LOCAL STRUCTURAL FEATURES

The chief local structural features are fractures approximately parallel to the margin of the intrusion of albite granite. The main trend of the outcrops of the contact of albite granite with its intruded "green" rock is north-south, with west dip on the west side and with east dip on the east side of Sulphur Gulch. In the vicinity of the mine the contact locally strikes nearly east-west for over 1,000 feet, and dips south. Sheeting, nearly parallel to the contact, is well developed; mine workings show these fractures in the granite in a zone 100 to 300 feet wide. The parallelism of fractures and contact is more apparent than real for in every instance the fractures converge toward the contact and eventually cross into the "green" rock where they are lost in soft, broken, chloritized ground. The zones of intersection of fractures with the contact contain the most important ore bodies that have been discovered and without exception both ore and fractures pinch out away from the contact.

Another important system of fractures trend nearly east-west and dip northerly; these have been referred to previously in a paragraph on regional structural features. Dikes parallel in strike and dip, both to the east and west of the stock of granite are regarded as evidence that this structure is not directly related to the contact. These fractures occur in poorly defined zones. They steepen in dip as they approach the contact and finally merge with fractures nearly parallel to the contact.

As most of the ore occurs in the zone of intersection of fractures with the contact this relationship has a great practical importance. Within these favorable zones smaller cross fractures and branching fractures have exerted a favorable influence on ore deposition. This local structural detail is very complicated and is responsible for very abrupt changes in the ore bodies.

THE MOLYBDENITE DEPOSIT

EXTENT AND APPEARANCE OF OUTCROPS

The molybdenite area in Sulphur Gulch covers an area about one-half a mile square. Outcrops throughout the area of mineralization are conspicuous because of iron stain and the highly fractured character of the rock. The iron stain is an alteration product of pyrite which is more widespread in its occurrence than molybdenite. Extensive oxidation of molybdenite has produced numerous showings at the surface of the characteristic bright yellow oxide, molybdite. However, erosion is so rapid that the oxide does not extend far underground and there are numerous showings of molybdenite at the very surface. On the whole, the commercial bodies of ore did not crop out so as to attract attention through exposures of unusual amounts of oxide or sulphide. The abundant iron stain and relatively numerous occurrences of molybdite and occasional appearances of molybdenite roughly outline the area of mineralization but these surface indications have not often proved a direct guide to ore. Ore has been found most often as a result of careful prospecting by drifts and crosscuts. A large part of the ore mined has been taken from blind veins which have no recognizable surface expression.

ROCK ALTERATION

The rocks in the area have been extensively altered, not only near veins but also at some distance from them, both through mechanical crushing and shattering of the rock, and by solutions. The solutions have effected a selective replacement, changing much biotite to chlorite and albite crystals to clay minerals, but replacement of rock in mass has not occurred except for some silicification of granite along quartz veins. As a rule the original character of the rock is recognizable even where the combined effects of both mechanical and chemical changes have been relatively strong. Inasmuch as both mechanical and chemical processes have been important, each will be considered separately.

Mechanical alteration of rocks.—Crushing and shattering of rocks is very pronounced in the mine workings. Closely spaced joints are evident in all outcrops but shattering so intense that it virtually pulverized the rock is best seen underground. In places, alteration by (1) solution and by (2) crushing is closely related and the relative effects of each process is not clear. The effects of each process also can be seen separately so that the changes produced by each can be observed with dependable accuracy. It is not uncommon to find, in a vein in originally hard albite granite, apparently massive hard quartz which crumbles to gravel under light blows of a hammer. In places the granite along fractures, away from apparent effects of solution, has been similarly shattered. Numerous fractures can be seen on newly broken faces, and upon a close scrutiny with a hand lens, many more are evident. Under the microscope in thin sections, shattering approaching granulation can be seen, much of which is not visible megascopically.

In spite of the crushing and its shattered condition the weakened rock stands well in mine openings. Soft ground requiring timbering is confined to gougy zones along veins and even there swelling ground is not encountered.

Some of the crushing is clearly post-mineral for quartz in veins is affected, but much fracturing occurred early because many walls are coated with molybdenite, pyrite, chlorite, or calcite—all of which are products of mineralization. Indisputable evidence of either pre-mineral or post-mineral displacements has not been found, although movement is suggested in several places. The cause of the crushing and fracturing, although it is not evident, reasonably can be ascribed to some of the tectonic movements to which the Sangre de Cristo Range is known to have been subjected.

Chemical alteration of rocks.—The chemical changes most commonly found in the rocks are the development of a white clay gouge, chloritization with formation of pyrite, and alteration of albite crystals in the albite granite.

A white clay gouge is generally present in the veins and fractures, and along joints in both the albite granite and the "green" rock throughout the mineralized area. The gouge is largely a mixture of orthoclase and quartz with minor amounts of fluorite, calcite, and clay minerals—all in the form of grains of microscopic size. The gouge in the granite could result from slight bleaching of crushed granite and the addition of small amounts of fluorite and calcite, but I am of the opinion that most of the gouge is a product of chemical alteration by mineralizing solutions. This opinion is based on the observation that white orthoclase gouge occurs in relatively tight joints along which the granite shows no apparent crushing; and also because there is a general association of orthoclase gouge with the sulphides and other minerals that are characteristic of molybdenite mineralization. And finally the gouge is not confined to the granite but is common also in fractures in schist and sedimentary rock both of which contain little or no primary orthoclase.

