted in the high-grade sulphide ores of the Montana Tonopah, where it is associated with silver sulphides, chalcopyrite, and pyrite. A picked specimen from the 460-foot level which contained galena was analyzed for the Survey by R. H. Officer & Co., of Salt Lake City, and showed 8.9 per cent lead, 5.08 per cent silver (1,481.8 ounces per ton), and 38.26 ounces gold.

Blende.—What is probably zinc blende has been detected microscopically by the writer in the primary ore of the Midway shaft. Zinc sulphide has been detected chemically in the Montana Tonopah primary ores.

Gold.—Gold is present in the average ore in the proportion of gold to silver of 1:100 by weight. It has never been detected by the eye in the sulphide ores, either in the hand specimen or under the microscope, though it has been found in metallic particles both macroscopically and microscopically in the oxidized ores.

ANALYSIS OF PRIMARY SULPHIDE ORES.

Picked samples of rich primary sulphide ore were taken from the Montana vein of the Montana Tonopah mine at depths ranging between 460 and 512 feet. These were crushed and the sulphides were concentrated by panning. The analysis of the concentrates by Dr. W. F. Hillebrand of the U. S. Geological Survey, is as follows:

Analysis of concentrates of primary sulphide ore from Montana Tonopah mine.

	Per cent.
Siliceous matter	15.18
Gold	.82
Silver	25.92
Lead	6.21
Copper	1.32
Iron	9.87
Manganese	1.36
Zinc	5.84
Selenium	2.56
Tellurium	None.
Arsenic	.19
Antimony	.92
Magnesia	1.49
Lime	3.70
Carbon dioxide	6.34
Sulphur	Not det.
	81.72

The composition of the carbonate is as follows:

	Per cent (in terms of whole analysis).
Lime carbonate ($CaCO_3$)	6.71
Magnesia carbonate ($MgCO_3$)	3.13
Iron carbonate ($FeCO_3$)	2.36=Fe =1.14
Manganese carbonate ($MnCO_3$)	2.57=Mn=1.32

The whole of the manganese, therefore, exists as carbonate.

Doctor Hillebrand remarks:

"Prolonged boiling with hydrochloric acid decomposed all the sulphide except pyrite (and chalcopyrite if present). Hot dilute nitric acid then dissolved the pyrite and also considerable selenide of silver (and copper?). The residue remaining after this treatment consisted, aside from quartz, of very malleable black scales and particles which showed under the microscope the corroding action of the reagents used. When boiled with concentrated nitric acid, these black particles became golden in color, and the solution contained little or no selenium, but of this last I am not positive. So far as can be judged, the whole of the gold exists in the form of this malleable black alloy, which is so high in silver that the latter can all be extracted by strong nitric acid. The cause of the black color is not apparent, and it puzzles me not a little."

SUMMARY OF VEIN MINERALS.

The principal minerals of the primary veins are, then, quartz, adularia, and some sericite, carbonates of lime, magnesia, iron, and manganese, sulphides of silver, antimony, copper, iron, lead, and zinc (sulphides occurring in the form of argentite, stephanite, polybasite, chalcopyrite, pyrite, galena, and blende), silver selenide, and gold in a yet undetermined form. The remarkable thing about the metallic contents is the scarcity of the common elements and the abundance of the rare ones.

OXIDATION.

The chief alteration of the rocks, as will hereafter be explained, is due to the action of ascending underground waters. The effects of descending surface waters are seen chiefly in oxidation and similar processes acting upon the altered rocks. The oxidation or other alteration of metallic sulphides is the chief change, and, on account of the universal presence of pyrite formed by hot-spring action, this change can be observed both in the veins and in the country rocks.

DEPTH OF OXIDATION.

The depth to which this oxidation of pyrite has penetrated is exceedingly irregular, being quite different in neighboring shafts, and is very variable in different parts of the same workings. The difference plainly depends on the porosity and fracturing of the rock. Where these are greatest the oxidizing waters have penetrated farthest downward. Along veins the oxidation generally penetrates much deeper than in the rock, so that the ores may be oxidized while the country rock is pyritiferous. This is plainly due to the greater rigidity and brittleness of the vein as compared with the rock, so that it has been more fractured by strains, and therefore offers a readier channel. Even in veins the depth of oxidation is very irregular, dependent upon the amount of fracturing.

CAP ROCKS AS PROTECTION FROM OXIDATION.

The veins which outcrop are most deeply oxidized, as the Mizpah and Valley View veins. The former is for the most part oxidized down to a depth of nearly 700 feet; the latter is oxidized at the lowest level developed (about 500 feet). At a depth of 400 feet in both mines the vein is almost completely oxidized or otherwise altered by surface waters, while at 300 feet and below, in the Valley View, the pyrite in the country rock is usually unaltered.

Where veins do not outcrop, but are covered with a blanket of overlying rock, there is usually comparatively little oxidation. The ore in the Fraction, at a depth of a little over 200 feet, is a sulphide ore; in this case the vein has been protected by a covering of soft volcanic rock (Fraction dacite). Similarly, heavy sulphide ores were found in the Montana Tonopah at a depth of about 460 feet, the veins of this mine apexing under the later andesite, which is decomposed and not readily susceptible of fracturing. The depth of general oxidation of the country rock is only about 90 feet in the Montana Tonopah shaft, between 115 and 185 feet in the Wandering Boy, and a little over 200 feet in the Stone Cabin. In the Wandering Boy the vein is oxidized on the 300-foot level, while the country rock is unoxidized.

A single fracture line often locally divides the oxidized from the unoxidized ore and rock. This line of demarcation frequently coincides with a fault line, on which account it was suspected that some of the oxidation might be earlier than the faulting; but other considerations render it more probable that, by faulting, rocks of different degrees of porosity and permeability are brought together and thus the result is accomplished.

SILVER CHLORIDE IN OXIDIZED ZONE OF VEINS.

In the ores, the effects of oxidation are to change pyrite to limonite, and also to deposit wad (oxide of manganese), which is formed from the manganese carbonate in the primary ores; while horn silver (cerargyrite) becomes plentiful. This abundance of horn silver, being characteristic of the oxidized zone, is evidently due to the effects of chlorine contained in the surface waters. Silver bromides and iodides also sometimes accompany the chloride. Free gold has been deposited.

The large quantities of the haloid metallic compounds in the weathered portions of veins in the desert regions of America have been especially discussed by Prof. R. A. F. Penrose, jr.,[a] who suggests that they are probably due to the arid climate which has prevailed in the present and during the more recent geologic periods, and which has rendered the scanty ground waters saline. It is suggested that these saline waters have accomplished this alteration.

At Tonopah it is regarded as probable that the primary ore contains some silver chloride, and it is possible that the chloride therein contained may have been concentrated in the zone of weathering, and may also have contributed to the predominance of chlorides in this zone.

[a] Jour. Geol., vol. 2, p. 314.

ANALYSIS OF OXIDIZED ORE.

Concentrates from a picked sample of thoroughly oxidized ore from the 300-foot level of the Valley View vein were found by Doctor Hillebrand to have the following composition:

Analysis of oxidized ore from Valley View vein.

Siliceous matter	16.53
Gold	.62
Silver	[a] 62.54
Lead	.32
Copper	[b] .09
Iron	1.39
Manganese	.07
Zinc	.10
Selenium	.78
Tellurium	None.
Arsenic	.03
Antimony	.15
Sulphur	Not det.
Total	82.62

Concerning this analysis Doctor Hillebrand adds:

"After extraction of all the silver chloride by ammonia the residue was boiled with hydrochloric acid until silver no longer appeared in the filtrates. The insoluble matter then consisted, aside from gangue, of a little pyrite, of the same black gold-silver alloy found in the unoxidized ore, and of a pyritic-looking mineral, which latter yielded to dilute nitric acid much silver and some selenium, leaving a residue of gold."

COMMENT ON THE ORE ANALYSES.

Aside from the complex carbonate of lime, manganese, magnesia, and iron, the analysis of the primary sulphide ore indicates (p. 89) the presence of a large amount of silver sulphide—argentite. Antimonial sulphides of silver, polybasite, very likely stephanite, and smaller amounts of galena, blende, pyrite, and chalcopyrite are also indicated. Of very great interest is the presence of a considerable amount of selenium, which occurs, in part at least, as a silver selenide, and the absence of its usually closely associated element tellurium. The chemical form of the gold is yet uncertain.

It is fair to assume that the oxidized ore in its primary sulphide state may have had a composition somewhere relatively near that of the primary sulphide analyzed. The two analyses may then be compared with the object of perceiving the changes effected by oxidation. There is no element which can be considered as having

[a] 38.10 as sulphides; 24.44 as chloride, selenide, and alloy. [b] Mostly oxidized.

remained quantitatively unaffected during oxidation, so that merely the large relations can be glanced at. All the metals except silver and perhaps gold are present in the oxidized ore in much diminished proportions. The lead, copper, and zinc are present in small quantities. The manganese is now in the form of oxide, but very little remains; the iron is in the form of oxide, with some residual or secondary pyrite. There is much less gold in proportion to silver in the oxidized ore than in the sulphide ore; but this may be fortuitous and depend on the specimen selected. More than half the silver is in the form of sulphide, and from the very small quantity of arsenic and antimony present this portion must be nearly all in the form of argentite. The antimonial silver sulphide is very probably pyrargyrite (ruby silver), judging from microscopic observations. It is noteworthy that antimony and arsenic are present in the same proportions to one another in both analyses. There is less than a third as much selenium in the oxidized ore as in the sulphide ore, but the discrepancy is not so great as in the case of lead, copper, manganese, zinc, arsenic, and antimony; and this selenium seems to be still in the form of a silver selenide.

Therefore it is probable that during the process of oxidation the primary carbonates were attacked by surface waters, and the lime and magnesia, together with most of the iron and manganese, removed in solution. Some of the iron and manganese remain as oxides. No important change in the amount of gold and silver is proved. The argentite has largely remained unaltered, but the polybasite (and stephanite if present) has probably been attacked, and much of the silver selenide. Part of this silver has been reprecipitated with little change of position as secondary argentite, not distinguishable from the primary argentite, while a large portion has been altered to chloride by the action of chlorine contained in the shallow underground waters. Most of the arsenic and antimony in the original polybasite and stephanite has been removed in solution; the rest goes to form the secondary sulphide pyrargyrite, as indicated by numerous field observations. The pyrite and the chalcopyrite have been attacked. Most of the iron in these sulphides has been removed; a small part remains as oxide, or rarely as residual or secondary pyrite. Nearly all the copper has been removed, a little remaining in the probable form of oxide.

It is thus seen that the so-called oxidized ore of the Tonopah district, like that of many other deposits in desert regions, is really a modified ore consisting of an intimate mixture of original sulphides (and selenides), together with secondary sulphides, chlorides, and oxides. This case is without doubt characteristic of the whole zone of oxidation from the outcrop downward, for the ores throughout the zone are identical microscopically.

As to the reprecipitation lower down of materials dissolved in the process of oxidation there is little light. The plainly secondary sulphides within the sulphide zone are argentite and pyrargyrite, the latter always coating cracks or cavities, with probably chalcopyrite. Possibly the copper of the secondary chalcopyrite is formed by the action of copper solutions from above on primary pyrite, but galena or blende have not been noted as secondary sulphides, and at best are rare. Moreover, the secondary silver minerals argentite and pyrargyrite are more abundant than secondary pyrite and chalcopyrite, and all these usually occur on cracks in rich primary sulphides and not in barren or low-grade ore, suggesting the derivation of the secondary minerals from this rich ore by lateral secretion rather than an exotic origin.

FORMATION OF GYPSUM BY OXIDIZING WATERS.

Gypsum frequently occurs as veinlets or incrustations in both the earlier and the later andesites where these are altered. It is more rare in the earlier andesite, which has become highly silicified, and is abundant in the later andesite, which has developed a large amount of calcite as a decomposition product. This association with calcite suggests derivation from it, and the proximity in many of these cases of partly oxidized pyrite indicates that the sulphuric acid derived from the pyrite has wrought the change. The surface waters containing oxygen would decompose the pyrite and form limonite (which is found near the surface) and sulphuric acid. The latter would decompose the calcite (which itself was formed by hydrothermal processes from the calcareous silicates of the andesite) and produce gypsum and carbonic acid.

In the Fraction workings, at a depth of 400 feet and in the West End and the MacNamara (the latter at 280 feet), fissures were tapped which contained a heavy odorless gas that put out lights and necessitated temporary interruption of work. This gas was immediately dispersed by the ventilation, indicating that the fissures were reservoirs and not outlets. The writer has not been able to collect any of the gas, but in all these cases it was encountered near calcareous, pyritiferous, and gypseous andesite, and it is likely that it may have been carbonic acid, the final result of the reactions indicated, which accumulated in cavities.

SECONDARY SULPHIDES.

PYRARGYRITE, ARGENTITE, AND NATIVE SILVER.

Wherever observed macroscopically, pyrargyrite (ruby silver) and to a great extent, also, argentite (silver glance) coat crevices which cut the primary ore and are evidently of secondary deposition. These minerals were found in comparative abundance in the Fraction, in the unoxidized ores on the 237- and 300-foot levels; on the 237-foot level native silver occurred also, coating cracks, and also plainly secondary. In the Mizpah, ruby silver is rare, but it has been noted in the 250-foot level, where, from microscopic examination, it appeared that both ruby and horn silver are secondary to the original black silver sulphide.[a]

ARGENTITE, POLYBASITE, AND CHALCOPYRITE IN DRUSES.

In the Montana Tonopah, at a depth of about 500 feet, were found specimens showing good crystals of argentite, polybasite (in part, perhaps, stephanite), and chalcopyrite, often sitting free in cracks and little druses in the solid rich sulphide ore. Evidently these minerals were formed subsequent to the solid ore, and the silver seems to have been concentrated from the main mass and to have been precipitated in the crevices. Secondary pyrite has also been noted, for example, in the Fraction mine, sitting free upon quartz crystals which line druses in the vein.

COMPARISON OF SECONDARY SULPHIDES AT NEIHART AND TONOPAH.

At Neihart, Mont., Mr. W. H. Weed[b] has described polybasite and pyrargyrite (ruby silver) incrusting impure galena, blende, pyrite, quartz, and barite. These crusts are now forming in vugs and watercourses filled by sluggish descending surface waters. The polybasite seems to be an alteration product of galena, and in some cases pyrargyrite is undoubtedly derived from it. Blende is also in some cases secondary. Argentite is probably present. Mr. Weed explains the secondary precipitation by lixiviation of the ores by iron sulphate, formed by oxidation of iron sulphide (pyrite).

The Tonopah occurrence is analogous, except that here satisfactory evidence of the manner of deposition has not been found. There is little doubt that the pyrargyrite and argentite found along cracks were formed subsequently to and are probably derived from the primary ore. This primary ore is, however, richer than that at Neihart; indeed, it consists largely of silver sulphide, in part antimonial. For this reason the mode of occurrence of polybasite and argentite in druses in the rich Montana Tonopah ore is not of such plain import. In the Montana Tonopah it has been shown that during the period of primary deposition the vein, after being filled, was crushed and reopened, and again cemented by similar rich sulphides, somewhat richer apparently than those of the first deposition (see p. 172); and the polybasite, argentite, and chalcopyrite in druses may mark a third and final stage in the primary deposition. Also, chalcopyrite occurs in the bulk of the ore as more or less definite seams, apparently somewhat later than the rest, but not clearly of different origin.

[a] Probably argentite (see p. 92).

[b] Trans. Am. Inst. Min. Eng., vol. 30, p. 434.

EVIDENCE FAVORING SECONDARY DEPOSITION OF SULPHIDES BY DESCENDING WATERS.

On the other hand, the formation in the oxidized zone of limonite from pyrite and of cerargyrite from sulphides affords evidence that the metallic minerals of the ores have actually been dissolved and reprecipitated by surface waters, and in several cases the occurrence of ruby silver (pyrargyrite) in cracks in these partially oxidized ores shows beyond a doubt that it also is due to descending surface waters. Moreover, some of the ores, when studied microscopically, show argentite fringing cerargyrite, as if secondary to it. The iron sulphate necessary to the solution of the silver sulphide has been present (as is shown in the alteration of calcite to gypsum) and the silver has actually been dissolved, and such occurrences of secondary sulphides as have been described would be the natural result. The evidence therefore favors the view that these secondary sulphides in the oxidized zone originated from descending surface waters and probably part, but not all, of the sulphides in druses in the sulphide ore have a similar origin.

The characteristics of the superficial alteration of the ores are those which naturally result from the climatic and topographic conditions.[a] In all of the mines discussed (yielding ores) standing ground water is lacking; at least, none has been encountered up to the considerable depths attained (over 1,100 feet). Therefore the alteration is spotty and incomplete, but extends irregularly to very considerable depths in various places.

No definite secondary sulphide zone has been noted, the secondary sulphides being associated with the predominant oxides, chlorides, etc., in the oxidized zone and coating crevices in the primary sulphides.

VEINS OF THE TONOPAH RHYOLITE-DACITE PERIOD.

In many mine workings there are quartz veins of a certain class which are large and may carry values, but which are to be separated from the principal ore-bearing system. These are easily confounded with the veins of the earlier andesite, just as the silicified Tonopah rhyolite-dacite, in which they usually occur, may be confounded with certain highly silicified phases of the earlier andesite. Such veins have been encountered in the Belle of Tonopah, the King Tonopah, the Mizpah Extension, the Desert Queen, North Star, Montana Tonopah, Mizpah, Midway, MacNamara, West End, Tonopah Extension, and Ohio Tonopah, and are described in the detailed account of these mines. On account of their resemblance to the earlier andesite veins they have been the object of a good deal of exploration and development work, which, on the average, has been decidedly unprofitable.

In connection with the occurrence of such veins, which are described elsewhere in the report in the mine descriptions, another occurrence, somewhat different from the rest and having considerable interest, may be described.

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[a] Spurr, J. E., Geology Applied to Mining, pp. 275-276.

Just beyond the western corner of the area mapped (Pl. XI), opposite Siebert Mountain, a group of three low hills rises above the plain. One of these hills is capped by a patch of dacite, whose resistance to erosion has probably caused the hill. The rest of this hill and all of the other two are composed of white tuff mixed with beds of conglomerate, plainly referable to the white tuffs of the area mapped. The origin of the two hills, which are composed entirely of tuffs, is due to two elliptical areas where these tuffs and conglomerates have been thoroughly silicified and changed to a quartzite-like condition. Some mineralization has accompanied the silicification. A random specimen of the silicified material from the smaller of the two hills thus formed was reported to the writer to have yielded on assay $8 in gold and no silver. This silicification and mineralization is evidently the work of powerful hot springs, and the elliptical shape of the silicified areas shows that the springs rose along pipe-like channels and not along definite fractures. These deposits are probably of practically the same age and origin as the veins in the Tonopah rhyolite-dacite.

CHARACTERISTICS OF RHYOLITE-DACITE VEINS.

The veins of this period are characterized by irregularity and by lack of definition and persistence, though their size may locally be great. As a rule they are elongated and have the appearance of veins, but can not be followed as far either on the strike or dip as true veins may. They may disappear by scattering and passing into a silicified wall rock, or may be cut off along a cross-wall fracture in the same manner as some of the veins in the earlier andesite described on p. 85. The quartz is as a rule dense and jaspery, and is white, gray, or black; it is therefore usually of different appearance from the white quartz of the earlier andesite veins. The veins are usually barren or contain only very small quantities of gold and silver, except locally, as in the Desert Queen, where rich bunches of ore may occur, though usually of limited and irregular extent (fig. 13). Like the veins of the earlier andesite the rhyolite-dacite veins very frequently contain adularia, and in one case probable albite was noted (see p. 197), a mineral which has not been detected in the andesite veins. In the Ohio Tonopah barite has been found as a gangue mineral with the rhyolite-dacite veins. This mineral has not yet been found in connection with the earlier andesite mineralization. In the Desert Queen and the North Star, where quartz of the rhyolite-dacite period has been cut by drifting, a green stain forms on the walls, which is a basic copper sulphate. This phenomenon has not yet been noted in connection with the earlier andesite mineralization. A characteristic of the rhyolite-dacite veins, to which there are, however, numerous exceptions, is the

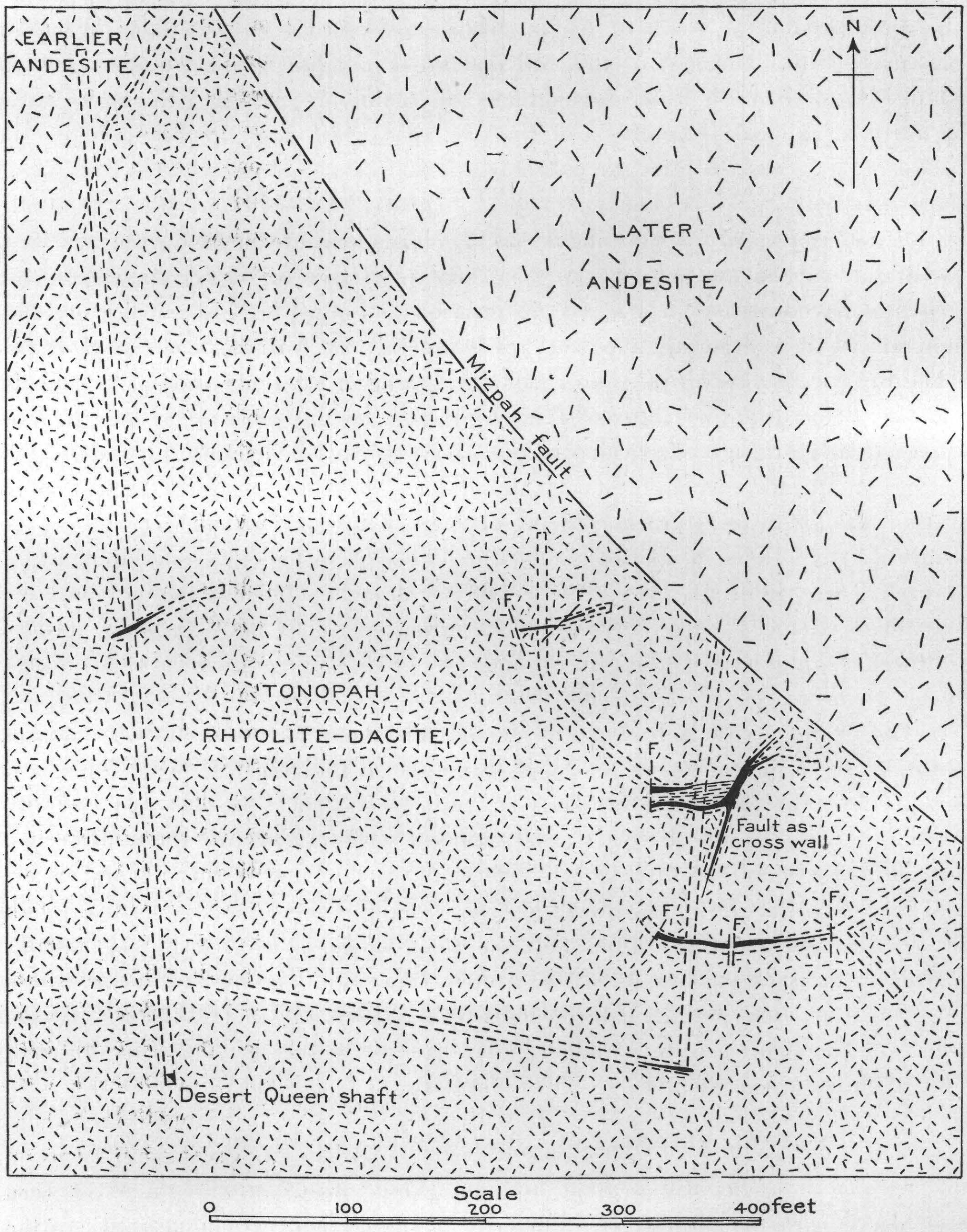


FIG. 13.—Rhyolitic veins (later period) in Tonopah rhyolite-dacite, 814-foot level, Desert Queen shaft, showing irregularity and lack of persistence. Horizontal plan.

greater ratio of gold to silver in them as compared to that in the earlier andesite veins. In the earlier andesite veins the gold averages about two-fifths of the value, the silver three-fifths, while in the rhyolite-dacite veins the gold is likely to exceed this amount and sometimes occurs with practically no silver, although the proportion is very changeable. Very often again the proportion of gold and silver is the same as in the earlier andesite veins.

AGE OF TONOPAH RHYOLITE-DACITE VEINS.

These veins are younger than the Tonopah rhyolite-dacite, in which they usually occur. In the mine workings referred to above this lava is a deep-seated injection corresponding in age and composition to a great mass of surface breccias and tuffs in the southern half of the area mapped. Even in the lower part of the white tuffs or lake beds which succeeded the deposition of the volcanic ejectamenta of this period there are intrusive sheets of the rhyolite-dacite. In this portion of the tuffs occur the elliptical outcrops of the pipe-like deposits, formed by hot springs in the hills west of Siebert Mountain. Thus the period of this mineralization was, in broad terms, contemporaneous with the volcanic activity of the Tonopah rhyolite-dacite period, and very likely persisted for some time afterwards. These veins are plainly the results of ascending hot waters, and represent the effects of the Tonopah rhyolite-dacite eruption. They have the same relation to these eruptions that the earlier andesite veins had to the eruptions of the earlier andesite.

The characteristic lack of definition and persistence in these veins as compared with the veins in the earlier andesite shows that at the time they were formed no definite fracture zones were available as channels, so that the ascending waters had to force themselves up along irregular courses. This means that the faulting now so characteristic of the district had not begun at the time of this mineralization, and therefore that this mineralization ceased before the beginning of that period of rhyolite and dacite injections and eruptions which is marked by the rhyolite and dacite necks that form the hills around Tonopah. The mineralization is then probably the same in time, nature, and origin as that at Gold Mountain, 4 miles south of Tonopah,[a] and very likely similar to that in the newly discovered camp of Goldfields, about 28 miles south of Tonopah.

GENERAL RESTRICTION OF VEINS TO RHYOLITE-DACITE.

At first it seems strange that in underground workings like the West End, the MacNamara, etc., these rhyolite-dacite veins do not extend into the earlier andesite in which the rhyolite-dacite is intrusive. The fact that such veins

[a] Bull. U. S. Geol. Survey No. 213, p. 87.

extend to the contact of the andesite and do not enter it, raises at first a doubt as to whether the andesite is not really the younger rock instead of the older. In some of the shafts mentioned the andesite is soft and very little silicified, while the amount of silicification in the rhyolite-dacite is very great. However, there is no doubt of the relative age of the rhyolite-dacite as given on p. 43, and the reason for the described phenomenon appears upon reflection. The rhyolite-dacite consists mainly of volcanic glass and was injected into the earlier andesite after this was thoroughly decomposed and softened as the result of the action of hot spring waters that accompanied and caused the principal mineralization. Any slight subsequent strains in the earth resulting from volcanic action shattered this fresh and glassy rock, but formed no fractures or fissures in the soft adjacent andesite. The hot waters that rose immediately after the rhyolite-dacite eruptions found almost their only channels in the fractured and fissured glassy rock to which they owed their origin. Therefore the veins that they formed are confined chiefly to this rock. Evidence of the correctness of this explanation is furnished by the thick veins of this period that are found on the contact of the rhyolite-dacite sheet with the overlying decomposed andesite. Such veins are often found at this place and the accompanying silicification is very great, but is almost invariably confined to the rhyolite-dacite near the contact. Such, for example, is the situation in the Mizpah Extension, the MacNamara, Tonopah Extension, and West End, and to a less degree in the Ohio Tonopah. These things show that the ascending hot waters, circulating through the fractured rhyolite-dacite, rose until at the contact with the overlying soft andesite they found a practically impervious barrier, along whose lower contact they circulated and deposited the materials which they held in solution.

Subsequent to this formation of quartz veins and attendant silicification, similar differences between the rhyolite-dacite and the andesite with reference to brittleness continued, so at the present day the silicified rhyolite-dacite is found to be extremely faulted and fractured and to contain open fissures, features which are not present to the same extent in the adjacent andesite.

EFFECT OF WATERS PRODUCING THE TONOPAH RHYOLITE-DACITE VEINS ON EARLIER FORMED VEINS.

Although as a rule decomposed andesite seems to have presented a formidable barrier to the circulating waters accompanying the Tonopah rhyolite-dacite, in some places the waters must have traversed the andesite and found their way along the andesitic veins. Indeed, it is along these brittle veins and the brittle silicified adjacent andesite that fractures and fissures must have been most easily formed at this period. In the case of the Tonopah Extension, as described elsewhere (see p. 182), the earlier andesite vein has been reopened and a new vein of barren jaspery quartz formed along the hanging wall. This is probably due to waters of the rhyolite-dacite period of mineralization. In the case just mentioned the new quartz is barren as compared with the old. It is evident, however, that such solutions must have dissolved a great deal of the gold and silver contained in the earlier veins, and naturally may have reprecipitated it elsewhere. In this case the ores might be reprecipitated in a concentrated form. This very likely has been the case in the Montana Tonopah, where, as described (see p. 171), the original vein has been reopened and in the fissure thus formed minerals similar to those in the older vein, but richer in gold and silver, have been precipitated in crustified form. It is very likely that this was the work of the waters of the rhyolite-dacite period, of the same kind and character as those to which the barren quartz hanging-wall portion of the vein in the Tonopah Extension is due.

Again, it is natural that such waters may have dissolved some of the metallic contents of the older veins and, instead of precipitating them within these veins, may have carried them out and deposited them elsewhere, as, for example, in the veins of the rhyolite-dacite, forming bunches of high-grade ore in these usually barren veins. This may be the explanation of the comparatively small amount of rich ore found in the rhyolite-dacite veins, as, for instance, in the Desert Queen and the MacNamara. These are practically the only cases of high-grade ore in the district in veins of this period, and in both cases the veins are in the vicinity of rich earlier andesite veins and the ores have a character altogether similar to that of the earlier veins. Outside of the earlier andesite vein region, the veins in the rhyolite-dacite have been found to be frequently large, but typically are low grade or barren.

THE CALCITIC VEINS OF ARARAT MOUNTAIN.

THE RHYOLITE OF ARARAT A VOLCANIC PLUG.

The top of Ararat Mountain is composed of white rhyolite like that of Mount Oddie. On the southwest side this is intrusive into the later andesite, and on the other sides into the glassy Tonopah rhyolite-dacite, which is itself intrusive into the later andesite. The area of white rhyolite is broadly ellipical in outline, with the longer axis of the ellipse, as in the case of most of the other hills on the map, lying in a general east-west direction (Pl. XIV).

The contact, as is shown by the Wingfield tunnel and the Boston Tonopah shaft and in other places, pitches steeply all around. The rhyolite is then in the nature of a volcanic column or plug which has been forced up into the older rocks, and which probably occupied the vent of an old volcano, now removed by erosion.

FLOW BRECCIATION NEAR CONTACT.

Near the contact in many places the rhyolite is peculiarly brecciated, showing great blocks jumbled together, with, however, rhyolitic matrix between. The dim outline of these blocks and the rhyolitic matrix show that they were formed when the lava was in the process of cooling and only partly rigid. This brecciation decreases away from the contact, but in places occupies a zone upwards of 100 feet wide. The breccia indicates that the plug was forced upward while cooling.

FISSURE VEINS IN THE RHYOLITE PLUG.

Many sharp fractures cut the rhyolite, increasing in number as the contact is reached. These are chiefly parallel to the contact. They have been filled with

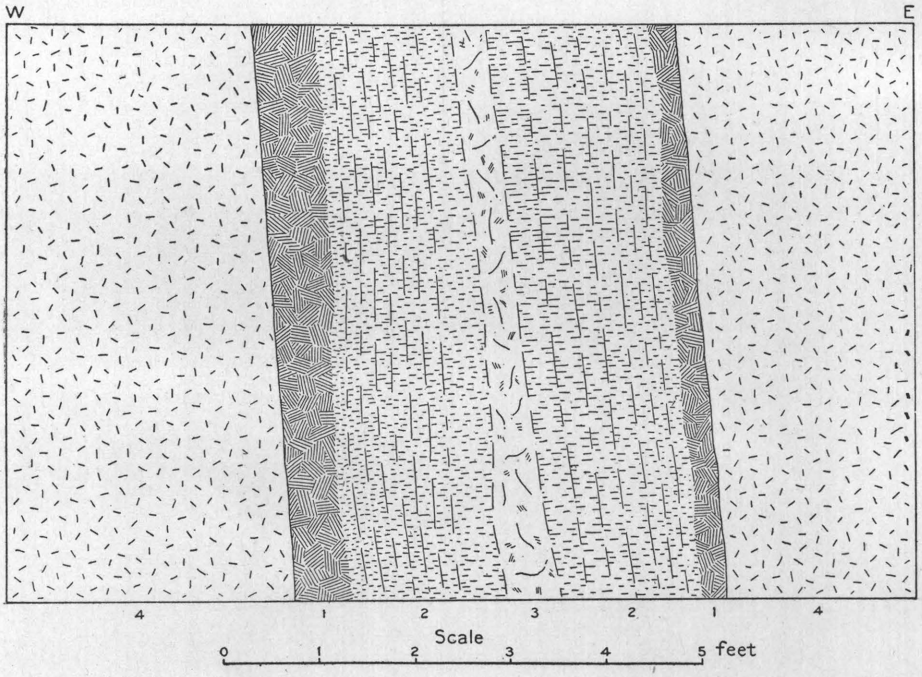


FIG. 14.—Cross section of outcropping fissure vein in Ararat rhyolite neck near margin. Reptile claim, north of the Boston Tonopah shaft. 1, Dark-brown calcite and siderite, mixed; 2, white calcite, beautifully banded; 3, quartz mixed with calcite; 4, white rhyolite (wall rock).

material as described below, and constitute veins that are locally as much as 20 feet thick, but are exceedingly irregular and nonpersistent. These veins conspicuously follow the contact and are coterminous with it; they do not extend into the older intruded rocks, but often run back into the rhyolite. A prominent line of veins, as shown in Pl. XIV, extends due north across the top of the hill, from the vicinity of the Wingfield tunnel. These are fine examples of veins which have filled open fissures.

On the Reptile claim, above the Wingfield tunnel, an outcropping vein of this material is beautifully banded, and consists of brown and white calcite and some quartz (fig. 14).[a] Some assays of this are said to show a value as high as $20, all in gold, but it is mostly barren. Several small veins near by are of the same character. One of these distinctly shows quartz as a later deposit than calcite (fig. 15). These veins have a general northerly trend, and the vein zone can be followed all the way across the hill to the contact on the north, but no farther. Each vein can be followed only a short distance, however, when it becomes confused by reason of splitting, straggling, and thinning, while a lateral vein may thicken up so as to become of predominating importance.

At the contact between the white rhyolite plug and the glassy Tonopah rhyolite-dacite, on the east side, an 8-inch vein of banded white and brown calcite and siderite, cementing a fissure in the white rhyolite, was observed. This has a strike of N. 10° W. and a dip of 70° to the east.

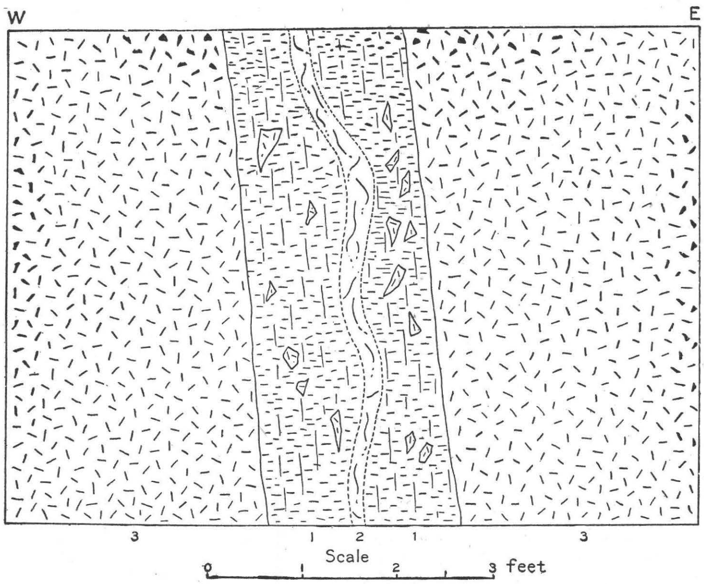


FIG. 15.—Vertical cross section of outcropping fissure vein, 20 feet west of section shown in fig. 14. 1. Calcite with angular rhyolite fragments; 2, quartz; 3, white rhyolite.

On the opposite or west side of the intrusive plug, near or at the contact between it and the later andesite, there is a vein of beautifully crustified crystalline calcite, locally 20 feet thick. The rhyolite on one side of the vein has been silicified so as to form a pale-yellow jasper.

It will be noted from Pl. XIV that these veins, although their position and trend are governed to a large extent by the contact, have a general north-south trend independent of it. This indicates that the chief strain at the time the fissures were formed was in a direction nearly at right angles to the longest axis of the elliptical horizontal cross section of the volcanic plug. This north-south trend is at right angles to the principal trend of the ore-bearing veins in the earlier andesite, formed at an earlier epoch (fig. 12, p. 84).

[a] Dr. W. F. Hillebrand kindly examined the dark-colored carbonate for the writer. He finds it essentially calcite, with very small amounts of iron and manganese carbonates, a considerable amount of mechanically included hematite, and some black manganese oxide.

FISSURES DUE TO MOVEMENT AFTER CONSOLIDATION.

These fissures and fractures, judging from their distribution and direction, plainly resulted from the continuation of the driving upward of the plug after consolidation was practically complete.

The movement thus indicated is like that which was manifested by the plug of Mont Pelée in Martinique subsequent to the late eruptions, when it was forced upward after solidification, so as to tower several hundred feet in the air.[a] Around the base of such a plug as Pelée's, phenomena like those on Ararat must have taken place.

The fillings are evidently the result of ascending hot water which followed the channels thus opened and cemented them. That such large open spaces due to rending could have been formed indicates that the spot was not very far distant from the surface.

PARAGENESIS OF VEIN MATERIALS.

The substances deposited in the openings also are simple, as compared with those of other periods of vein formation in the district. The alteration of the rhyolite is confined to silicification and slight bleaching of the biotite. Some of the specimens from the Wingfield tunnel show feldspar phenocrysts completely altered to microcrystalline and cryptocrystalline silica. In many cases this silicification seems to have preceded the deposition of the carbonates, for the latter are deposited in cavities upon the silicified rhyolite. In other cases, however, the jaspery and chalcedonic quartz, which is often part of the fissure filling, is plainly later than the carbonates. In several cases white calcite was observed to be later than the dark or ferruginous calcite in origin.

COMPOSITION OF VEIN-FORMING WATERS.

No sericite was observed to be developed in the wall rocks, hence it seems probable that the waters did not contain fluorine (see p. 232), or that their temperature was very moderate, or both. Indeed, they do not give evidence of having contained anything beyond silica, lime, iron, and manganese carbonates. Their content of gold was small, for the veins are generally practically barren. No larger amount of this metal is likely to have been present than has been detected in many hot springs issuing at the surface. The presence of iron is contrasted with the probable absence of iron in the solutions which produced the earlier andesite.

[a] Hovey, E. O., Am. Jour. Sci., 4th ser., vol. 16, pp. 269-281. Russell, I. C., Science, vol. 17, pp. 792-795; Am. Jour. Sci., 4th ser., vol. 17, 1904.

CHAPTER III.

PRESENT SUBTERRANEAN WATER.

WATER ENCOUNTERED IN MINING OPERATIONS.

The Desert Queen shaft is 1,114 feet deep. It is perfectly dry, except at the contact of the rhyolite and later andesite at a depth of a little over 300 feet, where water following the contact zone was encountered. Along the watercourse, which strikes north and south and dips 60° east, the rocks have been altered to clay. Fragments of rocks in the channel show fresh pyrite on cracks, indicating that these waters have deposited the sulphide. The water tasted very slightly astringent; when first encountered it was tepid, but afterwards it became cool.

The water was encountered in October, 1902, when the flow was about 3,000 gallons per twenty-four hours; it gradually diminished, till in six weeks it was only 250 gallons, and later in the fall shrunk to 100 gallons. In the spring, however, the flow increased to 250 gallons, and the water was cold.

These data show that the water of the contact zone was contained in a comparatively small basin or reservoir, whose surface was quickly lowered, and the increase in the spring with the melting snow indicates that this basin is fed from the surface.

The Halifax shaft encountered water below 600 feet; at 640 feet the flow, on July 17, 1903, was estimated by the manager at 12,000 to 15,000 gallons a day, and on July 20 at 20,000 to 30,000, so it was necessary to stop work pending the arrival of a pump.

A similar copious flow was encountered in the Rescue, situated just south of Mizpah Hill. At a depth of 250 feet an estimated flow of 6,000 to 7,000 gallons a day was encountered along a crevice in the rhyolite, striking northeast and dipping southwest at an angle of about 40°. Below this there was no water till a depth of 300 feet was reached, at which depth more water came in along fractures striking northwest and dipping northeast. When this second water zone was struck the supply of water in the first was reduced, showing that the two zones are connected. On July 10, 1903, the combined flow from the two was about 8,000 gallons; on July 17 it was estimated by the manager to be from 25,000 to 30,000 gallons.

The Gold Hill shaft was dry to the bottom (490 feet), but a drift running northward from the bottom struck water in fractures a short distance from the shaft. The south drift was dry. The water here was estimated at one time to be 7,000 or 8,000 gallons a day.

The Belle of Tonopah shaft encountered water along fractures at a depth of 150 feet. This was drained, and another water seam was cut at 190 feet. The rock is soft later andesite, very full of pyrite, indicating, as at the Desert Queen shaft, that these waters deposit pyrite.

The Golden Anchor struck water at a depth of 130 feet and also farther down along fractures. One fracture from which water issued, seen by the writer at 200 feet, was perpendicular, and had a course of N. 70° W. This fracture had been cemented by calcite and reopened. The Silver Top, east of the Golden Anchor, encountered water at a depth of 180 feet.

The Mizpah Extension encountered water at a depth of 430 feet at the contact of Oddie rhyolite and Tonopah rhyolite-dacite. The water runs on top of 14 feet of wet clay, formed by rock decomposition. The water zone strikes N. 30° W. and dip northeast at an angle of 40°. At the time of the writer's inquiry, in November, 1902, the flow was about 300 gallons a day. The shaft was sunk to a depth of 800 feet without encountering any more water.

The other shafts in the district were quite dry at the time the writer made his observations. Their depths at that time or soon afterwards were as follows:

Depths of dry shafts in Tonopah district.

	Feet.
King Tonopah	300
Boston Tonopah	300
Belmont	340
North Star[a]	1,050
Siebert	938
Valley View	700
Stone Cabin	400
Molly	468
Montana Tonopah	765
Midway	635
Tonopah Extension	485
MacNamara	500
West End	780
Fraction	400
Wandering Boy	500
Tonopah and California	650
Tonopah City	500
Ohio Tonopah	756
Big Tono	300
Fraction Extension	300
New York Tonopah	745

[a] A little seepage along a fault zone at a depth of 720 feet.

OUTCROPPING WATER ZONES.

Previous to the discovery of the water in some of the shafts described the entire water supply of the town of Tonopah was obtained from wells 4 miles to the north, where geologic and topographic conditions are similar to those at Tonopah. Here, in a distance of a half mile or more, along a small east-west valley, are a number of wells, most of which reach water within 30 to 40 feet of the surface. The wells are in solid later andesite, and the water circulates along a fractured (probably faulted) zone. The trend of the water zone corresponds with that of the valley, which has probably been eroded along this belt of fractures.

These water zones can often be recognized at the surface by the presence of taller and greener vegetation or by plants requiring so much water that they would not thrive under the usual arid conditions.

DISTRIBUTION AND EXPLANATION OF WATER ZONES.

The above data show that while some of the Tonopah shafts have reached depths of over 1,000 feet (in the case of the Desert Queen over 1,100) no general body of ground water has been encountered, though the rocks are extremely fractured; yet along certain steeply inclined fracture zones water is found sometimes quite near the surface and occasionally in considerable quantity. This water is cool, is sufficiently nonmineral to be fair drinking water, and is undoubtedly the storage of precipitation.

These water zones appear to be widely spaced. They have been noted only in rigid and brittle rock—rhyolite and andesite. They seem to occur especially along intrusive contacts, where one rock has been shattered by the intrusion of another. They are often, perhaps usually, accompanied by a clayey state of the decomposed rock. This decomposed rock, while itself undoubtedly due to the waters, now forms an impervious bottom or foot wall of the fractured zone and keeps these waters from penetrating the underlying dry and fractured rocks. Thus the water channel or basin has a dike-like shape. It appears probable that similar clays may limit these water basins in depth, limiting the downward extent of the zone-shaped basins, and thus explain why they are found sometimes so near the surface in a region apparently without universal ground water.

USUAL ABSORPTION OF PRECIPITATION BY ROCKS.

In the southern half of the area shown on the Tonopah map (Pl. XI), in the depressed area capped by volcanic breccias, no water has been encountered, even in shafts over 700 feet deep, although some shafts, as the Ohio Tonopah for instance, have passed through the soft breccia to a rigid and fractured rock below. Furthermore, in the breccia-covered region to the south, the writer does not know of any water or water signs, while to the north, in the hard rock, water zones outcrop in various places, both on and beyond the area mapped. The explanation of this is probably that the porous breccias and tuffs absorb the scanty precipitation like a sponge.

Even where rigid fractured rocks outcrop, the scanty descending water normally sinks as through a sieve, using itself up in kaolinization, the formation of limonite, and other hydration processes, and moistening the dry rocks with interstitial water. Fresh rock taken from the Fraction and other shafts in frosty weather was observed by the writer to steam vigorously in the cold air, though the mines are perfectly dry. It is doubtful if there is enough of this water left to form a standing body of ground water at any depth. Where, however, kaolinization and other processes have formed clay seams, the water may be detained and even stored at any depth from the surface downward; and other impervious rock materials may operate in the same way.

CHAPTER IV.

PHYSIOGRAPHY.

ORIGIN OF THE RANGE OF HILLS.

The area of the Tonopah map has been, from the dawn of its available record in the middle Tertiary down to the present day, essentially a land surface, save during the period when the white lake beds were deposited. At present the region consists of isolated buttes (which are usually denuded volcanic necks), and intervening depressions. These buttes are irregularly grouped, but occupy in general a definite north-south belt, although this belt can not be distinguished upon the small detailed map which accompanies this report. The belt becomes higher on the north, where it is known as the San Antonio Range, and rather lower toward the south, where it gradually loses its individuality. The character of the rocks throughout is volcanic, and evidently a large part of the topographic relief is due to the fact that this has been a chain of Tertiary volcanoes.

SKETCH OF TERTIARY AND QUATERNARY EROSION.

GENERAL FEATURES.

The Tonopah district, as limited by the mapped area, is in the central part of this north-south topographic ridge. The surface run-off drains mostly to the west, but in the eastern corner of the area mapped the slopes indicate that the drainage is eastward. On both sides of this volcanic range are broad, flat, desert valleys. On the west, which is reached by a moderate and regular though decided slope down from Tonopah, is the east branch of Great Smoky Valley, and on the east lies Ralston Valley. These general topographic conditions must have existed during most of the period embracing the volcanic history of the region. Erosion was steadily at work attacking the uplifted and outpoured rocks of the range, and transferring them to the deep flanking valleys; and since much of the volcanic material was loosely consolidated it must have been transported with extraordinary rapidity, especially as periods of greater humidity than the present alternated with the arid periods.[a] Since the region was probably all this time without any outlet to the sea, enormous amounts of detritus accumulated in the valleys, partly

[a] Spurr, J. E., Bull. Geol. Soc. Am., vol. 12, p. 250.

filling up these originally profound depressions. This process has continued up to the present day, and is still going on, until the volcanic range in which Tonopah lies, like other ranges in the district, is flanked on both sides by nearly level stretches of waste—veritable waste lakes—which constantly rise as the degradation of the mountains progresses. These waste lakes (kept level chiefly by the terrific winds that travel up and down between the mountain ranges, sweeping the fine material, unbound by moisture or by vegetation, before them) invade the deeper mountain valleys and overflow the lower hills. Their surface portion consists of Pleistocene subaerial accumulations, and it has been unwarrantably assumed that this material has a depth of thousands of feet, but observations by the writer in the western part of the State lead to the conclusion that in many, perhaps most, cases the Pleistocene cover is only a veneer, beneath which lie Tertiary accumulations.[a]

MEASURES FOR THE AMOUNT OF MATERIAL ERODED.

Under the conditions sketched above a large amount of material must have been stripped from the area of the Tonopah quadrangle and carried to the valleys. Study of the local geology affords us more detailed data for this conclusion. The thick volcanic agglomerates (chiefly dacitic), which occupy a large part of the southern half of the area mapped and are probably upward of a thousand feet thick, are not represented in the northern half. It is true that these are local accumulations and may be essentially the remnants of bomb and cinder cones of the earlier dacitic eruptions which occurred in the southern and not in the northern region. Still, such material must also have fallen over the northern half of the area mapped, even if the quantity was smaller; and it is only about three-quarters of a mile from the New York Tonopah shaft, where nearly 800 feet of the dacite breccia has been passed through and the bottom not reached, to the region east of Mizpah Hill, where the dacite breccia is missing. This disappearance must be due to erosion, which, moreover, was accomplished before or during the deposition of the lake beds (Siebert tuffs), for these in places south and east of Mount Oddie lie directly upon the earlier andesitic rocks.

That part of the erosive work accomplished since the last important geologic occurrences—the intrusion of the volcanic necks and the faulting—or since about the beginning of the Pliocene (see pp. 69–70) can be estimated in a more detailed way, since the evidences are not obscured by subsequent events. The volcanic necks are much modified by erosion, and on the higher ones, as on Butler Mountain, lateral drainage has pushed back and formed sharp dividing ridges. It is hard to say how much the solid lava columns have been lowered, but the cinder and agglomerate cones which once surrounded them have been swept away and only vestiges of them

[a] Spurr, J. E., Bull. U. S. Geol. Survey, No. 208, pp. 139–140.

remain (p. 45). These outer cones must have been very extensive in comparison with the necks and must have covered the whole area of the quadrangle deeply. There is a difference of 700 feet in elevation from the top of Butler Mountain to the lowest point, near its base, where the dacite neck cuts the intruded rock, so that 700 feet is less than the minimum possible thickness of the material that has been removed between these two points.

A still better measure of the amount of erosion is supplied by a study of the faulting. In general, the southern half of the area has been depressed by faulting below the northern half by a distance which has not been closely measured, but which is certainly many hundred feet; yet this differential movement has been entirely compensated by erosion, and there has been stripped from the northern half a crustal layer of a thickness equal to the sum of the amount of the displacement and the thickness of the material removed from the southern half during the same period. Similarly, the individual faults, elsewhere considered, show that erosion has compensated for their dislocations.

FEATURES OF EROSION IN ARID CLIMATES.

In the arid Great Basin region the conditions governing the origin of topographic forms are different from and more complicated than those which exist in well-watered regions, where most of the reliable physiographic conclusions have been formulated. It is therefore important that in a region where the topography is well mapped and the geology fairly well understood, as in Tonopah, the origin of the forms should be examined.

The writer has previously remarked that in the greater part of the arid Great Basin region the effect of the scant moisture as an agency of erosion is equaled or exceeded by disintegration, gravity, and wind action, with the result that in the lower valleys leveling instead of dissection is brought about, and in the higher ones dissection is much less marked than in moister regions.[a] The general conclusions reached by the writer concerning processes of erosion in the Great Basin region, as expressed in an unpublished paper read before the Geological Society of Washington in the spring of 1903, are as follows:

Climate controls not only the speed of erosion, but its manner. In moist climates the precipitated moisture gathers into permanent bodies of running water, a stream system is maintained, and erosion goes on chiefly along these lines. Thus even those rocks which offer no differences in weakness are thoroughly dissected, not because the materials in the valleys are less resistant, but because there the eroding activity is concentrated. The disintegrated rock or soil, except along these naked stream beds, is cemented with moisture and bound together by vegetation, and so

[a] Bull. Geol. Soc. Am., vol, 12. p. 237.

is fairly well armored against the attacks of erosion, which can make but comparatively slow progress.

In a truly arid region, where there are extremes of heat and cold, rock disintegration at the surface is much more rapid. Streams are rare, transient, and relatively unimportant, and stream erosion is slight compared with that of moister regions. Yet erosion is active, so that in the Great Basin region even moderately steep slopes are stripped of débris and consist of hard, unweathered rock. The lack of vegetation renders the whole surface equally susceptible of attack by frosts, thaws, rains, and snows, and the disintegrated material creeps by the nearest way, in the form of a sheet, into the depressions. Thus the fronts of many of the Basin ranges are bordered by a continuous apron of débris sloping down into the center of the valley, an enormous mass of waste which is relatively slightly increased by the alluvial fans at the mouths of the gulches (Pl. XV, *B*).

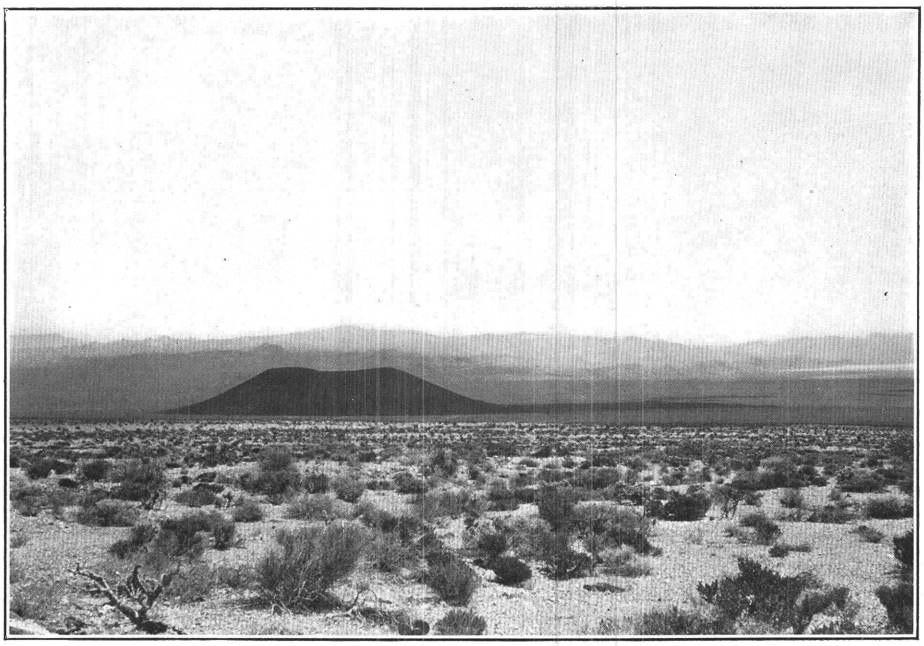
In desert regions the more nearly equable distribution of the eroding agents causes the differences in hardness of the attacked rocks to be far more prominent in determining the lines of relief. In proportion as the aridity increases the topographic forms show more and more faithfully the resistance of the rocks. If the rocks are folded and faulted the ridges will follow the lines of strike and of faulting. In a country of igneous rocks a new element is introduced, but here also erosion tends to preserve the original lines of structure. In intervals of moister climate streams will cut gorges, a tendency which is probably antagonized in succeeding arid periods.

It is proper to insist here that these distinctions apply to truly arid climates, and are more applicable as the aridity increases. Semiarid regions, where violent rains are not infrequent, have a different topography. The abundant waters of the storms flow down the slopes in rushing torrents, which cut their beds all the more deeply because the rock is naked and disintegrated as the result of the intervening periods of aridity. A rugged, well-dissected topography may sometimes result, often wrongly described as typical of arid regions.

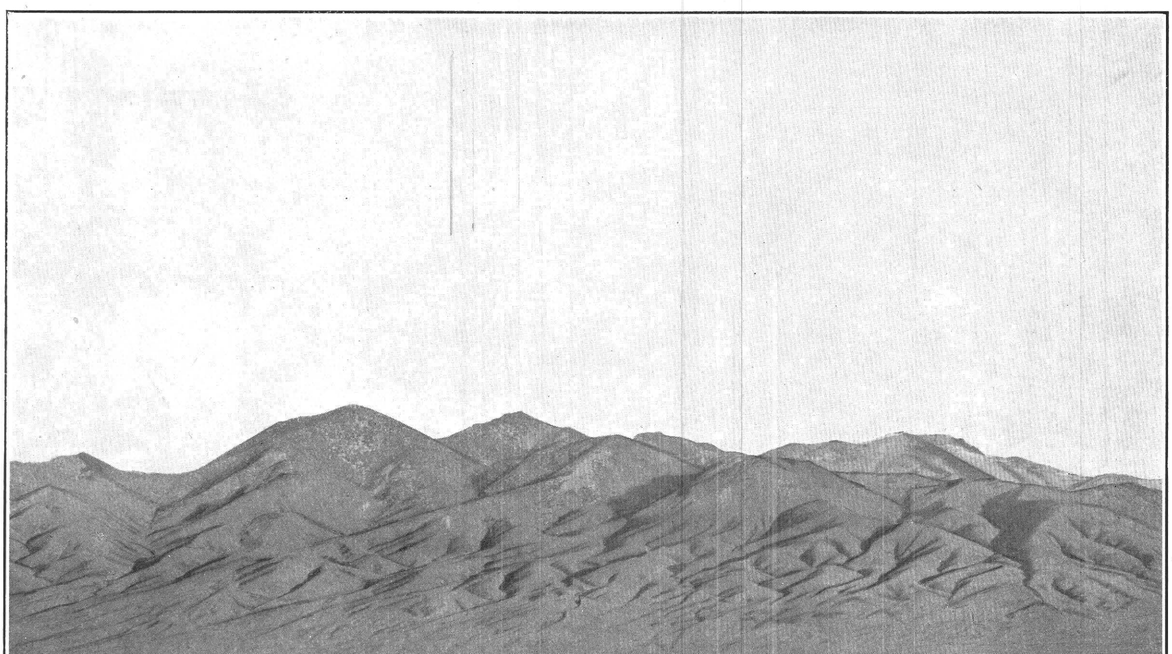
PRECIPITATION IN REGION NEAR TONOPAH.

Although violent rains sometimes occur at Tonopah, especially in the spring, they are rare, and the region can not be classed as semiarid; it approaches more nearly true aridity, and the channeling by torrents is not so important as the universal downward working of disintegrated material.

No records of precipitation have been kept in Tonopah, for the town is only a few years old. The observations made by the United Sates Weather Bureau in Sodaville, 60 miles farther northwest, are as follows:



A. RECENT BASALTIC CONE NEAR SILVER PEAK.



B. EAST FRONT OF QUINN CANYON RANGE, SHOWING WASH APRON TYPICAL OF REGION.

Precipitation, in inches, at Sodaville, Nev.

1898	4.72
1899	2.30
1902	1.68
1903	2.16

Average for these four years (others not completely observed), 2.71 inches.

DEPENDENCE AT TONOPAH OF TOPOGRAPHIC RELIEF UPON ROCK RESISTANCE.

After the great amount of erosion which the Tonopah district has undergone, the relief is to-day determined in a very remarkable way by the character of the rocks. The relief here is not like that resulting from the work of stable and strong streams, concentrating and almost monopolizing the erosion, pushing back their systematic valleys from one rock formation into another and constantly broadening their domains. It is rather like that produced by the warm breath of the sun on a mass of ice and snow, where the softer material fades into the air and the harder skeleton of ice protrudes above the surface.

The most prominent topographic features in the Tonopah district are the denuded volcanic necks—such as Butler, Brougher, Golden, Siebert, and Ararat mountains, and Mount Oddie—where the hard lava column has resisted erosion, while the surrounding softer material has been worn down. The map shows how closely the contours conform to the irregularities of the intrusion and to how great a degree the difference of resistance has controlled even minor features of the topography. Around the margins of the white (Oddie) rhyolite intrusions very well-marked and closely set division planes parallel to the contact (platy structure) render these border zones often more easily attacked. The outlying rhyolite dikes also show this markedly, so that (as around Mount Oddie) such dikes, when relatively narrow, have been easily degraded to the level of the intruded rocks.

The smaller eminences are also almost always due to a harder intrusive rock, as, for example, Heller Butte. The intrusive glassy Tonopah rhyolite-dacite in the northern portion of the area mapped is evidently harder than the intruded later andesite and occupies in general higher ground. Study of the map shows how outlying bodies of this rhyolite-dacite are frequently responsible for hills and ridges, while depressions have formed along the strips of later andesite flanked on the sides by the rhyolite-dacite.

Mizpah Hill and Gold Hill are fault blocks whose relative relief is due to the greater resistance of the silicified earlier andesite, of which they are made up, as compared with surrounding rocks. On the east of Mizpah Hill, where the adjacent rocks are the soft lake beds, the scarp is fairly well developed; on the west side the difference of resistance between the earlier and the later andesite is not great, so that the slope is more uniform. The fact that the contours on the southwest corner of the Mizpah Hill fault block are parallel to the contact of the softer lake beds shows the minuteness with which the relief has been determined by the rock resistance.

EFFECTS OF FAULTING UPON THE TOPOGRAPHY.

The effect of faulting on the topography in general is comparatively unimportant. The two earlier andesite hills above mentioned are the most conspicuous cases where faulting has been (though indirectly) a factor. The volcanic (dacitic and rhyolitic) agglomerates and tuffs, which, by the accidents of faulting, usually adjoin faulted blocks of the Siebert tuffs in the southern half of the map, are not much harder than these. Nevertheless, the lake beds (Siebert tuffs) are undoubtedly the most easily eroded of all the formations, and areas occupied by them are characterized for the most part by a smooth, flat surface, bounded frequently by a slight scarp where the tuff adjoins more resistant rock. In most cases, however, as is shown by the map, the tuff block is surrounded on all sides by the harder blocks, and as there is no outlet for eroded material the tuff block can not be now much below the harder blocks.

GEOLOGIC MAP OF THE PRODUCTIVE PORTION OF THE TONOPAH MINING DISTRICT, SHOWING OUTCROPPING VEINS AND AREAS PARTIALLY DEVELOPED BY UNDERGROUND WORKINGS

By J. E. Spurr

1904

Enlarged from Tonopah Mining Camp Sheet Surveyed in 1902-3

Scale

300 0 300 600 900 1200 1500 feet

Contour interval 20 feet

LEGEND

Latest rhyolite or dacite

Brougher dacite

Oddie rhyolite

Siebert tuffs (lake beds)

Tonopah rhyolite-dacite

Fraction dacite breccia

Heller dacite

Later andesite

Earlier andesite

Areas partially developed by underground workings in autumn, 1894

Faults

Veins

Prospect

CHAPTER V.

DESCRIPTIVE GEOLOGY OF MINES AND PROSPECTS.

THE KNOWN EARLIER ANDESITE VEINS.

MIZPAH VEIN SYSTEM.

MIZPAH VEIN.

EXTENT OF VEIN.

Limitation of vein by Mizpah fault.—The Mizpah vein has a strong outcrop (Pl. XVII), extending for a distance of about 800 feet in a nearly due east-west direction. Toward the east end it is broken by a number of small faults, mostly, it appears, with a north-south strike and an easterly dip, by which the vein is offset, now in one, now in the other direction; and it is cut off abruptly by the great northwest-southeast break, which may be called the Mizpah fault (Pl. XVI). This fault is clearly recognizable at the surface and in the underground workings on the several levels (Pl. XIX), as well as in the Desert Queen, the Montana Tonopah, and the North Star workings. It has a moderate dip to the northeast. Wherever the veins have been followed to this fault, they have been found to be cut off abruptly; and the presence of a zone of clay due to rubbing or trituration, and frequently of a drag of fragments from the quartz veins along this zone, give evidence of a great movement subsequent to the vein formation. On the upper side of the fault, overlying the earlier andesite in which the veins lie, is the later andesite. Since the later andesite is normally above the earlier andesite, a normal fault, with a downthrow on the northeast side, is shown.

Limitation of vein by Burro fault.—On the west side the outcrop of the vein is abruptly cut off by the Burro fault, beyond which the later andesite again outcrops. This fault, traceable on the surface only by the use of the utmost skill, runs northeastward. A break corresponding to this, and probably identical with it, has been encountered underground in the west workings of the mine, farther west than on the surface, showing that the fault dips northwestward.

Limitation of vein by Siebert fault.—The vein normally dips north at an average steep angle, but alternately flattens and steepens, and is even locally overturned (fig. 16). It has been followed on the dip to a depth of nearly 700 feet, where it is cut off by nearly flat fault, which dips west at a moderate angle. This may be called the Siebert fault (fig. 17). On the upper side of the fault the rock is chiefly light-colored, partly oxidized, silicified earlier andesite, mixed with much barren quartz; on the lower side it is unoxidized and has a different appearance, and though study shows it to be probably the earlier andesite there is much chlorite and sometimes calcite among its decomposition products, thereby separating it sharply from the andesite inclosing the veins, which has characteristically been

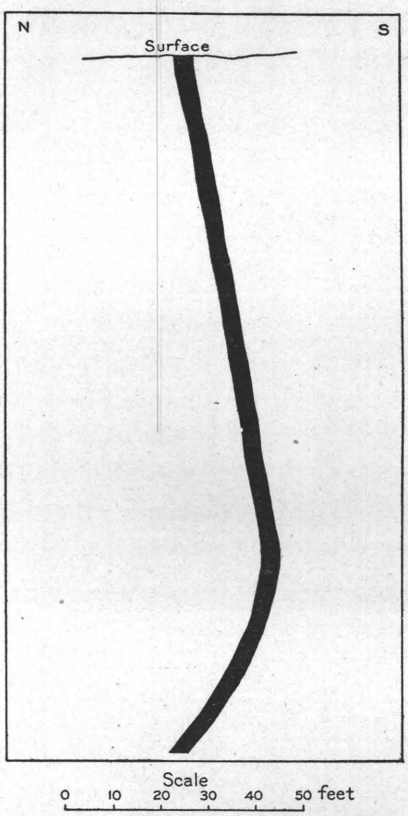


FIG. 16.—Vertical cross section of a portion of Mizpah vein as exposed in the Oddie shaft, showing reversed dip near the surface.

