JOURNAL

OF THE

FRANKLIN INSTITUTE

OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

VOL. CLX, No. 1 80TH YEAR JULY, 1905

Mining and Metallurgical Section.

(Stated Meeting, held Thursday, March 9, 1905.)

Tonopah Mining District.

BY J. E. SPURR, U. S. Geological Survey.

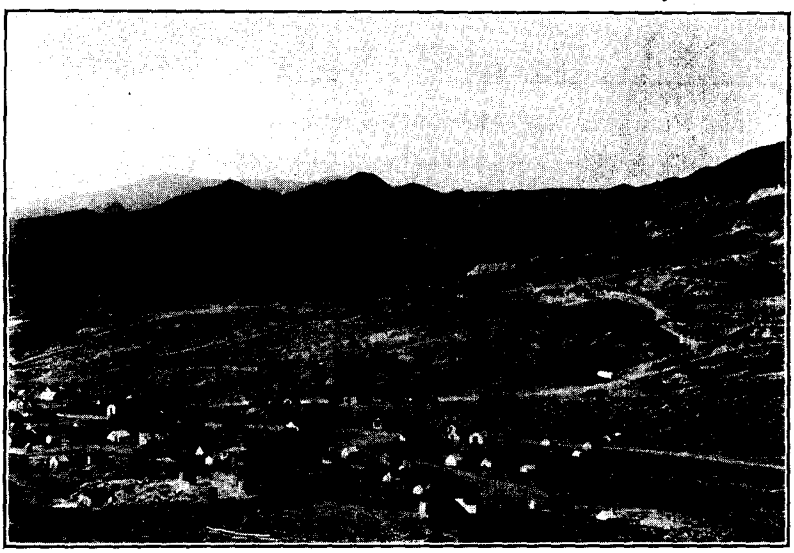
[The Tonopah mining district is one of the fresh discoveries of rich ores of gold and silver in the west. The geology of the region is extremely complicated and there are many features of especial scientific and practical interest. In very few mining districts is the discovery and proper development of the ores so dependent upon a knowledge of the principles of economic geology. The author of this paper has spent the larger part of several years studying the district, and some of the most interesting results are outlined below.—THE EDITOR.]

The mining district of Tonopah, in Western Nevada, has attracted much attention among mining men during the last few years, on account of the considerable quantity and rich character of its gold-silver ores. This district lies in an arid region, which, although formerly considerably explored and exploited by miners, had, for a long time previous to the discovery of

*Published by permission of the Director of the U. S. Geological Survey.

this camp, been practically abandoned. Within this same region lie the famous camps of Virginia City and Eureka, which twenty or thirty years ago were very heavy producers, but which have gradually dwindled more and more in importance. Numerous other camps were, in those old ways, scattered thoughout this desert country, such as Silver Peak, Hot Creek, Tybo, Reveille, Candelaria, and many others, but most of these had become nearly or quite deserted.

A preliminary event which is directly responsible for the discovery of Tonopah was the location of a small camp, called



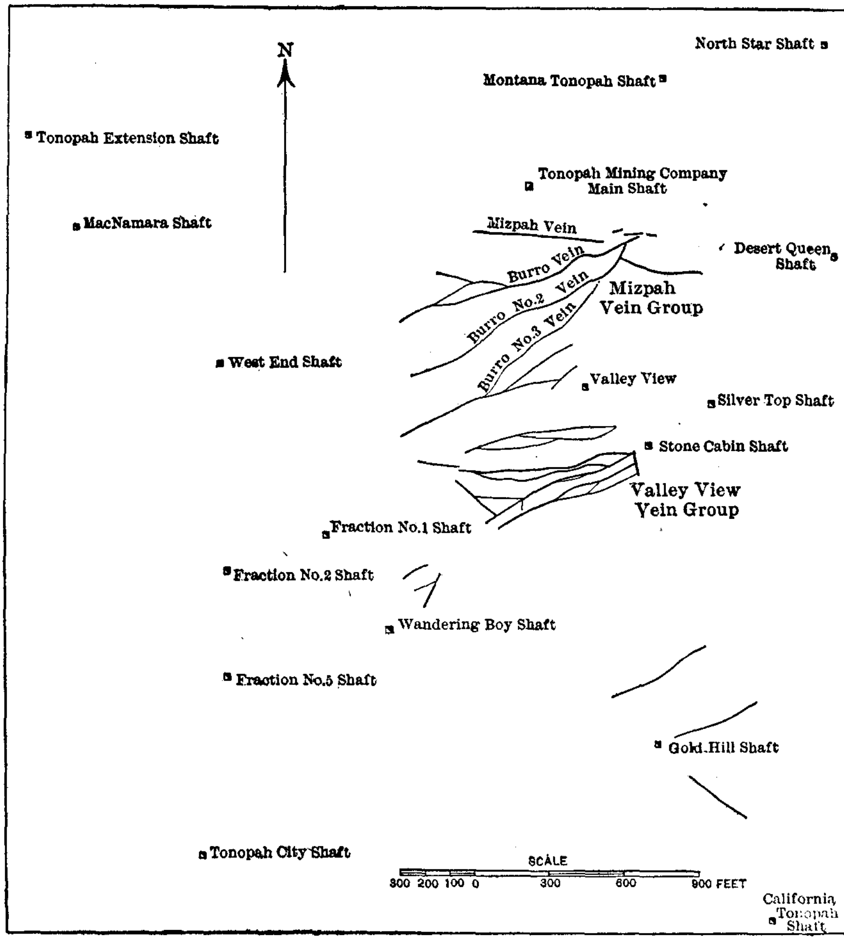
Tonopah.

