Bulletin No. 219

Series { A, Economic Geology, 27
B, Descriptive Geology, 33 }

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE ORE DEPOSITS OF TONOPAH, NEVADA

(PRELIMINARY REPORT)

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

Reprinted in January, 1904.

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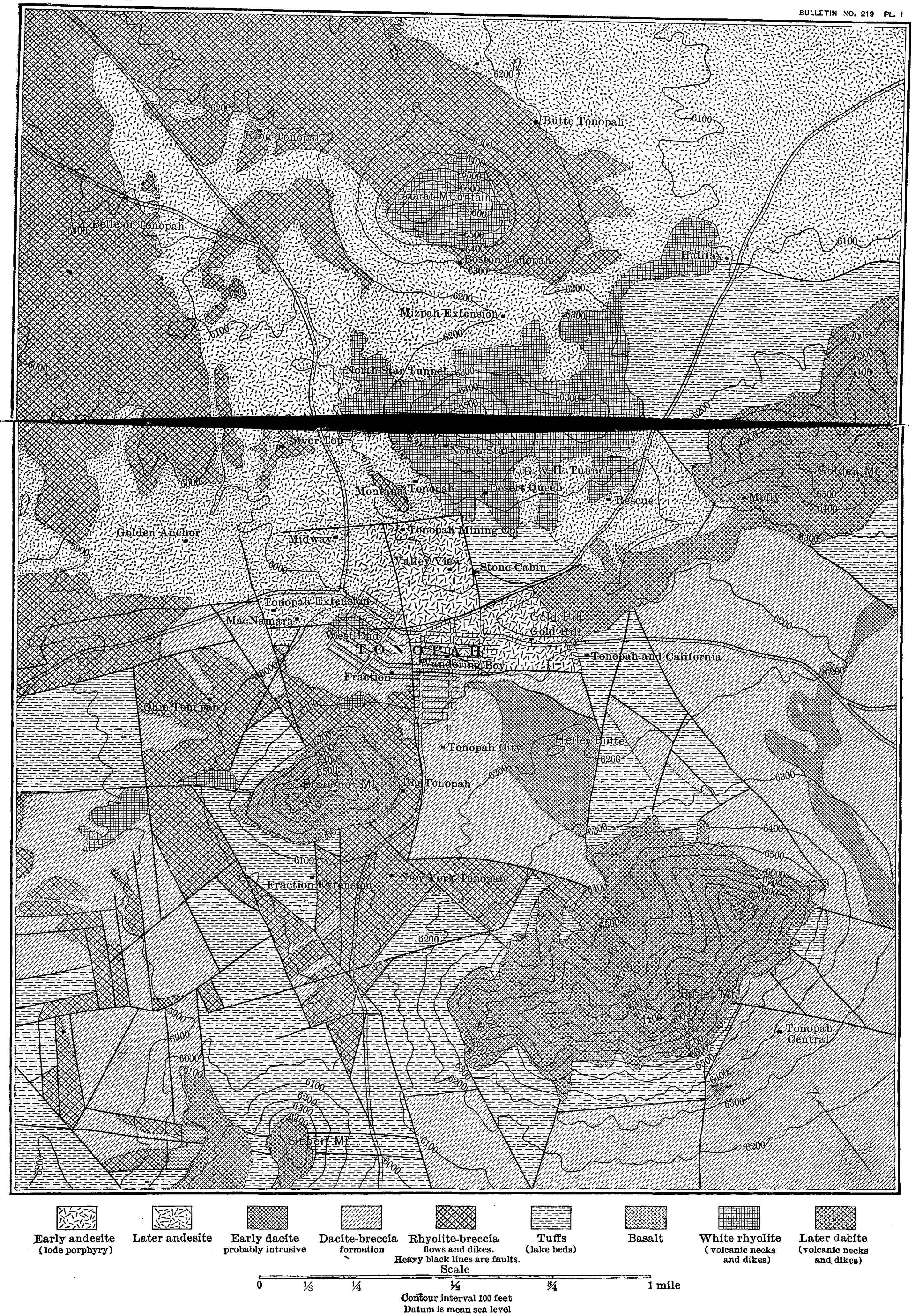

GEOLOGIC MAP OF TONOPAH MINING DISTRICT.

ORE DEPOSITS OF TONOPAH, NEVADA.[a]

By J. E. SPURR.

LOCATION, CLIMATE, AND POPULATION.

Tonopah is situated in Nye County, Nev., near the Esmeralda County line. It lies south of Belmont, and about 60 miles east of Sodaville, which is on the Carson and Colorado Railroad. The camp is reached by semidaily stage from the latter point.

The climate is arid, with rare rains and occasional snows. The present water supply is pumped from wells in a water zone some 4 miles north of the town.

At the present writing the camp has an estimated population of 5,000. It has electric lights, waterworks, two newspapers, and has attracted enterprising men from all parts of the country.

DISCOVERY AND DEVELOPMENT.

Tonopah was discovered in 1900 by J. L. Butler, who was on a prospecting trip. He gave his samples to Mr. T. L. Oddie, of Belmont, who had them assayed for him. These samples showed values of from $50 to $600 to the ton. 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 2 tons of ore was 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.

In December, 1900, a few leases were let, and in the spring of 1901 over a hundred more. Before the end of 1901 the lessees are said to have extracted ore to the value of about $4,000,000. In January, 1902, the leases having expired, the Tonopah Mining Company commenced development work, in which it is still engaged.

[a] The writer has spent about five months in field work at Tonopah and four months at Washington studying material collected at Tonopah. A satisfactory final report on the district calls for more detailed office study, microscopic examination of thin sections, chemical investigation, etc., which will now be carried on, and the completed report issued as soon as possible. Since, however, there is an urgent call by the mining public for some immediate information concerning the region, the Director has authorized the writer to issue a preliminary report containing an outline of the results to date.

Following is a table of the weight and value of the ore shipped, taken from smelter returns:[a]

Weight and value of ore shipped to April 1, 1903.

Year.	Weight.	Gold.	Silver.
	Pounds.	*Ounces.*	*Ounces.*
1901	5,067,852	9,780.95	623,487.83
1902	22,836,355	27,003.84	2,408,946.60
1903 (to April 1)	3,481,443	4,212.96	399,186.30
Total	31,385,650	40,997.75	3,431,620.73

Total value, $2,662,401.25.[b]

There are now[c] on the dump close to 25,000 tons of ore, of an average value of $50 per ton.

Subsequently ledges were cut in a number of different localities, such as the Montana Tonopah, Mizpah Extension, California Tonopah, West End, etc. Some of these are low grade, while some show high values. All are in the development stage.

Besides the Mizpah the only mine in the Tonopah district proper which has actually made shipments of importance, so far as the writer is aware, is the Montana Tonopah, where ore was discovered in depth by prospecting under the later andesite capping after the discovery and earlier development of the Mizpah vein. The shipments[d] of the Montana Tonopah to and including July 15 of the present year (1903) are as follows:

Shipments from the Montana Tonopah mine to July 15, 1903.

