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deposition of the Paleozoic strata and previous to the Tertiary sediments and lavas. The date of their intrusion is therefore post-Ordovician and pre-Tertiary. A short distance north of the Silver Peak quadrangle granitic rocks similar to those at Silver peak are probably intrusive into Triassic and Jurassic strata at several points in the Pilot, Excelsior, Ellsworth and Star Peak ranges.[10]

The work of Mr. Turner has shown that the granitic rocks in the southern part of the Silver Peak range cross Fish Lake valley, which lies west of the range, and are represented in the White Mountain range, which is separated from the Sierra Nevada only by Owen's Valley. This adjacent portion of the Sierra Nevada is made up almost wholly of granitic rocks, consisting mainly of granodiorite and granite, and the date of their intrusion has been fixed as in the epoch known as post-Jurassic.

It appears probable, therefore, that the granitic rocks of the Silver Peak quadrangle and of various other ranges of western Nevada are similar in general nature, age and origin, to the granitic rocks of the Sierra Nevada, and are late Jurassic or early Cretaceous in age.

(c) *Dioritic Rocks.*—Small dikes of diorite are abundant in the Silver Peak region. They are almost always more or less altered, sometimes completely. In their fresh form they consisted essentially of feldspar and hornblende in varying proportions, but by alteration they have become a mass of secondary products. They are thus conveniently designated by the field name of greenstones. The alteration products include chlorite, quartz, calcite, zeolites, epidote, zoisite, kaolin, talc, biotite, etc.

These dioritic rocks appear, from Mr. Turner's mapping, to be associated with the areas of associated granitic rocks. In point of age the dioritic rocks are always younger than the granitic rocks, which they frequently cut. When they occur associated with the aplitic rocks (alaskites) they are also younger than these, and, as Mr. Turner has found, they are younger than the quartz-veins of Mineral ridge, which I have determined to be the siliceous extreme of the alaskitic injec-

[10] J. E. Spurr, *Professional Paper No.* 208, U. S. Geological Survey, 2d edition, pp. 102, 103, 109, and G. D. Louderback, *Bulletin of the Geological Society of America*, vol. xv., pp. 318, 336.

tion. These greenstone-dikes are older than the Tertiary rocks, since they are not found in them. Therefore, the only direct evidence of their age is that they are post-Ordovician and pre-Tertiary. The apparent association with the granitic areas and the limited quantities of the diorite, whose habit and amount approximate those of the alaskites, suggest, however, that the dioritic rocks may be a later manifestation of the granitic intrusions.

(d) *Tertiary and Quaternary Lavas.*—In the area under consideration, lavas were erupted in large quantity during most of the Tertiary, and the volcanic activity continued into the Quaternary. The knowledge of the Tertiary lavas of the Silver Peak region is entirely the result of the work of Mr. Turner, who has mapped the different rocks separately and has distinguished and studied rhyolites, andesites, basalts and some dacites. These lavas seem to have been repeated at different periods.

2. *Mineral Veins.*

(a) *Genetic Relations of the Ores of Mineral Ridge.*—The auriferous quartz-ores of Mineral ridge are economically the most important in the quadrangle, and some of the mines here have had a considerable production. The Drinkwater mine, with some adjacent mines, make up the most important group.

The typical auriferous quartz of Mineral ridge is white and crystalline and is seen under the microscope to be crowded with liquid inclusions. Its appearance is that of the characteristic gold-quartz found in so many districts in the world. Occasionally this quartz contains original muscovite and, rarely, original chlorite crystals. Contemporaneous sulphides are sparsely disseminated, principally pyrite, more rarely galena. Occasional copper pyrite has been observed. The quartz throughout contains gold and a little silver, the proportion of the latter to the former being about 1 to 100. The gold is finely disseminated in a free state through the quartz and is also contained in the scattered sulphides. It is estimated that about 87 per cent. is in the free disseminated form and the remainder in sulphides. The gold-values are irregularly concentrated into certain groups of quartz lenses and certain lenses within these groups. Thus, in certain portions, it is high grade, while in others it is low grade or nearly barren.

the calcareous strata intruded by the granite, a type of noble silver-gold veins (that is, veins often containing a comparatively small proportion of the baser metals) characteristic of this period.

This metallographic province appears to be most typically developed in California, for which reason we may call it the California province, while the province characterized by the ores in Neocene lavas is best represented east of the Sierra Nevada in the State of Nevada, and may therefore be called the Nevada province. In western Nevada the Nevada province overlaps upon the California province, and along this overlap the ore-deposits belonging to one group are superimposed upon the other. The Nevada province is coextensive with the appearance of Neocene andesites and rhyolites at the surface, the California province with the appearance at the surface of post-Jurassic granitic rocks. Where, as in western Nevada, these granitic rocks and the strata which they intrude are exposed by erosion in patches lying in the midst of Tertiary volcanics, we may have veins belonging to both periods very close together.

IX. Magmatic Origin of Ores of Both Provinces.

According to the previously expressed conclusions, all the ore-deposits of this rich region of Nevada can be referred to two chief periods of intrusive igneous activity. The various ore-deposits discussed appear to be genetically connected with one or the other of these two great periods. In both cases the mineralization has been ascribed, as the result of close study, to the final processes of rock solidification subsequent to intrusion, the residual solutions and gases resulting from consolidation having been the agents which produced the mineralization. The metals also are in all cases considered to have been derived, together with the mineralizing solutions, from the respective magmas. In this whole district, therefore, the effect of the concentrating action of ordinary circulating ground-water does not enter perceptibly into our conclusions, and so far as we yet know it is negligible, except for some minor effects in rearranging the ores of the oxidized zone.

deposition was associated with contact-metamorphism. The granitic and alaskitic rocks which make up these intrusive bodies are similar in those districts which the writer has examined, namely, Silver Peak, Southern Klondike and Belmont, and from Mr. Emmons' description, in the Toyabe range.[13]

In the three districts which I have examined there are similar peculiarities of the intrusive rocks, notably the segregation of small contemporaneous quartz masses within the rock, and the alteration of the feldspar to muscovite by magmatic processes.

In the Sierra Nevada, associated with the granitic intrusions, are auriferous quartz-veins whose formation immediately succeeded the granitic eruption. The relation between these quartz-veins and the granite has long been noted.[14] Recently Mr. Lindgren has adopted the hypothesis that the solutions which deposited the veins were of magmatic origin. These California gold-quartz veins are characterized by the common occurrence of albite as a gangue mineral.[15]

VIII. Conclusions Concerning the Silver Peak Type of Ores.

The general conclusion is that the Silver Peak deposits are part of a larger province, which is represented more abundantly in the Sierra Nevada of California, with only outlying smaller areas in adjacent portions in Nevada. All the ore-deposits of this province seem to owe their existence to the intrusion of the post-Jurassic granite. The ores of this province have been concluded to be due to siliceous solutions, which were due to the crystallization of the granitic rocks. These solutions deposited the minerals they contained (silver, gold, etc.) along fractures or shear-zones or other channels, thus forming the typical gold-quartz veins of the region. In Nevada these solutions formed, where the wall-rock consisted of

[13] *U. S. Geological Explorations of the Fortieth Parallel*, vol. iii., p. 324.