Chloritization occurred on an important scale both in the granite and in the "green" rock. Mineralogically, it is as interesting as the white clay gouge described above, for its occurrence appears to be analogous to sericitization in other molybdenite deposits. Here, chlorite has replaced much of the biotite of the schist and abundantly fills the interstices between sand grains in the sandstones and throughout the hornfels, uniformly coloring dark green all rocks adjacent to the albite granite. The concentration of chlorite in the schist and sedimentary rock through a zone in close proximity to the albite granite suggests that chloritization might have been produced by metamorphic processes of the granite rather than by molybdenite mineralization. Also, the presence of hornfels is a good indication of igneous metamorphism, but typical contact minerals are lacking in this area. Chlorite, generally with associated pyrite, has also developed in the albite granite, but nowhere does it replace the granite as a whole. Apart from the general chloritization of biotite over relatively large areas, the chlorite is confined to fractures, forming mud seams in veins

FIGURE 3

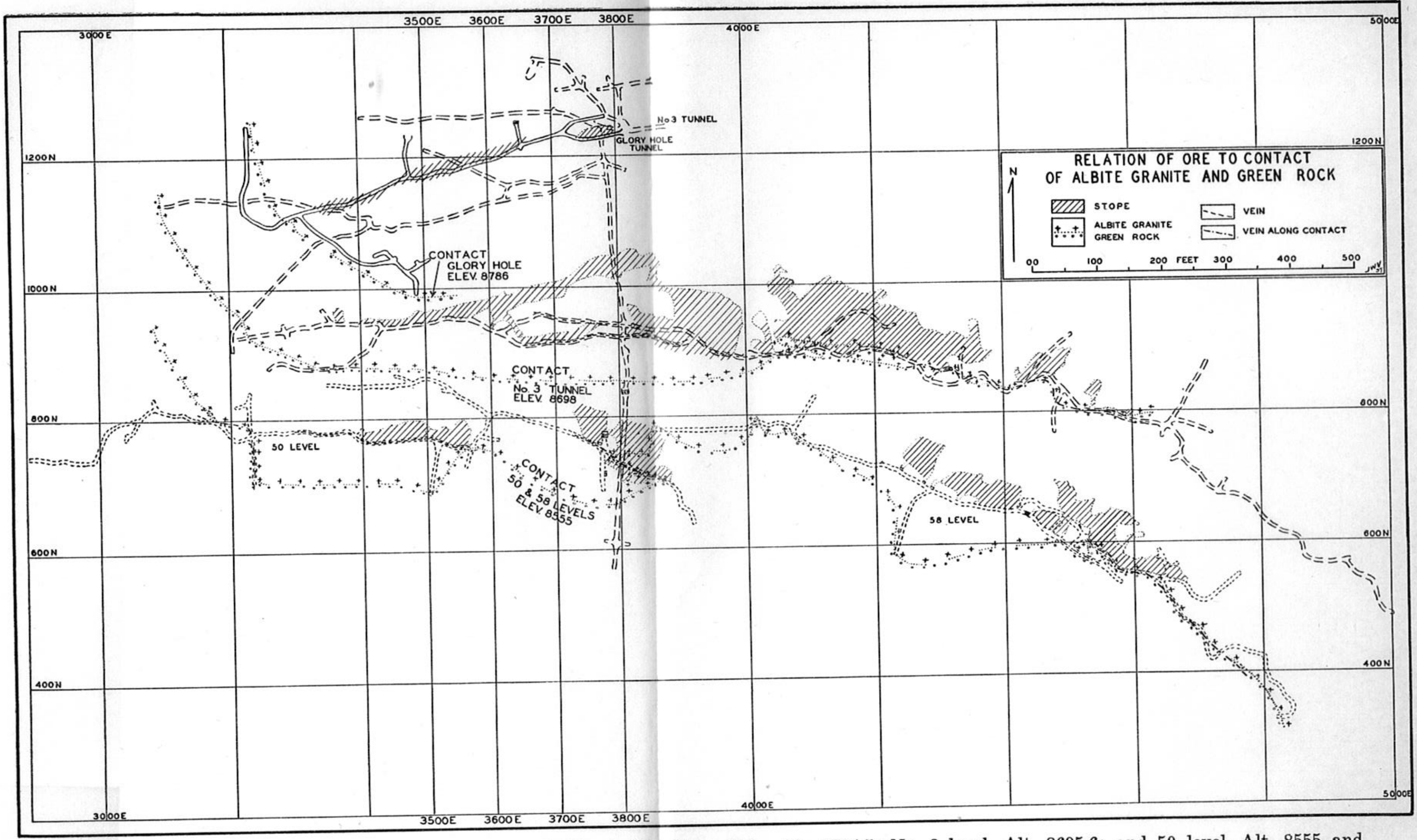

Figure 3.—Mine maps showing geology of: No. 1 Sublevel, Old Glory Hole, Alt. 8784.5; No. 3 level, Alt. 8695.6; and 50 level, Alt. 8555 and 58 level, Alt. 8561.

and coating walls of joints. In addition, films of chlorite have formed on some of the biotite in the veins where it is intergrown with molybdenite. The development of chlorite along joints is so intensive that in places where joints are numerous newly opened rock faces in the mine workings show only the dark green of chlorite and thus superficially look more like sedimentary and schist wall rock than albite granite.

The association of chlorite with important molybdenite mineralization is of particular interest because it does not seem to have been described previously in geologic literature. A similar relation was observed in the molybdenite deposit on Copper Creek, Arizona, and its occurrence elsewhere is to be expected.