the Southern Klondike, some ten miles south of the present Tonopah. This was located a short time previous to my first trip, by ranchers who visited the locality in connection with their sheep herding. This district has never attained any importance, although some ore has been taken from it. In traveling from his home, in Belmont, the county seat of Nye County, to the Klondike camp, James L. Butler collected specimens from the veins outcropping on what is now called Mizpah Hill, at Tonopah, and thus led to the discovery of this now famous camp. The properties that Mr. Butler located were at first worked by him on the leasing system, and afterwards disposed of to the Tonopah Mining Company, the stock of which is chiefly held in Philadelphia. The group owned by this company on Mizpah Hill comprises the Mizpah and Valley View veins, which are the chief outcropping lodes. Subsequently it was discovered that the veins might be covered up by later volcanic rocks, and following up this information, shafts were sunk at random, some of which succeeded in finding rich veins of the same class as those just mentioned. The Montana Tonopah, Tonopah Extension, Fraction, and others, are among those which were thus successful. A camp of this sort was evidently a rich field for the mining speculator and promotor, for it was not necessary to have even a showing of ore to have a possible mine, so that the region for a long distance round about was soon staked and came upon the investment market. Up to the present time, however, there have been no veins of importance developed more than a short distance away from the original discoveries. The whole of this district in which ore has been found in paying quantities can easily be included within a circle three-quarters of a mile in diameter. At the present time the important producing mines, besides those of the Tonopah Mining Company, are the Montana Tonopah and the Tonopah Extension, and also the properties of the Tonopah Belmont Company.

In the Tonopah district more than in any other region that has ever come under my observation, the details of geology are connected in a most intimate way with the value and prospects of the mines. Therefore, I shall briefly sketch the general geology of the immediately contiguous region before mentioning in any detailed way the mineral-bearing veins.

Like the Comstock lode, the Tonopah veins lie in a district made up almost entirely of volcanic rock of Tertiary age. The actual date of these volcanics has been determined as Neocene, reaching from the early part of the Miocene down well into the Pliocene. The Tertiary volcanic activities began somewhat before the earliest period mentioned and continued after the latest manifestation which we have at Tonopah. At the neighboring camp of Silver Peak, sixty miles west of Tonopah, there is a basalt crater which can hardly be more than a few hundred years old.