[14] Whitney, J. D., *The Auriferous Gravels of the Sierra Nevada*, p. 353. Kemp, J. F., *Ore-Deposits of the United States and Canada*, 3d ed., p. 370. Lindgren, W., Gold-Quartz Veins of Nevada City and Grass Valley, *17th Annual Report*, U. S. Geological Survey, part 2, pp. 175–6.

[15] *American Journal of Science*, vol. xxxiii., p. 249; and Ransome, F. L., *Mother Lode Folio*, U. S. Geological Survey, p. 8.

The quartz lenses are intimately associated with alaskite intrusions, one not occurring without the other. Petrographically, typical quartz and typical alaskite form two ends of a rock series, between which every gradation is abundantly represented. The alaskite becomes quartzose and passes to a state where it contains quartz blotches and veinlets and so gradually passes over into typical vein-quartz. Nearly every quartz lens which has been mined or prospected shows in places considerable feldspar mixed with the quartz. As a rule, the gold-content grows rapidly less with increasing feldspar, although occasionally feldspar-bearing rock carries good values. In one place primary free gold has been found in pegmatite.

It was long ago recognized that granitic rocks (which family includes the alaskites) had originated from magmas essentially different in nature from those which form the more basic plutonic rocks and from those which produce surface lavas. This recognition was due to the discovery of many minerals in granite which cannot be formed from dry melts. Moreover, the relative order of crystallization of the chief granitic minerals is not the order of their relative fusibility, showing that the different materials were not held in the fluid state by the power of heat alone. All the granitic minerals have been artificially formed in the presence of mineralizers, such as water, fluorides, boron compounds, tungstic acid, etc., at a relatively moderate heat, but most of them cannot be formed by cooling from a dry melted mass. The contact-metamorphism which intrusive granitic rocks exert upon the rocks which they cut is of such a character as to show the presence of mineralizers. Minerals like tourmaline, scapolite, muscovite, etc., frequent in the contact-metamorphic aureoles of granites, testify to the emanation of boron, chlorine, fluorine, acid, water, etc., from the consolidating granitic magma. From these and other considerations it is probable that granite has crystallized at a relatively low temperature (compared with that of less siliceous igneous rocks) and that it has remained mobile below the fusing-point of most of the granitic constituents on account of the intermixture of water and other mineralizers. It is likely that water was one of the most abundant and efficient factors in these processes. The quantity of water in a magma has never been even approximately determined. Scheerer[11] estimated it as between 1 and 50 per cent., but believed that the actual quantity approached much nearer the minimum than the maximum of these figures.

Microscopic study of thin sections of the alaskite of Mineral ridge shows that the crystallization of the rock was slow and interrupted. Two distinct periods or generations of crystals are always represented. In different sections the nature and relative amounts of the minerals belonging to each generation varies greatly, but the following observations apply to all cases:

1. Quartz is usually absent from the first generation, or if present is subordinate. In the second generation it is always predominant. In some cases the first generation is made up entirely of feldspar and the second entirely of quartz; but the separation is usually not so marked, some of the feldspar crystallizing with the second generation together with the predominating quartz.

2. Microcline is almost always of the second generation.

3. Albite and oligoclase-albite occur generally in both the first and second generations.

4. Zircon and pyrite have been noted included in the minerals of the second generation, but not in those of the first.

In some cases the rock is almost entirely made up of crystals of the first generation, with the second generation represented in a very subordinate way. Other sections show the first generation only as scattering idiomorphic crystals, with the second generation making up the greater area. In most cases, however, the division is fairly equable.

The chief lesson taught is that the quartz is slightly, but distinctly, younger than the feldspar. It is frequently segregated into irregular chains of grains, which lie between bands of more feldspathic material.

In nearly every section muscovite is present, generally in fine fibers. This muscovite in many cases is plainly an alteration product which has formed at the expense of feldspar. It is, however, only the feldspars of the first generation which have been thus altered, while those of the second generation

[11] *Bulletin Société Géologique de France*, 1846–47, 2d Ser., IV., 1, p. 490.

mineral-bearing quartz-veins, it was suggested, were probably contemporaneous with those which were found to occur in irregular form within the intrusive rock, and which were held to represent the final product of the magma. In these quartz-veins the metallic minerals are chiefly stetefeldtite and some lead, copper and iron.

In the Toyabe range there are numerous ore-deposits, of which the chief ones lie near Austin, about 65 miles north of Belmont. Mr. S. F. Emmons has described many of the deposits, which in nearly every case consist of white quartz-veins carrying metallic sulphides. In the vicinity of Austin the veins are mainly in granite. In other parts of the district, however, the veins occur in the stratified rocks. In some of the veins the chief silver-bearing mineral is a mixed sulphide of antimony, as is the case in the neighborhood of Belmont. There is probably here an intimate connection between the metalliferous quartz-veins and intrusive rocks.

About 15 miles east of the eastern edge of the Silver Peak quadrangle is the Southern Klondike district, which I have visited and studied briefly. At this camp the main country-rock is Paleozoic limestone, which is intruded by a long, dike-like mass of siliceous granitic rock, of a composition similar to alaskite. The rock as a whole is closely related to that which I described from Belmont, and also to the alaskite of Mineral ridge at Silver peak. Occasionally there are in the igneous mass small segregated portions of pure quartz, in which bunches of pyrite and, more rarely, galena occur. The limestone near the contact has been altered to hornstone containing epidote, zoisite and other characteristic products of contact-metamorphism. Not many yards from the contact, in the altered limestone, is a quartz-vein which follows parallel to the contact closely for a mile or more, and carries scattered values of silver and gold. The minerals contained are chiefly galena and pyrite, with small bunches of the rich black copper silver sulphide or stetefeldtite, which has been described as characteristic of those veins in the Silver Peak quadrangle which are near the contact of the intrusive granite, but not in the granite itself.

All these mineral districts are closely similar. All the ores have evidently originated as the result of the intrusion of granitic bodies into Paleozoic sediments, and in all cases the ore-movement-zones following bedding-planes in the intruded strata; also in cross-cutting movement-zones in the strata, and to a less degree in the granites. They were formed contemporaneously with the re-crystallization and contact-metamorphism of the sediments under the influence of the granite intrusion. They are more or less typical quartz-veins in the pure carbonate rocks and in the granites, but in the argillaceous rocks the quartz is often intermixed in various degrees with metamorphic silicate minerals, such as garnet, epidote, etc. The metallic elements present are principally silver, gold, lead, arsenic, antimony, copper, iron, etc., in various combinations. There is more gold in the granite, more silver and lead in the intruded strata. In the granite the metallic mineral is mostly pyrite, sometimes arsenical. In the sedimentary strata the characteristic metallic minerals are the altered sulphide containing silver, copper and antimony, which we may provisionally call stetefeldtite, and galena. The different character of the metallic minerals is believed to be largely due to the wall-rocks, which have precipitated certain things from solution. Aside from the quartz the nature of the gangue is also believed to be chiefly due to the nature of the walls.