Some of the albite in the albite granite has been altered to a clay mineral, probably montmorillonite. In liquids the mineral shows a fine grain and a mean index of about 1.53 with moderate bi-refringence, on which its tentative identity is based. Underground, this alteration is conspicuous, owing to the fact that after exposure to the atmosphere the clay-like material swells slightly, thus emphasizing the outline of the altered grains and giving the rock a pseudo-porphyritic structure. A search was made for montmorillonite in the white clay gouge but none could be identified definitely. It appears that the development of montmorillonite is confined to the walls or at least to zones near fractures and joints for commonly it was not found in the more solid rock and it was not found in several thin sections of the albite granite taken from the walls of veins with a few inches of ore. However, this relationship could not be definitely proved but, if true, the seemingly widespread alteration of albite is less than it appears to be. Furthermore, the clay could represent an alteration product of acidic surface waters instead of mineralization associated with the molybdenite.

MINERALS

Quartz, biotite, fluorite, pyrite, and rhodochrosite are the most commonly associated minerals of the molybdenite deposit, and one or more of them may be found with the molybdenite, which also occurs alone. In addition chlorite, orthoclase, calcite and small amounts of chalcopyrite, sphalerite, galena, and sericite are also present. Mineral relationships, relative ages, and other characteristics of each of the minerals are described in alphabetical order in the following paragraphs.

Apatite, $(CaF)Ca_4(PO_4)_3$, was reported and described by Larsen and Ross.[13] I was unable to find this mineral. Apparently it was confined to a relatively small area that happened to be open at the time Larsen and Ross examined the deposit.

Biotite, black mica, $(H,K)_2(Mg,Fe_2)Al_2(SiO_4)_3$. Biotite is generally associated with molybdenite and quartz. It is not quantitatively important but it is developed widely and its presence is regarded by the miners as a favorable sign for finding molybdenite because it was conspicuous in the richest ore bodies. In places it is intimately intergrown in a crudely banded structure with molybdenite and the two probably were deposited simultaneously. Small veins of quartz with biotite unaccompanied by other minerals, and streaks of pure biotite are occasionally seen. The mineral generally occurs in coarse flakes, soft and crumbly, with a rather dull luster, probably largely due to crushing. In places a thin coating of green chlorite is formed along crystal boundaries. Under the microscope only a minor development of chlorite is evident.

Calcite, $CaCo_3$, occurs in the larger veins, and it is also disseminated widely through the albite granite and the "green" rock in small seams. It is one of the later, if not of the group of latest minerals to form, for commonly it is concentrated along the central part of the veins or lines cavities in well formed scalenohedrons. It is not quantitatively important nor very continuous along a vein and occurs in scattered bunches. Calcite is more characteristic of the margins of ore bodies than of the ore itself. Its distribution appears to be co-extensive with the more widely distributed minerals, pyrite and chlorite.

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[13] Op. cit., p. 571.

Chalcopyrite, $CuFeS_2$, is present in minor quantities and occurs in small scattered pockets which also contain a few crystals of galena and sphalerite. Its relative age could not be determined, but if it follows its usual relationship, it is later than molybdenite.

Chlorite, hydrous magnesium aluminum silicate, is widely developed. Propylitization of the schist, sedimentary, and igneous rocks intruded by the albite granite, is widespread. Chlorite occurs in the molybdenite veins, and along joints coats the walls much the same as the molybdenite "paint." These chlorite seams are scattered through all of the area prospected and are termed "mud" seams by the miner; they are black, suggesting molybdenite, but their luster is dull in comparison with the brilliant bluish black of molybdenite. Chlorite is one of the latest minerals, for it coats biotite and cuts both calcite and rhodochrosite, each of which is a late mineral.

Fluorite, CaF_2, is very characteristic of the deposit, widely distributed and about third in abundance. It is confined to veins and its color varies through shades of purple, green, red, and white with more than one color commonly showing in a single grain. Purple and red shades of fluorite predominate where it is associated with molybdenite and lighter colors where it occurs apart. It is common in ore, but probably is more abundant in the marginal areas of important molybdenite concentration. Fluorite veins locally 12 inches thick unaccompanied by other minerals occur both close to and at considerable distances from molybdenite veins.

Galena, PbS, occurs only in minor quantities, in small scattered pockets with chalcopyrite and sphalerite. Its relative age could not be determined from its occurrence here, but its usual relationship elsewhere is later than molybdenite.

Gold is often found as a "trace" in assays of mill concentrates. The amounts are too small to be of commercial importance. Its presence is interesting.

Hübnerite, $MnWO_4$, was found but once—a few scattered crystals in the quartz of a vein. Its occurrence is of interest because it is relatively common in the Climax (Colo.) molybdenite deposit where it occurs as one of the late minerals to be deposited.

Molybdite, $Fe_2O_3. 3MoO_3. 7\frac{1}{2}H_2O$, or molybdic ochre, is conspicuous in places at surface. Below a few feet of the surface, it is not found.

Molybdenite, MoS_2, is widely distributed in veins. Its most characteristic occurrence is as paper-thin coatings, termed "paint", on the walls of joints, which however do not constitute ore. Ore forms in distinct veins. Quartz is the most common associated mineral, and next in order are biotite, fluorite, pyrite, and rhodochrosite. Molybdenite also occurs alone. It is commonly fine-grained, almost like mud, but when intergrown with quartz or biotite is usually an aggregate of coarse flakes some of which measure nearly an inch across. Masses of almost pure molybdenite weighing several hundred pounds are occasionally found but break and crumble so easily that large pieces rarely remain intact.

Molybdenite is distinctly later than some of the quartz but in part is contemporaneous. Most of the other minerals, such as pyrite, fluorite, rhodochrosite, and calcite are later than molybdenite for they occur largely in the central parts of the veins. However, small seams of molybdenite were noted in a few places cutting all of these younger minerals. Study of the relationships of mineral deposition indicates that although much molybdenite was deposited during an early stage, it continued to deposit (apparently alone) in appreciable amounts until near the closing period of vein formation.