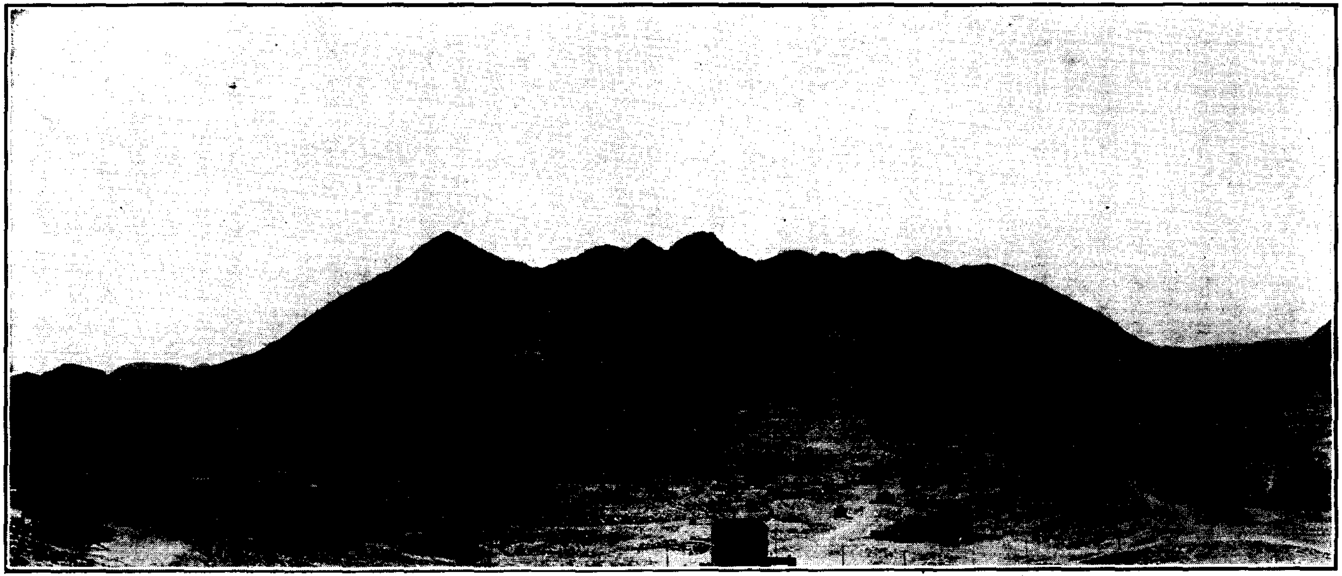
The earliest of the volcanics at Tonopah, and the one with which the principal ore deposits are most closely connected, was an andesite, which I have called the earlier andesite, to distinguish it from a subsequent erupted rock of very nearly simi-



Map showing outcropping veins at Tonopah

lar composition. In the camp it is often called the lode prophyry, since in it the most valuable veins lie. The later andesite succeeded the earlier andesite after an interval. Subsequently the continuation of the volcanic activity is attested by a series of rhyolites and dacites. These rocks are very closely connected in every way, chemically, mineralogically, in point of distribution, and in manner and time of eruption. They were, however, erupted at different periods and constitute distinct formations. These divisions I have variously denominated the Heller dacite, the Fraction dacite breccia, the Tonopah rhyolite-dacite, the Oddie rhyolite, and the Brougher dacite. These rhyolite-dacite formations consist of flows, tuffs due to showers of material from volcanic eruptions, and of injections into older rocks. The Fraction dacite breccia and that part of the Tonopah rhyolite-dacite area which lies south of Tonopah, in particular, consist of great masses of fragmental volcanic material. Among the latter rhyolite-dacite formations are the Brougher dacite and the Oddie rhyolite, which constitute the isolated hills around Tonopah. These hills represent the necks of Tertiary volcanoes, or the liquid lava which cooled in the throats of the volcanoes, whose main mass was made up of cinders and ash, now almost entirely swept away by erosion.

An incident in the geological history which broke the monotony of the repeated volcanic eruptions, was the formation of a great lake basin, and the deposition in it of a great thickness of stratified materials worn from the volcanic shores and carried out to settle in its depths. These deposits form the white stratified tuffs, beautifully bedded and well assorted, which are a conspicuous feature of the geology near Tonopah. Since these characteristics persist for thicknesses of several hundred feet, it is plain that the sediments were laid down in a body of standing water of considerable size and duration; and that this body was a lake is indicated by numerous general considerations and by the presence of fresh water infusoria in some of the strata. This lake must have been deep and of such an extent as to make it a very important geographic feature, so that the area around Tonopah must represent only a very small fraction of its whole extent. It came into existence at the close of the most active period of the Tonopah rhyolite-dacite eruptions. The formation of the lake was due to a depression of the crust, forming an enclosed basin, and I look with favor upon the hypothesis that this depression represents a collapse of the crust consequent upon the outpouring of so great a bulk of lava, gas and steam. I have proved that a similar



Mount Butler. A denuded volcanic neck.