In all the types of ore-deposits studied, the character of the solutions is believed to have been highly siliceous and alkaline, with mineralizers, such as fluorine, boron, etc., present, but in a limited amount. The presence of gold and silver and other metals is sufficiently explained by the composition of solutions such as described, in which the necessary solvents are present.

VII. Comparison of Silver Peak with Other Ore-Deposits.

Fifty miles northeast of the northeast corner of the Silver Peak quadrangle is the Belmont district, at one time productive, but long since abandoned. The ore-deposits consist of quartz veins which occur in the immediate vicinity of an intrusive mass of granite. From some microscopic work done by me[12] on this granite, it appears that magmatic solutions have been active, producing quartz and muscovite at the expense of the orthoclase in the intrusive rock, and altering the siliceous limestone of the wall-rock to jasperoid and mica-schist. The

[12] *American Journal of Science*, vol. x., Nov., 1900, p. 355.

are clear. From study of numerous sections, three general points in regard to the muscovite are learned:

1. The microcline is almost always clear and subsequent to the muscovitization.

2. The quartz is almost always clear and subsequent to the muscovitization, but sometimes encloses fibers and blades of muscovite.

3. The orthoclase and striated feldspars (chiefly albite and oligoclase-albite) are in part muscovitized and in part clear, as is natural from their belonging to both generations.

From this it appears that a partial alteration of the feldspar to muscovite took place when the magma was partially consolidated, and before the deposition of the remainder of the magma, which formed the second generation.

These observations show that the crystallization process of the alaskite was slow, so that in many cases the magma became filled with contiguous idiomorphic feldspar crystals of the first generation, the interstices between which were filled with residual fluid. The mass composed of the first generation of crystals was sometimes rigid enough to be partially cracked and fissured. In these cracks and fissures, as well as in the interstitial spaces between the crystals, the residual fluid solidified. Study indicates that many of the fissures were formed by contraction consequent upon partial consolidation; others seem to have been due to movements brought about by pressure. Thus the quartz (which makes up always the chief part of the second generation), besides forming as intergranular quartz within the unbroken alaskitic fabric, filled the small fissures, and collecting in larger masses formed by itself on a small scale an independent intrusive in nearly the same sense as the alaskitic magma had done. We may logically conclude that this quartz left upon consolidation a residue which was still finer and more aqueous.

The ore-deposits are lenses of such magmatic quartz, which have various dimensions, as seen both on horizontal and vertical planes. These lenses are most abundant along certain zones in the intruded formation and overlap on one another. They disappear by wedging or by forking and by splitting into two or more branches. These lenses are original, and not fragments of larger dike-like bodies which have attained their form as a consequence of shearing. The wedging-out of the lenses is not attended by evidence of unusual movement; moreover, the phenomena of splitting and uniting forbid the assumption that the form is not primary.

In the chief mines of the district the formation of ore-minerals subsequent to the primary consolidation of the quartz-lenses has taken place on an unimportant scale. Occasionally, however, some later precipitation has taken place. Along cracks in the quartz, frequently near the contact of the quartz with decomposed greenstone (altered diorite) dikes, subsequent vein-material has formed, having a gangue of quartz with some calcite and chlorite, and carrying pyrite and galena. The inference is that subsequent to the first or primary deposition of minerals, and subsequent to the intrusion of the diorite, minerals were again deposited along cracks in the original quartz. These minerals are the same as those first deposited, and might be thought to be due to subsequent concentration, the material being derived from the first formed minerals, and simply concentrated by subsequent circulating waters. This perhaps has sometimes been the case, but in one mine where the subsequent ore is economically important (the Mary mine), the amount of the subsequent deposition is so large as to suggest a fresh and independent supply of material. The phenomena in the Mary mine indicate the work of ascending waters, and these new solutions must have had a composition much like that of the solutions from which the primary ore was deposited.

The close association of the diorite dikes with the quartz-alaskite bodies, and frequently with the subsequent ores, easily leads one to the hypothesis that this subsequent mineralization was dependent on the diorite; but most of the diorite dikes have no later ores in their vicinity, and in the mine where the largest deposit of subsequent ore was noted (the Mary) there is no diorite.

The general conclusion is that in this district a series of shaly limestones have been intruded by a highly siliceous alkaline magma. From this magma crystallized principally feldspar and quartz, the consolidation of the feldspar in general preceding that of the quartz. The local phenomena indicate that the crystallization was practically all accomplished subsequent to the injection. This crystallization, however, was

consolidated. Another type of veins occurs in calcareous and argillaceous sediments near the contact of the granite. The gangue is chiefly quartz, the metallic minerals chiefly stetefeldtite, galena, copper, pyrite, etc. The values are chiefly in silver with some gold. The country-rock consists of metamorphosed sediments containing typical contact-metamorphic minerals. Veins of this type follow fracture-zones and along such a zone vein-formations may outcrop at intervals for short distances. In one case veins of this type in calcareous strata lie apparently along the same fracture-zone as auriferous quartz-veins, of the second type above described, which lie in granite, the fracture-zone crossing from the granite into the intruded rock. The fact that along what seems to be the same great fracture-zone the ores are of different types in the granite and in the intruded sediments, suggests that they were probably formed by the same solutions, and the different character of the veins is assumed to be due to the different character of the wall-rock.

(f) *General Conclusions as to the Origin of the Metalliferous Ores.*

An intimate inter-relation has been recognized for all the metalliferous ores of the quadrangle, and all have been traced to the consequences of one event, namely, the intrusion of granitic rocks into Paleozoic sediments in probably post-Jurassic time. This district is favorable for such determinations as have been made, since the granitic masses are small and the grouping of the ore-deposits around them is therefore more evident than in a region, like the Sierra Nevada, where the masses of granite are vastly larger.

The ore-deposits may be divided into the two chief groups:

1. Bodies of auriferous quartz, probably separated out in gelatinous form from alaskite, during the process of crystallization, and of the same age and nature as the intergranular quartz of granite and alaskite. In such quartz bodies gold is in places segregated in commercial quantities.

2. Quartz-veins due to replacement or impregnation of crushed material along fracture-zones by siliceous solutions more attenuated than those described above and residual from the crystallization of the magmatic quartz of the first type. These solutions were probably in various degrees of dilution by magmatic water. Such deposits were formed chiefly along

mony, described in the case of the silver-mines of Mineral ridge, occurs, together with galena and pyrite. This mineral is similar to that which has been described under the name stetefeldtite, and will be referred to under this name in the present article. Copper, silver and gold are present in these ores. The ores of another type are characterized by typical contact-metamorphic minerals as gangue, chiefly epidote and garnet. In this type the metallic minerals are magnetite, specular iron, pyrite, chalcopyrite, galena, gold and silver. In another type a quartz gangue contains a small amount of stetefeldtite, with galena, free gold, and a little copper. In another type the primary ore is galena, now largely altered to carbonate. In general there is a strong likeness among the different ores of this district.