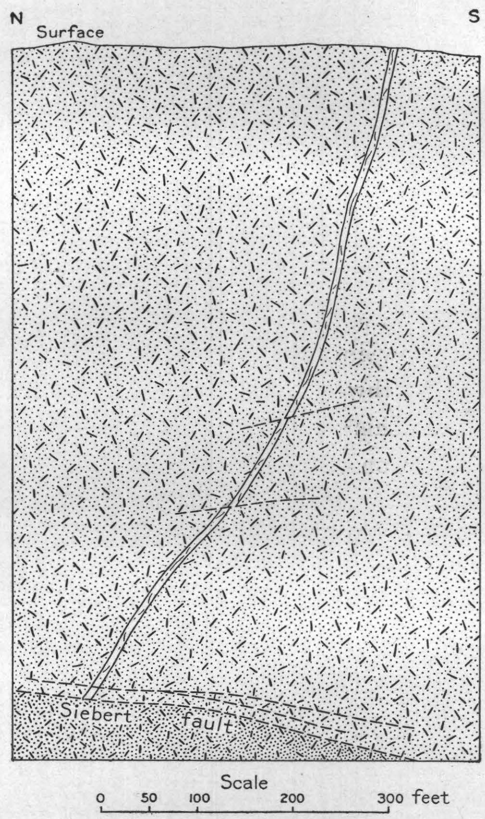
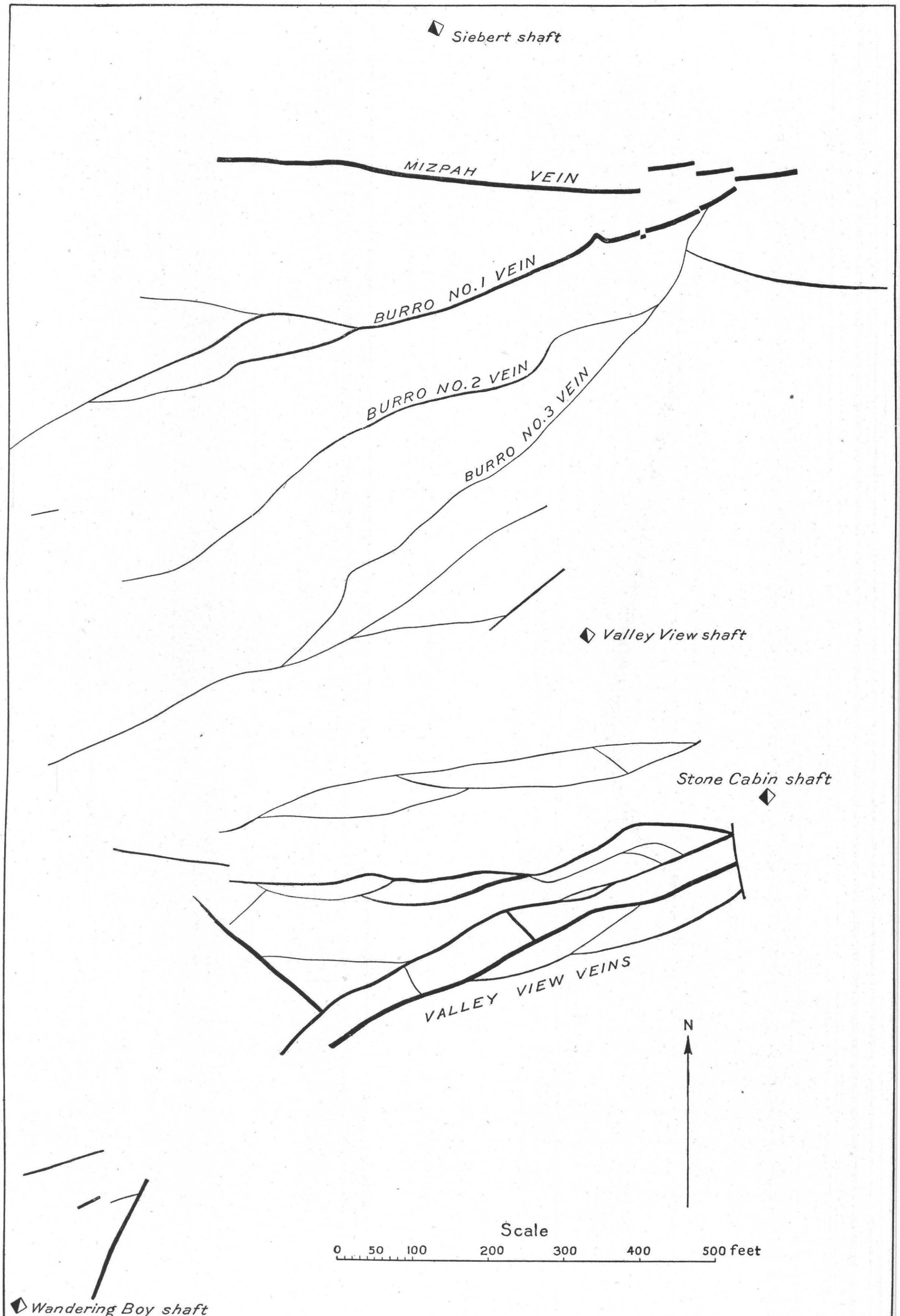


FIG. 17.—Vertical cross section of Mizpah vein along Brougher shaft and inclines.

altered to quartz and sericite. Below the 700-foot level in the Siebert shaft (Pl. XVIII) this rock in places is altered chiefly to quartz and sericite, and even contains silicified zones or quartz veins giving assays of a few dollars to the ton. At a depth of about 935 feet there was encountered a body of dacitic or rhyolitic rock resembling the rock in the lower part of the Mizpah Extension, and probably referable to the Tonopah rhyolite-dacite; below this a vertical drill hole shows that the same rock is continuous to nearly 1,400 feet from the surface, where the boring was stopped.


Siebert shaft
MIZPAH VEIN
BURRO NO.1 VEIN
BURRO NO.2 VEIN
BURRO NO.3 VEIN
Valley View shaft
Stone Cabin shaft
VALLEY VIEW VEINS
N
Scale
0 50 100 200 300 400 500 feet
Wandering Boy shaft

On the 700-foot level, south drift, above the Siebert fault, there was encountered a higher body of Tonopah rhyolite-dacite containing some barren quartz, and similar rock occurs on an east drift on the same level. An east drift on the 500-foot level ran into a mass of the same formation.

VEIN STRUCTURE.

The Mizpah vein is usually several feet wide. Its walls are always earlier andesite, which is generally completely altered to quartz, sericite, etc. The vein may be succinctly described as a silicified and mineralized sheeted zone in the andesite. There are all stages of transition from the sheeted altered andesite (Pl. XX) to solid quartz. Both extremes may be observed at many places along the vein, and sometimes not very far apart. More frequently the vein is intermediate in character, showing a variable amount of quartz in the altered porphyry. Sometimes the quartz forms parallel streaks or veinlets and sometimes it occurs reticulated in the decomposed rock. Frequently some of these small veinlets possess comb structure, which shows that they originated by deposition in open cavities; but their frequently irregular branching and their distribution indicate that these cavities were caused by solution by circulating waters and not by fracturing. Their very existence proves that the main zone did not originate by fracturing. As a rule, however, even the small veinlets give no evidence of having been deposited in cavities, but have evidently been formed by a process of silicification of the porphyry involving replacement, the extreme of the process which has altered the andesite near the veins. This profound alteration of the zone which became the vein was caused by close-set parallel fractures, which marked this zone, and which afforded a favorable channel for the silicifying and mineralizing solutions.

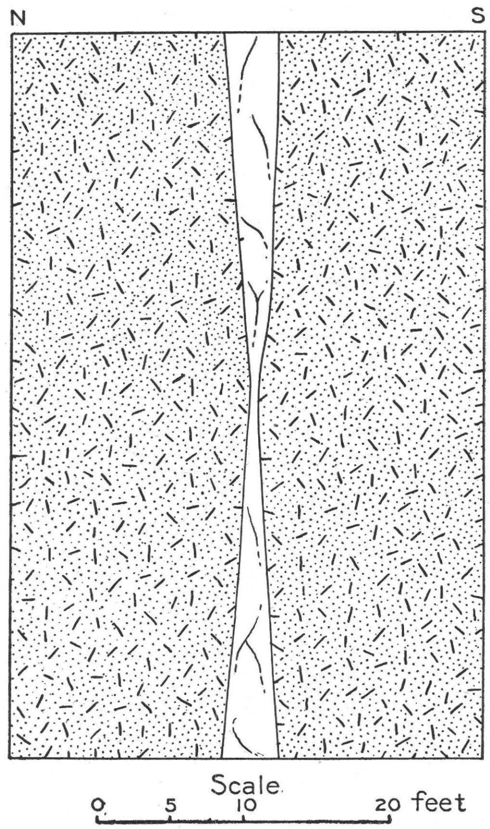


FIG. 18.—Vertical cross section of Mizpah vein, Oddie and McMann lease, showing diverging walls.

The main premineral fractures had therefore the course of the present vein, striking east and west and dipping steeply north. Frequently, also, the walls are locally not parallel (fig. 18).

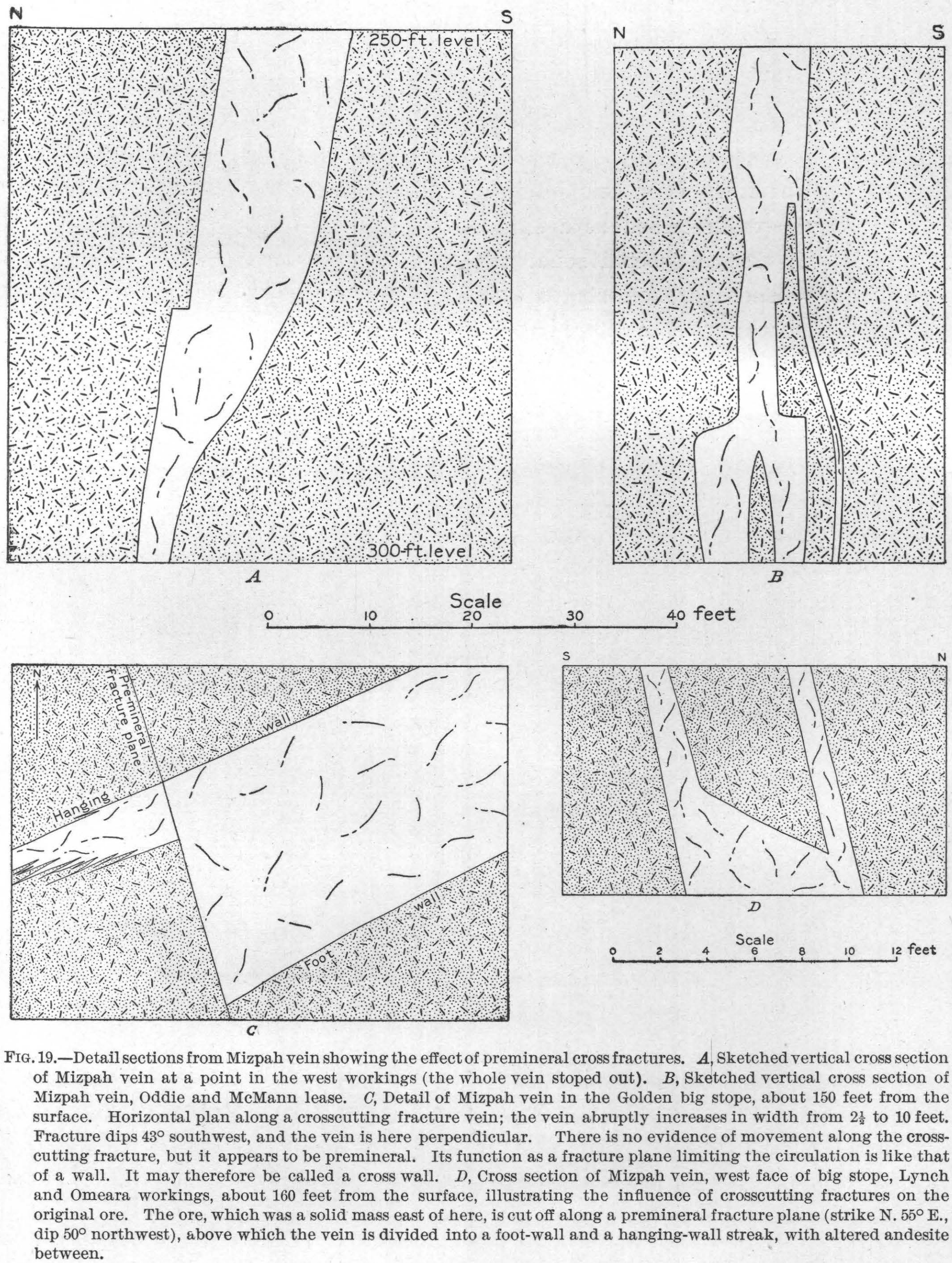
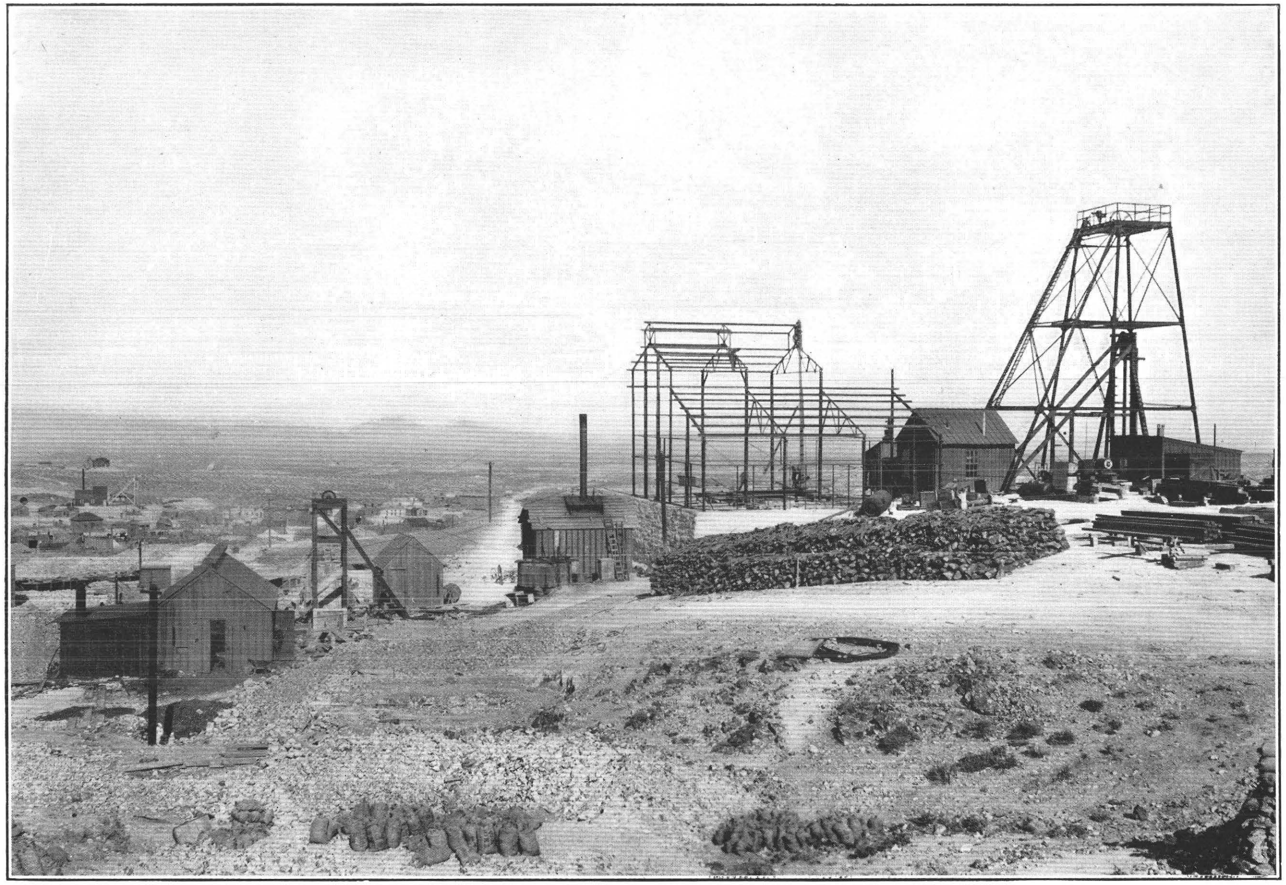


FIG. 19.—Detail sections from Mizpah vein showing the effect of premineral cross fractures. *A*, Sketched vertical cross section of Mizpah vein at a point in the west workings (the whole vein stoped out). *B*, Sketched vertical cross section of Mizpah vein, Oddie and McMann lease. *C*, Detail of Mizpah vein in the Golden big stope, about 150 feet from the surface. Horizontal plan along a crosscutting fracture vein; the vein abruptly increases in width from 2½ to 10 feet. Fracture dips 43° southwest, and the vein is here perpendicular. There is no evidence of movement along the crosscutting fracture, but it appears to be premineral. Its function as a fracture plane limiting the circulation is like that of a wall. It may therefore be called a cross wall. *D*, Cross section of Mizpah vein, west face of big stope, Lynch and Omeara workings, about 160 feet from the surface, illustrating the influence of crosscutting fractures on the original ore. The ore, which was a solid mass east of here, is cut off along a premineral fracture plane (strike N. 55° E., dip 50° northwest), above which the vein is divided into a foot-wall and a hanging-wall streak, with altered andesite between.



SIEBERT SHAFT, TONOPAH MINING COMPANY.

EFFECTS OF TRANSVERSE PREMINERAL FRACTURES.

There were also minor fractures, among which some striking in a general north-south direction, and dipping east, can be recognized.

Cross walls.—These are shown by jogs in the vein following these planes, or, very frequently, by a change from a highly silicified or mineralized condition to a less altered one, while the vein zone is continuous and undisturbed. These jogs or offsets may occur on both sides of the vein, and thus may simulate faults, from which they are distinguished by the lack of evidence of movement; or they may be restricted to one side of the vein (fig. 19), in which case they can not be mistaken. Sometimes the vein may jog in opposite directions on the two sides of such a critical cross plane or premineral fracture, and so become markedly larger or smaller (fig. 19, *B*).

Branching veins.—Small veins which diverge from the main vein also testify to these crosscutting premineral fractures.

Besides the north-south premineral fractures, there were other fractures having a variety of strikes intermediate between that of the main vein zone and the cross fractures. Among other things this is evidenced by the portions of the veins which split up from the main vein and reunite with it. This splitting and reuniting takes place in both a horizontal and a vertical direction, and the general result can best be explained by illustrations (fig. 20). The veins thus belong to the class of linked veins, and this same relation is exhibited on a larger scale between some of the larger veins, and will be described.

The intersections of the minor veins with the vein zone seem, as a rule, to pitch to the east also, like the main crosscutting premineral fractures.

Origin of ore shoots.—The main crosscutting fractures, striking north and south and dipping east, as above explained, in many places separate the highly silicified and mineralized vein zone, often by a sharp division, from a portion which has not been so much altered. These richer portions may be considered ore shoots; and while their internal size and richness are very irregular, a careful plotting of the results of the assay chart[a] shows that the richer portions of the vein may be separated into broad east-dipping shoots, of which there are three within the developed vein. The internal distribution of the ore in these shoots would make an interesting study if enough data were on hand.

Fig. 21 shows the shoot-like distribution of the richest portions. The space between and beyond the shoots is, however, good ore. The company does not desire to have the figures published, but it may be said that the amount of gold and silver in those parts of the vein left blank on the diagram is fully equal to that contained in the greater part of the ore produced by the Comstock during

[a] Kindly furnished to the writer by the Tonopah Mining Company.

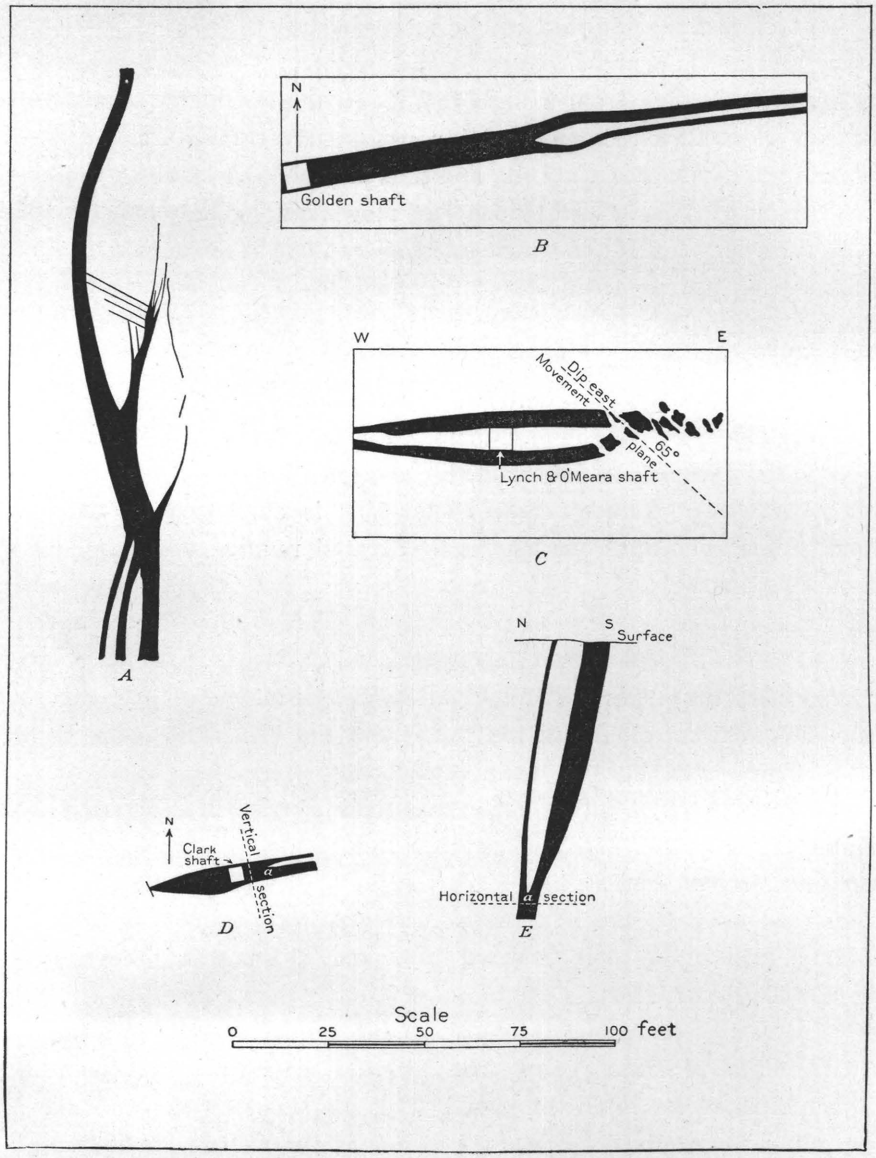
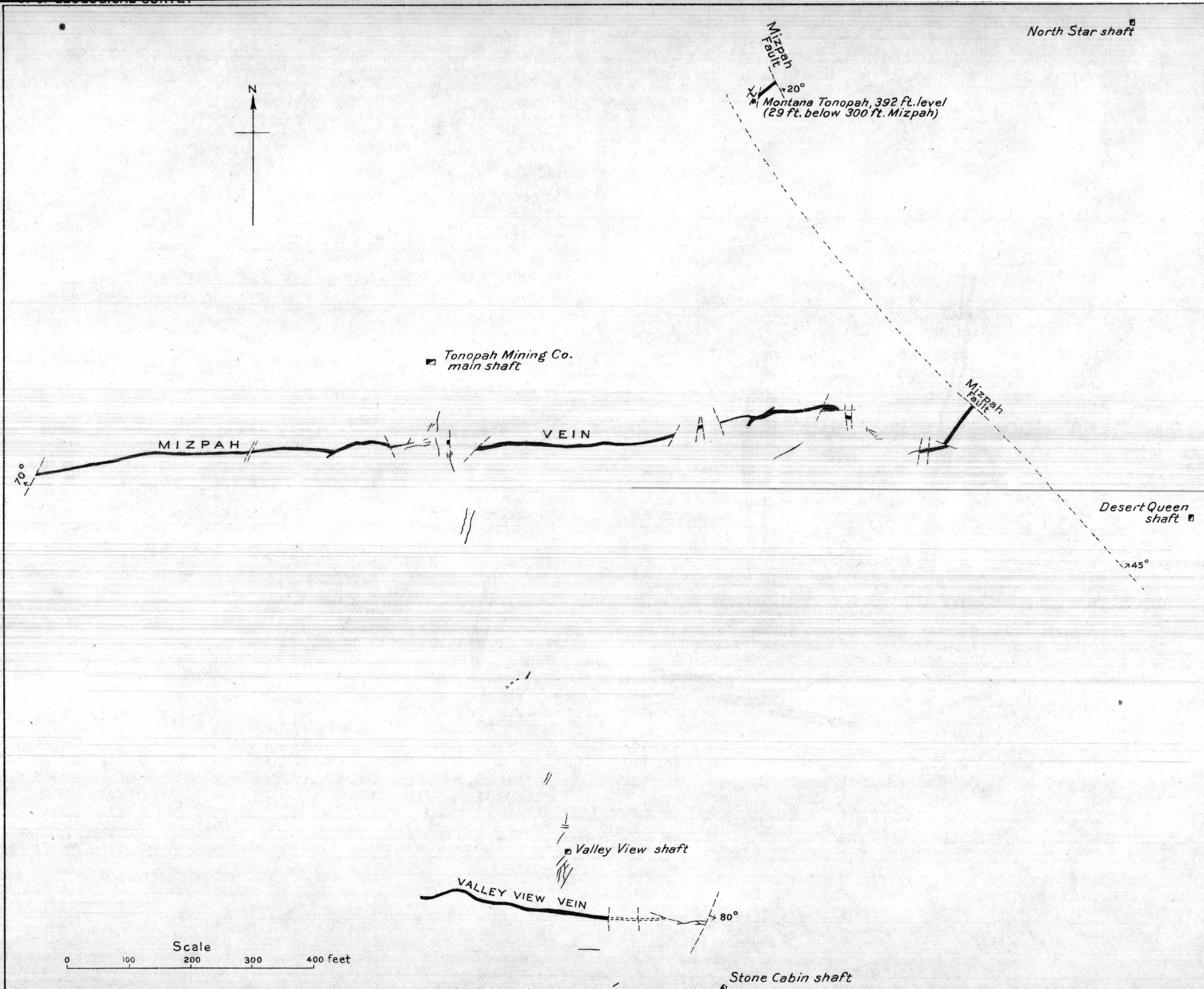


FIG. 20.—Sections to show the splitting of the Mizpah vein. *A*, Horizontal plan of portion of Mizpah vein as developed on the 250-foot level, Mizpah mine, east of the Brougher shaft. *B*, Horizontal plan of portion of Mizpah vein as exposed in the Golden and Kendall and McMann leases, about 130 feet below the surface, showing splitting of solid vein into foot-wall and hanging-wall seams. *C*, Horizontal sketch section of Mizpah vein, big stope, Lynch and Omeara workings, showing splitting of vein in two. *D*, Vertical sketch cross section of a portion of the Mizpah vein at the Clark shaft, from the surface down. Junction of veins (*a*) pitches east on the vein at an angle of about 45°. *E*, Horizontal section of same, taken at 60 feet below the surface.



HORIZONTAL PLAN OF VEINS ON THE PLANE OF THE MIZPAH 300-FOOT LEVEL

THE NORRIS PETERS CO., PHOTO-LITHO., WASHINGTON, D. C.

its best days.[a] This whole plan, therefore, shows, in the large sense, a single bonanza, comparable in size and richness to those of the Comstock (fig. 78, p. 277).

As a rule, within the mine, great size of the vein coincides with increased richness, although exceptionally this is not true.

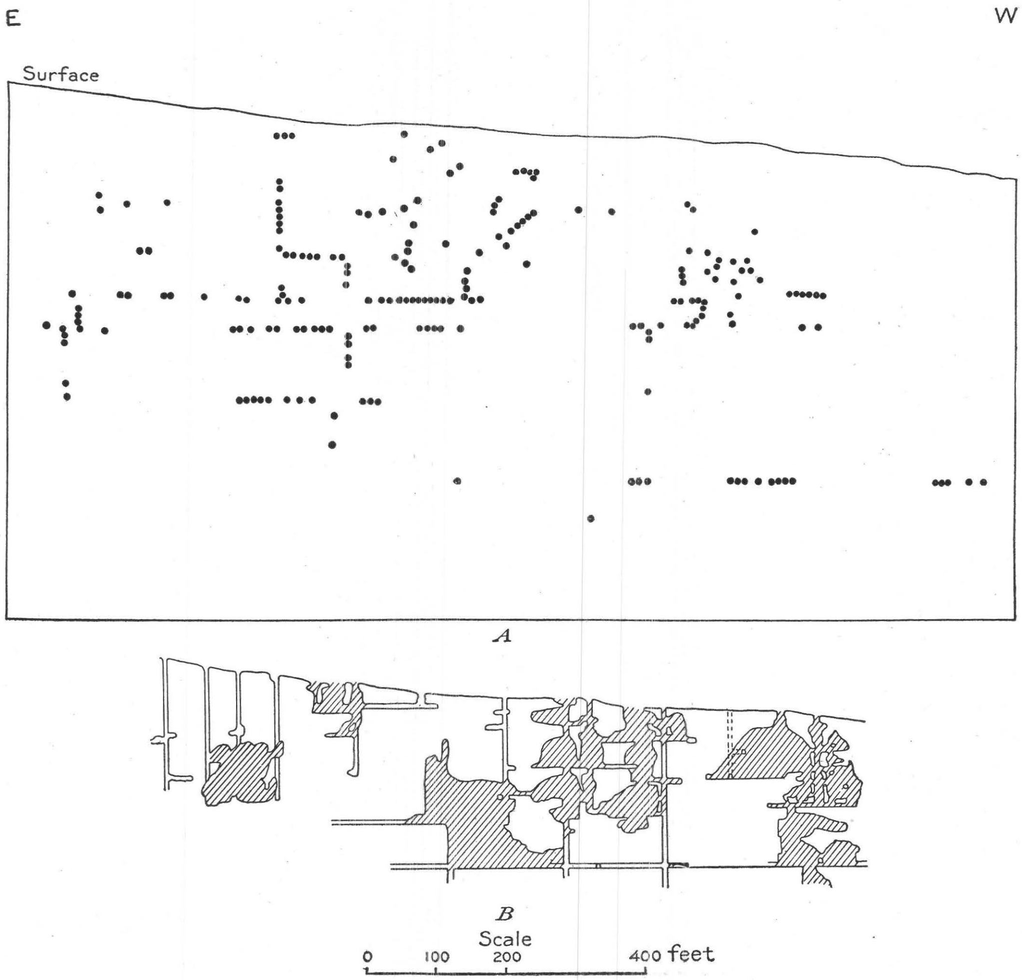


FIG. 21.—Diagram showing the distribution of the richer ores in the Mizpah vein. *A*, Distribution of the richer ores as indicated by assays; black dots indicate assays above a certain figure; lower assays not indicated. Diagram of the Mizpah vein projected on a vertical plane. The diagram indicates, roughly outlined, broad eastward-pitching shoots of rich ore. *B*, Mizpah vein projected on a vertical section, showing stopes from which ore has been removed above 300-foot level. Previous to the making of the assay plan (fig. 21, *A*) the distribution of these stopes indicated the eastward-pitching richer shoots.

From what has been said, it is seen that the ore shoots are primary. Along certain portions of the east-west fracture zone (those portions being governed by north-south striking and east-dipping fractures) the circulation of mineralizing

[a] Mon. U. S. Geol. Survey, vol. 3, p. 10.

waters has been freer and the result greater. In these portions the channels must have been more open, and since the main vein zone was a single set of fractures, with fairly uniform conditions, the difference in degree of openness, influencing circulation, must have depended largely on the cross fractures. In other words, it appears likely that where these cross fractures were most numerous rude east-dipping columns or chimneys, speaking generally, were formed, in which the circulating solutions were relatively concentrated.

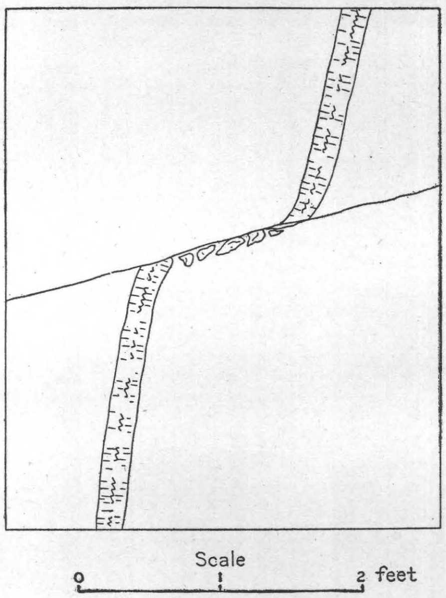


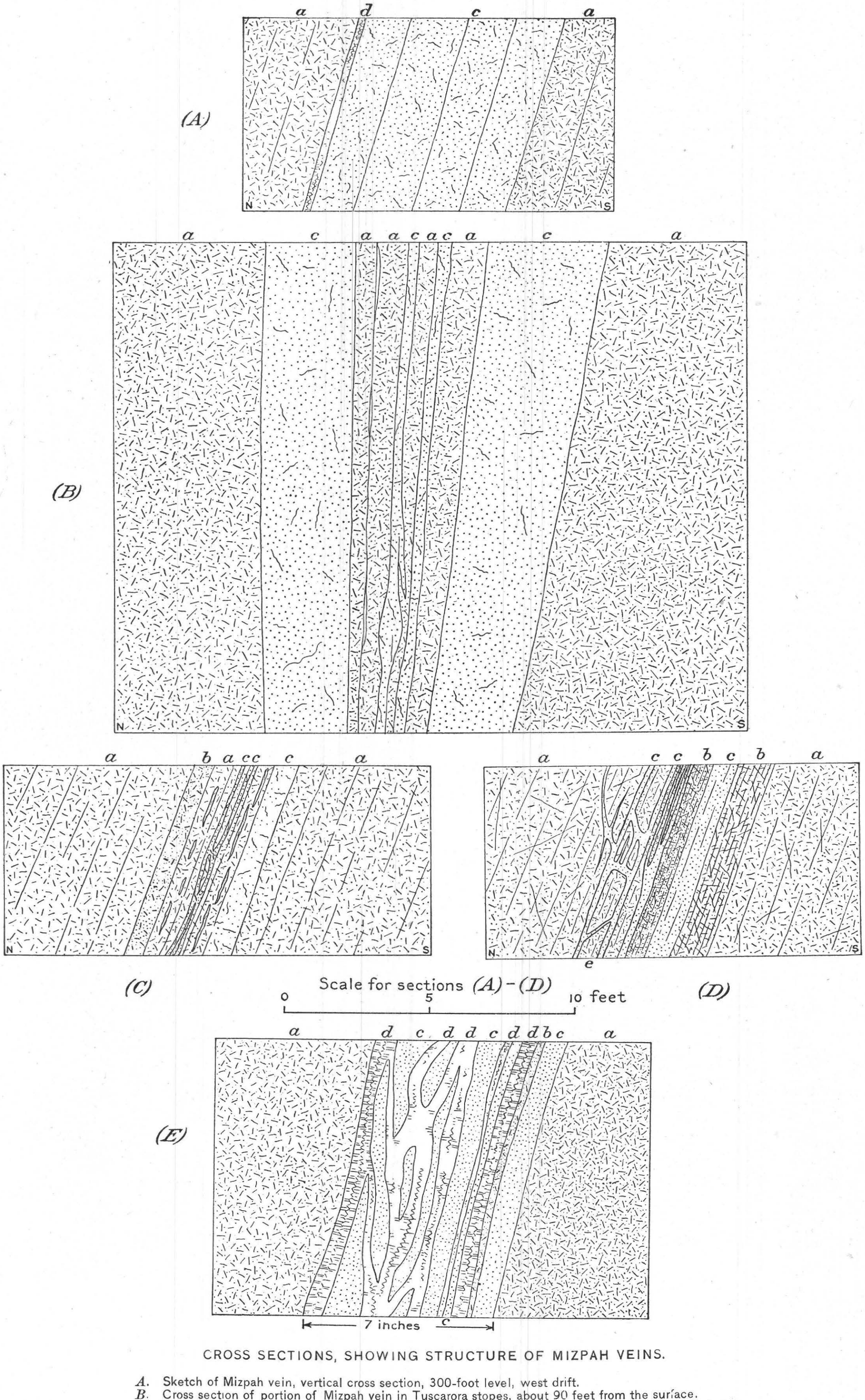
FIG. 22.—Sketch of faulted quartz veinlets in andesite, 300-foot level, Mizpah, just south of the Valley View shaft.

POSTMINERAL FAULTS AND FRACTURES.

Postmineral fractures and faults are common. Besides the great faults mentioned there are continually encountered in the mine many minor ones (figs. 22 and 23) which may prove puzzling to the miner. Small faults are very numerous in the workings in the vicinity of the great Mizpah fault. These faults usually strike north-south and dip east, though they may have other attitudes. Numerous postmineral fractures, along which there has been no movement, have the same general north-south strike and easterly dip, while others have a variety of positions (fig. 24). Postmineral fractures parallel to the vein are always present. In other words, the postmineral fractures in general have the same directions as the premineral fractures, and stress subsequent to the ore deposition has reopened the old wounds, which had been more or less completely healed by the vein formation (fig. 25).

VEIN COMPOSITION.

The quartz of the vein is fine and cloudy. Poor quartz and rich quartz are often much alike in appearance, save for a purplish tinge in the latter. Under the microscope this tinge is seen to be due to disseminated particles of argentite. This mineral is found from the outcrop of the vein downward, through all the oxidized zone. Silver chloride is also very abundant, though usually, like the other metallic minerals, it is determinable only microscopically. Orange and yellow amorphous minerals were also observed, and surmised to be the combinations of silver with chlorine, bromine, and iodine, and chemical examination of the specimens showed the presence of all these elements. Free gold is sometimes observed,



CROSS SECTIONS, SHOWING STRUCTURE OF MIZPAH VEINS.

A. Sketch of Mizpah vein, vertical cross section, 300-foot level, west drift.
B. Cross section of portion of Mizpah vein in Tuscarora stopes, about 90 feet from the surface.
C. Vertical cross section of portion of Mizpah vein, 300-foot level, west drift, 200 feet west of shaft.
D. Mizpah vein, 300-foot level, east drift, near main crosscut.
E. Sketch of vein in crosscut south from east drift, 300-foot level, Mizpah mine.

especially under the microscope. A slight copper stain has been reported on the ore, but the writer has never seen any. Ruby silver and argentite sometimes occur on cracks, but as a rule these minerals, if present, are not visible to the naked eye.

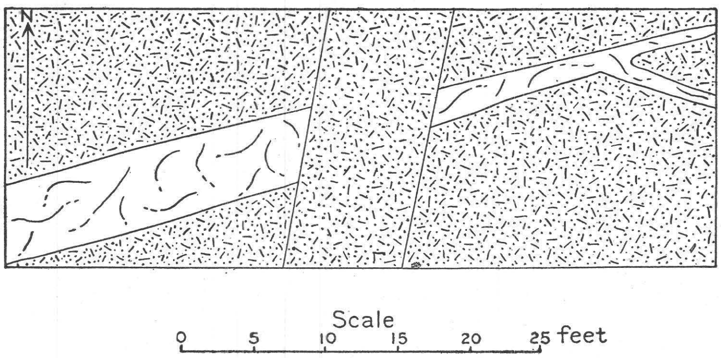


FIG. 23.—Horizontal sketch plan of portion of the Mizpah vein in stopes east of Lease 52, about 70 feet from surface, showing probable compensating faulting.

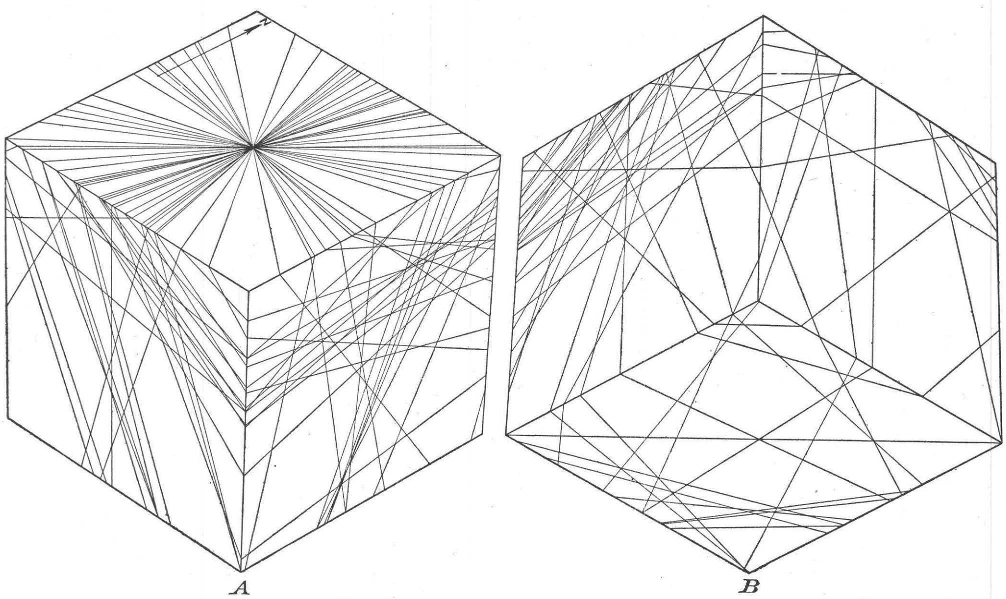


FIG. 24.—Reproduction of drawing of model, showing the principal postmineral fractures and faults observed in the Mizpah mine workings. The strikes of these fractures have been plotted through a center point on the top of the cube, and the intersection of the fractures with the other faces of the cube has been drawn. The endless variety of patterns which are made by the same systems of fracturing by their intersection with different planes is here shown. *A*, Front view of block, looking down. *B*, Rear view of block, looking up.

Black manganese oxide is frequent and often concentrated in little vugs. Iron oxide, the result of the alteration of pyrite, occurs, and sometimes pyrite itself, but this mineral is much less abundant in the veins than in the wall rock.

SECONDARY NATURE OF ORE MINERALS.

It is probable that all these metallic minerals are nearly always secondary. Ruby silver and argentite are often observed in this camp as secondary minerals coating cracks, as well as horn silver (silver chloride) and the bromides and iodides. The free gold appears probably secondary. In a few microscopic sections studied argentite has formed as an alteration of silver chloride, itself probably secondary.

REARRANGEMENT OF VALUES DURING OXIDATION.

All the ores in the mine are oxidized or semioxidized, for the zone of oxidation goes down to the 600-foot level or below, beneath which the vein is cut off by the flat Siebert fault.

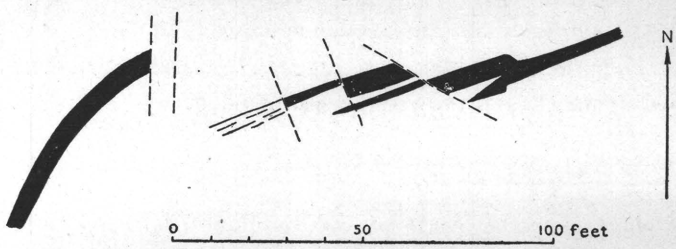


FIG. 25.—Horizontal diagrammatic plan of Mizpah vein as exposed in the Oddie and McMann lease, 20 to 30 feet below the surface. Of the crosscutting fractures (dotted lines) limiting the ore, as is shown, some are evidently premineral fractures or cross walls, and some postmineral fractures. In the latter case it appears probable that in some cases the postmineral fracture has originated by the continuation of movement along a premineral fracture.

The facts that the ores in their present form are largely altered and that many postmineral fractures are present suggest the inquiry as to how far the values have been rearranged and concentrated during the alteration process.

A study of the assay plan of the mine failed to show any decisive change at different depths in the relative proportion of gold and silver, the chief metallic minerals present in the ores. A more accurate statement of this investigation may be of interest.

Proportion of gold to silver in Mizpah vein.

Lifts.[a]	Number of assays.	Percentage of gold by weight.	Proportion of gold to silver.
First 50 feet	22	1.00	1 to 100.
Second 50 feet	42	.86	1 to 116.
Third 50 feet	40	.85	
Fourth 50 feet	57	.88	
Fifth 50 feet	55	.88	
Sixth 50 feet	72	.95	
Seventh 50 feet	19	.77	
Eighth 50 feet	8	.73	1 to 137.

[a] The word "lift" is here used to designate one of the horizontal zones into which the vein and mine have been divided for the purpose of measurement. The use of the word is similar to that in speaking of the different "lifts" of leather on a shoe heel, and the writer is under the impression that the word is in use by mining engineers with the same significance as given above.

In value the gold constitutes 25 to 30 per cent of the ore.

The percentage of gold may be smaller in the lower lifts, but the data are not sufficient to support this idea, and a proportion similar to the average (1:100) has been found in the shipments of primary sulphides from the rich ores of the Montana Tonopah.

Moreover, the rich shoots seem, under microscopic study, to be original, though the ore is largely altered—that is, the ore seems to have altered essentially in place, without any thorough rearrangement. This may be ascribed in part to the relatively scanty supply of surface waters in this arid region.

Some transportation, nevertheless, was inevitable, and it is probable that to a minor degree the ores have been redeposited. The result has probably been that values are more evenly distributed over the oxidized vein than they were originally; and the vein has been enriched to some degree by the downward penetration of minerals leached from the outcrop as it was eroded.

GEOLOGY OF THE DESERT QUEEN SHAFT.

The Desert Queen is the chief working shaft of the Belmont Company, and the ores discovered in the workings from this shaft are usually referred to as the Belmont ore bodies. The shaft is one of the deepest in the camp.

INTRUSIVE NATURE OF RHYOLITE CONTACT.

As shown on the map (Pl. XVI), the Desert Queen shaft starts in the rhyolite, on the southeast slope of Mount Oddie. It passes downward through this rhyolite for 250 feet, below which it encounters a mass of dark-blue or brown clay, containing harder residual bowlders of the later andesite. This has a thickness of more than 50 feet in the shaft, and is evidently a broken and ground up later andesite, altered to a clay by traversing waters. Below this water occurs along a fracture.

This zone of movement strongly resembles a fault zone. However it is to be noted that the movement has affected only the andesite and not the rhyolite, that the rhyolite is not noticeably decomposed, and that there are no rhyolite fragments in the breccia. This indicates rather that the disturbance was caused by the intrusion of the rhyolite into the andesite. The exact attitude of the rhyolite contact could not be observed, but it may be assumed to be roughly parallel to the watercourse just mentioned, which strikes north and south and dips east at an angle of 60°.

At the surface this rhyolite is in contact with the Siebert tuff lake beds about 120 feet west of the shaft, as shown on the map; this contact strikes north and south. Beneath the lake beds in this block lies the later andesite, as shown for example in the Silver Top shaft, a short distance to the southwest. A line drawn from this rhyolite-andesite contact at the surface near the Desert Queen to the contact in the shaft has a general angle of dip of about 68°. The contact at the surface is evidently an intrusive one, being on the western side of one of the intrusive lobes which radiate from the main rhyolite mass of Mount Oddie.

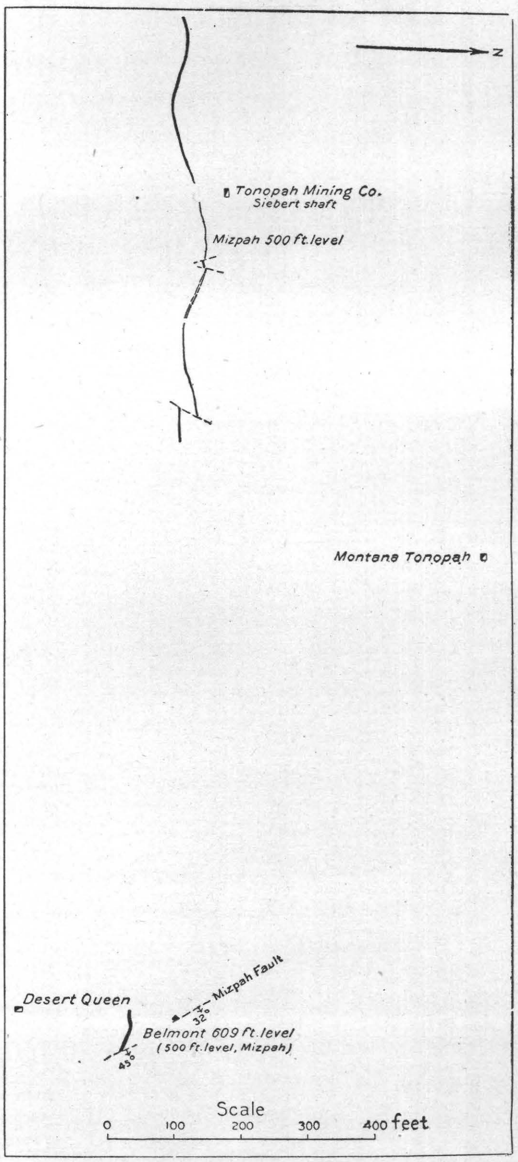


FIG. 26.—Horizontal plan of mine workings, showing the relation of the vein in the Desert Queen workings to that on the corresponding level of the Mizpah mine.

VARIABLE ATTITUDE OF MOUNT ODDIE INTRUSIVE CONTACT.

The steep dip of the contact between the andesite and the intrusive rhyolite at this point is in contrast with the flat portion of the same contact in the North Star shaft, where the lower surface of the rhyolite is very flat, dipping toward the mountain at an angle not greater than 10°, although the later andesite shows the same brecciation as at the contact in the Desert Queen shaft, indicating that the rhyolite is intrusive. This difference in dip, however, is in accord with other observations made along the contact of the rhyolite, all possible variation being found, the contact being sometimes flat, sometimes vertical, sometimes, indeed, dipping away from the mountain rather than toward it, but always showing the intrusive character of the rock.

MIZPAH VEIN IN DESERT QUEEN WORKINGS.

The Desert Queen shaft cut the Mizpah fault at 512 feet, and beneath it the earlier andesite. At 500 feet a drift run a short distance north from the shaft cut the Mizpah fault again and exposed an important vein (fig. 26). The vein is sharply cut off by the fault on the east and is much sheeted and broken by the fault movement, so that its course is not immediately evident. The general trend, however, appears to be east and west, or perhaps more correctly N. 70° E., and it appears to have a steep northerly dip and a width of several feet. It is somewhat dragged in the neighborhood of the fault. Some very rich ore was found here, which was chiefly oxidized and contained a large amount of silver chloride. The Mizpah fault here has its usual northwest strike and northeast dip, but the dip is steeper than it is farther northwest, being from 35° to 45°.

FORMATIONS ENCOUNTERED IN THE LOWER WORKINGS.

At a depth of 814 feet from the top of the shaft the rocks to the north and west are extensively explored by drifting. These workings are almost entirely in a white, dense rock which study shows to be Tonopah rhyolite-dacite. The quartz masses characteristic of this formation were encountered, showing the usual irregularities, nonpersistence, and barrenness; on the other hand, some portions are exceptional in containing high-grade ore.

At a depth of 920 feet the shaft cut a sheet of white Oddie rhyolite, which contained a flat vein of some size, but showed no values of importance (see p. 193). The bottom of the shaft, at a depth of 1,114 feet, is in the Tonopah rhyolite-dacite. This rock is much like that at the bottom of the Siebert shaft.

THE BURRO VEINS.

On the south side of the Mizpah vein there are several weaker auxiliary veins. Most of these converge and unite with the Mizpah on the surface at a point not far west of the outcrop of the Mizpah fault. The principal ones have been called the Burro veins, and they have been numbered 1, 2, and 3, No. 1 being nearest the Mizpah.

These three veins are all branches of the system of which the Mizpah is the trunk vein; on the surface the No. 2 and the No. 3 probably come together about 200 feet south of the Mizpah; this united vein joins the No. 1 just south of the Mizpah, and unites with the trunk a very short distance farther northeast.

VEIN STRUCTURE.

These veins are all essentially silicifications of definite fracture zones in the altered andesite. The zones average perhaps 4 feet in thickness, and along them quartz has formed (almost entirely by replacement of the altered and silicified andesite) to a varying degree, so that in places the vein zone may be entirely of andesite, distinguishable from the wall rock only by its peculiar and greater fracturing, and in other places may be entirely filled with quartz, carrying good values in silver and gold. All intermediate stages are also seen (fig. 27).

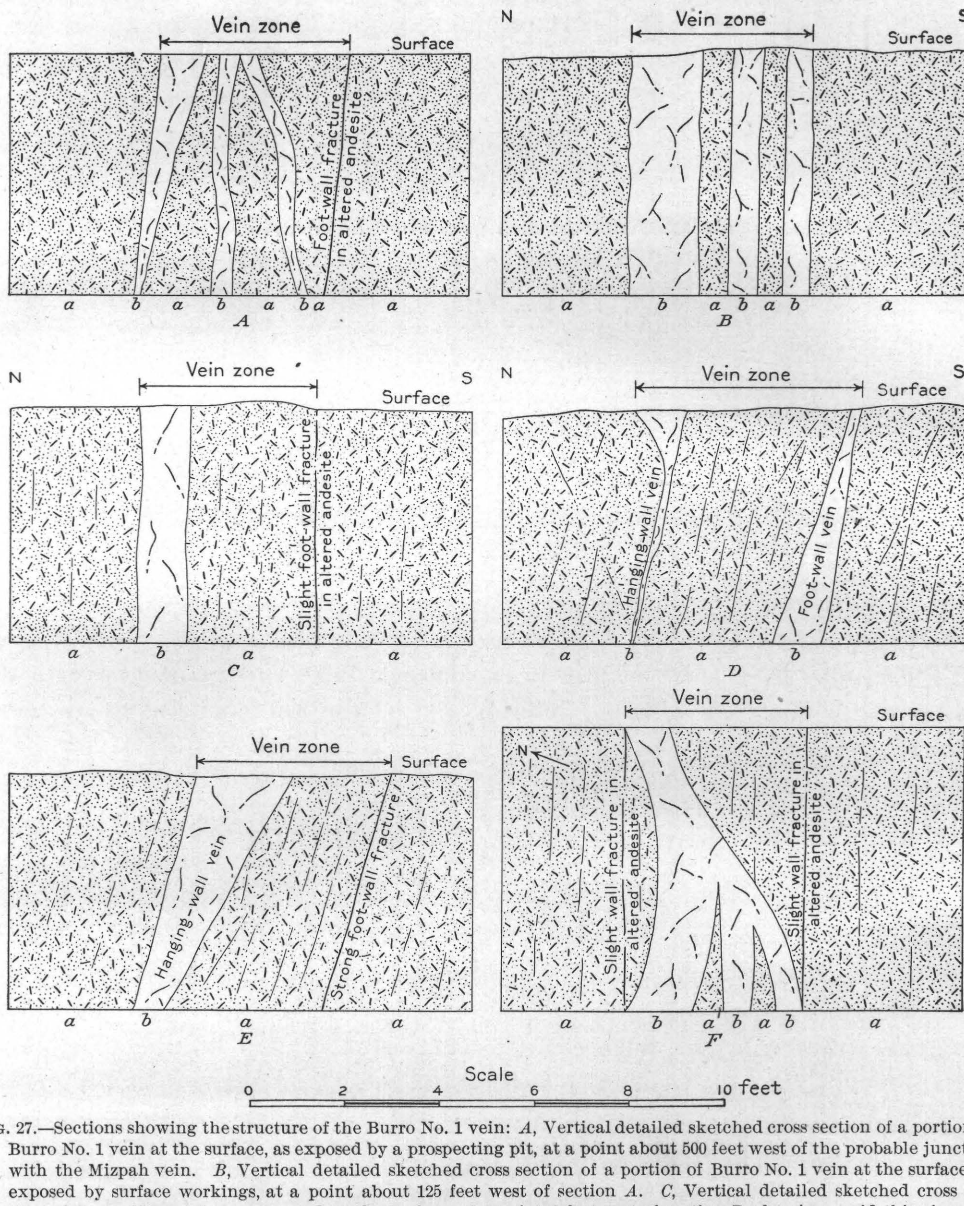


FIG. 27.—Sections showing the structure of the Burro No. 1 vein: *A*, Vertical detailed sketched cross section of a portion of Burro No. 1 vein at the surface, as exposed by a prospecting pit, at a point about 500 feet west of the probable junction with the Mizpah vein. *B*, Vertical detailed sketched cross section of a portion of Burro No. 1 vein at the surface, as exposed by surface workings, at a point about 125 feet west of section *A*. *C*, Vertical detailed sketched cross section of Burro No. 1 vein, as exposed at the surface, at a point 6 feet east of section B, showing rapid thinning and disappearance of quartz from the vein zone. *D*, Detailed sketched vertical section of Burro No. 1 vein at a point about 180 feet west of sections *B* and *C*, showing hanging-wall and foot-wall veins in the vein zone. *E*, Vertical detailed sketched cross section of a portion of Burro No. 1 vein, as exposed at the surface by a prospecting pit, at a point about 150 feet west of section *D*, and near the farthest point west that the vein has been traced, showing vein zone with only hanging-wall streak, and also the manner of dying out and disappearance of this class of veins. *F*, Horizontal sketched plan of Burro No. 1 vein, uniting the two vertical sections *B* and *C*, showing the manner in which the change takes place. In all these figures *a*=altered andesite; *b*=quartz

STRENGTH AND EXTENT OF THE BURRO VEINS.

Of the three Burro veins, that next the Mizpah, No. 1, is the strongest, No. 2 is next, and No. 3, the farthest away, the weakest; thus an evident dependence on the main vein is shown. Moreover, No. 1 is strongest as it approaches its junction with the Mizpah. Here it is at the outcrop composed of solid quartz 4 feet wide, and appears to be as important as the Mizpah itself. To the west, however, the quantity of quartz in the vein zone decreases till the vein is difficult to follow, and very likely actually dies out. Vein No. 2 is not regularly mineralized and has not the characteristics of a strong fracture zone. While in general it grows stronger on approaching the Mizpah, the only place from which high-class ore has been taken is several hundred feet west of its junction, where the volume of quartz in the vein increases. No. 3 follows a definite fracture zone in the andesite and ordinarily has very good walls. In this zone the quartz is mostly in stringers, irregular and bunchy. High-grade ore was taken out only from one small portion of the outcropping vein, that being opposite the productive portion of No. 2. The relation of good walls to a strong vein is continually shown. Good walls denote a strong fracture zone, which is a good channel for mineralizing waters.

These veins have not been found to continue downward in general with the same strength that they show on outcrop, and on the 300-foot level of the mine they are represented only by weak silicifications or quartz seams, and not all of them are with certainty identifiable.

VALLEY VIEW VEIN SYSTEM.

THE VALLEY VIEW VEINS ON MIZPAH HILL.

The Valley View vein outcrops, in its strongest portion, about 1,000 feet south of the Mizpah vein. Its surface exposures are stronger and more complicated than those of the Mizpah system, showing a number of veins which are of various sizes, many of them being several feet thick. These are connected by branches, so that the whole is interlaced. The general course is a little north of east, practically parallel to the Mizpah vein, and the different veins show a tendency to fan out or diverge toward the west, as the Mizpah vein system does to a more marked degree. The dip of the veins at the surface is nearly perpendicular, some of them dipping north and some south, at angles usually approaching 90°.

CROSS VEINS AND ALLIED PHENOMENA.

Cross veins of considerable strength also occur, both on the east and on the west side of the main outcrop, nearly at right angles to the main course. These cross veins cut off the veins following the main course, though all are of the same age. On the east, the strong cross vein near the Stone Cabin shaft probably cuts off the complicated vein system in this direction; beyond this cross vein the other veins will be found, for a space at least, abruptly of a different character. Similarly the strong northwest-striking and northeast-dipping vein, which heads off a number of the Valley View veins on the southwest side of Mizpah Hill, seems to mark the boundary of a relatively poorer continuation of the main vein system on the west (see Pl. XVII). Nevertheless, some of the veins escape and persist, and are found across the gulch, in outcrops and in the workings of the Wandering Boy. The veins of the Fraction may be a continuation of this system.

Apparently the mineralizing solutions flowing along the east-west fracture zones were deflected where the transverse fracture zones were strong enough to control the circulation, and did not follow the old channel farther.

The same principle is shown by the numerous splitting and reuniting branches, all running in the main direction of the vein system. Any of these branches may divert the main strength of the vein along it and into a parallel vein of the group.

This heading off of the main course of veins by crosscutting veins is entirely analogous, though on a larger scale, to the crosscutting premineral fractures which have produced the cross walls, as studied out on the Mizpah vein, and so have brought about the localization of the ore deposits. The cross walls produce richer shoots, both as regards quartz and precious metals, within the main fracture zone; the cross veins cause relative differences in mineralization and vein formation along portions of a belt of interlacing fracture zones which is similar to though larger than that occupied by the main Mizpah vein. In the ordinary splitting of the veins, as seen in both systems, the diverging branches have not so radically different a direction from the main vein as have the cross veins, but have often operated to deflect the solutions from the main fracture zone, and hence are called vein robbers.

VEIN STRUCTURE AND ORIGIN.

On studying the different veins of the system, as exposed excellently in an almost continuous series of surface openings, the fact that these veins are due to the replacement, in varying degrees, of andesite by quartz along a zone of especial fracturing is well illustrated. This is shown by the ever-changing amount of replacement, at one point the vein zone being little more than fractured porphyry and at another solid quartz, with all conceivable transitional stages represented between. These points are illustrated by the sections forming fig. 28.

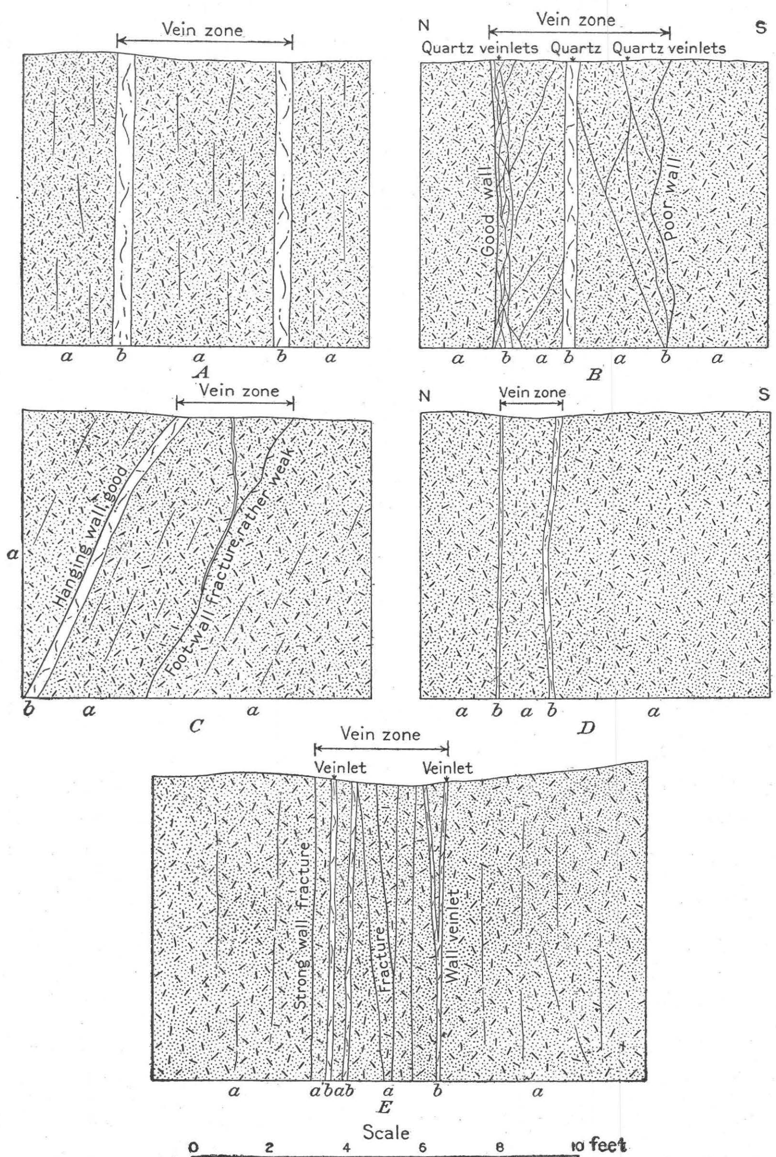


FIG. 28.—Sections showing the structure of the Valley View veins; *a*, altered andesite; *b*, quartz. *A*, Detailed vertical section of one of the minor Valley View veins at surface. *B*, Detailed vertical cross section of the same vein as *A*, taken about 30 feet east of it. *C*, Detailed sketched cross section of the same vein as *A* and *B* taken about 70 feet east of *B*. *D*, Vertical sketched cross section of the same vein as *A*, *B*, and *C*, at the surface, taken at a point about 50 feet east of *C*. *E*, Detailed sketched vertical cross section of a fracture zone near Valley View shaft, at surface, showing the nature of the fracture zone, which by replacement may form a solid quartz vein. Even the small stringers shown here have unquestionably originated by replacement of the andesite along mere cracks.

ORE IN THE VEIN.

As a rule the Valley View vein system contains a larger volume of vein material than the Mizpah system, but a smaller amount of the precious metals. Therefore the Mizpah has produced more ore than the larger vein. Considerable ore of the kind locally considered low grade (up to $50 per ton, for example) has been found in the Valley View veins, and some other portions have been found to be very rich; this rich ore lies in masses, without, so far as yet developed, any regular extension.

THE VALLEY VIEW VEIN SYSTEM UNDERGROUND.

Underground on the Valley View vein system are the workings from the main Valley View shaft, those from the near-by Silver Top shaft (both of these shafts belong to the Tonopah Mining Company), and those of the Stone Cabin shaft, and, as before stated, outside of Mizpah Hill, probably the Wandering Boy and Fraction workings.

VEINS IN THE VALLEY VIEW WORKINGS.

Of these underground workings those of the Valley View are the most extensive. There were levels at depths of 200, 300, 400, and 500 feet at the time of the writer's last visit. Instead of the several parallel strong veins outcropping at the surface, these workings show a single main vein, which is thicker than any at the surface. Furthermore, while the surface veins are nearly perpendicular, the underground vein has a dip to the north of less than 45°. This vein is 6 or 8 feet or more thick in various places.

Other veins disclosed in the workings are weak and nonpersistent, though locally they may be a few feet thick and may hold out promising indications. Frequent quartz stringers, which may be so numerous in places as to form nearly a network, occur; and plainly, from what is known of the general geology, these scattered threads might at any point unite vertically or laterally and form a decided vein, and thus account for the veins which outcrop and are not cut in underground workings, or those encountered in one mine level and not in the expected place in another. Many of these stringers are vertical, so that they would merge with the flatter-lying main vein in a short distance. The general situation would seem to be represented in fig. 29. A strong east-west striking and north-dipping vein (associated with parallel and crosscutting minor veins and stringers, many of them nearly vertical) has given its strength near the present surface to a number of vertical transverse fractures, so that the main vein splits into a number of vertical ones.

On the 500-foot level the vein is still strong. The crosscut on the 700-foot level, however, did not encounter it, but passed through a body of white, dense rock, which microscopic study showed to be probably the Tonopah rhyolite-dacite. This rock is a part of an intruded sheet, which would cut off the vein and terminate it below, at least temporarily (fig. 30).

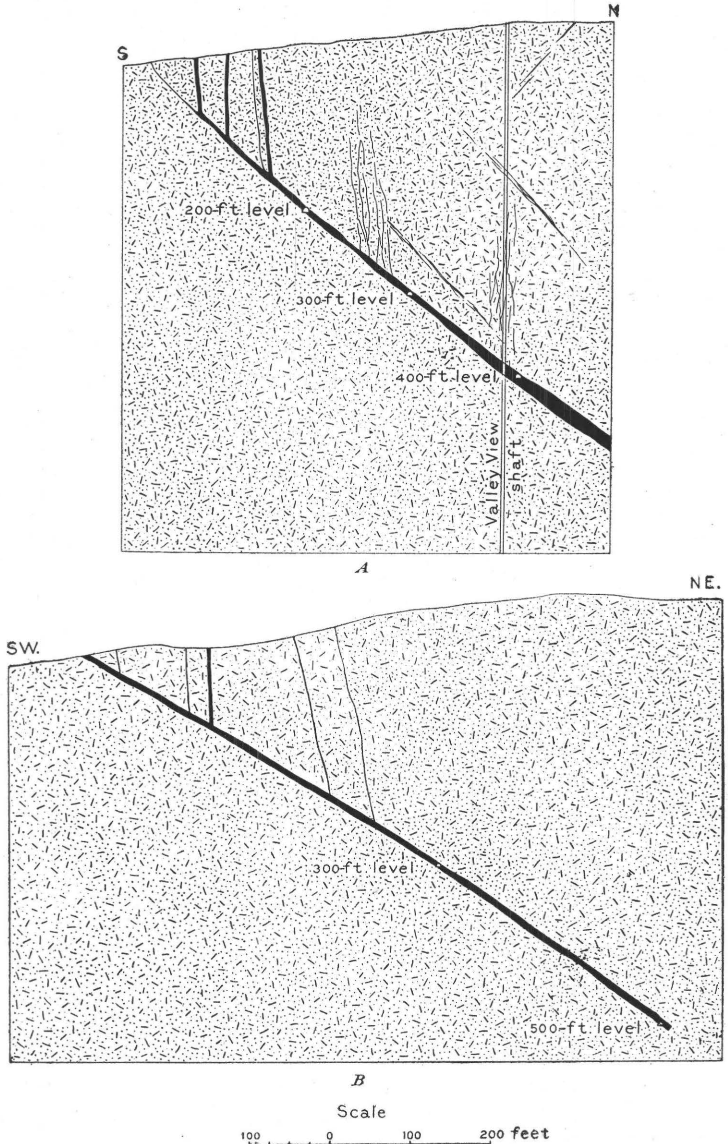


FIG. 29.—Cross sections of the Valley View vein. *A*, Through the Valley View shaft. *B*, Cross section of Valley View vein taken a short distance (averaging 200 feet) west of section *A*.