subsidence, due beyond question to this cause, followed upon the eruption of the dacite and rhyolite volcanoes which are now represented by the volcanic necks already referred to. This lake basin, in this area at least, was terminated by an uplift of the crust, accompanied by a regional tilting. The area remained for a short time a quiet land surface, but soon there was an explosive eruption of basalt, followed by a thin flow of the same material. The formation of the dacite volcanoes, represented by the present hills, followed almost immediately upon this basaltic eruption. In connection with this last dacitic outburst there was a phenomenon of great importance, both to the scientist and to the miner, namely the faulting. I have shown that the principal faulting followed directly upon the formation of these dacitic cones. I have also shown that the area occupied by this dacite, which I have called the Brougher dacite, is coextensive with the region of observed complicated faulting. This complexly faulted region, which makes up the southern half of the small area which I have mapped,* is also down-sunken in comparison with the little-faulted region further north. 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 in the dacite have sunk down in reference to blocks farther away. From these intrusive necks the faults run in a roughly radial fashion, and seem to follow no regular system or 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.

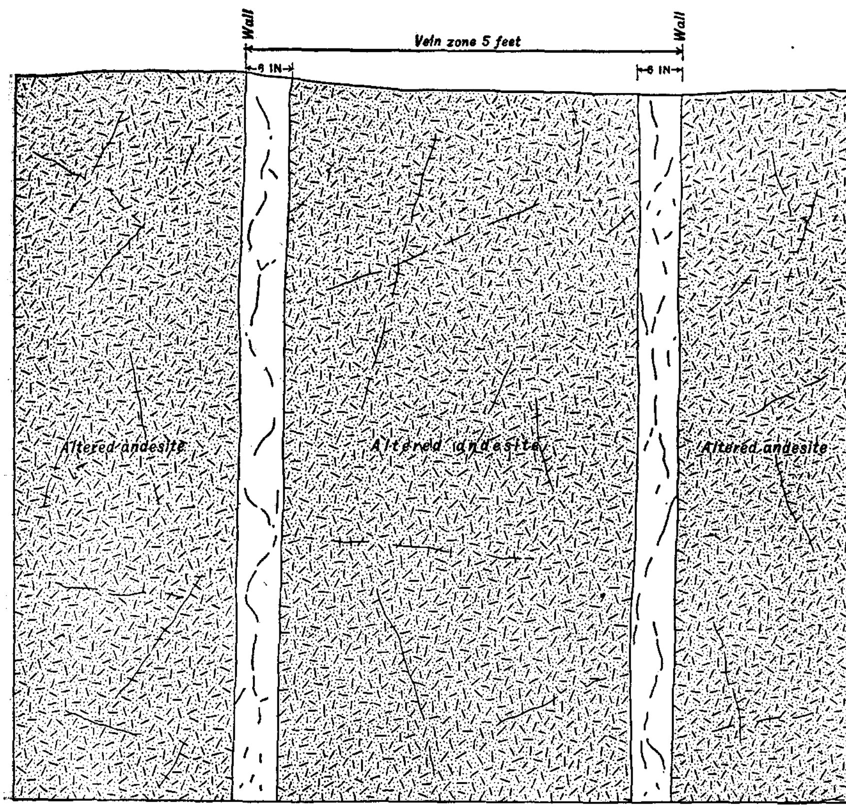
From these facts I have reached the following conclusions. The faulting was chiefly initiated by the intrusion of the massive dacite necks. After this intrusion and subsequent eruption there was a collapse and sinking of the various vents. The still viscous lava sank, dragging downward with it the adjacent blocks of the intruded rock, accentuating the faults, and causing the described phenomena of downfaulting in the vicinity of the dacite.

The observations made upon faulting in this district are of extraordinary interest, for in this case the origin, time and

*Professional Paper No. 42, U. S. Geological Survey.

cause of the faulting are clearly understood. It is rare that any explanation other than a general unsubstantiated hypothesis can be applied to any particular case of faulting, but here it is plain that the faulting was the result of adjustments of the crust to suit violent migration 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 it was continued after the cessation of the eruptions by the irregular sinking of the crust into the unsolid deposits from which the lava 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; moreover, that the first faults were due rather to upward and lateral irregular shoves, while the latter ones, in many cases along the same planes as the first, were due to gravity. Thus reversed or normal faults are equally natural and both occur frequently. I will refer in detail later on to some special cases of faulting, after having described the mineral veins.