It is interesting that at "Questa" as at Climax, Colorado, molybdenite is not associated intimately with any other sulphide. Pyrite is the only other sulphide present in abundance in both places and although clearly an associated mineral it is not anywhere intimately intergrown with molybdenite. At Climax pyrite veinlets cut molybdenite stringers and likewise at "Questa" some of the pyrite clearly cuts the molybdenite, although this relationship is not always so clearly developed.

Molybdenite at "Questa" finds its way into most minute fractures. The coatings along joints, termed "paint", are exceedingly thin and are evidence that the solutions could penetrate very small openings. "Paint" seams are continuous coatings of finite thickness, probably comparable to a coat of paint. Molybdenite also occurs along joints in scattered crystals which show very faintly in cross section. There appears to be a complete gradation from scattered crystals along joints to the continuous coatings of molybdenite "paint" and from these to stringers a few millimeters or more thick. Molybdenite "paint" mostly is unaccompanied by other minerals.

Orthoclase, $KAlSi_3O_8$. Much of the white gouge occurring along veins is orthoclase. The gouge usually contains quartz; fluorite may or may not be present. Sericite is present only in a few isolated places. I believe this orthoclase is secondary and formed by the mineralizing solutions. However, crushing has literally pulverized some of the albite granite in places along the veins and such pulverized granite would require very little alteration, chiefly bleaching, to yield a product similar to the gouge described above. The chief evidence in favor of a wholly secondary origin for the orthoclase gouge is that it not only is found in the "green" rock but also occurs in places without associated quartz in the albite granite; granulated granite should invariably contain quartz. Orthoclase gouge is distributed throughout the mineralized area and is not always closely associated with molybdenite. The evidence is not everywhere conclusive, but general relationships suggest that the orthoclase gouge was one of the late products to form.

Pyrite, FeS_2, is widely distributed not only in the area affected by molybdenite mineralization but also throughout the surrounding altered volcanic rocks. Only pyrite related to molybdenite mineralization is considered here. It occurs disseminated through both albite granite and "green" rock and also occurs in veins at great distances from molybdenite. Pyrite is also common along joints or small seams, where it occurs with or without quartz. The disseminated pyrite in the albite granite is a product of alteration of biotite, a relationship which is clear in thin sections. In the veins, pyrite occurs in bunches and may or may not be characteristic of a particular ore body. When pyrite is present in ore it is not at all intimately mixed with molybdenite but occurs in streaks, usually along a wall of the vein in such a manner that it is mixed with the ore in the process of mining. Wherever galena, sphalerite, or chalcopyrite is encountered these minerals are associated with pyrite.

The relative age of the disseminated pyrite is not clear but its occurrence generally is the only evidence of alteration other than chloritization, with which it appears to have been associated. Molybdenite crosscutting pyrite was not noted, but reverse relationships can be found and some pyrite is therefore the later mineral of the two. Its relation to the other minerals was not found.

Quartz, SiO_2, is the most common vein mineral associated with molybdenite. It also occurs in the albite granite in small white veinlets free of other minerals. Although abundant in the molybdenite veins it is not everywhere present and where present it tends to be bunchy or lenticular and is regarded as a favorable indication for ore. Vein quartz cut by stringers of molybdenite, producing a banded structure, is common. Some of the banded molybdenite and quartz may represent a contemporaneous deposition but mostly molybdenite clearly cuts the quartz; similar banding is not uncommon in the albite granite.

Quartz was deposited both in early and late periods but the bulk of it appears to have been deposited early. Except locally, the veins are not predominated by quartz so they cannot be regarded as typical quartz veins.

Rhodochrosite, $MnCO_3$, was not found in the Old Glory Hole workings and very sparingly in the workings under Highline Ridge. It is, however, relatively abundant and very generously distributed in and near the flat veins under the contact. It is fine-grained and has a delicate pink color which soon takes on a distinct iron stain when exposed to atmospheric conditions. It occurs alone or with disseminated fluorite; and in places with calcite. An analysis was not made but the iron stain suggests that the rhodochrosite is not pure manganese carbonate. Rhodochrosite commonly forms the central part of veins with fluorite or molybdenite along the walls; it is clearly one of the later minerals, for, although in a few places small streaks of molybdenite cut it, it tends, like calcite or fluorite, to occur in the central part of veins and along the marginal areas of the ore.

Sericite, secondary potash (muscovite) mica, is relatively unimportant. It is not uniformly present in the veins and was found only in small amounts in thin sections. The white gouge, often mistakenly called sericite, is mostly orthoclase with some quartz and fluorite.

Silver, like gold, generally shows in assays of mill concentrates, and in samples containing some galena or chalcopyrite. It has no commercial value. However, the possibility that a pocket worth mining might be encountered cannot be denied.

An interesting occurrence of silver occurs in the albite granite about a half a mile south of the mine. Prospecting is confined to shallow openings. The silver occurs in small irregular fractures and assays of 50 ounces to the ton are not uncommon in picked samples, most of which consist largely of oxidized material. Among the associated minerals are a little quartz, pyrite, galena, sphalerite, and hematite. The contact of albite granite and other rocks here lies several hundred feet to the north of the prospect holes and the question naturally arises whether the silver may not be localized near the contact similarly to the molybdenite deposition farther north.

Sphalerite, ZnS, is very sparingly present. It is associated with chalcopyrite and galena and like them probably a late mineral.