THE VALLEY VIEW FAULT.

Postmineral fractures are abundant in the mine workings, and a notable fault occurs on the 200-foot level, by which the main vein is completely cut off and lost on the east side. This fault has here a strike of N. 15° E. and a dip of

50° E. On the 300-foot level east the vein is likewise cut off by a broken and fractured zone, with finally a straight slip face running N. 28° E. and dipping steeply east. These occurrences on the two levels represent probably the same general fault or fault zone. This fault, which may be called the Valley View fault, is therefore approximately parallel in strike and dip with the Stone Cabin

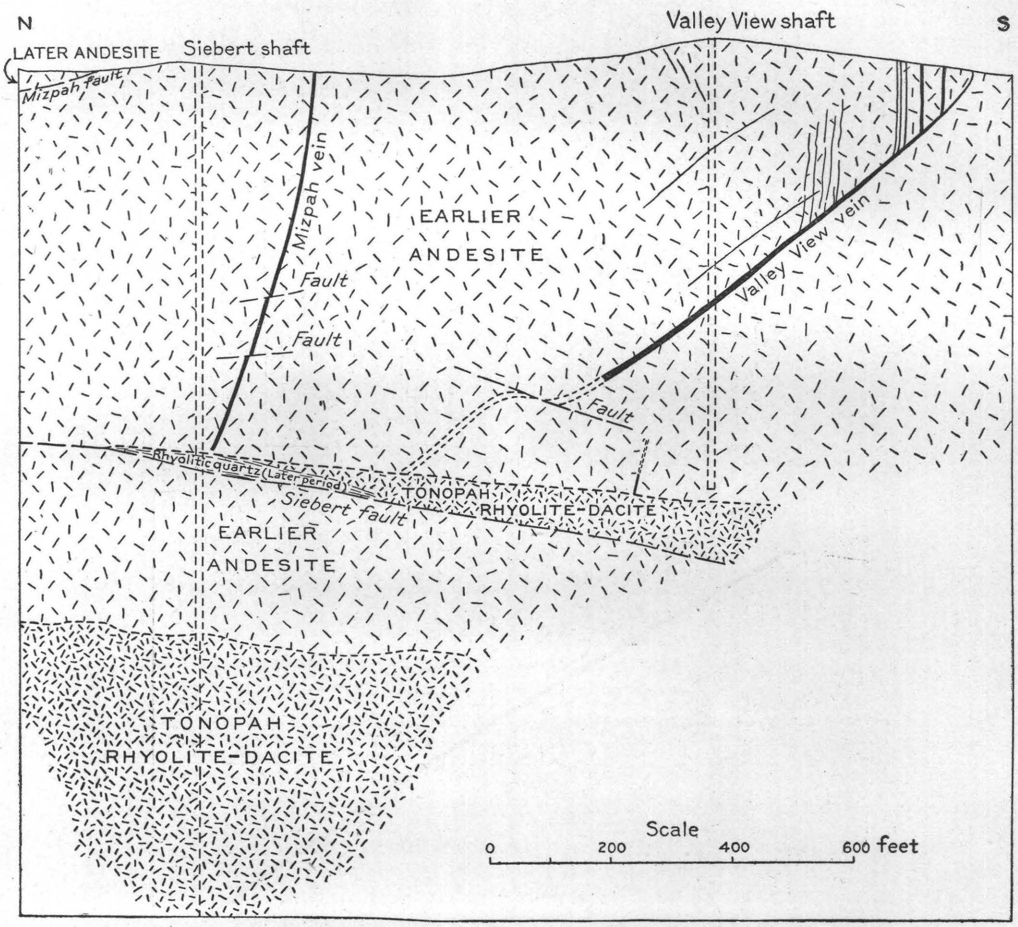


FIG. 30.—Vertical section on plane of Siebert and Valley View shafts.

fault, which bounds, on the east side, the earlier andesite of Mizpah Hill, and separates it at the surface from the tuff formation (Siebert lake beds) on the west.

The Stone Cabin and the Silver Top workings, therefore, are on the east side of the Valley View fault, or between the Valley View and the Stone Cabin faults, while the Valley View workings are on the west side of the fault of the same name.

VEINS IN THE STONE CABIN WORKINGS.

The Stone Cabin shaft had followed a strong vein from near the surface to a depth of 400 feet at the time of the writer's last examination (fig. 31). This vein varies in thickness from 1 to 8 feet, averaging perhaps 3 feet. It strikes N. 45° to 50° E., and is evidently one of the main east-west veins of the Valley View system, which here swings around more to the north. From the surface to the 200-foot level it dips steeply to the southeast, and thence to the 400-foot level it is vertical.

About 30 feet east of it a parallel vein is encountered on the 100-foot level, but it is so much broken up by small faults that it can not easily be followed. These faults strike chiefly N. 25° to 40° W., and dip southeast at an angle of

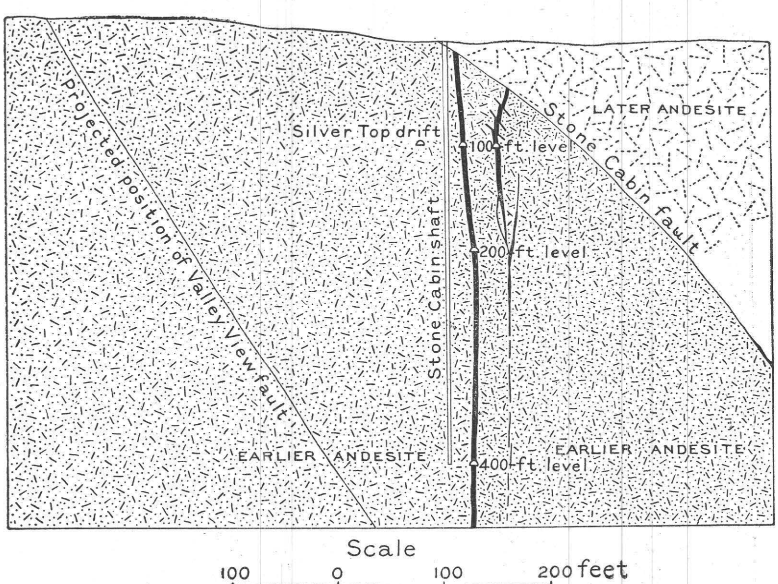


FIG. 31.—Cross section of veins in Stone Cabin workings.

55°. They are probably auxiliary to the main Stone Cabin fault, which must be close at hand, judging from its position in the near-by Silver Top workings. On the 200-foot level the same vein is encountered, at the same relative position with regard to the main vein. Here, being farther away from the eastward-dipping fault, it is not broken. On the other hand, it is not so heavy as above, and consists of two diverging branches, each 1 foot thick, which unite in the bottom of the crosscut. On the 400-foot level, 200 feet below, this vein was not recognized.

Thus there is a single nearly vertical strong vein in the Stone Cabin, as in the Valley View workings, with another lesser vein parallel to it on the east, which seems to grow weaker and tends to disappear in depth. The main workings have been driven on the first vein.

Much of the ore is of low grade, and not much runs over $100 to the ton. A considerable quantity of moderate grade ore has been found. This ore lies largely in an ore shoot, which pitches steeply east on the vein, and which was followed from near the surface to below the 400-foot level.

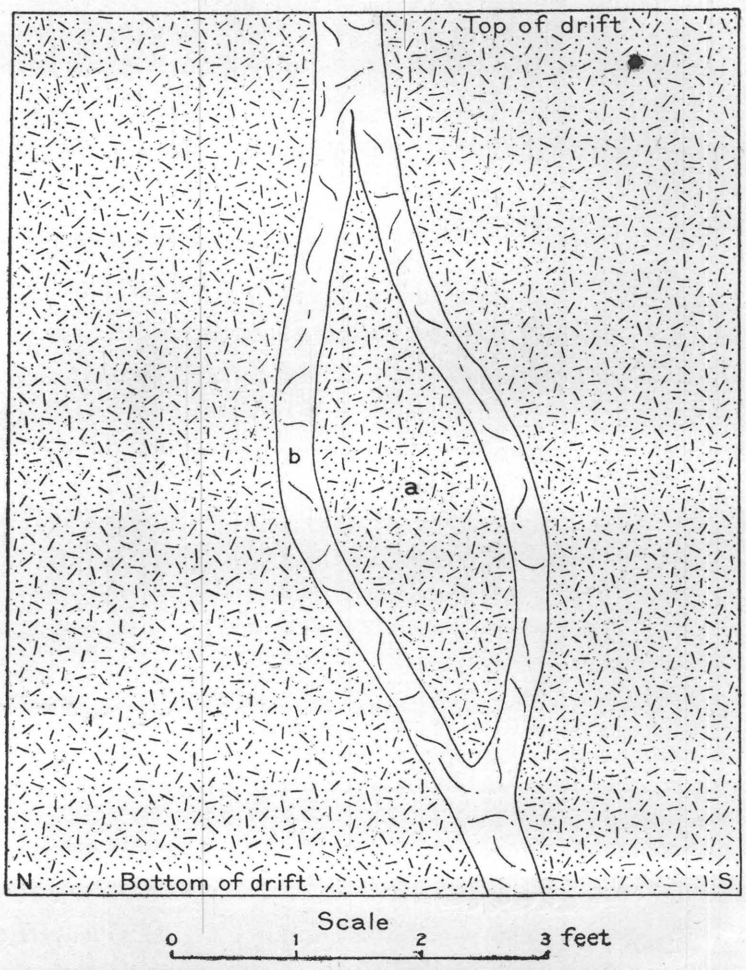


FIG. 32.—Sketch of vertical cut on the east wall of the Silver Top 120-foot level, 3 feet south of main vein, showing splitting and reuniting of a minor vein.

VEINS IN THE SILVER TOP WORKINGS.

The Silver Top shaft of the Tonopah Mining Company[a] starts on the east side of the Stone Cabin fault, in finely bedded white tuff, striking N. 20° W. and dipping southwest. Below this is the later andesite to the bottom of the shaft,

[a] There is another Silver Top shaft northeast of the Golden Anchor, as shown in the general map.

which is 120 feet deep. An easterly drift cuts the fault and passes into the earlier andesite. On this drift are found the veins encountered in the Stone Cabin workings (fig. 32). The chief vein here seems to run N. 50° to 70° E. and to dip south at an angle of about 80°. It is encountered, though in a broken-up condition, just west of the fault, but it is undoubtedly cut off by this on the east. To the southwest of this fault the vein lies in the Stone Cabin ground, and has been developed by the workings on the 100-foot level of this mine for about 100 feet. Still farther southwest the vein comes again into the Silver Top ground, and is followed southwest from the Stone Cabin ground for about 140 feet. At somewhat over 100 feet southwest of the Stone Cabin ground the vein forks, and at the end of the drifts both forks are cut off by a fault striking N. 22° W. and dipping eastward at an angle of 60°. The vein is also developed by a vertical winze 60 feet in depth in the portion west of the Stone Cabin ground.

THE STONE CABIN-SILVER TOP VEINS A PART OF THE VALLEY VIEW VEIN GROUP.

The second weaker and parallel vein noted in the Stone Cabin workings, to the south of the main vein, appears also in the Silver Top workings, but has not been developed.

The probable equivalents of both of these veins, which are shown in the Silver Top and Stone Cabin workings, can be recognized on the surface, almost immediately above, at the east end of the outcrop of the Valley View veins, where they have the same characteristics that are given for the corresponding veins underground. Even the forking of the vein in the Silver Top west drift, as described above, corresponds with a similar forking of the corresponding vein at the surface.

It is plain, then, that the veins in the Stone Cabin and the Silver Top belong to the Valley View group; and that, as in the case of the Valley View mine, this outcropping group resolves itself underground into a single strong and persistent vein with parallel weaker veins.

CORRELATION OF VEINS IN DIFFERENT MINES.

If this is the case, why does the vein go down nearly vertically for a known distance of 450 feet in the Stone Cabin and Silver Top, while in the Valley View the vein dips north at an angle less than 45° for a known vertical depth of 500 feet?

Effects of the Valley View fault.—In approaching this problem we confront first the fact that underground the veins of the Stone Cabin and Silver Top have not been followed westward beyond a certain point, and that the Valley View has not been traced eastward beyond a certain point. The veins are clearly cut off by strong faults that strike north and dip east. Strangely enough these faults have not been recognized on the surface, at the points where they should outcrop, but of their importance underground there is no doubt.

The slip and cut-off at the west end of the Silver Top workings must be only about 70 feet perpendicularly distant from the slip which cuts off the Valley View vein on the east, on the 200-foot level. The two can be treated together, then, as a fault zone, in which the main slip may or may not have been cut, but must either be one of those cut or must lie in the narrow zone between them. Moreover, the flat-dipping Valley View vein, which is thus cut off on the 200-foot level,

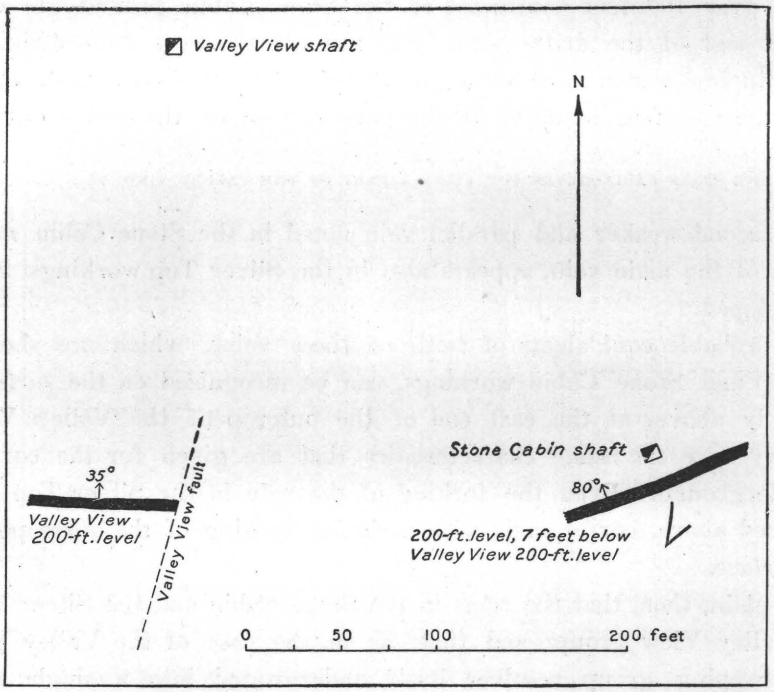


FIG. 33.—Horizontal plan of veins in Valley View and Stone Cabin workings on the plane of the Mizpah 200-foot level, to show the probable connection between the chief veins on the two sides of the Valley View fault.

would, if continued, almost exactly strike, at this level, the nearly vertical main Silver Top ledge, which trends in the same direction (fig. 33).

Hypotheses to explain fault movement.—The suggestion arises that the Silver Top and the Valley View may be really parts of the same vein, and that faulting is responsible for the remarkable differences in dip on the two sides of the fault. Both are plainly the downward extension of the strongest portion of the same outcropping vein system. We may at first consider the hypothesis whether the fault has had a twisting movement so as to tilt the vein on one side more than on the other. This difference in tilt, however, would be about 45°, and would involve such an extraordinary rotation of the rocks on one side of the by strong faults that strike north and dip east. Strangely enough these faults have not been recognized on the surface, at the points where they should outcrop, but of their importance underground there is no doubt.

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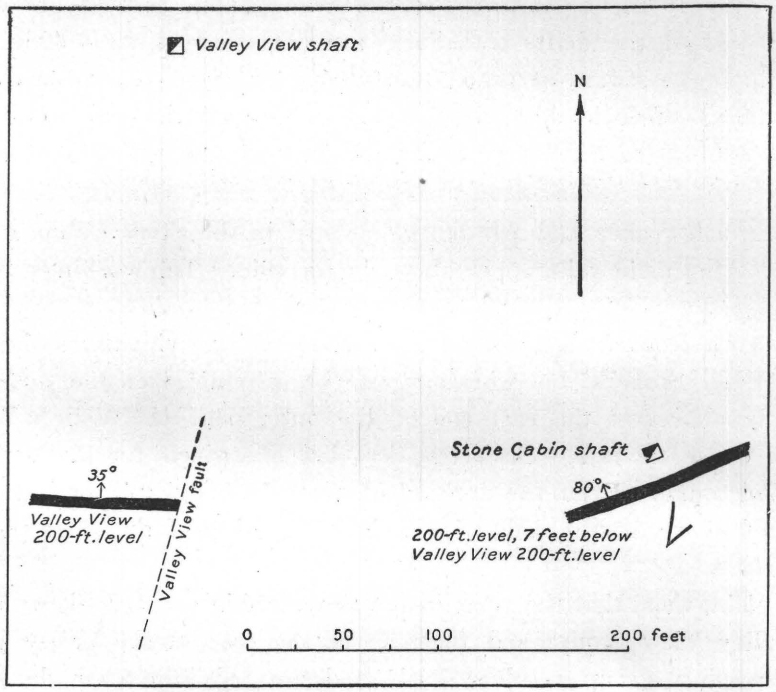

FIG. 33.—Horizontal plan of veins in Valley View and Stone Cabin workings on the plane of the Mizpah 200-foot level, to show the probable connection between the chief veins on the two sides of the Valley View fault.

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It is not easy of explanation on either hypothesis why the fault has not been recognized on the surface. Especially under the hypothesis of rotation or differential tilting is this fact inexplicable, for such rotation must have been likewise manifested at the surface as a great and sustained difference in the vein dips; whereas actually no such change occurs, the steep, nearly vertical, dip being unvarying over the area which the fault would naturally cut. If, however, according to the second hypothesis of simple downward displacement, the movement is assumed to have been absolutely vertical, there is at least a possible explanation of the failure to detect the fault—namely, that in the surface portion of the group the vertical veins, broken by a vertical fault, would not show any displacement, while below, where the vertical veins come opposite the flat ones, the displacement would be marked.

The probability of this latter hypothesis is strengthened by a consideration of the main Stone Cabin fault, which has a general parallelism in strike and dip with the Valley View fault, and lies about 250 feet horizontally east of it. This fault is a normal one, having a heavy downthrow on the east side, bringing the tuffs, and below these the later andesites, opposite the earlier andesite of Mizpah Hill on the west. It is probable that a near-by parallel fault, like the Valley View fault, would have a movement in the same direction. The Valley View fault is evidently much the smaller of the two, and may, indeed, be considered auxiliary to the main displacement.

Amount of vertical separation of Valley View fault.—The amount of vertical movement at the Valley View fault, on the basis reached above, would be something over 400 feet. This affords some basis for understanding the movement on the greater Stone Cabin fault, which may reasonably be expected to be several times greater.

FRACTION NO. 1 VEINS.

DISCOVERY AND DEVELOPMENT.

The No. 1 Fraction shaft was sunk blindly in the outcropping dacite of the Fraction dacite breccia in the fall of 1901, and was one of the first explorations outside of Mizpah Hill and Gold Hill. The shaft was sunk to the depth of 238 feet by means of a horse whim. The shaft passed through 150 feet of soft dacite, 20 feet of crushed material probably representing the later andesite, several feet of breccia indicating a probable fault zone, and ended in the earlier andesite. At the depth of 238 feet, the rope not being long enough to sink any farther, drifting was started, which, in 20 feet, cut a body of quartz that had a width of several feet and showed some rich ore. Subsequent to this a great deal of development work has been done, but the results have been unsatisfactory, the vein being very badly faulted and there being very little rich ore.

NATURE AND RELATIONS OF THE FRACTION VEIN.

By looking at the detailed map of the mining district it will be seen that the Fraction workings lie close to two faults which were drawn from surface indications. A study of the underground workings indicates that the faulting has been so intense and complicated as to defy working out of the smaller details and as to make the mining under these conditions practically hopeless, unless the ore were very rich.

Apparently a single strong vein is represented in the Fraction workings. This strikes in general east and west, but frequently north of west, and dips south at varying angles. This vein is in line with the outcrops of the Valley View veins across the gulch to the east on Mizpah Hill. It is possible, therefore, that it belongs to the Valley View system. On the other hand, the Valley View and the Fraction veins underground, when plotted on a given level, show no signs of being part of the same body, following quite different lines. Indeed, the two veins dip in opposite directions—the Valley View to the north, the Fraction to the south. The two are also separated, as shown on the map, by one or more faults, which makes correlation still more doubtful. If the Fraction is part of the Valley View system, its vein, dipping in the opposite direction, might be considered as making up with the Valley View vein a pair of conjugated veins. It is barely possible, though perhaps not probable, that the fault movement has in the case of the Fraction reversed the original dip by tilting the block in which the vein lies.

Some of the numerous faults which cut the vein have been exposed in the mine workings, and such have been shown in the accompanying detailed plans and cross section (Pl. XXI).

THE NORTHEAST (FRACTION) FAULT SYSTEM.

When the strikes of all the different faults observed in the workings are plotted together, as in fig. 34, they are seen to run in almost every direction without any fairly recognizable system. Considered as to their relative importance, however, systems are clearly traceable. The most important one is, perhaps, that striking in a general northeast direction and dipping, as a rule, southeast at varying angles, perhaps approximating 45°. By these faults the vein, as seen on a horizontal plan, is moved to the north on the west side. There are many of these, which distribute the faulting between them and constitute a fault zone

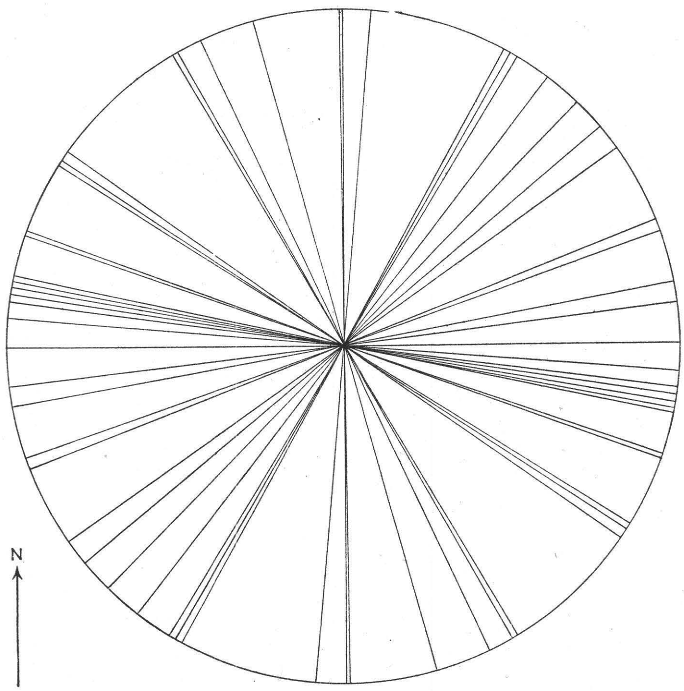


FIG. 34.—Plotting of the strike of the faults in the Fraction workings.

whose limits and total displacement are not known. If this fault zone had a uniform dip it would reach the surface about where the fault line had been independently drawn, from surface phenomena, up the gulch on the southeast side of Brougher Mountain. This fault line, as will be seen, seems to be a direct continuation of that bounding the earlier andesite of Mizpah Hill on the northeast, but the fault movements probably do not correspond in the two localities.

On the 237- and 300-foot levels of the Fraction this northeast faulting has divided the vein into a series of blocks of very limited extent horizontally, which have been dragged apart and separated one from another, and, finally, the vein has been lost on account of these faults, both on the east and on the west side.

On the 237-foot level there is a distance of about 200 feet between the portion of the vein just north of and that south of the shaft, as exposed in the drifts, but connecting bunches of quartz probably exist in the undeveloped country to the southeast of the shaft (fig. 35). On the 300-foot level the exploration has been more thorough, as far as it went, and the different steps of the faulting are almost continuously shown (fig. 36). On the 400-foot level a single block of quartz, probably belonging to the same vein, and bounded on all sides by faults, was found about

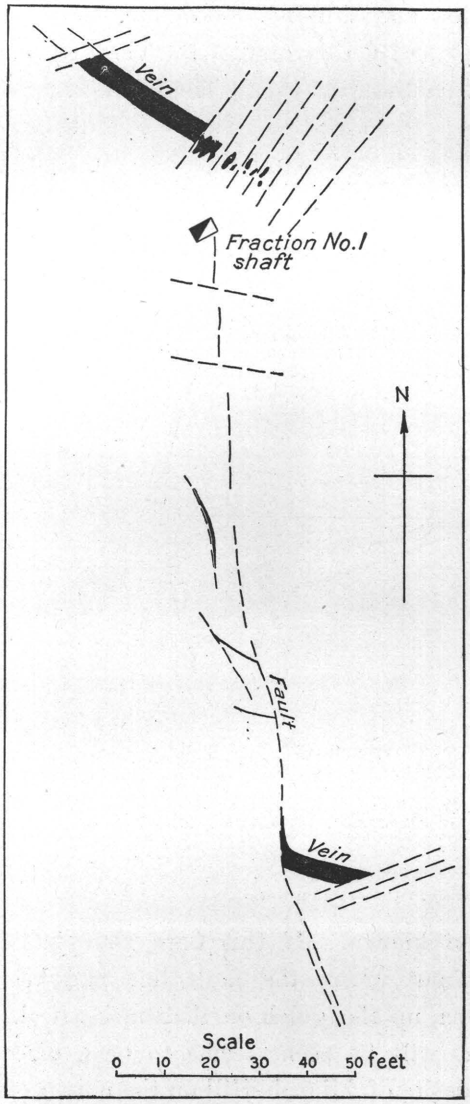


FIG. 35.—Horizontal plan of vein and faults on the 237-foot level, Fraction No. 1 workings.

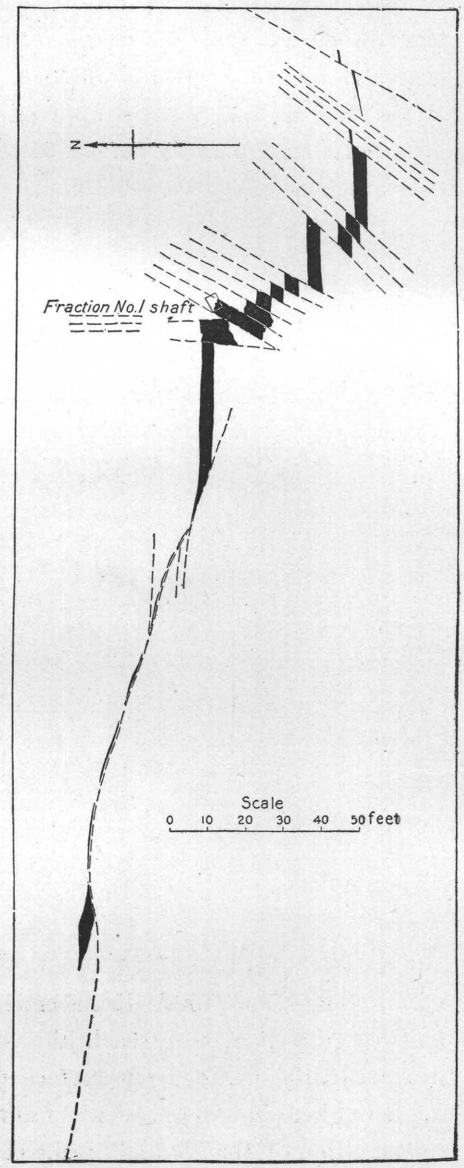


FIG. 36.—Horizontal plan showing vein and faults on the 300-foot level, Fraction No. 1 workings.

300 feet south of the shaft (fig. 37). On account of the eastward dip of the northeast-striking fault zone this bunch of quartz would lie to the west of the fault and would correspond in position to the quartz near the shaft on the two upper

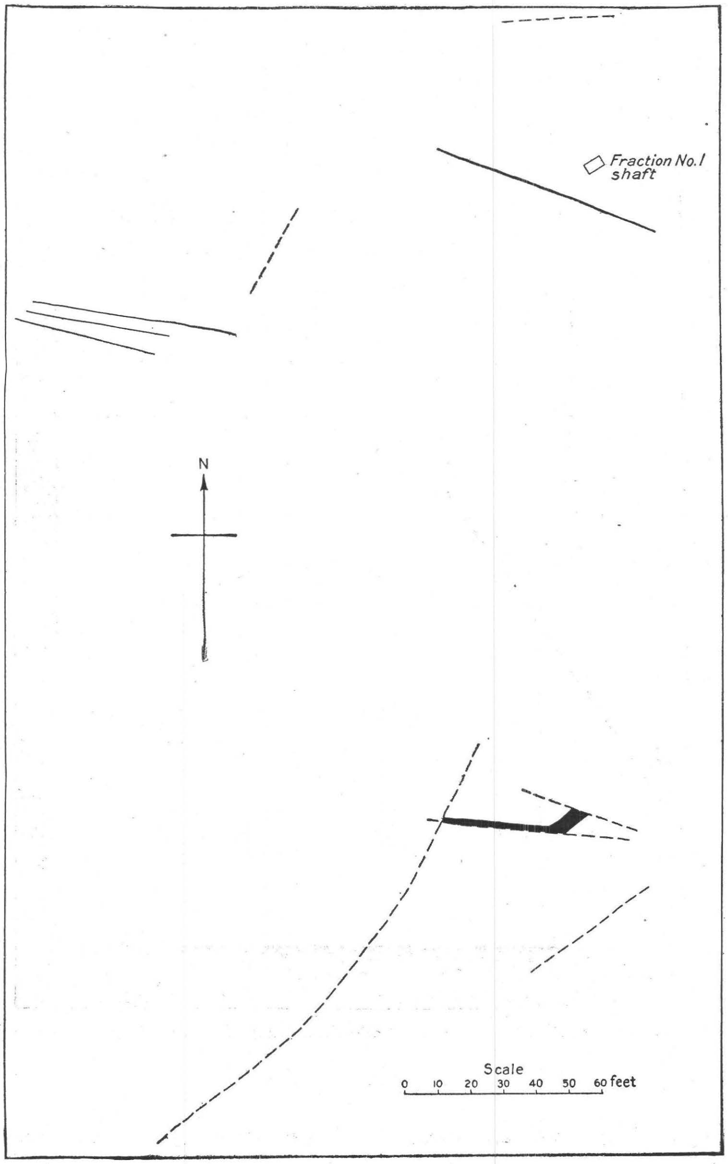


FIG. 37.—Horizontal plan showing veins and faults on the 400-foot level, Fraction No. 1 workings.

levels. This is shown also by the connection made between the 300- and the 400-foot levels, where the relations of the vein on the west of the northeast-striking fault zone are as shown in the accompanying cross section (fig. 39).

Abundant and strong striations on the fault planes of the northeast system, together with the evidence afforded by minute faulting and stringers and by the dragging of faulted veins, indicate that while the main movement was complicated by numerous smaller ones, the general result was that the blocks on the west side of the separate northeast faults were shoved northward past the blocks on the east side, nearly horizontally, but with a slight downward plunge (fig. 38).

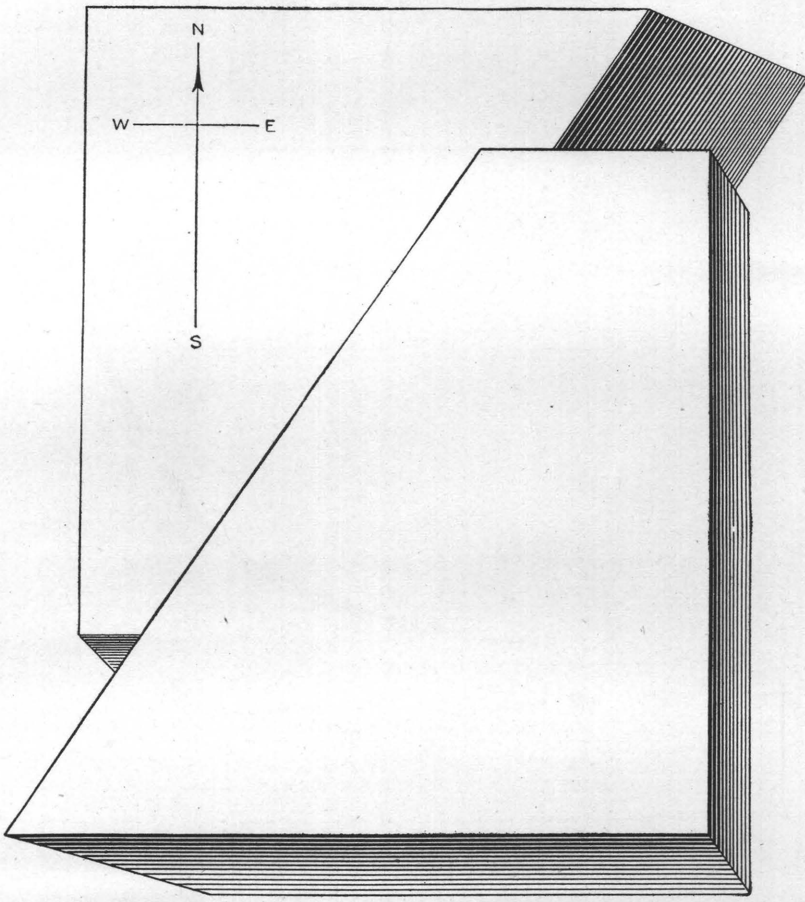


FIG. 38.—Stereogram showing nature of movement along the main northeast faults in Fraction No. 1 workings.

THE NORTHWEST FAULTS.

There is also a well-marked system of faults striking north of west, sometimes parallel to the veins, but generally cutting across them at slight angles. These faults may have some connection with the northwest fault, which is shown on the map as running just east of the Fraction workings (the Wandering Boy fault). They have a great variety of dips, sometimes vertical and sometimes nearly horizontal, with intermediate angles. An illustration of their effects is seen in the cross section (fig. 39), which is transverse both to the vein and to the faults. This cross section is taken along the series of inclined workings on the vein, which run from a point about 60 feet above the upper level to below the lower level. The portions actually exposed are indicated by solid lines, the intervening portions are dotted. It will be seen that the vein follows a series of pronounced rolls, steepening and flattening alternately. In the mine it is evident that these rolls are the result of pressure and deformation in the rock, and are in the nature of folds. On the two upper levels, at the sharp bend or apex of these folds, as shown in the cross section, tangential fractures or slight faults leave the

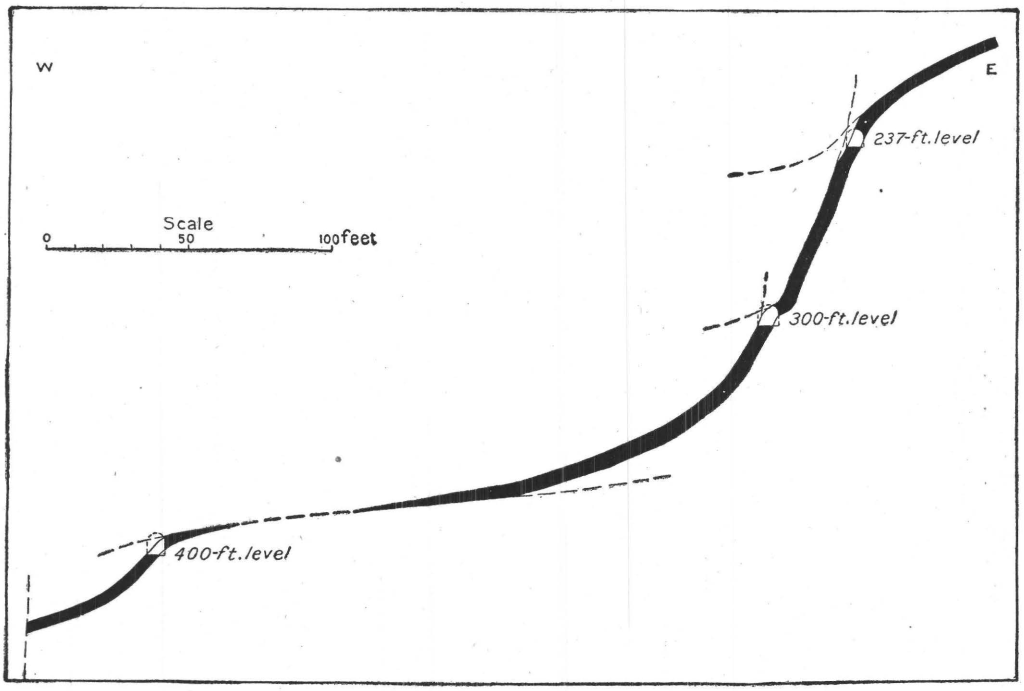


FIG. 39.—Cross section of Fraction No. 1 vein, along drifts and winzes.

vein and pass off into the surrounding andesite. Some of these become horizontal, some nearly vertical, and both strike nearly parallel with the vein. Between the 300- and the 400-foot levels, a flat fault, striking and dipping in the same way as the vein, has probably the same origin as the flat tangential slips in the upper levels, but is here of greater magnitude, so that the vein has actually been faulted considerably along it. The incline from the 300- to the 400-foot level follows this fault for some distance after the disappearance of the vein. The fault which terminates the vein at its lower end in the cross section belongs to the northeast system, and is thus different from any other of the faults shown in the figure.

The deformation displayed in this section of the vein is analogous to the monoclinal folding of strata, in which the fold passes into a fault if the deformation be carried farther than the stretching strength of the rocks. Since all the veins in the Tonopah district have normally decided dips, ranging from vertical to about 30°, it may be believed that the flatter-dipping portions of the Fraction vein as seen in the cross section have been deformed, and that the steeper portions represent more nearly the original attitude. It appears then that the vein has been deformed by movements acting in a nearly horizontal plane. These movements have shoved the vein and the inclosing country rock to the north on the upper side, and being distributed have caused rolls or folds which in places break and form faults.

These west-northwest tangential faults are, however, not persistently parallel to the veins, but may trend across them at a slight angle. The result is seen in the western part of the workings on the 237- and 300-foot levels, as shown in the figures. On the 300-foot level the west-northwest fault cuts out the vein gradually. The vein runs parallel with the fault for some distance, appearing and reappearing as lenses of quartz along the fault zone, until it entirely disappears.

CAUSE OF FAULTING.

To explain this singularly intense, complicated, and peculiar faulting there must be found a cause competent to thrust the blocks on the northwest side of the northeast faults to the north in a nearly horizontal direction, and to shove the upper layers of rock and vein past the lower layers in a nearly horizontal direction also. The volcanic neck of Brougher Mountain, whose edge is only about 1,400 feet southwest of the Fraction No. 1 workings, has been thrust up after the other rocks were erupted and the mineral-bearing veins formed. Its smallest diameter in a north-south direction is about 1,200 feet, and the examination of its contact zone shows that it probably extends downward in much the same form as it appears at the surface, as a solid column of lava. The intrusion of this column was probably competent to produce this complicated faulting, and to exert the violent horizontal pressure indicated in the Fraction workings. It has been determined independently that the faults of the region, as a whole, came into existence at about the period of the intrusion of the dacitic necks, of which Brougher Mountain is one. The conclusion arrived at therefore falls in line with the general facts.

COMPOSITION OF VEIN.

A small quantity of rich ore was taken from the upper levels. This ore showed ruby silver and argentite and in one case native silver, all in leaves or films on cracks or crevices, evidently secondary. The rich quartz itself, as in other mines of the district, has a dull purplish color, due to the presence of fine silver sulphide. Most of the quartz discovered, however, has proved to be of low grade. Adularia (valencianite) is very abundant as a gangue material.

FRACTION NO. 2 WORKINGS.

ROCKS EXPOSED IN SHAFT.

The Fraction No. 2 shaft, which was sunk after the No. 1 shaft and became the main working shaft, lies about 450 feet west-southwest of the No. 1 shaft and is connected with it at the 400-foot level. The collar is slightly higher than that of the No. 1 shaft, and the geologic section exposed is about the same. The shaft passed through about 215 feet of soft dacite and about 8 feet of white breccia (consisting in large part of rhyolite resembling the Oddie rhyolite) into the earlier andesite. The contact of the overlying rocks with the earlier andesite dips to the east at an angle of about 30°, but this dip is probably only local.

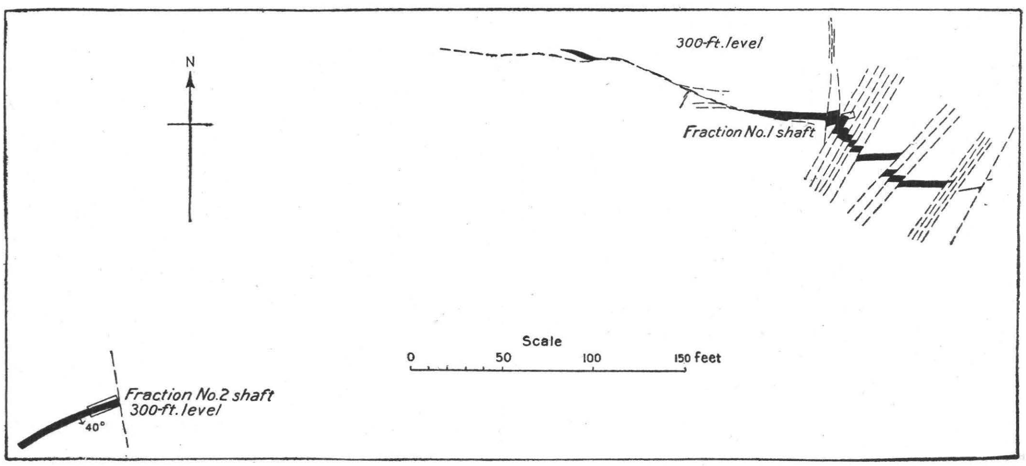


Fig. 40.—Horizontal plan of veins and faults exposed on the 300-foot level, Fraction workings, showing the relation of the vein fragment in the Fraction No. 2 to the vein on the corresponding level of Fraction No. 1.

FAULTED VEIN FRAGMENT.

At about 300 feet from the shaft a body of quartz was drifted on for a short distance to the southwest. This quartz is a definite vein about 3 feet thick. It strikes northeast and dips southeast at an angle of about 40°. Some good assays were obtained from it, although most of it was very low grade. On the northwest side of the shaft this vein seems to be cut off by a flat fault that strikes a little west of north and dips at a slight angle to the east. It is very likely that this vein, which has not been very largely explored, may be part of the same vein which is exposed in the Fraction No. 1 workings, although a plotting of the vein on the corresponding levels in the No. 1 and No. 2 workings shows how difficult it is to establish any definite connection (fig. 40). Only the size and nature of the veins and the corresponding strike and dip warrant the above suggestion, for the faulting is so complicated in this region that in any space actually undeveloped by mining operations, little more than guesses can be made in many cases.

TONOPAH RHYOLITE-DACITE.

The Fraction No. 2 workings lie mostly on the 400-foot level, and besides a connection with the No. 1 shaft there is a drift running nearly 600 feet to the north-northwest and more than 200 feet in the opposite direction. Only small quartz veins, of no importance, occur in these workings. The rock encountered is a rather dark-colored earlier andesite, sometimes considerably kaolinized, like that encountered in the No. 1 workings. In the south drift from the shaft, however, a white rock is encountered. This is solid at the end of the south drift, and between this point and the shaft occurs as fragments and large bowlders up to several feet in diameter in the darker andesite. The geologic features here indicate that the breccia is due to movement in the rock, and this conclusion is corrroborated by microscopic study. In this breccia are encountered several strongly marked slip planes, which strike N. 30° or 40° E., and dip southeast at an angle of 40° or more. These correspond in altitude to the northeast-striking and southeast-dipping faults in the Fraction No. 1 workings, and it appears probable that the hard white rock at the south end of the drift has been brought against the darker and softer andesite of the north drift by means of this faulting. Some perplexity has arisen concerning the nature and relation of these two rocks. After study, however, the author is of the opinion that the latter rock is a phase of the earlier andesite, while the white rock is a coarse-grained phase of the glassy Tonopah rhyolite-dacite.

Microscopic examination shows that this hard, white rock is considerably altered. The phenocrysts are of altered feldspar, in part andesine-oligoclase and in part orthoclase; they are now largely changed to muscovite (sericite) and adularia. Small original biotite crystals are thoroughly bleached. The glassy groundmass contains veinlets of calcite and abundant pyrite. The chemical analysis of the rock, by Mr. George Steiger, is as follows:

Analysis of altered Tonopah rhyolite-dacite.

[Specimen 299.]

SiO_2	68.19
Al_2O_3	15.13
Fe_2O_3	1.31
FeO	.42
MgO	.29
CaO	1.19
Na_2O	3.13
K_2O	6.56
TiO_2	.32
P_2O_5	.15

WANDERING BOY VEINS.

About 200 feet northeast of the Wandering Boy shaft there outcrop several quartz veins whose position and course, as will be seen on the map (Pl. XI), suggest that they form a continuation of the Valley View system.

RELATIVE ELEVATION OF FAULT BLOCKS CONTAINING VALLEY VIEW AND WANDERING BOY VEINS.

The veins above mentioned are in earlier andesite, probably in the same fault block as is Gold Hill. That Gold Hill is bounded on the north by a fault is shown by stratigraphic evidence, for the Siebert tuff on the north is in rectilinear contact with the earlier andesite on the south, indicating a very considerable displacement. Along this fault line a valley has been eroded, up which the road runs. The fault block north of this fault is bounded on the west by the Stone Cabin fault, which has an upthrow on the west, bringing up the earlier andesite of Mizpah Hill. Therefore the movement of the Stone Cabin fault compensates to a large degree for that of the Gold Hill fault; and a prolongation of the Gold Hill fault northwestward between Mizpah Hill and the Wandering Boy finds the earlier andesite coming together and lying on both sides of this prolongation. There is, however, some reason for believing that the fault actually continues along this line, though with much diminished displacement.

RELATION OF VALLEY VIEW AND WANDERING BOY VEINS.

According to the tentative conclusion stated in the last sentence above, the outcropping veins northeast of the Wandering Boy, if they are a part of the Valley View system, are separated by a west-northwest fault from the Valley View veins of Mizpah Hill. They are represented on Pl. XVII and on fig. 42 (p. 153). The strike is northeast and the dip, like that of the Fraction veins, and unlike that of most of the veins of Mizpah Hill, is to the south at angles of from 50° to 75°. In size and course they are not unlike the westernmost outcrops of the Valley View veins on the western edge of Mizpah Hill, about 300 feet away. The southerly dip, also, is found represented in this portion of the Valley View outcrops, the westernmost veins dipping, at the surface, south at angles of from 70° to 80°.

At a depth of a few hundred feet the veins which occur in the Wandering Boy workings, and which are probably identical with those outcropping northeast of the shaft, acquire a flatter dip—30° to 40° to the south—and thus correspond in dip with the vein shown in the Fraction workings. On Mizpah Hill, however, the Valley View veins, at a corresponding distance underground, have a similar dip of about 30° in the opposite direction—to the north. The veins in the two localities can not be directly correlated, and their prolongations on a given uniform level underground would be several hundred feet apart, though nearly parallel.

Opposing dips of the veins probably original.—The reason for the opposing underground dips of these veins, which have nearly the same line of outcrop and a nearly identical dip at the surface, is not clear. As before stated, the Wandering Boy and the Valley View veins seem to lie in different fault blocks, being separated by a probable fault which runs along the road between them; and it is possible that the faulting may have been of such a differential nature as to partially revolve the block containing the Wandering Boy veins and to reverse the dip. Evidence obtained both in the Wandering Boy and in the Fraction demonstrates that the dip of a vein may be changed and even reversed by faulting, and by accompanying deformation which corresponds nearly to folding, but which is probably the result of an aggregate of small faults.

Against this interpretation is the fact that the steep south dip of the Wandering Boy veins at their outcrop corresponds with the similar surface dips of the heavy Valley View vein, which is the vein of the outcropping Valley View group lying farthest east, and the one with which the Wandering Boy vein would naturally be correlated. If the different dip of the veins in the two blocks is due to the revolving of one block on another this difference should appear at the surface as well as underground; that it does not is evidence rather in favor of the conclusion that the displacement has occurred without any notable change in the attitude of the veins aside from local and minor effects. In this case it follows that the veins of the Valley View system present, if the perplexing faulting were eliminated, marked differences in dip, the main Wandering Boy vein dipping at a moderate angle to the south, as the main Valley View vein does toward the north.

Change of dip shown by the comparison of the Valley View and the Stone Cabin.—In this connection the studies already made on the Valley View veins are important. It has been shown that the outcropping heavy vertical veins of this system on Mizpah Hill do not persist, as demonstrated by the Valley View workings, to a depth of as much as 200 feet, but are represented at this depth and below by a strong vein dipping about 35° to the north. In the Stone Cabin and Silver Top workings, however, a vein, which is certainly the continuation of the outcropping heavy Valley View vein, continues down almost vertically to a demonstrated depth of over 400 feet, beyond which point exploration has not been made. This portion of the vein is separated from the larger portion in the Valley View workings by a fault, along which the displacement of the vein seems to have been normal, so that the vertical portion shown in the Stone Cabin workings has been dropped down below the north-dipping portion of the Valley View.

According to this the part of the main Valley View vein which has been eroded to expose the present outcrop on Mizpah Hill must originally have extended vertically up above the present surface for a distance of several hundred feet, at least.

Wandering Boy and Valley View conjugated veins.—If the conditions on the west side of Mizpah Hill, where the Valley View veins approach the Wandering Boy veins, are like those on the east end near the Stone Cabin, the Wandering Boy block, if depressed, should have brought down the vertical portion of the vein, a condition which is not found. What the relative movement of the two blocks has actually been is not certain. Siebert lake beds are exposed in the southwest corner of the Mizpah Hill block, and are assumed, from the topography, to occur in the southeast corner, but have not been actually observed

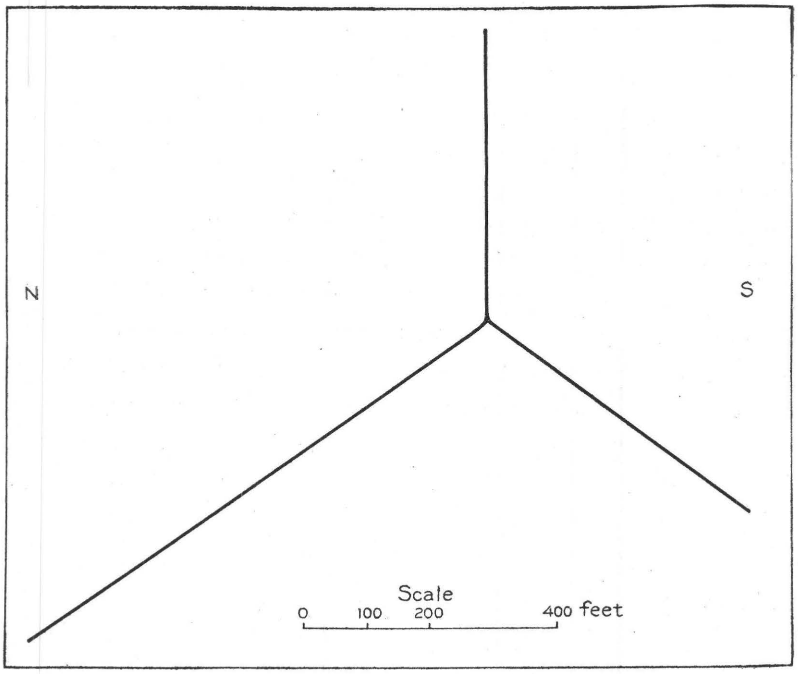


Fig. 41.—Hypothetical diagrammatic vertical cross section of the Valley View vein system (represented by its principal and strongest vein) before faulting and erosion. The upper part is considered to be now represented in the Stone Cabin and Silver Top workings and for a short distance below the outcrop of Mizpah Hill. The north vein is considered to be represented by the main vein in the Valley View workings, the south vein by that of the Wandering Boy and Fraction.

there. This indicates that the Mizpah Hill block has been depressed, relatively to the Gold Hill block, so that the Wandering Boy vein would represent an originally lower portion of the Valley View vein system than the portion now outcropping on Mizpah Hill. If this is so, the vertical portion of the Valley View vein system should be expected to pass in depth to veins dipping south at angles of 30° or 40°. From the Valley View workings, however, it is known that in depth the vertical veins here actually pass into north-dipping veins and continue so several hundred feet downward, at least. The north-dipping and the south-dipping flat veins, represented, respectively, in the Valley View and in the Wandering Boy, are then probably not parts of the same vein, but represent a pair of veins dipping at equal angles in opposite directions (fig. 41).

OUTCROPS OF WANDERING BOY VEINS.

The outcrop veins northeast of the Wandering Boy all have a northeast strike and a southeast dip. As observed at the surface they are designated as 1, 2, 3, and 4 on fig. 42.

REPRESENTATION OF OUTCROPPING VEINS UNDERGROUND.

The heaviest vein, No. 1, as there is reason to believe, may be the main vein of the underground workings shown in the 300-foot level. The 8-inch vein represented on the 300-foot level, northwest of the probable position of the main vein at this point, may very well be the same as No. 2. The 6-inch vein followed on the 115-foot level may perhaps also be No. 2, in spite of the fact that though it has a southeast dip it lies almost directly over the supposed No. 2 vein on the 300-foot level. The general result of the faulting here has been to place the veins in the lower levels in a position farther north, on the west side of the numerous faults, than would be the case if the veins continued regularly downward. The inclined shaft shown in the figure was inaccessible at the time of the writer's visit, but drifts were run on two veins at distances of 65 and 95 feet from the surface. It is likely, as shown in the figure, that the former was on the No. 3 vein,[a] the latter on the No. 4.

FAULT SYSTEMS IN THE WANDERING BOY.

In the Wandering Boy workings the veins are thrown into great confusion by faulting. Analysis of the disturbance leads to the conclusion that the faulting can be referred to two major systems—that of the Wandering Boy fault, which strikes northwest and outcrops just east of the Wandering Boy shaft, and that of the Fraction fault, which strikes northeast and whose outcrop is drawn on the map as lying between the Fraction No. 1 and the Fraction No. 2 shafts. In the Wandering Boy workings the Wandering Boy fault dips southwest at an angle of approximately 50°, while in the Fraction workings the Fraction fault dips southeast at an angle of about 45°. In the north corner of the block inclosed by these two faults, therefore, the line of intersection of the faults pitches south, and the faults rapidly approach as they go deeper. The estimated position of these two faults on the 300-foot level is shown in Pl. XXI, and may be compared with the surface outcrops, as shown on the map (Pl. XVI).

[a] Mr. J. M. Healy informs the writer that the vein shown in the figure, as drifted on at the 65-foot level, was 3 feet thick and of low grade.

DISPLACEMENT OF THE WANDERING BOY FAULT.

The Wandering Boy fault, as shown on the map, separates the earlier andesite on the northeast from the Fraction dacite breccia on the southwest. It has

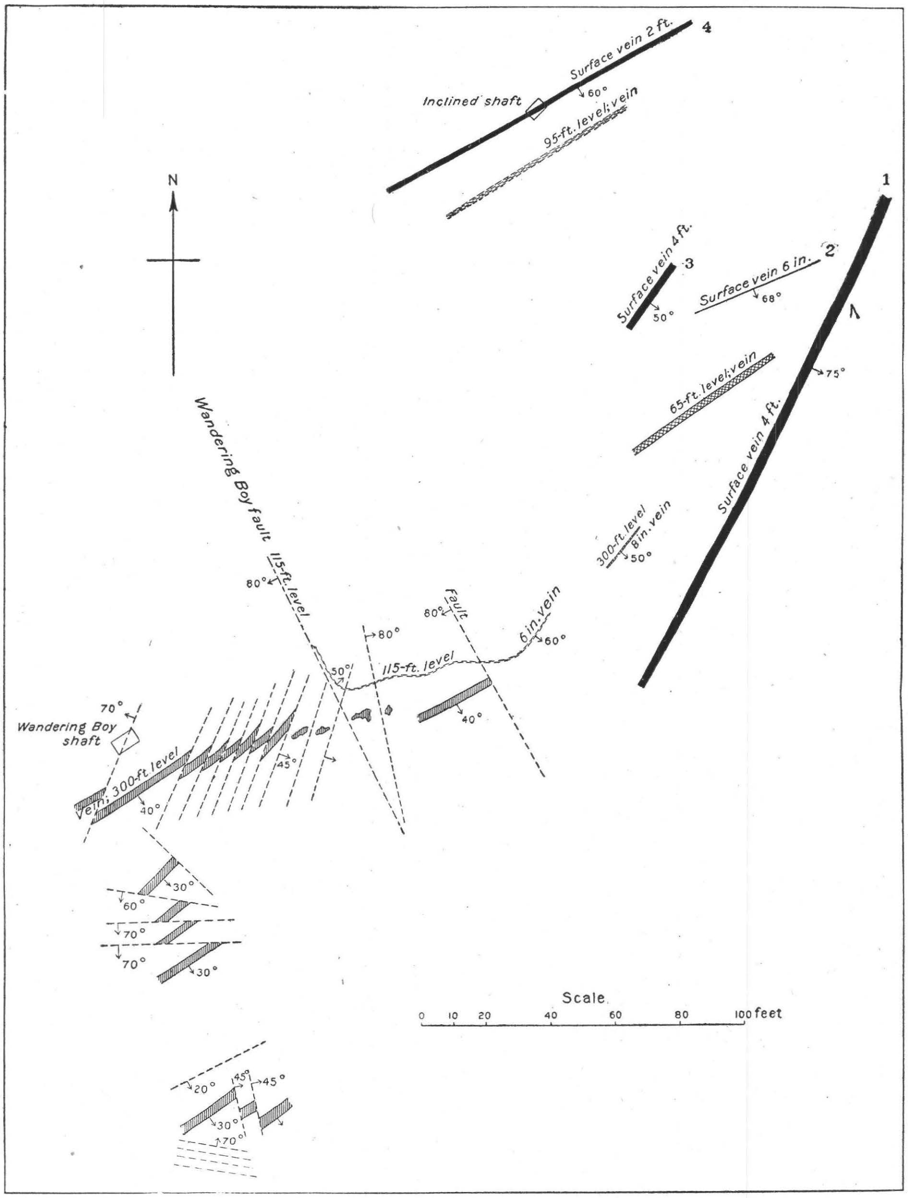


FIG. 42.—Plan showing outcropping veins near the Wandering Boy and their probable relation to the veins encountered underground.

therefore a downthrow on the southwest, and underground workings show that it has a southwest dip, making it a normal fault (fig. 43). That the contact is really due to a fault of very great displacement is shown by the occurrence underground along it of a thick friction breccia containing fragments of later andesite, of granitic rock, and of the adjacent rocks.

On the 115-foot level the main Wandering Boy fault is well developed (fig. 44). The small 6-inch vein followed on this level shows a repeated breakdown to the southwest as the main fault is approached, a movement corresponding to the chief normal faulting. Besides this there are horizontal grooves along the main fault plane, and similar striations are found on it where it is cut in the shaft below at a depth of 185 feet. Furthermore, on the 115-foot level, the vein is bent and dragged to the northwest along the fault plane (fig. 44), and here the dip becomes north instead of south, as normal. These phenomena show a horizontal movement to the northwest on the southwest side of the fault, and the reversal of the dip shows some differential or torsional movement. The striæ on a fault plane indicate the last movement, the records of previous and often more important movements being erased by each new one. The combined result of all the movements indicated, therefore, is that the block on the southwest side of the fault has moved downward, and also to a less degree (probably) northwestward, along the fault plane. This horizontal movement is also shown in the Fraction, where the northwest faults (see p. 144) are probably auxiliary slips related to the Wandering Boy system. In the Fraction, especially on the 300-foot level, important horizontal movement is registered by the striation.

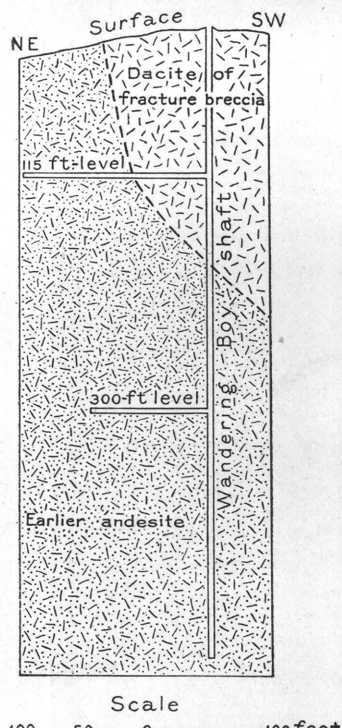


FIG. 43.—Vertical section on the Wandering Boy shaft, showing the main Wandering Boy fault.

CROSS FAULTING ON THE 300-FOOT LEVEL.

Complicated faulting is shown in the 300-foot level of the Wandering Boy. The main workings consist of two drifts run at right angles, one running nearly east and the other south. The vein shown in this level has a thickness of 3 or 4 feet, strikes northeast or east-northeast, and dips southeast at an angle of 30° or 40°. The east drift, therefore, runs somewhat diagonally to the strike of the vein, though more nearly along it, while the south drift also runs diagonally though somewhat more across the strike (fig. 48). The vertical section along the east drift is given in fig. 45, that along the south drift in fig. 46. Near the end of the south drift a short east drift has been run, following a portion of the vein, and the vertical section along this drift is given in fig. 47. In fig. 45 it is shown that the vein (which normally, following its strike and dip, would disappear from the drift) is continually thrust up to the east by close-set faults, so as to persist in the drift.

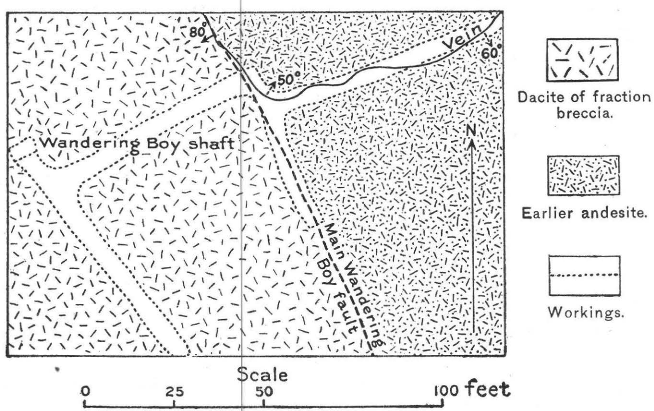


FIG. 44.—Horizontal plan of 115-foot level, Wandering Boy workings, showing minor vein and Wandering Boy fault.

Judging from the section (fig. 45), most of the faults are apparently reversed faults, while some are normal. In the south drift, the vein has been repeatedly thrown

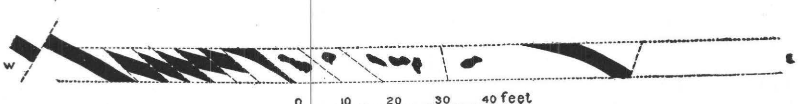


FIG. 45.—Vertical section along east drift, 300-foot level, Wandering Boy mine, showing faulting of vein.

up to the south by close-set, normal faults, as shown in fig. 46. There is no question as to the identity of the fragments of vein in the east drift and those in the northern half of the south drift, for the connection is nearly continuous. The fragment shown in the south end of the south drift is 30 or 40 feet distant from the fragments farther north, and may represent a closely parallel vein; on the other hand, it is identical with the

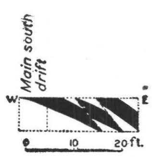


FIG. 47.—Vertical section showing short crosscut to east near south end of south drift, 300-foot level, Wandering Boy, showing faulting of vein.

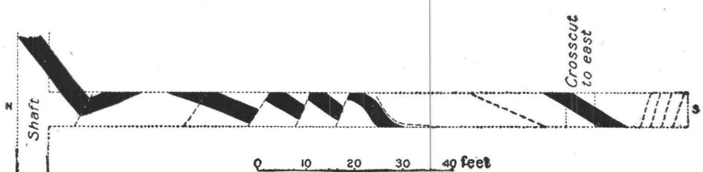


FIG. 46.—Vertical section along south drift, 300-foot level, Wandering Boy mine, showing faulting of vein.

other vein blocks in size, strike, dip, and appearance, and there is no necessary reason for separating it from them. The short drift running east on this southernmost vein fragment shows conditions identical with those in the main east drift (fig. 47), the vein being upfaulted to the east by close-set, apparently reversed faults.

The situation is shown in horizontal plan in fig. 48, where the strikes of the faults and the vein blocks may be studied and compared, as the dips may be compared in the vertical sections. Here it is seen that the faults on the east drifts have essentially a north-south course, some trending to the west of north, and perhaps most of them to the east of north; and that those in the south drift are

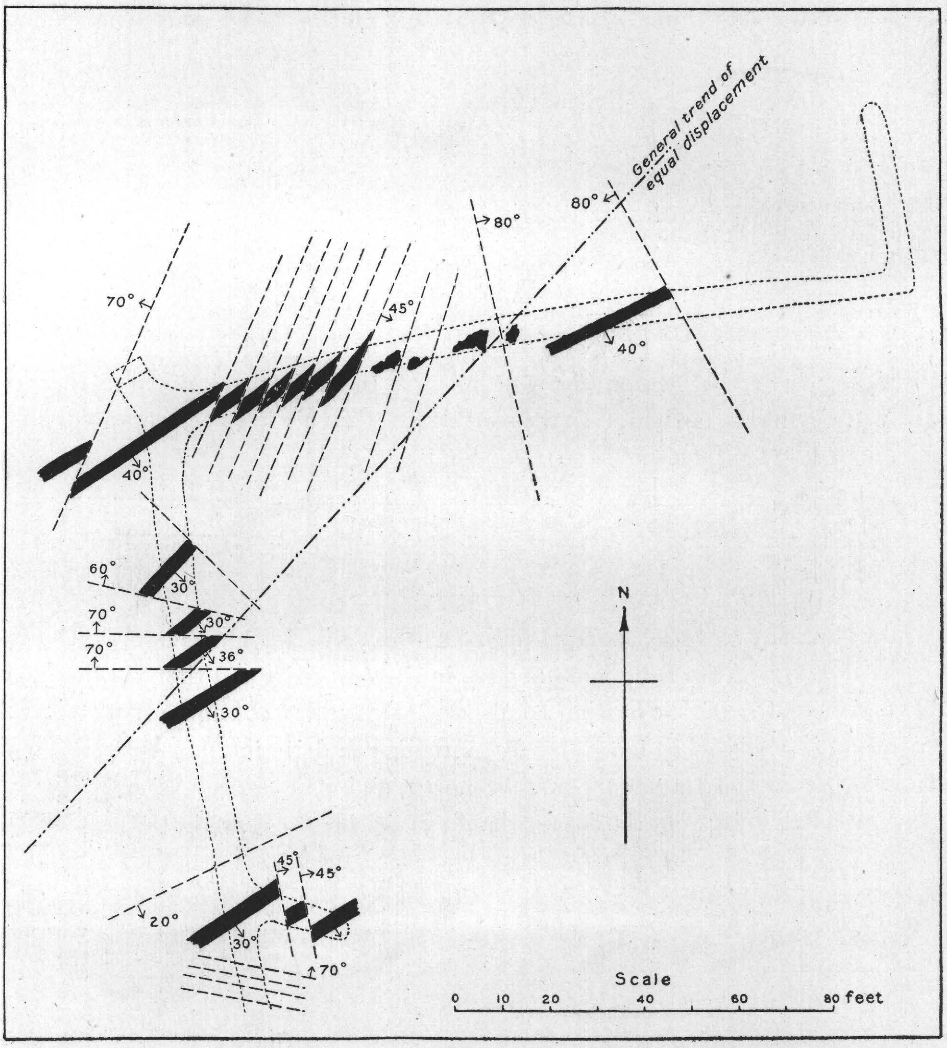


FIG. 48.—Horizontal plan of Wandering Boy, 300-foot level, showing fragments of vein and cross faults, with the general trend of equal displacement.

essentially east and west faults, though usually trending north of west. Therefore the vein may be considered, for the sake of clearness, as cut by two intersecting systems of faults, one striking north and south and the other east and west. The vein is repeatedly upthrown on the east by the north-south system and on the south by the east-west system.