The veins in the earlier andesite at Tonopah have the regular extent, strike and dip characteristic of true veins. I have found out, however, by studying them, that they are not the fillings of open cavities, but rather that they have formed along zones, of maximum sheeting, these zones being from 3 to 8 feet wide, and having a regular strike and dip. For this reason I have announced that the veins were not true fissure veins, but were chiefly due to replacement. It is only fair to state, however, that the definition of a fissure vein is not universally agreed upon, so that veins having the origin which I have described would still be called fissure veins by some prominent geologists. Personally, I limit the term to veins which have filled open fissures, but by some the term is extended to any vein which is formed along what they denominate a fractured or fissured zone, even if it has formed by replacement of the rocks of this zone. The chief set of fractures along which the veins were formed extended in an east and west direction, and along zones which attain the maximum thickness of several feet, the close-set parallel fractures were especially abundant. These became the chief channels of circulation. In places the circulating waters divided into separate channels, which diverged and frequently re-united, and often a lateral channel was found, of a character favorable to the egress of the water. Along these branch veins were formed. These channels, however, were apt to grow poorer as the distance from the main fracture zone increased, and these characteristics have been inherited by the veins which formed along them. The circulation channel now occupied by the Mizpah



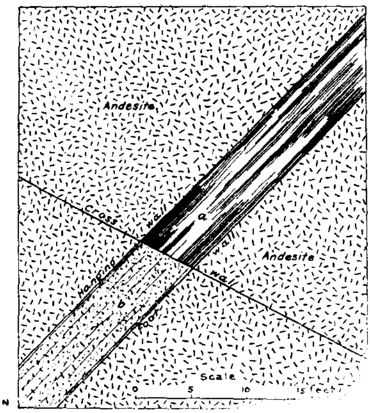
Detailed vertical section of one of minor Valley View veins at surface.

vein may be taken as typical of the main fracture zone, and the diverging Burro veins, dwindling as they increase their distance from the master vein, as representing the lateral channels. The splitting and re-uniting is shown by the structure of the veins at many points.

The fact that the circulation channel was a fracture zone and not an open fissure is shown by a study of the veins, revealing all stages in the change from a fracture zone in andesite 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 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 fractured zone becomes altered to quartz, the main wall fractures have often 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 them. 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 with 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, there is more or less of decomposed andesite forming part of the vein.

As exceptions there are streaks of quartz, usually small, within the vein, which show crustification and comb structure, and thus bear evidence of having been formed in cavities. Many of these cavities are of irregular shape and were not fissures, properly speaking, but spaces of dissolution, and were the effect of the mineralizing waters themselves. The largest examble of the crustified vein is found in certain parts of the Montana Tonopah workings, where the cavities were sometimes two or three feet in diameter and gave rise to well banded ore.

The fractures transverse to the main system have also a not inconsiderable effect in determining the course of the ore-bearing solutions. Along important transverse fractures I have found that the vein narrows, the cross fractures playing the same part as the lateral wall fractures, even if not always to such an extent, and so earning the name which I have given them, of *cross walls.* I am not aware that this feature of cross walls in vein structure has ever before been recognized, but it is a conception that is extremely important to the miner. It can readily be seen that once the conception of the main vein as due to the effect of maximum circulation along an especially fractured zone is understood, the effect of strong cross fractures in limiting or even locally cutting off the circulation from some portions of the vein zone becomes clear and even follows naturally and almost necessarily. 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.



Cross-wall in Montana Tonopah vein. a—rich ore, b—low-grade vein stuff.

The primary ores, where practically unaffected by oxidation, as in the Montana Tonopah and Tonopah Extension mines, consist mainly of solid sulphides. The gangue of these veins is chiefly fine-grained quartz, with a great deal of potash feldspar, adularia, a pure variety of orthoclase. Sericite, the fine variety of muscovite, is also frequently present, and sometimes also a mixed carbonate of lime, iron, magnesia and manganese. The principal metallic mineral of the ores is argentite, and there is considerable polybasite and probable stephenite, often in characteristic crystals. Chalcopyrite and pyrite also occur, with some galena and probably some blende, although the latter mineral has not been detected in the hand specimen. Gold is present in the average ore in the proportion of gold to silver equals 1 to 100 by weight. It therefore makes up about two-fifths of the ore values,—the silver three-fifths. In the sulphide ores it has never been detected by the eye, whether in the hand specimen or under the microscope, although it has been found in metallic particles under both these circumstances in the partially oxidized ore. An analysis of the sulphide ores by Dr. W. F. Hillebrand shows about 2½% of selenium, part of which at least exists as a silver selenide.

