# CONTACT-METAMORPHIC TUNGSTEN DEPOSITS OF THE UNITED STATES.

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## INTRODUCTION.

*Production of tungsten ores in the United States.*—For years the United States has been not only one of the largest producers of tungsten concentrates but the largest producer of scheelite and ferberite, and in 1918 it was by far the largest producer of tungsten concentrates from contact-metamorphic deposits. Of the 5,061 short tons of concentrates carrying 60 per cent of tungsten trioxide ($WO_3$) produced in this country in 1918, 2,734 tons was scheelite, and of this scheelite 1,427 tons was obtained from contact-metamorphic deposits, a quantity equaled by the total output of only a few other countries. The quantity would probably have been increased materially had not the price of tungsten fallen after the signing of the armistice. Our total output of tungsten in 1918 was, however, less than half the output of wolframite from the Chinese placers (including a small quantity from veins), probably equivalent to more than 11,200 tons of concentrates carrying 60 per cent of tungsten trioxide.

*Definition.*—Contact-metamorphic tungsten deposits have been formed through the combined action of the heat and solutions emanating from a cooling intrusive granitic magma on limestones and the other intruded rocks and to a less extent on the granitic rock itself, by which the rocks are altered to or replaced by an aggregate of garnet, epidote, diopside, quartz, calcite, scheelite, and other minerals. Most deposits of this class are at or very near the contacts, and they clearly represent replacement of the limestones and other rocks. The tungsten mineral of such deposits is invariably scheelite.

*Distribution.*—Most of the known contact-metamorphic tungsten deposits in the United States are in the Great Basin region in California and Nevada and northwestern Utah, but Oregon, Arizona, and New Mexico are known to contain one deposit each, and it is probable that other such deposits will be found in widely different parts of the country, as prospectors and geologists have only recently learned that material so unpromising looking as nearly all the contact-metamorphic tungsten ore may carry the difficultly detectable scheelite in paying quantities. Indeed, the scheelite in the Oregon and Arizona deposits was first found by Mr. Larsen, after a systematic search, although both deposits were being exploited for other metals. Adolph Knopf found scheelite in contact-metamorphic material he had collected on Cape Mountain, back of Cape Prince of Wales, Alaska.

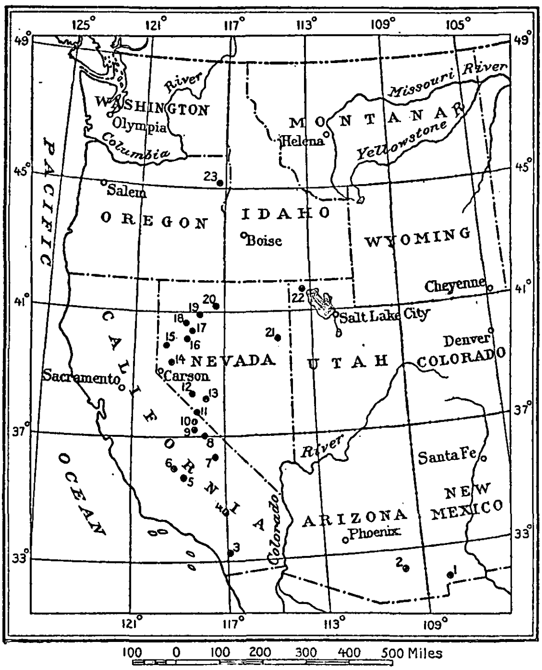



FIGURE 38.—Map showing distribution of the contact-metamorphic tungsten deposits in the United States. 1, Hachita, N. Mex.; 2, Johnson, Ariz.; 3, Aguanga, Calif.; 4, Morango district, Calif.; 5, Weldon, Calif.; 6, Glendale, Calif.; 7, Darwin, Calif.; 8, Bishop, Calif.; 9, Pine Creek, Calif.; 10, Benton, Calif.; 11, Queens, Nev.; 12, Hawthorne, Nev.; 13, Mina, Nev.; 14, Churchill Butte, Nev.; 15, Nightingale Mountains, Nev.; 16, Toy, Nev.; 17, Toulon, Nev.; 18, Lava Beds, Nev.; 19, Mill City, Nev.; 20, Golconda, Nev.; 21, Ruby Range, Nev.; 22, Lucin, Utah; 23, Joseph, Oreg.