Shipment.	Pounds.	Total value.
First shipment, May 5:		
First-class ore	29,128	$6,596.5[illegible]
Second-class ore	23,331	2,472.7[illegible]
Second shipment, third-class ore for mill test	21,200	749.2[illegible]
July 15	29,019	4,381.8[illegible]
	15,664	715.6[illegible]
Total	118,342	14,915.8[illegible]

Shipments have been made by both companies since these data wer collected.

[a] For this table and the preceding information the writer is indebted to Mr. T. L. Oddie, manager, at Tonopah, of the Tonopah Mining Company.

[b] Estimated by the writer.

[c] May, 1903.

[d] Courtesy of Mr. C. E. Knox, president Montana Tonopah Mining Company.

The values in the ores are entirely gold and silver. The proportion of gold to silver is usually remarkably uniform, and is the same in both the oxidized and the sulphide ores, namely: The gold is to the silver, by weight, as 1:90 or 1:100, making the values about two-sevenths gold and five-sevenths silver. In some of the excessively rich ores the proportion of gold becomes greater, occasionally making up half of the total value.

TOPOGRAPHY.

That the mountain range in which Tonopah is situated is of volcanic origin is shown by its topography. It consists of a series of eroded mesas and detached or connected hills. These mesas and hills are irregularly distributed, with no definite valley systems between. They are separated by patches of sloping or rolling country, largely covered with "wash," or débris worn from the hills. The mesas are the remnants of volcanic flows; the isolated or connected irregular hills are denuded volcanic necks.

An excellent topographic map of the country immediately around Tonopah, on the scale of 800 feet to an inch, has been made by Mr. W. J. Peters, of the United States Geological Survey. On this it is seen that the general elevation of the slight valley-like depression in which the town of Tonopah lies is about 6,000 feet above sea level, while the top of Butler Mountain, which is the highest mountain near the town, is 7,160 feet.

GENERAL GEOLOGICAL HISTORY.

Pre-Tertiary formations.—In the immediate vicinity of Tonopah the rocks are all Tertiary volcanics or sedimentary tuffs belonging to the volcanic period, and composed partly of ash and partly of silt derived from the erosion of the lavas. Eight or nine miles south of the camp, however, there is limestone, very likely of Cambrian or Silurian age, and in this granitic rock is intrusive. Limestones and granites occur also several miles north of Tonopah, and at intervals between there and Belmont. At Belmont the limestone, into which granite is intrusive, is known to be Silurian.

At Tonopah itself occasional limestone fragments and more abundant fragments of a fine, even-grained pegmatite occur in the volcanic breccias. They are blocks which were hurled out from the volcanoes at the time of their eruption. Thus it is shown that at an uncertain depth below the present surface the ascending lavas broke through rocks of this character.

Early andesite eruption.—The oldest rock outcropping in the immediate vicinity of the camp is a hornblende-andesite, or, rather, was such, for no fresh portions have been found and the rock has been altered so as to acquire an aspect in general very different from its original one.

Subsequent to the eruption of this rock fractures were formed in it, and these became the channels for circulating solutions, probably ascending hot waters, closely connected with the volcanism. The waters were remarkable for intensity of action. The rocks which they traversed have been chemically transformed, the chief process being silicification, so that they are now found more or less completely altered to quartz and sericite (fine muscovite). Along fracture zones the rock has been replaced almost entirely by quartz carrying silver and gold, and these constitute the veins by which Tonopah is known. Some parts of the hornblende-andesite, on the other hand, show chiefly calcite and chlorite, with pyrite, as alteration products; but such phases have not yet proved to lie immediately adjacent to important veins, and, as a rule, do not seem to be indicative of the proximity of the best class of ore.

Later andesite eruption.—There is evidence that these events were followed by a considerable period of erosion, long enough to bring the veins to the surface. Then another eruption of andesite occurred. This later andesite, which was abundant in amount, differed from the earlier andesite in containing, as dark minerals, pyroxene and biotite rather than hornblende, and it also differed in some structural and textural points. It is probable that this andesite came up through the hornblende-andesite in places, and also flowed over it, completely covering it and its contained veins.

Rhyolite and dacite eruptions.—Following probably another period of erosion and volcanic rest, eruption was vigorously renewed and there were outbreaks at many closely adjacent points. The lavas were rhyolites and siliceous dacites, closely related to one another. Some vents emitted one, some the other rock. This period of volcanism was long and a number of different lava flows of dacite and rhyolite alternated or mingled. The eruptions were often explosive, as is shown by the considerable quantity of pumiceous and fragmental material in the volcanic breccias of this period.

Lake sediments.—During this volcanic epoch a large fresh-water lake formed, of unknown, but probably great extent. In it were deposited white, finely stratified ash and tuff, and some beds are entirely made up of late Tertiary infusoria. In places the sediments of this lake, exposed near Tonopah, are several hundred feet thick.

It is probable that this lake was partly filled by sediments and then drained by an uplift. Near the top of Siebert Mountain (a white tuff mountain southwest of Mount Brougher) there is what appears to be a river channel belonging to this post-elevation epoch, containing rounded waterworn pebbles of rocks such as now outcrop to the north and east of Tonopah, and fragments of silicified wood, showing the presence of vegetation at that time. This uplift may be ascribed to volcanism, for it was soon followed by renewed outbursts of lava.

Eruption of basalt and intrusion of later dacites and rhyolites.—Above the tuffs on Siebert Mountain is a thin sheet of slaggy basaltic rock, the first of the upwellings of the next period of volcanic activity. Soon afterwards great columns of dacite and rhyolite made their way to the surface. The eruptions from these vents must have been chiefly explosive, and the products light and scanty and easily swept away, for no trace of them has been found in the immediate vicinity of Tonopah. The volcanic necks, however, have been laid bare by erosion, and on account of their superior hardness to the tuffs and breccias, in which they were intruded, now stand up as low detached mountains. Brougher Mountain, Butler Mountain, Siebert Mountain, and Golden Mountain are all dacite necks of this period, while a group of rhyolite eminences, consisting of Oddie and Ararat mountains and Rushton Hill, represent necks of very nearly the same period as the dacite.

Faulting of the region.—At about this period occurred an event of great scientific and economic interest—the faulting. A considerable number of important and complicated faults have been found in the region. Their age, as denoted by their relations to the different formations, seems nearly uniform. All the rocks up to and including the stratified tuffs have been displaced by the faulting, and on Siebert Mountain the thin sheet of basaltic rock overlying the tuff has been faulted with it. But these faults invariably stop at the contact of the dacite necks, which are not affected, and the same is probably, though less certainly, true of the rhyolite necks above noted. Indeed, the dacite certainly (and the rhyolite less certainly) has been intruded as dikes along the faults.