ORE

The ore is entirely a filled vein. Replacement of rock by molybdenite has not occurred. The vein is largely molybdenite, although quartz, biotite, rhodochrosite and pyrite are locally abundant and, even where the molybdenite seems nearly pure, generally one or more of these minerals is present. Pure molybdenite ore is not common. The veins are narrow, averaging 6 to 18 inches in width. In mining, the vein filling is mixed with wall rock so that the ore as taken from the mine is seldom representative of ore as it occurred in the vein. Many veins have only one well-defined wall, the other being marked by ramifying seams or small veins each containing a film of molybdenite, the whole of which is rich enough to be mined even though considerable wall rock is mixed with the ore. In places parallel veins only a few feet apart extend for some distance in length and they are regarded as footwall and hanging wall streaks which are mined as one vein. Under these conditions admixture of wall rock is unavoidable. Ore taken from the mine averages about 3 to 15 per cent molybdenite. By means of hand sorting and screening an effort is made to produce a 6 per cent (MoS_2) or higher grade of ore for milling. Veins 3 feet wide averaging 15 to 20 per cent molybdenite have been mined but these are exceptional, for veins of this width mostly yield a lower percentage of the molybdenum sulphide than is found in narrower vein-filling. The character of the veins make it impossible to estimate closely the average grade of ore as it occurs in the veins.

VEINS

Definition.—A vein is commonly defined as a fracture along which mineralization has occurred. Unless this definition is restricted, a description of the veins at "Questa" would be exceedingly complicated, for mineralization has occurred along most of the numerous fractures both in the albite granite and in the rocks it intrudes. In this report, therefore, only mineralization along fractures that are well defined and relatively continuous will be regarded as veins. Veins (thus restricted in definition) have produced all of the molybdenite in the area and are confined to the albite granite in a relatively narrow zone along the margin of the stock and near its contact with the schist and sedimentary rock.

Structure and relation of veins to contact.—The veins occur in poorly defined but nevertheless definitely fractured or sheeted zones. The width of these zones is very irregular; in places it is fully 30 feet wide. The fractured zones diverge from the contact sometimes abruptly and sometimes gradually but well-defined veins are confined to places relatively near the contact. Down the dip or along the strike away from the contact a vein pinches and eventually is lost in a maze of branching seams that are conspicuous only because of molybdenite "paint" on them. At greater depth the fractured zones also pinch out; at least they cannot be recognized in the lower crosscuts. Upward a vein may follow the contact for some distance before it crosses into the "green" rock where it is soon lost in soft fractured schist or sedimentary rock. These conditions account for the lack of continuity of veins along both strike and dip. A vein which pinches out does not reopen, but along its strike, parallel to but not on the strike, a new vein may occur.

Sheeting has developed in the albite granite under two conditions: (1) Some distance from the contact in nearly east-west zones that dip northerly at 60 to 80 degrees, and (2) near the contact paralleling it—presumably an expression of contraction due to cooling of the magma. Upward both types of veins intersect the contact.

The principal production of molybdenite has come from an interval about 1,500 feet long in which the contact strikes east-west and dips south. Farther west the contact turns north with west dip, and to the east it turns south with west dip. In this interval of east-west strike the sheeting along the contact parallels in strike the east-west fractures that dip north, while elsewhere the two sets of fractures are oblique to each other in strike. Areas with obliquely intersecting fractures have not been prospected as much as in the more productive part of the mine, but all attempts to develop ore along a north-striking contact have failed. Blind Gulch tunnel is the only tunnel cutting the contact where it strikes northerly. The contact is virtually barren although the best showing of molybdenite, which did not prove commercial, occurs relatively near the contact in a more nearly east-west vein. Although it cannot be said that north-south striking contacts are wholly unfavorable for ore, they do not seem to offer possibilities for ore equal to those where the contact strikes east-west.

Favorable places for ore.—The favorable places for ore are in areas where sheeted or fractured zones converge toward the contact and where it strikes east-west; in these places vein intersections are the local control. A single vein, as a rule, predominates each fracture zone but there are also many subordinate and branching fractures or seams and ore commonly occurs along their intersections with the main vein. The intersections of nearly vertical veins that strike east with flat south-dipping veins that also strike east have produced excellent ore bodies. In mining, the problem of what constitutes the more favorable intersections must be studied continually. Each specific locality is a problem to itself which can be solved only through persistent and detailed observations during the course of development and mining. The only hope for a more specific solution lies in the accumulation of data from the mined areas; these data may eventually make it possible to recognize a clearer pattern or patterns of structure.

DESCRIPTION OF MINE

GENERAL STATEMENT

A close relationship between the veins and the contact is very clear. This important conclusion is the result of a study of the veins that have been mined; therefore, a discussion of the mine workings is necessary. The principal mine workings can be divided into two main areas, namely, the workings north and east of Sulphur Gulch and those to the south and west of Sulphur Gulch. The former will be referred to as the "north" workings and the latter as the "south" workings. This division, seeming arbitrarily based on topographic features, is nevertheless very logical for the veins and character of ore in each area differ greatly. The north workings represent ore horizons, the upper part of which has been removed by erosion so that the exact relation to the contact cannot be definitely determined, whereas the south workings are more closely confined to horizons either at or very close to the actual contact. The Old Glory Hole veins of the south workings represent conditions that are transitional between those found in the north and south workings.