Effects of cross faulting ideally considered.—In order to understand the resultant effect of such intersecting faults, let us take a simplified example such as is shown in the stereogram, fig. 49. This shows a rectangular block which has been affected by two sets of vertical faults, striking at right angles to each other. On the figure they are also represented as equally spaced and all having the same displacement, thus giving to the example an ideal simplicity which is

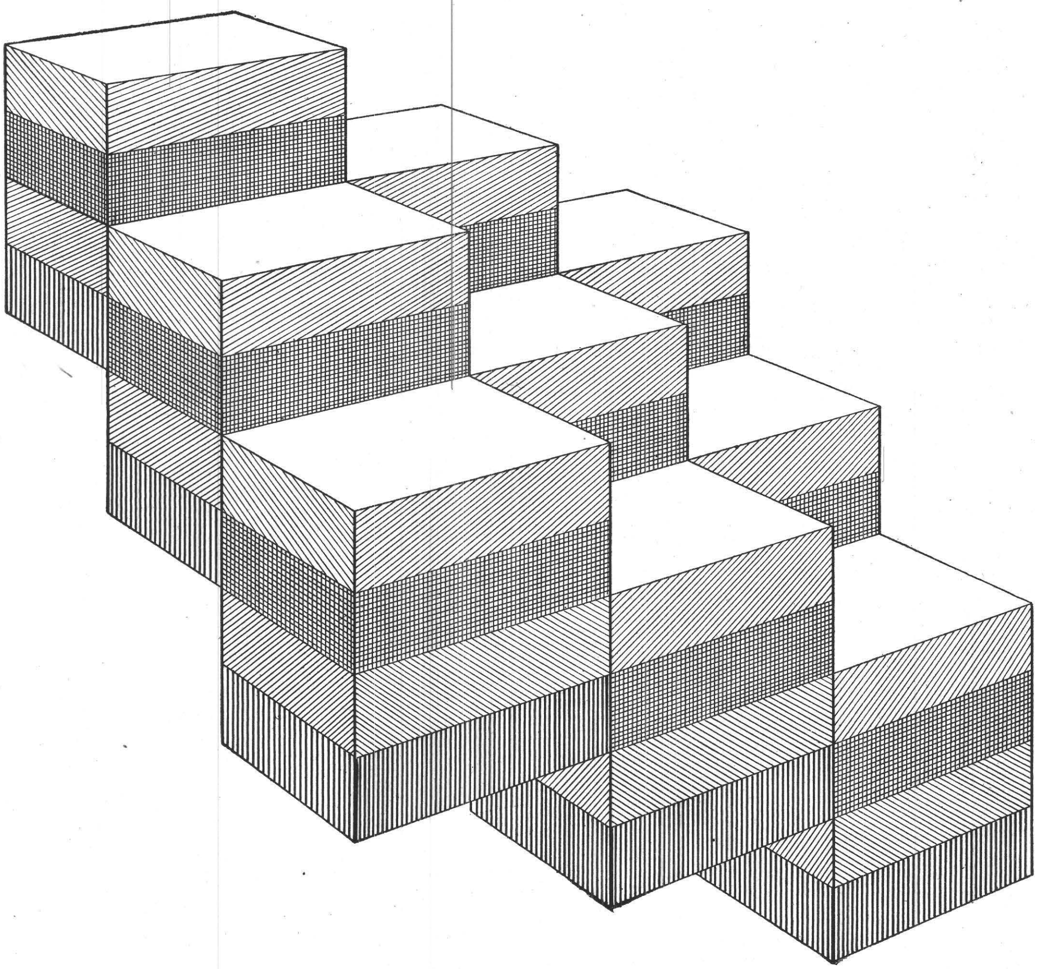


FIG. 49.—Stereogram showing the results of cross faults equally spaced and of equal throw.

probably rarely found in nature. The result of these intersecting faults, as is seen, is that lines or planes of equal displacement are zigzag, being made up of regularly alternating portions of each of the two fault-system planes, the length of each of the component straight lines being determined by the spacing of the faults, while the trend of the whole zigzag, and therefore of the lines of equally displaced blocks, is diagonal to both the fault systems. In effect, the resultant of these two intersecting directions of faulting has been a third diagonal system, which represents the direction of equal faulting.

On a plane projection, with closer spacing of faults, or a greater number of them shown on a smaller scale, the situation is again shown in fig. 50. It may be remarked that to obtain such a resultant there need not necessarily be any

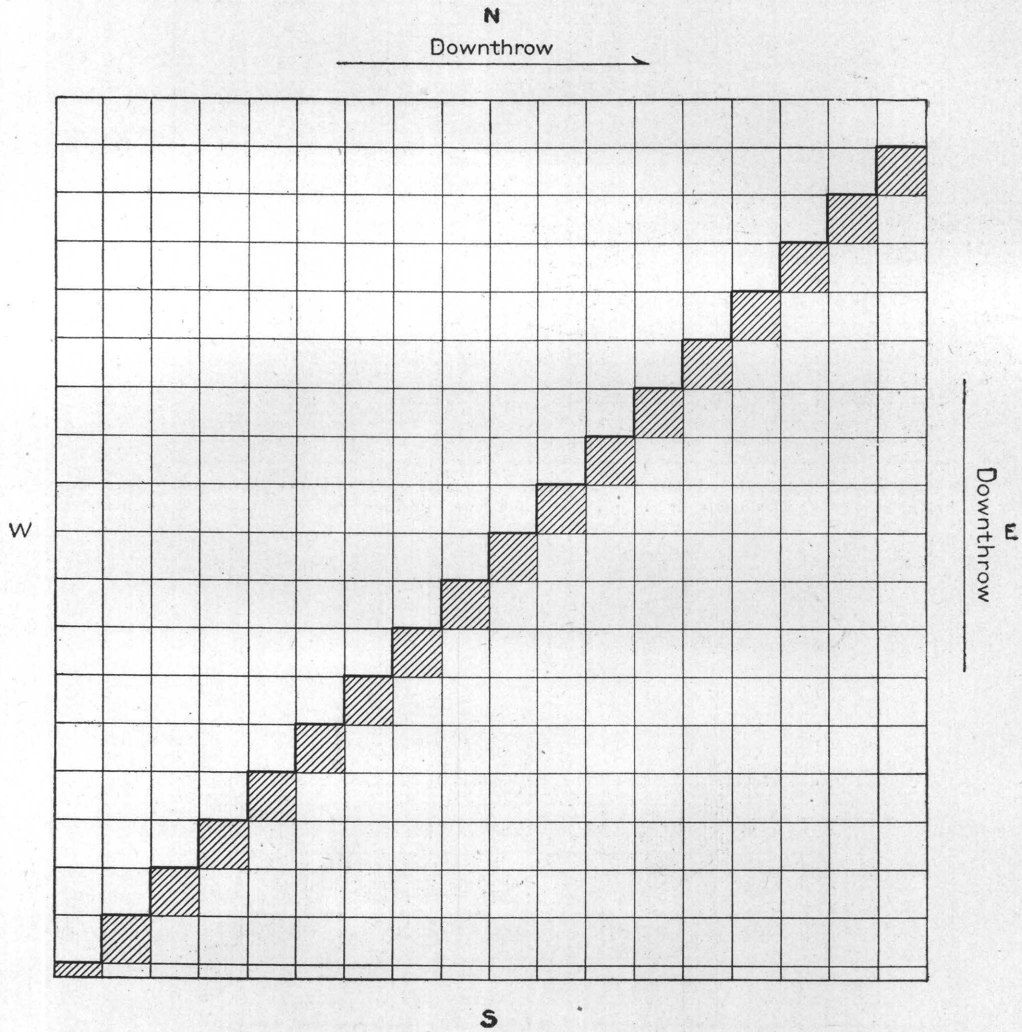


FIG. 50.—Diagram showing horizontal plan of equal and equally spaced faults belonging to two systems intersecting at right angles, the north-south system having a regular downthrow on the east, and the east-west system a regular downthrow on the south side. The heavy zigzag line represents one of the lines of equal faulting, the shaded squares one of the zones or blocks of equal displacement.

correspondence between the direction of displacement (whether up or down) of the two systems. If we reverse the movement of either of the fault systems, for example, if in the figure (to be understood with the aid of the stereogram) the north-south faults are downthrown to the west instead of to the east, a similar resultant faulting will be accomplished, but with a trend at right angles to that depicted.

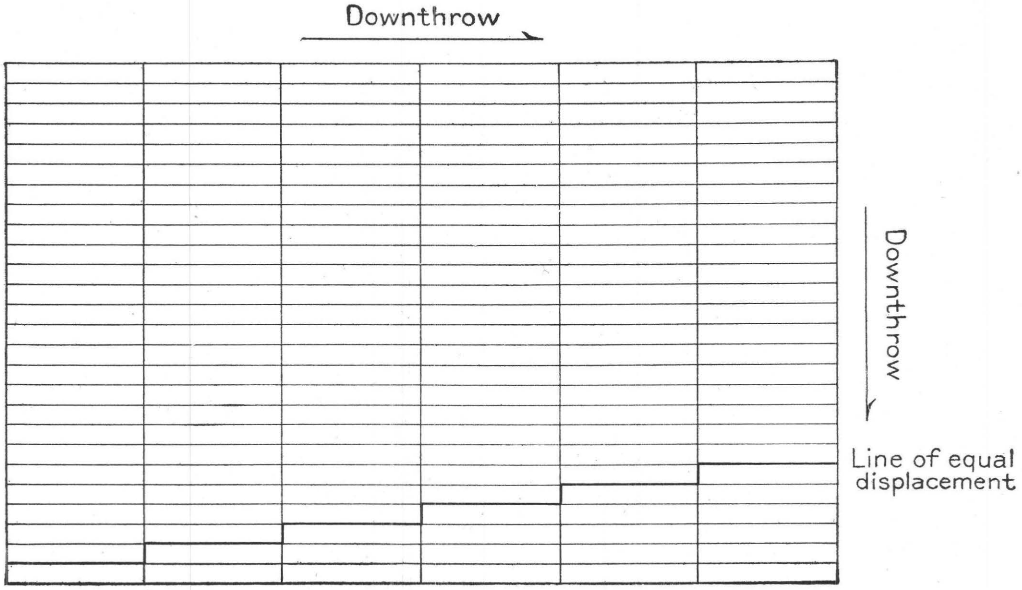


FIG. 51.—Diagram showing course of line of equal faulting for two systems of faults intersecting at right angles and having uniform displacements, the spacing being uniform within each system but different for each system.

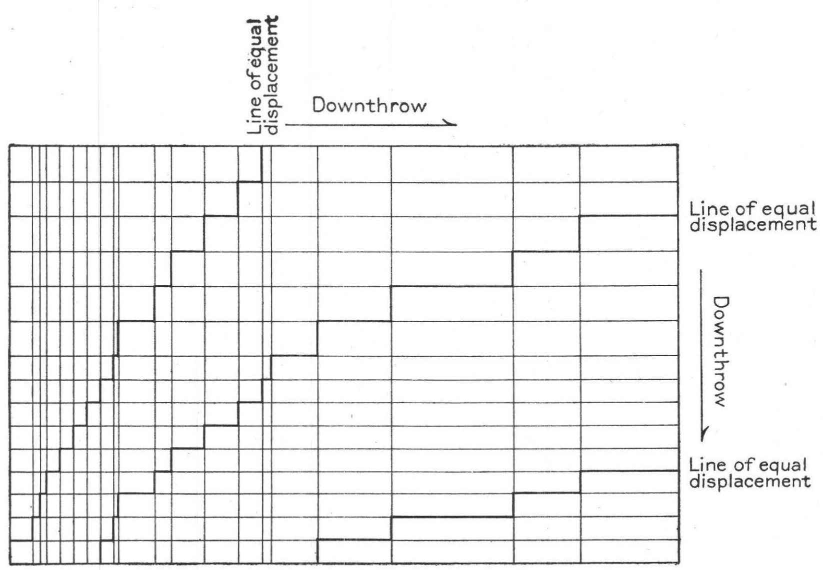


FIG. 52.—Diagram showing the diverse courses of lines of equal displacement which are the result of two systems of equal faults intersecting at right angles but unequally spaced.

From this simple case the variations and irregularities such as are usually met in nature bring about endless changes. A few of these may be ideally deduced. Fig. 51 illustrates a case of equal faulting in two systems which are at right angles, the spacing of the faults within each system being equal, but that of one system being different from the other. Fig. 52 represents a case similar in all respects, save

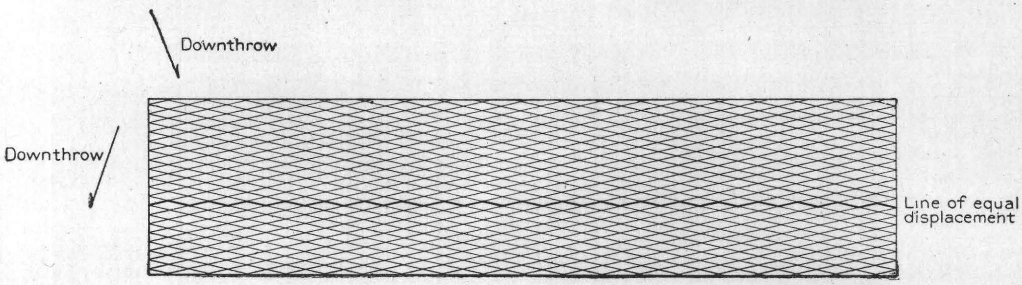


FIG. 53.—Diagram showing the line of equal displacement when the fault systems are oblique to each other instead of being at right angles, the conditions otherwise being like those in fig. 50.

that the spacing of the faults of both systems is irregular. Fig. 53 shows a case similar to fig. 50, save that the fault systems are oblique instead of perpendicular.

If, now, the amount of displacement in the two fault systems is different, even though it be constant within each system, blocks of equal displacement will no

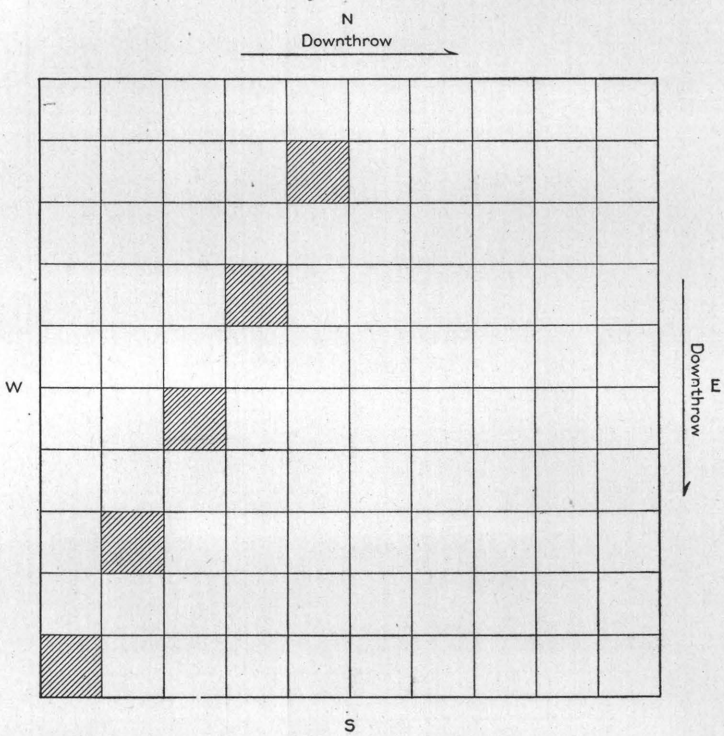


FIG. 54.—Diagram showing the effect of cross-faults when the faults of one system have twice the displacement of those of the other system. Here the north-south faults have double the displacements of the east-west ones. The shaded blocks are blocks of equal displacement.

longer be connected, and therefore there will be no continuous line of equal displacement. In fig. 54, for example, where the displacement of the faults is twice as great in one system as in the other, the isolated blocks of equal displacement will be separated from one another, as are the starting and stopping squares of the knight move on a chess board. If the displacement of one system is three times, instead of twice, as great as the other, the blocks of equal displacement will be removed (in the diagram) one square farther from one another, in a direction parallel to the faults of greater displacement, and so on. If, again, the faults in each system are unequal *among themselves* in regard to their amount of displacement, the fault blocks bounded by the two systems will be distributed in many apparently irregular ways, and each block will appear as a separate unit that has moved independently, rather than as the resultant of intersecting faults. Still, in all cases, it appears to hold good that in general the zones of blocks of equal displacement, roughly aligned though these may be, will lie diagonally between the two fault systems. Which diagonal it will be can be ascertained from the following diagram, fig. 55:

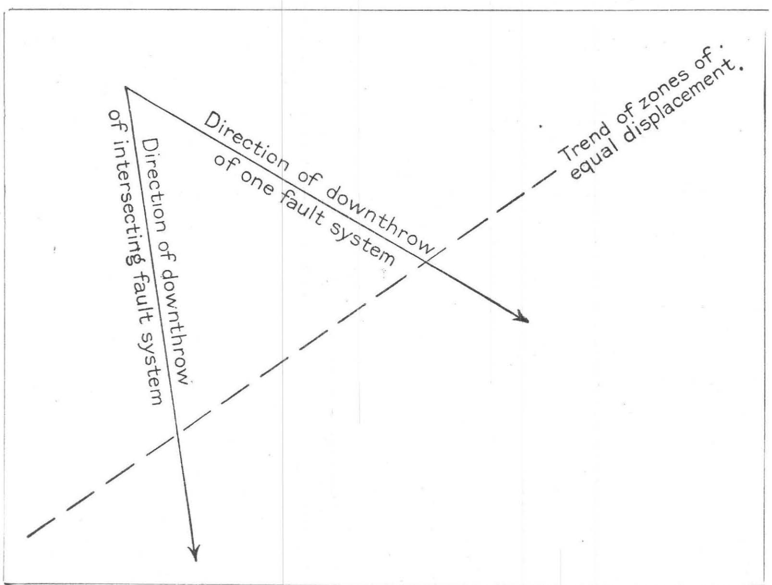


FIG. 55.—Diagram showing trend of zones of equal displacement with given directions of downthrow.

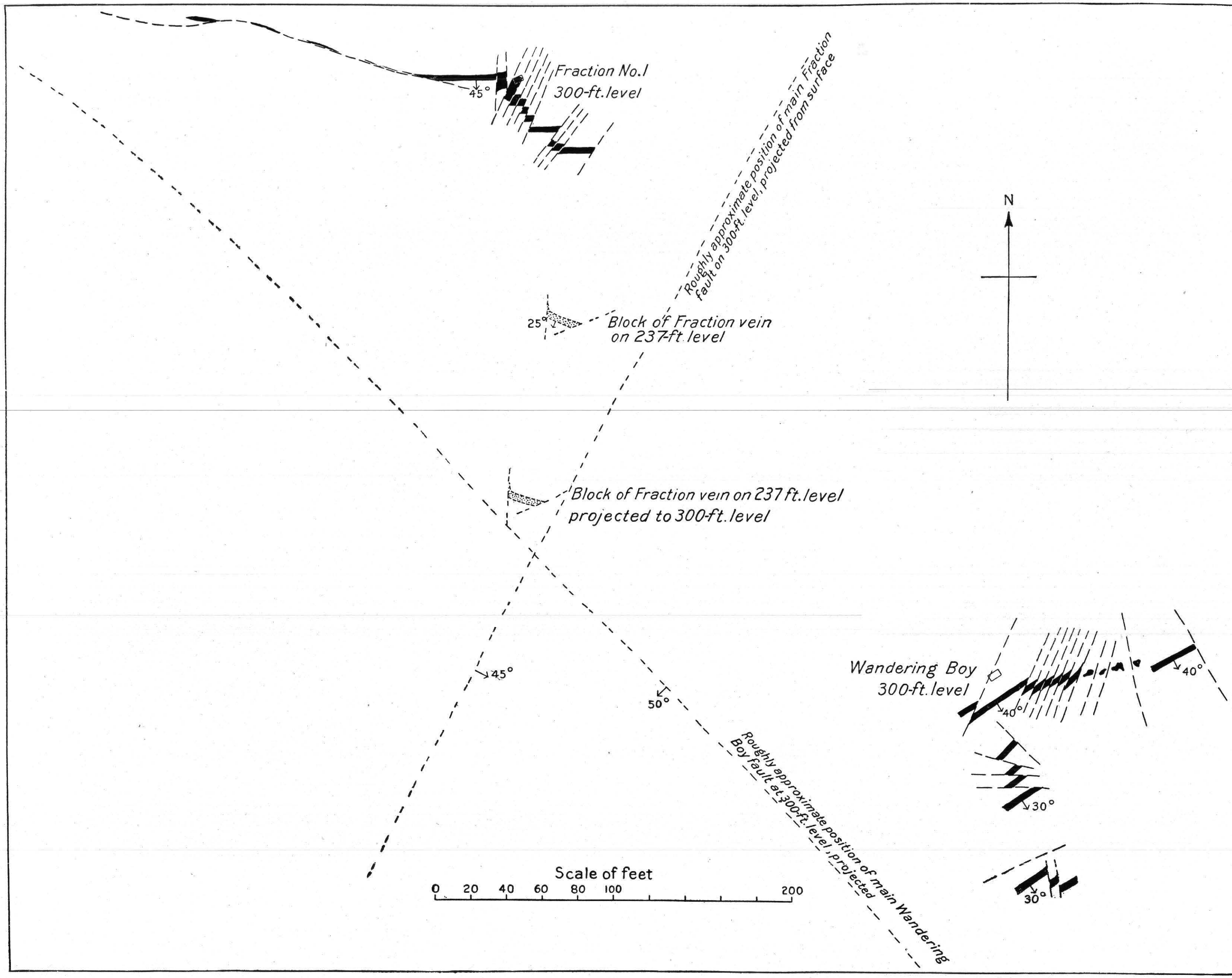
As illustrated in fig. 53, these conclusions hold good for faults striking obliquely to one another as well as at right angles. They also hold good for faults which dip obliquely instead of perpendicularly, and for cases where the dips in the two sets are different in angle or direction, or both.

Application of principles to Wandering Boy cross faults.—These deduced general principles enable us to understand the result of the intersecting faults in the Wandering Boy 300-foot level. The resultant of the east-west and the north-south faulting is a northeast trend of equal displacement, as indicated on the figure, nearly parallel, as it happens, with the strike of the vein. Blocks lying in zones with this general trend have been systematically elevated above adjacent parallel zones lying to the northwest.

The vein dip as a factor in the problem.—In the case of the faulting on the Wandering Boy 300-foot level, the problem takes on an added complexity, since the available test of faulting is not the relative position of the displaced blocks, but rather the position of the vein, whose plane is oblique to any of the planes of the fault blocks, and whose present position is what we seek ultimately to understand. The strike of the vein being nearly parallel with the trend of equal displacement, it results that if the dip is toward the direction of resultant equal downthrow, then the two factors of lowering the vein will be added and the fragments of the vein will gain depth faster than the inclosing rock blocks. If, on the other hand, the dip is against the downthrow, two factors of lowering the vein will be set off against each other. The vein then will gain depth more slowly than the inclosing rock blocks, if the faulting has a greater effect than the dip; will continue on a general horizontal plane, if the faulting has an effect about equivalent to that of the dip; or will ascend, in spite of the downfaulting, if the latter be sufficiently slight to have its effect overbalanced by the dip. In the Wandering Boy 300-foot level, we have, as may be seen from the sections, the second of these conditions. The dip is opposite to the downthrow, and the angle of dip, the displacement, and the spacing of the faults are fortuitously such (for a distance at least) that the one offsets the other, and the vein continues in a horizontal zone. This explains why the long east and south drifts and the short east crosscut from the south drift all encounter blocks of apparently the same vein; and it follows that other blocks of the vein probably exist on this same level in the angle between the two main drifts, and beyond the explored area as far as this peculiar intersecting faulting and the balance of dip and displacement is maintained.

CORRELATION OF VEINS IN FRACTION AND IN WANDERING BOY.

Pl. XXI, p. 140, shows the vein and faults of the corresponding 300-foot levels of the Fraction and the Wandering Boy, together with the estimated position of the lines of main faulting of both the Wandering Boy and the Fraction faults. It is here seen that the northeast faults in the Wandering Boy, which form the majority of those faults classed together, in describing the cross faulting on the 300-foot level, as north-south faults, are parallel in strike, dip, and direction of displacement, with the chief set of faults in the Fraction, and in strike at least with the main Fraction fault as determined on the surface. These minor faults involve a movement, as seen on a horizontal plane, to the north on the west side; as seen on a vertical section, downward on the west side. The real movement has probably been a compound of these two, as studied out in the Fraction workings. Along the main fault plane, then (if, indeed, there is one, and the displacement is not rather distributed over many par-



HORIZONTAL PLAN OF VEINS AND FAULTS IN WANDERING BOY AND FRACTION 300-FOOT LEVELS, TOGETHER WITH PROJECTED POSITION OF THE MAIN FRACTION AND WANDERING BOY FAULTS AT THIS LEVEL.

allel faults), the movement was undoubtedly similar to that of the minor faults, and would bring the two portions of a faulted vein into somewhat the position that the Wandering Boy and the Fraction veins, taken as a whole, occupy to each other. This leads to the suspicion that the two occurrences were originally the same vein and were separated by the Fraction fault. The veins in the two mines are similar in strike, dip, size, and general characteristics. A fragment of the Fraction vein lying farthest south on the 237-foot level and probably in a zone east of any exploration on the 300-foot level has been plotted on the map. There is also shown its approximate position on the 300-foot level, if it continues downward that far with the observed dip. This fragment lies midway between the main portions developed in the two mines, supporting the theory of the original identity of the veins.

FAULTS NOT CORRESPONDING TO THE MAIN SYSTEMS.

The northwesterly faults of the Wandering Boy 300-foot level are not so closely related to the Wandering Boy fault as the northeasterly faults are to the Fraction fault. Their trend is various, sometimes coinciding with that of the main Wandering Boy fault, sometimes not. Their dip, as shown in fig. 48, is usually steeply northeast, or in the opposite direction from that of the main fault, so that while, like the main fault, they are normal, the downthrow is on the northeast instead of on the southwest in accordance with the larger movement. Many of them are, therefore, perhaps to be accurately regarded as independent minor faults, resulting from the combined stresses of the major displacements.

RELATIVE AGE OF FRACTION AND WANDERING BOY FAULTS.

The Fraction fault movement partakes essentially of the nature of thrust faulting, and, as has been explained, seems to be due to the horizontal shove exerted by the intrusion of the Brougher Mountain volcanic neck. The Wandering Boy fault, on the other hand, is a normal fault, such as is ordinarily due to gravity; and the fact that faulted blocks are downthrown on the south, in the direction of the dacite volcanic centers, leads to the belief that the downthrow was a part of the general downfaulting in the neighborhood of these volcanoes, which, as described on page 47, probably took place subsequent to the last important outbursts as a result of collapse due to the expulsion of a large bulk of material from the underlying region. According to this the Wandering Boy fault is slightly but distinctly subsequent to the Fraction fault.

ORE IN WANDERING BOY VEINS.

Like most of the Fraction vein material, and much of the material in the Valley View, most of the quartz in the Wandering Boy thus far developed is low grade, or even practically barren. Good assays are obtainable, but even limited masses of rich ore, like those which occurred in the Fraction, were not encountered to any extent. Metallic minerals, other than a limited amount of iron, are not often noted in the veins. Some ruby silver and argentite, like that in the Fraction, have been reported, but were not seen by the writer.

VEINS OF GOLD HILL.

GOLD HILL A FAULT BLOCK.

The Gold Hill block is of especial interest, as being the only outcropping block of earlier andesite besides the Mizpah Hill block. It is, roughly speaking, a triangular area. It is bounded on the north and south by faults and on the east by the intrusive dacite of Golden Mountain. The fact that the contact of this dacite, as shown on the map, is nearly a straight line, suggests strongly the idea that it has been determined by a preexisting fault. This idea is strengthened by an inspection of the boundary just northeast of the Tonopah and California shaft, where the intrusive dacite contracts to a narrow dike, which separates the block in which the Tonopah and California shaft is situated from the Gold Hill block. The former block has at its surface the white tuffs (Siebert tuffs) of the lake beds, under which the Tonopah and California encountered the earlier andesite. This block is therefore depressed with reference to the Gold Hill block, and the dacite dike has been intruded along the fault plane.

NATURE OF GOLD HILL ANDESITE.

The character of the andesite of Gold Hill has been the subject of critical study. On the western extremity of the block at a point south of Mizpah Hill, the andesite has the same peculiar appearance as at Mizpah Hill. Farther east, toward the top of the hill, the andesite takes on a different appearance, being darker and showing somewhat larger feldspar phenocrysts and frequent phenocrysts of altered but easily recognizable biotite. The latter kind of andesite resembles in some ways the later andesite, and at one time aroused in the mind of the writer the same doubt as to its affiliation that the andesites of the Fraction, West End, and MacNamara did. Critical study, however, established the following points: That there is no real boundary between the typical Mizpah Hill variety of andesite and the biotite-bearing andesite of the eastern part of the Gold Hill block; that under the microscope the last-named phase showed many other characteristics of the earlier andesite, while it was seen to contain, as ferromagnesian phenocrysts, biotite to the practical exclusion of hornblende or pyroxene; and that the Gold Hill andesite contained small but typical quartz veins like those of Mizpah Hill. One of these Gold Hill veins has produced rich ore, although in limited quantity. Moreover, while the Gold Hill shaft shows in its upper portion the peculiar characteristics of the surface andesite, in its lower portion it gradually passes into fresher andesite, more like that of Mizpah Hill, and there is little question that the two phases form parts of the same body. Therefore, it has been concluded that there is here a phase of the earlier andesite which contains biotite rather than hornblende, and which also has a somewhat coarser feldspar crystallization. Similar phases can be found on Mizpah Hill, and even very close to the Mizpah vein, and, as stated elsewhere, the rock can be matched in the Fraction and neighboring shafts.

ALTERATION OF GOLD HILL ANDESITE.

The alteration of the Gold Hill andesite, as observed in surface specimens, results in the formation of quartz, sericite and secondary orthoclase or adularia. The plagioclase feldspars (oligoclase-albite) alter to orthoclase (adularia) and sericite, or to sericite and quartz. The biotite is usually altered to muscovite and quartz. Occasional pseudomorphs of secondary minerals after hornblende were detected, consisting chiefly of iron minerals (hematite, etc.). Numerous small crystals of apatite occur. Practically the same characteristics are found in the specimens from the Gold Hill shaft, with rather more pseudomorphs after hornblende and some chlorite as secondary mineral.

ENUMERATION OF THE GOLD HILL VEINS.

Gold Hill differs in an important manner economically from the Mizpah Hill block, in its comparative poverty in mineralization. The veins are shown on the map, but are narrow and weak. The most important outcropping vein may be called the Good Enough vein, from the name of one of the claims. At one point in the upper part of the Good Enough shaft the vein has a thickness of 1½ feet, but diminishes farther down, and also laterally along the outcrop in both directions, until it splits into diverging and unimportant stringers. This vein has an east-northeast strike with a northerly dip at an angle of about 70°. There is a parallel vein 250 or 300 feet to the northwest, which dips in the opposite direction, or to the southeast, at an angle of 70° or 80°. This vein has a thickness of 3 to 6 inches and is traceable across the hill. A number of other veins of the same character are found, one of which runs southeastward from the Gold Hill shaft, parallel to and just above the road. It strikes N. 60° W., has an average thickness of 6 inches, and is also evidently a weak vein. Veins of the same character, nearly parallel to that last mentioned, occur on the southwest side of the road, in the same block, as shown on the map (Pl. XVI). They are usually several inches thick, but have not been traced far.

PRODUCTION OF GOOD ENOUGH VEIN.

The only place on the hill from which much ore has been obtained was from one section of the surface portion of the Good Enough vein. According to the Annual Report of the Director of the Mint on the Production of Precious Metals for 1901, the vein had produced and shipped $15,000 worth of ore up to the time of the publication of that report. Not much further work has been done on this ore body.

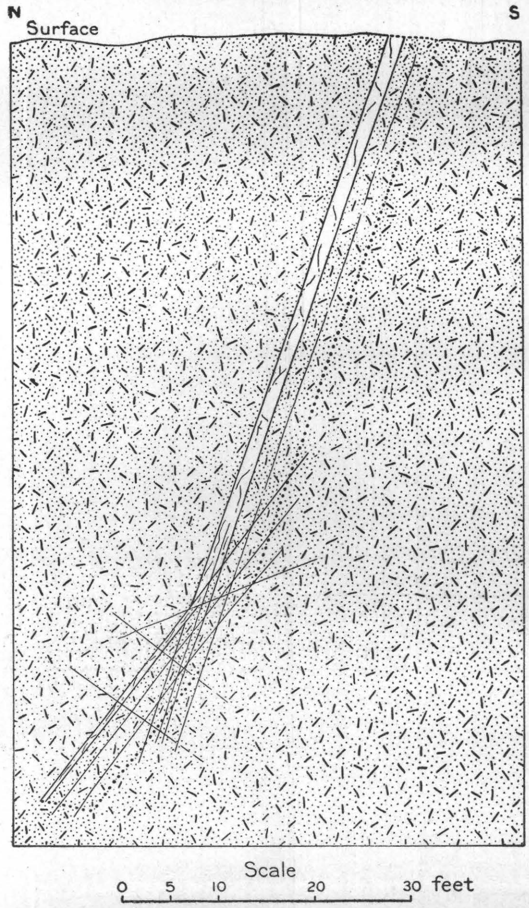


FIG. 56.—Section of Good Enough shaft, Gold Hill. Lower outlines of shaft indicated by dotted lines. Shows cross section of vein in early andesite, with minor cross walls. Also shows the control of the size and direction of the vein by dominating fractures. Straight lines represent some of the fractures.

VEIN STRUCTURE.

The condition of the Good Enough vein as seen in the chief working shaft is shown in fig. 56. From the standpoint of origin this vein is interesting, as it shows plainly the effect of fracture planes, in determining not only the walls, but in producing a diminution in the size of the vein and even a change of course.

There is no faulting in the section shown in the figure, and the change in size and dip of the vein is due simply to the control of the original mineralizing circulation first by one and then by another set of fractures (fig. 57). This is in accordance with the observations made on the Mizpah Hill veins.

GOLD HILL SHAFT.

The Gold Hill shaft at the time of the writer's visit was 490 feet deep, in earlier andesite of an unusually fresh character for this district. The workings consisted of crosscuts to the north and south at this level, of 30 feet each. There was another level at a depth of 300 feet, and a drift 20 feet to the north and 50 feet to the south. The north drift at this level showed a 2-inch vein, running N. 80° W. and dipping north at an angle of 67°.

TONOPAH AND CALIFORNIA WORKINGS.

SECTION EXPOSED IN WORKINGS.

The Tonopah and California shaft is situated several hundred feet southeast of the Gold Hill shaft. It starts in the white stratified tuffs of the lake beds, which here have a north-northeast strike and a westerly dip of about 20°. According to the report of the manager, 63 feet of these tuffs was passed through, and directly beneath them was the earlier andesite. A short distance south of the shaft the tuffs are thicker, as a shaft has gone down 100 feet in them and has not reached their lower limit.

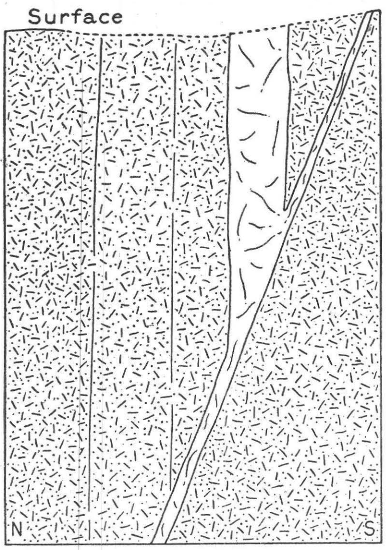


FIG. 57.—Cross section of Good Enough vein, Gold Hill, as exposed in openings just west of shaft, showing same characteristics as in fig. 56. Vertical lines in andesite are joints.

Some quartz stringers were found in the earlier andesite beneath the tuffs, at the depth of about 123 feet. At a depth of about 135 feet the shaft enters a brecciated zone, which consists of softened and broken earlier andesite and occasional bunches of broken quartz. This continues down in the shaft for about 40 feet. At a depth of 150 feet a short drift runs southward in this broken zone. The minor slips within this zone have a north-south strike and a dip of 30° to the east, and the bottom of the zone has a similar strike and dip. Below this there is hard earlier andesite, rather dark colored, with occasional north-south slips and some broken quartz stringers, evidently faulted. At a depth of 450 feet a drift runs in a southeasterly direction for over 220 feet. There is another level at a depth of 650 feet.

CALIFORNIA FAULT.

The broken zone described in the shaft is evidently a fault zone. Projected on the same dip to the surface, this zone coincides with the outcrop of the fault which separates Gold Hill from the block in which lies the top of the Tonopah and California shaft. At the surface, however, this fault zone is occupied by a dike of the Golden Mountain dacite, which is not present in the shaft. Evidently the dacite is straighter than the fault or happens to be missing at this point.

According to this the shaft below the fault, that is to say, below 180 feet, is in the Gold Hill block. Moreover, the east drift on the 450-foot level does not run far enough to cut the fault, so that these workings are in the same block.

VEINS.

Some of the broken fragments in the fault zone show a small quantity of material that is probably black silver sulphide.

On the 450-foot level a small quartz vein, a few inches thick, with an east-southeast strike, and a northerly dip (45° to 60°), was followed. This has a gangue of quartz, with some calcite, and contains pyrite. In some places good values are shown. On the 650-foot level, a short distance south of the shaft, in very dense and fine-grained earlier andesite, a ledge of 3 feet of mixed quartz and altered andesite has been cut. This quartz contains argentite and shows some good values.

MONTANA TONOPAH VEIN SYSTEM.

MONTANA TONAPAH MINE.

ABSENCE OF VEINS IN THE LATER ANDESITE.

The Montana Tonopah shaft was sunk in the later andesite, on the northeast or upper side of the Mizpah fault (Pl. XVI). It passed through 372 feet of the later andesite before reaching the fault. Most of this rock was extraordinarily decomposed and thoroughly bleached, while much was intensely brecciated, containing hard bowlders in a clayey matrix, with strong fractures and slickensided surfaces. This indicates a great deal of faulting, of which no measure could be obtained.

Above the Mizpah fault only small veinlets of calcite and quartz were encountered, but 4 feet below the fault a heavy quartz vein in the earlier andesite was encountered and followed in the shaft to a depth of 392 feet, where the first mine level was made. The other main levels are at 460, 512, 612, and 765 feet.

The Mizpah fault was cut in a northeast drift on the 392-foot level, as shown in fig. 58, at a point about 60 feet from the shaft; it was also encountered in the 512-foot level, as shown in Pl. XXII. Its strike and dip are therefore fairly well determined; the strike is about N. 55° W., and the dip is northeast, at an angle of about 29°. The later andesite has been found on the northeast or upper side of this fault, at all depths thus far examined, both in this mine and in neighboring ones.

This rock (the later andesite) has been extensively explored, both in this mine (as in the drift on the 512-foot level connecting the Montana Tonopah and North Star shafts) and in others, but no veins of size and value have been found, nor anything that does not confirm the theory that the principal veins are older than the later andesite.

VEIN ON THE 392-FOOT LEVEL.

The nature and relations of the Montana Tonopah veins are best seen from figures. Fig. 58 shows the upper or 392-foot level, and the plan of the vein first encountered in the shaft at that level. The vein is about 3 feet thick, of the normal Tonopah type, such as has resulted from a silicification and mineralization of the rock along a zone of close-set fractures; the values in it are moderate. It is sharply cut off on the east by the Mizpah fault. Near the shaft it is cut by a number of small northeast faults, generally steep and dipping in both directions. These faults nearly always have brought about an upthrow on the northwest side, so that in horizontal plan the vein is offset to the southwest on the southeast side. These faults are both normal and reversed (fig. 59). The vein dips northwest at an average angle of 45° or 50°.

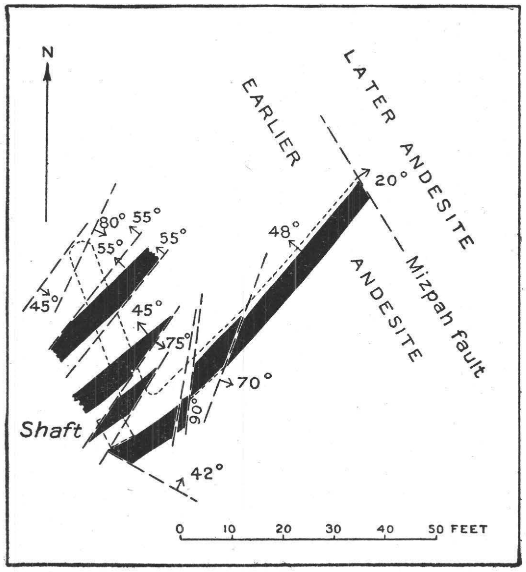


FIG. 58.—Horizontal plan of faults and vein on the 392-foot level of the Montana Tonopah.

This level, continued as a cross-cut about 150 feet to the northeast, cuts another vein, supposed to be the Macdonald vein of the lower levels. This vein strikes northeast and dips northwest at an angle of 40°; it is from 2 to 4 feet thick and contains some good ore. Two portions of it, separated by a northeasterly striking, southeast dipping (60°) fault, are successively cut in the drift. On account of this faulting the vein has not been much explored.

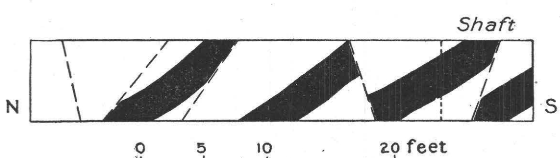


FIG. 59.—Vertical section along north drift, 392-foot level, Montana Tonopah.

BRANCH VEIN ON THE 460-FOOT LEVEL.

At 440 feet the shaft cuts a minor vein below the one just described (fig. 60). This vein is about 4 inches thick at the shaft and was followed a short distance northeast along its strike. At a distance of about 25 feet it was represented only by stringers 2 inches or less thick, and was not farther drifted upon. To the southwest of the shaft, what is probably the same vein was followed a longer distance, becoming stronger and being from 8 to 18 inches thick. The ore in this part of the vein is often of high grade, consisting of black and white quartz, crustified or irregularly mingled. The black quartz owes its color to a large amount of included black silver sulphide and other sulphides.

In this drift southwest of the shaft the vein dips to the northwest at an angle of about 60°.

CONNECTION OF BRANCH VEIN WITH MONTANA VEIN.

This vein was followed southwest on the strike and downward on the dip to its junction with a larger and more important vein—the Montana. At a point a little over 40 feet southwest of the shaft, an incline on the vein went down 38 feet to the Montana vein, while the same junction along the strike was effected at a point over 100 feet southwest of the shaft. The Montana vein

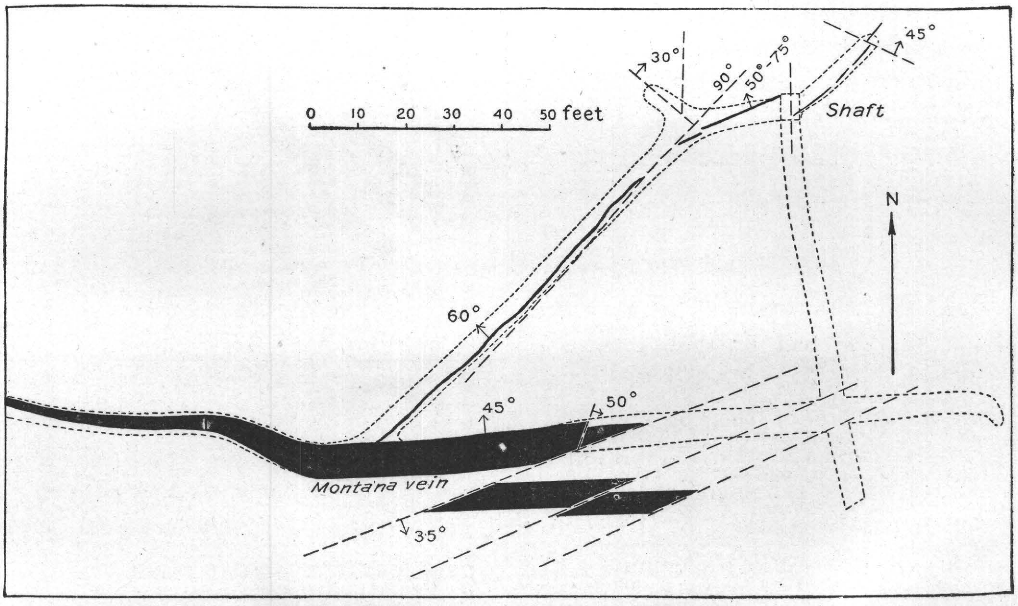


FIG. 60.—Horizontal plan showing veins and faults on the 460-foot level of the Montana Tonopah.

strikes at this point generally east and west, and dips north at an angle of 45° or 55°, the dip being somewhat less than that of the smaller vein. The junction of the two veins therefore pitches to the northeast at a comparatively low angle.

BRECCIATED STRUCTURE IN THE MONTANA VEIN.

The Montana vein as developed in this level was very strong. It was from 6 to 8 feet thick, being rather thicker than the average vein. It showed white quartz with dark-colored portions and had often a brecciated structure. The dark quartz, which contains a much larger amount of black silver sulphides than the light-colored quartz, proves on assay to contain three times or more the value of the white.

Examination of the breccia shows that frequently the black quartz occurs as angular fragments cemented by the white, while in other places, perhaps in the same exposure of the vein, fragments of the white quartz are cemented by the darker and richer ore. The whole is a solid, substantial vein, both dark and white quartz having every mark of primary origin. The only trace of movement is in the brecciation of the dark and white quartz, as above described.

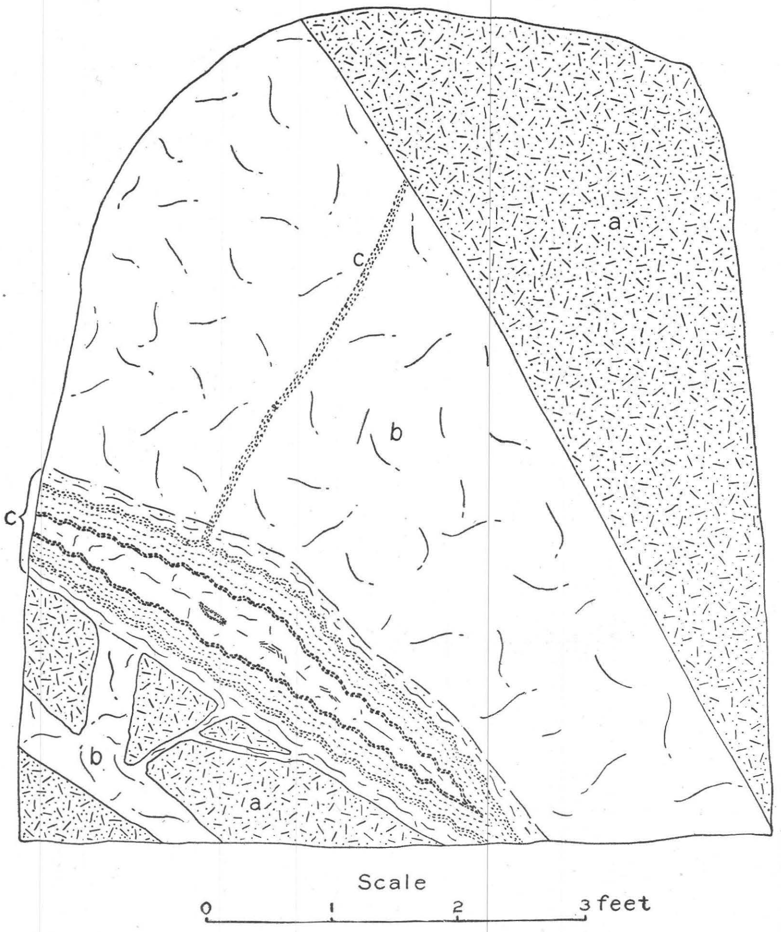


FIG. 61.—Figure drawn from sketch, showing face of ore of the Montana vein on the west drift, 460-foot level, Montana Tonopah mine. To illustrate fissure with crustified high-grade ores, subsequent to the formation of the ordinary veins, but within the period of primary ore deposition; a, altered andesite, wall rock; b, main Montana vein of ordinary type; c, subsequent fissure filling. Within this the dark streaks are rich black sulphide layers, with quartz and carbonates between. In the central quartz band are druses lined with adularia crystals.

CRUSTIFICATION IN THE MONTANA VEIN.

Another allied peculiarity of this vein, as compared with other veins of the district, is that portions are regularly banded or crustified.

Such crustification is not characteristic of the whole vein, for the crustified portion occurs surrounded by solid quartz possessing no banded or comb structure and having all the characteristics of the typical quartz vein of the district. The crustified vein also is not regular nor persistent, and seems to have filled uneven clefts or openings in the main vein, which itself has every appearance of having been formed by silicification along fracture zones in the way previously outlined for the outcropping veins of Mizpah Hill (fig. 61).

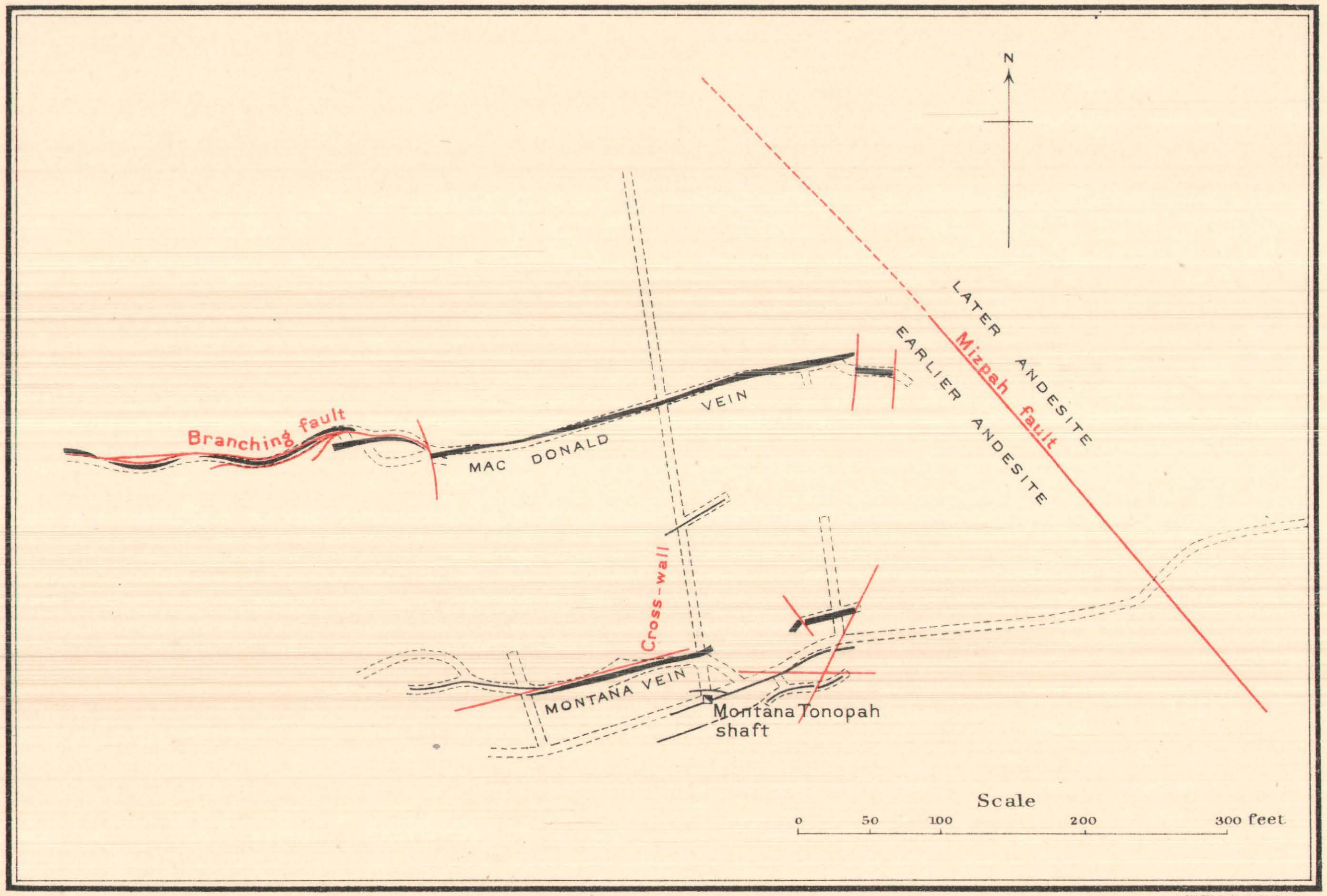
CONDITIONS OF FORMATION OF MONTANA VEIN.

The gangue and the metallic contents of the crustified vein are, however, of exactly the same kind as those of the ordinary inclosing vein. There is no reason to doubt that both portions of the vein are primary, like the different depositions noted in the breccia ore. The phenomena indicate that, in this portion of the vein at least, rock movement went on subsequent to the first ore deposition and to the first cementation of the fractures by quartz, producing in places a breccia, which was cemented with similar materials by vigorously circulating mineralizing waters, and even forming irregular open spaces, in which the ores and gangue materials were deposited in successive layers. It seems that the movement continued even after the beginning of the deposition of some of these crustified masses, for some of the breccia ores show fragments of very light and of very black quartz, such as are characteristic of the crustified veins and not of the ordinary type, intimately associated. The later part of the mineralization thus indicated may have occurred at a period when the solutions were richer in the metallic minerals than previously, for this portion of the vein is characterized by extremely rich ore, and some of the faces exposed in breaking down the vein showed great masses of the black sulphides, constituting ore of a richness that is rarely seen in such quantity.

FAULTS ON THE 460-FOOT LEVEL.

As shown on fig. 60, the northeast branch vein is interrupted by a number of minor slips or faults. On the east the Montana vein is sharply cut by northeast faults having a southeast dip of about 35°, and its eastward continuation has not been found. The smaller faults of this series show that the result as seen in horizontal section is an offset to the south on the east side. Such an effect might be due to a variety of displacements; in this case the strong striæ, pitching east at an angle of 30° on the fault planes, show a diagonal downthrow on the east. According to this, the continuation of the Montana vein should be offset to the south from the present course.

The relative positions of the Montana and Mizpah veins at this level are shown in fig. 62.



HORIZONTAL PLAN OF VEINS AND FAULTS IN THE MONTANA TONOPAH 512-FOOT LEVEL

VEINS ON THE 512-FOOT LEVEL.

The Montana vein has been followed from the 460-foot level up to the fault and has been traced downward to the 512-foot level. The situation on this level is shown on Pl. XXII. The vein marked on this diagram "Montana vein" has been shown, by tracing the actual connection, to be the same as the vein on the 460-foot level. On the northeast it grows less strong and definite on reaching the main north drift.

In the east drift a cross wall, striking nearly parallel with the vein, but dipping

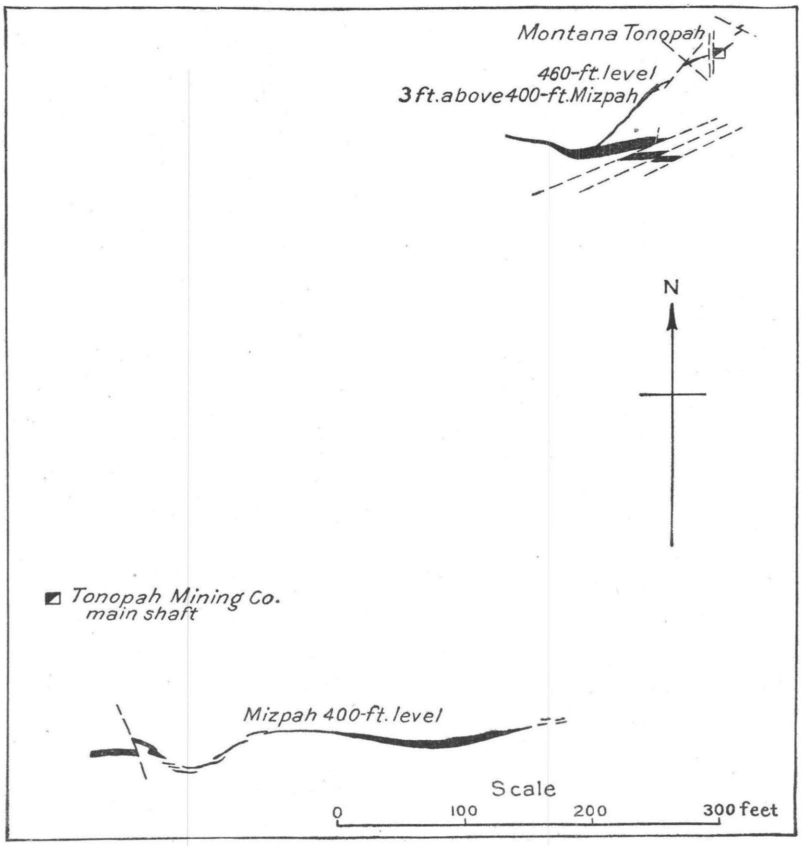


FIG. 62.—Horizontal plan showing relations of the Mizpah and Montana veins on the 400-foot level of the Mizpah.

in the opposite direction (to the south) constitutes the lower limit of this ore shoot. Above this cross wall the ore has been continuously stoped out. Below it the walls continue, and a good deal of quartz is present, but no rich ore has as yet been found below this point on the vein (fig. 63).

A long north drift from the shaft, on the 512-foot level, discloses two veins parallel to the Montana. These are shown in Pl. XXII. The one nearer the shaft shows in the drift a 2-foot zone of quartz stringers with altered andesite between.

This zone contains some silver sulphides and some good ore, although it is largely of low grade. The one lying farthest north has been called the Macdonald vein.

The Macdonald vein is a strong, rich vein having a strike a little north of east, and a northerly dip varying from 45° to 65°. It has been extensively drifted on, on this level, and has produced a great deal of high-grade sulphide ore, of the same character as the high-class ores of the Montana vein. It has been followed down to the 615-foot level.

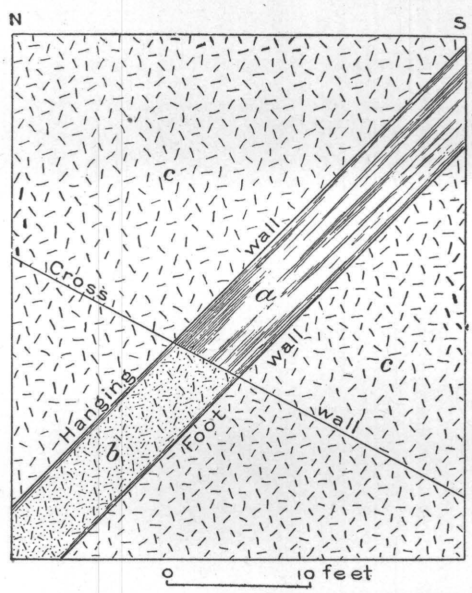


FIG. 63.—Vertical sketched cross section of cross wall limiting chief ore shoot of Montana vein below, as displayed on the 512-foot level of the Montana Tonopah. *a*, Rich sulphide ore, stoped out; *b*, silicified andesite, some quartz and ore, no rich ore; *c*, Earlier andesite, wall rock.

On both these levels and on the intervening stopes this vein shows a complex faulting, reminding one of the faulting that has affected the Fraction vein. In a vertical section such faults appear nearly parallel to the vein, but curve and continually branch and so become now steeper, now flatter in dip than the veins (figs. 64, 65). If straight this faulting would be like that which has affected the vein of the North Star, but the undulations of the faults here in the Montana Tonopah produce, in vertical section, displacements of the vein to the north on the under side of the faults. The line of faulting is not parallel in strike or dip to the vein, though it sometimes so appears in vertical section; in fact, the flat portions of the fault planes pitch east on the vein at moderate angles; and striæ along the faults show that the real direction of movement has been to the east along this pitch. In horizontal section, however, these faults are seen to curve and branch in as complicated a manner as in the vertical section, producing an unrivaled complexity (Pl. XXII).

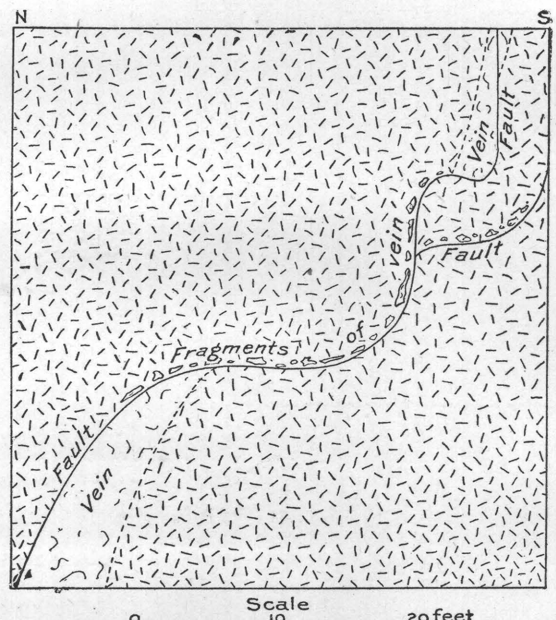


FIG. 64.—Vertical cross section (sketched), showing effect of curving and branching faults on Macdonald vein, in stopes above the 615-foot level on the Montana Tonopah.

EASTERLY PITCH OF ORE BODIES.

There appears to be an easterly pitch to the chief ore shoot on the Montana vein, as this has been developed in following down the vein from the 460- to the 512-foot level. Some of the richest ore in the 460-foot level lies vertically over a relatively poor part of the 512-foot level, the rich ore in the latter level lying farther east.

On the Macdonald vein the ore shoots pitch to the east.

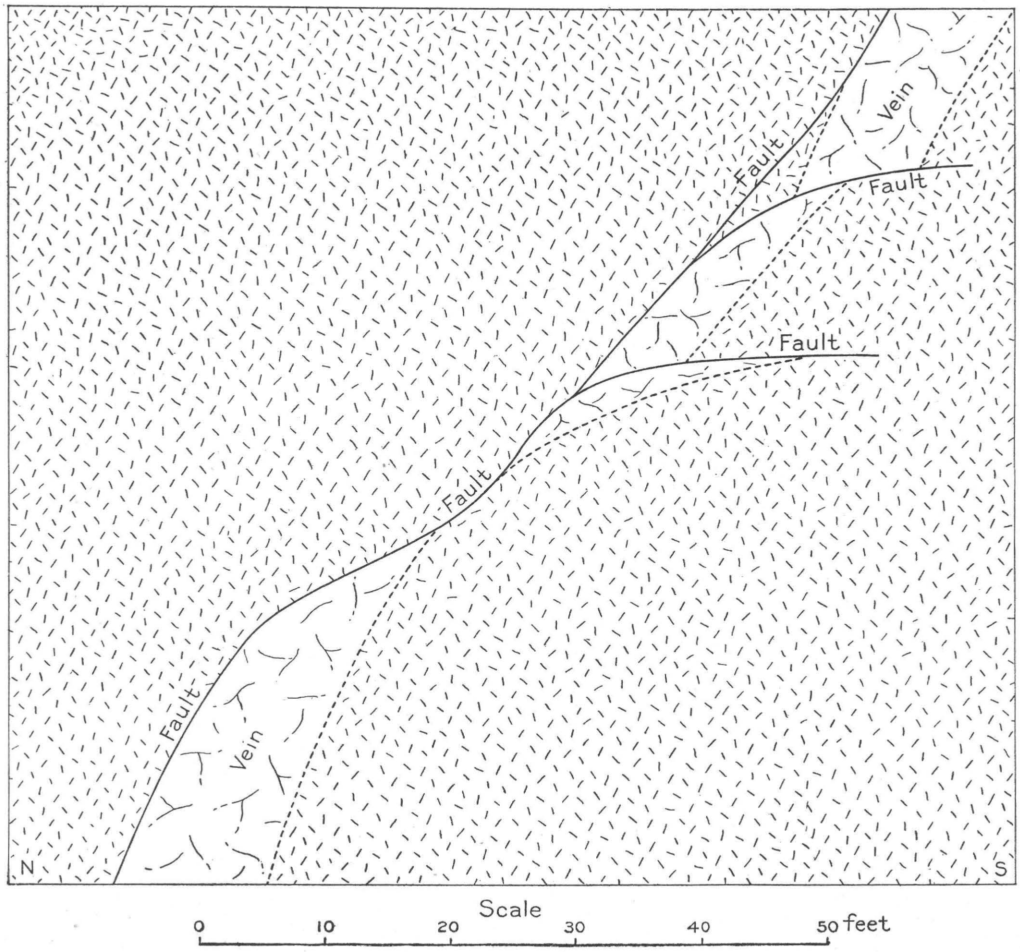


FIG. 65.—Vertical cross section (sketched), showing effect of curving and branching faults on Macdonald vein, in stopes above the 615-foot level on the Montana Tonopah.

TONOPAH RHYOLITE-DACITE IN THE MONTANA TONOPAH.

At a depth of 560 feet the Montana Tonopah shaft passed downward from the ordinary earlier andesite which contains the veins to a dense rock, which proves to be the glassy Tonopah rhyolite-dacite.

The same rock was encountered at the bottom of a winze, 20 feet below the west drift on the 512-foot level, where it seems to cut off the Montana vein. It

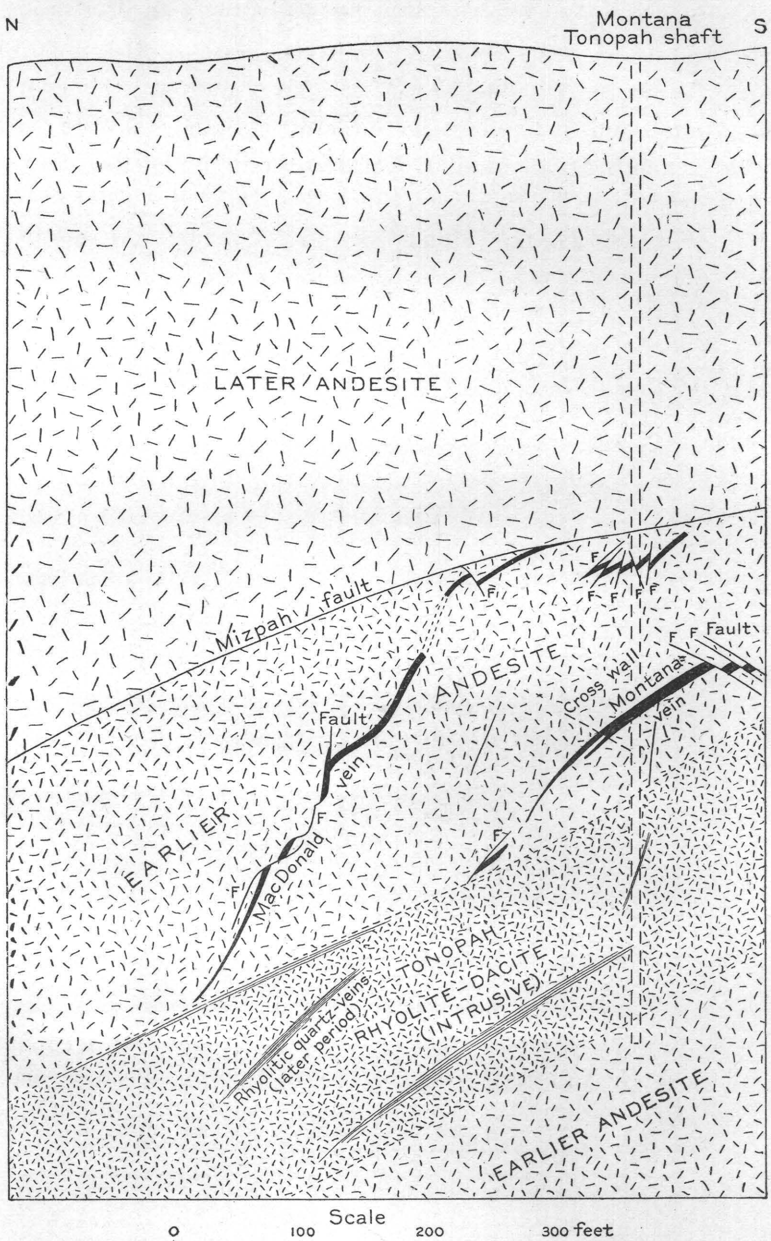


FIG. 66.—Cross section showing geology exposed by Montana Tonopah workings.

is also found on the 615- and 765-foot levels (fig. 66). As is usual in this formation irregular and bunchy quartz veins are encountered, which sometimes yield good assays, especially in gold; but no pay ore has yet been found.