The distribution in the western United States of the tungsten deposits of this type known to the writers is shown in figure 38. The chief producing districts are on the eastern slope of the Sierra Nevada near Bishop, Calif.; in the Eugene Mountains near Mill City, Nev.; and in several ranges near Lovelocks, Nev.

*History of mining.*—The first contact-metamorphic tungsten deposit discovered and worked in this country was near Lovelocks, Humboldt County, Nev. The property was located in 1908 for silver, but an assay showed scheelite and no silver. The Atolia Mining Co. acquired the property, forming the St. Anthony Mines Co., but only prospecting and development work was done until 1915. With higher tungsten prices a mill was built and work was carried on actively until the early part of 1917, when, owing to the apparent exhaustion of the ore and to the decrease in the prices of tungsten, the property was closed and later turned over to lessees.

In August, 1913, an unsuccessful attempt was made to develop a deposit in Ruby Valley, Elko County, Nev., and in the same month the now well-known deposits near Bishop, Calif., were discovered by J. G. Powning[1] through the finding of scheelite in gold placers. The unusual form of the deposits did not readily attract capital, but owing to the high prices paid for tungsten early in 1916, the Standard Tungsten Co. and the Tungsten Mines Co. acquired groups of claims and rushed work on mills, so that the former was operating a mill with a capacity of 30 to 50 tons of ore a day within 60 days and the latter a 300-ton mill within 76 days.

The building of these mills directed the attention of prospectors and investors toward the contact-metamorphic scheelite deposits, and early in 1916 others were located southwest of Lovelocks, Nev., where a mill was built by the Humboldt County Tungsten Mines & Mills Co. Other claims were located west and north of Lovelocks; in the Nightingale Mountains, east of Lake Winnemucca; in the Juniper Range west of Granite Spring Valley; in the Pahsupp Range; near Joy; on the west side of Smoky Valley; around Mount Osgood, north of Golconda; in the Eugene Mountains near Mill City; and in other places. Two modern mills were erected in the Eugene Mountains in the summer and fall of 1918 by the Nevada Humboldt Tungsten Co. and the Pacific Tungsten Co., and one on Pine Creek, 18 miles northwest of Bishop, Calif., was completed by the Pine Creek Tungsten Co., after the signing of the armistice. In Utah a small mill was erected in the Grouse Creek Mountains. Altogether 10 mills of different kinds have been erected at contact-metamorphic tungsten deposits. There are, however, other deposits which are yet to be exploited.

## GENERAL GEOLOGY.

### SITUATION.

The contact-metamorphic tungsten deposits are nearly all at or near the contact between a body of granular quartzose intrusive rock and other rocks, chiefly limestones. However, as will be shown later, their relation to the contact is not everywhere so intimate as their name implies. It is an interesting and significant fact that a considerable number of the more valuable deposits lie about small outcrops of granitic rock—many of them less than a mile across—surrounded by the older rocks. In a number of the districts there are several of these small outcrops of granitic rock close together, and the relations show clearly that there is a much larger body beneath and that erosion has removed the overlying rock only locally.

[1] Knopf, Adolph, Tungsten deposits of northwestern Inyo County, Calif.: U. S. Geol. Survey Bull. 640, pp. 229–249, 1917.