The geological map (Pl. I) reveals some important points. It shows that the area of observed complicated faulting is in general coextensive with the region of late dacite intrusion. This region, which occupies the southeastern portion of the district, is downsunken in comparison with the unfaulted or little-faulted region on the northwest. Near the dacite necks the observed faults are rather more numerous than elsewhere, and in many instances it may be established that the blocks adjacent to the dacite have been downsunken in reference to blocks farther away. From these intrusive necks the faults run in a roughly radiating fashion and seem to follow no regular system of trend. 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). After this intrusion and subsequent eruption there was a collapse and a sinking at the various vents. The still liquid lava sank, dragging downward with it the adjacent blocks of the intruded rock, accentuating the faults, and causing the described phenomena of downfaulting in the vicinity of the dacite. This sinking of volcanic centers after eruption has been well established by students of volcanism.

The economic interest in this faulting lies largely in the circumstance that the veins in the early andesite have been cut and displaced thereby.

Recent erosion.—To complete the geological history, we have to conceive of the considerable period of erosion which stripped from the surface a great thickness of volcanic material, leaving the resistant volcanic necks standing out as hills, and laying bare the present surface. Certain blocks of limited extent had been raised by the faulting above the level of the rest, and here the surface of erosion reached the early andesite and uncovered the rich veins contained in it; and it is the discovery of these veins which has made the subject of the geology of the still covered region of such lively interest to miners.

Sequence of formations and events.—The following, then, is the sequence of events as deciphered for the vicinity of Tonopah:

Sequence of formations and events in the vicinity of Tonopah.

Early andesite.
- Fracturing.
- Vein formation. (Primary minerals, quartz, valencianite, stephanite, pyrite, chalcopyrite?) Values good; gold and silver, silver predominant.

Erosion.
Later andesite.
Probable erosion.
Dacite.
Dacite breccia.
Rhyolite breccias, flows, and dikes, intermingled with slightly stratified or interstratified pumiceous or tuffaceous fragmental material.
- Vein formation. (Primary minerals, quartz, pyrite.) Values relatively low; gold and silver, gold apt to predominate.

Erosion.
Tuffs, with an occasional thin rhyolite flow.
Elevation of tuffs.
Tilting.
Basalt.
Chief faulting. (Affects everything preceding.)
Rhyolite (white) intrusion (probably Ararat, Oddie, Rushton hills).
- Vein formation. Primary minerals, quartz, chalcedony, calcite, siderite, pyrite.) Values low; gold and silver, gold apt to predominate.

Erosion.
Dacite intrusion (Butler, Brougher, Golden, Siebert mountains).
- Mineralization (chalcedony, manganese). Values slight to insignificant. Mud veins.

Erosion.
Glassy rhyolite flow (slopes of Oddie and Brougher).

DESCRIPTION OF THE ROCKS OF THE REGION.

Distribution and characteristics of the early andesite.—This was originally a hornblende-andesite, containing probably some biotite and pyroxene. In the immediate vicinity of Tonopah it outcrops only, so far as observed, on Mizpah Hill and Gold Hill, but it has been discovered under younger rocks in a number of different mines, such as the Montana Tonopah, the North Star, the Ohio Tonopah, the California Tonopah, the Wandering Boy, part of the Fraction at least, and probably the West End and MacNamara, the Midway, etc. Nowhere is it in even an approximately fresh state, but, as before noted, it has altered largely to calcite and chlorite, and (more commonly in the vicinity of the veins) to quartz and sericite. In the former condition it has a fairly deep-green or blue color, while in the latter phases it is lighter green or blue, and very often nearly white, or assumes, near the surface and along faults or fractures, a pale yellowish, brownish, or reddish color. This common quartz-sericite type has the appearance of rhyolite rather than of anything else, and does not at all resemble andesite, while the calcite-chlorite phase has more nearly the rightful aspect of a highly altered andesite.

It is difficult always to distinguish this early andesite with certainty on account of its many different phases. It is most likely to be confounded with the later andesite on one hand and with certain types of rhyolite on the other. The main points of difference will be outlined shortly.

Distribution and characteristics of the later andesite.—The later andesite outcrops over a considerable region in the northern part of the district. The upper portions, and in some cases the whole, of the following shafts are in it: Montana Tonopah, North Star, Midway, Golden Anchor, Little Tonopah, Boston Tonopah, Halifax, etc. It varies greatly in state of preservation, being frequently found nearly fresh, and again highly decomposed. In its fresher phases it is a dark-colored, hard rock, with large crystals of pyroxene, feldspar, and biotite. It has usually been more or less altered, and as secondary minerals calcite, chlorite, serpentine, etc., have been formed, giving the rock a dark-green color. Frequently, also, the altered rock has a deep-blue color. Near the surface the red of the oxidized iron combines with these colors to produce a characteristic rich purple. In some places the rock has been thoroughly altered to calcite, chlorite, and pyrite, with other secondary minerals, and again has been so completely leached as to be soft and white.

In these highly altered phases the later andesite becomes with great difficulty distinguishable from the early andesite, and where it is fine grained the resemblance may become almost exact.

For the distinction of the two rocks in general it may be noted that the early andesite is characteristically finer grained than the later andesite, and that in the former the feldspar crystals are slimmer and rectangular, while in the latter they are stouter and often of complex shape. In some of the hornblende-andesite (though not generally) the long dark crystals of altered hornblende may be distinguished, while in the later andesite the crystals of biotite are usually plainly visible, even in the considerably altered phases. The characteristic later andesite has a coarse, mottled appearance, and even when highly altered and bleached it has a dull clayey luster, which is rarely seen in the early andesite. Rocks which are highly siliceous from alteration are apt to belong to the early rather than the late andesite.

Distribution and characteristics of the rhyolites.—There have been several different rhyolite flows and intrusions, some before, some mainly subsequent to the faultings; and the rocks have a variety of appearances which defies any description in common. The lava of Oddie, Rushton, and Ararat hills is a characteristic siliceous white rhyolite. The Rescue shaft is mainly in this rock, and two long tunnnels, the North Star and the G. & H., have been driven in it into Mount Oddie.

Besides this, however, there is a formation of fine-grained gray or red, largely glassy rhyolite, which covers a still larger area. A large body of it occupies the northern portions of the district, where it is intrusive, with a sinuous contact, into the later andesite. It continues from here, along the western edge of the district, to the vicinity of the Ohio Tonopah, and occupies a considerable part of the basin inclosed between Butler, Brougher, and Siebert mountains. The formation here occurs as complicated dikes cutting the dacite-breccia formation, and as sheets underlying the tuff, or, to a less extent, intercalated in the tuff. In the rest of the district it is practically absent. It is in general between the dacite breccia and the stratified tuff in point of age, is older than the faults, and is therefore displaced by the fault movements. In the northern portion of the district a number of shafts are located on or near the contact of this rhyolite and the later andesite. Among these may be mentioned the King Tonopah, Belle of Tonopah, Miriam, Silvertop, Little Tonopah, etc. In the western portion the Ohio Tonopah and the New York Tonopah each encountered a considerable quantity of this rhyolite mixed with dacite breccia, while the Fraction extension is entirely in this rock, after having passed through the overlying tuff.