NORTH STAR WORKINGS.

SECTION PASSED THROUGH.

The North Star shaft was started in white rhyolite on the slope of Mount Oddie (fig. 67). Below the rhyolite comes the later andesite, the contact being practically horizontal and indicating the later age of the rhyolite. From this contact down to a depth of about 720 feet the shaft is in the later andesite, largely soft and decomposed. It is sometimes brecciated, indicating considerable movement, and in places contains much secondary pyrite. At depths of about

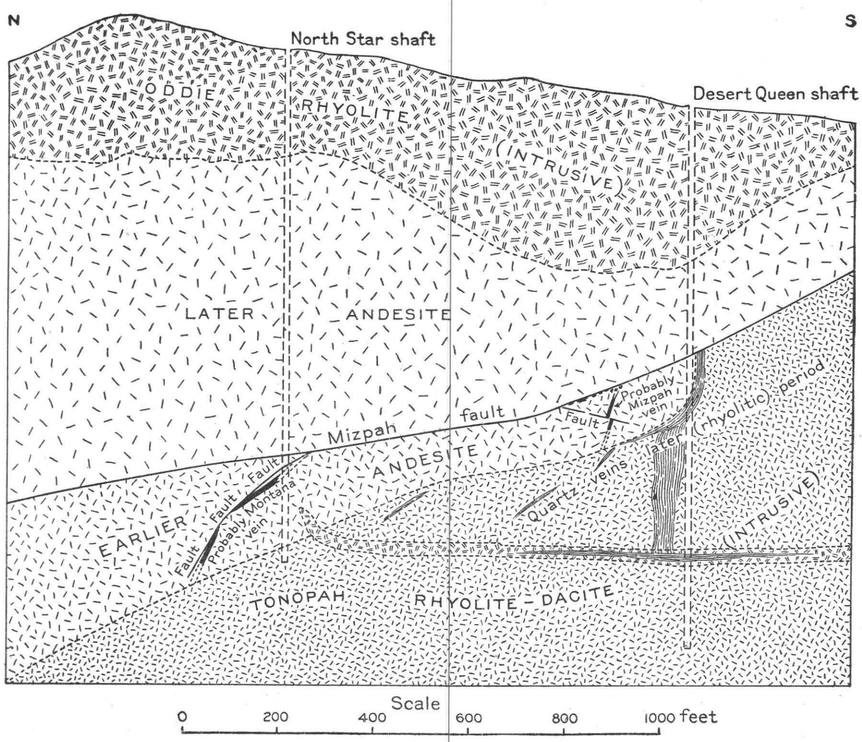


FIG. 67.—Section on plane of Desert Queen and North Star shafts.

720 to 740 feet the shaft cuts the zone of the Mizpah fault, which is characterized by 20 feet or more of clay, formed by trituration and decomposition along the fault. Beneath the fault the earlier andesite comes in.

Just above the bottom of the shaft, which is 1,050 feet deep, the Tonopah rhyolite-dacite comes in. It is the same sheet which is encountered on the 814-foot level of the Desert Queen.

The developments in the North Star consist of two drifts, at 950 and 1,050 feet. The lower one of these levels is the more extensive, having a drift to the north of over 500 feet. On the 950-foot level and on the north drift of the 1,050-foot level the rock is andesite, probably earlier andesite, largely altered to chlorite and calcite, like that below the Siebert fault in the Mizpah shaft. The station at the 1,050-foot level and a drift running southeastward from the shaft for over 200 feet are mainly in the Tonopah rhyolite-dacite. This rock is much silicified and is in places cherty quartz. At the shaft and on the walls of the drift in this formation there has formed, since the opening of the mine, a green coating. This was determined by Dr. W. T. Schaller, of the United States Geological Survey, to be a basic copper sulphate, insoluble in water. The cherty quartz on which this incrustation forms contains only traces of gold and silver. Since the mine is perfectly dry the formation of this copper sulphate on the walls is interesting. A similar incrustation forms on the quartz of the rhyolitic veins on the 840-foot level of the Desert Queen. It seems, so far as observed, to be a phenomenon peculiar to the quartz of the Tonopah rhyolite-dacite and to have no connection with gold and silver values.

On the 1,050-foot level in the earlier andesite a phenomenon was noted which was not observed elsewhere in the camp. This is the intrusion of one body of earlier andesite by another body of the same rock. The intrusive rock is finer grained than the rock which it cut, and near the margin showed flow structure. The coarser intruded rock is of the biotite-bearing variety, while the intrusive rock is of very similar composition and is very typical earlier andesite. This occurrence is analogous to the finding in the Tonopah City shaft of dikes of Heller dacite intrusive into a body of the same rock, and signifies successive injections of the earlier andesite, which may very well be of slightly different types as regards composition.

VEINS.

On the 950-foot level, north of the shaft, a vein of quartz several feet thick was cut in the earlier andesite. This has a general west-northwest strike and a northerly dip of 45° or 50°. This vein was cut also in the 1,050-foot level and is developed by an incline between the two levels. Some ore has been shipped from it, having the same characteristics as the ore of the Montana Tonopah; it contains polybasite, ruby silver, etc., in a white quartz gangue. This is very likely the same as the Montana vein of the Montana Tonopah.

FAULTING.

It has not been possible to follow this vein very far along the strike or dip in any one place on account of faulting, which follows the vein very nearly in strike and dip but curves and becomes oblique to it. On the 950-foot level this fault has a strike which is more northerly than that of the vein, and so has cut out most of the vein, leaving only a wedge. On this level the fault is below the vein, but in following the incline down to the level below, it is found to pass through the vein and to go into the hanging wall, as shown in fig. 67.

MIDWAY WORKINGS.

The Midway lies a short distance northwest of the Siebert shaft, and almost in line with and halfway between the Montana Tonopah and the Tonopah Extension.

LATER ANDESITE IN SHAFT.

The surface at this point is composed of the typical later andesite. A specimen taken a short distance from the Midway shaft has the characteristic relatively fresh appearance, dark color, and large feldspars of this rock. Under the microscope it is also typical, showing numerous phenocrysts crowded together, these phenocrysts being mainly feldspars, often large and compound, with pseudomorphs of serpentine after pyroxene.

The contact of this rock with the underlying earlier andesite is an obscure one. This is a condition similar to that noted in other workings, such as the West End and MacNamara, where, as described, the contact between the two andesites could not be located in the shafts.

TYPICAL EARLIER ANDESITE IN SHAFT.

In the case of the Midway, as shown in the section (fig. 68), the contact has been perhaps rather arbitrarily drawn at a depth of about 425 feet. From this point to a point just below 475 feet in the shaft the formation is regarded as probably all typical earlier andesite.

GLASSY TONOPAH RHYOLITE-DACITE IN SHAFT.

At a point in the shaft below 475 feet there is a change in the formation, and the rock is quite uniform and of the same hard, siliceous nature and light-green color as that at the main level of the Ohio Tonopah.

This rock contains jaspery quartz veinlets and fine quartz lines some of the cavities left by the removal of pyrite and other crystals.

FORMATIONS EXPOSED BY DRIFTING.

The workings of the Midway consist of two levels at depths of 535 and 635 feet, the former having a north drift over 400 feet long and a south drift about 150 feet long, while the latter has a north drift nearly 700 feet long and a south drift of about 150 feet. The formation in the upper level is entirely Tonopah rhyolite-dacite, except at the end of the north drift, which passes through the same contact as that encountered in the shaft and enters the earlier andesite. The shaft passes downward through the body of rhyolite-dacite and enters earlier andesite beneath it, of a type like that found on the 700-foot level of the Siebert shaft. Similar andesite is encountered on the south drift of the 635-foot level, while the whole of the north drift on this level lies in the rhyolite-dacite.

VEINS IN THE MIDWAY.

There are veinlets of calcite in the later andesite and these very often contain pyrite. In the shaft at a depth of about 430 feet there are quartz stringers containing pyrite. At a depth of 435 feet there is a short northwest drift, showing a vein of black, jaspery quartz, which is barren and irregular.

A fragment of a vein was cut at 475 feet in the shaft. The vein was largely barren but contained a rich bunch or shoot of original sulphide ore. This ore,

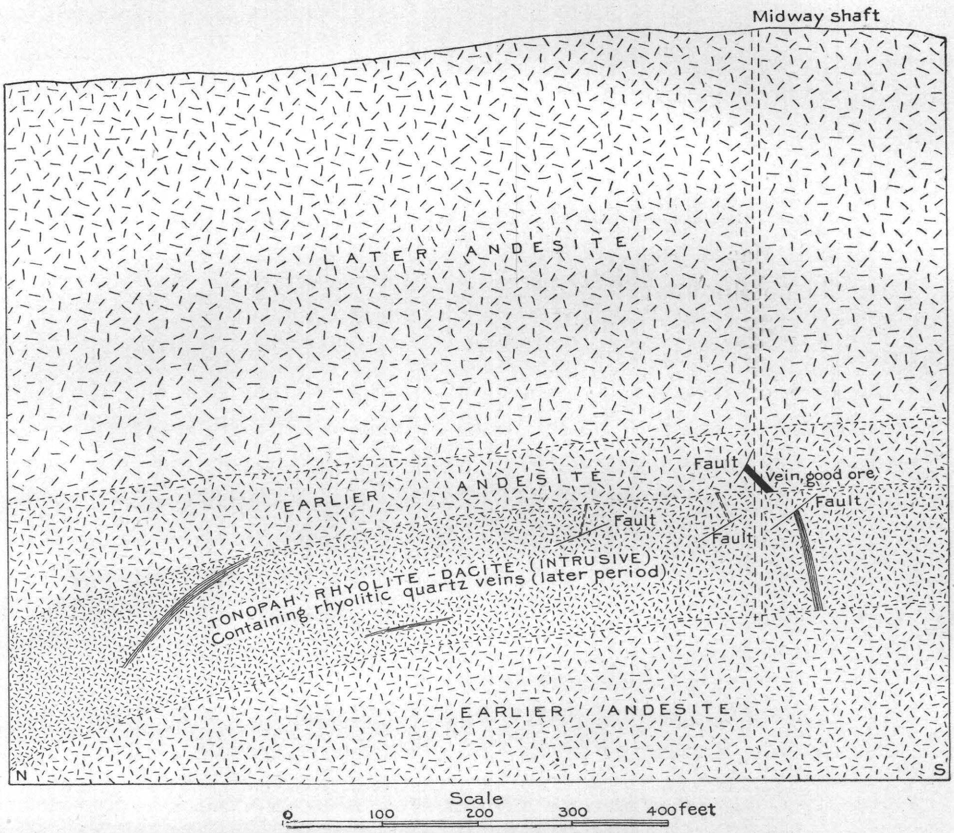


FIG. 68.—Section showing geology exposed by Midway workings.

when examined microscopically, shows the typical structure of the productive earlier andesite veins. The quartz has the usual varied grain, ranging from microcrystalline to medium crystalline. There is scattered pyrite seeming to have no relation to the values, which consist of black silver sulphide and silver chloride, both of which are relatively abundant. The relation between these two is remarkable, for the black sulphide forms rims around the chloride and in some cases is found along cracks, showing that it was formed later than the chloride and is very probably an alteration product of it. There is occasionally a little ruby silver, having the same relation to the chloride as does the sulphide. This black sulphide may be either argentite or stephanite.

This quartz vein is much broken, so that the general strike and dip could not be determined. It may very well be the extension of one of the veins developed in the Montana Tonopah.[a]

As usual in other parts of the camp, the Tonopah rhyolite-dacite in the Midway contains a number of quartz veins which, however, are irregular, nonpersistent, and faulted, and are usually barren. The most important vein of this class was encountered on the 535-foot level, a short distance south of the shaft. This shows several feet of quartz, striking in a west-northwest direction and having a steep dip. On the southeast this vein becomes irregular and passes into barren, cherty quartz, which in turn disappears, turning to silicified rhyolite-dacite. Most of the vein is barren, but at one point 400 tons of ore, having a value of $30 to the ton, were taken out and milled. A winze follows this vein to the lower contact of the rhyolite-dacite with the earlier andesite, a short distance above the 635-foot level. The silicification and the vein, however, cease at the rhyolite-dacite contact and do not enter the earlier andesite, into which the rhyolite-dacite is intrusive.

A second vein, having an east-west course, was encountered about 50 feet north of the shaft on the 535-foot level. It dips about 65° to the south and is terminated on the east by a fault, so far as explored. It is about 2 feet in thickness and contains a little good ore, of which a few tons have been shipped; the rest of the vein is barren. About 150 feet north of this last-named vein, on the same level, there is another 2-foot vein of white barren quartz, which has a west-southwest strike and a northerly dip of 80°. This contains no ore, but only white, barren quartz, although assays of from $20 to $30 can be had.

That these veins are nonpersistent is shown not only by the developments upon this level, but by the fact that they are not found in the same formation on the 635-foot level 100 feet below. Although this level runs through 650 feet of rhyolite-dacite it encounters no strong and definite veins.

TONOPAH EXTENSION MINE.

CONTACT OF EARLIER AND LATER ANDESITES.

The Tonopah Extension shaft starts in the later andesite and extends down about 183 feet to the contact of the earlier andesite (see fig. 71). This contact is marked by 1 to 2 feet of soft, decomposed rock, and is very flat. Below it the earlier andesite is very full of quartz veinlets. This phase of the earlier andesite resembles in many places some of the phases of the later andesite, although just below

[a] Since the writer's visit more ore has been found in the Midway, in a drift at about this level.

the contact above referred to it is fairly typical. The contact is probably not due to faulting, but is normal and indicates that the veins in the earlier andesite outcropped at the surface at the time of the later andesite extrusion.

VEINS IN THE EARLIER ANDESITE.

At a depth of 230 feet, in the earlier andesite, a heavy vein was cut near the shaft. This has been developed by levels at depths of 244 and 385 feet, and by an incline between the levels. The general strike of the vein is west-northwest and the dip north from 30° to 45°. The vein is from 3 to 8 feet thick and shows shoots of high-grade sulphide ore like that of the Montana Tonopah. So far as had been developed at the time of the writer's visit, in November, 1904, the vein has not been faulted.

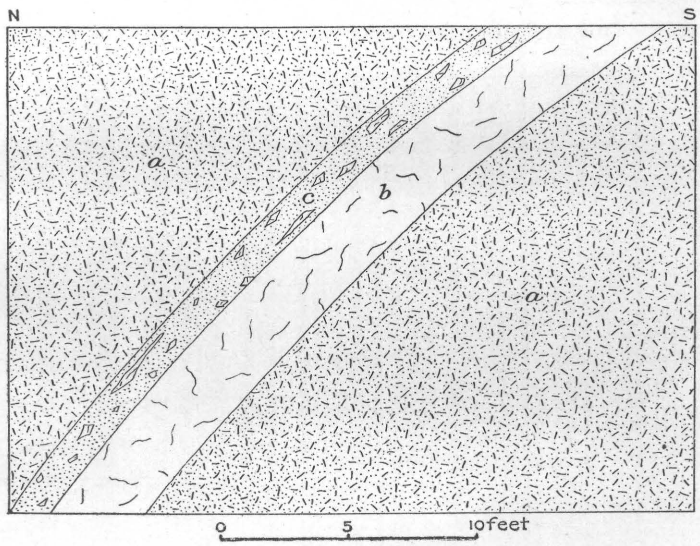


FIG. 69.—Diagrammatic vertical cross section of Tonopah Extension vein. *a*, Altered earlier andesite, wall rock; *b*, typical white vein of earlier andesite period, containing black silver sulphides, with values of several hundred dollars per ton; *c*, black, jaspery quartz of later introduction than original vein, of which it contains fragments. Values of black quartz and fragments, $20 to $30 per ton.

An interesting phenomenon is displayed by the Tonopah Extension vein. Whereever it has been followed, a portion of the vein, generally that lying next to the hanging wall, is of different character from the rest. The main body is composed of white quartz containing black silver sulphides, and has exactly the same character as the other earlier andesite veins in the camp. The upper portion, however, is of black or gray jaspery quartz, like so many of the veins in the Tonopah rhyolite-dacite. Moreover, this portion contains angular fragments of the ordinary quartz vein in such a way as to show conclusively that the jaspery quartz was of later introduction than the main vein. Evidently renewed pressure reopened the vein subsequent to the first ore deposition, and caused a new fracture or fissure, following in general the old hanging wall. Along this opening waters have circulated and deposited jaspery quartz, cementing the broken fragments of the old vein. On the 244-foot level the thickness of the jaspery subsequent quartz is about 1½ feet, while that of the typical antecedent quartz is about 3 feet. At the place where the sketch (fig. 69) was made, the lower part has a value of about $600, while the jaspery quartz has values of from $30 to $35. Moreover, it is probable that these last-named values are in large part derived from included fragments of the true vein, and also from the ruby silver which is sometimes found in cracks in the jaspery quartz as well as in the true vein, this ruby silver being a secondary mineral derived from the primary ore.

The general character of this subsequent vein filling renders it highly probable that this vein is of the same nature and period as the veins in the Tonopah rhyolite-dacite. While the main vein was formed after the eruption of the earlier

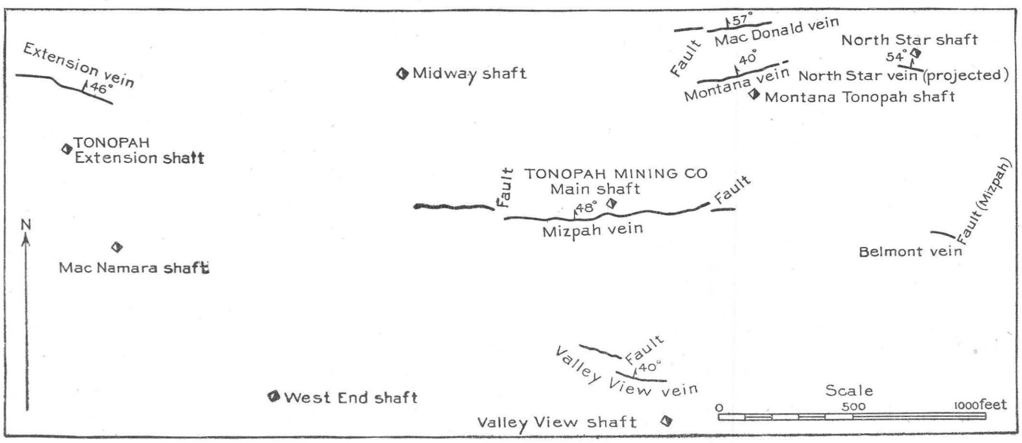


FIG. 70.—Map showing principal earlier andesite veins now developed undergound, within the main productive area: shown on the horizontal plane of the Mizpah 500-foot level.

andesite, the subsequent filling took place after the eruption of the rhyolite-dacite. This main vein in the Tonopah Extension is probably identical with one of the veins in the Mizpah or the Montana Tonopah. Very possibly it is the same as the Montana vein, but this can not be definitely proved as yet.

VEINS IN THE TONOPAH RHYOLITE-DACITE.

The above conclusions as to subsequent filling are strengthened by certain other occurrences in this same mine. On the 385-foot level a south drift from the shaft cut the upper contact of a flat-lying north-dipping body of Tonopah rhyolite-dacite. In this last-named rock, near the contact with the earlier andesite, there is a great deal of silicification, amounting often to the formation of bodies of pure jaspery quartz, of very irregular size and extent, and practically barren for the most part. The main shaft passes through this contact between the 385-foot level and the bottom, which is at a depth of 485 feet, and from the bottom a north drift runs out about 100 feet to the contact again. The heavy silicification resulting in the formation of jaspery barren quartz, especially near the contact, is shown also on this level.

This contact was followed upward from the 385-foot level by means of an incline for some distance, and showed more or less of the same rhyolitic quartz. The dip of this silicified contact is less than that of the Tonopah Extension vein in the earlier andesite, so that very likely these may come together at a greater depth, in which case the barren jaspery portion of the Tonopah Extension vein will unite with the similar quartz in the rhyolite-dacite, with which it has undoubtedly a common origin. In this eventuality, however, the productive portion of the Tonopah Extension vein may be cut off.

The relative position of the Tonopah Extension vein in regard to that of other known veins of similar character is shown in fig. 70.

OTHER EXPLORATORY WORKINGS WHOLLY OR PARTLY IN EARLIER ANDESITE.

WEST END WORKINGS.

OUTCROP OF WEST END FAULT.

As the map (Pl. XVI) shows, the West End shaft is near the contact of the Fraction dacite breccia on the southwest and the later andesite on the northeast. This contact follows a straight line, and was judged, from a study of the surface only, to be due to faulting. By projecting the known outcrops of the Gold Hill and the Wandering Boy faults it is seen that they would normally come together in the vicinity of the West End shaft. Here they probably unite to form a fault which is a direct continuation of the Gold Hill fault, and which is thought to have been recognized farther on, in the line separating the later andesite from the Fraction dacite breccia, in the vicinity of the MacNamara shaft. This united fault may be called the West End fault. In general this fault appears to be downthrown on the southwest, for the Fraction dacite breccia on this side is younger than the later andesite on the northeast. Moreover, both the Gold Hill and the Wandering Boy faults are downthrown on the southwest side.

RHYOLITE INTRUSION ALONG FAULT.

Near the West End shaft are seen rugged outcrops of dark-weathering rhyolite, which belong to a dike or neck of rhyolite that has ascended along the fault plane. Where encountered in the mine workings this rhyolite is white, and of the same type as the rhyolite of Mount Oddie, and is probably of the same age and origin.

The West End shaft when last visited by the writer was 780 feet deep. The soft Fraction dacite, which forms the block on the southwest side of the fault, is first encountered in the shaft, but at a depth of about 20 feet the Oddie rhyolite comes in. The contact of dacite and rhyolite strikes N. 35° to 55° W., or roughly parallel with the West End fault, and the dip is southwest at an angle of about 65°, suggesting that the fault also dips in this direction and is therefore normal. The contact is partly tight and partly separated by several feet of breccia, containing fragments of rhyolite and of later andesite, with the soft materials of the more fragile dacite. The rhyolite contact comes in on the north side of the shaft and continues straight down to a depth of about 62 feet, where it passes out on the south side. The general dip of the rhyolite dike is therefore to the south. At one or two places the rhyolite is evidently intrusive into the dacite. The shaft passes downward through the upper contact of the rhyolite with the breccia and traverses solid rhyolite for a short distance, showing that here the thickness of the dike or neck is about 20 feet. On the under contact of the rhyolite, at a depth of 84 feet, is green altered andesite, which has been referred to the later andesite. At this contact also there is a slight breccia.

The above phenomena are interpreted as indicating that the rhyolite ascended along a fault plane, which in the upper part of the shaft separates the Fraction dacite from the later andesite. The intrusion of this rhyolite caused some brecciation of the rigid intruded rocks near the contact, and it is possible that some subsequent slipping along the fault may have slightly brecciated the rhyolite itself. As a rule, however, it has been ascertained that rhyolite of this sort is younger than the faults and is little or not at all affected by them.

At a depth of 116 feet there is a zone of great movement and probable faulting, in which the chief slips strike N. 10° W. and dip west at an angle of 25°. This suggests a northwesterly faulting.

CHARACTER OF ANDESITE ABOVE 220-FOOT LEVEL.

Below the lower rhyolite contact, at a depth of 84 feet, the shaft is in andesite for some distance. All this andesite is extremely decomposed in consequence of the proximity of faulting, and is therefore difficult to study. Below a distance of perhaps 100 feet from the surface the character of the andesite has occasioned much perplexity in the mind of the writer. The earlier and the later andesites are so closely related that many times they have almost identical characteristics, and it is difficult or impossible to discriminate them in the hand specimen or under the microscope. A specimen taken in the shaft, at a depth of 116 feet, was judged to have the characteristics of the later andesite rather than of the earlier andesite. Another specimen taken in the shaft, at a depth of 196 feet, was supposed to represent the same rock, for no sharp division had been noted, but was judged, after microscopic study, to have rather the characteristics of the earlier andesite. This specimen was altered to quartz, sericite, and pyrite.

CHARACTER OF ANDESITE ON 220-FOOT LEVEL.

At a depth of 220 feet from the surface, drifts were run 338 feet to the north of the shaft and 285 feet to the south. In both these drifts only andesite was encountered and no general distinction was noted between the andesite in the different parts of the drifts. In both drifts the rock strongly resembles certain phases of the earlier andesite; in the south drift perhaps more than in the north. This resemblance also holds good on microscopic study. Some sections of the rock in the north drift showed occasional original phenocrysts of quartz, such as are occasionally found in the earlier andesite. This original quartz was found also in the specimen obtained in the shaft at a depth of 196 feet. On both these drifts there was evidence of considerable movement, the general strike of the slip or fracture planes being north and south and the dip west rather steeply. The andesite when examined microscopically was found to be highly altered, the chief alteration products being quartz, calcite, chlorite, serpentine, pyrite, siderite, kaolin, and adularia.

CORRELATION OF ANDESITES IN WEST END AND FRACTION WORKINGS.

After studying the delicate question as to whether this rock is the earlier or the later andesite the writer has satisfied himself that the andesite of the south drift in the West End is identical with that shown in the long north drift from the 400-foot level of the Fraction No. 2 shaft. The faces of the two drifts are only about 250 feet apart in a straight line, but there may be, and very likely is, intervening faulting. The writer was not able to distinguish between the general type of the andesite in this north drift of the Fraction and the typical Fraction andesite, which is often relatively dark and chloritic. In the Fraction No. 1 workings the andesite contains a large vein, carrying in places at least good values.

EXTENSION OF CORRELATION TO THE WANDERING BOY AND GOLD HILL.

It seems to the writer, moreover, that the andesite in the Fraction No. 1 is identical with that in the Wandering Boy, which is more nearly the Mizpah Hill type of earlier andesite. On following the chain still farther, the andesite in the Fraction and that in the Wandering Boy seem to be identical and are probably in the same fault block as the Gold Hill andesite. The rock of Gold Hill has certain peculiarities which at one time caused the writer to study for some time the question carefully as to whether or not it belonged to the earlier or later andesite, thus bringing up again the question of the exact age, which has just been raised with respect to what is probably the corresponding rock in the West End. It was found, however, that the peculiarities which suggested the correlation of the Gold Hill andesite with the later andesite, namely, the frequently large-sized feldspars and the presence of biotite, could be paralleled in specimens found in Mizpah Hill, even in the workings of the Mizpah mine, and again in the Montana Tonopah, where there was no question as to the andesite being other than the earlier andesite.

Moreover, in Gold Hill this andesite incloses veins having all the characteristics of the veins found in Mizpah Hill, such as have not been found in the undoubted later andesite. Therefore the evidence decidedly favors the conclusion that the Gold Hill rock is the earlier andesite. If it is true, as has been concluded, that the veins of the Wandering Boy and the Fraction were originally a part of the Valley View system and that they were displaced by faulting, the evidence grows still stronger.

THE WEST END ANDESITE PROBABLY EARLIER ANDESITE.

The writer is forced to the conclusion that the andesite exposed on the 200-foot level of the West End belongs to the earlier andesite.

CONTACT BETWEEN EARLIER AND LATER ANDESITES.

PLACE AND CHARACTER OF CONTACT.

The conclusion that the rock on the 220-foot level is the earlier andesite having been reached, the question comes up as to the line of demarcation between the earlier andesite below and the later andesite above. Since the West End fault probably dips southwestward and is normal, the shaft, after passing through the fault and leaving the rhyolite, is in the block lying northeast of the fault, which may be called the Midway block. This block is characterized at the surface everywhere by undoubted later andesite. It is, then, likely that the contact between the later andesite and the earlier andesite occurs in the West End shaft somewhere above 196 feet, and from considerations given it may be assumed, temporarily at least, that it lies between 116 and 196 feet (see p. 185).

This assumption is rendered somewhat doubtful by the fact that no contact was observed, but, on the other hand, the rock is thoroughly decomposed and much disturbed by faulting, so that the presence of a contact would be obscured.

NATURE OF SIMILAR CONTACTS ELSEWHERE.

At another point where the writer has seen the contact between the overlying later andesite and underlying earlier andesite, in the same fault block, at the Tonopah Extension, the contact is by no means striking, and could not be distinguished if the rock was much decomposed or faulted. In the Tonopah Extension this contact is at a depth of about 184 feet from the surface and is nearly flat.

Similarly in the Midway mine, which is very likely in the same block, the contact between the overlying later andesite and the underlying earlier andesite could not be definitely located, probably on account of the great decomposition of the rocks at this place.

The earlier andesite in the Tonopah Extension, moreover, partakes very largely of the characteristics of the Fraction andesite, and in many cases resembles somewhat the later andesite, but is elsewhere quite typical, and contains strong veins, which show in places high values and evidently belong to the earlier andesite series of veins, so that there can be no doubt as to its identity.

TONOPAH RHYOLITE-DACITE.

Andesite similar to that on the 200-foot level continues down in the shaft to 390 feet, at which point a slight breccia is encountered, striking N. 70° E. and dipping northwest at an angle of 45°. Below this a quartz vein is encountered, with highly silicified Tonopah rhyolite-dacite as its walls.

On the 500-foot level drifts run north and south about 300 feet in all. There are also crosscuts. The whole is entirely in rhyolite-dacite. The rock is intensely silicified, being in places nearly solid quartz, and contains pyrite throughout, but there are no definite veins. This quartz is barren, although assays of $1 or $2 have been obtained in places. The rock is characteristically intensely fractured, and in places contains open fissures running in a direction somewhat east of north. These fissures when cut contain the heavy gas elsewhere referred to as being probably carbonic acid (see p. 94). The probable explanation is that the gas was formed in the overlying soft andesite by the reaction of acids upon the contained calcite, and by its weight sank into the fissures in the underlying rigid rhyolite-dacite and there accumulated.

EARLIER ANDESITE AT BOTTOM OF SHAFT.

At a depth of about 680 feet in the shaft there is a sharp contact between the rhyolite-dacite above and a fine-grained green variety of earlier andesite below. This contact is said to dip east at an angle of about 40°. The bottom of the shaft is at a depth of 780 feet, and specimens taken from here and from below the contact show earlier andesite of a type very much like that on the 700-foot level of the Siebert shaft.

MACNAMARA WORKINGS.

LATER ANDESITE AT SURFACE.

The MacNamara shaft is situated a short distance northwest of the West End, and probably in the same fault block. The geology partakes of the same perplexing character as that described in the West End (see p. 184). The shaft was first sunk to a depth of 200 feet, from which point drifts were run 50 feet to the north and about 300 feet to the south. The rock in which the shaft started and which outcrops in the vicinity is undoubted later andesite, such as covers the whole surface of this fault block.

CHARACTER OF ANDESITE ON 200-FOOT LEVEL.

The rock encountered on the 200-foot level differs in character very slightly from that at the surface, except that the latter has the purplish color due to partial oxidation, while the former has a green color characteristic of andesite, containing a large proportion of chlorite as a result of subterranean alteration processes. Also the andesite at the surface is decidedly fresher than that on the 200-foot level, where it is always highly altered.

CORRELATION OF MACNAMARA AND WEST END ANDESITES.

There would, however, be hardly sufficient reason for dividing the upper and the lower andesite were it not that study and comparison make it seem clear that the rock on the 200-foot level is practically identical in characteristics with that on the 220-foot level of the West End, which the writer, for reasons previously given, is obliged to believe to be a phase of the earlier andesite rather than of the later andesite.

The MacNamara rock can be matched almost exactly with specimens of the West End rock. When studied under the microscope it is found to be altered largely to chlorite and calcite, with pyrite, quartz, siderite, and sericite. If it is the earlier andesite, therefore, it belongs to that phase which has altered to calcite and chlorite rather than to that which has altered to quartz and muscovite, such as the phase found on the 700-foot level of the Siebert shaft and below, which is believed by the writer to have been formed usually at some distance from the mineral-bearing veins rather than in their immediate proximity.

This rock contains calcite blotches and veinlets, and occasional stringers of mixed quartz and calcite, one of which, it is claimed, afforded assays showing a value of $2.

CONTACT OF EARLIER AND LATER ANDESITES.

Since it therefore seems necessary to distinguish between the andesite near the surface and that on the 200-foot level, the question as to the line of contact comes up. According to the conclusions arrived at this must exist, although it is very difficult to distinguish it. From a study of the rock in the shaft and from specimens taken there, the approximate boundary line has been placed at a point 125 feet from the surface, where a change of formation was recognized by the miners in sinking. This also would correspond fairly well with the conclusions in respect to the West End, where the contact was placed between 116 and 196 feet from the surface, and with that in the Tonopah Extension, where it has been placed at 184 feet from the surface.

TONOPAH RHYOLITE-DACITE AND INCLUDED VEINS.

At a depth of 285 feet a light-colored altered rock (Tonopah rhyolite-dacite) was struck beneath the green andesite. At the contact, which strikes east and west and dips north at an angle of 45°, was a heavy zone of ground-up material. The rock immediately beneath this breccia contained a barren quartz ledge, about 16 feet thick, striking and dipping nearly parallel with the contact, while beneath this were numerous quartz stringers. This rhyolite-dacite proves on examination to be entirely altered, chiefly to quartz and sericite, with probable kaolin. Original phenocrysts consisted of small and rather sparse crystals of feldspar and biotite, and in one case a small crystal of quartz. This rock is the same as that which was found in the lower part of the neighboring West End shaft.

Besides the level at a depth of 200 feet, already described, there are levels at depths of 355 and 500 feet. At the 355-foot level a drift runs a short distance northwest of the shaft and encounters a heavy but irregular quartz vein, having a general east-northeast strike, and a moderate northwest dip. This vein, as shown in the section (fig. 71), lies very nearly parallel with the upper contact of the rhyolite-dacite and the earlier andesite, a short distance above. It consists of white quartz, and also of gray and black jaspery quartz. It is in general barren, but in places small assays have been obtained. It is cut by several faults, of which the chief ones strike northeast and dip steeply southeast. The effect of these seems to be in general to cause a movement as if the vein had been thrown down on the southeast side. One of these faults, marked by a heavy drag of quartz and rock breccia, has been followed by a drift for a few hundred feet to the southwest. Near the end of the drift the fault splits and both forks have been followed a short distance. In one of these branch drifts a small bunch of ore, carrying very good values, is reported to have been found. Specimens of this ore, shown to the writer, were composed of white quartz containing argentite, ruby silver, polybasite, or stephanite. This occurrence of bunches of high-grade ore, probably belonging to veins of the later rhyolite-dacite period, is similar to that of ore in veins of the same period in the Desert Queen.

At the 500-foot level, which is at the bottom of the shaft, the formation is all rhyolite-dacite. It has been explored for a short distance north, south, and west by drifts. No bodies of quartz of any importance were found, although a drift along a northeast fault plane shows a breccia partly cemented by jaspery quartz.

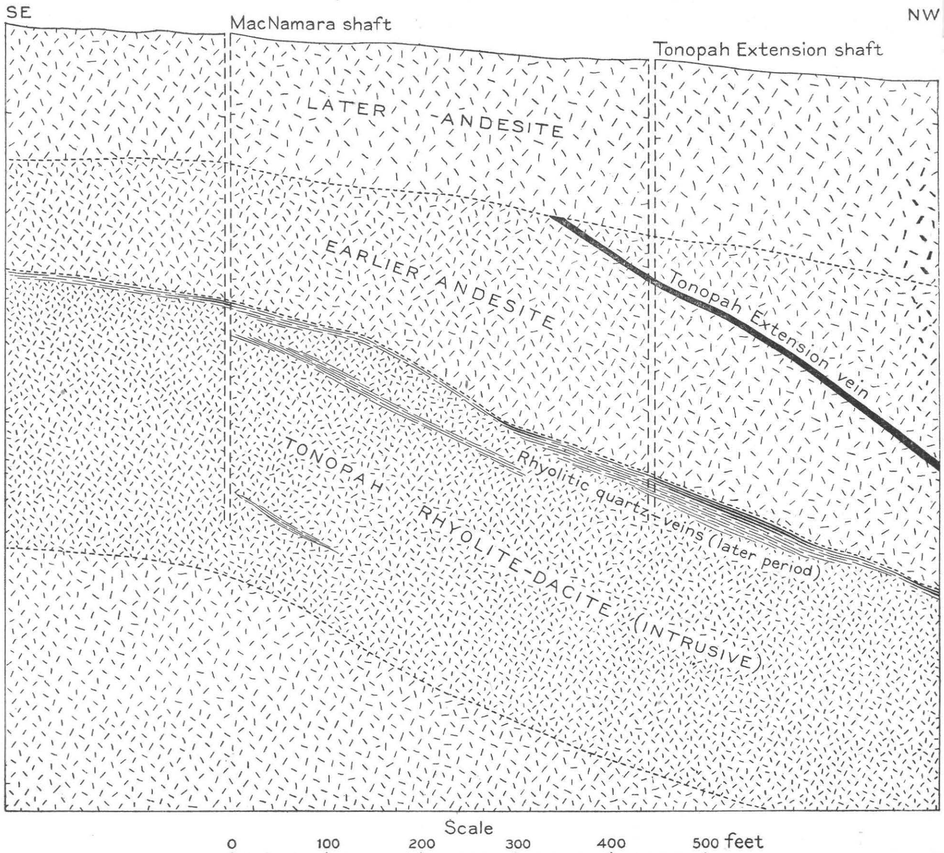


FIG. 71.—Vertical section through MacNamara and Tonopah Extension shafts.

EXPLORATIONS ON VEINS AT THE CONTACT OF THE ODDIE RHYOLITE.

WINGFIELD TUNNEL.

The Wingfield tunnel is situated on the southwest slope of Ararat Mountain. It starts in later andesite near the contact of this rock with the Oddie rhyolite, which forms the summit of the mountain, and passes from the later andesite across the contact into the rhyolite. It is 160 feet long and runs N. 60° E. At the breast of the tunnel the rock is very much shattered Oddie rhyolite containing openings filled with brown iron-lime carbonate and white calcite. From this point to the contact with the later andesite the rock is mostly a dense rhyolite breccia of volcanic origin, the fragments being of very large size. Strong open fractures striking N. 25° W. and dipping east at an angle of 60° are lined with white and brown carbonates, oxidized in places to iron oxide and manganese oxide. Throughout the breccia, filling all the interspaces, are veinlets, filled chiefly with ferriferous carbonate and to a less degree with calcite and chalcedony. Veins of smooth brown or bluish jasper, indicating silicification of the rhyolite, have the same course and the whole breccia is largely silicified. Some of this material is claimed to run $8 or $9 to the ton, the values being all in gold.

The contact of the andesite with the rhyolite is 70 feet from the mouth of the tunnel, and strikes N. 35° W. and dips east at an angle of 50°. The rhyolite is plainly intrusive. The brecciation, fracturing, and silicification of the rhyolite increase in measure as the contact is approached. Near the mouth of the tunnel two dikes of rhyolite breccia, one 6 inches thick and one 3 feet thick, lie in the andesite. These are in general parallel to the main contact, but dip 50° in an opposite direction. The fracturing and brecciation are confined to the rhyolite, and are not notable in the later andesite, which, however, is highly decomposed and crumbling, while the rhyolite is hard.

The evident interpretation of these phenomena is that this rhyolite column was intruded into the andesite and that the upward movement continued after the beginning of cooling. The result of this upward impulse was that the cooler rhyolite for a zone of nearly 100 feet thick near the contact was intensely brecciated while in a semisolid state. The upward pressure continued even after further cooling, causing open fractures, mostly parallel to the contact, but sometimes cutting across the rhyolite, as has been described elsewhere (p. 101). Along these open fractures ascending hot waters, whose advent followed the eruption, deposited iron and lime carbonates, silica, some manganese, and probably some gold.

BOSTON TONOPAH SHAFT.

The Boston Tonopah shaft lies 200 or 300 feet south of the Wingfield tunnel, farther down the slope. At the time of the writer's visit it was 300 feet deep, 230 feet in the later andesite and the last 70 feet in white rhyolite like that constituting the central plug. The contact between the andesite and the rhyolite in the shaft, according to Mr. McCambridge, the superintendent, pitches northwest.

MIRIAM SHAFT.

On the Miriam claim a shaft about 40 feet deep had been sunk at the time of the writer's visit. This shaft lies about 1,200 feet southeast of the Belle of Tonopah and is at the contact of rhyolite and later andesite. It cuts at the top 30 feet of brown decomposed later andesite and below this 10 feet of white rhyolite, which is intrusive into the andesite. The rhyolite is typical and shows abundant quartz and orthoclase phenocrysts with brown glassy groundmass. From some streaks along this contact assays in gold were obtained, with no silver.

DESERT QUEEN SHAFT.

At a depth of 920 feet the Desert Queen shaft passed into the Oddie rhyolite, the contact being flat. Twelve feet below this there was encountered a nearly flat quartz vein, which is parallel with the rhyolite contact and consists of white or red

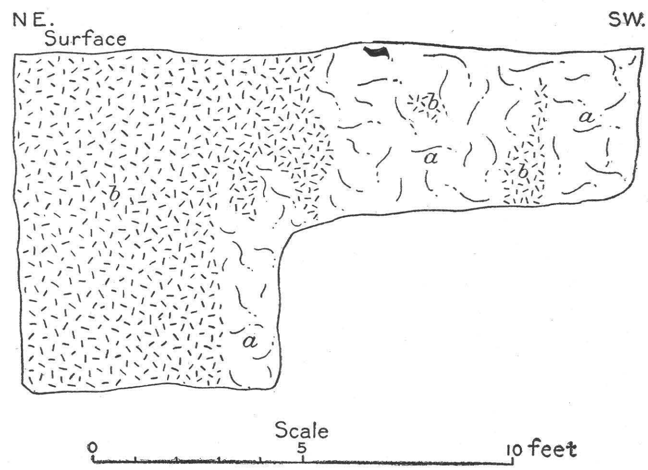


FIG. 72.—Vertical sketch section of shallow trench just north of Belmont shaft, showing contact of the Oddie rhyolite intrusion with the later andesite. *a*=Oddie rhyolite; *b*=later andesite.

quartz carrying some pyrite. This quartz was 7 feet thick and had as a foot wall the same body of rhyolite. The highest of several assays made showed 0.08 ounce gold and 2.12 ounces silver, with a little galena and traces of arsenic and copper. As this practically barren vein is within the Oddie rhyolite, it must be of later origin than the rich veins in the earlier andesite.[a]

SHAFTS AT THE UNMINERALIZED CONTACT OF THE ODDIE RHYOLITE.

BELMONT SHAFT.

The Belmont shaft (distinct from the Desert Queen shaft, which is also on the Belmont property) is situated on the north side of Rushton Hill. At the time of the writer's last visit, in July, 1903, the shaft was 340 feet deep, all in

[a] For the description of the geology of the rest of the Desert Queen shaft, see p. 125.

hard white rhyolite. It is located about 200 feet south of the contact of the rhyolite with the later andesite. This contact is exposed in a short trench and in a pit about 8 feet deep, and the rhyolite is seen to be intrusive into the andesite, with an approximately perpendicular contact (fig. 72). This, together with the depth of the Belmont shaft, indicates that it is being sunk in the Rushton Hill neck (which is a part of and is connected with the Mount Oddie neck) at a point where the contact is very steep.

RESCUE SHAFT.

The Rescue shaft is located south of Mount Oddie, about one-fourth of a mile southeast of the Desert Queen shaft. It is near the contact of the white rhyolite which makes up Mount Oddie and Rushton Hill with the later andesite. The contact is exposed at the surface, about 120 feet north of the shaft, and here has a general east-west strike and a southerly dip of from 45° to 60°. The contact is intrusive and there is some slight brecciation of the intrusive rock in the bends of the lobes which jut into the intruded rock, showing squeezing of the upflowing lava at these points.

The shaft, which starts in the later andesite, cuts the same contact as has been described in outcrop, at a depth of 60 feet. This contact pitches in the shaft about 45° to the south. From this point to a depth of 410 feet, which the shaft had attained at the time of the writer's visit in November, 1904, the rock was entirely white rhyolite of the Oddie Mountain type. From this it will be seen that the shaft is being sunk in the intrusive rhyolite neck.

Water has been encountered in this shaft (see p. 105).

EXPLORATIONS ON VEINS AT THE CONTACT OF THE TONOPAH RHYOLITE-DACITE.

MIZPAH EXTENSION SHAFT.

LATER ANDESITE AT TOP OF SHAFT.

The Mizpah Extension shaft is sunk in the hollow between the two white rhyolite intrusions of Mount Oddie and Ararat Mountain. The later andesite outcrops between these two intrusions, and on account of its relative softness has been worn away to form the depression separating the two hills. The shaft was started in this later andesite, and continued in it down to a depth of about 200 feet. The rock is of a general purplish color, with large white feldspars and biotite phenocrysts. At a depth of about 200 feet, however, a variety of this is fine grained, black, almost basaltic looking, and is fresher than the rest of the rock, which is sometimes considerably decomposed.

RHYOLITE AND RHYOLITE-DACITE IN SHAFT.

At a depth of 300 feet the andesite is in contact with an underlying typical white rhyolite, like that of Mount Oddie. This contact strikes about N. 60° W. and dips northeast at from 20° to 25°. Both andesite and rhyolite have been softened near the contact by circulating waters, so that their contact phenomena are not observable. At a depth of about 430 feet in the shaft the rhyolite comes in contact with a rock referred to the glassy Tonopah rhyolite-dacite. This contact strikes N. 30° W. and dips northeast at an angle of 40°, and is marked by about 14 feet of wet clay, decomposed and containing bowlders. Some water runs on top of this clay zone.

VEINS AT CONTACT OF TONOPAH RHYOLITE-DACITE.

Immediately below the contact, but in the Tonopah rhyolite-dacite, a large quartz vein comes in. This vein is several feet thick, and has the same attitude as the contact. Indeed, it appears to follow the contact, although it lies in the rhyolite-dacite. At a depth of 500 feet a drift was run for the purpose of developing this vein. The lower contact of the vein in the shaft (at 465 feet) has a strike of N. 70° W. and a northeast dip of 45°, but it is much flatter between this point and the point at which it was cut in the drift, where it has, however, the same general strike. In this drift, which runs in an irregular course for upward of 150 feet, the vein is displaced, not far from the shaft, by a vertical fault having a strike of N. 45° E. The displacement of this fault is not known, as the vein was not looked for on the southeast side. On the northeast side it was drifted on for some little distance, and continued strong. This vein is an ordinary quartz vein which is not very dissimilar in appearance from the average vein in the earlier andesite, but which contains a notably large amount of pyrite. It has locally a banded structure, which is probably due chiefly to replacement. Nevertheless, the vein is ordinarily nearly barren, the highest assay obtained having been about $12. The proportion of values differed from the ordinary Tonopah vein in that they were about 75 per cent gold and 25 per cent silver.

At a depth of 505 feet in the shaft another quartz vein was encountered, several feet thick, with characteristics like the one above. This vein has a strike of N. 55° W. and a dip of 55° to the northeast. A specimen of the wall rock taken immediately below this vein proved to be andesite, probably later andesite. Therefore this vein appears to occur on the under contact of the Tonopah rhyolite-dacite with the later andesite, while the first-mentioned vein occurs on the upper contact of the same rhyolite-dacite body.

This rhyolite-dacite is similar to that which outcrops to the north of Ararat Mountain, is like that discovered in depth in the Desert Queen and Siebert shafts, and is very similar to some of the rock at Gold Mountain (4 miles south of Tonopah) in the Tonopah Union shaft. It has a pyroclastic structure, with occasional phenocrysts of quartz and more common crystals of feldspar, chiefly orthoclase, which are largely altered to quartz and muscovite. Small biotite crystals are also altered to white mica by bleaching. The groundmass is a microfelsitic devitrified glass. Some secondary adularia was observed.

From the lower contact of this rhyolite-dacite body the shaft passes through later andesite again to a depth of about 620 feet, making the thickness of this body of andesite traversed somewhat over 100 feet. At this point again there is a contact between the later andesite above and Tonopah rhyolite-dacite below similar to that just described. A short distance from the contact a vein of quartz 2 feet thick, containing pyrite and otherwise having the same characteristics of the upper veins, was encountered in the rhyolite-dacite. This also seems to be very nearly a contact vein. The bottom of the shaft, at a depth of 800 feet, is still in the same rhyolite-dacite.

From the bottom of the shaft a drift was run due east 525 feet since the visit of the writer. A specimen of the rock sent to the writer from the end of the drift is rhyolite-dacite, like that at the bottom of the shaft, but a specimen taken from an intermediate point in the drift is later andesite. Mr. C. E. Knox, the president of the company which has conducted these explorations, reports that the veins cut in the shaft were cut again in this drift in regular order. It is probable, therefore, that the alternating bands of rock, striking northwest and dipping southeast, were encountered in the drift also, with the exception perhaps of the white rhyolite, which has not been reported as occurring in the drift. It is interesting to note that the end of the drift has been carried somewhat past the surface contact of the rhyolite-dacite with the later andesite perpendicularly above on the slopes of Ararat Mountain.

CORRELATION OF THE RHYOLITIC ROCKS IN THE SHAFT.

As before stated, the contact phenomena were not observable in the mine on account of alteration by circulating waters, but from what has been observed at other points in the district it may be believed that here, too, the andesite is the older of the rocks exposed; that it has been cut by the Tonopah rhyolite-dacite, and that the white rhyolite was the last of all and is also of an intrusive nature. The form of the different igneous bodies underground must be very complex, and it is difficult or impossible to even outline the connections between the similar lavas. It seems likely, however, that the white rhyolite is connected with that of Mount Oddie, and the Tonopah rhyolite-dacite with that around Ararat Mountain.

AGE OF THE VEINS.

The veins clearly belong to a period subsequent to the formation of the veins in the earlier andesite, as shown by their having the Tonopah rhyolite-dacite for a wall rock. The relatively high content in gold as compared with silver seems to be very common in these post-andesitic veins connected with the dacite-rhyolites.

KING TONOPAH SHAFT.

GEOLOGICAL SITUATION.

The King Tonopah shaft lies at the contact of the Tonopah rhyolite-dacite with the later andesite. At many points along the irregular contact of these two rocks phenomena were observed indicating that the rhyolite-dacite is intrusive into the andesite. The rhyolite-dacite sends out intrusive irregular projections into the andesite, and isolated dikes or necks appear in the andesite some little distance away from the contact.

The shaft starts in the later andesite, and at a depth of 38 feet passes into silicified rhyolite-dacite. The total depth of the shaft is 300 feet, and from the bottom a drift was run to the north and, at the time of the writer's visit, extended 48 feet from the shaft.

VEIN MATERIALS.

At a depth of 226 feet a zone of silicified rhyolite-dacite with quartz stringers was cut in the shaft. It is several feet in thickness, but was practically barren of values, the highest assay reported being only about $2. Some of this vein material contains, besides quartz, abundant adularia, as is shown by microscopic study. There is also some finely striated feldspar, which may be albite. Some of the adularia shows the characteristic rhombic cross sections, and many of these crystals are entirely inclosed in quartz.

NATURE OF ROCK INCLOSING VEIN MATERIALS.

The rock in which this material lies and in which the entire shaft and drift has been driven below a depth of 38 feet is the Tonopah rhyolite-dacite. It is a glassy lava made up for the most part of a glassy groundmass, usually more or less devitrified and altered to quartz, kaolin, and sericite aggregates. In some specimens abundant fine adularia of secondary origin has been found in the groundmass. Scattered small crystals of feldspar usually occur, but they are mostly nearly or quite altered to sericite and sometimes to adularia. The blunt form of some of these crystals shows probable original orthoclase, while some are more elongated, suggesting a more basic species.

CORRELATION OF VEINS WITH OTHER OCCURRENCES.

The formation of pyritiferous quartz veins in this rock is therefore a contact phenomenon near the edge of the intrusion, for the glassy rhyolite-dacite outcropping away from the contact is usually quite fresh and unsilicified. This idea gains corroboration from the fact that near by, at other points on the contact, namely, in the vicinity of the Belle of Tonopah shafts and elsewhere, silicification and the formation of veins has occurred. This vein is, then, of the same class as the veins at the contact of the glassy Tonopah rhyolite-dacite in the Mizpah Extension and other shafts.

BELLE OF TONOPAH SHAFT.

GEOLOGICAL CONDITIONS.

The Belle of Tonopah is situated in the northern corner of the area mapped, about 1,600 feet west of the King Tonopah, on the irregular contact of the glassy Tonopah rhyolite-dacite and the later andesite. At a number of places along this contact the phenomena show that the rhyolite-dacite is intrusive into the andesite. Just south of the Belle of Tonopah shaft a number of rhyolite-dacite dikes occur in the later andesite near the contact. These are considerably decomposed and are accompanied by small and nonpersistent quartz veins, which give assays showing generally small and irregular quantities of gold, with little silver.

The Belle of Tonopah shaft starts in such a rhyolite-dacite dike, very close to the contact, and passes downward through 20 feet of this material, when it enters the later andesite. The contact of the two rocks strikes west-northwest and dips southwest at angles ranging from 65° or 70°. The contact is marked by a decomposed zone, and the later andesite below is soft and is very full of pyrite which, however, is quite barren.

At the time of the writer's visit the shaft was 230 feet deep, all except the upper 20 feet being in the later andesite. Since then, in January, 1904, Mr. A. C. Stock, the manager, has sent the writer a specimen of the rock from the bottom of the shaft at a depth of 460 feet. This is later andesite.

The rhyolite-dacite in the upper part of the shaft resembles the rock from the King Tonopah. It is highly decomposed, but has the structure of a nearly glassy volcanic rock and contains many very small crystals, nearly all of which seem to have been feldspar, with no original quartz. Now the whole rock is altered to kaolin, chert, hematite, siderite, etc. This rock unquestionably belongs to the glassy Tonopah rhyolite-dacite and is intrusive into the later andesite at this place.

VEINS.

The quartz stringers found along the edges of the rhyolite dikes near the edge of the shaft are stated by Mr. Stock to run as high as $13 in gold. These consist of dark, rather dense quartz, carrying a great deal of pyrite. In the shaft also small stringers have been found up to the time of the writer's visit, generally striking parallel with the slips but dipping in the opposite direction, and affording assays running up as high as $18, being all in gold. Mr. Stock reports that at a depth of 440 feet a stringer was cut which gave an assay of $39.60 in gold and $3.80 in silver, while at the bottom of the shaft (460 feet) another stringer 2 inches thick gave an assay of $4.14 in gold and $6 in silver, the latter being the first which showed preponderating silver values, the other assays from the shafts of the neighborhood showing chiefly gold. This mineralization is therefore comparable with the low-grade pyrite-bearing quartz veins, with the values chiefly in gold, which occur at various other points in or near the glassy Tonopah rhyolite-dacite near its contact. It is due to the action of heated waters circulating along the contact, subsequent to the intrusion of the rhyolite-dacite, and is of a different and later period from that of the veins in the earlier andesite.

The abundance of pyrite in the altered later andesite seems to indicate that the pyritization here, as probably in the case of similarly altered later andesite on Mizpah Hill, is associated with present water courses. The pyrite, like that of the later andesite on Mizpah Hill, is barren of gold and silver values.

SHAFTS AT THE UNMINERALIZED CONTACT OF THE TONOPAH RHYOLITE-DACITE.

BUTTE TONOPAH SHAFT.

The Butte Tonopah shaft, at the eastern base of Ararat Mountain, was 35 or 40 feet deep at the time of the writer's visit. It was in the Tonopah rhyolite-dacite, at the contact of this rock with the later andesite. This contact, apparently vertical, is plainly and continuously shown about 30 feet east of the shaft. The rhyolite-dacite contains many inclusions of the andesite, and is intrusive into it.

LITTLE TONOPAH SHAFT.

This shaft is located about 150 feet from the edge of the area mapped and about one-half mile west of the Golden Anchor shaft. It is situated at the contact of the glassy Tonopah rhyolite-dacite with the later andesite. The shaft starts in the rhyolite-dacite and runs down about 50 feet to the contact with the andesite. The rhyolite contains fragments of the later andesite, and the contact dips west at angles of 50° or 55°. The shaft was, at the time of the writer's last visit in the fall of 1904, about 585 feet deep, and the lower part was all in the later andesite. At the surface the contact seen in the shaft outcrops 50 or 60 feet east of the shaft. No mineralization was observed.

SHAFTS AT THE CONTACT OF THE BROUGHER DACITE.

BIG TONO SHAFT.

This shaft is sunk in the intrusive dacite neck on the east side of Brougher Mountain. It was started in the glassy contact phase of the neck at the very contact with the dacite breccia, into which the neck is intrusive. The shaft is somewhat over 300 feet deep, and is entirely in the Brougher dacite.

For a depth of about 50 feet the glassy phase persists in the shaft, below which is the ordinary porphyritic phase. This indicates that with depth the shaft departs from the contact, which at this point must pitch away from the mountain.

MOLLY SHAFT.

The Molly shaft is situated at the west end of Golden Mountain. It was sunk in the summer of 1903 and was 468 feet deep when work was stopped. A rough estimate of the section passed through, made by climbing down the somewhat tightly lagged shaft, was that the Brougher dacite occupied the upper two-thirds, and the Fraction dacite breccia most of the lower third, with 25 feet of later andesite at the bottom. There seems to have been some Tonopah rhyolite-dacite sheets in the Fraction dacite breccia. No water was encountered.

As shown on the map, the shaft lies about 250 feet east of the nearest point of contact of the Golden Mountain intrusive dacite neck with the older rocks. This contact, therefore, has here a pitch of about 45° toward the mountain, a fact which is also indicated by the inward pitch of the outcropping contact and by the flow structure in the dacite at the contact for some distance to the north and east. The shaft has thus passed downward out of the dacite neck into the older formations.

SHAFTS WHOLLY OR CHIEFLY IN DACITIC TUFFS.

NEW YORK TONOPAH SHAFT.

The New York Tonopah lies between Butler and Brougher mountains and when last visited by the writer the workings consisted of only a shaft 745 feet deep. At the point where the shaft was sunk the surface consists chiefly of brecciated lavas and tuffs which have been referred to the glassy Tonopah rhyolite-dacite. However, the rocks belonging to this formation, when they are chiefly fragmental, as they are here, are often not easily distinguishable, or perhaps not at all, from the tuffs of the Fraction dacite breccia, which in general is considered to underlie the first named. In the shaft portions were passed through which resemble the Tonopah rhyolite-dacite; these may represent dikes, especially in the lower portion. As a whole, however, the shaft may be considered to lie within the Fraction dacite breccia.

The first 150 feet is rather fine volcanic breccia, followed by 275 feet of fragmental tuff, light-colored and generally moderately coarse. This is horizontally coarsely stratified and contains one bed, 1½ feet thick, of finely stratified fine-grained material. This passes gradually into a fine breccia and this into a very coarse breccia containing included fragments up to 2 or 3 feet in diameter. Most of these inclusions are various phases of the later andesite, but some are probably earlier andesite. Others are of dacite and tuff, much like the matrix. At the time of the writer's examination the shaft was 475 feet deep, and had passed through 50 feet of this coarse breccia. Specimens obtained from the shaft during its progress farther downward showed that it remained in practically the same material, some of the included bowlders of earlier and of later andesite being several feet thick. The bottom of the shaft is in soft dacite that contains later andesite inclusions. This dacite is much like that which caps the Fraction shafts.

The stratified tuffs referred to do not belong to the Siebert tuffs of the lake beds, but are included in the Fraction dacite breccia. They are described elsewhere as the interbreccia tuffs, and are found in the upper part of the Fraction dacite breccia at various places in the district. The great thickness of the Fraction dacite breccia, here shown, indicates that the block in which the New York Tonopah lies has sunk down very considerably in respect to the blocks farther northeast—to those, for example, in which the Fraction shafts are situated. The breccias and tuffs of the New York Tonopah are considered to be surface formations, formed chiefly by explosive outbursts; and the included blocks of earlier rocks are considered to be fragments hurled out of the volcanoes at the time of the explosions.

FRACTION EXTENSION SHAFT.

GEOLOGICAL SECTION.

This shaft is situated at the south base of Brougher Mountain, somewhat over a thousand feet northwest of the New York Tonopah shaft. When visited by the writer it was approximately 300 feet deep. On account of the tight lagging the section of the shaft could not be observed, but a roughly estimated thickness of 75 or 80 feet of the white finely stratified tuffs of the lake beds was first passed through. Below the tuffs the whole shaft is in hard gray or red brecciated lava, belonging to the glassy Tonopah rhyolite-dacite.

FAULT.

This same rhyolite-dacite outcrops about 35 feet east of the shaft, on the farther slope of a little gully. A northeast fault running along this gully is thus evidenced, and indeed is shown farther northeast up the hill slope. By this fault the block in which the Fraction Extension is located is downthrown in respect to that on the east side.

TONOPAH CITY SHAFT.

GEOLOGICAL SECTION.

The Tonopah City shaft lies on the outskirts of the town, about 1,100 feet south of the Fraction No. 2. It was driven to a distance of 500 feet before work was stopped. On the surface at this point is a very thin covering of black glassy rhyolite or dacite (latest rhyolite-dacite flow), generally only a few feet thick, and often broken up into bowlders rather than in place.

Practically none of this black lava is exposed in the shaft itself, the first solid formation cut being the Fraction dacite breccia. The upper 100 feet of this was a coarse breccia, evidently detrital, which contained large and small inclusions, mostly of later andesite. From 100 to 300 feet the breccia was finer grained and denser, and apparently had an explosive origin, being full of small, angular, white pulverulent fragments, which are probably decomposed pumice. At a depth of 300 feet solid Heller dacite (see p. 37) came in and continued for 200 feet to the bottom of the shaft.

At a depth of 400 feet in the shaft this dacite was observed to be cut by a dike of exactly similar material, the only difference being the presence in the dike of a greater abundance of light-colored intrusions. This dike is 10 inches thick and has a N. 70° W. strike and a dip of 75° to the northeast.

INDICATED DISPLACEMENT OF FAULT BLOCKS.

Since neither the earlier nor the later andesite was encountered in this shaft, and the dacite breccia is so much thicker than in the Fraction shaft to the north, it is plain that the fault block in which the Tonopah City is situated is depressed relatively to that in which the Fraction shafts lie.

OHIO TONOPAH SHAFT.

DACITE TUFFS IN SHAFT.

The Ohio Tonopah is situated about 1,600 feet west of the MacNamara shaft. At this point the surface formation is a volcanic tuff due to dacitic outbursts. Some of the harder portions are more clearly referable to the glassy Tonopah rhyolite-dacite, while other portions, especially where the rock is softer, approach more closely the character of the Fraction dacite breccia. However, as has been said in discussing these formations in general, there is much admixture, and on account of the intimate relation of the two lavas the tuffs often can not be properly distinguished and separated.

The shaft is at present about 770 feet deep, and has a working level at 756 feet. Passing downward from the surface, the shaft passed through a considerable thickness of the rhyolite-dacitic tuffs above referred to. These tuffs continue down to about 485 feet. They are usually rather soft; under the microscope they are plainly fragmental and are little assorted, indicating probably showers of detritus from volcanic outbursts. On account of their original glassy character and their subsequent decomposition (chiefly kaolinization) very few definite characteristics can be distinguished. A specimen of one of the harder portions, at 396 feet, however, showed, under the microscope, a glassy groundmass with phenocrysts of quartz, striated feldspar, orthoclase, and altered biotite. In this slide the chief secondary minerals were calcite and muscovite.

LATER ANDESITE IN SHAFT.

From about 485 feet to 525 feet there is andesite having the appearance of the later andesite. Well-marked slips near this contact indicate that it is very likely a fault contact. One of these slips had a north-south strike, and a westerly dip of 50°.

SOLID TONOPAH RHYOLITE-DACITE.

Below the later andesite, from 525 feet to the bottom of the shaft, comes a dense, siliceous rock, which is discussed elsewhere and is undoubtedly referable to the Tonopah rhyolite-dacite.

At the contact of this rock with the overlying andesite movement is indicated by the presence of 30 to 40 feet of ground-up material, which contains fragments of hard rock and occasionally of quartz. The dip of this contact is northwest, at an angle of about 25°.

At the 756-foot level the ground has been extensively explored to the south, north, and east by drifting, the main southeast drift running about 700 feet from the shaft. The formation is almost entirely Tonopah rhyolite-dacite, characteristically showing angular white fragments in a dense gray groundmass. The brecciation indicated by these fragments took place before the cooling of the rock. The only andesite shown on the level is a small patch about 150 feet southeast of the shaft. This is a biotite-andesite, and may be either the earlier or the later andesite. It has a sharp contact with the rhyolite-dacite, which is probably intrusive into it. On the south side of the andesite patch, as exposed in the drift, the contact dips north at an angle of about 55°.

CHARACTERISTICS OF THE RHYOLITE-DACITE.

The specimens of the rhyolite-dacite examined microscopically are of a highly altered, very glassy lava. The groundmass is glassy, often kaolinized. It is very abundant, constituting nearly all the rock, and often shows marked flow structure. The phenocrysts are rare and small, and consist chiefly of short, blunt feldspars, biotite, and occasional very small quartz grains. Some of the feldspars are striated. The feldspars are usually almost or entirely altered to kaolin, sericite, and secondary adularia. The biotite is usually altered, sometimes to chlorite. Secondary quartz and pyrite are usually common in the rock, and sometimes there is calcite.

MINERALIZATION.

As a rule the rock is very much silicified. Cracks in this rock are filled with coatings of calcite, quartz, and pyrite, and excellent free crystals of barite. Some streaks are considerably silicified, and contain silver and gold, as is shown by assay. Up to the time of this writing, however, no veins of importance have been struck in this formation.

The chief veins are irregular, barren, and nonpersistent. They have a general northeast or east strike, and die out along the strike by scattering into the silicified rock, or are cut off by faulting. At the upper contact of the rhyolite-dacite with the patch of andesite above mentioned, there are 2 feet of jaspery barren quartz, illustrating again the tendency of the rhyolitic quartz to form at the upper contact of the rhyolite-dacite body, under the impervious decomposed andesite, as elsewhere described in the discussion of the MacNamara, the Tonopah Extension, the Mizpah Extension, and other mines.

Some faulting is shown in this level, the chief being in a north-northwest direction, and indicating in places considerable displacement.

PITTSBURG SHAFT.

The Pittsburg shaft lies near the eastern edge of the area mapped, on the south side of the main road which runs east out of Tonopah. It is not shown on the topographic map, having been started since this was made. At the time of the writer's visit, in November, 1904, it was 570 feet deep, all in volcanic breccia, probably belonging chiefly to the Tonopah rhyolite-dacite period. This formation contains some harder layers, which may be flows, but as a whole is to be considered a surface formation, the product of volcanic explosions.

RED ROCK SHAFT.

This shaft lies about halfway between the Pittsburg and the Ohio Tonopah. It was at the time of the writer's visit, in November, 1904, 230 feet deep in volcanic breccia like the Pittsburg and the upper part of the Ohio Tonopah.

SHAFTS ENTIRELY OR CHIEFLY IN LATER ANDESITE.

HALIFAX SHAFT.

The Halifax shaft was sunk in the depression lying just north of Golden Mountain in the later andesite, just northeast of a probable fault line which separates the later andesite on the northeast from the white tuffs on the southwest. The shaft was 800 feet deep at the time of the writer's last notes in November, 1904, and was entirely in the later andesite. The andesite is very fresh—fresher than that examined in any other part of the district. The phases exposed in the upper part of the shaft are very glassy, suggesting that they are near the upper part of a flow, while those in the bottom are also relatively finer grained than the rock exposed for most of the distance down the shaft. Much of this latter is so coarse, with so great a development of phenocrysts compared with the quantity of the groundmass, that it has in the hand specimen almost a granular texture. Nevertheless the different phases all belong to a single mass.

At a depth of 200 feet in the shaft a drift was run a little east of south for 270 feet, and in the opposite direction for 100 feet along a heavy fault, which runs parallel to the drift and dips west at an angle of 45° or steeper. Along this fault plane there is a thick brecciated or ground-up zone 8 or 10 feet thick. The striæ indicate that the faulting was normal, the downthrow being on the west side. The same conclusion is suggested by the difference in the texture of the andesite on the sides of the two fault, that on the foot wall side being coarser and almost granular, while that on the hanging wall is finer grained. It is probable that the coarser textured andesite cooled at a somewhat greater depth than the finer grained and, therefore, that this side has been relatively upthrust.