NORTH WORKINGS

The north workings are those found on the southwest side of Highline Ridge between Sulphur Gulch proper and its tributary Blind Gulch. They include the Highline, B, C, and D ore areas, which combined have yielded about 20 per cent of the total production of Sulphur Gulch. In all of the "north" areas the bulk of the ore has been derived from two main stopes along veins in fractured zones that strike east-west and dip northerly at 40 to 70 degrees. The ore occurs chiefly at vein intersections but except in the larger stopes prospecting has been difficult and discouraging, for two reasons, (1) the veins are often discontinuous, making projections even for short distances extremely unreliable, and (2) much more than half of the intersections of veins do not contain sufficient concentrations of molybdenite to make ore.

The overlying "green" rock and the contact between the albite granite and "green" rock over this area have been removed by erosion and consequently the position of the contact with respect to the ore bodies is not definitely known and cannot be projected with accuracy because the form of the contact is known to be irregular. This irregularity, although subordinate to the form of the albite granite stock, is locally very important, as dips vary as much as 15 to 90 degrees in distances of several hundred feet. The contact is exposed high on the ridge not far north of the north workings and by joining it with an average dip to the contact on the south and west side of Sulphur Gulch its former relative position projects not far above the present crest of Highline Ridge.

The character of the veins and the ore are similar to that in the Old Glory Hole area in the south workings where the contact is close by. On the upper levels of the Old Glory

Hole workings, the vein dips south and is at the contact while on a lower level the vein diverges from the contact and stands vertical. Still lower the dip changes to north. In directions away from the contact both vertically and horizontally the vein becomes smaller and eventually is lost in a fractured zone devoid of commercial concentrations of ore. The vein conditions found on the lower levels of the Old Glory Hole levels are almost identical with those of the Highline area of the "north" workings. The similarity is so marked as to make it difficult to come to any other conclusion than that they are in equivalent horizons.

SOUTH WORKINGS

Principal features.—The "south workings" include the Old Glory Hole ore bodies and those of "No. 3", "W", and "Z" tunnels, with intermediate levels. The ore bodies of the Old Glory Hole workings distinctly lie apart from the other ore bodies, which occupy a more or less continuous belt over an area about 300 by 1,000 feet through a vertical range of less than 300 feet. The "south workings" area has yielded over 80 per cent of the molybdenite produced from the entire mine.

The boundary or contact between the albite granite and "green" rock strikes nearly east-west and dips south throughout this area. To the west the contact changes to a northerly strike with a westerly dip forming a synclinal surface also plunging steeply to the southwest. The dip of the contact in the mine is everywhere southerly and through the vertical range of 300 feet which has been well explored and an additional 200 feet which has been partly explored in the mine, varies from 60 degrees to less than 17 degrees, averaging 30 to 40 degrees over relatively large areas. The variations in dip of the contact where it trends north and south has not been determined but it appears to average about 30 degrees westerly and changes as great as those encountered where the strike is nearly east may be expected.

The contact is well exposed throughout the extent of this area as well as in numerous drifts, crosscuts, and raises.

A map showing the relation of the stoped ore to the contact on 3 typical levels is given as figure 4.

A summary of the maps and cross sections is given by means of four selected cross sections shown in figure 4. Each map section on figure 4, except the top section, represents a vertical mine section 100 feet east of the one shown immediately above it. Figure 4 represents two important structural conditions: (1) Veins under the contact sharply convex downward exemplified by the Old Glory Hole veins in the vicinity of coordinate 1,200 N, and (2) veins under the contact where it is concave downward as exemplified by the stopes in the No. 3 and W tunnel levels between coordinates 800 N and 1,000 N. Veins of the first type are relatively steep and do not continue far along the strike where the curvature of the contact flattens out to an average dip. Veins of the second type more commonly have a relatively flat dip and are fairly continuous, often extending along the contact well under those areas where the contact has flattened out.

Considering first the area along and west of coordinate 1,200 N (See fig. 4) on coordinate 3,500 E the vein is along the contact above the Upper Drift (alt. 8,854); east only 100 feet on coordinate 3,600 E and 100 feet farther east this vein was stoped to the surface. Below 109 Drift (alt. 8,832) the vein steepens and assumes a steep north dip in contrast to the steep south dip of the upper levels. The sharp change in dip of the contact on coordinate 3,500 E decreases to the east and the stoped veins are a little farther from the contact. On coordinate 3,700 E, still farther east, the contact is relatively flat and the veins though continuous are small with little or no stoping ore. Still farther east, on coordinate 3,800 E, small veins, none of which make ore, are present in drifts and crosscuts. Thus east of coordinate 3,500 E, the veins with ore diverge from the contact, grow smaller, and are lost.

Turning now to the zone between 800 N and 1,000 N (See fig. 4) where the contact is concave downward, conditions unlike those described above are encountered. The