This finer grained gray or red rhyolite has many different aspects. Fine brecciation, with bright red, gray, and white colors, is frequent; in other cases it is dense and characterless. The best test of it is the detection of the small quartz crystals that dot the glassy groundmass, which distinguishes the rock satisfactorily from the andesites. Sometimes, however, these quartz crystals may be rare and small. Near the contacts of the rhyolite (intrusive into the earlier rocks) there has also frequently been alteration—silicification, the formation of pyrite, etc.—and then the rock may become almost identical in appearance with the early andesite which has been similarly altered. The best method for distinguishing the rhyolite from andesite in this case is the tracing of the connection with the less-altered rhyolite farther away from the contact.

Distribution and characteristics of the dacites.—The bold knob north of Butler Mountain, known as Heller Butte, is made up of what is regarded as probably the oldest dacite exposed at the surface. It is a compact, relatively coarse-grained rock, finely brecciated, and carrying included fragments of older rocks, notably the later andesite. It is surrounded and probably overlain by the softer dacite-breccia formation. The Tonopah City shaft after passing through the dacite breccia has continued in solid Heller dacite to a total depth of over 500 feet. East of Butler Mountain, on the edge of the district, another strip of this dacite is exposed, also surrounded by the dacite breccia. It is regarded as probably intrusive.

The *dacite-breccia* formation, on the other hand, is essentially a surface formation, and not intrusive. It consists of flows of often very pumiceous and friable dacite, dacitic mud flows, and some rudely layered or even stratified fragmental material. In places it is very thick. It is exposed over a large fraction of the southern portion of the district, around Butler, Brougher, and Siebert mountains. The Ohio Tonopah and the New York Tonopah shafts passed through considerable thicknesses of this formation, and the Fraction No. 3 is entirely in it. The Fraction Nos. 1 and 2, and Wandering Boy, and the West End, passed through this formation at the surface and reached the underlying formations.

The *later intrusive dacite*, which makes up Butler, Brougher, and Golden mountains and the central portion of Siebert Mountain, has usually a characteristic appearance. It is darker than the rhyolite of Mount Oddie, has a slight purplish tinge, and contains more crystals (of feldspar, quartz, and mica) embedded in the glassy groundmass. The Big Tono shaft, at the east foot of Mount Brougher, starting at the outward-pitching contact of this rock and the intruded dacite-breccia formation, goes down several hundred feet in the former. The Molly, starting near the dacite contact on Golden Mountain, passed through several hundred feet of this rock, then through the inward-pitching contact to a slight thickness of loose material belonging to the dacite-breccia formation, and so into the later andesite.

PERIODS AND NATURE OF MINERALIZATION.

Mineralization subsequent to the early andesite intrusion.—The most important veins of the Tonopah district, and all those that have been proved to be of immediate economic importance, occur in the early andesite, and do not extend into the overlying rocks. Hence, when the early 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 circumstance shows pretty plainly that the vein deposition took place before the eruption of the later andesite, and immediately after that of the early andesite (for the period of erosion between the two andesites seems to have exposed the veins at the surface, showing 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 early andesite intrusion, and that these waters had apparently become inactive by the time of the later andesites.

The mineralization at this period was extraordinarily active, as the profound alteration of the early andesite testifies. Among the known veins formed at this period those of the Valley View, Mizpah, and Montana Tonopah groups are the most important, though certainly there are others which have not yet been discovered. These veins carry gold and silver, in the proportion of about 1 part of gold to 100 of silver, by weight. They are unusually free from base metals—no lead, arsenic, etc., has been detected. In some places there is a very little copper, in others none. The gangue is quartz, with frequently a mineral which is a variety of orthoclase feldspar (valencianite). The sulphide ores, so far as developed, show primary stephanite, with probably some polybasite, scant pyrite, and comparatively rare chalcopyrite. Secondary sulphides coating the cracks in these ores are ruby silver, argentite, and probably pyrite and chalcopyrite. The oxidized ores show abundant silver chloride, with occasional bromides, etc., and sometimes free gold.

Mineralization subsequent to the early rhyolite intrusion.—Along the borders of the gray or red glassy rhyolite intrusions, especially in the northern portion of the district, there has been, as before noted, considerable alteration and mineralization, which must be attributed to a cause similar to that which produced the veins in the early andesite—namely, the action of hot ascending waters immediately succeeding and genetically connected with the rhyolite intrusion. This alteration is in the form of silicification and the formation of pyrite, and has acted on the rhyolite as much as the intruded rock. Quartz veins have been formed, in the majority of cases relatively small. These veins contain precious metals, but usually very irregularly distributed. High assays, especially on the surface, may even be obtained, but it is likely that some of these are the result of the well-known process of increase of values at the surface during oxidation. Specimens of the veins have a general resemblance to those of veins of the early andesite, and show pyrite, often finely disseminated in a quartz gangue. Some of these veins have been found to be of considerable size; therefore it may often be difficult to distinguish them from the andesitic veins without study of the rock in which they lie. Chemically they appear to be characterized, so far as yet developed, by very low average values and by the frequent but not regular preponderance of the gold values over those of silver.

Mineralization subsequent to the later rhyolite intrusion.—It has been described how the white rhyolite of Oddie, Rushton, and Ararat hills is probably later than the dense, usually gray rhyolites referred to above. For example, the top of Ararat seems to be a plug or neck of white rhyolite forced up into the earlier gray rhyolite. This later white rhyolite shows near its contacts, and to a less extent away from these, in itself or in the intruded rock, veins which are ascribed to causes similar to those which probably brought about the preceding mineralizations—namely, ascending heated waters following the lava intrusion, genetically connected with it, and, like the previous similar processes, dying out after the lapse of some time. These veins, which are in places very large, are of calcite, siderite or ferriferous calcite, chalcedony, etc. They contain some pyrite and sometimes give low values in the precious metals, gold preponderating.

Mineralization phenomena may also be observed in some places near the contact of the Oddie Mountain rhyolite, where there is silicification and the formation of pyrite, with quartz veins of various sizes, sometimes containing calcite. These veins are generally small, but may be large. Galena and chalcopyrite have been exceptionally found in them. They carry low values in gold and silver, the gold being apt to predominate.

Mineralization subsequent to the dacite intrusions.—Finally, the contacts of the large dacite necks (Butler, Golden, and other mountains) are accompanied in many places by the deposition of chalcedony, manganese, etc., in cracks and crevices. These are not usually in veins, or when so are small and irregular. Considerable values in the precious metals have been claimed in some cases, but it is the writer's experience that the content of these metals is insignificant.