The shaft stays in this same granular andesite for 50 feet below this level, when another fault zone comes in, along which is also a clay seam. This dips 60° to the west. Below this, hard and finer grained andesite comes in again and continues downward.

This is one of the few shafts in the district which have struck a large flow of water. Chiefly below 600 feet in the shaft, water was encountered, which rapidly increased from 10,000 to 30,000 gallons a day, and owing to this the sinking of the shaft was for a long time suspended (see p. 105). Some drifting is being done, from the bottom, north and south, in the later andesite.

GOLDEN ANCHOR SHAFT.

The Golden Anchor shaft was started in the center of the later andesite area west of the Midway. When last visited, in the middle of November, 1904, it was 640 feet deep. At a depth of 400 feet a south crosscut runs 510 feet from the shaft, and at a depth of 500 feet a north crosscut runs 463 feet. The upper part of the shaft is in typical later andesite. On the 400-foot level the andesite is of somewhat different character, being greenish and altered, but its characters still indicate that it is probably the later andesite. On this level it contains some calcite veinlets, but no quartz. On the 500-foot level the andesite is finer grained than on the 400, and has some of the features of the earlier andesite, but there is little doubt that it belongs to the same body as the 400-foot level, and the balance of evidence is therefore in favor of considering it probably later andesite. On this level there are some calcite stringers and some narrow quartz veinlets, containing, however, practically no values. At a depth of 550 feet in the shaft a change of formation was reported, and the material seen on the dump taken from beneath this point is largely a dense, green, siliceous rock containing quartz stringers. A specimen of this examined microscopically proved to be of the glassy Tonopah rhyolite-dacite. Inspection of the dump indicates that this rhyolite-dacite is mixed with some andesite, which may be either the earlier or the later andesite, so far as microscopic characteristics go.

The above data indicate that at this point the later andesite is considerably thicker than in the territory farther east. Indeed, its lower limit is uncertain.

CHAPTER VI.

ROCK ALTERATION.

ALTERATION OF THE EARLIER ANDESITE.

The alteration of the earlier andesite by thermal waters has been profound, indicating that these solutions were present in large quantity and were very active.

ALTERATION OF EARLIER ANDESITE CHIEFLY TO QUARTZ, SERICITE, AND ADULARIA.

On Mizpah Hill the andesite is entirely altered and has a siliceous, light-colored rhyolitic appearance nearly everywhere, except in depth, where the Mizpah shaft on the 700-foot level shows earlier andesite altered largely to chlorite, separated from the quartz-sericite alteration by a fault, and, so far as yet explored, marked by the absence of veins.

ALTERATION OF HORNBLENDE AND BIOTITE.

Various stages in the alterations are observable. The ferromagnesian minerals, hornblende and biotite, have usually been completely destroyed. Their areas are marked by liberally sprinkled pyrite crystals, by siderite, and often by some sericite. Frequently the grouping of the iron minerals, which follows with more or less clearness the well-known outlines of an original hornblende or biotite, affords the only evidences of the former existence of these phenocrysts, at the same time plainly showing the demarcation of the pyrite and siderite from the original ferromagnesian minerals. In further stages of alteration the pyrite and siderite have escaped from the confines of the original crystal and are scattered through the rock; in this case they are usually less abundant, showing a leaching of iron out of the rock as the silicification increases. It has been determined by assay that the pyrite in these rocks does not contain appreciable amounts of gold and silver, even close to the veins.

In other phases the ferromagnesian minerals have been entirely altered to fine muscovite (sericite) and quartz.

The alteration of biotite has been sometimes not so complete as just sketched, the mineral having been bleached and the separated iron represented by pyrite and siderite.

RELATIONS OF PYRITE AND SIDERITE.

The relations of the siderite to the pyrite in these rocks have been carefully studied. In some cases the siderite has been observed distinctly pseudomorphous after the pyrite. Often the two exist side by side in such a way as to suggest contemporaneous deposition, pyrite showing usually, and siderite frequently, some characteristic forms (Pl. XXIII). In observing the alteration of these minerals from ferromagnesian crystals it has been repeatedly noticed that the carbonate had more intimate relations with the original crystal than did the pyrite, the carbonate occurring all through the decomposed mineral, while the pyrite was distinctly confined to the outer zones.

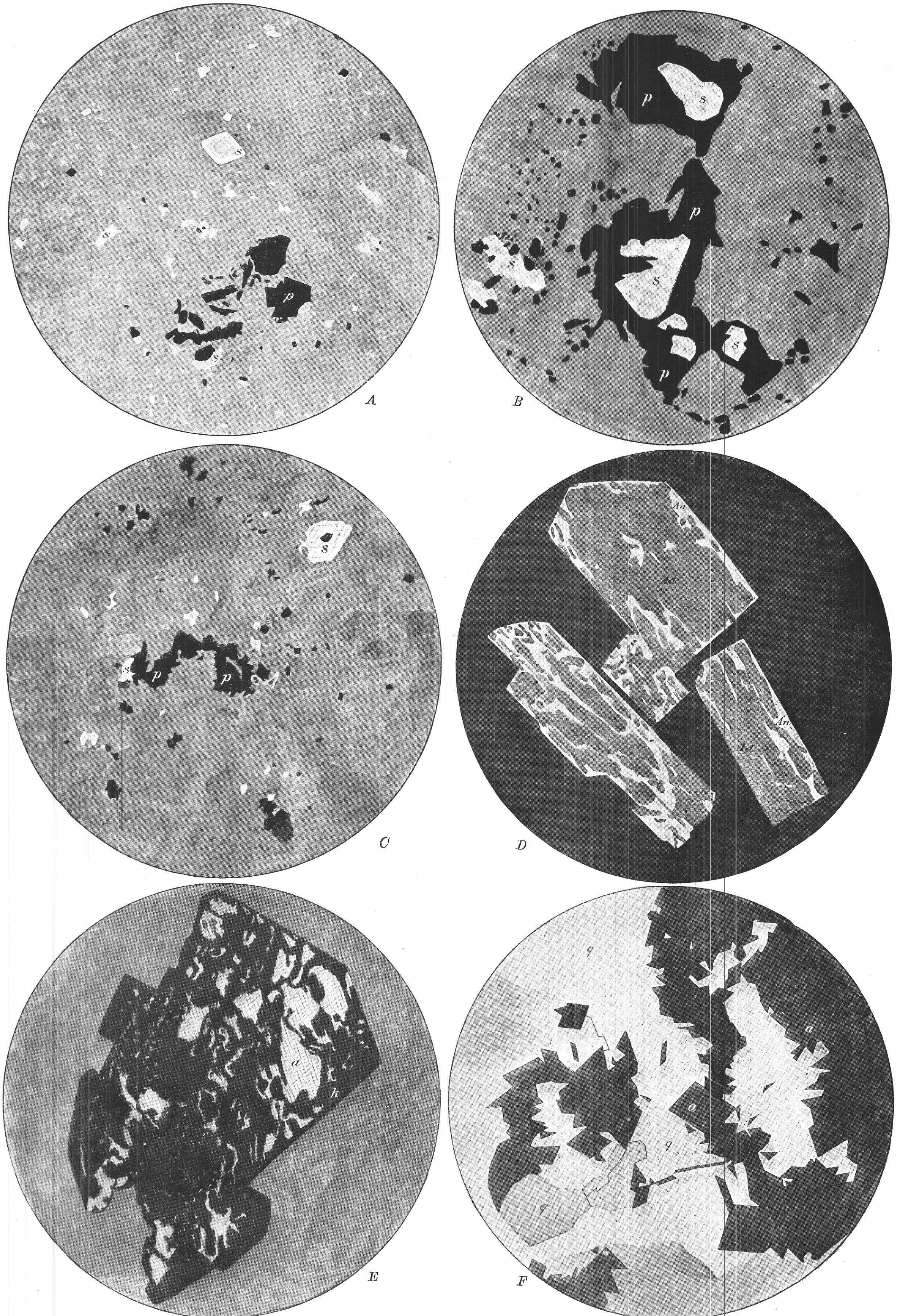
ALTERATION OF SODA-LIME FELDSPAR TO QUARTZ AND SERICITE.

The feldspar phenocrysts, which are sometimes fresh enough to be determined, are typically andesine-oligoclase, though sometimes they become more calcic. Labradorite occasionally occurs. They are usually partly or completely altered.

The alteration to adularia is one of the most commonly observed changes, but hardly so common as that to quartz and fine muscovite. These two last-named minerals frequently form a pseudomorphous aggregate in the space occupied by the original feldspar. With increasing alteration the outlines of these pseudomorphs become more and more indistinct and finally indistinguishable. Even within the veins, however, careful observation may often succeed in distinguishing the traces of these original crystals in the highly silicified mass, for sometimes they are marked by quartz that is relatively coarser grained than that in the groundmass, and consequently they appear slightly lighter in transmitted light. These two processes of alteration of the feldspar, either to adularia or to quartz and sericite, although present in the same rocks, are not very commonly associated in the same specimens and appear to be distinct. Occasionally the feldspar is altered to kaolin, as described later.

ALTERATION OF SODA-LIME FELDSPAR TO ADULARIA.

The alteration of the soda-lime feldspar to adularia can be observed in all its stages in different rock specimens. The alteration proceeds along the edges and the cleavage cracks of the crystal, so that the brightly polarizing andesine, somewhat turbid from decomposition, becomes reticulated with the fresh glassy adularia, which shows markedly lower polarization colors (Pl. XXIII). Characteristic complete or incomplete crystals of adularia with rhombic outline frequently form within the older crystal. In some cases the alteration is completely carried out and the feldspar is completely pseudomorphosed to adularia, whose perfect crystal outlines give the idea of a fresh primary crystal, but whose optical



A, B, C. RELATIONS OF PYRITE AND SIDERITE IN TONOPAH ANDESITE.
D, E, F. ADULARIA IN EARLY ANDESITE AND VEINS.

Drawings from thin sections.

A. Rhomb of cloudy siderite (*s*) associated with contemporary pyrite (*p*); earlier andesite, Fraction workings. Incident light. Magnified 11 diameters.

characters prove the truth of the change demonstrated in other cases by observed transitions. Sometimes the alterations to adularia and to sericite go on side by side, the original feldspar altering in part to one and in part to the other and the two minerals sometimes forming an interlocking aggregate.

ALTERATION OF THE GROUNDMASS.

The microlitic, nearly glassy groundmass has been very largely decomposed to or replaced by fine granular quartz, with fine muscovite (sericite), etc. The quartz in the more highly silicified specimens shows grains of larger growth and is often segregated in bunches or veinlets. Pyrite and siderite are very commonly disseminated throughout. Original zircon is frequently present. Sometimes adularia can be made out as a portion of the fine secondary aggregate. Tiny veinlets of adularia and others of quartz also seam the rock.

Apatite, usually brownish or yellowish and slightly pleochroic, is relatively abundant, and not being easily attacked by the agents which have brought about the alteration of the rest of the rock is very characteristic in the considerably silicified phases.

ADVANCED STAGE OF ALTERATION.

In the advanced stages of alteration nearly all the iron has disappeared; the similar alteration products of the feldspars, the ferromagnesian minerals, and the groundmass merge to form a quartz-sericite aggregate. The quartz varies in grain from microcrystalline or nearly cryptocrystalline to moderately coarse, a characteristic applying also to the quartz of the mineral-bearing veins, which are mostly the extreme alteration product of the andesite, as is shown by both field and microscopic study. In these extreme phases the quantity of sericite becomes less and that of the quartz more.

OCCURRENCE OF KAOLIN.

While kaolin is not an ordinary alteration product in the siliceous alteration of the earlier andesite, it is frequently present. Specimens in which it has been detected have usually been taken from near a fault or fracture, or other water course connecting with the surface. Therefore the hypothesis has been formulated that while the sericite is manifestly the work of the vein-forming solutions the kaolin is the work of descending surface waters, and is probably of later origin, the kaolinization attacking the unsericitized residual feldspar. Kaolin and sericite are frequently found together in varying proportion.

16843—No. 42—05——14

ALTERATION OF EARLIER ANDESITE, CHIEFLY TO CALCITE AND CHLORITE.

In the earlier andesite at points sufficiently remote from the important veins, calcite and chlorite appear as distinct alteration products, which do not occur in the rock nearer the veins and which take the place, partly or wholly, of the quartz and sericite of the phases described above. This phase has a green color, growing in depth of shade as the proportion of chlorite increases, and the rock has no resemblance to the light-colored quartz-sericite alteration phases. Iron in the form of pyrite and siderite is common to both phases, but while in the quartz-sericite alteration it is characteristically in small quantity and diminishes with increasing alteration, in the chlorite-calcite alteration it is abundant and remains so when the rock is completely altered.

In this process of alteration the feldspar is usually largely altered, chiefly to calcite with a little quartz. Rarely the alteration is to quartz and epidote. Original hornblende and pyroxene are always completely altered, usually to chlorite (ripidolite) pseudomorphs. Biotite has been observed altered to sericite, with a little calcite and hematite.

The groundmass is similarly altered to chloritic material, intermixed with secondary quartz, etc.

TRANSITIONS BETWEEN ALTERATION PHASES OF EARLIER ANDESITE.

There are all transitions between the typical quartz-sericite alteration phase, in which calcite and chlorite are always absent, and the typical calcite-chlorite phase, in which quartz, and especially sericite, are decidedly subordinate. Thus in a specimen from the 700-foot level of the Siebert shaft (from the same rock mass as some of the typical calcite-chlorite phases) the feldspars are chiefly altered to sericite, with a little chlorite; the hornblende and biotite crystals are altered chiefly to chlorite; and while calcite is present, it is not prominent.

DIFFERENT ALTERATIONS THE EFFECT OF THE SAME WATERS.

The conclusion is thus reached that the chemical effects of the same mineralizing waters became continually different as they penetrated to a greater and greater distance from the circulation channels. Along these channels, which became veins, the transformation or replacement of the rock by the addition of silica and the sulphides of silver, antimony, etc., with gold and selenides, and by the complete leaching out of soda and magnesia and the partial leaching out of lime and iron, was profound. In the siliceous phase of the altered andesite near the veins a similar alteration, though weaker, is recorded. The metals did not penetrate here, but the partial replacement of lime, iron, magnesium, and soda by silica and potash is present in all its stages. In the rock more remote from the vein channels the alteration has been often complete, yet there has been no very great increase or decrease in the original elements. The original combinations of these elements have been broken up, and hydrated silicates, with abundant carbonates and sulphides, have formed, indicating only the presence of carbonic acid and hydrogen sulphide in the altering waters. Since the quartz-sericite alteration of the earlier andesite grades into the chlorite-calcite alteration by all possible stages, it is probable that both were produced at the same time and by the same waters; and since the transition from the quartz-sericite alteration to the metalliferous quartz veins is similarly perfect, the waters are clearly those which have produced the mineralization. Within the main circulation channels, therefore, these waters introduced silica, potash, and the metallic sulphides, and abstracted other materials. As they penetrated the rock away from these channels they ceased to deposit metals, except possibly in trifling quantity,[a] while the excess of silica and potash was still deposited, failing with increasing distance. Finally, the changes in the calcite-chlorite alteration show that only the common gases above mentioned, so commonly present in surface hot springs, were left in the mineralizing waters, which therefore had little to precipitate and small power to abstract.

The successive precipitation so plainly demonstrated probably took place by reactions with the wall rock, which therefore acted as a screen for the traversing solutions.

REFRACTORINESS OF POTASH FELDSPARS.

In arguing that the formation of potash minerals in the veins and in the wall rock shows a relative excess of potash in the mineralizing waters, it must be taken into consideration that potash feldspars are ordinarily more refractory to altering waters than the soda-lime varieties. Comparison of analyses of fresh rocks and of rocks altered by surface weathering usually show that the loss of soda is greater than that of potash.[b] It is also true, as pointed out by Lindgren,[c] that one of the most prominent minerals formed by metasomatic processes in and near veins is a potassium mica, such as muscovite, and that the most prominent process brought about by the waters is the progressive increase of potash and the decrease of soda. At the Boulder Hot Springs, described by Weed,[d] sericite and in one case adularia had been deposited from the waters, which contain chiefly sodium sulphate, carbonate and chloride, calcium carbonate, and silica; no potassium is recorded. Near the Comstock lode, potash, as compared with soda, is more important in the altered than in the fresh rock,[e] showing that

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[a] Sampling of the Mizpah mine, under the direction of Mr. John Hays Hammond, showed that the earlier andesite forming the walls of the vein runs in values from $0.50 to $2 a ton, as compared with many times that value in the vein.

[b] Merrill, G. M., Rocks, Rock-weathering, and Soils, p. 236.

[c] Lindgren, W., Trans. Am. Inst. Min. Eng., vol. 30, p. 690.

[d] Weed, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, p. 246.

[e] Lindgren, W., Trans. Am. Inst. Min. Eng., vol. 30, p. 647.

the fresh rock has been attacked more than the altered rock. Complete analyses of the mine waters show chiefly carbonates of lime and magnesia in about equal proportions, next, sulphate of magnesia and silica, a smaller amount of carbonate of soda, about one-tenth as much carbonate of potash as soda, small amounts of sodium chloride, and very small proportions of alumina and ferric oxide.[a]

MEANING OF ADULARIA AND ALBITE AS GANGUE MINERALS.

While it might be inferred from this that ordinary waters, even those containing a large amount of soda and little or no potash, tend to produce potash minerals in veins and owe their composition to the leaching out of the soda while the potash is left behind, the fact remains that potash feldspar is contained, so far as known, only in a relatively limited number of veins.

Soda feldspar or albite, a mineral as easily formed in the wet way as orthoclase, occurs in a number of other veins and in rocks as the result of the alteration of soda-lime feldspars, and, what is more interesting, of potash feldspars. Dr. G. L. Gentil[b] has shown that in the granites of the Tofna basin in Algeria the soda-lime feldspars have been largely transformed into albite, and the same phenomenon has been described by other authors. On St. Gothard and other places in the Alps albite has been described as pseudomorphous after adularia, and as occurring in porous aggregates of fine crystals in the form of the original potash-feldspar crystal. Comparative analyses of the feldspar's various phases of alteration show that the original adularia contains very little soda and the resultant albite no potash. Bischof[c] explains this process of pseudomorphism as a decomposition of the original adularia by waters into a perfectly soda-free adularia and a potash-free albite. The potash, silica, alumina, and lime of the adularia were dissolved and carried away, leaving the albite; in some cases the albite substance seems to have been concentrated. Bischof suggests[d] that in some cases part of the adularia has been transformed into albite by replacement. Also in localities in the Riesengebirge in Austria small fresh albite crystals were observed in several cases upon altered orthoclase, which was in part altered to muscovite.[e] Bischof and Rose agree that the explanation of this is that the soda-feldspar has been abstracted while the potash feldspar remains. Bischof remarks, "Such opposite effects[f] presuppose beyond question, if not opposite, certainly different causes, i. e., different substances in solution in the waters."

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[a] Becker, G. F., Mon., U. S. Geol. Survey, vol. 3, p. 152.

[b] Gentil, G. L., Review in Am. Geol., Apr., 1903, p. 254.

[c] Bischof, Gustav, Chemische Geologie, vol. 2, p. 409.

[d] Op. cit., p. 412.

[e] Op. cit., pp. 406, 407, 412.

[f] That is, in one case the adularia molecule was dissolved out, the albite molecule being insoluble; in the other the albite molecule was dissolved out, while the adularia molecule was insoluble.

Bischof[a] notes that albite occurs in quartz veins in gneiss in Sweden, and F. A. Genth described it in pyritiferous gold quartz veins in California,[b] and it has been noted as a common occurrence by subsequent observers.[c]

It seems to the writer to be unquestionable that waters that deposit albite without orthoclase in a vein are different from those which deposit orthoclase without albite, and that the difference must consist in part in the relatively greater quantity of soda in the waters in the first case and of potash in the second. The many observed instances in the earlier andesite at Tonopah of complete pseudomorphs of adularia, quartz, sericite, etc., after soda-lime feldspars show a process of replacement (not leaching and concentration), the soda and lime being removed and potash and silica introduced. The waters which accomplished these changes thus must have had abundant potash as well as silica in solution.

STUDY OF TYPICAL SPECIMENS.

MICROSCOPIC DESCRIPTIONS.

For the purpose of estimating more accurately the changes which have been described as observed microscopically, a number of analyses were made and studied. The specimens selected, arranged in their natural order, were as follows:

1. Earlier andesite (408) from lower part of Siebert shaft.—Dense dark-green rock, Siebert shaft, Mizpah mine, 670 feet from surface. Contains scattered phenocrysts of rather small size in a fine microlitic groundmass, showing flow structure. The microlites in the groundmass are chiefly feldspar. A little zircon and apatite are present. Quartz grains also occur, of which some may be original.

Among the phenocrysts the feldspars are prominent. A determination in another similar specimen near the same locality showed the species to be andesine-oligoclase. They are largely altered to calcite with a little quartz. Abundant pseudomorphs after hornblende, in which no trace of the original mineral remains, consist of dark blue-green chlorite (ripidolite) with some specular iron. The hornblende cleavage is still visible in the pseudomorphs. Pseudomorphs after biotite consist of fine muscovite, with a little calcite and hematite.

2. Earlier andesite (358) from Tonopah and California shaft.—Green, but much lighter than No. 1. Shows relatively sparse and small phenocrysts in a fine microlitic groundmass, with much felty devitrified glass. Apatite is abundant. Secondary chlorite occurs throughout the groundmass.

The feldspar phenocrysts have the optical characters of andesine, and are only slightly attacked by decomposition. The ferromagnesian minerals are

[a] Bischof, Gustav, Chemische Geologie, vol. 2, p. 412.
[b] Genth, F A., Am. Jour. Sci., 2d series, vol. 28, p. 249.
[c] Ransome, F. L., Description of Mother Lode district: Geologic Atlas U. S., folio 63, U. S. Geol. Survey, 1900, p. 8.

entirely altered; pseudomorphs of chlorite after hornblende can be distinguished. Numerous amygdule-like portions are lined with chlorite and filled with granular quartz.

3. *Earlier andesite (293) from Fraction No. 2 shaft, at depth of 218 feet.*—Purple rock with white feldspar phenocrysts. Phenocrysts rather abundant, but relatively small, the feldspars being the largest. The groundmass is glassy and microlitic, with flow structure. There is abundant magnetite, frequent apatite, and occasional zircon.

The feldspars were determined as andesine; they are only partly altered to fine muscovite. Pseudomorphs after original ferromagnesian minerals are abundant, though small; biotite, pyroxene, and hornblende can be distinguished, though no traces of the fresh minerals are left. The biotite has altered to muscovite, with a small amount of siderite scattered through, and hematite forming a zone around the edge. Rutile or sagenite needles are included in the biotite. Pseudomorphs after hornblende are of sericite or talc, with inclusions and heavy rims of magnetite. Pseudomorphs after pyroxene or biotite are of quartz, with a little calcite and hematite around the borders. Other pseudomorphs, which are probably after hornblende, but may be in part after pyroxene, consist of quartz and sericite.

4. *Earlier andesite (53) from near Mizpah Hill.*—Pale pinkish-purple groundmass, with white phenocrysts. This shows what was originally a microlitic glassy groundmass, now containing abundant secondary quartz and sericite, with disseminated fine limonite, hematite, and siderite. Pseudomorphs after biotite phenocrysts are of muscovite, with a very little siderite. Other phenocrysts, possibly of hornblende, are represented by pseudomorphs of quartz, sericite, and a little siderite. Abundant pseudomorphs after feldspar are of clear, translucent material, which appears isotropic, but which high magnification often resolves into a fine aggregate, the grains of which may sometimes be made out as spherulitic. This substance has a very low double refraction and also a low single refraction, but the latter is apparently higher than that of balsam.[a]

5. *Earlier andesite (194) from Mizpah mine, lease 86, 180-foot level, near Mizpah vein.*—Rock of a light salmon-pink color. Shows several phenocrysts of feldspar, whiter than the rest of the rock. No original mineral is left anywhere. The groundmass, of which the fine microlitic glassy composition and fluidal structure

[a] Some of this material was isolated and analyzed by Mr. George Steiger, showing 62.1 per cent SiO_2, 19 per cent Al_2O_3, and 4.8 per cent K_2O. Sodium was absent. These figures correspond to a composition of about 28.4 per cent adularia, 30 per cent kaolin, and 27.5 per cent silica. Water, probably contained in the kaolin and the silica, was not determined, and was disregarded in the computations. The substance is therefore probably to be regarded as a colloidal mixture of these three alteration products of the original soda-lime feldspar, in nearly equal parts. As bearing upon the change which this feldspar has undergone, the proportions of the different constituents in rather siliceous andesine, such as we may believe, from examination of fresher rock, that this altered feldspar originally was, are given: SiO_2, 60.35; Al_2O_3, 25.45; CaO, 5.14; Na_2O, 7.63; K_2O, 1.21. The change evidently has consisted mainly in a removal of the soda and lime, and a substitution in part of exogenetic potash.

may be distinguished, is altered to an aggregate of quartz and sericite, with a little iron oxide. The pseudomorphs after phenocrysts are frequent and well defined. Numerous ones after feldspar form an aggregate of fine felty muscovite, with a little quartz. Those after biotite consist of muscovite, with a little siderite. Pseudomorphs after hornblende or pyroxene, or both, are barely distinguishable from the groundmass. They consist of fine muscovite (sericite) and quartz, with some siderite, which marks the outlines of the original phenocrysts. In this rock the secondary quartz varies in grain, some areas becoming more coarsely crystalline.

6. *Typical earlier andesite (398) from Mizpah Hill.*—Hard white rock with small glistening feldspar crystals. This rock has a microlitic groundmass, showing flow structure. It has the appearance of being unusually fresh, and fresh striated feldspar can be seen in it. Nests of fine granular adularia and quartz (both secondary) occur here and th re. There is a little finely disseminated siderite and limonite.

The feldspars are mostly altered to adularia. The original mineral has the optical characters of an oligoclase, near andesine. The alteration of this to adularia can be seen in all its stages. Polarized light brings out this change strongly, the bright white of the soda-lime feldspar contrasting with the dark gray of the potash feldspar. The latter penetrates the former irregularly and minutely, yet with a fairly high power the characteristic crystal outlines (usually rhombic) of the adularia can be distinguished. The process can be observed in all its stages in different crystals, up to the complete pseudomorph. A little sericite accompanies the alteration in some cases. Traces of original ferromagnesian phenocrysts can be determined, but wi h difficulty. In one case a pseudomorph after probable hornblende was of sericite, with apparently a little adularia and traces of siderite.

7. *Earlier andesite (143) from hanging wall of Mizpah vein, 300-foot level, Mizpah mine.*—Light gray, nearly white rock, with uneven fracture and dull luster.

This rock is so much altered as to be hardly recognizable. It consists of an aggregate of quartz and fine muscovite, with small scattered pseudomorphs of hematite after pyrite (the result of oxidation), and some siderite (?). The quartz is irregular and is segregated throughout into areas and little veinlets, which are of coarser grain than the quartz of the less altered rocks, while the muscovite is apparently finer than usual. Original phenocrysts of feldspar are indicated by pseudomorphou areas characterized by different groupings of the quartz and muscovite and freedom from iron, while others of ferromagnesian minerals are marked by similar differences of grouping and by a relatively greater abundance of the iron minerals. In all cases, however, the decomposition products are similar. In many areas also the vestiges of the phenocrysts have been effaced.

8. *Ore material (152) of Mizpah vein, 300-foot level, west drift.*—Shows in the hand specimen dense quartz, intermixed irregularly with apparently kaolinic material.

The microscope shows fine to moderately coarse granular and retiform quartz, with much fine muscovite. The quartz contains inclusions. Intermixed with the quartz in the finer-grained areas is adularia in characteristic rhombic-sectioned crystals.

ANALYSES OF DESCRIBED TYPES.

Following are the analyses of these rocks by Mr. George Steiger:

Analyses of different phases of altered earlier andesite.

	1.	2.	3.	4.	5.	6.	7.	8.
SiO_2	55.60	58.47	60.45	71.14	72.98	73.50	76.25	91.40
Al_2O_3	16.70	16.85	17.78	15.24	14.66	14.13	12.84	4.31
Fe_2O_3	2.23	2.04	5.86	1.77	1.01	1.51	.54	.77
FeO	3.51	3.12	.25	.26	.16	.26	.33	.11
MgO	2.60	3.84	1.55	.16	.33	.21	.56	.18
CaO	4.27	1.35	1.04	.09	.18	.12	.16	None.
Na_2O	4.08	4.30	3.58	.24	None.	.24	.12	.06
K_2O	3.17	3.14	2.11	6.31	6.03	5.11	3.20	1.68
H_2O-	.88	1.10	2.86	.85	.97	1.07	2.14	.46
H_2O+	3.06	3.59	2.93	2.87	2.95	2.81	3.17	.98
TiO_2	.72	.77	.81	.48	.44	.47	.37	.07
ZrO_2	Undet.	....	....	....	....	....	....	.02
CO_2	2.76	.52	None.	None.	None.	None.	None.	None.
P_2O_5	.28	.35	.28	.05	.16	.09	.12	.04
SO_3	None.	None.	None.	.05	....	.17	....	None.
Cl	....	....	....	....	....	....	....	None.
F	....	.12	....	....	....	....	....	Trace.
S	None.	....	....	.02	....	.03	....	None.
FeS_2	....	.49	.06	....	....	....	....	....
NiO	....	....	....	....	....	....	....	(a)
MnO	Undet.	.26	(a)	(a)	(a)	(a)	(a)	.06
BaO	.12	.11	.07	.17	(a)	.19	....	.02
SrO	(a)	(a)	(a)	(a)	(a)	(a)	....	(a)
	99.98	100.42	99.63	99.70	99.87	99.91	99.80	100.16

a Not looked for.

1. Lower part of Siebert shaft.
2. Tonopah and California shaft.
3. Fraction No. 2 shaft.
4. Near Mizpah Hill.
5. Near Mizpah vein.
6. Mizpah Hill.
7. Wall of Mizpah vein.
8. Mizpah vein.

DIFFERENCES OF PHASES EXPRESSED BY DIAGRAMS.

The changes in the proportions of the various elements in the rocks can be illustrated by diagrams in such a way as to be clearer than discussion. In fig. 73 the proportions are represented by straight lines. As is usual and more accurate, the proportions plotted are the quotient figures obtained by dividing the weight percentages by the molecular weights. The scale is 0.01 in the quotient figure = one-fortieth inch (fig. 73).

The diagrammatic lines representing the different elements may be grouped together for each analysis, and be arranged as radii of a circle, with lines connecting the ends of the radii to form an irregular polygon, forming a diagram slightly modified from that used by Brögger[a] (Pl. XXIV).

STUDY OF ALTERATIONS INDICATED BY ANALYSES.

ALTERATION OF EARLIER ANDESITE FROM LOWER PART OF SIEBERT SHAFT.

The proportions of the different constituents represented by the diagrams of rock No. 1 (Pl. XXIV) are practically identical with those in a fresh andesite. That this is so is shown by the diagram (*a*), prepared in a similar way to those referred to above, by Prof. W. H. Hobbs, to illustrate the typical composition of andesite.[b] The analysis upon which this diagram was based was obtained by averaging seven analyses of mica and hornblende andesites from the Eureka district, Nevada; Custer County, Colo.; Cartagena, Spain; the Siebengebirge on the Rhine; Panama; and Colombia. The scale of the diagram has been adjusted by the writer to correspond with the scale of his own. From this general correspondence it becomes apparent that the profound alteration which rock No. 1 has undergone has resulted in decomposing the original minerals and changing the constituent elements to new minerals more stable under the new conditions—that is, in the presence of the permeating waters.

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[a] Hobbs, W. H., Jour. Geol., vol. 8, pp. 1-31.

[b] Op. cit., p. 23.

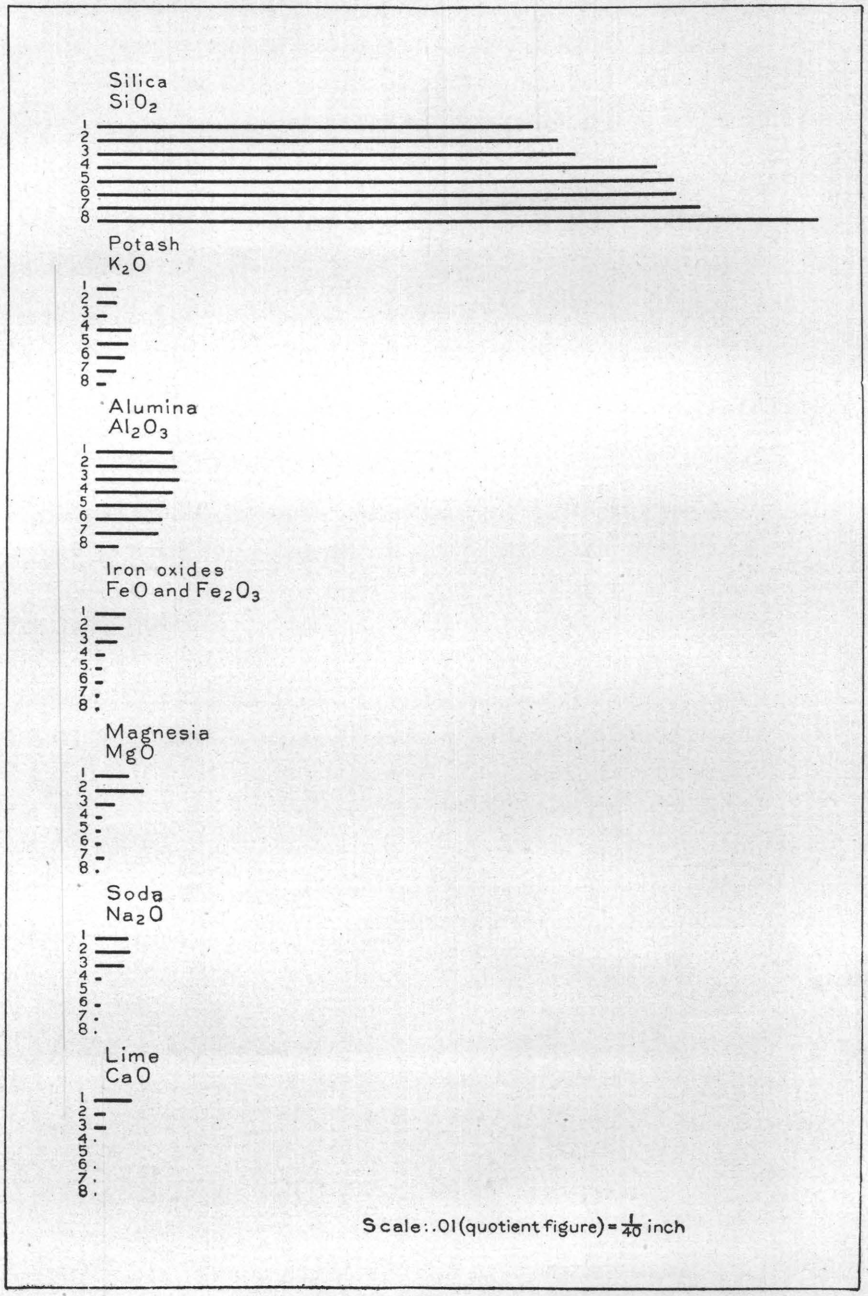
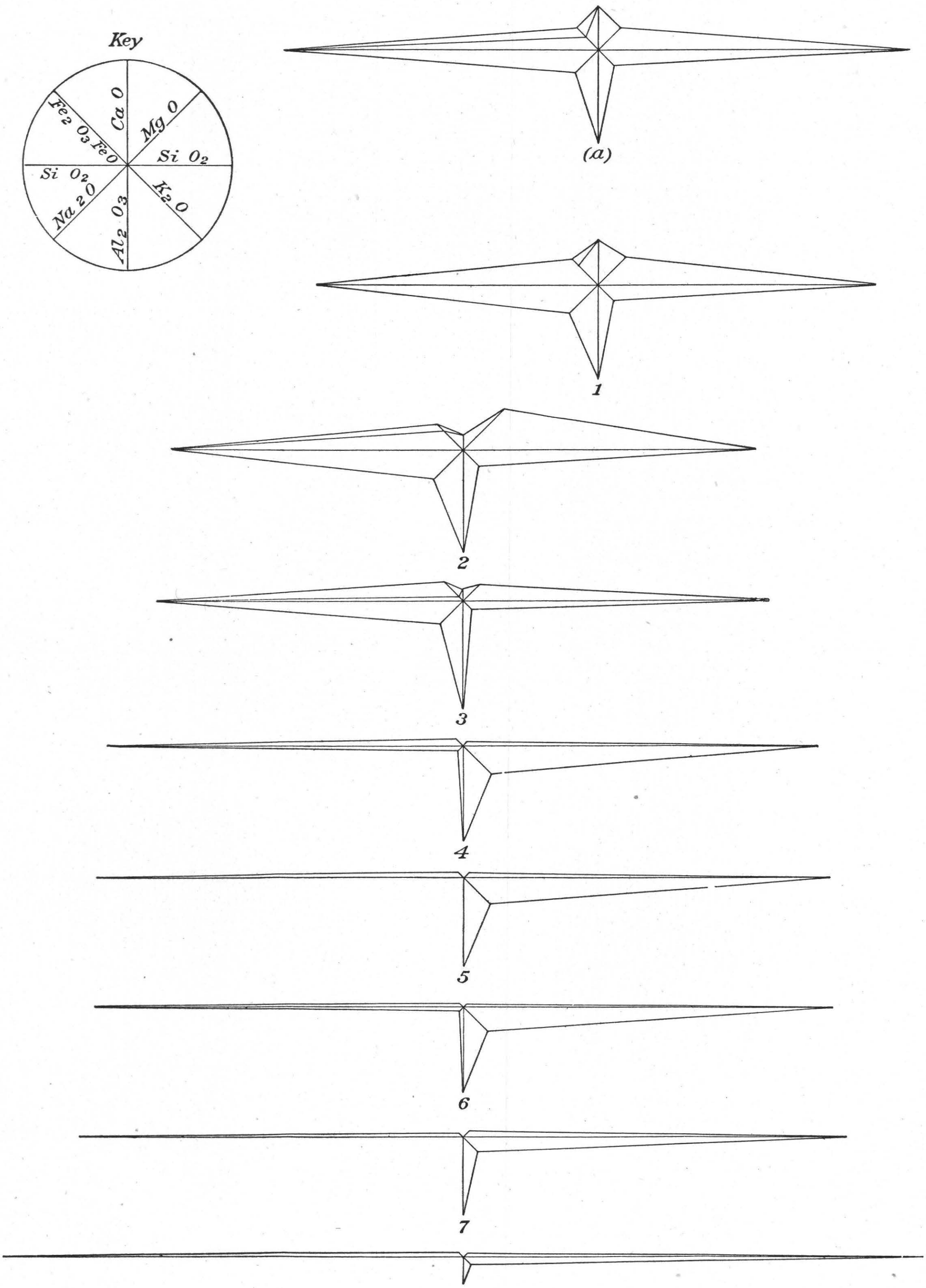


Fig. 73.—Diagram to show changes in amounts of commoner elements during stages of alteration of earlier andesite.


Key
Ca O
Mg O
Si O2
K2 O
Al2 O3
Na 2 O
Si O2
Fe2 O3 FeO
(a)
1
2
3
4
5
6
7
8

A similar conclusion is reached by comparing the analysis of the Tonopah rock with analyses of Eureka and Washoe andesites. For the purpose of comparison, the following table is presented:

Comparison of Tonopah with Washoe and Eureka rocks.

	1. Tonopah.	2. Average type mica-hornblende-andesite.	Washoe rocks.			Eureka rocks.	
			3. Hornblende-mica andesite, Mount Rose.	4. Hornblende-mica andesite, Cross Spur quarry.	5. Mica-andesite, east of Waller Defeat shaft.[a]	6. Andesite-pearlite, south of Carbon Ridge.	7. Pyroxene-andesite, Richmond Mountain.[b]
SiO_2	55.60	62.16	63.30	63.13	65.68	65.13	61.58
Al_2O_3	16.70	16.45	17.81	16.00	15.87	15.73	16.34
Fe_2O_3	2.23	3.27	3.42	4.34	1.78	2.24	....
FeO	3.51	2.71	.83	1.52	1.25	1.86	6.42
MgO	2.60	2.20	2.07	2.07	1.79	1.49	2.85
CaO	4.27	4.13	5.12	4.45	3.50	3.62	5.13
Na_2O	4.08	4.07	4.27	3.87	3.20	2.93	2.69
K_2O	3.17	3.45	2.26	2.65	3.37	3.96	3.65
H_2O	3.94	1.15	....	....	....	....	....
CO_2	2.76	....	....	....	....	....	....
	98.86	99.59	....	....	....	....	....

[a] These are the designations given by Hague, Mon. U. S. Geol. Survey, vol. 20, p. 282. The designations previously given by Becker, Mon. U. S. Geol. Survey, vol. 3, p. 152, are 3 and 4, later hornblende-andesite; 5, mica-diorite.

[b] Mon. U. S. Geol. Survey, vol. 20, p. 264.

The difference between the sums of the first two analyses is largely accounted for by the difference in titanium, of which the Tonopah rock contains 0.72 per cent and the average rock 0.23 per cent. When these are added the sums are 99.58 and 99.82 respectively.

It will be seen that there is a remarkable similarity in the amounts of the bases present in the first two analyses. In the Tonopah rock more of the iron is in the ferric condition, but the amounts of iron in the two rocks are almost identical.

In the altered Tonopah rock the percentage of silica is about 6½ less than in the average type, while that of water is 2¾ greater. The Tonopah rock contains 2¾ per cent of carbonic acid, which is lacking in the average type. Thus the increase of 6½ in the percentage of water and carbonic acid in the Tonopah rock offsets the increase of 6½ in the percentage of silica in the average type. Since free primary quartz is apparently rare in all these rocks,[a] the silica is combined with the bases to form the silicates, feldspar, hornblende, and mica; and since the amounts of the bases are equal in both analyses, the original amount of silica was probably nearly

[a] For the Eureka type see Arnold Hague, Mon. U. S. Geol. Survey, vol. 20, p. 234.

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Comparison of Tonopah with Washoe and Eureka rocks.

	1. Tonopah.	2. Average type mica-hornblende-andesite.	Washoe rocks.			Eureka rocks.	
			3. Horn-blende-mica andesite, Mount Rose.	4. Horn-blende-mica andesite, Cross Spur quarry.	5. Mica-andesite, east of Waller Defeat shaft.[a]	6. Andesite-pearlite, south of Carbon Ridge.	7. Pyroxene-andesite, Richmond Mountain.[b]
SiO_2	55.60	62.16	63.30	63.13	65.68	65.13	61.58
Al_2O_3	16.70	16.45	17.81	16.00	15.87	15.73	16.34
Fe_2O_3	2.23	3.27	3.42	4.34	1.78	2.24	....
FeO	3.51	2.71	.83	1.52	1.25	1.86	6.42
MgO	2.60	2.20	2.07	2.07	1.79	1.49	2.85
CaO	4.27	4.13	5.12	4.45	3.50	3.62	5.13
Na_2O	4.08	4.07	4.27	3.87	3.20	2.93	2.69
K_2O	3.17	3.45	2.26	2.65	3.37	3.96	3.65
H_2O	3.94	1.15	....	....	....	....	....
CO_2	2.76	....	....	....	....	....	....
	98.86	99.59	....	....	....	....	....

[a] These are the designations given by Hague, Mon. U. S. Geol. Survey, vol. 20, p. 282. The designations previously given by Becker, Mon. U. S. Geol. Survey, vol. 3, p. 152, are 3 and 4, later hornblende-andesite; 5, mica-diorite.

[b] Mon. U. S. Geol. Survey, vol. 20, p. 264.

The difference between the sums of the first two analyses is largely accounted for by the difference in titanium, of which the Tonopah rock contains 0.72 per cent and the average rock 0.23 per cent. When these are added the sums are 99.58 and 99.82 respectively.

It will be seen that there is a remarkable similarity in the amounts of the bases present in the first two analyses. In the Tonopah rock more of the iron is in the ferric condition, but the amounts of iron in the two rocks are almost identical.

In the altered Tonopah rock the percentage of silica is about 6½ less than in the average type, while that of water is 2¾ greater. The Tonopah rock contains 2¾ per cent of carbonic acid, which is lacking in the average type. Thus the increase of 6½ in the percentage of water and carbonic acid in the Tonopah rock offsets the increase of 6½ in the percentage of silica in the average type. Since free primary quartz is apparently rare in all these rocks,[a] the silica is combined with the bases to form the silicates, feldspar, hornblende, and mica; and since the amounts of the bases are equal in both analyses, the original amount of silica was probably nearly

[a] For the Eureka type see Arnold Hague, Mon. U. S. Geol. Survey, vol. 20, p. 234.

the same; that is, the transformation of pyroxene, hornblende, and mica in the Tonopah rock largely to calcite, chlorite, muscovite, and hematite was effected without appreciable gain or loss of the bases, but some of the silica was abstracted, its place being taken by water and carbonic acid, which entered into the decomposition products mentioned.[a] Therefore, since these waters abstracted instead of precipitating silica, they were characterized by relative poverty in silica. They were also carbonated. The lack of sulphur and sulphides in rock No. 1 also shows the absence of sulphur combinations in the altering waters.

ALTERATION OF EARLIER ANDESITE FROM CALIFORNIA AND TONOPAH SHAFT.

Tonopah rock No. 2 and the average type may also be compared as to their chief constituents:

Comparison of Tonapah rock No. 2 with average type.

	Tonopah rock No. 2.	Average type.
SiO_2	58.47	62.16
Al_2O_3	16.85	16.45
Fe_2O_3	2.04	3.27
FeO	3.12	2.71
MgO	3.84	2.20
CaO	1.35	4.13
Na_2O	4.30	4.07
K_2O	3.14	3.45
H_2O	4.96	1.15
CO_2	.52	....
FeS_2	.49	....
Total	99.08	99.59

The difference between the totals of these two analyses is again accounted for mostly by the difference in titanium, the percentage of which in the Tonopah rock is 0.77 and in the average rock 0.23. When these are added the total of the Tonopah analysis is 99.85 and that of the average analysis 99.82.

The bases present correspond very closely, the only noticeable difference being in the proportions of lime and magnesia. In the average type the percentage of lime is three times as much, or 2.78 more, and that of magnesia is somewhat more than half as much, or 1.64 less. If the lime and magnesia in each rock are added together the percentage of these constituents is only 1.12 greater in

[a] It is only the water given off above 100° C. (H_2O+ in the analyses, p. 27) which can be considered chemically combined. The rest (H_2O-) is probably mainly hygroscopic, mechanically contained. In the average analysis compared, as well as the Washoe and Eureka analyses, however, this distinction is not made. Therefore all the water in the Tonopah rocks is considered together in comparing with these analyses, and the hygroscopic water in one is supposed to be offset by that in the other. Most of the water in the Tonopah analyses, it will be seen, is chemically combined.

the average type. This change is probably due to the alteration of the hornblende to chlorite, the lime being in part carried out of the specimen instead of being entirely precipitated in place as carbonate, its place being taken by magnesia. These changes are, however, mainly compensating, and probably indicate a local rather than a widespread interchange. Apart from this the correspondence of the bases is close. In the average fresh type, however, the percentage of silica is 3.69 greater than in the Tonopah rock, and that of water is 3.80 less, while the Tonopah rock contains 0.52 per cent carbonic acid. The conclusion is the same as in comparing the first Tonopah rock, that in this second specimen there is an increase of over 4 in the percentage of water and carbonic acid, which has entered into the composition of chlorite and calcite, while this gain has been compensated by a decrease of 3.69 in the percentage of silica. The process of alteration, while not quite so far advanced, is similar to that in rock No. 1, except that the lime has been abstracted and compensated for by an increase in magnesia. The presence of sulphur in the waters is indicated by the relatively small amount of iron oxide which has been changed to pyrite, a change which did not take place in rock No. 1. The carbonic acid present is only a fifth of that in rock No. 1, showing that in the case of rock No. 2 the conditions were favorable to the acid acting as a solvent and transporting the lime from the rock, rather than as a precipitant and entering into the rock's composition. A poverty in lime in the circulating waters is the apparent explanation.

ALTERATION OF EARLIER ANDESITE FROM FRACTION NO. 2 SHAFT.

The comparison between rock No. 3 and the average fresh type may be made as follows:

Comparison of Tonopah rock No. 3 with average type.

	Tonopah rock No. 3.	Average type.
SiO_2	60.45	62.16
Al_2O_3	17.78	16.45
Fe_2O_3	5.86	3.27
FeO	.25	2.71
MgO	1.55	2.20
CaO	1.04	4.13
Na_2O	3.58	4.07
K_2O	2.11	3.45
H_2O	5.79	1.15
CO_2	None.	....
FeS_2	.06	....
Total	98.47	99.59

As in the two former comparisons, the difference in the titanium determined accounts for most of the difference between the totals of these analyses.

In this case the bases have been more plainly affected than in the first two. The most noticeable change is, as before (in rock No. 2), the abstraction of lime, which seems to have been carried farther than in rock No. 2. Yet in this case the loss has not been compensated for by the deposition of magnesia—which has itself been abstracted, though not in so great degree—so that the combined amount of lime and magnesia in rock No. 3 is less than half what it is in the average type. Similarly the alkalies have been extracted; the potash more than the soda. The iron has become more oxidized, but its bulk remains the same. The proportion of alumina has slightly increased, perhaps owing to the loss of weight of the rock, caused by the removal of more material than was brought to replace it. In all, the percentages of lime, magnesia, and the alkalies are 5.57 less in this rock than in the average fresh type. There is also less silica, but the difference in percentage is by no means so great as it was in rocks No. 1 and No. 2, being only 1.71. In the Tonopah rock (No. 3) the percentage of water is 4.64 greater than in the average type, carbonic acid is absent, and there is a very small amount of iron sulphide. In this case, therefore, the gain in water, carbonic acid, etc., is by no means offset by the loss of silica. The chief loss is plainly lime, magnesia, and the alkalies, more particularly lime and next to that potash. In this case the waters have extracted silica to a very slight extent only, and were therefore solutions whose silica capacity was more nearly satisfied than in the case of rocks 1 and 2. The tendency to dissolve and carry away lime—displayed in No. 2—was more vigorous in this rock, and the same action was displayed in regard to magnesia and the alkalies.

ALTERATION OF EARLIER ANDESITE FROM NEAR MIZPAH HILL.

Rock No. 4 may be compared with the average type thus:

Comparison of Tonopah rock No. 4 with average type.

	Tonopah rock No. 4.	Average type.
SiO_2	71.14	62.16
Al_2O_3	15.24	16.45
Fe_2O_3	1.77	3.27
FeO	.26	2.71
MgO	.16	2.20
CaO	.09	4.13
Na_2O	.24	4.07
K_2O	6.31	3.45
H_2O	3.72	1.15
CO_2	None.	....
Total	98.93	99.59

In this rock, as in rock No. 3, the removal of magnesia, iron, and soda has gone on till only trifling quantities remain. In this rock also, the iron, which was relatively free from attack in the first three specimens, has been partly dissolved, so that over half has been removed. Even the difficultly soluble alumina has apparently lost a little, though this is doubtful. Of the metallic bases, iron, lime, magnesia, and alumina, about 40[a] per cent has been removed, and of the same, excluding alumina, about 73 per cent. On the other hand, while soda has diminished, the amount of potash has increased, the increase of one nearly compensating for the loss of the other. The silica also has increased largely.

In this case, then, the waters which altered the rock were charged with an excess of silica and potash, which they deposited, attacking and dissolving all the other components of the rock, the relative order of attack, dependent on their solubility in the attacking waters, being lime, magnesia, soda, iron, and alumina.

[a] In this case, as in many of the similar cases in the following pages, the percentages given are in terms of each constituent. The reader will notice, however, that the percentages are elsewhere given in terms of the entire rock, where such presentation has best lent itself to statement. This is the case with all of the figures on the preceding pages and some in those which follow. The writer believes there will be no confusion brought about by the use of these two methods of presentation; if any such should arise, a glance at the compared analyses will suffice for an explanation.

ALTERATION OF EARLIER ANDESITE FROM NEAR MIZPAH VEIN.

The alteration of No. 5 may be compared as follows:

Comparison of Tonopah rock No. 5 with average type.

	Tonopah rock No. 5.	Average type.
SiO_2	72.98	62.16
Al_2O_3	14.66	16.45
Fe_2O_3	1.01	3.27
FeO	.16	2.71
MgO	.33	2.20
CaO	.18	4.13
Na_2O	None.	4.07
K_2O	6.03	3.45
H_2O	3.92	1.15
Total	99.27	99.59

Here the same processes have been carried on as in rock No. 4, but more thoroughly. As in No. 4, only tiny amounts of the magnesia and the lime are left, while the soda has entirely disappeared. The removal of the more refractory constituents—alumina and iron—has apparently proceeded farther than in No. 4. Of the iron 80 per cent has been removed, against 70 per cent in No. 4; of the alumina about 11 per cent, as compared with about 7 per cent in No. 4. On the other hand, the silica has increased 17 per cent, as against 14 per cent in No. 4. But the potash, while still showing an increase of 75 per cent over the normal proportion in the type analysis, is somewhat less than in No. 4. It appears from this (in conjunction with the succeeding analyses) that the increased activity of the altering solutions, as indicated in the above figures, has begun to attack some of the introduced potash and to replace it by silica, or, perhaps, rather that the balance is more in favor of strong silicification than of the introduction of potash.

ALTERATION OF TYPICAL EARLIER ANDESITE FROM MIZPAH HILL.

The relations of No. 6 are as follows:

Comparison of Tonopah rock No. 6 with average type.

	Tonopah rock No. 6.	Average type.
SiO_2	73.50	62.16
Al_2O_3	14.13	16.45
Fe_2O_3	1.51	3.27
FeO	.26	2.71
MgO	.21	2.20
CaO	.12	4.13
Na_2O	.24	4.07
K_2O	5.11	3.45
H_2O	3.88	1.15
Total	98.96	99.59

This shows the characteristic alteration of No. 5, with some further advances. As in Nos. 4 and 5, the magnesia, lime, and soda are almost entirely eliminated. The alumina is further reduced than in No. 5, 14 per cent of it having apparently been abstracted, while the iron is slightly stronger. The decrease of the excessive potash to make room for the increasing silica noted in No. 5 is here carried further, No. 6 containing 0.92 per cent less potash than No. 5, and 0.52 per cent more silica (in proportion of the whole rock composition).

ALTERATION OF EARLIER ANDESITE FROM WALL OF MIZPAH VEIN.

No. 7 may be compared as follows:

Comparison of Tonopah rock No. 7 with average type.

	Tonopah rock No. 7.	Average type.
SiO_2	76.25	62.16
Al_2O_3	12.84	16.45
Fe_2O_3	.54	3.27
FeO	.33	2.71
MgO	.56	2.20
CaO	.16	4.13
Na_2O	.12	4.07
K_2O	3.20	3.45
H_2O	5.31	1.15
Total	99.31	99.59

This is an intensification of the alteration shown in the immediately preceding analyses. The lime, magnesia, and soda are reduced to trifling quantities. The refractory alumina and iron are further reduced than before, 22 per cent of the alumina and 85 per cent of the iron having been removed. The substitution of silica for potash (as well as the other elements) has made marked progress, the percentage of potash being 1.91 less than in No. 6, and that of silica being 2.75 per cent more. In this way the excessive potash, caused in some of the preceding cases by introduction of this element by the circulating waters, is here again brought down to the original quantity.

ALTERATION OF EARLIER ANDESITE TO VEIN MATERIAL.

Rock No. 8 may be compared as follows:

Comparison of Tonopah rock No. 8 with average type.

	Tonopah rock No. 8.	Average type.
SiO_2	91.40	62.16
Al_2O_3	4.31	16.45
Fe_2O_3	.77	3.27
FeO	.11	2.71
MgO	.18	2.20
CaO	None.	4.13
Na_2O	.16	4.07
K_2O	1.68	3.45
H_2O	1.44	1.15
Total	99.95	99.59

This shows the further continuation of the changes indicated in the preceding analyses, the alumina and potash being gradually removed to make way for the increasing silica.

MAXIMUM ALTERATION LOCATED ALONG THE VEIN ZONES.

The specimens thus examined, selected as being fairly well representative, show an increasing intensity of alteration, beginning with only a slight modification of the constituents of the decomposed rock and terminating with the intense silicification which reaches its maximum in the quartz mineral-bearing vein of the district. Considering the alteration from the standpoint of the altering waters rather than the altered rocks, the order in this transition series is reversed, for these changes have been brought about by solutions which circulated along the fracture zones which are now largely transformed into veins, and penetrated the adjoining rock so thoroughly that no even moderately fresh representative of this earlier andesite has as yet been found in Tonopah. The last stage of alteration in the rock (in the vein zones) was then in a sense the first work of the waters, and the first stage, remote from the main circulation zones, the last; and although the transition as studied is gradual, it by no means follows that the rock near the veins went through all of the stages represented, but may have reached its present condition much more directly.

COMPOSITION OF MINERALIZING WATERS IN THE VEIN ZONES.

In the unoxidized quartz veins the predominating gangue mineral is quartz, with frequent adularia, subordinate muscovite (sericite), and comparatively rare carbonates of lime, magnesia, manganese, and iron. The metallic minerals are most prominently silver sulphide, containing sometimes antimony, arsenic, etc.; silver selenide, gold in some form, copper-iron sulphide (chalcopyrite), iron sulphide, and probably silver chloride. The mineralizing waters were then charged with an excess of silica, and also probably, as the comparative analyses indicate, of potash, together with silver, gold, antimony, arsenic, copper, lead, zinc, selenium, etc. They were noticeably deficient in iron, since they have removed this metal from the vein zones and the adjacent rock, more and more completely in proportion as their work has been thorough, and the iron left in the veins is clearly a residuum. That they contained carbonic acid and sulphur is shown by the formation of sulphides and carbonates, not only in the veins but in the altered rock. That they contained some chlorine and fluorine, though not in excessive amounts, is indicated by the presence of a little original silver chloride and by their work in forming muscovite, as will presently be explained.

In the vein zone the maximum effect of these waters was a replacement of nearly everything by precipitated silica. By a similar process of replacement the sulphides, of which silver sulphide was the most prominent, were precipitated, and the residue of the comparatively refractory iron was combined with free sulphur to form pyrite. The residue of the comparatively refractory alumina combined with the excessive silica and potash of the waters to form adularia and muscovite (sericite).

RELATION OF ADULARIA TO SERICITE AS ALTERATION PRODUCTS.

It is necessary at the present point of the inquiry to investigate the conditions of formation of adularia and of muscovite. Both are silicates of aluminum and potassium, and both are conspicuous as secondary products in the altered andesite, especially of the feldspar. The typical andesine-oligoclase alters sometimes to adularia, sometimes to quartz and muscovite, sometimes to both. That one of these products is not the alteration product of the other is shown by the fact that they are often intercrystallized, each mineral being perfectly fresh. That, however, they depend upon slightly different conditions for their formation is indicated by the fact that some profoundly altered specimens show the feldspar almost entirely altered to adularia without muscovite, while others show complete alteration to quartz and sericite without adularia. Adularia requires more silica than muscovite, but its formation in preference to the latter does not necessarily depend on this fact, for when muscovite is formed in these rocks an amount of free quartz is separated out equivalent to the quantity which would have gone into the adularia, as is shown by the analyses of rocks 5, 6, and 7, of which 5 and 7 are altered chiefly to quartz and sericite, and 6 chiefly to adularia. This difference is not shown in any way by the bulk analysis of the rocks, the relation of the elements harmonizing in the two cases.

FORMATION AND OCCURRENCE OF ADULARIA.

CONDITIONS REQUIRED FOR THE FORMATION OF ADULARIA.

Adularia is a variety of orthoclase, which is a silicate of aluminum and potassium. It is distinguished from ordinary orthoclase chemically by being nearly pure,[a] while ordinary orthoclase contains a variable and often large amount of soda. Crystallographically adularia has usually an entirely different habit from ordinary orthoclase, and this crystallographic difference is apparently controlled by the difference in chemical composition. While ordinary orthoclase is one of the commonest primary minerals in igneous rocks, especially in the more siliceous varieties, the writer is not aware of adularia occurring in this way. On the other hand it is known as a secondary mineral in metamorphosed rocks and in veins. Still, experimental investigations do not seem to show any essential difference in the conditions of formation.

Orthoclase, muscovite, and quartz are all minerals which have not yet been artifically reproduced by the cooling of dry melts, in spite of many careful attempts.[b] All these may, however, be formed in the presence of such agents as water, chlorides, fluorides, boron compounds, tungstic acid, etc., without which they apparently can not crystallize. These agents, so potent in the formation of minerals, but entering into their composition slightly or not at all, are called "mineralizers" (agents minéralisateurs).

Friedel and Sarasin heated a mixture of potassium carbonate, alumina, silica, and water in a platinum-lined iron tube to about 500° C., for fourteen to thirty-eight hours, and obtained tiny quartz crystals and rhomboidal tablets of feldspar. Similar more abundant feldspar crystals were obtained by heating aluminum chloride,

[a] It usually contains, however, a little soda, lime, etc.

[b] Vogt, J. H. L., Mineralbildung in Silikatschmelzlösungen, p. 6.

potassium silicate, a little potassium carbonate and water. Analysis showed that this mineral had the composition of adularia mixed with a little quartz. The feldspar crystals were sometimes of the ordinary orthoclase habit, and sometimes of the adularia habit.[a] The same investigators obtained orthoclase crystals by heating potash, silica, and muscovite in water in the same apparatus as mentioned above, and at the same temperature.

Calcite, in rhombohedral crystals, it may be remarked,[b] was also obtained under similar conditions (temperature 500° C.) by heating precipitated calcium carbonate and calcium chloride with water for ten hours.

ADULARIA AS A METAMORPHIC MINERAL.

Apart from the primary orthoclase in igneous rocks, secondary orthoclase, due beyond question to attenuated watery solutions, distinct in every way from rock magmas, has been often described as occurring in nature. Van Hise[c] showed that clastic grains of orthoclase in sandstones on the north shore of Lake Huron had been enlarged by a secondary similarly oriented growth. In St. Gotthard, in the Alps, little druses in a fine-granular quartz-albite rock contain clear crystals of adularia intercrystallized with calcite, both of which are younger than the constituents of the rock. In some cases the adularia is provedly younger than the calcite, and in one case it incloses older calcite and chlorite—both water-formed minerals—showing that the feldspar originated as a precipitate from solution.[d] In Chester County, Pa., orthoclase occurs in dolomite, indicating that no intense heat was present at its formation.[d] In the metamorphosed zones near the contact of intrusive igneous rocks it is frequent, as was shown by Allport, and later by Teall,[c] to be the case in altered lower Silurian slates in England, and by Lossen[c] in the Harz.

ADULARIA IN VEINS.

Adularia as a gangue mineral in veins has also been described a number of times. In a vein in the Herzog Ulrich mine at Kongsberg, in Norway, Hausmann[e] found adularia with quartz, pyrite, and dolomite. In veins in Schemnitz, in Hungary, Wiser[e] found crystalline adularia associated with quartz, dolomite, pyrite, chalcopyrite, blende, and gold. In the Lake Superior copper mines orthoclase occurs in veins, associated with calcite and native copper; the feldspar, like the other minerals, is plainly formed in the wet way, and was deposited later than the copper and the calcite. Adularia occurs also in several places of special

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[a] Bull. Soc. française de min., vol. 4, 1881, pp. 171–175, Chemisches Centralblatt, 1892, vol. 1, p. 865.
[b] In connection with the occurrence of calcite and adularia in the same veins at Tonopah.
[c] Cited by Zirkel, Lehrbuch d. Petrographie, vol. 1, p. 243.
[d] Bischof, Gustav, Chemische Geologie, vol. 2, p. 401.
[e] Cited by Bischof, Chemische Geologie, vol. 2, pp. 398–399.

interest because of their geographic and geologic relations to the Tonopah district. It is found sparingly in the Apollo vein, Unga Island, Alaska (adularia or orthoclase). It has been described from the Valenciana silver mine, in the State of Guanajuato, Mexico, where it was called valencianite. Lindgren has described it as a common gangue mineral in the Silver City, Idaho, veins (see p. 272). These ores are probably post-Miocene, and Mr. Lindgren gives reasons for considering that the deepest ore bodies were formed at a distance of 700 to 2,000 feet below the original surface. He therefore considers that the temperature at the time the vein was formed can hardly have exceeded 100° C.[a]

At Boulder Hot Springs, Montana,[b] are springs of a temperature varying from 120° to 164° F.[c] which contain a slight amount of sulphureted hydrogen, sodium chloride, soda sulphate, and carbonates of soda, lime, and magnesia. The granite through which they rise is altered in the vicinity of the springs, the most notable products being sericite and kaolinite, the result of the alteration of feldspar and quartz. Calcite does not occur in the altered rock, and has apparently been carried out of it by the altering waters into the fissures, where it has been deposited. Veins which have formed in this granite contain chiefly medium-grained quartz, calcite, and stilbite, and a little adularia. These veins contain slight but perceptible amounts of gold and silver.

At Cripple Creek, Lindgren found that adularia has been formed in the granite near the veins, together with sericite and chlorite. Within cavities produced by the removal of the granite, iron pyrite, fluorite, and tellurides have been deposited.[d]

CHEMISTRY OF THE ALTERATION OF SODA-LIME FELDSPAR TO ADULARIA.

The chemistry of the change from andesine-oligoclase to adularia seems to be fully explained by the following statements of Bischof,[e] in speaking of observed cases where adularia was altered to albite:

"The unequal effect of water upon different mineral substances is mainly based upon the fact that it holds materials in solution, which decompose one mineral but not another. Sodium chloride decomposes potassium silicate, and potassium chloride and sodium silicate are formed. Thus waters which hold sodium chloride can decompose potash feldspar, while it leaves soda feldspar undecomposed.

"In this way it is possible that such water may either change potash feldspar to soda feldspar, or that it may take up and remove the alteration products of the former. We can realize then how water containing sodium chloride (and this is

[a] Lindgren, W., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 165-167.

[b] Weed, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 235-248.

[c] By personal communication with Mr. Weed the writer learns there is evidence that these springs reach the boiling temperature not many feet below the surface.

[d] Lindgren, W., Trans. Am. Inst. Min. Eng., vol. 33, p. 589.

[e] Bischof, Gustav, Chemische Geologie, vol. 2, p. 411.

rarely absent in waters) breaks up the potash silicate in the adularia and removes the new-formed soda silicate with the separated alumina silicate, while the sodium silicate contained in the adularia, with the combined alumina silicate, remains as albite.

"*On the other hand, potassium carbonate decomposes sodium silicate. It is therefore possible that water containing potassium carbonate may either transform soda feldspar into potash feldspar or that the alteration products of the former may be taken up and removed. Such water brings about the opposite of that in the first case.*"[a]

This explanation corresponds with the conclusion as to the excess of potash in the mineralizing waters, derived from a comparison of the rock analyses.

FORMATION AND OCCURRENCE OF MUSCOVITE.

CONDITIONS REQUIRED FOR THE FORMATION OF MUSCOVITE.

Muscovite, as previously noted, has never been formed artificially by cooling from dry fusion. Concerning its formation, as well as that of other micas, Doelter observes:[b]

"Mica results from heating aluminum silicate with potassium fluoride or magnesium fluoride; the fluorides seem to assist on the one hand because the fluoric vapors which form bring about the crystallization, and so play the same part as in the transformation of amorphous alumina into corundum; on the other hand the influence is also chemical, since small quantities of fluorine enter into the composition of the mica."

Brauns remarks:[c]

"Any mica can be easily formed if one melts any mineral containing its elements with any fluoride at a temperature below 800° C.; for in higher temperatures the micas are not stable."

Of the micas, biotite or magnesia mica is found in many volcanic rocks, such as rhyolites, dacites, and andesites, while muscovite is not; neither does muscovite occur in the deeper seated igneous rocks save in granites, where it is common,[d] and generally occurs together with quartz and potash feldspar.[e] Evidently, then, muscovite demands for its formation special conditions not present in lavas or in ordinary rock magmas and different from those necessary for biotite.