## THE INTRUSIVE ROCKS.

The intrusive rocks associated with the deposits everywhere appear to be siliceous or rarely of intermediate character, and without exception they carry some orthoclase and free quartz. In most places the intrusive rock is granodiorite, the most common and abundant granitic rock in the western United States. Granite, soda granite, quartz diorite, and quartz-bearing pyroxene diorite are locally associated with the deposits. Biotite and hornblende are the chief dark minerals of the rocks, and titanite is commonly abundant; rarely pyroxene is the chief dark mineral. The contact metamorphism appears to be associated with the general batholithic intrusion rather than with any particular phase of the intrusive rock, for in some places where two distinct granitic intrusives are in contact with the sediments the ore is present without essential change at or near the contact of both granitic rocks.

## THE SEDIMENTARY ROCKS.

The sedimentary rocks from which the ores are derived are nearly all limestone or dolomite. In some places the limestone is in thin beds intercalated between other sediments, as at Mill City, Nev.; in other places limestone makes up most of the beds for a thousand feet or more in thickness, as at Pine Creek, near Bishop, Calif. The ore may replace any limy bed that is intruded by granitic rock, and contact-metamorphic scheelite has been found in rocks that are probably of pre-Cambrian age [2] and in rocks of Upper Triassic age near Mill City, Nev. The character of the rocks, especially the limestones, both before and after metamorphism, their thickness, their age, and their relation to other rocks vary greatly.

## CONTACT METAMORPHISM.

### GENERAL FEATURES OF THE PROCESS.

When a large body of hot, molten igneous rock invades other rocks, especially carbonate rocks, under a more or less thick cover, the heat and the emanations from the molten magma cause a series of changes in the invaded rocks and also in the invading rock itself. The most pronounced changes are ordinarily those which take place close to the contact of the invaded and the invading rock, and so the process is commonly called "contact metamorphism." The metamorphism proceeds in zones, which show less noticeable alteration as they are farther removed from the contact or the channels along

[2] Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, Calif.: U. S. Geol. Survey Prof. Paper 110, pp. 24–25, 1918.

which the solutions move. The process is one of solution, the formation and deposition of new minerals, and the emigration of some old minerals, carried on by moving gases or liquids, the heat from the molten magma greatly increasing the solvent power of the solutions and consequently the interchange of minerals, and the degree of heat probably largely determining the kind of minerals deposited. There is, however, a great difference in the quantity of the solutions accompanying a magma, or, in a word, its wetness, and in the material carried in solution, both in kind and in quantity. The solutions naturally follow along cracks or other open spaces in the igneous rock, in the sediments, and between the two, and not uncommonly tabular or less regular bodies thus deposited extend along a certain bed of limestone or along a fracture that cuts across the beds for several hundred feet or even several thousand feet from the contact. Some deposits of the same character show no visibly close relation to any granitic body. At the same time the solutions may form veins and the metamorphism may spread from them.

The chief minerals of the contact-metamorphic scheelite deposits are different from those of most other mineral deposits, comprising the silicates garnet, diopside, epidote, vesuvianite, and hornblende. Quartz, calcite, and both potash and magnesian micas are common; and pyrite, chalcopyrite, pyrrhotite, molybdenite, sphalerite, magnetite, hematite, fluorite, zeolites, and a large number of other minerals are present in some deposits. It is noteworthy that in the many scheelite-bearing contact-metamorphic deposits examined no boron minerals and, except in one, little original hematite or magnetite have been found.

In places the miners refer to the material of these deposits as garnetite, and for many deposits the term is appropriate, but it does not cover those deposits in which garnet is almost or wholly absent. Its use, however, shows the need of a single word by which to designate these products of contact metamorphism, and the word "tactite" (from the Latin tactus, touch), which has been coined for the purpose, will be used in this paper.[3]

## SIZE AND FORM OF THE DEPOSITS.

### GENERAL FEATURES.

The size and form of the contact-metamorphic deposits depend chiefly on the size and form of the sedimentary and intrusive bodies, the quantity and character of the solutions accompanying the intrusive, the fractures in both the sedimentary and the intrusive rock at the time of the metamorphism, the relative susceptibility of cer-

[3] Hess, F. L., Tactite, the product of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 48, pp. 377–378, 1919.

tain beds or bodies to metamorphism, and the structure of the sedimentary rocks. Owing to the presence of fractures, which afford channels for the emanations, the metamorphism is not uniformly distributed about the intrusive contact; large bodies of metamorphic rock may occur near one part of the contact, while only a few yards away there may be none. Likewise chunks of limestone may be wholly immersed in the intrusive mass and be only slightly metamorphosed.