From their location and the nature of their gangue the ore-deposits in the Lone mountain district are plainly connected with the metamorphism of the sediments produced by the granite. At the time of the granite intrusion siliceous solutions emanated from the hardening mass and penetrated the surrounding sediments, which were thus re-crystallized and metamorphosed. Such solutions circulated most vigorously along openings which had been formed by the intrusion. These openings were chiefly along bedding-planes, sometimes along cross-cutting shear-zones. Along them circulating granitic waters deposited quartz and metallic minerals, forming the veins.

(e) *Genesis of the Ores in the Southern Part of the Quadrangle.*—In the southern part of the quadrangle the ore-deposits are all prospects, no paying deposit having yet been discovered. One type of deposits consists of quartz-veins of granitic origin, similar to the primary quartz of the Mineral Ridge district. These quartz segregations, however, are small in quantity and unimportant economically. As in the Mineral Ridge type they contain some gold and very little silver. Other quartz-veins of a different type follow shear-zones in granite. The quartz contains pyrite and gold, and the wall-rocks are altered. The resemblance of these veins in composition to the magmatic quartz-veins of the first type leads to the belief that this second type also is due to siliceous residual solutions derived from the consolidation of the granite, which have circulated along available channels in portions of the granite which had already

slow, so that the residual quartz was, before its final consolidation, in part drawn off into large and small reservoirs, and so could play the rôle of an independent intrusion. A process of magmatic differentiation by partial crystallization is here proven.

That the lenses are the fillings of cavities which were present in the schist is out of the question. The parallelism of the schistosity with the curving walls of the lenses shows that the intrusion filled spaces which it itself created. The lenticular form of these alaskite and quartz masses (including the ore-bodies) is like that of the masses of pegmatite and pegmatitic quartz which have been observed in many places in schists near intrusive granitic contacts. I believe that this form is the normal one for attenuated, aqueous, but still viscous, granitic material, injected into schists. The fact, that the same characterizations apply as a rule to the alaskite lenses and the quartz lenses, indicates that the alaskitic fluid must have been much the same as that of the quartz, both being less viscous than that which has formed the true granite, which neither in this quadrangle nor in similar provinces is accustomed to form lenticular intrusions, but rather bold and well-defined dikes and sheets of which all the ramifications are easily traceable.

After the last crystallization of the intrusive alaskite and quartz, diorite dikes were injected, and, probably directly afterward, relatively thin aqueous solutions circulated along cracks and produced a subsequent mineralization, not approaching, however, in commercial importance (in this especial district), the primary mineralization. The brittle quartz of the lenses having been cracked offered the best channels, and here the subsequent mineralization took place, generally under the relatively impervious schist hanging-walls, indicating ascending waters.

For various reasons it is believed that these subsequent mineralizing solutions represented a residue from the granitic eruptions, more aqueous than that from which the primary quartz crystallized.

(b) *Genetic Relations of the Great Gulch Ores.*—One of the gold-mines of Mineral ridge displays, at first examination, a different character from the general type which has just been discussed. At the Great Gulch mine the general geology is, for the most part, like that of most of the typical gold-ores of the district. The country-rock is a thin-bedded limestone-slate, considerably altered and schistose. Alaskite and quartz, frequently feldspathic, occur in interbedded lenses in the schist. The ore is auriferous arsenopyrite, which occurs in solid streaks of all thicknesses up to 1 or 2 feet. It is distinctly later than the quartz, but the larger streaks are noticeably associated with the alaskite and quartz lenses, especially with the latter. The hanging-wall of quartz lenses is an especially favorable locality.

Here, fracturing has occurred subsequent to the intrusion of the primary alaskite and quartz. Along the channels thus formed ascending waters arose and deposited sulphur, iron, arsenic and gold. The period of this mineralization is uncertain from the local data, but from the resemblance of the phenomena here to those of the subsequent mineralization in the Mary mine of the Drinkwater group, it is probable that the ore in the two cases has a similar origin.

(c) *Genetic Relations of the Silver-Ores of Mineral Ridge.*—On the periphery of the gold-quartz district of Mineral ridge there are at several points ores which contain more silver than gold. The chief of these are at the Pocatello and Vanderbilt mines. The general geology here is like that of the Great Gulch mine. Alaskite and quartz lenses are intrusive into a schist which represents an altered shaly limestone. Greenstone dikes and sheets are present, following especially a zone of quartz lenses. Near the greenstone the quartz is frequently cracked, broken and mineralized, and in these cracks the silver-bearing ore has been deposited. The most characteristic mineral is a mixed sulphide and oxide containing copper, antimony, silver and gold.

Here the schists were first injected by a siliceous magma which crystallized as alaskite and quartz. Basic dikes were subsequently injected, which followed along the zone of quartz and alaskite lenses, because here fracturing was more easy on account of the greater brittleness of the materials. The intrusion of the diorite produced considerable additional fracturing in the quartz. Along the cracks thus produced mineralizing solutions circulated and deposited the ore. The whole history indicated is analogous to those cases of mines of the typical

gold-quartz type which show notable subsequent mineralization, although the character of the ore is somewhat different in that more silver and copper in proportion to gold are present.

In other deposits on the periphery of the Mineral ridge auriferous quartz district there are ores which have the same type of metallic minerals as in the Pocatello and Vanderbilt group, but which have formed by replacement of a dolomitic marble which overlies the schist formation in which the gold-bearing veins lie. In these cases the enclosing quartz of the vein is contemporaneous with the metallic minerals, instead of being antecedent to them as in the previously described silver-mines.

The mineralization in all these silver-mines seems to differ from the subsequent mineralization described in the case of the gold-mines and prospects, in the presence of more silver and copper; otherwise the facts are not unfavorable for regarding all of this subsequent mineralization as belonging to the same period. I desire to put forth here, as a plain hypothesis, an idea which has been arrived at by considering and reasoning from the distribution and character of ore-deposits throughout the quadrangle. The hypothesis is, that solutions of granitic origin have deposited predominantly gold in the granite or in rocks silicified by the metamorphic effect of the granite, and that in or near calcareous or dolomitic rocks more silver and copper were deposited from the same solutions, the difference being due to the different precipitative influence of the wall-rocks.

(d) *Genetic Relations of the Ores of Lone Mountain.*—The Lone Mountain group of mines are all situated in Paleozoic limestones, dolomites and shales which have been more or less metamorphosed by intrusion of granitic masses. Metamorphism is most intense near the contact, and fades away gradually as the distance increases. The limestones and dolomites are changed into marble, the shales into hornstones and schists with the development of typical metamorphic minerals. The veins characteristically follow the stratification of the sedimentary rocks. Where they thus occur along bedding-planes these planes have evidently been the sites of differential movement, producing crushing and greater openness. More rarely the veins occur in cross-cutting shear- or fault-zones. In one type of ores, the black mineral containing copper and antialong the stratification, forming chiefly interbedded, more or less lenticular, bodies, and often penetrating the intruded rock thoroughly and altering it to a schistose or gneissic condition. The prevalent phase of the intrusive rock is alaskite or quartz alkali-feldspar rock, having a granular texture like that typical of granite, which very frequently becomes coarser or finer (pegmatitic or aplitic). A frequent, but not common, facies of this alaskite is a siliceous biotite-granite like that at Lone mountain. On the other hand, the alaskite passes by gradual transitions, by a diminution of the feldspar, into pure quartz veins (dikes), which have very much the same chemical and genetic relation to the alaskite that the alaskite has to the granite. The alaskite consists almost wholly of quartz and feldspar, the chief species of the latter having been determined as orthoclase, microcline and oligoclase-albite.