Résumé.—To sum up, no fewer than four periods of hot-spring action, accompanied by more or less vein formation and mineralization, have been noted at Tonopah. Each of these periods was consequent upon a lava intrusion, and the mineralization was the result of a process which is known to accompany and follow volcanic eruption at the present day. In general, the values found in the veins of these different periods increase with increasing age. Also, the general phenomena indicate that the younger veins were formed nearer the surface than the older ones. Although ascending hot waters are not known to deposit more than traces of metals at the surface, it is supposed that an important precipitation takes place at some depth; so in the case of Tonopah it may be that the later periods of mineralization have produced some rich ores, but that erosion has not yet had time to expose the level at which they lie, whereas in the case of the oldest period this has been accomplished. At Gold Mountain, about 4 miles south of Tonopah, veins belonging to the rhyolitic period and having the same characteristics as some of these veins at Tonopah contain considerable values in gold and silver, while at Tonopah no such values have been discovered in this class of veins.

At Tonopah, therefore, the earliest and most important class of veins can be found only in the earlier andesite. The rhyolite veins, on the other hand, may occur in the rhyolites, as in any of the older rocks; indeed, they must also occur sometimes in the early andesite itself. The mere fact of a vein lying in the early andesite, therefore, is not always evidence that it belongs to the early andesite period. In some such cases it may be extremely difficult, if not impossible, to tell to which period it belongs.

The later andesite is in many cases thoroughly decomposed and altered, and there has been extensive formation of pyrite, calcite, etc., in it, especially in the regions where the richest veins have been found. The nature of this alteration is such as to indicate copious percolating waters as the agents, and to suggest that the waters may have been heated. It is quite possible that some of the small sulphide-bearing veins, which are frequently found in the later andesite, may have been formed contemporaneously with this alteration. These veins are nonpersistent, and the values contained are small. Physically they resemble the rhyolitic veins, and as they have been noted chiefly in the general vicinity of rhyolite, which is intrusive into the later andesite, they have been classed with the undoubtedly rhyolitic veins. It is possible, however, that a moderate mineralization, similar in quantity to that which succeeded the rhyolite eruptions, followed that of the later andesite.

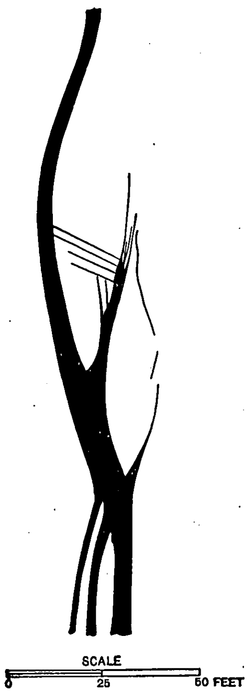

FIG. 1.—Horizontal plan of portion of Mizpah vein, as developed on the 250-foot level, Mizpah mine, east of the Brougher shaft.

VEIN GROUPS OF THE EARLY ANDESITE MINERALIZATION.

The only productive veins thus far discovered in the Tonopah district proper are those of the early andesite period. On account of the later volcanic rocks which cover the early andesite in most of the district, these productive veins outcrop only in a very small area, outside of which little is known as yet. It is probable, however, as indicated by the great amount of alteration in the early andesite, that the vein formation has been extensive, and that the veins at present known are only a small portion of those that will eventually be developed.

The veins already discovered all belong to the type of "linked veins." Their physical characteristic is that they branch and reunite in both a horizontal and a vertical direction (fig. 1). There is generally in each group a main or master vein from which the smaller veins branch. These smaller veins again may subdivide and so finally die out. The main vein and its branches may together be termed a "vein group."

Veins probably of the early andesite period have been discovered in various mines outside of Mizpah Hill, where the first discoveries were made. Among these later developments may be mentioned the California Tonopah, the MacNamara, the West End, the Ohio Tonopah, and other workings. But it is only the veins on Mizpah Hill

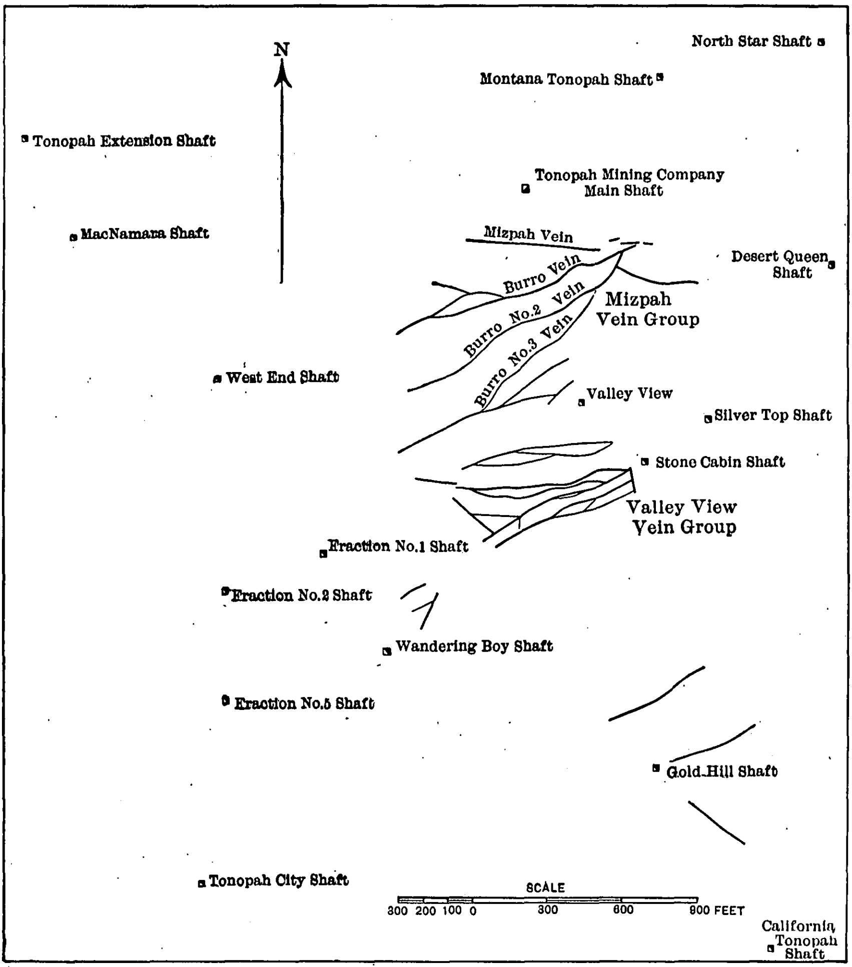

FIG. 2.—Map showing outcropping veins at Tonopah.

that have been sufficiently developed to give information concerning the vein system. On Mizpah Hill there may be recognized at present three main groups of veins—the Valley View group, the Mizpah group, and the Montana Tonopah group. These are all strong and distinct (fig. 2).