FIGURE 4

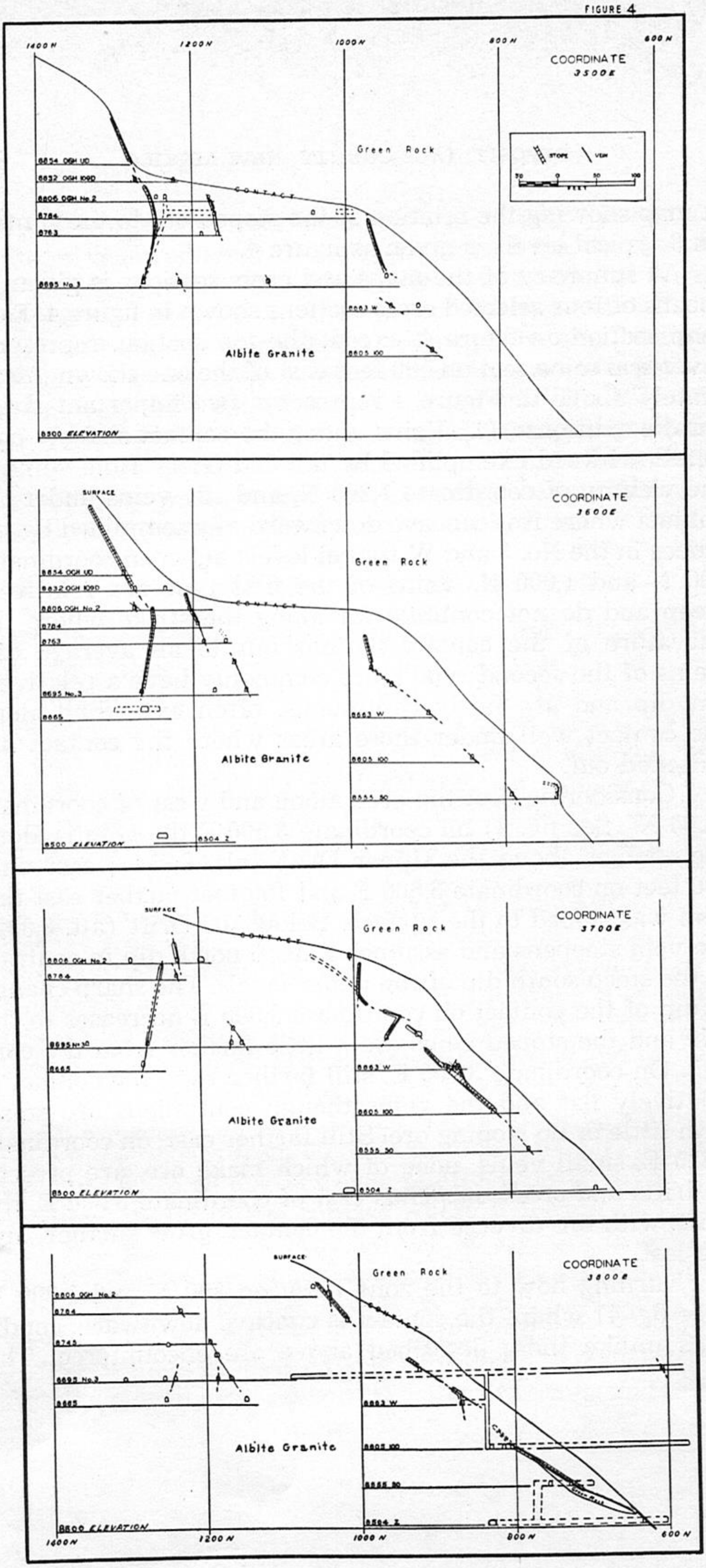

Fig. 4.—Cross sections summarizing relationship of veins to contact.

steep stope, though persistent, has a very limited vertical extent along the strike for over 400 feet. The flat vein on and below W level (alt. 8,863) on coordinate 3,700 E, and below 100 Level (alt. 8,805) on coordinate 3,800 E was well defined and contained good ore, but to the west on coordinates 3,600 E and 3,500 E where it is farther from the contact the vein was less well defined and devoid of stoping ore. West of coordinate 3,800 E the band of "green" rock enlarges and the wedge of albite granite above it gets smaller until it pinches out; that is, the vein passes from albite granite easterly into "green" rock where it pinches out. Again, the ore is limited to that area where the vein is close to and finally comes to the contact.

The first group (near 1,200 N) of veins extends downward farther from the contact than the second. Both groups are alike in becoming smaller and discontinuous away from the contact, a condition to which no exception has been found. Some of the veins in the second group are not continuous to the surface; that is, they do not crop out. Furthermore, the ore bodies occur not in any one vein but in a series of veins. All of the observations point to a close relationship between the series of veins and the contact. The contact itself, without any doubt, is continuous and the veins may be expected to continue with it in depth. No evidence contrary to this conclusion has been recognized.

Summarizing briefly the characteristic features shown by the distribution of stopes and veins and their relation to the contact in various workings, the following observations are important:

1. Sharp changes in dip of the contact.
2. Zones of convergence of fracture zones and their associated veins with the contact.
3. Intersection of a strong vein with seams and slips within a fracture zone near the contact.
4. Intersection of vein with cross fractures near the contact.

ORIGIN OF ORE

The molybdenite was deposited by solutions that penetrated the rock along fractures. Solutions naturally concentrated where openings were most favorable and in zones dammed by adjacent and impervious rock. The marginal zone of the stock of albite granite with its numerous fractures under impervious "green" rocks of schist and sedimentary rocks is a favorable horizon for concentration of rising solutions responsible for the ore. This relationship of ore to a contact is therefore a purely mechanical one, structurally analogous to localization of ores in sandstone or limestone beds under shale, and not in any way related to so-called contact deposits.

Fracturing and sheeting in the marginal zone of an intrusion is a common phenomenon believed to be due to contraction resulting from solidification and cooling of the magma and therefore not peculiar to the mineralized area in Sulphur Gulch. Similar conditions occur at the north end of the Bear Canyon stock, well exposed in the small canyons north of the highway along the Red River. The structural conditions clearly have controlled the course of the solutions that brought in the molybdenite but they do not offer any satisfactory clues as to the ultimate source of these solutions.

Molybdenite is generally associated with granitic rocks. The albite granite in Sulphur Gulch and neighboring areas is very siliceous and the occurrence in it of molybdenite deposits is naturally suggestive of a genetic relationship. A direct relationship is not evident; the molybdenite is confined to fractures distinctly later than the granite. It is not unreasonable to suppose, however, that the molybdenite and albite granite have a common source, or that the molybdenite came in solutions emanated from the magma chamber at depth after the albite granite of the upper part of the stock had completely solidified. Molybdenum is being deposited by hot springs in the Valley of Ten Thousand Smokes, Alaska, where thermal springs are regarded as a late phase of the volcanic activity. This is analogous to the relationship conceived between the albite granite and molybdenite in Sulphur Gulch.