The granitic masses studied by Mr. Turner in the southern part of the quadrangle show a variety of different phases. In composition the rock varies from normal granite to alaskite on the one hand, and to quartz-monzonite or granodiorite on the other, the proportions of lime, soda and potash being variable.

In connection with the granitic areas near Lone mountain and in the southern part of the quadrangle there are numerous aplitic dikes which clearly represent the later facies of the intrusions. They are mostly quartz-feldspar rocks or alaskites, more siliceous than the related granites. At Mineral ridge this rock is the predominant type, but in the other regions is subordinate to the granite proper. In many phases of these alaskitic rocks a tendency is seen under the microscope for the feldspar and quartz to segregate in bunches, which are irregular or more frequently elongated. These segregations increase in size until they are conspicuous to the naked eye, and by further enlargements quartz masses (veins), often feldspathic, are formed. Such granitic and magmatic quartz is found in all the granite areas, but in the siliceous alaskitic area of Mineral ridge occurs in great quantities, in thick veins or lenses. The various closely related phases of the granitic intrusions are regarded as variations from a single general granitic magma.

It is probable also that the different bodies present represent essentially a single period of intrusion. In the Silver Peak quadrangle the granitic rocks were intruded subsequent to the

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Genetic Relations of the Western Nevada Ores.*

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CONTENTS.

I. INTRODUCTION.

The region here discussed is that part of Western Nevada in which, during the last few years, discoveries of rich gold- and

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silver-ores have been made at Tonopah, Goldfield and other camps. The special studies which have been made of the ore-deposits have chiefly to do with Tonopah and the older camp, Silver Peak, about 25 miles southwest of Tonopah. Other camps in the same region have also been visited.[1]

II. Tonopah.

1. *General Geology.*

Only those features of the general geology which are essential to the understanding of the ore-deposition will here be discussed. Tonopah is situated in a region of Tertiary volcanics and the study of the general geology has chiefly to do with the nature, period and effects of the different volcanic eruptions. The volcanic rocks comprise andesites, rhyolites, dacites (latites) and basalt. There are also present Tertiary lake-beds, mostly stratified tuffs derived from the volcanic out-bursts. The structure and succession of these lavas indicate a varied history, comprising many volcanic eruptions, which brought forth showers of ash and pumice, or streams of lava. The volcanic activity was accompanied by movements in the crust, which produced tilting of the rocks and a very intense and complex faulting.

There are grounds for believing that beneath the Tertiary volcanics of Tonopah there is an older formation of Paleozoic limestone and intrusive granite. Such formations outcrop both to the south and to the north at frequent intervals. At Tonopah fragments of limestone and granite are among the blocks which were hurled out from the volcanoes at the time of some of the dacitic eruptions.

The oldest of the Tertiary volcanic rocks is an andesite which I have called the earlier andesite, to distinguish it from a subsequently erupted rock of similar composition. This earlier andesite, wherever found, is decomposed to a variable extent. From microscopic study it appears that the original fresh rock was a hornblende-biotite andesite, the feldspar being typically andesine-oligoclase. In the present altered condition, no actual biotite or hornblende has been found, these minerals being

[1] I have described these camps in Professional Papers of the U. S. Geological Survey, soon to be issued.

Peak quadrangle. They belong entirely within the Cambrian and Ordovician periods. Most of our knowledge of the Paleozoic strata is due to the work of Messrs. Turner, Walcott and Weeks, of the U. S. Geological Survey. The known fossils show the presence of strata belonging to the lower Cambrian, the upper Cambrian and the Ordovician. The rocks, however, are characteristically considerably folded and faulted and frequently metamorphosed, and the series, which is several thousand feet thick, presents no very striking and constant lithologic differences. The detailed stratigraphy and structure, therefore, are still in some doubt.

In the district where the principal gold-mines are situated, near Silver Peak village, there is, below the fossiliferous Cambrian, a series of considerable thickness consisting of limestones and slates, with some dolomitic marble beds. This series has been intruded by numerous alaskitic sheets and by quartz-veins. (Alaskite is a granitic rock composed essentially of quartz and alkali feldspar.) It has become largely schistose and gneissic.

No sedimentary rocks intermediate in age between the Ordovician and the probable Eocene have been found within the area of the quadrangle, but there are extensive and thick deposits belonging to the Tertiary. These Tertiary deposits flank the edges of the mountains and underlie in part at least the Pleistocene veneer of the valleys. They consist of soft shales, sandstones, marls, tuffs, volcanic breccias, etc., with interbedded layers of andesitic and rhyolitic lava. The thickness of the whole accumulation is very likely several thousand feet.

(b) *Granitic and Aplitic Rocks.*—Granitic rocks, intrusive into the Paleozoic strata, are well represented in the quadrangle, especially in three chief areas—in the northeast corner near Lone mountain, on Mineral ridge near Silver Peak village, and in a long belt running northwesterly across the southern part of the quadrangle. In the first-named region, near Lone mountain, Mr. H. W. Turner has found that the granitic rocks are chiefly true granites, composed of alkali feldspar and quartz, with some biotite and muscovite. The feldspar includes orthoclase, microcline and albite.

In Mineral ridge, the interbedded slates and thin limestones have been thoroughly injected by siliceous granitic rock, mostly consisting of calcite, chlorite, pyrite, epidote, etc. The rich ores occur in irregularly outlined portions of the lode called "bonanzas," which are of limited extent, both horizontally and vertically, and are believed to have arisen as a consequence of the irregular intersection of transverse fractures or fissures with the main vein-channels.

Unquestionably the close relation between the different mineral districts mentioned shows a metallographic province, which in this case coincides with a portion of a petrographic province.[8] It is probable indeed that the co-extension of the metallographic and petrographic provinces is greater than thus established. At many points along the belt of the petrographic province, in the Andes of South America, veins are reported having, so far as can be made out, a similar mode of occurrence, age and composition, as those of Mexico,—for example, in Peru.[9]

In that better established portion of the metallographic province which comprises Mexico and Nevada, the ores occur in Miocene andesites in a great majority of cases. In occasionally recurring cases they appear in Miocene-Pliocene rhyolites which succeeded the andesites. The ores are believed to be due to the after-actions of the eruptions, in the shape of fumaroles, solfataras and hot springs. Moreover, since these manifestations follow all volcanic eruptions, it is probable that the metals deposited by the after-processes owe their nature and amount to an unusual proportion of them in the magma with which they are genetically connected.