The Mizpah group lies in the center, between the other two, and was the first discovered. The trunk vein of the group is called the "Mizpah" vein, and crosses Mizpah Hill in an east-west direction, showing a strong outcrop. This outcrop is cut off both to the east and to the west by heavy faults, so that it is adjoined on the east by the rhyolite of Oddie Mountain and on the west by the later andesite. From the Mizpah vein a succession of branches depart, running chiefly in a southwestern direction from the eastern end of the outcrop, and each successive branch diverges more than its predecessor from the strike of the main vein, so that the whole group is like a section of the spokes of a wheel, the spokes uniting some distance east of the main shaft. The chief of these branches are known as the Burro No. 1, No. 2, No. 3, etc. They are strongest near the main vein, and those which diverge most from the strike of the latter are weaker than those which are more nearly parallel to it. The intersections of the branches with the main vein and with one another usually pitch to the east at a moderate angle. These easterly pitching intersections are significant, since they have the same general course as certain shoots of especially rich ore in the same vein, and correspond also in direction to some post-mineral fracturing and faulting. The main vein has in general a steep northerly dip, which is locally overturned so as to dip steeply to the south.

The Valley View mine shows a group of veins of the same general type as the Mizpah, but with minor differences. The main Valley View vein as exposed in the workings has, like the Mizpah vein, a northerly dip, but is very much flatter. It is very large, and the rich ore in it is unequally distributed, occurring in shoots or bunches. As the large vein approaches the surface it splits into several somewhat smaller veins, which assume a nearly, or quite, vertical position. This vein group is in general very nearly parallel to the Mizpah group; the linked character, forking and reuniting, is quite as well marked as in the Mizpah group; and there is some radiation in the strike of the veins, although not so much as in the former case. The Valley View veins are affected by post-mineral faulting, like the Mizpah vein.

The Montana Tonopah group shows a strong main vein running east and west and dipping north at a moderate angle. A number of lesser veins have been cut in the workings, and although development at the time of the writer's examination was comparatively slight, it is probable that most of these veins will eventually unite with one another or with the trunk vein. The indications are that the branches lie mostly on the north side of the trunk vein and diverge in trend from it, opening out to the east. These branches as a rule dip more steeply than the main vein, and will, therefore, also tend to unite with it vertically. The Montana Tonopah veins are, like the others, displaced by considerable post-mineral faulting.

In all these veins the union of two branches to form one is generally attended by corresponding enrichment, and, conversely, the place where a small branch vein leaves the main one is generally impoverished, often to a much greater degree than the size of the branch vein would seem to warrant. The recognition of this fact by the miners has led to the use of the highly descriptive term "vein robbers," for these small branches.

From the above it will be seen that the chief developed Tonopah veins have a decided east-west trend. From the fact that there is a predominant north-south trend in some of the chief veins of California and the western part of Nevada, east-west veins have been looked upon with some prejudice in Tonopah, many miners being inclined to doubt the value of the veins on account of their strike, and others forming the theory that they were simply the offshoot of a great undiscovered north-south vein which would prove to be vastly richer than these; but the Tonopah field is in an entirely different region, geologically, from California, and this objection seems to the writer to have little weight. In Idaho, where the geological conditions are perhaps more like those of Nevada than they are in California, the usual trend of the veins is east and west.

Minor veins run northwest and northeast and even north and south, but so far as yet observed the east-west veins are the chief ones, and it seems likely that the mineralization will be extensive in an east-west belt rather than in a north-south one.

OCCURRENCE OF ORES IN THE VEINS.

Physical character.—The veins of the Tonopah district are usually strong, straight, and well defined, yet they are not fissure veins. They have at first sight all the appearance of fissure veins, but a little close examination shows that they have been formed almost entirely by replacement of the andesite in which they occur. They seem to have originated along zones of especially strong fracturing in the andesite, formed during a period of movement subsequent to the consolidation of this rock. These zones of maximum fracturing, which are usually 4 to 6 feet wide, but may be much wider or narrower, became the chief channels of circulation for the mineralizing waters. It has already been stated, in describing the alteration of the early andesite, that the andesite near the veins has been silicified to a very great extent, and the veins themselves seem to be the final stage of alteration, the andesite being mostly or entirely altered to quartz. A slight detailed study of the veins gives abundant proof of this origin, for all stages in the development can be seen in different portions. 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 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 fracture zone becomes altered to quartz, the main wall fractures have been the most favorable, so that sometimes a hanging-wall streak of quartz and a foot-wall streak are found with only altered andesite between (fig. 3). 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

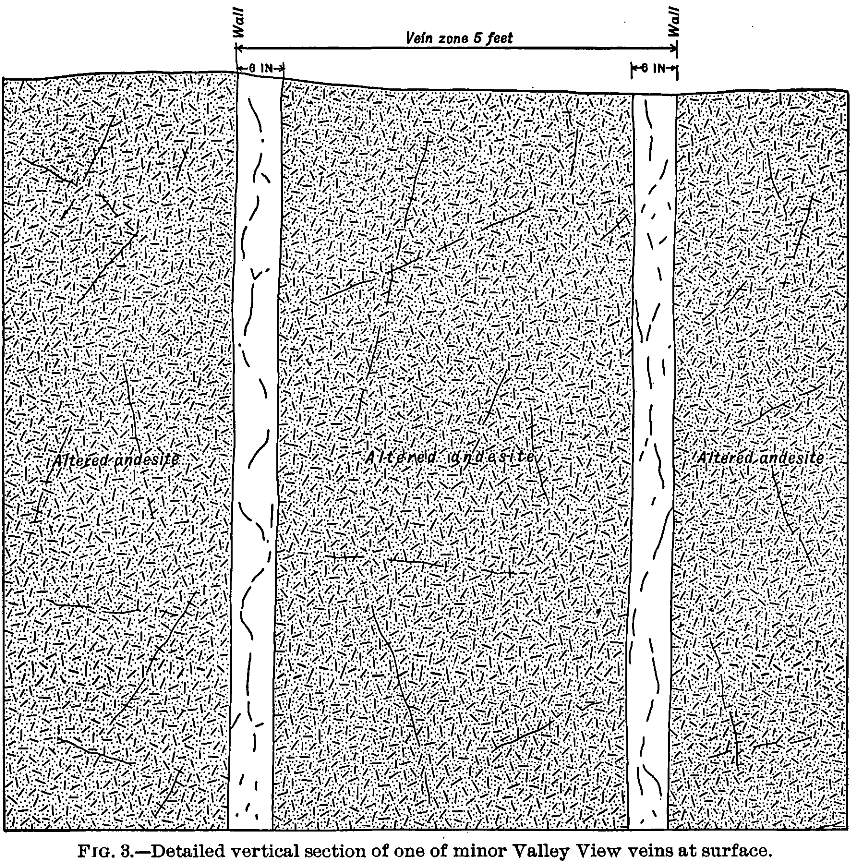

FIG. 3.—Detailed vertical section of one of minor Valley View veins at surface.

rule, however, there is more or less decomposed andesite forming part of the vein.

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 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.