Although there is a great difference in the variety of minerals found in the deposits, and garnet, epidote, clinozoisite, calcite, pyrrhotite, gray muscovite, hornblende, or diopside may be the prevailing mineral, yet there is a family resemblance that almost invariably allows immediate recognition of the mixture as a product of the contact metamorphism of limestones.

### METAMORPHISM OF SMALL INCLUSIONS OR ROOF PENDANTS.

Small inclusions or roof pendants of sediments are likely to be tabular in form, with their greater dimensions parallel to the bedding planes. Such bodies are favorable for metamorphism on account of the nearness of so great a proportion of their material to the granite, but, on the other hand, they may offer less favorable channels for the passage of solutions, and it has been observed in a number of places that very small limestone inclusions near a larger body are but slightly replaced, though the larger body is replaced in greater part. Bodies of limestone of small or moderate size may be completely replaced, or the parts next to the contact may be replaced, as shown in figure 39 (p. 266), or the replacement may follow a certain bed or be less regular. Where limestone is interbedded with slate or sandstone the replacement occurs along the beds of limestone, as shown in figure 40 (p. 272). It is not possible to forecast the size or form of the inclusion beneath the surface, but, unless some features of the exposures indicate otherwise, the most reasonable supposition is that the included blocks are of various size and shape but tend to be tabular parallel to the bedding of the sediment, and that they are arranged in the granite without system except for a tendency toward a parallel arrangement of the tablets. Tactite is resistant to erosion, and flat-lying bodies tend to form flat, broad outcrops that give a much exaggerated impression of their size. (See fig. 45, p. —.)

### ALTERED PORTIONS OF CONTINUOUS BEDS.

Where the intrusive rock is in contact with a large body of sediments the tactite may follow the contact rather regularly, it may replace certain beds in the sediments, or it may follow fissures cutting across them.

One of the largest and most striking of the deposits along a contact is at the head of Pine Creek, about 30 miles west of Bishop, Calif. (See Pl. XII, p. 273.) It is an interesting fact that only a few hundred feet to the south of the broadest part of this deposit the granodiorite and the limestone are in contact, with little, if any, intervening contact-metamorphic rock. The outcrop of this deposit is much like the outcrop of a vein; and as the limestone is a large body and the tactite body is long, the deposit probably attains a considerable depth.

Certain beds in a thick series of limestone may be replaced, as in the deposit on the Summerfield lease, near Mina, Nev. A typical deposit, in which comparatively thin limestone layers interbedded with slates are replaced, occurs at Mill City, Nev. Both of these deposits are described on succeeding pages. Some deposits that are chiefly of scientific interest, although they may locally become of importance, follow and branch from fissures cutting across the beds. In all contact-metamorphic deposits the position and extent of the mineralization will depend both upon the structure of the sediments and upon the relation of the sediments to the granite, and careful geologic work is essential to their understanding.

### ZONES OF METAMORPHISM.

The contact-metamorphic material is arranged in zones of different character either across the contact or, for the bodies not closely related to the contact, across the fracture or other opening through which the solutions moved. In many deposits the granite itself is somewhat metamorphosed; next to the contact on the limestone side is the main body of metamorphic material, characterized by dark-colored silicates with a moderate quantity of iron; beyond this is a zone of light-colored silicates and finally the main body of marble with more or less light-colored silicates. In general the altered granite tends to merge into the zone of dark-colored silicates, but the zones of light and dark silicates in the limestone are commonly rather sharply separated, and the zone of light-colored silicates tends to merge into marble.