VI. Silver Peak Quadrangle.

Of quite a different class of ore-deposits from that described in the preceding pages are those of the Silver Peak quadrangle, whose northeastern corner is only about 10 miles west of Tonopah. The deposits of this quadrangle have been made the subject of a Professional Paper, to be published by the Geological Survey.

1. *General Geology.*

(a) *Stratified Rocks.*—Paleozoic limestones with slates and some quartzites are well represented in the area of the Silver

[8] Spurr, J. E., *Trans.*, xxxiii., 332–3.

[9] Fuchs et de Launay, *Gîtes Métallifères*, vol. ii., p. 829.

represented by their decomposition-products,—quartz, sericite, pyrite, siderite and hematite, sometimes chlorite and calcite. The feldspar is usually altered to quartz and sericite or quartz and adularia. As a result of the alteration-processes the whole rock is usually more or less completely altered to an aggregate which is composed of quartz and sericite, with usually some pyrite and siderite, and frequently adularia, kaolin and iron oxides. Chlorite and calcite are not so common, but may be abundant. They indicate a process of decomposition different from the ordinary. As a rule the rocks may be divided according to their processes of decomposition into two classes: (1) Quartz-sericite-adularia-pyrite-siderite rocks,—most abundant and most closely associated with the metalliferous veins; and (2) Chlorite-calcite rocks,—not associated with the ores.

The next oldest rock is the later andesite. This is much like the earlier andesite, but is slightly less siliceous. It is often nearly fresh, and is in other places largely decomposed. The general process of decomposition is usually different from that of the earlier andesite. The phenocrysts are larger and more abundant than in the earlier andesite, and consist of biotite, augite, hornblende, and feldspar which is predominantly andesine-labradorite. In general the decomposition products are quartz, chlorite, calcite, pyrite and siderite. The later andesite overlies the earlier andesite and covers up the metalliferous veins which occur in the latter rock.

Younger than the andesites are a series of rhyolitic rocks (rhyolite-dacites or latites). These lavas differ slightly in composition among themselves and were erupted at different times during a single general period of volcanic activity. In the complete report upon this district,[2] several of these eruptions have been distinguished and separately mapped, but only three of these need here be mentioned. One of these, which I have called the Tonopah rhyolite-dacite, is a dense, glassy rock, occurring in intrusive masses and thin sheets. This rock contains porphyritic crystals of biotite, feldspar and quartz in a glassy ground-mass. The most common feldspars are orthoclase and andesine-oligoclase. Near its intrusive contacts, this rock is often greatly silicified, the alteration having evidently been

[2] *Professional Paper No.* 42, U. S. Geological Survey (1905).

accomplished by hot-spring action succeeding the intrusion. Secondary quartz, pyrite and sometimes siderite are the chief results.

A dacite of later age and of somewhat different character is the rock which forms the hills around Tonopah. These eminences represent the columns of lava which rose from the abysmal regions to the surface. Near the contacts of these necks the intruded rocks are usually hardened and silicified and the cracks are coated with chalcedony.

A few of the volcanic necks consist of white siliceous rhyolite (Oddie rhyolite) of nearly the same age as the dacite necks. This rhyolite has a micro-granular ground-mass of quartz and feldspar, with porphyritic crystals of coarse quartz, orthoclase and occasional plagioclase and biotite.

2. *Mineral Veins.*

(a) *Veins of the Earlier Andesite.*—The most important veins of the Tonopah district are in the early andesite and do not extend into the overlying rocks. Where the early andesite is not exposed at the surface the later rocks form a capping to the veins. This fact shows plainly that the veins were deposited before the eruption of the later andesite and immediately after that of the earlier andesite; indeed, there is every evidence that they were formed by ascending hot waters succeeding and connected with the earlier andesite intrusion, and that these waters had become inactive by the time of the later andesite. The openings which afforded channels for these ascending waters were sheeted zones in the rock. The rock was complexly fractured, apparently soon after cooling, and certain zones of maximum fracturing became the chief circulation channels. These fractured zones have become veins, largely by a process of replacement of the rock. That the mineralizing agency was water is evident from the character of the vein and the nature of the alteration of the wall-rock; that its action was probably connected with the earlier andesite eruption is shown by the fact that it followed this, and, at least so far as mineralizing activity was concerned, was of limited duration, for its effects have not been discovered in the succeeding later andesite. It appears probable, therefore, that the mineralizing agents were volcanic waters, such as are usual among the after-

districts of Silver City and Delamar in southwestern Idaho.[7] These districts are similar to Tonopah in that the ores occur in Tertiary volcanics and are probably in both cases post-Miocene in age; to a striking degree in the character of the ores and gangue materials; in the structural characteristics of the veins, which form a group knit together by branches; in the general character of the alteration of the wall-rock; and in the occurrence of the rich ores in irregular "bonanzas." The chief difference is that the wall-rocks are mainly rhyolite in these Idaho districts and not andesite.

V. Characteristics and Significance of the Vein Group.

The different mineral districts, mentioned above, exhibit a definite group of veins, characterized by the following features: They occur in Tertiary volcanic rocks of similar character in the different localities, being chiefly Miocene andesites or rhyolites. They constitute strong masses or veins which have as gangue essentially quartz with frequently a little calcite, while adularia, barite, rhodochrosite or rhodonite may also be present in limited quantity. The ore is characteristically a silver-gold one, silver being usually predominant in the values in varying proportions, though the relative value may be reversed, and in some extreme cases either metal may occur with little admixture of the other. In any case the abundance of silver or gold, or both, in reference to lead, zinc, iron, etc., is characteristic. Silver sulphides, especially argentite, also stephanite and polybasite (together with ruby silver), and gold, probably largely in a free state, are a distinguishing feature in the great majority of cases. Tellurides and selenides may also be present. Pyrite, blende, chalcopyrite and galena are usually present in varying quantity. Where they become predominant the vein becomes relatively low-grade. Tetrahedrite, stibnite and bismuthinite are also known to occur. The wall-rocks are much altered to quartz, sericite, chlorite, calcite, epidote, pyrite, etc., and sometimes to adularia. Frequently the rocks nearest the veins are chiefly altered to quartz and sericite; those farther away to the softer "propylitic" alteration,

[7] Lindgren, Waldemar, *20th Annual Report U. S. Geological Survey*, pt. 3, pp. 107–188.

camp a close analogy to Goldfield, the ore-bodies occurring in similar rocks and being of the same character. Mr. Rohn reports that one of the principal formations at Bullfrog is rhyolite and rhyolite-breccia, which he regards as equivalent to lavas of the Tonopah district. The veins occur in part at least along fault or fracture-zones in the volcanic rock. The gangue is chiefly quartz, and the values are gold and silver.

IV. Comparison of the Tertiary Nevada Ores with Those of Other Regions.

Among the nearest analogies to Tonopah yet described elsewhere are the contiguous mining-districts of Pachuca and Real del Monte, in Mexico.[5] These districts are similar to Tonopah in character and age of the wall-rocks (Miocene andesites); in the nature of the alteration of the rock near the veins (silicification near the veins, propylitic alteration farther away); in the structural character of the veins (splitting and reuniting); the general character of the ores (both oxide and sulphide), and of gangue (though adularia as a gangue material and selenides as ores have not been recognized at Pachuca); and in the occurrence of the rich ores in bonanzas, which seem to be due to the intersection of transverse fractures with the main vein-zone.