There is no tellurium so far as yet determined. The veins have been oxidized in part from the surface downward, but owing to the fact that there is no regular groundwater, the oxidation has been partial, extending very irregularly downward. Along veins the oxidation generally penetrates much deeper than in the rock, so that the ores may be partially oxidized while the country rock contains unaltered pyrite. 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 affords a readier channel. Where veins do not outcrop but are covered with a blanket of overlying rock, there is usually comparatively little oxidation. In the ores the effects of oxidation are to alter pyrite into limonite, and also to deposit black oxide of manganese, which is formed from the manganese carbonate in the primary ores. Horn silver becomes abundant, and silver bromides and iodides sometimes accompany the chloride. The gold, which exists in some undetected combination in the sulphide ores, is largely deposited as metallic particles in the oxidized zone. Analyses of the typical ore of the oxidized zone, such as that in Mizpah vein, shows that it still contains a large amount of argentite. No important change in the amount of gold and silver, as compared with the unoxidized ores, has been proved. It is thus seen that the so-called oxidized ore of the Tonopah district, like that of many other deposits of desert regions, is really a modified ore, consisting of an intimate mixture of original sulphides and selenides, together with secondary sulphides, chlorides and oxides.

In both the oxidized and unoxidized zone secondary sulphides are frequent. These are chiefly pyrargyrite and argentite, and occur coating cavities which cut the primary ore. They are of later deposition than the primary ore, and are probably due to descending waters. They have not, however, so far as detected, caused any important readjustment in the values of the different zones.

In studying this mining district I have compared it with certain others which are closely similar to it. Probably the nearest analogies yet described anywhere in the world are the contiguous mining districts of Pachuca and Real del Monte, in Mexico. These are among the most important districts in Mexico, and have produced enormous quantities of ore. They are situated in a range made up of Tertiary andesites, rhyolites and basalts. The veins are argentiferous with an appreciable amount of gold. They represent in a vertical sense two zones, the upper composed of oxides (red ores) and the lower of sulphides (black ores). The first, which has a downward extent of nearly 1,000 feet, contains chlorides and bromides of silver; the lower zone contains sulphides of lead, silver, etc. The lower limit of the upper zone corresponds to the groundwater level. The ore occurs in rich masses, called bonanzas, which are of irregular form. The impoverishment of the veins at great depth is admitted.

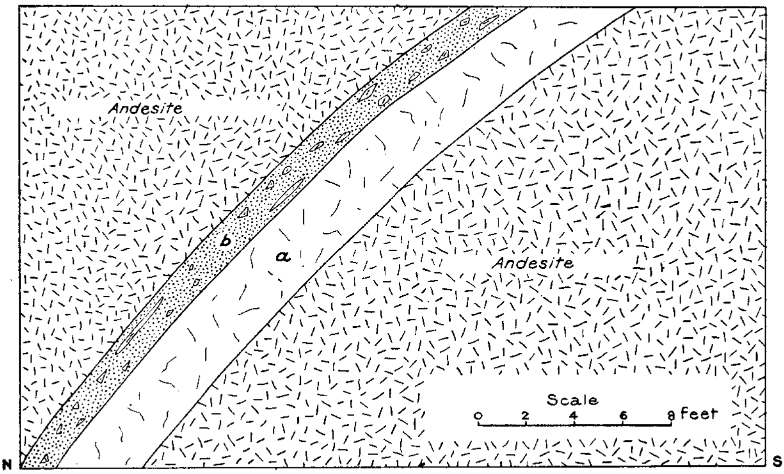
Besides these districts there are many others in Mexico which have been described as having very nearly the same characteristics. They occur chiefly in andesite. Senor Aguilera, Director of the Mexican Geological Survey, remarks in an article on the ore deposits of his country:—"It would be tiresome to enumerate all the silver veins of Mexico which occur in andesite, but it has been said that the majority of the silver veins are in various species of this rock, which Humboldt designated as metalliferous porphyries."

The Comstock lode, which lies nearly 150 miles northwest of Tonopah, presents also a very close analogy to it. The lode is formed along a fault line in Tertiary eruptive rocks, chiefly andesites. The lode material is quartz, certain limited portions of which contain large quantities of silver and gold, and so constitute bonanzas, while the rest is low grade. Most of the bullion has been derived from a black quartz like that of Tonopah, the color being mainly due to disseminated argentite, which is the principal ore mineral and which is accompanied by gold, probably free. Bunches of stephenite, 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 quantities of galena, zinc-blende, etc.