MUSCOVITE AS AN ALTERATION PRODUCT.

Muscovite is common as a secondary mineral—the alteration product of many other minerals, such as feldspar, nepheline, leucite, etc.—and in these cases is evidently the result of the action of waters, probably heated. It is very abundant

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[a] The italics are the writer's (J. E. S.).
[b] Doelter, C., Allgemeine Chemische Mineralogie, p. 161.
[c] Brauns, R., Chemische Mineralogie, p. 247.
[d] Rosenbusch-Iddings, Microscopical Physiography of the Rock-making Minerals, p. 264.
[e] Brauns, op. cit., p. 301.

in the metamorphic rocks, such as the crystalline schists. It forms pseudomorphs after orthoclase in tin veins,[a] where it is associated with cassiterite, tourmaline, and quartz, and owes its origin plainly to the action of water and other mineralizers, among them undoubtedly fluorine; near the veins the granite is entirely altered to a mixture of quartz and muscovite by the same processes. Weed has described it as produced in granite by the action of hot-spring waters in Montana.[b]

DISTINCT CONDITIONS REQUIRED FOR MUSCOVITE AND FOR BIOTITE.

While muscovite is the alteration product of so many minerals, it seems itself not at all subject to ordinary alteration, but is characteristically fresh, even in highly decomposed rocks.[c] Here again it shows its distinction from biotite, which in rocks traversed by waters is easily altered to chlorite, iron oxides and carbonates, quartz, epidote, etc., showing that its conditions of formation were different. In many granites, indeed, muscovite and biotite have been found side by side, and in these rocks the conditions for the formation of the two coincide, but on the one hand stands the range of biotite into the more basic igneous rocks and the lavas where muscovite does not occur, and on the other is the range of muscovite among the minerals formed by circulating waters, where biotite does not ordinarily occur. Plainly, then, the average or ordinary conditions under which biotite forms are more heat and less water than muscovite, in whose formation the evidence of comparatively little heat and abundant water is often conclusive; and the upper extreme of the muscovite range overlies the lower extreme of the biotite range only in the granites, a fact which affords some insight into the conditions of formation of this rock.

THE SERICITIC VARIETY OF MUSCOVITE.

The fine-grained muscovite (which is often the secondary product of other minerals and occurs as fine fibrous aggregates) is called sericite. Sericite, however, does not differ from muscovite, and has the same relation to the coarser variety (between which and it transitional grades of coarseness are often observable) that the fine secondary quartz has to the coarser grains. For that reason the author uses the words muscovite and sericite interchangeably in referring to the fine-grained variety.

FLUORINE NECESSARY TO THE FORMATION OF MICA.

Not only has the presence of fluorine been shown to be necessary for the artificial reproduction of mica, but fluorine enters into the composition of the mineral, being most abundant in the best crystallized varieties.[d] The sericitic variety, then,

[a] Rosenbusch-Iddings, Microscopical Physiography of the Rock-making Minerals, p. 286.
[b] Weed, W. H., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, p. 247.
[c] Zirkel, Lehrbuch d. Petrographie, vol. 1, p. 340.
[d] Bischof, Gustav, Chemische Geologie, vol. 2, p. 79.

may be assumed to have crystallized in the presence of a less potent amount of fluorine, and indeed the analyses given by Dana[a] do not show any fluorine, while the analyses given for ordinary muscovite sometimes do and sometimes do not show it. To determine its presence in the altered Tonopah andesite, two tests for it were made, in No. 2 and No. 8 (pp. 213, 216). No. 2 showed 0.12 per cent, No. 8 a trace. No sericite was identified in No. 2, while No. 8 (the vein) contains it. The tests therefore are not convincing as to the fluorine being contained in the mica, but indicate its presence in the waters which altered the rock. No. 2, it may be noted, now contains between three and four times as much water as No. 8.[b]

CHEMISTRY OF THE ALTERATION OF SODA-LIME FELDSPAR TO SERICITE.

The alteration of soda-lime feldspar by carbonated waters, according to Rosenbusch,[c] may produce calcite, sericite, and quartz. If the former is carried away by the permeating waters only quartz and sericite results, as in the case of orthoclase.[d] Where orthoclase is similarly altered, some potassium carbonate goes into solution. Similarly Bischof[e] suggests, as an explanation for pseudomorphs consisting largely of muscovite (sericite) after feldspar, such as he describes, that part of the alkaline silicates of the feldspar was decomposed by carbonic acid, their silica remaining and their alkalies being removed as carbonates; another part of the silicate was removed as such; and the rest of the silicate went to form the mica. In this way a mixture of mica and quartz originated.

The analyses of sericite pseudomorphs after feldspar, given by Bischof in connection with his above-cited explanation, show in many cases the presence of fluorine; whence the suggestion arises that though carbonic acid decomposes the feldspar, it may still require the help of a small quantity of fluorine for the decomposition products to crystallize as muscovite.

CHANGES IN RARER CONSTITUENTS DURING ALTERATION OF EARLIER ANDESITE.

The evidence afforded by the rarer constituents of the rock is less trustworthy, on account of the small amounts present. The percentages of titanium, barium, and phosphorus in the different rocks are represented in the diagram forming fig. 74, the scale being ten times that employed for the commoner rock constituents in fig. 73 (p. 218). It is here seen that the titanium behaves much like the alumina, increasing with the increasing silica in the first three specimens, and

[a] System of Mineralogy, p. 618.

[b] Fluorine is abundant among the exhalations of cooling igneous rocks, is also found in many ordinary waters, in spring waters, and even in sea water. (Bischof, Gustav, Chemische Geologie, vol. 2, pp. 86-89.)

[c] Elemente der Gesteinslehre, Stuttgart, 1898, pp. 70-71.

[d] This change involves the substitution of potash for soda.

[e] Bischof, Gustav, Chemische Geologie, vol. 2, p. 743.

slowly decreasing with the increasing silica in the last. The phosphorus, though present in still smaller amounts, behaves in much the same way, while the record of the barium seems irregular. It appears, then, that even the resistant rutile and apatite of the andesite were slowly attacked and in part dissolved by the mineralizing waters. The amount of combined water in the different rocks does not vary in any symmetrical way, and, indeed, remains nearly the same (about 3 per cent) except in No. 8. Carbonic acid was noted only in Nos. 1 and 2, but microscopic analysis shows that siderite is usually present, often in very small quantity, in most of the other rocks.

RÉSUMÉ OF EFFECTS OF MINERALIZING WATERS.

The mineralizing waters, penetrating vigorously the rock on each side of their main circulation channels, did not retain their metallic contents, which were all deposited in favorable places in the main channels or in special lateral channels which became lesser veins. However, they attacked the rocks vigorously by virtue of the carbonic acid, probably also sulphuric acid, and perhaps to a less extent by the acids of chlorine and fluorine. The ferromagnesian minerals were decomposed, the lime and magnesia were taken into solution, and the iron was mainly dissolved, but in part was altered to iron sulphide by the sulphur in the waters. The feldspar was altered, probably by potassium carbonate, to adularia, or to sericite and quartz, the lime and soda being taken into solution. To compensate for these dissolved materials, silica was deposited from the highly charged waters. So great was the necessity of depositing the silica that it probably takes the place of part of the alumina, and also seems to have replaced even part of the potash, though this is not certain. The waters, then, after passing through a rock like No. 8, emerged poorer in silica and richer in all the other rock constituents. On passing farther and traversing a rock like No. 7, the process was carried further, though the excess of silica was not so great, and the capacity of the solutions for the different rock materials became somewhat less. Hence the least soluble, such as the alumina, was not so much dissolved, while lime, magnesia, and soda were thoroughly extracted. On passing from rocks like 6, 5, and 4 the

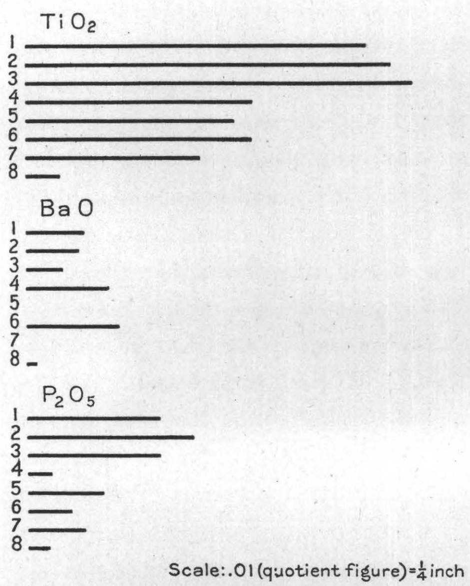

FIG. 74.—Diagram showing relative proportions of the less common elements in the various stages of alteration of the earlier andesite.

process is continued with diminishing strength. Potash here is thrown down by the waters, and its amount is greater than in the original rock. It might be argued that in these rocks it may be a concentration, and that its percentage increase is only apparent, and is due to its remaining constant while the volume of the rock increases; but the decrease in the similar rocks 7 and 8 shows that this can hardly apply. Again, it may appear that the increased potash in the zone represented by 4, 5, and 6 was extracted from the zone represented by 7 and 8, and that the original waters did not necessarily contain much potash; but the formation in the main vein zones of often large proportions of potash minerals bespeaks an original large amount of this element, as noted on a preceding page.

CHANGES IN WATERS AS A CONSEQUENCE OF ROCK ALTERATION.

The waters that traversed and altered this broad belt of rock,[a] by the deposition of silica and of potash, were themselves affected by the interchange and emerged into the outer zones quite transformed. Rock No. 3 indicates that they had no longer any excess of silica and that their solvent power was much weaker. Still they dissolved part of the lime and magnesia in the rock, as well as the alkalies, particularly potash. The fact that they dissolved potash shows that they no longer contained an excess of this element. Rock No. 2, still farther removed from the center of circulation, shows less change in the bases, the alkalies being practically unaltered. The lime and magnesia have been disturbed, but not to so great an extent as in No. 3. As in No. 3, much of the lime has been extracted (though not so much as in No. 3), but while in No. 3 the magnesia also has been extracted, this constituent is relatively increased in No. 4, and largely compensates for the loss of lime. Here, then, the waters replaced some lime by magnesia and abstracted another part. The analysis also indicates that some silica was abstracted. By this time, therefore, the waters had so effectually precipitated the great excess of silica indicated by their first effects (as, for example, in No. 8) that they were now able to take up fresh silica from the rocks which they traversed instead of precipitating it. The presence of carbonic acid and of sulphur is indicated by the pyrite and by the analysis. The carbonic acid, though undoubtedly active as an agent in the altering processes, was in the more highly altered types so hard pressed by the more urgent silicification that it was free to form very little carbonate; but on the

[a] On account of the small area of outcropping earlier andesite at Tonopah, the dimensions of these zones, such as the zone of silicification, can not be given. They are probably variable. The earlier andesite outcrops within the limit of the map only on Mizpah Hill and Gold Hill, covering a maximum east-west extent of over 2,000 feet. Several veins outcrop in this distance, principally on Mizpah Hill. Nearly all of this andesite is silicified in varying degrees, the less altered specimens coming principally from underground workings in areas where the andesite does not outcrop.

outer edge of the altered zone, as in No. 1, the case was different. Here calcite was abundantly formed and, with abundant chlorite, makes up a good part of the rock which now exhibits the typical "propylitic" alteration.

PROPYLITIC ALTERATION OF EARLY ANDESITE.

Propylite was a name applied in 1867 by von Richthofen to certain early Tertiary volcanic rocks of Nevada and California, especially to rocks observed near the Comstock lode in Nevada. It was defined as being always porphyritic, and very similar to porphyritic diorite, with oligoclase feldspars and dark-green fibrous hornblendes, in a green groundmass which owes its color to small particles of fibrous hornblende; as being very rich in mineral veins, and the earliest of the Tertiary volcanic rocks. These definitions were accepted and new areas of propylite were discovered by many prominent geologists. But Dr. G. F. Becker's work, published in 1882, showed that the "propylites" near the Comstock were altered rocks originally identical with fresh diorites, andesites, etc., from the same region; that the characteristic supposed green fibrous hornblende was chlorite, a decomposition product; and that this rock phase owed its association with mineral veins to the altering mineral waters which produced the veins and this rock at the same time.[a] Other investigators have come to the same opinion, and the name propylite, as signifying a rock type, has been dropped. It has, however, been sometimes used to signify this especial form of alteration, and is in this sense characterized by Rosenbusch as follows:[b]

"The characteristic feature of the propylitic facies consists in the loss of the glassy habit of the feldspars; in the chloritic alteration of the hornblende, biotite, and pyroxene (often with an intermediate stage of uralite), with simultaneous development of epidote; further, in alteration of the normal groundmass into holocrystalline granular aggregates of feldspar, quartz, chlorite, epidote, and calcite, and in a considerable development of sulphides (usually pyrite)."

Epidote has not been detected in the earlier andesite at Tonopah, and is rare in the district in general; otherwise the rocks like 1 and 2 correspond to the "propylitic" phase. At the Comstock Becker[c] found epidote uncommon underground, while abundant at the surface.

Mr. Waldemar Lindgren[d] has considered gold and silver veins accompanied by a "propylitic" alteration of the wall rock as a group, and has separated them from another class (the sericitic and kaolinitic gold and silver veins) whose wall rocks show characteristic alteration to sericite and kaolin. In a subsequent note he remarks that "it is perhaps not advisable * * * to retain the name propylitic for the whole group, as some of them do not show alteration in typical form.[e]

[a] Mon. U. S. Geol. Survey, vol. 3, p. 88, etc.
[b] Elemente der Gesteinslehre, Stuttgart, 1898, p. 302.
[c] Mon. U. S. Geol. Survey, vol. 3, p. 212.
[d] Trans. Am. Inst. Min. Eng., vol. 30, pp. 645-654, 658-666.
[e] Ibid., vol. 33, p. 798.

With this last conclusion the writer is in accord, for the Tonopah district seems to show clearly that the distinctions between the two classes of veins are artificial, the predominating alteration of the wall rock, whether to sericite and quartz, or to chlorite, calcite, etc., depending not so much upon the original character of the wall rock or the waters, as upon the abundance and intensity of the latter, and on the size of the circulation channels; and in each case the vein materials may be the same. The writer has already pointed out the close analogy of the Comstock and some other districts to the Tonopah district; in some of the districts the one phase of alteration is especially represented, in others the opposite extreme.

FINAL COMPOSITION OF MINERALIZING WATERS.

The waters which accomplished the "propylitic" alteration of Nos. 1 and 2, therefore, were capable by virtue of their carbonic acid, etc., of decomposing the original minerals and forming new carbonated and hydrated minerals which were more stable under the new conditions. They were not able to remove any large quantities of the bases, with the exception of a slight amount of lime, magnesia, and silica, and of the alkalies. The character of such waters would then be very different from what it was when they were fresh from their channels of active circulation. They were at first, if the reasoning is correct, highly charged with silica and potash, with some carbonic acid and sulphur, and with silver and gold and relatively small quantities of other metals. They would finally, as a result of their interchange with the rocks which they have so profoundly altered, be less highly charged with mineral substances and would contain soda largely in excess of potash, important amounts of lime and magnesia, some iron, a little silica, and a very little alumina; and at the best only traces of the rarer metals. The wall rock in fact has, by its reactions with the mineralizing solutions, acted as a screen, and has separated successively the different constituents from the waters. Similar phenomena have been previously observed, and a chemico-physical explanation (the hypothesis of osmotic action) has been offered.[a] Dr. G. F. Becker remarks:

"On this hypothesis the concentration of ores in deposits would be largely due to the fact of the lack of action between their solutions and the wall rocks; and the decomposition of the country rock, so often observed near veins, would be due to the absorption of solutions of gangue minerals by the walls. In short, there would be a species of concentration by dialysis."[b]

The writer's explanation, however, as indicated above, is of a purely chemical character. He assumes that the ores of the veins did not penetrate far into the wall rocks because they were all immediately precipitated in the main cir-

[a] Becker, G. F., Mineral Resources U. S. for 1892, U. S. Geol. Survey, p. 156; Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 68. Lindgren, W., Trans. Am. Inst. Min. Eng., vol. 30, p. 691.

[b] Mineral Resources U. S. for 1892, U. S. Geol. Survey, p. 157.

culation channels, just as the excessive silica did not penetrate to the "propylite" belt of the andesite because it was precipitated before it arrived there. The evidence, elsewhere offered, that the veins themselves have formed chiefly by replacement is plainly in favor of the writer's explanation.

If such changes take place within a space of a few hundred yards, more or less, laterally from main circulation channels, they must take place also along those channels upward (though they would require a much greater distance), for such veins as those at Tonopah, where the channels were for the most part not open fissures, but only zones of maximum fracturing in the rock, and the vein formation involved intense replacement and interchange. When the waters which accomplished this change emerged above they would be in the transformed condition described for the lateral moving waters emerging from the propylitic stage of alteration—that is, they would resemble the waters of many hot springs, or the hot mine waters of the Comstock (see p. 212). It is not necessarily true that springs, even hot springs, associated with mineral deposits have a composition similar to that of the mineralizing waters. As the mineralized area is eroded the critical area for mineralization will in many cases probably retreat lower down, and the same interchange between water and rock will be effected at a lower level. When such water reaches the surface, after flowing through and being again to some degree affected by the ores and the altered rock (which were stable under the conditions of original deposition, but now under different conditions are subject to solution and redeposition), it will still contain the solutions resulting from the mineralizing reactions, rather than those which accomplished the mineralization. This may perhaps explain in part why, although the formation of veins by hot springs has in many cases been pretty satisfactorily demonstrated, and many such springs emerge at the surface at the boiling point or over, no satisfactory observation has as yet been made of such a spring depositing near its exit a definite and typical vein.

ALTERATION OF THE LATER ANDESITE.

The later andesite is not altered as much as the earlier andesite; it outcrops over a much greater area, and is often found nearly fresh, save for the processes of surface weathering, under which it disintegrates and decomposes easily. At many places, both at the surface or underground, it is greatly decomposed. This alteration is extremely irregular.

STUDY OF TYPICAL SPECIMENS.

Four analyses have been made to show the composition and alteration of the later andesite. The rocks analyzed are described as follows:

1. *Nearly fresh later andesite (225) from Mizpah Extension shaft, 245 feet down.*—Rock nearly black, dense, and basaltic looking. A very dark green dense

groundmass shows fresh crystals of feldspar and augite largely altered to serpentine.

Under the microscope the groundmass is seen to be densely packed with microlites of feldspar and augite partly altered in the same characteristic way as the phenocrysts, which are to be next described. Magnetite is plentiful. Siderite in small specks is scattered throughout in characteristic cloudy, semitransparent white aggregates. Sometimes this mineral forms a rim around the magnetite, showing derivation from it. In some cases there may be discerned characteristic rhombic cleavage and even rhombic crystal outlines.

The phenocrysts vary in size from the microlites up to occasionally moderately large crystals. They are of feldspar and colorless augite.

The feldspar is in general remarkably fresh. It is usually striated, and is sometimes in complex forms. Two optical determinations by the Fouqué method showed, in one case andesine, in another labradorite. It is seamed and cracked, and the cracks are filled with calcite and serpentine, evidently infiltration products. In places the feldspathic substance is attacked and replaced by these minerals.

Idiomorphic colorless augite is abundant. Alteration to calcite and serpentine is present in all stages, so that while some augite crystals are unattacked others are completely transformed. Chlorite was not identified. Small apatite crystals were noted as inclusions in the augite.

2. Nearly fresh later andesite (349) from Halifax shaft, 275 feet down.— Greenish rock, showing phenocrysts of glassy feldspar (altered along the outside), greenish augite, and biotite.

Under the microscope the groundmass is glassy, with fine microlites of fresh feldspar and augite, magnetite, micaceous hematite, and considerable cloudy kaolin. Quartz (secondary?) is common.

The phenocrysts are relatively few. The feldspar is fresh, and one crystal was determined as andesine. Sometimes it is altered to a cloudy white aggregate of kaolin along its margin, and in one case a small crystal was completely altered to calcite, kaolin, and quartz, the clear quartz forming an envelope for the rest of the crystal. The fresh feldspar is cracked and infiltrated with micaceous hematite. The augite is pale green; no alteration of it was noted.

Fresh brown biotite crystals sometimes have a border of magnetite.

3. Entirely altered later andesite (331) from North Star shaft, 305 feet down.— This has a general gray color, with dull-white altered feldspar phenocrysts; it contains many small specks and seams of pyrite. Under the microscope it is seen to be entirely altered. In the fine groundmass can be distinguished fine secondary quartz and chalcedony, calcite, pyrite, siderite, and some zeolite needles.

The phenocrysts are also entirely altered. Pseudomorphs after biotite were distinguished, consisting mainly of quartz and siderite. Numberless tiny crystals are seen arranged in zones parallel to the rays of the pressure figure.[a] These have often the characteristic crystal form of siderite. They are translucent under high powers, but under lower powers show in aggregate the white, cloudy appearance characteristic of siderite. Between these siderite zones is quartz.

Pseudomorphs of calcite after pyroxene, with a few tiny zeolite needles and some siderite, were noted.

Pseudomorphs after feldspar consist of calcite and an aggregate of fibers resembling in large part sericite, with some zeolite needles.

Pyrite and siderite are abundant, disseminated or in clusters. The siderite frequently forms alteration rims around the pyrite. Aggregates of siderite sometimes show characteristic cleavage and even crystal outline.

Small smoky apatites occur in the pseudomorphs after biotite.

4. Entirely altered later andesite (219) from Montana Tonopah shaft.—Type for first 278 feet. Green pyritiferous rock, mottled with white feldspar phenocrysts, and with apparent kaolin coatings on joints.

Under the microscope the rock is seen to be entirely decomposed. The groundmass is a white, opaque aggregate containing quartz, some siderite, and much cloudy material (which is very likely kaolin), with some chloritic material.

The feldspars are completely altered to pseudomorphs, made up of calcite and a clear, colorless aggregate showing sometimes rather low interference colors, while many fibers reach yellow, red, and even blue of the first order. The individual grains are fine, and are often in the shape of vermicular strips, made of fibers perpendicular to the long direction of the strips. Along these strips the extinction is wavy, traveling from one end to the other, similar to the behavior of spherulites. Also occasionally similar clear areas are nearly isotropic, low, doubly refracting and faintly spherulitic, like the pseudomorphs after feldspar described in specimen 53 (p. 214), where the material seems to be a kaolinic mixture. Other areas are of low-refracting spherulitic material, resembling chalcedonic silica.

Portions of this white pseudomorphous mixture, showing still the feldspar cleavage, were separated from the rock, and were tested chemically by Mr. George Steiger, of the United States Geological Survey. The calcite was leached out of these pseudomorphs and the remainder was examined and found to contain, besides considerable combined water, principally silica and alumina, with a small proportion of magnesia, roughly estimated at about 4 or 5 per cent. The material therefore appears to be a mixture of an aluminous mineral with some magnesian mineral, probably talc, and with free silica.

[a]See Rosenbusch-Iddings, Microscopical Physiography of the Rock-making Minerals, 2d. ed., p. 257.

The optical characteristics above described indicate that the aluminous mineral is probably largely hydrargillite,[a] while kaolin is also very likely present.

Abundant pseudomorphs after pyroxene consist chiefly of a pale green, very faintly crystalline fibrous aggregate, which in part seems to be chlorite and in part is certainly uralitic hornblende or actinolite.

The occasional biotite crystals are bleached and contain secondary quartz in seams parallel with the cleavage.

To determine the character of the carbonates in this rock they were separated and analyzed qualitatively. They were found to consist of an abundance of siderite, though the larger part is calcite. No magnesium carbonate was present.[b]

Analyses of described types of later andesite.

[Nos. 1 and 4 by Mr. George Steiger; Nos. 2 and 3 by Dr. W. F. Hillebrand.]

	1.	2.	3.	4.
SiO_2	57.51	56.26	51.64	43
Al_2O_3	16.55	16.18	15.58	16.49
Fe_2O_3	3.20	5.56	.16	2.86
FeO	2.02	1.17	.58	6.31
MgO	2.30	2.78	2.79	6.19
CaO	6.06	5.07	6.25	5.69
Na_2O	2.76	3.23	.27	.12
K_2O	2.81	3.43	2.46	.84
H_2O-	1.45	2.07	2.56	3
H_2O+	2.56	2.61	4.43	7.93
TiO_2	.80	.73	.73	.89
ZrO_2	....	Trace.?	Trace.?	....
CO_2	1.91	.62	4.24	4.19
P_2O_5	.30	.32	.31	.36
SO_3	None.	None.	.03	.08
Cl, F	....	([c])	([c])	....
FeS_2	.04	.03	7.89	2.55
Cr_2O_3	....	None.	....	....
NiO	....	Trace.	None.	....
MnO	.17	.21	.21	....
BaO	....	.12	([d])	.07
SrO	....	.06	Trace.	None.
Li_2O	....	Trace.	(?)	....
	100.44	100.47	100.13	100.57

[a] Rosenbusch-Iddings, Microscopical Physiography of the Rock-making Minerals, 3d ed., p. 351.
[b] Determined by Mr. George Steiger, of the United States Geological Survey.
[c] Not looked for.
[d] Not estimated; very little.

DIFFERENCES OF COMPOSITION EXPRESSED BY DIAGRAMS.

The four analyses may be represented by the Brögger diagram (fig. 75), in the same manner as employed for the earlier andesite.

The diagrams show the principal elements of fresh rocks, and fulfill all

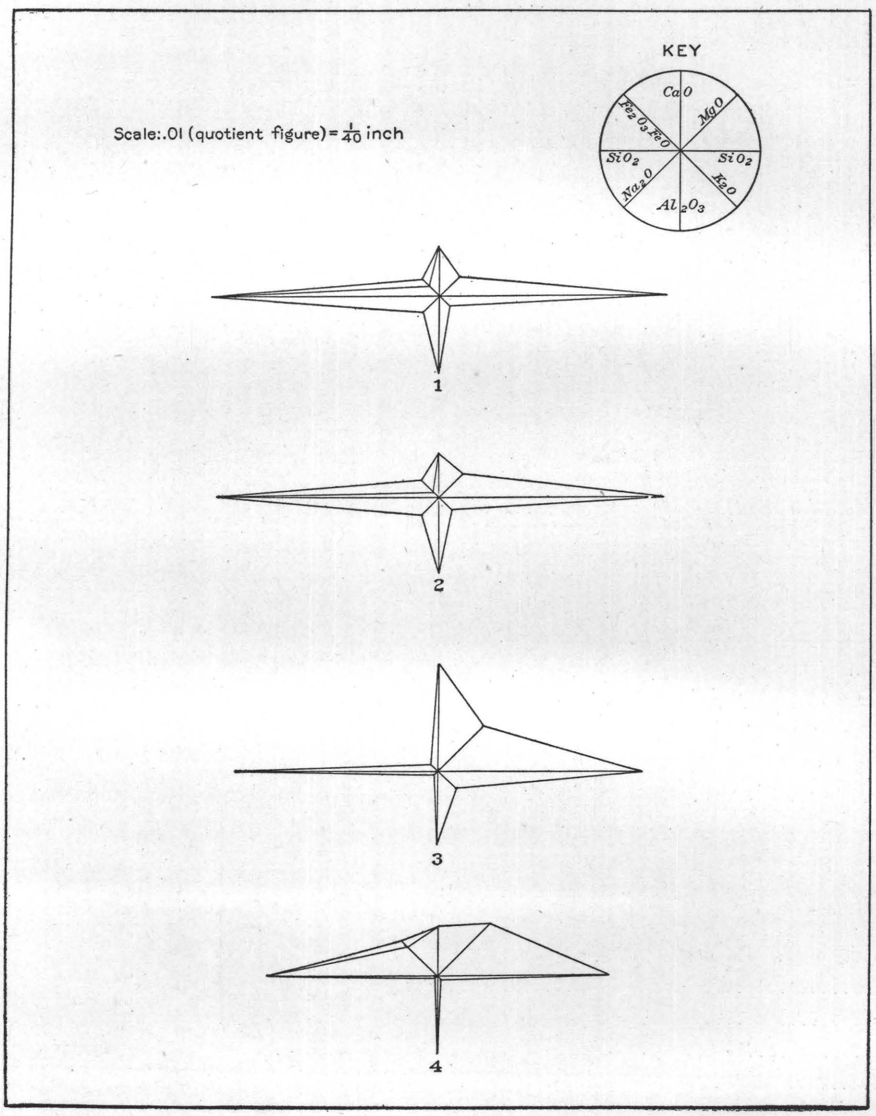

FIG. 75.—Diagram showing changes in composition during alteration of the later andesite.

ordinary purposes for these, but in altered rocks the altering agents have frequently entered into the rock and constitute an important part of its bulk. To take cognizance of three of the most important of these agents in this case—water, carbonic acid, and sulphur in the form of iron sulphide—the writer has constructed diagrams altered from the preceding, so that these may also be represented (fig. 76). Ten radii instead of eight are taken, representing the different elements as

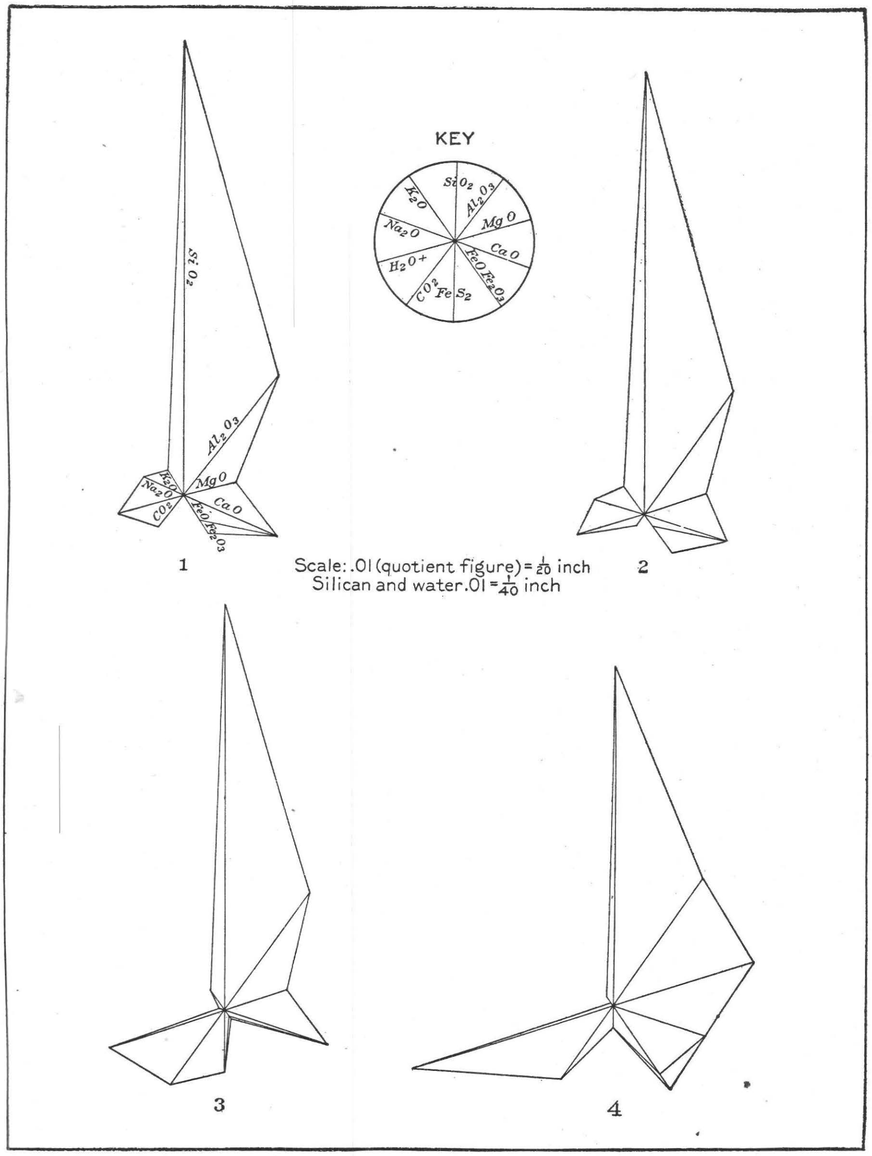

FIG. 76.—Diagram showing changes in composition during alteration of the later andesite.

shown in the key. The arrangement of the elements differs from that in the preceding diagram, the water, carbonic acid, and iron sulphide being grouped together, as well as lime, magnesia and iron, and soda and potash. Silica is assigned one radius instead of two, as in the preceding diagrams, and since its quantity results in an impracticable length for this radius, it is represented on half the ordinary scale. Water was so abundant in some of the analyses that it has been represented in the diagrams on the same scale as silica for a similar reason. Only the water given off above 106° C. has been represented, that being chemically combined, while that given off below this point is mostly hygroscopic. Otherwise the scale used is the same as for the preceding diagram.

COMPARISON OF LATER ANDESITE WITH WASHOE AND EUREKA ROCKS.

The first two analyses of nearly fresh rocks are similar to analyses of pyroxene-andesites from the Comstock region and from Eureka, as shown in the following table. Nos. 1 and 2 in the preceding table are here called A and B.

Analyses of andesites.

	A.	B.	C.	D.	E.
SiO_2	57.51	56.26	56.71	56.40	61.58
Al_2O_3	16.55	16.18	18.36	15.99	16.34
Fe_2O_3	3.20	5.56	....	3.26	....
FeO	2.02	1.17	6.45	3.82	6.42
MgO	2.30	2.78	3.92	3.54	2.85
CaO	6.06	5.07	6.11	6.98	5.13
Na_2O	2.76	3.25	3.52	3.83	2.69
K_2O	2.81	3.43	2.38	1.91	3.65
H_2O-	1.45	2.07	} 1.94		
H_2O+	2.56	2.61		....	....
TiO_2	.80	.73	....	1.14	.68
CO_2	1.91	.62	....	....	....
P_2O_5	.30	.32	....	.32	.28
FeS_2	.04	.03	....	....	[a].64

[a] Loss on ignition.

A. Mizpah Extension shaft, Tonopah, Nevada.
B. Halifax shaft, Tonopah, Nevada.
C. Granular pyroxene-andesite, Eldorado, outcrop, Washoe, Nev.[a]
D. Pyroxene-andesite, Sutro tunnel, Washoe, Nev.[a]
E. Pyroxene-andesite, Richmond Mountain, Eureka, Nev.[b]

DEGREE OF ALTERATION OF FRESHEST TONOPAH LATER ANDESITE.

The freshest Tonopah specimens (A and B) show, not only under the microscope but by the analyses, the beginnings of alteration more than do the Eureka and Washoe rocks with which they are compared. The presence of carbonates, of a greater amount of water, and of a small quantity of pyrite indicates that the former have been somewhat attacked by waters containing oxygen, carbonic acid,

[a] Hague, A., Mon. U. S. Geol. Survey, vol. 20, p. 282. [b] Op. cit., p. 264.

and sulphur, and there has resulted partial hydration, oxidation, carbonation, and sulphuration. The minerals developed, as shown by the microscopic description, are serpentine, siderite, calcite, kaolin, quartz, hematite, and pyrite. The considerable degree of oxidation of the iron, as compared with C and E, is shown by the analysis. There is no evidence, however, that this incipient decomposition has been attended by any change in the relative amount of the rock constituents; it was rather a rearrangement of the materials into new minerals that were more stable under the new conditions.

PRINCIPLES OF STUDYING ALTERATIONS OF LATER ANDESITES.

No attempt has been made to follow the different stages of the alteration of the later andesite by analysis, as in the case of the earlier andesite, although these stages have been minutely studied under the microscope. Therefore, while the first two analyses (p. 241) are of the freshest rocks obtainable, the last two, 3 and 4, are of entirely decomposed rocks. In 3 and 4 not only has the original mineral composition, as shown by microscopic examination, been completely obliterated, but in the process there has been an important change in the chemical composition of the rock as a whole. This is well illustrated by the diagrams forming figs. 75 and 76.

It will be noted that in all four analyses the amount of alumina remains practically constant. This oxide is perhaps the most refractory among rock constituents, and computations in regard to loss or gain during rock alterations are often based on the assumption that alumina remains unaltered. That it probably does not exactly do this, under intense action, is shown by the study of the earlier andesite analyses, where the percentages of alumina in the bulk analyses decrease. The constancy of the alumina in the four later andesite analyses under consideration, however, is taken to indicate that the alumina has not been noticeably attacked by the alteration, and therefore that the comparison of the percentages of the other constituents affords an approximately correct idea of the loss and gain.

ALTERATION OF LATER ANDESITE FROM NORTH STAR SHAFT.

To compare the completely altered rock No. 3 with No. 2 (which appears to be the freshest of the rocks analyzed, and may be taken as representing nearly the original composition of No. 3, except for the partial oxidation of the iron), the two analyses are given together in the following table:

Analyses of later andesite.

	Rock No. 2.	Rock No. 3.
SiO_2	56.26	51.64
Al_2O_3	16.18	15.88
Fe_2O_3	5.56	.16
FeO	1.17	.58
MgO	2.78	2.79
CaO	5.07	6.25
Na_2O	3.25	.27
K_2O	3.43	2.46
H_2O-	2.07	2.56
H_2O+	2.61	4.43
TiO_2	.73	.73
CO_2	.62	4.24
P_2O_5	.32	.31
SO_3	....	.03
FeS_2	.03	7.89

It is noticeable that both analyses show the same percentages of titanium, another highly refractory substance, as well as of phosphoric acid. The phosphoric acid is contained in the apatite, which resists decomposition very strongly. This strengthens the belief that these percentages afford a measure of the change of the other constituents.

Nearly all of the soda has been extracted, and the silica has been somewhat attacked and removed. On the other hand, the magnesia is unchanged, as are probably the lime and potash[a] and the iron. The loss of bulk of the rock occasioned by the removal of the soda and silica is compensated by the addition of large quantities of carbonic acid and sulphur, producing carbonates of lime and iron and sulphide of iron. It will be noticed that most of the remaining iron oxide is in the ferrous condition; this probably is present as siderite. No dark iron or magnesian silicates were noted among the decomposition products. The amount of lime present is in excess of the amount required to form calcite with all the carbonic acid in the rock; indeed, a small portion of this carbonic acid is required

[a] For these conclusions compare not only the foregoing table, but also the table on page 219, showing variations of fresh rocks of this kind.

to form siderite with the ferrous oxide. There remains a small amount of lime (about 1.35 per cent) which it is difficult to assign to any of the recognized minerals except the zeolites, which therefore may be supposed to be chiefly lime zeolites.

As there are not present any recognizable colored minerals into which the magnesia has been transferred from its original combination in the pyroxene and the biotite, the magnesia is probably contained in one of the colorless minerals, and the presence of talc in the sericitic aggregate which forms a large part of the feldspar pseudomorphs is indicated, in accordance with the conclusions reached for specimen No. 4 (see p. 240). At the same time the analysis indicates that in this aggregate all or a large part of the original potash in the feldspar is now contained in the form of sericite.

The sulphur trioxide shown in the analysis of No. 3 is probably contained in gypsum, a mineral abundantly found elsewhere in this altered rock. It appears to result from the action of waters containing sulphuric acid (derived from oxidation of the pyrites) on the calcite. This is a recent process and one distinct from that by which the main alteration was produced.

The waters which produced this main alteration were, therefore, highly charged with carbonic acid and sulphur; they left these materials, with some water, in exchange for soda and silica, which they carried away.

ALTERATION OF LATER ANDESITE FROM MONTANA TONOPAH SHAFT.

The relation which the altered later andesite from the Montana Tonopah shaft (No. 4) bears to the fresh rock (No. 2) may be seen by comparing their respective analyses, which follow:

Analyses of later andesite.

	Rock No. 2.	Rock No. 4.
SiO_2	56.26	43
Al_2O_3	16.18	16.49
Fe_2O_3	5.56	2.86
FeO	1.17	6.31
MgO	2.78	6.19
CaO	5.07	5.69
Na_2O	3.25	.12
K_2O	3.43	.84
H_2O-	2.07	3
H_2O+	2.61	7.93
TiO_2	.73	.89
CO_2	.62	4.19
P_2O_5	.32	.36
SO_3	None.	.08
FeS_2	.03	2.55

In No. 2 and No. 4 again the close correspondence of the alumina, titanium, and phosphoric acid—the last two representing probably, respectively, the resistant rutile needles (sagenite) in the biotite, and the apatite—indicates that the relative bulk of the rock has not been greatly changed by decomposition. The fact, however, that the percentages of each of these constituents in No. 4 is slightly in excess of those in No. 2 may be taken as indicating that a slight reduction of density has taken place.

Like rock No. 3, rock No. 4 shows an almost complete loss of soda, and a similar loss of silica, both these processes being carried further than in No. 3. Like No. 3, the lime has not been noticeably affected. Unlike No. 3, most of the potash has been removed, while the iron, which in No. 3 had not been noticeably affected, is here present in quantity certainly largely exceeding the original amount. The writer has computed the total metallic iron present in the different rocks as follows: No. 1, 3.82 per cent; No. 2, 4.81 per cent; No. 3, 4.24 per cent; No. 4, 8.04 per cent. The magnesia, not noticeably affected in No. 3, is here doubled. Therefore the waters removed soda, potash, and silica, and brought iron and magnesia in partial compensation, the rest of the loss being compensated for by the addition of large amounts of water, carbonic acid, and sulphur.

Judging from the microscopic analysis, the iron of this rock is chiefly contained in pyrite, siderite, uralite, and chlorite; the magnesia in uralite, chlorite, and talc. The alteration of augite to chlorite or uralite involves a relative increase of magnesia and a decrease of lime. Dana, speaking of uralite pseudomorphs after pyroxene, remarks:[a]

"The most prominent change of composition in passing from the original pyroxene is that corresponding to the difference existing between the two species in general; that is, an increase in the magnesium and a decrease in the calcium. The change, therefore, is not strictly a case of paramorphism, though usually so designated."

Discussing the alteration of feldspar the same writer remarks:[b]

"When the waters contain traces of a magnesian salt—a bicarbonate or silicate—the magnesia may replace the lime or soda, and so lead to a steatitic change or to a talc when the alumina is excluded."

Dana indexes this "steatitic mineral" as "magnesia aluminate."

SIDERITE AS AN ALTERATION PRODUCT.

The abundance of siderite in the altered later andesite is of some interest, as it has not been often detected among the minerals resulting from hot-spring action.[c] It is almost always present as a decomposition product of the biotite, pyroxene,

[a] System of Mineralogy, 6th ed., p. 390. [b] Op. cit., p. 320. [c] Lindgren, W., Trans. Am. Inst. Min. Eng., vol. 30, p. 607.

magnetite, etc., and is nearly always closely associated with pyrite. Usually the two occur intercrystallized, yet so clearly separated as to show contemporaneous crystallization; sometimes, however, a rim of siderite around pyrite indicates later crystallization for the former, if not its derivation from the pyrite; while quite as often rims of pyrite around siderite indicate a reversal of this order of crystallization, and sometimes the phenomena clearly indicate that the pyrite has formed at the expense of the siderite (Pl. XXIII). This is in harmony with the conclusions arrived at that the rock has been altered by solutions at once highly carbonated and sulphureted.

The siderite occurs usually as a cloudy, opaque or semitranslucent substance, of a characteristic white color by incident light. It has indeed usually the appearance of the mysterious substance called *leucoxene* by petrographers, and observed as the decomposition product of ilmenite. In many examples of this mineral in the Tonopah andesites, however, rhombic cleavage has been observed, and characteristic rhombic crystal outlines. The nature of the mineral has also been determined by chemical tests (p. 241).

Concerning similar siderite in the iron-bearing rocks of the Mesabi range in Minnesota, the writer has made the following statement.[a]

"It is to be noted that siderite * * * surrounds magnetite as a decomposition product, and is cloudy and without crystal form. It thus comes under the group of decomposition products from magnetite called *leucoxene*. Rosenbusch describes it as an alteration product of ilmenite, titaniferous magnetite, and rutile. Concerning its nature he says:[b] 'Its chemical composition is not the same in all cases where it has been investigated, and has been considered the equivalent of a variety of minerals (titanite, anatase, and siderite) by different observers.' In every case where this mineral is present in these rocks, chemical tests show it to be siderite, and no signs of titanium can be found either in it or in the magnetite whence it is derived. The existence of this leucoxenic decomposition product surrounding magnetite has sometimes been held as sufficient evidence that the magnetite was titaniferous, but it is clear that it is not necessarily the case."

In the altered "propylitic" andesite of the Comstock lode, which in alteration resembles very nearly the later andesite of Tonopah, Dr. G. F. Becker suspected the presence of siderite. He remarks:[c]

"* * * It seems certain that the black border of many hornblendes has been attacked and has given place to a transparent mineral, which is more or less diffused in and obscured by the groundmass. The natural supposition is that it is ferrous carbonate."

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[a] Geol. Nat. Hist. Survey Minnesota, Bull. No. 10, p. 84.

[b] Microscopical Physiography of the Rock-Making Minerals, by H. Rosenbusch. Translated by Joseph P. Iddings. Second, revised edition, p. 165.

[c] Mon. U. S. Geol. Survey, vol. 3, p. 215.

SCARCITY OF EPIDOTE AS AN ALTERATION PRODUCT.

Epidote, so common in similarly altered rocks elsewhere, is rare in the later andesite at Tonopah, and where found is often in positions suggesting that the conditions of alteration may have been abnormal. For instance, bowlders of later andesite in explosive volcanic ash and breccia not far from the contact of the Golden Mountain dacite, east of Mizpah hill, show feldspar and biotite phenocrysts largely altered to epidote. Also rare epidote was noted in one or two specimens from the Halifax shaft. In a shaft sunk to a depth of 60 feet in decomposed later andesite, just west of the Siebert shaft dump, a specimen was collected which carried rather abundant epidote. This, however, is exceptional, and the typical alteration seems to be illustrated by the detailed descriptions and analyses given.

COMPOSITION OF ALTERING WATERS.

The waters which produced the widespread and often profound alteration of the later andesite were then, as it seems, highly charged with carbonic acid and sulphur and contained magnesia and iron. Since they did not attack the lime in the rocks, it is probable that they contained also this element in considerable quantity. In the rock alteration observed they changed their composition chiefly by the acquirement of the alkalies and silica. They were not ordinary cool ground waters, but clearly hot-spring waters. The extensive carbonation and sulphuration show this, as well as the formation of sericite and talcose material, uralite, chlorite, serpentine, zeolites, etc. Thorough as their work was, their effects were not so intense as in the case of the waters which affected the earlier andesite in the vicinity of the veins, where the most insoluble elements were attacked. Moreover, the chemical composition of the waters was evidently quite different.

PERIOD OF ALTERATION OF LATER ANDESITE.

ALTERATION MAINLY ANTECEDENT TO FAULTING.

The last and most altered specimen, No. 4, is, as already noted, the type in the Montana Tonopah shaft between depths of 90 and 278 feet. Specimens taken at various intervals show the persistence of this general type of alteration down to the Mizpah fault, which was encountered at 376 feet. Immediately beneath the fault, however, and in the rest of the workings, the earlier andesite was encountered, completely altered to the quartz-sericite phase. In the Mizpah mine, also, it was noted that earlier andesite altered to quartz and sericite was separated sharply by the Mizpah fault from later andesite marked by the strong development of carbonates and sulphides. The indications are, therefore, that the faulting was not only subsequent to the alteration of the earlier andesite (as is shown by the fact that it faults the quartz veins), but that it was subsequent to the alteration of the later andesite, which occurred at a later period than that of the earlier andesite; otherwise some trace or transition of the later andesite alteration would be found on the earlier andesite side of the fault line.

RELATION OF ALTERATION TO VEIN FORMATION.

EXUDATION VEINLETS IN LATER ANDESITE.

In the later andesite occur many veinlets of calcite, some of gypsum, and even of quartz. They are almost always very small and nonpersistent, filling cracks, and are evidently mainly the product of lateral secretion or exudation from the rock. The quartz generally has a chalcedonic or jaspery look, as compared with the quartz of the earlier andesite veins, although in some cases the resemblance of the two varieties of quartz to one another may be close.

METALLIFEROUS VEINS IN LATER ANDESITE.

Some larger veinlets, probably of a different origin, are composed of quartz or quartz and calcite, and contain pyrite. An assay[a] of such a bluish veinlet in later andesite, from the east base of Mount Oddie, and near the contact of the Oddie rhyolite showed only traces of gold and silver. It was noted that these veinlets were especially characteristic of a zone in the later andesite near the contact of the Oddie rhyolite.

Near the contact of the glassy Tonopah rhyolite-dacite at many points, as for example, near the Belle of Tonopah shaft, there are numerous small veins of this kind in the intruded later andesite. These veins gave variable but generally small assays for gold and silver, the gold predominating. In the Mizpah Extension, large veins of pyritiferous quartz were encountered in the later andesite, but this was at or near the contact with Tonopah rhyolite-dacite, which is, it will be remembered, of more recent date than the later andesite.

The pyrite in the altered later andesite is sometimes very abundant, and may be segregated so as to be of striking appearance, and to suggest an ore; but assays show in all cases that the mineral is barren of gold and silver.

CONCLUSION.

It thus appears probable that the more important quartz veinlets which appear in the later andesite in places were largely formed under the influence of solutions following the contacts of later intrusive rocks—the rhyolites and rhyolite-dacites. This being the case, it is likely that a large part of the rock alteration just described may have been due to the same causes. The entirely altered specimens 3 and 4, described and analyzed, were both near the intrusive contact of the Oddie rhyolite, and in general the more altered portions appear to be in

[a] By R. H. Officer & Co., Salt Lake City.

the vicinity of the large subsequent igneous intrusions. It is therefore likely that the alteration of the later andesite was largely produced by waters which followed later, chiefly rhyolitic,[a] intrusions into it.

ALTERATION OF THE ODDIE RHYOLITE.

Some partial analyses were made, to show the composition of the fresh and the altered white Oddie rhyolite. As a rule this rock is quite fresh, even when close to the intensely altered earlier and later andesites. Sometimes, however, especially along faults and watercourses, the rhyolite disintegrates and the feldspar is partly dissolved out, leaving cavities, while the scant biotite of the fresh rock has disappeared.

The partial analyses are as follows:

Analyses of Oddie rhyolite.

[By Dr. E. T. Allen.]

	1 (376).	2 (337).	3 (227).
SiO_2	75.66	76.57	77.71
CaO	.47	....	....
Na_2O	1.70	.96	.17
K_2O	4.94	5.81	4.04

The first two analyses being of fresh rock, the difference in the chemical composition is probably original. This difference was, indeed, noted in the field, where the rhyolite of Rushton Hill (No. 1) was observed to have a slightly more basic aspect than the rhyolite of Mount Oddie (No. 2), and to approach in appearance the siliceous dacite of Golden Mountain near by. No. 3, however, is Oddie rhyolite which was probably originally of a composition similar to No. 2, and the chemical change undergone on alteration seems to have been a slight increase in silica and a loss of the alkalies, especially soda.

The microscopic description of No. 3 is as follows:

3. (Specimen 227) Mizpah Extension shaft, 385 feet down. Hand specimen is white and hard, but shows cavities due to the dissolution of feldspar phenocrysts. There is no biotite. Under the microscope there are also no signs of biotite, and the feldspars are entirely altered to a sericite aggregate, both in the phenocrysts and in the groundmass. The phenocrysts consist of abundant quartz, with sericite areas representing original feldspars, while the groundmass consists of an aggregate of crystalline granular quartz, much coarser than in the fresh rock and sericite. The size of the quartz grains in the groundmass is evidently due to enlargement by the waters which produced the alteration, for crystal faces are frequent and such idiomorphic grains frequently impinge upon the area of the original idiomorphic feldspar phenocrysts, now altered to sericite.

[a] The glassy Tonopah rhyolite-dacite is a rhyolitic variety (p. 59.)

CHAPTER VII.

ORIGIN OF MINERAL VEINS.

ORIGIN OF THE MINERALIZING AND ALTERING WATERS.

ANTITHESIS BETWEEN WATERS AND ASSOCIATED ROCK.

In view of the composition of the waters which produced the veins and the chief alteration of the early andesite, it has been argued that they were rich in silica and potash and noticeably poor in the other common rock-forming elements. They seem to have directly followed the earlier andesite eruption. In considering the alteration of the later andesite in the vicinity of Mount Oddie, it has been concluded that the waters which wrought the change were rich in magnesia, lime, and iron, and low in silica and the alkalies; in this case the data seem to point to the explanation that the waters followed the eruption of the Oddie rhyolite. Both are concluded to have been hot-spring waters, which were active after volcanic eruptions for a relatively short time, geologically speaking, and which differed in composition as much as the rocks. If these conclusions are true, it is right to notice an apparent antithesis in each case between the composition of the erupted rock and that of the accompanying and succeeding hot solutions. The eruption of the earlier andesite, a rock of intermediate composition, containing perhaps about 60 per cent of silica, and about five times as much soda, lime, iron, and magnesia as it does potash, was followed by the advent of waters which were rich in the elements characteristic of extremely acid rocks (alaskites)—namely, silica and potash—with the proportion of silica probably largely in excess of that in these rocks and probably approximating that in feldspathic quartz veins of granitic origin, as the composition of the Tonopah veins indicates. The eruption of the Oddie rhyolite, a rock made up almost entirely of silica and potash, with alumina, and only trifling quantities of magnesia, lime, and iron, was followed by the advent of waters rich in these three last-named elements (which are characteristic of basic rocks) and poor in the elements represented in the rhyolite itself.

Testing this latter conclusion, we may recall the calcitic veins of Ararat Mountain, which are certainly directly due to hot solutions that ascended immediately after the eruption of the neck or plug of Oddie rhyolite (p. 101). It has been shown that these waters give evidence of having contained chiefly lime, iron, manganese, and silica. They have produced silicification, and have deposited silica in fissures, but the silica is usually greatly exceeded by the calcite (figs. 14, 15). These waters then were also characterized by the materials of basic rather than of acidic igneous rocks.

Along the contact of the dacitic rocks there has frequently been profound alteration of the later andesite, but the process has not been studied sufficiently to give definite conclusions. A specimen from the later andesite near the Molly shaft, at the contact with the Golden Mountain dacite, is entirely altered to calcite and quartz, the former unusually abundant, with siderite and pyrite, etc. At the Belle of Tonopah shaft specimens of the later andesite near the contact with the glassy Tonopah rhyolite-dacite are largely altered to calcite, together with quartz and probable sericite; other specimens near here are more plainly silicified, but are ferruginous. The glassy rhyolite-dacite itself, near the contact, is often silicified, but shows frequently considerable epidote. Calcification as well as silicification is therefore suggested in all these instances.

Omitting, therefore, as without sufficient data, the consideration of the solutions accompanying the rhyolite-dacites and referring only to the Oddie rhyolite and the earlier andesite, the conclusions, if correct, may have a bearing on the source of these solutions.

THEORY OF ATMOSPHERIC ORIGIN OF HOT SPRINGS.

There are two possible explanations of hot springs in general. One is that atmospheric water, of which such a large quantity sinks below the surface, becomes warmer in depth by the natural increment of temperature or in volcanic regions by the residual heat of the rocks, and on finding a channel ascends toward the surface as hot water, carrying with it materials which it has dissolved out of the rocks on its passage. A physical objection to this theory is that surface water could hardly work its way downward against pressure, to the depths necessary to become highly heated. This has been met by the experiment of Daubrée, which showed that water would work itself downward through a solid marble slab by capillarity, in spite of the resistance offered by a strong pressure on the underside of the slab. It has been argued that by such capillary circulation the supplies of hot springs may be replenished.

THEORY OF MAGMATIC ORIGIN OF HOT SPRINGS.

The other explanation goes back to the hypothetical origin of the atmospheric or surface water at the period of the consolidation of the globe. According to the commonly accepted theory, when the molten or fluid earth stuff cooled and was consolidated, a large part of the contained water was separated, and by reason of its great mobility formed the oceans. Processes similar to those which thus went on on a large scale in primeval times, it is argued, still go on whenever a body of magma consolidates; a large part of the water of this fluid material is separated and expelled and most of it escapes to the surface as hot springs, adding to the surface waters already originated by similar separations.

Of these two explanations, the former may seem more familiar and probable, because of our acquaintance with ordinary surface waters and our lack of intimacy with newborn magmatic waters. Yet the magmatic explanation is the only one of whose possibility we have ocular demonstration. We have no such demonstration that surface waters can penetrate downward till they are heated far above the boiling point and then rise again and emerge, and we can reach such an idea only by a process of speculation which is not even logical reasoning. On the other hand, the vast quantities of water vapor given off by lavas at many volcanic centers afford proof that water is present in these unconsolidated magmas and separates on cooling. Furthermore, the phenomena of contact metamorphism, especially that connected with siliceous rocks, show, as has often been pointed out, that in depth similar water vapor is expelled from cooling rock, even under great pressure.

Volcanic activity has sometimes been ascribed to the infiltration of surface water, which, on coming into contact with heated rocks below, causes explosions and extravasations of lava; and the water given off from the cooling lavas is thus thought to have a surface origin. Many facts, however, which can not be gone into here are against this hypothesis. Concerning the steam given off at Vesuvius, Prof. E. Suess remarks:[a]

"* * * it is at least certain that the quantities of steam issuing from the parasitic crater must have come from a zone in which the temperature equals or exceeds the melting point of most rocks, and in which there can be no question of porous or fragmental rocks, and therefore no question of infiltration of vadose[b] water."

That is, the principle of capillarity above referred to can not apply to rocks at these great temperatures and can not explain the water in lavas.

When the upward movements in the lava bodies have ceased and a crust of cooled and solid rock has congealed at the surface, consolidation will progress downward. The aqueous vapor given off from this lower cooling lava will become condensed to water on its passage through the cooled crust and will so emerge. It seems, therefore, impossible to escape the conclusion that at least some hot springs, the after-phenomena of volcanic activity, have the origin above described, and contain newborn water separated from the magma.[c]

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[a] Geog. Jour., vol. 20, p. 519.

[b] Surface.

[c] Such water has been called *juvenile* or *primitive* by Professor Suess, and *hypogene* by one of his translators, to distinguish it from the shallow underground water derived from the surface, or *vadose* water, the latter term having been proposed by Posepny in his essay on ore deposits.

Vadose or surface-derived descending water must meet and mingle with these escaping magmatic waters, must change their composition and mitigate their heat, and the mingled waters must in many cases emerge on the surface as warm springs.

CHARACTERISTICS OF THE NEVADA SPRINGS.

The conception that the hot springs of the volcanic region of Nevada were largely supplied by magmatic or primitive water from the cooling subterranean lava was formed by the writer in the field in 1902, before reading Professor Suess's paper, above referred to.

On account of the exceeding aridity of the Great Basin, there are, as a rule, no flowing surface waters, the whole supply emerging from the ground as springs. These springs are hot, warm, or cold. The cold springs usually emerge from depressions, fault or fracture lines, and are especially found near the base of the desert mountain ranges. They usually show two characteristics which indicate that they are of vadose origin: (1) They fluctuate with the season, being abundant in the spring and often becoming scanty or dry at the close of the summer, and (2) they become more numerous and copious in the regions of greater precipitation and very rare in the more arid portions. Near the Sierra Nevada and in the region just east, which receives the overdrift from the Sierra precipitation in the shape of relatively abundant snows and more frequent rains, the cold springs emerging from the base of the mountains are numerous and so large as to frequently form short streams, sufficing often for agriculture, and producing a fringe of ranches along the mountain base, such as that which borders the eastern base of the White Mountains in Fish Lake Valley. The hot springs, on the other hand, so far as the writer's experience and information go, do not show these characteristics of vadose origin; they show no change with the season and are not noticeably associated with regions of greater precipitation. They are noticeably associated with areas of volcanic rocks and are scattered all over these areas, being often very vigorous in the heart of an arid region and sometimes sufficiently copious to form short streams.

COUPLING OF HOT AND COLD SPRINGS.

It is a matter of frequent remark in this dry Nevada region that hot springs and cold springs are frequently coupled together and emerge within a short distance of each other. The writer has observed an instance of this at the village of Silver Peak, 25 miles southwest of Tonopah, where a spring of nearly scalding temperature and one at most lukewarm or tepid emerge from the edge of the desert plain at the east base of the Silver Peak Range within a score of feet of each other. These are evidently waters from different sources, and their coupling must be ascribed to their having neighboring and probably parallel channels along the same fracture zone. Decomposed rock along such a fracture zone would form an effective barrier, preventing currents from mingling the waters and averaging their temperatures. The cool water is evidently vadose, and probably represents a part of the atmospheric waters which fall upon the Silver Peak Range, while the hot waters have a distinct and vastly deeper origin. It is clear, however, that in many similar cases the two currents of water must mingle, appearing at the surface as springs of varying warmth and of composite origin.

In seeking to understand the nature of the Silver Peak hot springs the writer learned from the inhabitants of the village a significant fact. According to them the water of the hot springs is much hotter in winter and fall than in summer and spring, so that in the former seasons much more cold water must be added to bring it down to a temperature requisite for bathing. This indicates that the temperature of the hot water is really modified by the cool vadose water, the modifying being characteristic of the seasons when the melting of the snows provides a considerable supply to the shallow underground circulation.

THE DEVILS PUNCHBOWL.

Mr. J. L. Butler, the discoverer of Tonopah and an old inhabitant of the region, has described to the writer a hot spring in Monitor Valley, not far from Belmont, which is 45 miles northeast of Tonopah. This spring occupies a cup-shaped depression—probably formed by sinter accumulations—known as the Devils Punchbowl. This depression is reported to be 30 feet in diameter and to be full of hot water up to a point 30 feet below the top. The level of the water has gone down 3 feet in thirty years and the water has become cooler. Formerly more gas than at present was emitted, and occasional flames were seen. This change is apparently a secular one, strikingly different from the seasonal variations of vadose springs, and suggesting as a cause the diminution of volcanic energy in this region of abundant Tertiary volcanics.

AMOUNT OF PRESENT AND RECENT HOT-SPRING ACTION.

Similar hot springs, some of them boiling, abound in the region and surround Tonopah on all sides. Volcanic activity has been great in this province for a prolonged period, lasting from the beginning of the Tertiary to within a few hundred years ago. At Silver Peak is a small, undefaced basalt crater, which is younger than the detritus of the valley, and can hardly be more than a few hundred years old; and there are a number of other craters, such as those in and near Lake Mono—described by Russell—which are comparatively recent. That many of the hot springs which accompanied or followed the different manifestations of volcanic activity are now extinct is shown by the characteristic effects of these springs in many localities, indicating that the number of such springs was probably formerly greater than at present.

ORIGIN OF EXTINCT HOT SPRINGS AT TONOPAH.

CONNECTION WITH VOLCANIC ERUPTIONS.

At Tonopah evidence has been given to show that after several of the volcanic eruptions waters ascended, altered the rocks, deposited new and removed old material, and became extinct in a relatively short space of geologic time. If the reasoning given in the preceding pages is correct, it is very difficult to explain the totally different composition reasoned out for the waters at different periods on the hypothesis that the mineralizing waters were of atmospheric origin and derived their material from solution of the rocks which they traversed. These ascending waters followed channels practically side by side, if not in many cases nearly the same, and it is most natural to suppose that the rocks which they traversed were not greatly different.

CONSEQUENCES OF ANTITHESIS BETWEEN ROCKS AND WATERS.

A second important consideration is the apparent antithesis pointed out between the contents of waters at different periods and the composition of the lavas which they followed.[a] There is indeed apparently a relation, but it is the opposite one from what would result had the waters derived their mineral contents from the leaching of these lavas by ordinary atmospheric waters. The same difficulty presented itself to Professor Suess and many other investigators in considering the origin of the Carlsbad Springs in Germany.[b] The amount of soda and lime in these springs suggests that the bulk of the matter in solution must be derived, not from the granite of the country, but from some unknown source. The quantity of the water and the carbonic acid at Carlsbad were also inexplicable on the hypothesis that the waters were of meteoric origin, and led Professor Suess and others to believe that the waters and their contents were of magmatic origin.

MEANING OF NATURE OF METALS IN VEINS.

A third consideration is the peculiar combination of materials in the waters which produced the veins in the earlier andesite. Not only is the abundance of silica and potash, together with the lack of sodium, magnesium, lime, iron, etc.—elements more characteristic of the andesite—difficult of explanation on the theory of leaching from the traversed rocks, but also the presence of unusually large

[a] The writer has at present no explanation of this antithesis to offer.

[b] Suess, E., Geog. Jour., vol. 20, p. 517.

quantities of the rare metals silver and gold, and unusually small ones of the commoner ones copper, lead, and zinc.[a] The amount of silver by weight in these primary ores, so far as they have been developed, seems to exceed that of either of the three last-named metals. No such results as this could be expected were the metals derived from leaching of the andesite. Plainly some process of separation and concentration has furnished the noble metals contained in the mineralizing waters, separating them from the baser metals. Nickel is present in the fresh later andesite (p. 34) and was detected in the fresh earlier andesite of Eureka; yet this metal has not been detected in the ores in either camp. In the rocks near the Comstock lode analyses conducted by Dr. G. F. Becker[b] showed small quantities of silver and gold, whence it was concluded that the ores of the lode had been derived from the wall rocks (by lateral secretion). But later investigations on the subject of the presence of the precious metals in rocks show that these metals are very frequently present in rocks not associated with ore deposits, as well as in those that are;[c] and the results of the assays tabulated by Becker do not, to the writer's mind, indicate any connection between these traces of metals and the ores of the Comstock lode. At Washoe, as at Tonopah, the theory of leaching from wall rocks, or lateral secretion, indeed, leaves unexplained the presence of silver and gold in such large quantities, relatively to the commoner metals. The view concerning this problem at the Comstock, expressed by von Richthofen,[d] seems to the writer especially illuminating, and applicable, as well, to the similar situation at Tonopah. Von Richthofen remarks:

"We have in the elements evolved during the first two periods of solfataras—namely, fluorine, chlorine, and sulphur—all the conditions required for filling the Comstock fissure with such substances as those of which the vein is composed. Steam, ascending with vapors of fluosilicic acid, created in its upper parts (by diminution of pressure and temperature, according to well-known chemical agencies) silica and silicofluohydric acid, the former in solid form, the latter as a volatile gas, which acts most powerfully in decomposing the rocks it meets on its course. The chloride of silicon in combination with steam forms silica and chlorhydric acid. Fluorine and chlorine are the most powerful volatilizers known, and form volatile combinations with almost every substance. Besides silicon, the metals have a great affinity with them. All those which occur in the Comstock vein could ascend in a gaseous state in combination with one or the other of them. * * *

"It is a fact worthy of notice that there is scarcely a single chemical agent, excepting fluorine and chlorine, which would not carry metallic substances into

[a] Since the above was written the important discovery of the presence of selenides has been made by Doctor Hillebrand. See pp. 89, 90. Doctor Hillebrand remarks that the presence of selenides, and the absence of their closely associated element, tellurium, indicated some unusual process of separation. Tellurides have been found at Goldfield, 28 miles south of Tonopah, also in Tertiary volcanic rocks; and from that camp selenides have not yet been reported.

[b] Mon. U. S. Geol. Survey, vol. 3, pp. 154, 155, 223.

[c] As examples, see Wagoner, Luther, Trans. Am. Inst. Min. Eng., vol. 31, pp. 798-810.

[d] Mon. U. S. Geol. Survey, vol. 3, pp. 19, 20.

fissures in exactly or nearly the reverse quantitative proportion from that in which they occur in silver veins. Iron and manganese are not only more abundant in rocks, but also much more easily attacked and carried away by acids, than silver and gold. The proportion of these to the former ought, therefore, to be still smaller in mineral veins than it is in rocks, and lead and copper ought to be more subordinate, if their removal from their primitive place had been effected by other agents than fluorine and chlorine. Only these two will first combine with those metals which are most scarce in rocks and relatively most abundant in silver veins, and they are probably the only elements which have originally collected them together into larger deposits, though these may subsequently have undergone considerable changes, and water may have played altogether the most prominent part in bringing them into their present shape."

NATURE OF SOLFATARIC ACTION.