In the Montana Tonopah the chief vein shows in places a brecciation and subsequent cementation. Both the original material and the subsequent cement are of quartz and rich black silver ores, and seem to have been deposited under about the same conditions. The inference is that the strain which originally produced the fracture zones kept on during their cementation by the circulating mineralizing waters, and that in this case this strain resulted in the local shattering of the cement and the subsequent healing by similar materials.

Primary ores.—At the time of the writer's first investigation of Tonopah, in the autumn of 1902, only the oxidized ores of the upper levels of the Mizpah were available for examination. From a microscopic study of these he found that the original metallic mineral was still present in minute grains. It was black in color, and he supposed it to be a rich silver sulphide. Subsequent to this investigation the primary sulphide ores were found in the Montana Tonopah mine, and the correctness of the forecast above mentioned was shown. In the Montana Tonopah the ores are quartz veins carrying in places very large amounts of the rich black antimonial sulphide of silver, stephanite. This stephanite is undoubtedly primary. Besides the quartz, as gangue mineral, there is another having a milky appearance, but otherwise looking much like the quartz. This is a variety of orthoclase (valencianite). Some of the stephanite may contain some copper, making it a kind of polybasite. Chalcopyrite is very commonly present and is probably, in part at least, primary, although this is not certain.

Secondary sulphides.—Throughout the Tonopah district argentite and ruby silver occur in greater or less abundance, sometimes adding considerably to the value of ores, but they do not occur in such quantities as the stephanite ores or the oxidized products. Wherever found the argentite and the ruby silver are unquestionably secondary, having formed from the alteration of the stephanite. They occur along cracks in the primary sulphide ore and are occasionally found in the oxidized or semioxidized ore. The chalcopyrite above mentioned, as observed in the Montana Tonopah ore, seems to occur chiefly as small streaks cutting the original stephanite ore, giving it the appearance of being secondary to the latter. In some cases it occurs along cracks and is undoubtedly secondary. It is very likely that some at least of this mineral has been formed from the copper contained in the cupriferous silver sulphide. Some pyrite is also undoubtedly secondary. Pyrite, however, is relatively rare in these ores—much more so than in the country rock.

Oxidized ores.—In the Mizpah vein the oxidized zone extends nearly down to the 700-foot level. Observation shows, however, that the limit of oxidation is extremely irregular. For example, the oxidation extends much deeper along the vein than some distance away from it in the country rock. At 400 feet from the surface the Valley View veins show oxidized ore, while 100 feet higher the country rock away from the veins is unoxidized. In the Stone Cabin shaft the change from the oxidized to the unoxidized andesite came just below the 200-foot level, but at 400 feet the ore is partly oxidized. The reason for this appears to be that the quartz veins, on account of their brittleness, have been more readily fractured by strains than has the softer country rock, and so the veins afford channels for oxidizing waters coming from the surface. Strong fractures, such as those in the vicinity of faults, have the same effect as the open fractures in veins and carry down the oxidizing influences to a depth of several hundred feet. Where the rocks are protected above by relatively impervious formations the oxidation may be comparatively slight. Thus, in the Silvertop workings (near the Stone Cabin) the later andesite is unoxidized at a depth of 120 feet. Here it is protected at the surface by a deposit of fine-grained, stratified tuff.

In the oxidized zone of the veins the sulphides are mostly entirely altered or can be made out only with a microscope, yet in many cases the alteration is not complete and the purple color of the richer quartz is as a rule due to these finely disseminated sulphides. Most of the sulphides, however, are altered to silver chloride, with some bromides and iodides, and to iron oxide. Nearly all of the ore in the Mizpah vein, down to the lowest depths explored, is oxidized, while the ores of the Montana Tonopah are only slightly and exceptionally oxidized. In the latter case the veins and the inclosing early andesite have been protected from the atmosphere by several hundred feet of decomposed, soft, later andesite, whereas in the former case the veins outcrop at the surface and oxidizing waters sink readily into them.

In the process of oxidation and alteration of the metallic minerals there has probably been some transfer of material. Little is known of the primary or unoxidized veins, but some portions seem almost entirely barren and some very rich. It will probably be found that these rich portions form definite shoots or masses of ore in the relatively barren veins. In the oxidized ores the values are by no means uniform, but seem rather better distributed than in the deeper regions. The indications are that during oxidation some of the values have been distributed from the richer portions through the more barren portions, producing a larger supply of fair quality ore. It is also likely that during this process there has been some concentration of values, so that the oxidized ores as a whole may be found to be somewhat richer than the sulphide ores. It is possible, for example, that those portions of the veins which have been eroded furnished during the process of erosion a small share of their precious metals to the underlying portions of the vein, these underlying portions now having become the present oxidized zone.

It also seems probable that in places some relatively slight transfer and redeposition of the precious metals has taken place along the fault planes, which are later than the original veins and have displaced them. This action, however, is only exceptionally the case, and as a whole is insignificant. The main ore shoots of the oxidized portion of the Mizpah mine are regarded as primary, since evidence has been found that these coincide with the original ones and have been oxidized nearly in place; therefore it is improbable that the transfer of material during oxidation, bringing about local concentration or impoverishment, has been very great.

Ore shoots.—In the oxidized portion of the Mizpah vein the richer ores lie in roughly defined, broad shoots, which pitch east on the vein. At least three of these shoots, parallel to one another and with poorer ore between, have been recognized. In the unoxidized ores of the Montana Tonopah there is evidence of the existence of similar shoots or bunches, but enough exploration work has not been done to enable the writer to describe them more closely.

APPLICATION OF GEOLOGICAL PRINCIPLES.

From the short description of the occurrence of the veins which has been given, it is seen that it is of the first and highest importance to distinguish and determine, so far as possible, the position of the early andesite. As has been noted, this early andesite is likely to be confounded with the later andesite and with some forms of altered and silicified rhyolite, especially that gray, glassy rhyolite which occupies a considerable area in the northern corner of the district. As is seen on the accompanying map, the actual area where the early andesite outcrops is very limited, and in other portions of the district it is covered by later rocks or is cut through and displaced by them. These later cappings may consist of the biotite-andesite, the various rhyolites and dacites, the volcanic breccias, or the stratified tuff formation; or they may consist of two or more of these, superimposed one on the other. Those later rocks which are intrusive rather than in the form of flows (including some of the siliceous rhyolites, some of the dacites, and probably even some of the later andesites) can not be expected, however, to give way to the early andesite in depth. A shaft sunk in a dike or volcanic neck is very apt to continue in this same rock indefinitely downward (see fig. 4).