On the assumption that the albite granite and molybdenite are genetically related, the stock in Bear Canyon is plausibly a locality to search for molybdenite. However, the stock of albite granite exposed in Bear Canyon differs from the stock in Sulphur Gulch in one fundamentally important respect; erosion in Sulphur Gulch has exposed merely the top of a small stock, while the Bear Canyon stock has been deeply eroded. The albite granite in Bear Canyon is exposed through a vertical range of fully 2,000 feet and it originally extended to higher and unknown altitudes so that the margins found at the present surface lie well down the flank of the stock far below its original top, and less mineralization would be expected. Small stringers of molybdenite do occur and have been prospected in Bear Canyon and along the western margin of the stock. The contrasting conditions found in Sulphur Gulch and in Bear Canyon therefore bear out the well recognized theory that ore occurs at or near the tops of stocks or cupolas. This relationship is important in prospecting for molybdenite in bodies of albite granite.

Rock alteration, with the development of an abundance of chlorite, in Sulphur Gulch leads to the interpretation of intermediate or low temperature mineralization. Biotite in the veins is almost a sure indication of high temperature; some molybdenite is deposited contemporaneously with biotite. However, biotite is relatively limited in amount and distribution and, since a general change of biotite to chlorite in the albite granite took place, it can be assumed that the high temperature necessary for the formation of biotite did not continue long or prevail over the area as a whole. The occurrence of rhodochrosite is also indicative of relatively low temperature. The development of biotite, and presumably high temperature as well, was not only limited to veins but to small areas in the veins. Molybdenite, on the other hand, is not confined to those places where biotite formed, but is widely distributed and common along many tight joints where average rock temperature of the albite granite permitted chlorite to replace biotite. In "mud" seams the intimate mixture of chlorite and molybdenite suggests their contemporaneous deposition, although this age relationship cannot be definitely demonstrated. It is clear that molybdenite was deposited not only under conditions in which biotite was stable but also under conditions more favorable for chlorite. With biotite an indicator of high, and chlorite of low temperature, it is apparent that molybdenite was deposited through a relatively wide range of temperature. Such a wide range of temperature is readily explained if we assume the initially hot solutions were quickly cooled, except in the vicinity of the larger openings, as they moved along a somewhat poorly developed system of veins in a relatively cool rock.

Molybdenite has long been regarded as a characteristic high-temperature mineral chiefly because of its occurrence in pegmatites. There is also considerable evidence, generally overlooked, against this idea. The deposit at Climax, Colorado, is regarded as having formed[14] at intermediate temperature. Association of molybdenite with copper minerals deposited at intermediate temperature is well known and its occurrence in the Cripple Creek area with tellurides formed at low temperature has also been described.[15] The "Questa" deposit, therefore, exhibits no new temperature relationships. In most deposits of molybdenite a limited range of temperature is shown, while at "Questa" a rather wide range in temperature is represented.

CONCLUSION

The molybdenite deposit near Questa is unique in the production of so large a quantity of the mineral from veins. Structurally the veins are not unusual in size, number, or general habit; they resemble veins in which ores of other metals are found. The occurrence of commercial quantities of molybdenite in such veins, however, is out of the ordinary. This type of occurrence, regardless of the kind of ore,

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[14] Butler, B. S., and Vanderwilt, John W., The Climax molybdenum deposit of Colorado: Colorado Scientific Society Proceedings, vol. 12, No. 10, p. 349, 1931. Also U. S. Geol. Survey Bull. 846-C, pp. 233-6, 1933.

[15] Lindgren, W., and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, pp. 172, 193-5, 225, 484, 1906.

never permits of an accumulation of very large ore reserves, and such has been the history at "Questa"; development and mining have proceeded almost simultaneously. In spite of this condition the quantity of molybdenite produced from a single deposit is, to the end of 1934, the second[16] largest in the world. The interpretation based on geologic study in 1934 indicated that an additional production could be expected, and development through 1937 promises a further substantial production.

A full appreciation of the type of occurrence and the character of mineralization associated with the molybdenite deposit near Questa is not only of general interest to mineralogists, but also may be of much practical value to geologists and mining engineers. Conceivably it may be an aid in the recognition of worth-while prospects among the numerous occurrences of molybdenite. Until recent years molybdenite has been regarded as a pegmatite, or at least a high-temperature, mineral. The search for commercial deposits has undoubtedly been influenced, both consciously and unconsciously, by this view. The conditions at "Questa" bring out very clearly the fact that molybdenite has formed in commercial quantities under conditions in which relatively low-temperature prevailed. This fact, more or less overlooked in the past, furnishes a broader and more nearly correct understanding of the range of occurrence of molybdenite, and should aid in the search for commercial deposits. It is not to be expected that most of the known occurrences of molybdenite have not been correctly evaluated; many are obviously only of mineralogic interest. Nevertheless, it seems possible that a few occurrences, condemned under the older view, will appear more hopeful when considered in the light of the conditions under which molybdenite occurs near Questa. The validity of this thesis cannot be proved or disproved by further theoretical consideration; it requires actual application in the field.

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[16] Since 1934 production of molybdenite, as a by-product of copper, at Cananea, Sonora, Mexico, and since 1936 at Bingham Canyon, Utah, have each annually exceeded the production at "Questa."