Many other deposits in Mexico which have not been fully described seem, from their recorded characteristics, to be closely similar to Tonopah.[6]

Pachuca is about 2,000 miles southwest of Tonopah, but an analogous deposit lies 150 miles to the northwest,—the Comstock. The Comstock is similar to Tonopah in respect to the character and age of the rocks in which the lode lies (Tertiary andesite) and their "propylitic" alteration; in the nature of the gangue and ore; and in the occurrence of the rich ore in irregular "bonanzas." The chief distinction is that the Comstock consists of a single very strong lode, while at Tonopah there are a number, of lesser size.

Another region having many striking peculiarities in common with Tonopah lies about 400 miles due north of it,—the

[5] Aguilera and Ordoñez, *Boletin del Instituto Geologico de Mexico*, Numeros 7, 8 and 9.

[6] J. G. Aguilera, *Trans.*, xxxii., 513.

effects of volcanic outbursts, and that they were hot and ascending.

In the primary sulphide ores, lying below the oxidized zone, the principal gangue-minerals are quartz, adularia and some sericite, with occasional carbonates of lime, magnesia, iron and manganese. The ore-minerals consist of sulphides of silver, antimony, copper, iron, lead and zinc, in the form of stephanite, polybasite, argentite, chalcopyrite, pyrite, galena and blende. A considerable quantity of silver selenide is also present, and gold in a yet-undetermined form. The remarkable thing about the metallic contents is the relative scarcity of the common elements and the abundance of the rarer ones.

The depth of oxidation in these veins is very irregular, dependent upon the relative perviousness of the overlying rocks. In the oxidized zone, horn silver is abundant, with some bromides and iodides. Free gold has been deposited. The presence of limonite and black oxide of manganese is characteristic.

Pyrargyrite or ruby silver and argentite frequently occur, coating crevices in primary ore, and in such cases are evidently of secondary deposition.

(b) *Veins of the Tonopah Rhyolite-Dacite Period.*—The veins connected with the earlier andesite constitute the principal class at Tonopah, but veins belonging to a later period are frequently found. These veins are associated with the Tonopah rhyolite-dacite intrusions and are dependent upon them, in the same way as the earlier andesite veins depend upon the earlier andesite. The veins of the Tonopah rhyolite-dacite period are characterized by irregularity and the lack of persistence, though their size may locally be considerable. The veins are barren or contain small quantities of gold and silver, except locally, where rich bunches of ore may occur. A characteristic of the rhyolite-dacite veins, to which there are, however, numerous exceptions, is the greater ratio of gold and silver in them as compared to that in the earlier andesite veins. These rhyolite-dacite veins are also plainly the result of ascending hot waters. The lack of definition and persistence as compared with the veins in the earlier andesite shows that at the time they were formed no definite fracture zones were available as channels.

(c) *Veins Dependent Upon the Oddie Rhyolite.*—In one of the rhyolite volcanic necks (Mount Ararat) veins of a different character from those previously described have been formed. Near the contact of the rhyolite plug with the older rocks, the rhyolite is peculiarly brecciated, showing great blocks jumbled together, with, however, rhyolitic matrix between. The dim outlines of these blocks and the nature of the matrix show that the breccia was formed when the lava was only partly rigid and in the process of cooling. This brecciation is confined to the zone near the contact. Many sharp fractures, chiefly parallel to the contact, are present in the rhyolite. These have been filled with vein-material, consisting of quartz, and ferruginous calcite containing some manganese carbonate. This gangue material contains a little gold. These fissures and fractures plainly resulted from the continuation of the driving upward of the plug after consolidation was practically complete. The vein-fillings are the result of ascending hot waters which followed the channels thus opened and cemented them.

A consideration of these veins and their wall-rocks does not afford evidence of the mineralizing waters having contained anything beyond silica, lime and magnesian carbonates, and a trace of gold. The presence of iron is contrasted with the probable absence of iron in the waters which produced the veins in the earlier andesite.

(d) *Alteration of Wall-Rocks.*—In the altered phases of the earlier andesite there are all transitions between the typical quartz-sericite phase, in which calcite and chlorite are not abundant, and the typical calcite-chlorite phase, in which quartz and especially sericite are decidedly subordinate. Hence it has been concluded that these different phases are due to the chemical effects of the same mineralizing waters, which differed in nature as they penetrated to a greater and greater distance from the circulation channels. Along these channels, which became veins, the rock was transformed by the deposition of silica, sulphides of silver, antimony, etc., gold and selenides. The soda and magnesia, and part of the lime and iron, were removed. In the wall-rock near the vein, lime, iron, magnesium and soda have been replaced by silica and potash. In the rocks more remote from the vein-channels, though the alteration has been complete, there has been no very great increase or decrease in the original elements.

eruption of both lavas. It is therefore possible that the Goldfield deposits are identical in origin with the later series of veins at Tonopah, which accompany the Tonopah rhyolite-dacite, although at Goldfield these veins are of vastly greater economic importance.

There is also a resemblance in the physical characteristics of the later Tonopah veins and the ore-bodies at Goldfield; in the latter, however, the quartz-masses are still more irregular; the outcrops may be roughly elongated, nearly circular or crescentic. The quartz is gray and jaspery and is due to the silicification of the volcanic rock, which is undoubtedly the work of hot springs. Had the rocks been strongly fractured we should have had more definite veins like those of the earlier andesite at Tonopah.

The greater part of one of these quartz reefs at Goldfield contains little or no gold, although pyrite is disseminated throughout. Frequently, however, ore-shoots of relatively small size occur, which are difficult to distinguish, except by assaying, from the barren portion. It seems probable that these pay-shoots represent the main channels of circulation, while the siliceous casings are the result of water soaking through the adjacent rock. The values of the ores are chiefly, sometimes entirely, in gold, but in some cases considerable silver has lately been found.

The sulphide ores lying beneath the oxidized surface-ores contain tetrahedrite which is highly auriferous. Tellurium is present, probably in the form of gold telluride. Bismuth sulphide is not uncommon. In the gangue, barite is common, but not abundant.

3. *Bullfrog and Kawich.*

Since the opening up of Goldfield, more than a year ago, a number of promising new camps have been discovered in the neighborhood, especially to the south and east. Chief among these are perhaps the Bullfrog and the Kawich districts, the former of which lies 60 miles southeast of Goldfield; the latter 72 miles east. I have not yet visited these camps, but from personal correspondence I have obtained some idea of their nature. Mr. Oscar Rohn has sent photographs, samples and descriptions of the Kawich district, which indicate for this low, carried with them, separated and concentrated from the magma, metals of such kind and of such quantity as are present in the veins, together with silica and other materials. The nature of the metallic minerals in the veins is believed to have depended largely upon the particular magma whence the emanations proceeded.