Of the different rocks which cap the early andesite and the included veins, the oldest, the later andesite, is regarded as the most favorable for prospecting; and, in the light of present knowledge, a belt of this rock lying east and west of Mizpah Hill is probably especially favorable. On the other hand, although the veins indicate a general east-west trend of mineralization, it is by no means proved that the outcrops on Mizpah Hill occupy the center of the mineralized belt and show the greatest mineralization. It may eventually be proved that the strongest portion of this belt lies north or south of the locality known at present, which would make the whole width of the belt considerable. The whole later andesite region is worthy of careful yet cautious prospecting. The localities where the later andesite is intruded by the rhyolite ought, as a rule, to be avoided in this prospecting, for such places are not so favorable as those where the andesite is undisturbed. Such places, however, are likely to be preferred by many mining men, since they are apt to show some of the smaller and poorer veins of the later rhyolitic mineralization. Again, the region of faults should be avoided, for these faults have affected the ore-bearing veins, and if veins are found near them they are difficult, and sometimes almost impossible, to follow. The rocks along fault zones are often decomposed and the decomposed material may

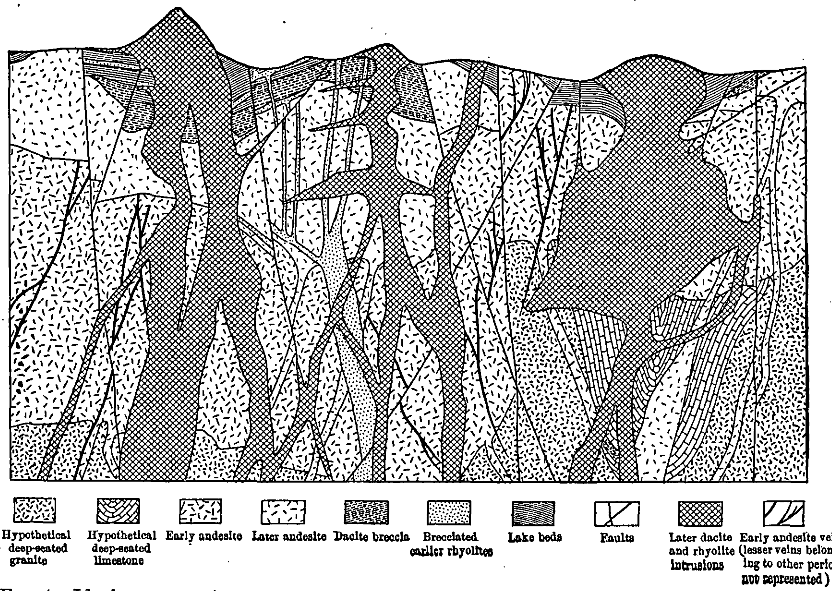

FIG. 4.—Ideal cross section of Tonopah rocks. (This section does not represent any particular place, and is simply intended to illustrate the geological conditions, as described in the text.)

have the appearance of what is known as "vein matter." From this material real or fictitious assays may be obtained, and such a locality may appear to the miner as more hopeful than less altered rock which does not look like a vein and does not show any assays. Some of the principal faults are shown on the accompanying map, but certainly not all of them have been detected, and underground developments will probably reveal many more.

Concerning the dacites and rhyolites of the later intrusions, the volcanic necks and the dikes should, as a rule, be avoided by prospecting operations. The greater parts of the principal low mountains and hills in the vicinity, such as Butler, Brougher, Siebert, most of Golden, etc., are regarded as offering very little hope for prospecting, and even near the rhyolite hills, like Rushton, Oddie, and Ararat, there has been a displacement of the veins, for the hills are essentially intrusive. The writer is aware that the proximity of the rich veins of Mizpah Hill to Oddie Mountain has caused this mountain to be regarded with great favor, but the fact that the veins are in this position has no connection with the mountain; they are there rather in spite of the mountain than by virtue of it, and it would certainly have been much better for mining operations if the rhyolite had not been erupted and the mountain formed.

Most of the dacite breccias and some of the brecciated rhyolite are in the nature of flows, and may be sunk through by shafts to lower formations, such as the later andesite or the early andesite. Much of the fine-grained, brecciated rhyolite, however, is intrusive, so that, as a rule, this rock also is not a good place to sink, except with caution.

The tuff formation, of course, is always sedimentary and can be sunk through to reach the underlying formation, which may be any one of the older rocks.

To sum up, then, the later andesite is the most favorable of the capping rocks; the pumiceous dacite breccia with interstratified, coarse, tuffaceous rocks is next, while the brecciated rhyolite should be prospected very cautiously to see whether it is intrusive. The tuff may be pierced to discover the underlying rock where the geological relations do not make this plain, while intrusive dacite and rhyolite necks should be approached very cautiously indeed.

It must be understood that these characterizations apply only to the immediate vicinity of Tonopah, or the Tonopah district proper. On account of the sudden rise and fame of the camp the name Tonopah has spread far beyond its limits, and has been applied to mines lying in quite other districts, sometimes 50 or 60 miles away. Here, and also in neighboring districts which have not borrowed the name Tonopah, the geological conditions are different. In the Gold Mountain district, for example, about 4 miles south of Tonopah, the veins lie in rhyolites and tuffs and evidently belong to the rhyolitic period; yet they carry in some cases considerable values in gold and silver.

The position of the early andesite away from the outcrops can be foretold to only a limited and uncertain extent, for in dealing with a complex of volcanic flows and dikes like that in Tonopah there is no rule which governs their distribution and by which their position in an unknown locality can always be defined with certainty. Therefore, the prospecting should be done cautiously and the district should be developed from the known region as a center; thus little by little a greater knowledge of the geological detail will be gained. On account of the lack of certainty of results in this work, in many cases it would probably be more economical, both of time and of money, to explore with a diamond drill rather than with shafts. Certainly the sinking of a two- or three-compartment shaft in an unproved portion of the district is often unwise.

The early andesite once located, the question of finding the veins remains, and after that the question of finding pay ore within the veins. The geological evidence goes to show that the mineralizing waters which produced the early andesite veins were unusually active, and a large amount of vein formation is indicated. It is beyond question, therefore, that the veins thus far found are only a fraction of those which exist in the vicinity. These veins will be chiefly unoxidized, since they are protected from oxidation by capping rocks. In them undoubtedly large portions—probably much the larger portions—will be relatively barren quartz, in which shoots, chimneys, or irregular bunches of rich ore may be expected to a considerable depth.

These quartz veins, carrying silver and gold and occurring in Tertiary andesite, belong to a larger group of veins occurring in similar andesite and found along a north-south zone. These veins are exemplified by the Comstock in Nevada and by the important district of Pachuca in Mexico. Probably Pachuca is the nearest analogue, and its description, as given by the Mexican geologist, Ordoñez, may be of value in considering the characters of the Tonopah veins. Judging from these districts it is possible that in depth a rather larger proportion of the baser metals, such as copper, and possibly lead and zinc (although no traces of the last two have as yet been found in the veins), may come in, and that the values in gold and silver may decrease somewhat. This, however, if it happens, should do so at a considerable depth.

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PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

[Bulletin No. 219.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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WASHINGTON, D. C.

DECEMBER, 1903.

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no. 219. Spurr, J. E. The ore deposits of Tonopah, Nevada, preliminary report. 1903.

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