From these and other instances it appears that ore bodies of the Tonopah type occur repeatedly in the Tertiary volcanic rocks, especially in the andesites. In this connection it is interesting to consider the relation of the lavas in which the ores occur. The lavas of the Great Basin region of Nevada were studied by myself in 1900, and this study led to the conclusion that the whole region southward into the Mojava 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 the different parts of the overlying surface. The limits of this sub-crustal basin are not yet defined. Subsequently the studies of the Mexican geologist Ordonez extended this petrographic province into Mexico; and it is also probable that it extends a long distance northwest of Nevada.

In a paper published by myself in the Transactions of the American Institute of Mining Engineers I have subsequently brought forward the idea of a metallographic province, characterized by the presence of certain metals, and pointed out that these provinces may or may not be closely identified with petrographic provinces, though they probably are to a certain extent. Unquestionably the close relation between the Nevada mineral districts of 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 the world show a metallographic province which in this case coincides with a portion of the petrographic province previously mentioned. It is probable that the coextension of the metallographic and the petrographic province is greater than thus established. For at many other points along the belt of the petrographic province, in the Andes of South America, and elsewhere, veins are reported having, so far as can be made out, a similar mode of occurrence, age, and composition as those of Mexico. In general the Miocene andesites of this region are, as Humboldt noted, the metalliferous formation *par excellence*. And if the conclusions arrived at in the case of Tonopah are correct, the ore is due to the after actions of the eruptions, in the shape of fumaroles, solfataras and hot springs.

Besides the earlier andesites, some of the other volcanic eruptions of the Tonopah district were followed by ascending hot waters, which produced veins carrying some values in gold and silver. None of these, however, are comparable in size and importance to the veins of the earlier andesite. The chief of these lesser periods followed upon the eruption of the rock called the Tonopah rhyolite-dacite. On account of their resemblance of the earlier andesitic veins, these later rhyolitic veins have been the object of recent exploration and development work, which on the average has been decidedly unprofitable. These veins are characterized by irregularity and a lack of definition and persistence, though their size may locally be great. The nature of the quartz is as a rule dense and jaspery, the color being white, gray or black. It is, therefore, usually of a different appearance from the white quartz of the early andesitic veins. The rhyolitic veins are usually barren, or contain only very small quantities of gold and silver, except locally, where rich bunches of ore occur. They are usually of irregular form and extent. A characteristic of the

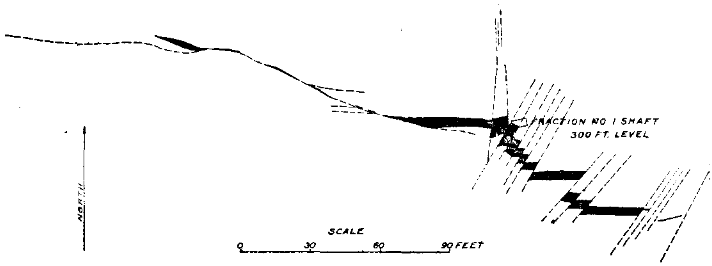


Cross-section of Tonopah extention vein, sh owing older, earlier andesite vein (a), and later filling (b) of rhyolite-docite period.

rhyolitic veins, to which there are, however, exceptions, is the greater ratio of gold to silver in them as compared to that in the earlier andesitic veins. The veins are, as a rule, confined to the rhyolite-dacite with which they are genetically connected. Yet 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 silicified adjacent andesite that fractures and fissures must have been most easily formed at this period, in the case of the Tonopah Extension an earlier andesitic vein has been reopened and along the hanging-wall a new vein of barren jaspery quartz formed. This is probably due to waters of the rhyolite-dacite period of mineralization.

The period of intrusion of the white rhyolite, which forms two of the hills near the town of Tonopah, was also accompanied by manifestations of hot spring activity. The top of Mount Ararat is composed of a volcanic plug of rhyolite. In this plug are veins which are locally as much as twenty feet thick, but are irregular and non-persistent. These veins conspicuously follow the contact and are co-terminous with it, and sometimes they cut across the rhyolite plug. They are fine examples of veins which have filled open fissures. The gangue consists mostly of brown and white calcite containing some iron and manganese carbonates, and low values in gold are frequently found.