III. Districts Near Tonopah and Similar to It.

1. *Gold Mountain.*

The mining-district of Gold mountain, 4 miles south of Tonopah, has been prospected for several years, but has not developed into a camp of any importance. The rocks here are rhyolite, rhyolite breccia and tuffs, in which fracture- or breccia-zones have been formed, and have been transformed into veins by circulating waters. The vein-material is quartz, often chalcedonic, and the metallic mineral chiefly pyrite, which sometimes contains gold and sometimes silver. In some cases the veins contain gold only, while in others considerable silver is also present. Some of the richest ore is oxidized and occurs in pockets near the surface. From such ore, shipments have been made, but most of the veins are of low grade.

The rocks at Gold mountain are similar to the Tonopah rhyolite-dacite series of lavas, breccias and associated tuffs at Tonopah, and the characteristics of the Gold mountain veins are similar to those of the rhyolite-dacite veins at Tonopah. In both cases the veins, while they are locally strong, have not the regularity or persistence of the earlier andesite veins.

2. *Goldfield.*

I have visited Goldfield, about 24 miles south of Gold mountain, but I have not yet studied the geology thoroughly. The rocks, chiefly volcanic, consist of rhyolites, rhyolite tuffs, andesites and basalts, all probably of Tertiary age. One andesite examined microscopically resembles the earlier andesite at Tonopah, and a specimen of basalt resembles the basalt of that district. The rhyolite also resembles the rhyolite of Gold mountain. The ores occur in both rhyolites and andesites, showing that the mineralization occurred subsequent to the

From a study of these different effects of the mineralizing waters, it has been concluded that they were charged with an excess of silica and potash, together with silver, gold, antimony, arsenic, copper, lead, zinc, selenium, etc. They were notably deficient in iron, but contained carbonic acid and sulphur, as well as some chlorine and fluorine. The presence of the two last-named gases is shown by some probably original silver chloride and by the presence of muscovite in the gangue, a mineral which is believed to crystallize almost invariably in the presence of fluorine.[3]

The later andesite is not altered as much as the earlier andesite, but is, however, locally greatly decomposed. From a study of the nature of this alteration, the conclusion has been drawn that the waters which produced it were highly charged with carbonic acid and sulphur, and that they contained magnesia and iron, and also probably lime, in considerable quantity. They were clearly hot-spring waters, as shown by the excessive carbonation and sulphuration, as well as the formation of sericite and talcose materials, uralite, chlorite, serpentine, zeolites, etc. Their chemical composition was quite different from that of those waters which altered the earlier andesite. From a study of the localization of the decomposition of the later andesite, it seems likely that it was due to the influence of solutions following the contacts of later intrusive rhyolitic rock.

(e) *Source of Mineralizing Solutions.*—The waters which produced the veins and the rock decomposition in the early andesite were rich in silica and potash and poor in the other common rock-forming elements. They seem to have directly followed the earlier andesite eruption. Those that altered the later andesite were rich in magnesia, lime and iron, and low in silica and the alkalies, and seem to have followed the eruption of rhyolitic rocks, especially the Oddie rhyolite. Both were hot-spring waters, which differed in their composition as much as the rocks which they accompanied. There is an apparent antithesis in each case between the composition of the erupted rock and the accompanying hot solutions. The

[3] Doelter, *Chemische Mineralogie*, p. 161; and Brauns, *Chemische Mineralogie*, p. 247.

earlier andesite, a rock of intermediate composition, was followed by the advent of waters rich in the elements characteristic of extremely acid rocks. The eruption of the Oddie rhyolite, a very siliceous rock, was followed by the advent of waters rich in elements characteristic of basic rocks and poor in the elements represented in the rhyolite. The exact explanation of this antithesis is a matter for future study.

There are two possible explanations of hot springs; one is that they are due to atmospheric water which has sunk down from the surface to such a depth that it becomes highly heated and then rises again; the other is that they are due to water which forms a part of the molten material in the earth's interior and which is concentrated and separated from the magma upon the cooling of a molten mass. Lavas which cool at the surface give off vast quantities of water-vapor, and the phenomena of contact-metamorphism, especially that connected with siliceous rocks, show that in depth similar water-vapor is expelled from cooling rock. It seems therefore impossible to escape the conclusion that, at least some hot springs, the after-phenomena of volcanic activity, are due to magmatic water.

In the arid Nevada region there are, as a rule, no flowing surface-waters, the whole supply emerging from the ground as springs. These springs may be either warm or cold. The cold springs usually show two characteristics which indicate that they are of vadose or atmospheric origin: (1) they fluctuate with the season, and (2) they become more numerous in regions of greater precipitation and rarer in the more arid portions. The hot springs, however, so far as the writer knows, do not show these characteristics. They are notably associated with areas of volcanic rocks and they are often very vigorous in the heart of an arid region.

Volcanic activity has lasted in this province from the beginning of the Tertiary to within a few hundred years ago, but many of the hot springs which accompanied or followed the different manifestations of volcanic activity are now extinct. At Tonopah, waters ascending after several of the volcanic eruptions, mineralized and altered the formations through which they passed, and became extinct in a relatively short space of geologic time. It is difficult to explain the totally different composition of the waters of the different periods on

the hypothesis that they were of atmospheric origin, and the antithesis pointed out between the contents of waters of different periods and the composition of lavas which they followed is equally difficult to account for on this hypothesis. A third consideration is the peculiar combination of materials in the waters which produced the veins of the earlier andesite, especially the presence of unusually large quantities of the rare metals silver and gold, and unusually small ones of the commoner ones, copper, lead, zinc and iron. Plainly some process of separation and concentration has furnished the noble elements contained in the mineralizing waters, separating them from the baser metals. A view concerning this same problem at the Comstock, expressed by Von Richthofen,[4] appeals to me as an explanation of the Tonopah ores also. Von Richthofen pointed out that the volatile materials, chiefly fluorine, chlorine and sulphur, given off during solfataric action, would extract from the cooling rock metallic substances of much the same character and proportion as those present in the Comstock lode, while ordinary waters would furnish primarily the more abundant metals, such as iron and manganese, and only small amounts of silver and gold.

(f) *Summary of Genesis of Tonopah Ores.*—The considerations pointed out appear to indicate the following conclusions.

The Tonopah district was during most of Tertiary time a region of active vulcanism, and probably after each eruption, certainly after some of them, solfataras and fumaroles, succeeded by hot springs, thoroughly altered the rocks in many parts of the district. At the surface, during these periods, the phenomena of fumarolic, solfataric and hot-spring action were similar to those witnessed to-day in volcanic regions; but the rocks now exposed were at that time below the surface. The veins have cemented the conduits which were formed by the fractures due to the heavings of the surging volcanic forces below, and along which gases, steam and finally hot waters, growing gradually cooler, were expelled, relieving the explosive energies of the subsiding volcanism. The water and other vapors, largely given off by the congealing lavas be-

[4] Cited in *Monograph*, U. S. Geological Survey, vol. iii., pp. 19–20.