#### ALTERED GRANITIC ROCK.

The zone of altered granitic rock wherever seen is very much narrower than the main zone of dark silicates, and it is not everywhere present.

The altered granite is generally much more highly siliceous than the rock in any of the other zones and is made up mostly of quartz with subordinate dark silicates. These dark silicates increase in amount toward the contact, and the material thus tends to merge into that of the dark-silicate zone, on the limestone side of the contact. The silicates of the altered granite are everywhere similar to those of the adjoining dark-silicate zone, although garnet is commonly less abundant. Thus, if the dark-silicate zone is made up mostly of garnet and diopside the altered granite consists of quartz with pyroxene and a little garnet, and if epidote characterizes the dark-silicate zone it is also the principal dark mineral in the altered granite but is of darker green. The accessory minerals apatite, zircon, and titanite remain in the altered granite.

#### ZONE OF DARK SILICATES, THE TACTITE.

In the deposits examined the zone of dark silicates, the tactite, is everywhere much wider than the metamorphosed part of the igneous rock and is in most places apparently wider than the zone of light-colored silicates. In the thin limestones the tactite in many places occupies the full width and there are only patches of the lighter-colored minerals. The comparative widths of the respective zones undoubtedly vary in accordance with the composition and quantity of the metamorphosing solutions and the texture and purity of the limestones. The contact between the tactite zone and the zone of light silicates wherever observed is fairly sharp.

The composition and texture of the tactite are variable, and any individual mineral may be present in large or small quantity or in large or small particles. The quantity of iron in most tactite deposits examined is moderate. In three it was high, and in a few it was low. Garnet is usually the dominant mineral; in a few deposits epidote or its colorless or nearly colorless form clinozoisite is dominant. In many it is second to garnet, and in some it is subordinate or scarce. A pyroxene between diopside and hedenbergite is common and in a few deposits is much more plentiful than the epidote. Such deposits also contain garnet and as a rule are rather uniform in both texture and mineral composition. Dark-green hornblende, largely uralitic (derived from pyroxene), is common and is one of the chief minerals in some deposits. Pyrrhotite is the dominant mineral in a deposit at Glennville, Calif. Pyrite is abundant in the deeper workings near Mill City and on the east side of the Nightingale Range, Nev., and has been observed in other deposits. It is probably much more abundant below the zone of oxidation, but few of the deposits have been opened to that depth. Calcite and quartz are everywhere present in some quantity, the calcite usually the more plentiful; phlogopite, muscovite, and fluorite are abundant in a few deposits. Titanite (sphene) is an unusually common mineral in some deposits and titanite and apatite are present in all. Chloropal forms numerous greenish-yellow veins as much as an inch wide and occurs as an alteration product of diopside. Sphalerite, chalcopyrite, molybdenite, galena, bismuthinite, feldspars, scheelite, zeolites, and chlorite generally occur in small quantity, though laumontite, one of the zeolites, is conspicuous in deposits on the east side of the Nightingale Range, Nev., and elsewhere. The tactite zone is the chief host of the scheelite, though much tactite carries only a trace of scheelite.

Neither axinite nor tourmaline was observed, though axinite occurs in large quantity in some of the Nevada tactite in which scheelite has not been found,[3a] and tourmaline is common in the Yerington contact-metamorphic copper deposits.[3b]

Vugs are common in the tactite and may be lined with quartz crystals as much as a foot long. In a number of deposits there are caves of irregular size and shape, some of which are large enough to allow a man to walk upright in them. These caves are merely large vugs and are situated in the midst of the highly metamorphosed rock. They have many crystals projecting into them and were therefore formed at the time of the metamorphism. Some vugs, as those in the Grouse Creek Mountains, Utah, after forming were filled with quartz.