Concerning the nature of solfataras, the following extracts are quoted from Professor Bonney's Volcanoes (p. 52):

"In the intervals between the paroxysmal phases most volcanoes emit simply steam, and all in their decadence pass through a longer or shorter period when it alone is ejected. This is often termed the solfatara stage, from the crater of that name in the Phlegræan Fields. Like most of those in this district, the cone is low and the crater wide; the floor is a level, sometimes marshy, plain, surrounded by steep walls of ashy materials, perhaps a hundred feet in height. The last eruption was in 1189, when a stream of trachytic lava was discharged from the southern side of the crater; but now the sole sign of activity, except some boiling puddles in one part of the floor, is to be found at the foot of the crag on the side. Here, from a fissure in the inclosing wall, something like the adit of a mine, a column of steam is ejected to a height of 6 or 7 yards. The steam commonly is more than the vapor of water. Such acids as hydrochloric or sulphuric are often present;[a] that of the solfatara, as we can see from the sulphur abundantly deposited round the aperture and the rotten condition of the adjacent rocks, is no exception to the rule. No doubt the materials in and about a vent must undergo considerable chemical changes when the volcano is passing through this stage in its history."

Professor Bonney finishes his summary of the description of volcanic eruptions as follows (p. 62):

"An eruption is generally ushered in by earthquake shocks, is always associated with explosions, and is frequently concluded by the emission of a considerable mass of lava. Great quantities of water are discharged in the form of steam, and the phenomena of an eruption are closely imitated by geysers. Other vapors also are discharged, and the solfatara stage of a dying volcano commonly ends with the exhalation of carbonic acid or some such gas; perhaps the last stage of all may even be a cold mineral spring."

[a] The steam emitted from Vesuvius in January, 1876, was acid with these, particularly the former. Steel was rusted and clothes were slightly altered in color in the course of an hour or two.

Professor Suess, in the essay referred to,[a] thus describes the fumarolic activity at Vesuvius:

"Turning now to the gases accompanying the eruptions. After steam, chlorine and gases containing sulphur are the most important, and carbonic acid gas comes next. Their occurrence follows a definite law. So far as it has been possible to approach them, all fumaroles actually within vents contain steam; but the hottest fumaroles (over 500° C.) on the surface of cooling lava streams, where approach is easier, are dry. In the emanations from these high-temperature fumaroles are found chlorine compounds, and along with them fluorine, boron, and phosphorus—substances which are the first to disappear as the temperature of the fumarole sinks. Sulphur persists longer, often combined with arsenic. Carbonic acid is given off freely till a much later stage, sometimes till the fumarole is comparatively cool, notwithstanding that it is observed in the hottest dry fumaroles. Fumaroles in different 'phases of emanation' may occur quite near one another. The steam of the volcano can not be derived from vadous infiltration, for if it is, whence the carbonic acid? Both must come from the deeper regions of the earth. They are the outward sign of the process of giving off gases which began when the earth first solidified, and which to-day, although restricted to certain points and lines, has not yet come to a final end."

MINERALS DEPOSITED AROUND FUMAROLES.

Around the orifices of the steam jets (fumaroles) at Vesuvius sulphides of arsenic and mercury and chlorides of copper and lead have been deposited, showing the efficacy of such gases in separating, dissolving, and precipitating these relatively rare substances. Dana[b] quotes Mallet as authority for the statement that native silver ore occurs rarely in volcanic ashes.

CONCLUSIONS AS TO GENESIS OF TONOPAH ORES.

The considerations above pointed out appear to the writer to indicate strongly the following conclusions:

The Tonopah district was, during most of Tertiary time, a region of active volcanism, and probably after each eruption, certainly after some of them, solfataric action and fumarolic action, succeeded by hot springs, thoroughly altered the rocks in many parts of the district. At the surface, during those periods, the phenomena of fumarolic and solfataric action and of hot springs were similar to those to-day witnessed in volcanic regions; but the rocks now exposed were at that time below the surface. The veins fill conduits which were formed by the fractures due to the heavings of the surging volcanic forces below and along which the gases, steam, and finally hot waters, growing gradually

[a] Suess, E., Geog. Jour., vol. 20, p. 520.

[b] System of Mineralogy, 6th ed., p. 20.

cooler, were forced, relieving the explosive energies of the subsiding volcanism. The water and other vapors, largely given off by the congealing lava below, carried with them, separated and concentrated from the magma, metals of such kind and of such quantities as are present in the veins, together with silica and other materials.

The nature of the metallic minerals in the veins in this case is believed to depend largely upon the particular magma whence the emanations proceeded. In the chief Tonopah veins this was the earlier andesite. Other factors, such as relative depth, have evidently an important controlling influence.

CHAPTER VIII.

INCREASE OF TEMPERATURE WITH DEPTH.

Some measurements were made by Mr. Leon Dominian, field assistant, under the direction of the writer, with a view to ascertaining the increment of temperature with depth in this district.

METHOD OF MEASUREMENT.

The best opportunities were offered by the Mizpah Extension and the Ohio shafts, both fairly deep shafts with (at that time) very little side workings and no through system of ventilation. Holes were drilled dry into the rock at the sides of the shafts at the points where the temperature was to be taken, deep enough to take in the thermometers, which were especially procured for this purpose. After the thermometer was inserted the hole was stopped up, and the reading was taken after fifteen to twenty-five minutes—in some cases twenty-four hours. Check measurements were taken in every case. In the Ohio Tonopah the holes were driven 18 inches; in the Mizpah Extension not so deep.

The Ohio Tonopah shaft is perfectly dry. The Mizpah Extension encountered a very little water on a contact zone at a depth of 300 feet, but is otherwise quite dry.

TEMPERATURES IN THE MIZPAH EXTENSION AND THE OHIO TONOPAH.

The results of the measurements of temperatures are given in the following table:

Temperatures in Mizpah Extension and Ohio Tonopah shafts.

Feet below surface.	Temperature.		Rate of increase per 100 feet.		Depth required for increase of 1 degree.	
	Mizpah Extension.	Ohio Tonopah.	Mizpah Extension.	Ohio Tonopah.	Mizpah Extension.	Ohio Tonopah.
	Degrees F.	*Degrees F.*	*Degrees F.*	*Degrees F.*	*Feet.*	*Feet.*
100	60.25	60	----------	----------	----------	----------
200	61.75	61	1.5	1	$66\frac{2}{3}$	100
300	64	62.5	2.25	1.5	$44\frac{1}{2}$	$66\frac{2}{3}$
400	66.5	64	2.5	1.5	40	$66\frac{2}{3}$
500	69	66.5	2.5	2.5	40	40
600	70.5	69	1.5	2.5	$66\frac{2}{3}$	40
700	72	74	1.5	5	$66\frac{2}{3}$	20
766 (bottom Ohio Tonopah)	----------	78	----------	7.6	----------	$16\frac{1}{2}$
780 (bottom Mizpah Extension)	73.5	----------	1.9	----------	$53\frac{1}{3}$	----------

	Mizpah Extension.	Ohio Tonopah.
Average increase	1° in 51.3 feet	1° in 37 feet.

TEMPERATURES IN THE MONTANA TONOPAH.

Some observations were also taken in the Mizpah and in the Montana Tonopah workings, but with a less range of depth. Those in the Montana Tonopah, however, were taken at intervals along the vertical shaft, in holes drilled for the purpose, and the thermometers were left in place 15 minutes, check readings corresponding exactly. They are, therefore, worthy of confidence, and are given in the following table:

Temperatures in Montana Tonopah shaft.

Feet below surface.	Temperature.	Rate of increase per 100 feet.	Depth required for increase of 1°.
	Degrees F.	*Degrees F.*	*Feet.*
317	64		
460	68	2.8	36
600	70.5	1.8	56

Average increase, 1° in 43.5 feet.

Although the average increment of temperature (1° F. in 43.5 feet) for the Montana Tonopah measurements differs from that shown by the Mizpah Extension measurements (1° in 51.3 feet), comparison of the tables shows that the temperatures for the corresponding levels in each case practically coincide.

These separate temperature measurements have been plotted as curves (fig. 77). The Mizpah Extension curve, as shown, is distinct from the Ohio Tonopah curve, while the Montana Tonopah curve coincides with the corresponding portion of the Mizpah Extension.

TEMPERATURES IN MIZPAH HILL WORKINGS.

Six measurements were taken in the Mizpah Hill workings, but under less exact conditions. They were taken at various points in the drifts, and so at variable distances perpendicularly from the surface, sometimes in drilled holes and sometimes at the ends of unventilated drifts. These mines, however, had, at the time of examination, a thorough system of ventilation (which the others did not) and the measurements do not check exactly, and indicate that the temperature was affected by air currents. They are therefore not published.

THERMAL SURVEYS ON THE COMSTOCK.

During his study of the Comstock Dr. G. F. Becker made careful thermal surveys along deep vertical shafts and along the Sutro tunnel, which runs in and taps the vein. On plotting the temperatures taken in the shafts no indication of curvature could be perceived, although the increment showed constant local irregularities, and the line, plotted from point to point, was often zigzag. On this account a straight line was assumed as expressing the relation of temperature depth. The Sutro tunnel line, however, though also irregular in detail, shows an unmistakable curve, clearly a conduction curve. It is to be noted, on the other hand, that in the Sutro tunnel the temperature measures extended over a distance

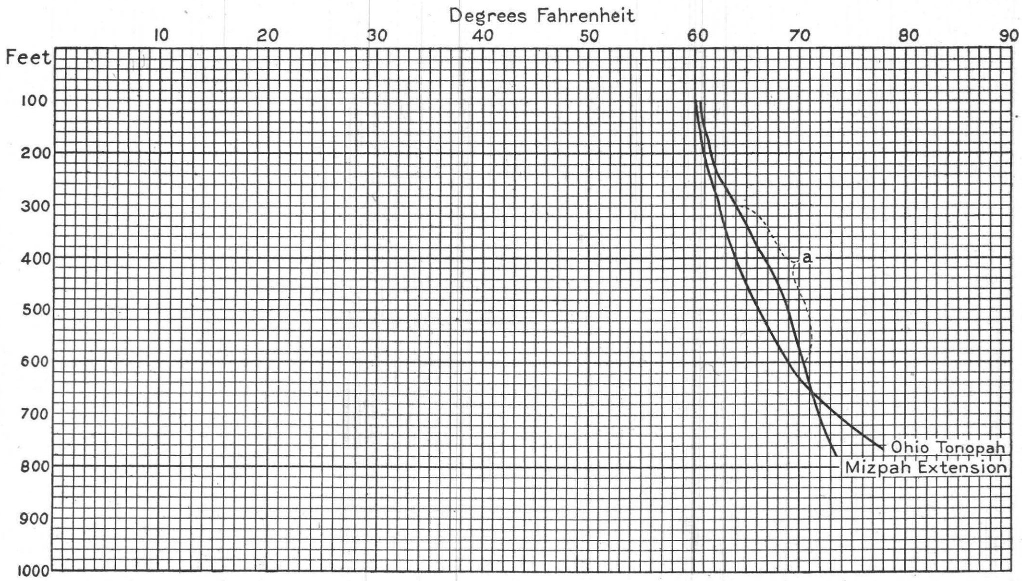

FIG. 77.—Plotting of temperature observations in the Ohio Tonopah, Mizpah Extension, and Montana Tonopah mines, showing increase of temperature with depth. a=This part of the curve coincides with that of the Montana Tonopah.

of 11,000 feet, while the vertical shaft measurement did not extend more than 2,000 feet; and that any given 2,000 feet of the Sutro tunnel curve would not by itself suggest a curved line.

COMPARISON OF COMSTOCK AND TONOPAH DATA.

Comparing the Tonopah and Comstock data, the temperature of 78° F., obtained in the Ohio Tonopah at 766 feet from the surface, was encountered in the Forman shaft at the Comstock at about 900 feet; while the bottom temperature of 73.5° F. in the Mizpah Extension at 780 feet was encountered in the Forman at between 600 and 700 feet. It seems likely, therefore, that the average increase at

Tonopah may be as great as at the Comstock, where it is 1° F. for each 33 feet vertical of extent.

The decided and characteristic curve in the Ohio Tonopah has no counterpart in any of the vertical sections at the Comstock. It is probably, however, a local deviation in a curve of vastly greater magnitude; though its form suggests a conduction curve, and it is possible that the extremely rapid increase of heat at the bottom indicates the proximity of a local heat focus, such as a hot spring. The larger and much less rapid conduction curve of the Sutro tunnel section is due to the heat from a similar local focus—the hot waters which rise along the lode.

CHAPTER IX.

COMPARISON WITH SIMILAR ORE DEPOSITS ELSEWHERE.

It is often advisable to study an ore deposit or a mining district not by itself alone, but also in comparison with others. Similar districts often present information, through their likeness or dissimilarities, concerning the nature, origin, and future possibilities of the district under examination.

VEINS OF PACHUCA AND REAL DEL MONTE, IN MEXICO.

Among the nearest analogies to Tonopah yet described anywhere in the world are the contiguous mining districts of Pachuca and Real del Monte, described by Aguilera and Ordoñez.[a]

These celebrated districts are 62 miles north of the City of Mexico, on opposite slopes of the Pachuca Mountains, which bound the great valley of Mexico. The mines support the city of Pachuca, which contains 35,000 people, most of whom are actually engaged in mining. The ore deposits were discovered in 1522, and have been worked almost continuously to the present day. Pachuca is the most important mining district in Mexico, and is estimated to have produced since its discovery 3,500,000 kilos of silver.[b]

The geology is similar to that of numerous other mineral regions of Mexico. The whole Pachuca Range is formed of Tertiary andesites, rhyolites, and basalts. The andesites are of Miocene age and have a varied appearance, due to alteration, the normal type being green and propylitic. The feldspar (labradorite) has often been transformed to sericite, calcite, chlorite, epidote, and clayey products; the pyroxene to chlorite, viridite, and epidote. The rocks are silicified near the veins, so as often to resemble dacites or rhyolites, this alteration being due to the influence of hot solutions during the formation of the veins. Rhyolites cover the andesites, occurring as flows and dikes. The last eruptions were of basalt. The veins strike east and west. Secondary veins branch out from the smaller ones, and splitting and reuniting are common phenomena. The veins are more remarkable for constancy and extension than for thickness. They seldom exceed 20 feet in thickness, while they have a length of from 2½ to 10 miles.

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[a] Boletín del Instituto geológico de México, Nos. 7, 8, 9; Trans. Am. Inst. Min. Eng., vol. 32, pp. 224–241.
[b] About 112,000,000 ounces, valued at $145,600,000 (1 oz.=about $1.30).

The quartz croppings carry pyrite and oxides of manganese. They are always argentiferous, with an appreciable amount of gold. They may be divided into two zones, one overlying the other. The upper is composed of oxides (red ores) and the lower of sulphides (black ores). The upper contains, besides iron oxide (always auriferous), oxides of manganese and chlorides and bromides of silver; it has a maximum downward extent of nearly 1,000 feet. The lower zone contains sulphides of lead, silver, etc. The lower limit of the upper zone corresponds to the ground-water level.

Calcite is found only in small quantities. Of the sulphides, pyrite, galena, and argentite were in most cases deposited simultaneously with the quartz. The abundant manganese oxide in the upper zone is replaced in the sulphide zone by a lesser quantity of the silicate, rhodonite. Pyrite is frequent in the mineralized parts of the veins, and is also abundant in the country rock, but in the country rock it does not contain even traces of the precious metals. Native silver has been found at all depths; ruby silver has not been observed at Pachuca, but is found at Real del Monte.[a]

Rich ores occur in certain parts of the veins called bonanzas, which are of irregular form, frequently nearly elliptical. The bonanzas of the different veins group themselves in a northeast-southwest zone nearly normal to the vein strike. Some are in the oxidized, some in the sulphide zone; the former are more numerous. In some cases bonanzas were encountered at the surface; in others they were found in depth, where the vein was barren at its outcrop. The size of the bonanzas varies; one of the largest was encountered at a depth of over 300 feet and was elliptical, the greatest axis being over 3,000 and the smaller 1,300 feet, with a thickness of 8 feet.

The veins become impoverished at great depths. At the bottom they change to barren galena and blende, too poor to repay working. However, certain developments lead to the belief that at still greater depth new bonanzas might be found. Most of the mines are only about 1,300 feet or less deep; in only one has a little work been done as deep as 1,800 feet.

This district is similar to Tonopah in the character and age of the wall rocks (Miocene andesites); in the nature of the alteration of the rock near the veins (silicification near the veins, propylitic alteration farther away); in the structural characters of the veins, which form a splitting and reuniting group; in the general character of ores (both oxide and sulphide), and of gangue, though adularia as a gangue material and selenides as ores have not been recognized at Pachuca; and in the occurrence of the rich ores in bonanzas, which seems to be due to the intersection of transverse fractures with the main vein zone.

[a] Beck, Richard, Erzlagerstätten, 2d ed., p. 277.

OTHER SIMILAR MINERAL DISTRICTS IN MEXICO.

The deposits of Pachuca are similar in many respects to many other Mexican ores. J. G. Aguilera remarks concerning the ores of Mexico in general:

"The silver deposits proper are found in eruptive rocks. A very few are found in sedimentary rocks, and in these the silver is accidental and variable in quantity. Where silver veins occur in sedimentary rocks it is evident that they are related to and dependent upon andesitic Tertiary eruptive rocks."[a]

* * * "The majority of the silver-veins of Mexico are in hornblende- and pyroxene-andesite. As examples of fissure veins in eruptive andesitic rocks, we may mention the following: In Zopilote, Tepic, the veins have a northwest course, and consist of quartz, blende, and pyrite, sulphides of silver, and small amounts of galena. At Topia the veins extend northeast-southwest, and contain galena, blende, a very small amount of pyrite, argentite, and pyrargyrite with a gangue of quartz and calcite. At the mines of Tecatitlán, Jalisco, the veins strike about N. 40° W., and dip 45° to the southwest. The gangue is quartz with a little calcite, carrying sulphides and antimonides of silver, pyrite, and chalcopyrite. At Chinipas, Chihuahua, the veins occur in diorite and hornblende-andesite. The strike is northeast, or in some cases northwest. The vein filling is quartz with argentite and pyrite, oxides of iron, and dendritic manganese. At Ajijic, Jalisco, the veins are in hornblende-andesite, with an east-west strike; there is an oxidized zone, and as depth is reached complex sulphides are encountered. At San Sebastián and Los Reyes, Jalisco, the veins have a quartz gangue with some calcite, complex sulphides, and tellurides of silver and gold, a very little galena, blende, and pyrite. The veins of the Rosario mines and San Nicolas del Oro mine, Guerrero, are in hornblende-andesite; their course is northwest, or in some cases northeast, and they contain an oxidized zone. Below this is the sulphide zone, containing argentite, ruby silver, pyrite, and a small amount of chalcopyrite. The gangue is quartz, carrying gold. Some of the veins of Sierra de Tapalpa, San Jose del Amparo, and Rosario, etc., have a north-south course, and dip west; the gangue is quartz with some barite. In the oxidized zone they contain the carbonates of copper, and beneath this gray copper and stibnite occur. At Tlalchapa, Guerrero, the lodes have a northwest-southeast course, dipping to the northeast. The vein-filling is quartz with argentite, pyrite, and blende; occasionally the vein quartz contains calcite and, in addition to the minerals named above, galena and chalcopyrite. At the mines of Chacoaco, south of Fresnillo, the veins extend nearly north and south, and contain quartz with marcasite and pyrite. Some of the veins strike northeast-southwest, and contain quartz, pyrite, and sulphides of silver. The veins of Real del Espíritu Santo are found in augite-andesite.

"In the pyroxene-andesites may be found the deposits of Pachuca, Real del Monte, El Chico, Tepenené, Capula, Santa Rosa, in Hidalgo; the mines of Santo Domingo, in Jalisco; and some of the mines of Noxtepec, Guerrero. Among the veins in andesite may be mentioned those of the following mines: San Pable Analco, which in the oxidized zone somewhat resembles those of Pachuca; the California

[a] Trans. Am. Inst. Min. Eng., vol. 32, p. 513.

mines, in which part of the veins strike northeast and dip southeast and others have their course toward the northwest and dip northeast. The gangue is quartz, carrying galena, pyrite, chalcopyrite, and tetrahedrite. In the San Rafael mine, Jalisco, the veins have a course N. 25° W. In the mines of Hostotipaquillo the veins contain calcite and quartz with some rhodochrosite, a small amount of pyrite and black blende, argentite, galena, chalcocite, and chalcopyrite. In the oxidized zone they contain native silver, carbonates of copper, and a very small amount of copper oxide. It would be tiresome to enumerate all the silver veins of Mexico which occur in andesites, but as has been said, the majority of the silver veins of the country are in various species of this rock, which Humboldt designated as metalliferous porphyries."[a]

Rarely similar veins are found in rhyolite.[b]

Perusal of the instances mentioned above by Aguilera shows that the veins are all closely alike, not only in regard to their country rock, but to their filling.

THE COMSTOCK LODE.

Pachuca is about 2,000 miles southwest of Tonopah, but a similar analogous deposit (the Comstock) lies 150 miles to the northwest.

The Comstock lode is a vein 4 miles long which has formed in Tertiary eruptive rocks, chiefly andesites, along a fault line having a maximum displacement of 3,000 feet. At both ends it branches and so dies out. It strikes east of south and dips east. It was discovered in 1859, and worked up till the present day, but most actively from 1861 to 1880. Up to June, 1902, it had yielded $369,566,112.61 worth of ore, of which about 42½ per cent was gold and 57½ per cent silver.[c] The rocks of the district in the order of their succession are, according to Hague and Iddings,[d] andesite, dacite, rhyolite, andesite, and basalt. The andesites are coarse grained in depth (diorites and diabases). Near the lode, and for some distance away, in a space about 5 by 2 miles, the country rock (chiefly andesitic) is extremely decomposed, the period of alteration having succeeded an andesitic eruption. The hornblende, augite, and biotite have altered to chlorite, pyrite, epidote, etc., the feldspar to quartz and an undetermined white aggregate. This altered andesite is the famous "propylite." The basalt, which is the latest rock of the district, has not been altered in the same way as the andesites. The alteration of the rocks and the lode was due to solfataric action which accompanied the faulting.

The lode material is quartz, certain limited portions of which contained large quantities of silver and gold (bonanzas), while the rest is low grade. Calcite is much less than quartz in amount and is generally insignificant. Most of the bullion has been derived from a bluish quartz, like that at Tonopah, the color being mainly

[a] Trans. Am. Inst. Min. Eng., vol. 32, pp. 515–516.

[b] Ibid., p. 517.

[c] Becker, G. F., Mon. U. S. Geol. Survey, vol. 3, pp. 9, 11. Also Rept. of the Director of the Mint for 1901, p. 169.

[d] Hague, A., and Iddings, J. R., Bull. U. S. Geol. Survey No. 17. Doctor Becker's determinations and succession are somewhat different, as follows: Granite, diorite, quartz-porphyry, diabase, andesite, basalt.

due to disseminated argentite, which is the principal ore mineral and is accompanied by gold, probably free. Bunches of stephanite, polybasite, and ruby silver were also found. In the bonanzas, near the surface, chlorides and native silver occurred. Frequently the ore grew base, and carried large quantities of galena, zinc blende, etc.

Pyrite occurs abundantly both in the altered country rock and in the ore. The mineralizing solutions are thought to have derived their heat from volcanic rocks, and thus the general phenomena are classed as due to solfataric action, but the materials precipitated, including the ores, are thought to have been derived from the decomposed wall rock.

The workable bodies or bonanzas represent the smaller portion of the lode. The value of the ore in them ranges from $15 a ton to (very locally) several thousand dollars. They are encountered at various depths, from the surface down to 3,000 feet. The vein down to nearly 2,000 feet contained 16 workable ore bodies, while below this level the ore has proved mostly low grade. One large bonanza (that of the C. & C. and Con. Virginia) extends vertically from about 1,250 to 1,950 feet below the surface, and has a greatest diameter of about 1,100 feet. It yielded about one-tenth the product of the lode.[a] The ore minerals were chiefly stephanite, argentite, and gold, the latter probably free.

The source of the heated waters which are encountered in the mines, and which are thought to have accomplished the rock alteration and ore deposition, is concluded from thermal surveys to be not less than 2 miles deep, and the heat and the active reagents, such as carbonic and sulphydric acids, are thought to have had a volcanic origin, while the waters may have had an atmospheric source. The waters above 800 feet had a temperature of about 70° F., while from about 1,000 feet down hot waters of above 100° F., rising under pressure, were repeatedly encountered.

The Comstock district is similar to Tonopah in respect to the character and age of the rocks in which the lode lies (Tertiary andesites), in their "propylitic" alteration, in the nature of the gangue and ore, and in the occurrence of the rich ores in irregular "bonanzas." The chief distinction is that the Comstock consists of a single very strong lode, while at Tonopah there are a number, of less size.

SILVER CITY AND DE LAMAR DISTRICTS, IDAHO.

Another region having many striking peculiarities in common with Tonopah lies about 400 miles due north of Tonopah. The districts of Silver City and De Lamar (5 miles apart) are situated in the Ohwyee Range, in southwestern Idaho.[b] The range has a granite core, almost covered by Miocene rhyolite and basaltic

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[a] This ore averaged about $80 per ton, with silver at $1.29 per ounce.
[b] Lindgren, W., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 107-188.

lavas. The ores were discovered in 1863. The total production to 1899 was 313,448 ounces gold and 10,540,000 ounces silver. The deposits are normal fissure veins, chiefly in rhyolite. In one type the principal ore minerals are small quantities of argentite and chalcopyrite, with a gangue of quartz and orthoclase (adularia). The proportion of gold to silver by weight averages 1:120. In the other type scarcely any sulphides are ordinarily visible, though occasionally pyrite, argentite, and pyrargyrite occur. The gangue is quartz, pseudomorphic after calcite or barite. The relation of gold to silver by weight is about 1:10. At De Lamar there is a strong silicification of the country rock near the veins, with the formation of abundant pyrite and marcasite, and a little sericite. Farther away from the veins the country rock is softer and more pyritized. The veins strike northwest and dip southwest, both strike and dip varying considerably. The system comprises ten veins, 20 to 80 feet apart. The strike of these veins is such that parts of the group are like some of the radii of a circle, as is the case at Tonopah, and each vein may join and fork in the manner of linked veins, both horizontally and vertically. The width of the veins is from 1 to 6 feet, averaging 3 or 4 feet. The rich ore occurs in large, continuous bodies extending from the surface to a depth of a 1,000 feet, dipping gently (20°–30°) southeastward along the plane of the vein. They are generally about 200 feet long and ordinarily 1 to 6 feet thick.

In other veins the ore bodies do not extend so deep, and, while having often a generally definite course, are so irregular and discontinuous as to constitute irregular bonanzas rather than definite shoots.[a] No considerable ore shoots have been yet found below 1,000 feet, though the veins remain strong. Cerargyrite, pyrargyrite, and argentite occur locally (the latter being common to nearly all the mines), as well as polybasite, proustite, native gold and silver.

Besides occurring in rhyolite, some of the veins are also in granite and basalt.

The rock alteration and the ore deposition are considered to have been accomplished by ascending hot waters, whose nature is indicated by the silicification of the rhyolite and the formation of adularia, chlorite, and epidote. The period of formation is post-Miocene. The veins extend along the strike sometimes for a mile or so, but average less; they die out on both ends. The ore at present mined at De Lamar goes $14 in gold and $2 in silver; in 1872 the average value of the ore mined was from $12 to $60 per ton in different mines.

The districts of Silver City and De Lamar just described are similar to Tonopah in that the ores occur in Tertiary volcanics, and are probably in both cases post-Miocene in age; to a striking degree in the character of the ores and gangue materials; in the structural character of the veins, which form a group knit together

[a] Op. cit., p. 152.

by branches; in the general character of the alteration of the wall rock; and in the occurrence of the rich ores in irregular bonanzas. The chief difference is that the wall rocks are mainly rhyolite and not andesite.

RELATION OF THE DESCRIBED DISTRICTS TO TONOPAH.

Of all the described ore deposits of North America, therefore, Tonopah appears to be most closely related to many of the Mexican silver veins, and also to the Comstock in Nevada and the Silver City-De Lamar veins of Idaho. With Pachuca, as is seen, the relation is intimate, and Ordoñez's description of the veins of this district would do, with a very little change, for a report on the Tonopah veins. The chief difference is in the occurrence of manganese silicate in depth at Pachuca, which has not been found at Tonopah,[a] and also the less content of gold, with the absence of ruby silver. Ruby silver, however, occurs in the cognate and contiguous Real del Monte district; also gold in considerable quantity occurs with silver in some of the Mexican districts of this type. Those enumerated by Aguilera[b] all occur in hornblendic andesite.

This group of veins is characterized by the following features: They occur in Tertiary volcanic rocks of similar character in the different localities, being chiefly Miocene andesites or rhyolites. They constitute strong masses or frequently branching and "linked" veins of quartz, which have as gangue essentially quartz, with frequently a little calcite, while adularia, barite, rhodochrosite, or rhodonite may also be present in limited amount. The ore is characteristically a silver-gold one, silver being usually predominant in the values in varying proportions, though the relative value may be reversed, and in some extreme cases either metal may occur with little admixture of the other. In any case the abundance of silver or gold, or both, in reference to lead, zinc, iron, etc., is characteristic. Silver sulphides, especially argentite, also stephanite and polybasite (with ruby silver) and gold, probably largely in the free state, are distinguishing features in the great majority of cases. Tellurides[c] and selenides may also be present. Pyrite, blende, chalcopyrite, and galena are usually present in varying quantity. Where they become predominant the vein becomes relatively low grade. Tetrahedrite, stibnite, and bismuthinite[d] are also known to occur. The wall rocks are characteristically much altered to quartz, sericite, chlorite, calcite, epidote, pyrite, and sometimes adularia, etc. Frequently the rocks nearest the veins are chiefly altered to quartz and sericite, those farther away to the softer "propylitic" alteration, consisting of calcite, chlorite, pyrite, epidote, etc.

[a] Since the above was written manganese carbonate has been found in the sulphide ores at Tonopah. See p. 89.
[b] Aguilera, J. G., Trans. Am. Inst. Min. Eng., vol. 32, p. 519.
[c] At Goldfield, Nev., and Jalisco and Tepic in Mexico (Trans. Am. Inst. Min. Eng., vol. 32, p. 501).
[d] At Goldfield. See Bull. U. S. Geol. Survey No. 260, p. 138.

The rich ores occur in irregularly outlined portions of the lode called bonanzas. These bonanzas are of limited extent both horizontally and vertically. They are believed to have arisen as a consequence of the irregular intersection of transverse fractures or fissures with the main vein channel, producing maximum deposition in these portions. Intervening portions may be low grade or barren.

In the oxidized zone, silver chlorides and bromides, free gold, manganese oxide, etc., occur.

THE PETROGRAPHIC PROVINCE OF THE GREAT BASIN.

After a study of the lavas of the Great Basin region of Nevada in 1900 the writer[a] came to the conclusion that the whole region "southward into the Mojave Desert, together with a portion at least of the Sierra Nevada, constitutes a petrographic province; that is to say, it is underlain by a single body of molten magma, which has supplied, at different periods, lavas of similar composition to all the different parts of the overlying surface. The limits of this subcrustal basin, however, are not yet defined in any direction."

The general sequence of lavas, roughly outlined, was concluded to be as follows:

1. Rhyolite (Eocene).
2. Andesite (Miocene).
3. Rhyolite with occasional basalt (Miocene–Pliocene).
4. Andesite (Late Pliocene–Early Pleistocene).
5. Basalts and occasional rhyolites (Pleistocene).

EXTENSION OF THE GREAT BASIN PETROGRAPHIC PROVINCE INTO MEXICO.

Later in the same year, Ordoñez, in a study of the rhyolites of Mexico[b] over a northwesterly trending belt extending from the northern boundary southward past the City of Mexico, found that the author's conclusions were also applicable to this province. He writes as follows:

> With very slight differences, which are without decisive importance, one may say that everywhere the relative order of eruptions, judging from the composition and structure of the rocks, has been the same. Let us here present the example of the Great Basin of Nevada. Many ranges of that region show a succession strictly comparable with that of Mexico.

The general succession is found to correspond with that given by the writer above, and the rhyolites occupy the same position and are of the same age (Miocene-Pliocene) as those under No. 3. The andesites, which preceded the rhyolites, correspond with No. 2, and are Miocene.[c]

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[a] Spurr, J. E., Jour. Geol., vol. 8, 1900, p. 638.
[b] Ordoñez, E., Boletín del Instituto geológico de México, No. 14, p. 65.
[c] Op. cit., p. 67.

PROBABLE STILL FURTHER EXTENSION OF THE GREAT BASIN-MEXICO PETROGRAPHIC PROVINCE.

In 1902 the author[a] recalled his description of the petrographic province, which includes the volcanic region of Nevada, and noted the work of Ordoñez. He also called attention to the fact that later developments showed similar lavas of similar age and succession in localities in the State of Washington and on the California coast. His statement was as follows:

"Without being in danger of carrying this correlation to excess I may point out that the Pliocene olivine-basalts of the Sierra Nevada[b] are abundantly present in Oregon and Washington; that the British Columbia basalts are approximately, at least, of the same period,[c] and that throughout the whole of Alaska and into the Bering Sea occur olivine-basalts of Pliocene age.[d]

"Again, the abundance of basic andesities (typically augitic, often hypersthene-bearing, and verging toward basalts) all belonging to one epoch (very late Pliocene-Pleistocene), in a continuous belt in Alaska, running the whole length of the Aleutian Islands and peninsula, turning the same angle as the chief orographic and topographic features, and running down the coast past Sitka;[e] the occurrence of the same rocks, belonging to the same age, in Washington and Oregon (Mount Rainier, etc.); the extension of the belt through the Sierra Nevada and along the western part of the Great Basin; finally its extension into Mexico[f]—this is all striking and deserves recognition. Moreover, this belt of late Pliocene-Pleistocene augite (hypersthene) andesites extends through Central and South America, in the Andes.[g] In Alaska and in the Andes some of the cones of this epoch are still active, but the majority have become extinct.

"It appears, then, that the whole extreme western part of the western hemisphere (the Pacific coast of the Americas) is a zone occupied by what (at some periods, at least) is and has been a single petrographic province.

"It remains to be seen whether this province is not continued into Asia with the change of orogenic trends in Alaska from northwest to southwest. The line of late Tertiary-Pleistocene volcanoes, which extends along the Aleutian Islands to Kamchatka, is represented by 15 or 20 cones in this peninsula; this line, following the general orogenic trend, runs southwest through the Kurile Islands, the islands of Japan, and the Philippines, into the East Indies. Andesites—largely pyroxene andesites, and frequently hypersthene andesites—are characteristic of this chain also, as far as the famous volcano of Krakatua."

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[a] Spurr, J. E., Trans. Am. Inst. Min. Eng., vol. 33, pp. 332–333.

[b] Spurr, J. E., Jour. Geol., vol. 8, No. 7, chart, p. 643.

[c] Dawson, G. M., Ann. Rept. Geol. Nat. Hist. Survey Canada, vol. 3, pt. 1, p. 37, B; also, Trans. Royal Soc. Canada, vol. 8, sec. 4, p. 15.

[d] Spurr, J. E., Geology of the Yukon gold district, Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 250.

[e] Spurr, J. E., Reconnaissance in southwestern Alaska, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, map 13.

[f] Ordoñez, Ezequiel, Las rhyolitas de México, Boletín del Instituto geológico de México, No. 14, p. 66.

[g] Zirkel, Lehrbuch d. Petrographie, 2d ed., vol. 2, pp. 831–832.

A METALLOGRAPHIC PROVINCE COEXTENSIVE WITH THE PETROGRAPHIC PROVINCE.

In the paper above referred to the writer brought forward the idea of metalliferous provinces (perhaps better, metallographic provinces) characterized by the presence of certain metals; and pointed out that these provinces may or may not be closely identified with petrographic provinces, although they probably generally are so, to a certain extent at least.[a]

Unquestionably the close relation between the Nevada mineral districts, Tonopah and the Comstock, with the far more numerous array in Mexico, and the individuality of this group as compared with other known veins of North America, shows a metallographic province, which in this case coincides with a portion of the petrographic province previously mentioned.

In this metallographic province ores occur in Miocene andesites in the great majority of cases, and their formation followed soon after the eruption of these rocks. In occasionally recurring cases (such as Silver City and De Lamar, Idaho, and others) they appear in Miocene-Pliocene rhyolites, which succeeded the andesites.

In general, however, the Miocene andesites of this province are, as Humboldt noted, the metalliferous formation par excellence, and if the conclusions which have been arrived at regarding Tonopah are correct (which coincide with a number of similar conclusions concerning other districts reached by other authors), the ore is due to the after actions of the eruptions in the shape of fumaroles, solfataras, and hot springs. Moreover, since similar manifestations (of fumaroles, solfataras, and hot springs) follow most volcanic eruptions, it is probable that the metals deposited by the after processes at this period arose from an unusual proportion of them in the andesitic magma; indeed, the very definition of a metallographic province implies this. The existence of such metallographic provinces is evident; and the theory of their origin, as propounded by the writer, is like that long entertained by many petrographers for the origin of petrographic provinces—namely, that they are formed by magmatic segregation.[b]

ORIGIN OF SHOOTS OR BONANZAS IN THE VEINS OF THIS METALLOGRAPHIC PROVINCE.

Light is thrown upon the origin of the shoots, chimneys, or bonanzas in this class of veins by the studies of the influence of cross fractures on their formation in Tonopah, and the similarity between these bonanzas and those at Silver City and De Lamar, Idaho, the Comstock and Pachuca (fig. 78). At De Lamar the shoot or chimney form is evident, some of the bonanzas having been

[a] Trans. Am. Inst. Min. Eng., vol. 33, p. 336.
[b] Spurr, J. E., Trans. Am. Inst. Min. Eng., vol. 33, p. 336.

followed downward over a thousand feet, yet the local irregularity of the outline is like that of the typical bonanza. At Tonopah a similar shoot-like form with a definite pitch has been discerned, but the developments thus far made do not

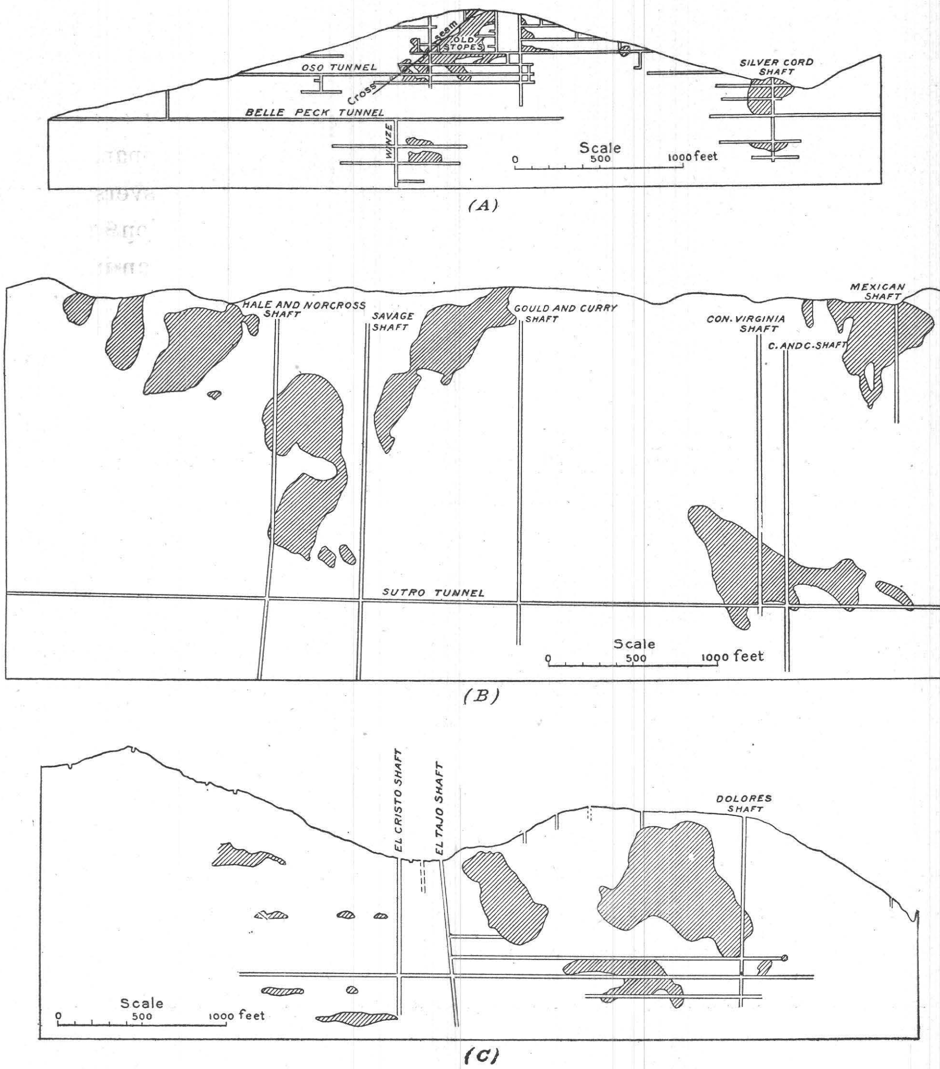

FIG. 78.—Vertical cross sections showing forms of ore bodies or bonanzas in districts similar to Tonopah. (*A*) Vertical section of Poor Man and Silver Cord veins, showing extent of rich ore body in De Lamar district; after Lindgren, Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, p. 152. (*B*) Portion of projected vertical section of the Comstock lode, Nevada, showing some of the chief bonanzas on the vein; adapted from Becker, Mon. U. S. Geol. Survey, vol. 3, atlas. (*C*) Projected vertical section of a portion of the Cristo vein, Pachuca, Mexico, showing bonanzas on the vein; after Aguilera and Ordoñez, Boletín del Instituto geológico de México, Nos. 7, 8, and 9.

show so great a persistency as at De Lamar. At Tonopah the connection of the shoots with cross fractures is evident, and the localization of the ore deposition at intersections of especially fractured zones seems the correct explanation. It is doubtful, however, if, when the bonanzas in the Tonopah veins shall have been worked out, the shoot-like form will always be discernible; in the case of the richer eastward-pitching shoots of the Mizpah vein, for example, the spaces between the shoots should probably be considered together with them, in the larger sense, as parts of one great bonanza, whose eastward pitch and shoot-like form would be less emphasized or not at all.

In the case of Pachuca, the bonanzas are irregular or roughly elliptical and are not shoot like; yet the fact observed by Ordoñez, that the bonanzas on the different veins group themselves into a definite zone running transversely across the strike, is hardly to be accounted for except by the explanation[a] arrived at in the case of Tonopah, that the bonanzas are due to the influence of an intersecting fracture system. At the Comstock the bonanzas are similar to those in Pachuca, although no local evidence has been found explaining their origin.

The above explanation is readily acceptable for bonanzas that are elongated into definite shoots, and are actually known to be associated with and dependent upon cross fracturing, as in Tonopah; but it is not so easily acceptable, perhaps, in the case of wholly irregular bodies, such as those of the Comstock. Yet at Tonopah the bonanzas are irregularly cut off, and do not continue indefinitely downward on the pitch; and to this limitation the explanation of the controlling effect of cross fractures must unavoidably be extended. Indeed, an inspection of the platting of fig. 24, showing the principal observed faults and fractures in the Mizpah mine, and a reflection that this is diagrammatic, while the real fractures and their intersections will be much more varied and localized, shows that the intersections of such mazes (such intersections constituting the tortuous channels of most active circulation) with the main vein fractures will often be quite irregular—will only approach a shoot-like form when dominated by some stronger set of cross fracturing, and will cease to produce ore bodies or bonanzas of definite form when there is no controlling fracturing, and now one fracture, now another, invites and controls the circulation.

EXISTENCE OF A MAJOR PACIFIC TERTIARY PETROMETALLOGRAPHIC ZONE.

Some further notes may be added to the above references (see p. 275) to the extension of the belt of late Tertiary-Pleistocene andesites.

In the region of Krakatua (situated between Sumatra and Java) the belt of recent and active volcanism turns eastward and passes through the East India Islands and adjoining island groups, paralleling the Australian coast, then curving

[a] Mr. S. F. Emmons informs me, on reading the manuscript of this report, that the above explanation had been adopted at Pachuca when he was there in 1901.

southward extends through New Zealand. Still farther southward the zone extends through the Macquarie Islands, and beyond this, in antarctic regions, in Victoria Land, where are the volcanic cones of Erebus, Terror, Melbourne, and Discovery, of which one—Erebus—is in almost continuous eruption.

The prolongation of the zone goes through the unexplored antarctic regions, very near to the south pole, and on the other side there are Pleistocene and recent volcanoes in the South Shetland Islands and other near-by land. Not far beyond this the belt comes to Tierra del Fuego, a desolate volcanic region. Thus the entire circuit of the earth has been made. This girdle, extending around the world and measuring some 35,000 kilometers, has been called the "circle of fire" by geographers, and is the theater of the world's most extensive and active volcanic manifestations. Within this circle, in the Pacific Ocean, are lesser volcanic belts.[a] The major volcanic belt, when viewed on a globe or a perpendicularly projected map,[b] has not a circular form, but rather that of a great somewhat elongated rectangle, inscribed upon the sphere; the two longer sides run northwestward and consist of the northwest American Pacific coast on one side and the stretch from the Philippines to the south pole on the other; the two shorter sides run northeastward and consist of that portion lying parallel to the Asiatic coast line on the one side and that portion in and near the antarctic regions on the other. This figure, however, is broken by irregularities consisting of curves and angles; and the volcanic chains are characteristically arranged in curves or "garlands,"[c] though in many cases it may prove true that such apparent curves are in reality combinations of straight lines, as is the case with the changes of trend in the volcanoes of Java and Sumatra.[d]

The Pleistocene-Recent volcanoes of the East Indies belt, which began their activity toward the close of the Tertiary,[e] have emitted chiefly andesites with a less amount of closely related basalt. Hornblende or pyroxene andesite, or both, occur in Java, Borneo, Celebes, and neighboring islands. Most of the pyroxene andesites have more hypersthene than augite.[f]

In New Zealand hornblende-andesites are common.[g] Concerning the recent lavas of the Macquarie Islands and other antarctic volcanic regions, there appears to be little information; the lava of Mount Terror, in Victoria Land, is reported as "basic."[h]

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[a] See Réclus, Élisée, Nouvelle géographie universelle, vol. 14, pp. 41, 42; Suess, E., La face de la terre, Paris, vol. 2, p. 837; Bonney, Volcanoes, London, 1899, pp. 259-260; Ferrar, H. T., Geog. Jour., Apr., 1905, pp. 374, et seq.

[b] Réclus, op. cit., p. 43.

[c] Suess, E., op. cit., p. 339.

[d] Bonney, Volcanoes, London, 1899, p. 226.

[e] Zirkel, Lehrbuch d. Petrographie, vol. 2, p. 828.

[f] Zirkel, op. cit., pp. 615, 616, 828, 829.

[g] Hutton, F. W., cited by Zirkel, op. cit., vol. 2, p. 618.

[h] Ferrar, H. T., Geog. Jour., Apr., 1905, p. 375.

There appear, then, reasons for believing that the belt of very late Pliocene-Pleistocene-Recent andesitic eruptions continues farther than suggested in the writer's paper quoted above (p. 275), and even that they are characteristic of the whole great "circle of fire;" and this uniformity seems to indicate a single major petrographic province for this period, extending around the whole zone.[a]

In some cases the analogy of the less-known Asian and Australasian portions of this belt with the North American part is known to extend back of the Pleistocene. In the East Indian archipelago, according to Zirkel, there was a general eruption of pyroxene-andesite at the end of the Eocene or beginning of the Miocene, since the early Miocene sediments already contain some andesitic material. This period would correspond to group No. 2 of the scheme of succession presented on page 68.[b]

In New Zealand the Hauraki Peninsula is made up almost wholly of Tertiary igneous rocks, mostly andesites, with accompanying heavy deposits of volcanic agglomerates; these andesites and accompanying tuffs and breccias are regarded as of late Eocene and early Miocene age. In places they are covered by rhyolites and rhyolitic tuffs of early Pliocene age.[c] These andesites and rhyolites, respectively, fall into groups 2 and 3 of the scheme on page 68.

It is also probable that the coextension of the metallographic and the petrographic provinces is greater than above established, for at many other points along the belt of the petrographic province, in the Andes of South America (for example, in Peru[d]), veins are reported having, so far as can be made out, a mode of occurrence, age, and composition similar to those of Mexico. The mines at Quespasia in that country are in highly altered augite-andesite. The ore minerals are pyrargyrite, polybasite, and other rich silver ores, with galena and blende, and a little copper pyrite and iron pyrite. In their richest portions they contained on an average 2 per cent silver.[e] These richest portions in the Peruvian mines of this type are like the Mexican bonanzas, and are called, in Peru, *tajos*.[f]

At Cerro de Pasco, also in Peru, the argentiferous formation is a metamorphosed Mesozoic sandstone intruded by altered andesite. The ore consists of free silver, silver sulphides and antimonides, lead carbonate and sulphide, various

[a] These andesites, constituting the most recent lava of this province, appear to be a distinctly later group in the volcanic succession than the youngest (No. 5) enumerated in the scheme on p. 68. They may be designated as group No. 6, Pleistocene and Recent, and the recurrence of lava of this composition, similar to Nos. 2 and 4 (early Miocene and late Pliocene andesites, respectively), suggests the beginning of a new cycle of magmatic differentiation, whose continuation will bring about, for the fourth time in the history of this volcanic epoch, the eruption of basalts and rhyolites similar to Nos. 1, 3, and 5. (See Spurr, J. E., Jour. Geol., vol. 8, No. 7, pp. 637-646.)

In the region near Tonopah there is one probable representative of these latest andesites. In Mono Lake, California, 90 miles west of Tonopah, are ten or fifteen volcanic cones of very recent date, the lavas being in part hypersthene-andesite, in part rhyolite. (Russell, I. C., Eighth Ann. Rept. U. S. Geol. Survey, pp. 374, 375, 377, 380.)

[b] See Spurr, J. E., Jour. Geol., vol. 8, No. 7, p. 637.

[c] Park, James, cited by Lindgren, W., Eng. and Min. Jour., Feb. 2, 1905, p. 218.

[d] Fuchs et de Launay, Gîtes métallifères, vol. 2, p. 829.

[e] Beck, Erzlagerstätten, 2d ed., p. 277.

[f] Fuchs et de Launay, op. cit., vol. 2, p. 831.

copper minerals, zinc, and iron pyrite. Twenty-seven miles from Cerro de Pasco are veins in quartz-porphyry (rhyolite?). The ore contains, besides silver minerals, various copper minerals, galena, sphalerite, bismuthinite, and stibnite.[a]

In view of the presence of selenium at Tonopah, the occurrence of this element at other places along this Pacific petrographic province in America is of interest. At Guanajuato, northwest of the city of Mexico, selenides, including a sulpho-selenide of silver, occur in argentiferous veins in hornblende andesite.[b] At Tasco, 180 miles southeast of Guanajuato, crystallized selenide of silver occurs.[c] In the South American Andes selenides occur at the Cacheuta silver mine, province of Mendoza, Argentina, whose vein is in "trachyte."[d] They include the selenide of lead and copper, that of copper and silver, and others. The latter selenide occurs also in the Chilean Andes, at Copiapo and Flamenco, and elsewhere.[e]

It is also interesting, in regard to the speculations of the author above quoted concerning the Asiatic prolongation of the petrographic province, to note that in Japan veins of argentiferous quartz are being worked, which occur in the midst of Tertiary eruptives, and which belong to the Comstock type.[f] Explicit information concerning these has lately come to hand.[g] Tertiary and Quaternary volcanic rocks are widely distributed in northern Japan. The Tertiary rocks include rhyolite (as old as the beginning of the Tertiary), andesite, and basalt. Metalliferous veins in Tertiary andesite and rhyolite are among the most important mineral resources in Japan. The older andesites have often suffered alteration by mineral waters and gases.

The Hoshino mines, in Hoshino-mura, Chikugo province, are in augite-andesite. The deposits are quartz veins containing pyrite, blende, gold, and silver. The Serigano mine, in Satsuma province, is in augite-andesite; the gangue is quartz, and the metallic minerals are pyrite, chalcopyrite, gold, and silver. The Yamagano district, between Satsuma and Osumi, is at present the most promising in the country. Here are numerous veins in augite-andesite. The gangue is quartz, often containing calcite and pyrite. The ore is native gold associated with argentite, and rarely with chalcopyrite. The proportion of gold to silver is about 5 to 1. At the Ponshikaribets mine, Shiribeshi province, the country rocks are Tertiary tuffs, cut by andesite dikes. The gangue is rhodochrosite and quartz, the ores are auriferous argentite, galena, chalcopyrite, and blende. The mine of Aikawa, in Sado province, has had an enormous production. The veins are in augite-andesite and Tertiary

[a] Mason, Russell T., Eng. and Min. Jour., June 8, 1905, p. 1092.
[b] Trans. Am. Inst. Min. Eng., vol. 32, p. 501. Dana, System of Mineralogy, 6th ed., p. 1025.
[c] Dana, op. cit., p. 52.
[d] Fuchs et de Launay, Gîtes métallifères, vol. 2, p. 832. The "trachyte" is probably andesite.
[e] Dana, op. cit., pp. 53, 54.
[f] Fuchs et de Launay, op. cit., p. 832.
[g] Geology of Japan, Geol. Survey, Tokyo, 1902, pp. 18, 19, 118, 124–171.

tuffs. The gangue is quartz, with calcite, rarely with dolomite and gypsum. The ores are chiefly native gold and silver, and argentite, associated with chalcopyrite, pyrite, blende, and galena; rarely stephanite, pyrargyrite, marcasite, and arsenopyrite. At the Kōsen mine, in Tajima province, the veins are connected with "propylite" dikes in granite. The gangue is quartz, the ore auriferous argentite, with pyrite and galena. The Tasei mine, Tajima province, is in "propylite," rhyolite, and Tertiary tuffs. The gangue of the vein is quartz, with some calcite and rhodochrosite. The ores are argentite and native gold and silver, with chalcopyrite, pyrite, galena, blende, and malachite. At the Kanagase mine, not far distant, the country rocks are similar; the gangue is quartz and calcite, and the ores are chalcopyrite, bornite, pyrite, tetrahedrite, argentite, galena, stibnite, pyrargyrite, blende, bismuth, and native silver and copper. At the Omori mine, Iwami province, the rocks are hypersthene-quartz-andesite, andesite agglomerate, and Tertiary strata. The ores are in veins and impregnation deposits. The gangue is quartz; the ore native silver, argentite, siderite, malachite, and auriferous and argentiferous chalcopyrite. The Ōkuzu mine, in Ugo province, is in Tertiary tuff and augite-andesite. The gangue is quartz; the ore auriferous chalcopyrite, with pyrite and rare blende. Silver is rare. At the Mizusawa mine, Ugo province, the country rock is augite-andesite and Tertiary strata. The ore is a mixture of barite, argentite, blende, galena, pyrite, quartz, calcite, chalcopyrite, and probably stephanite. At the Tsubaki and Hachimori mines, Ugo province, veins in andesite carry ores like the last named. At the Shirayama mine, Ugo province, veins in Tertiary tuff and augite-andesite have a gangue of quartz and barite, and contain argentiferous galena, blende, pyrite, and chalcopyrite. At the Innai mine, Ugo province, the country rock is Tertiary "propylite," the gangue is quartz and rhodochrosite, the ore minerals stephanite, argentite, pyrargyrite, chalcopyrite, pyrite, galena, and blende. At the Towada mine, in Rikuchū province, the vein occurs in Tertiary tuff, associated with augite-andesite. The ore is auriferous argentite and chalcopyrite in a clay and gypsum matrix. At the Omāki mine, Ugo province, the country rocks are Tertiary tuffs and andesite. The ore is argentite, silver oxide, copper and iron pyrite, and galena, with barite and gypsum as gangue minerals. At the Hisanichi mine, Ugo province, is a vein in Tertiary strata and augite-andesite. The ore is galena, chalcopyrite, blende, and pyrite.

Many of the important metalliferous veins in northern Japan and Chūgoku are also in rhyolites. In the Kanahira mine, in Kananomura, Kaga province, the veins are in rhyolite; the gangue is barite and quartz, the ores are native gold, blende, and pyrite. At the Matsuoka mine, in Ugo province, the ore is a stockwork at the contact of rhyolite with Tertiary strata; the ores are argentiferous galena, blende, and pyrite, carrying gold. At the Handa mine, Iwashiro province, the veins are in rhyolite and Tertiary strata. The gangue is quartz with calcite and amethyst; the ore is auriferous argentite, with blende; galena, pyrite, and native silver are sometimes found. At the Takadama mine, Iwashiro province, quartz veins containing auriferous argentite occur in rhyolite and Tertiary strata. The Kuratani mine, in Kaga province, contains veins in rhyolite and Tertiary tuffs. The gangue is rhodochrosite, with barite and calcite; the ores contain argentiferous galena, blende, pyrite, and jamesonite, and carry gold. At the Tagonai mine, Ugo province, the veins are in Tertiary tuff, augite andesite, and rhyolite; the gangue minerals are quartz and barite, the ores argentiferous galena, blende, and pyrite. At the Hata mine, Ugo province, the rocks are Tertiary tuff and rhyolite; gangue minerals are quartz, calcite, and barite; the ores are argentite, galena, pyrite, and chalcopyrite. At the Kuromori mine, Iwaki province, the vein is in rhyolite. The gangue is quartz, often amethystine; the ore is argentite, with blende. At the Kosaka mine, in Rikuchū province, the ore is an impregnation in Tertiary tuff, with rhyolite and dacite intrusions; it consists of lead and copper carbonates, copper sulphate, native copper and silver, and barite. At the Hatasa mine, Mino province, the rocks are rhyolite (quartz-porphyry) and andesite. The veins consist of quartz containing argentiferous chalcopyrite, galena, argentite, blende, and pyrite. The Waidani mine, Bizen province, is in rhyolite; the ores are argentiferous chalcopyrite, blende, and galena.

Besides the examples above cited, other veins of closely related types, but often containing a larger amount of the baser ores (lead, zinc, and copper) than the more abundant cases above, occur in or near Tertiary andesite or rhyolite.

Some information is available concerning certain East Indian ore deposits on islands lying south of Japan along the belt characterized by similar Tertiary and Pleistocene volcanics. In the whole of the Dutch East Indies, according to S. J. Truscott,[a] the gold (which is always accompanied by a larger amount of silver) occurs in reefs, veins, and impregnation zones, in altered andesite (porphyrite), or near the contact of such a rock with Devonian slates, in which slates there are sometimes similar though less extensive occurrences. The ore deposition probably took place in the Tertiary.

One of the principal productive centers in this region is the mine Redjang Lebong, in the southwest part of Sumatra. Here the ore, which occurs in altered andesite, has a gangue of fine-grained silica, with often some calcite. The gold is finely disseminated and is rarely visible; it exists free and in combination with silver, in the proportion of 1 to 10. At depth this silver probably exists as sulphide, connected with pyrites. Bullion from this mine gives the following analysis: Gold and silver, 91.52 per cent; selenium, 4.35; copper, 1.82; lead, 1.65; zinc, 0.48; iron, 0.14; total, 99.96. Tellurium was not found.

[a] Trans. Inst. Min. Metal., vol. 10, pp. 52–73.

The similarity of Redjang Lebong to Tonopah has been commented upon by Mr. Percy Morgan,[a] judging from the writer's earlier description of Tonopah[b] and from reports concerning Redjang Lebong. This similarity was also called to the writer's attention by Mr. L. Hundeshagen, who has personally visited both districts. The discovery of selenium in the Tonopah ores, in somewhat the same proportion as indicated in the above analysis, subsequent to the comparisons made by these gentlemen, strikingly strengthens the resemblance.

Five miles west of Redjang Lebong is a similar occurrence of gold ore in altered andesite, at Lebong Soelit.

In southeastern Borneo gold occurs in altered andesite.[c]

The northern arm of Celebes is gold bearing. The mine at Palehleh is in altered andesite, often having a dioritic aspect. The ore contains pyrite, galena, zinc-blende, and copper pyrite, with a little antimony and arsenic, and carries gold and silver, of which the sulphides contain gold about 4½ ounces and silver 12 ounces to the ton.[d] Forty miles west of Palehleh, at Soemalata, the ore is in andesite or "porphyrite."[e] The ore is like that at Palehleh—heavy sulphides with some quartz gangue, more often feldspar. Ten miles west of Palehleh, at Denuki Bay, are ores similar to those at Soemalata, but containing more quartz, in altered andesite. Analysis of the sulphides shows zinc, 31 per cent; lead, 8 per cent; copper, 1 per cent; gold, 5.3 pennyweights to the ton; silver, 4.9 ounces to the ton; arsenic, 2 to 4 per cent; antimony, 4 to 6 per cent. On the south coast of the peninsula, at Totok, are heavy auriferous quartz veins in altered andesite; also 6 miles southwest of Totok, at Kataboenan, where the andesite has been intensely silicified on each side of a central fracture, forming a wide mass of ore of the following average composition: Gold, 4 pennyweights per ton; silver, 1 ounce per ton; sulphides, 6 per cent; vein quartz, 3 per cent; the remainder being altered andesite.

Still farther along the Tertiary-Pleistocene volcanic zone lies New Zealand. The late Eocene-early Miocene andesites of the Hauraki Peninsula, in the north island of New Zealand, contain throughout veins bearing gold and silver. The whole peninsula has produced $50,000,000. Near the veins the andesite has been altered to calcite, chlorite, serpentine, quartz, and pyrite. The ore in the Thames district is chiefly native gold alloyed with 30 to 40 per cent silver. Associated minerals are dolomite, pyrite, chalcopyrite, zinc-blende, galena, stibnite and ruby silver, arsenopyrite, and native arsenic.[f] Great masses of quartz are very low grade, but bonanzas of very rich ore occur at the intersection of feeders with the main vein.

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[a] Eng. and Min. Jour., May 4, 1905, p. 862.
[b] Ibid., May 2, 1903.
[c] Truscott, S. J., loc. cit., p. 63.
[d] Truscott, loc. cit., pp. 65–67.
[e] Truscott, loc. cit., p. 68; also Suess, E., La face de la terre, vol. 3, p. 341.
[f] Lindgren, W., Eng. and Min. Jour., Feb. 2, 1905, p. 218.

At Karangahake the ore is argentite, with a little pyrite and free gold, in drusy, fine-grained quartz; stibnite and calcite, with some siderite and a little nickel and cobalt, also occur. At the Waihi mine, which up to the end of 1903 had produced $15,000,000, the ores are in altered andesitic rock, and have been covered by later rhyolitic flows. The oxidized quartz contains argentite and free gold, with black oxide of manganese, and oxides of nickel and cobalt; the sulphide ores contain pyrite and blende, with a little nickel, cobalt, and selenium. The country rock is altered, the secondary products including pyrite, carbonate (calcite?), and serpentine. In the veins and veinlets the gangue minerals are quartz, calcite, and adularia.

There are two distinct flows of rhyolite overlying the andesite, of which the older has a remarkable flow structure, giving it a brecciated appearance.[a] There has been a later period of mineralization, producing gold-bearing lodes in rhyolite.[b]

Mr. Lindgren calls attention to the striking similarity between the Waihi mine and the De Lamar mine, in Idaho, described by him—a mine already likened to Tonopah by the writer (see p. 271). Mr. Morgan, judging from a personal knowledge of Waihi and the writer's description of Tonopah,[c] calls attention to the close resemblance of these two districts.

Tellurium occurs in some of the New Zealand districts, varying from traces up to 12 ounces per ton, in picked samples. Samples from various districts show the following types of ores in regard to gold, silver, and tellurium: Coromandel, 25 per cent mispickel, gold 200 ounces, silver 90 ounces, a little tellurium; Tapu, 2¼ ounces gold, 250 ounces silver, 7½ ounces tellurium; Waiomo, gold 15 ounces, silver 600 ounces, tellurium 12 ounces; Waiomo, Monawai, gold 2 ounces, silver 40 ounces, tellurium 4 ounces. No tellurium was detected in samples from Waihi, Jubilee, Komata, Karangahake, and Great Barrier, in which the gold and silver bore the following proportions: Gold 24 ounces, silver 760 ounces; gold 8 ounces, silver 150 ounces; gold 600 ounces, silver 160 ounces; gold 2 ounces, silver 256 ounces; and gold 2 ounces, silver 200 ounces. Thus tellurium has been found in a line stretching from Coromandel to Maratoto, but nowhere to the east.[d]

Besides the selenium noted above in the Waihi mine, Mr. Allen found selenium in the ore at Great Barrier. In this New Zealand region selenium and tellurium have not been proved to be present in the same district. This is especially interesting in comparing New Zealand with the Nevada region, where selenium

[a] Compare the description of the Tonopah rhyolite dacite, p. 41.
[b] Lindgren, ut supra; also Morgan, Percy, Eng. and Min. Jour., May 4, 1905; Trans. Austral. Inst. Min. Eng., pp. 164–187.
[c] Eng. and Min. Jour., May 2, 1903.
[d] Allen, F. B., Trans. Austral. Inst. Min. Eng., vol. 7, p. 94.

without tellurium has been found at Tonopah, and tellurium without selenium at Goldfield, 28 miles south.

Enough data has been given above to indicate the coordination of an interesting set of phenomena. The greatest of the earth's oceans is rimmed by the greatest of the earth's volcanic belts. This "circle of fire," whether it runs along the coast of the mainland, as in the Americas, or along chains of islands, as in the Asian and Australian regions, follows faithfully the Pacific-fronting outlines of the continents of South America, North America, Asia, and Australia, and demarks the continental from the oceanic areas. In the Asian, Australasian, and Australian regions, indeed, the outlying islands rather than the continents have been held, from a geological viewpoint, to represent the limits of the Pacific Ocean.[a] Topographically the volcanic belt is also marked throughout its course by a line of bold and towering mountains, the consequence of active and comparatively recent extravasation and uplift.

For the next step in coordination the data are not so complete, but our information goes to show that remarkably similar lavas have been erupted from the active and recently extinct cones which are ranged along this belt.

A still smaller fund of information is available for the next step, but we are led to it by all that we can learn. It is that the "circle of fire" existed as such throughout most of the Tertiary, and, moreover, that the similarity of the more recent lavas was paralleled by like similarities at the different earlier stages of eruption. Roughly speaking, the idea is suggested that throughout the zone the order, period, and nature of the different erupted lavas have been approximately the same.

This belt also contains an extraordinary number of extraordinarily rich silver-gold ores (as well as those of lead, copper, zinc, etc.). These ores are contained in or associated with Tertiary andesites and to a less extent rhyolites (chiefly Miocene andesites and Pliocene rhyolites); and wherever they occur the nature and proportion of the ore and gangue minerals and the nature of alteration of the country rock are uniform to a surprising degree.[b] Similar mineralizing solutions, dependent upon the eruption of similar lavas at the same geological period, are attested.

The significance of the geographic coincidence of these different phenomena, occurring on so stupendous a scale as to stand out unmistakably from the confusion of detail of the world's geology, has yet to be thoroughly understood. These geographically coinciding phenomena may be summed up as follows:

1. The borders of the earth's greatest ocean.
2. The most persistent of the earth's lofty and bold mountain belts.

[a] Von Drasche, P., cited by Suess, E., La face de la terre, Paris, vol. 2, p. 339.

[b] At and near Schemnitz, in Hungary, are veins and ore similar to those of this great Pacific province, and they occur under simiar geologic conditions. Otherwise no good example outside of the province has come to the writer's notice.

3. The belt of the earth's most active and extensive recent vulcanism.

4. A belt showing similar recently erupted lavas.

5. A belt showing similar lavas erupted during the Tertiary.

6. A belt of enormous and roughly uniform later Tertiary mineralization, involving great concentration of silver and gold.

When it is considered that solutions accompanying (and presumably emanating from) Miocene andesites (to a less extent Miocene-Pliocene rhyolites) in this particular restricted zone have produced a very large proportion of the world's available supply of the precious metals, the rare and special nature of the occurrences which have called these ore deposits into being becomes evident, and it becomes impossible to entertain any explanation based upon processes uniformly distributed throughout the world.

INDEX.

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