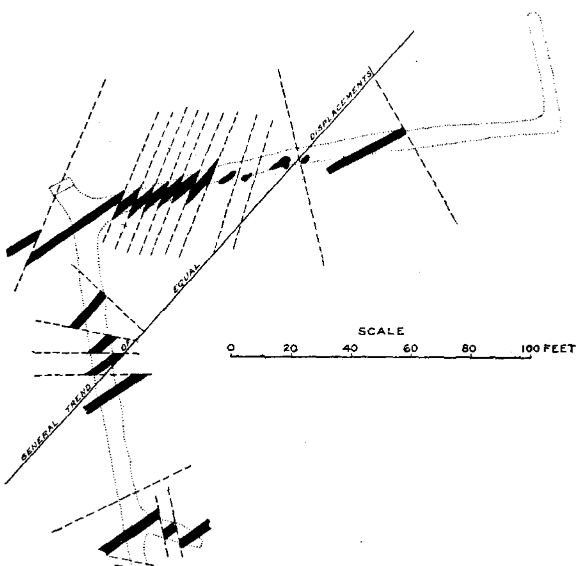
In closing my address I will return to a subject of which I have spoken in general terms earlier, namely, the faulting of the veins as displayed in the mine workings. The complexity of



Faulting in Fraction mine. Horizontal plan. Dashed lines are faults.

faulting exhibited at Tonopah is greater than that in any reported district. It would be useless to describe all the variations of rock movement brought out by underground workings. I will briefly call attention, however, to some of the most interesting cases.

The Fraction No. 1 shaft was the first which encountered ore beneath the overlaping cap rock. Some of this ore was rich, but with development the vein was found to be so badly faulted that development has been for a long time discontinued Apparently originally there was a single vein, but it has been cut by numerous faults, which, however, may be separated into definite systems. The most important system strikes northeast and dips southeast 45°. By these faults the vein, as seen on a horizontal plane, is moved to the north on the west side. There are many of these, which disturb the faulting between them and constitute a fault zone, whose limits and total displacement are not known. Abundant and strong striations on these fault planes, together with evidence afforded by the minute faulting and stringers and by the dragging of faulted veins, indicate that 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. 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.



Faulting of "Wandering Boy" vein. Horizontal plan. Heavy black bands are veins. Dashed black lines are faults. Dotted lines show mine workings.

In cross section it is seen that the veins follow 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. In the two upper levels, as shown in the cross section, at the sharp bend or apex of these folds, tangential fractures or slight faults leave the vein and pass off into the surrounding andesite. Between the 300- and 400-foot levels a flat fault striking and dipping in the same sense as the vein has probably the same of regularly alternating portions of each of the two fault systems, while the trend of the whole zigzag, and therefore of the lines of equally displaced blocks, is diagonal to both the fault systems. From this simple case the variations and irregularities may be ideally deduced. In all cases it appears to hold good that the zones or blocks of equal displacement, roughly aligned though these may be, trend diagonally between the two fault systems. In the case under consideration the problem takes on an added complexity, because the vein dip enters as a factor. The dip in this case is opposite to the downthrow of the faults, and the angle of the dip and the displacement and spacing of the faults are such that one offsets the other and the vein continues in a horizontal zone. This explains why the drifts all encounter blocks of the same vein, and it follows that other blocks exist on this level so far as this peculiar intersecting faulting and the balance of the dip and displacement is maintained.

In the Montana Tonopah the Macdonald vein has been affected by complex faulting. In vertical section such faults appear nearly parallel to the vein, though curved and branching, and so become now steeper, now flatter in dip than the veins. The line of faulting is not parallel in strike or dip to the vein, however, though it so appears in vertical section. In fact, the flat portions of the fault zone pitch east on the vein at moderate angles, and striae along the faults show that the real direction of movement has been to the east along this pitch. In horizontal section these faults are seen to curve and branch in as complicated a manner as in the vertical section, producing an added complexity.

EUTECTIC COPPER.

The autectic is that mutual mixture which freezes out last, after the ingredient which is, or the ingredients which are, in excess shall have been removed by gradual cooling. In the case of casting copper, some cuprous oxide is sure to be formed; here the eutectic is a mixture of copper metal and 3.4 per cent. of cuprous oxide, or 0.38 per cent. of oxygen. This eutectic can be seen under the microscope as a thin groundmass surrounding grains of pure copper. It is transparent; blue, in reflected, and red in transmitted light. This eutectic may be a source of weakness, as in copper tubes which carry hot and reducing gases, when the resulting action may form fine cracks by forcing the metal apart, a condition popularly known as the "hydrogen disease" of Hehn. This general problem of the eutectic of copper, tin and oxygen has been the subject of a recent paper by O. Bauer in a recent number of the *Zeitschrift für angewandte Chemie.*