### ZONE OF LIGHT-COLORED SILICATES.

The zone of light-colored silicates, as already stated, varies much in width and grades into the zone of marble that forms the outermost part of the contact-metamorphic aureole. The commonest silicates are tremolite and wollastonite, followed by colorless diopside, scapolite, alkali feldspar, quartz, and vesuvianite; colorless garnet is less common. In this zone pyrite is rare, scheelite is unknown, and calcite is abundant. At Bishop, Calif., and some other places the material of this zone is granular and friable and is made up mostly of pale-green vesuvianite. There is an apparent tendency for those minerals that have a notable elongation in one direction to stand at right angles to the edge of the tactite or to a bedding plane in the limestone. The silicate minerals of this zone are about the same as those disseminated in the marble, and those in the lenses and nodules of silicate minerals that are scattered through the marble at some distance from the contact.

### MARBLE.

The marble is mostly granular calcite, with scattered grains or bunches of the minerals found in the zone of light-colored silicates. Some of the bodies of silicates are of considerable size, and commonly

[3a] Schrader, F. C., A reconnaissance of the Jarbidge, Contact, and Elk Mountain mining districts, Elko County, Nev.: U. S. Geol. Survey Bull. 497, pp. 114–115, 1912 (deposits at Contact). Ransome, F. L., Notes on some mining districts in Humboldt County, Nev.: U. S. Geol. Survey Bull. 414, p. 64, 1910 (deposits at Coppereid).

[3b] Knopf, Adolph, Geology and ore deposits of the Yerington district, Nev.: U. S. Geol. Survey Prof. Paper 114, p. 33, 1918.

they are of lenslike form along the bedding planes or cracks. No scheelite has been observed in this zone, although in some places quartz veins carrying scheelite may cut the marble or lie along its bedding planes.

## PROGRESSION OF THE CONTACT METAMORPHISM.

The evidence is clear that in many of the deposits, at least, the minerals were not deposited contemporaneously, but that one followed another in a regular order. In places there appears to have been a progressive change in the minerals formed, as at Hawthorne, Nev., where garnet was first deposited without diopside-hedenbergite, but later diopside-hedenbergite appeared and gradually increased in amount. In other places there is evidence of a break in the deposition, and the later minerals either replace earlier ones or fill in veinlets or cracks across them. In most deposits the hornblende replaces pyroxene; and epidote commonly replaces calcite, garnet, and diopside or fills in veinlets or cracks.

In the Pine Creek deposits near Bishop the earliest result of mineralization was the garnet-diopside-fluorite-calcite-quartz rock, with some scheelite. This rock was shattered, and the blocks were recemented by the deposition of vesuvianite and feldspar. Lenses of quartz carrying scheelite followed, and still later solutions arose along fractures and altered the pyroxene to quartz and calcite and deposited rather abundant sulphides, chiefly pyrite and molybdenite. Bodies of the zeolite laumontite replaced the calcite of some of the marble, and tiny veinlets of prehnite and epidote were later phases of the metamorphism.

Southwest of Hawthorne the main change was a replacement of the limestone by massive garnet. The resulting garnet rock was much shattered, and the fractures were filled with darker crystalline garnets, diopside, quartz, and abundant scheelite.

In general, garnet was one of the first minerals to be deposited, diopside was in part contemporaneous with the garnet and in part a little later. Epidote was somewhat later. The sulphides were still later and are associated with quartz and calcite or with the decomposition of the diopside and epidote. Hornblende was formed later than the epidote and is in large part derived from the pyroxene. Quartz and calcite were deposited throughout the metamorphism and fill spaces around the garnet, diopside, and epidote and occur as veinlets cutting the other minerals. Scheelite was also deposited throughout except possibly in the latest stages of the metamorphism, as it is found intimately associated with the garnet, diopside, and epidote and also in quartz or calcite veinlets that cut the normal tactite. The time relation between the zones of dark and light silicates is not entirely clear. In many places the wollastonite and tremolite of the former zone grow out from the walls of the zone of dark silicates, and in the Bishop district veinlets of vesuvianite were observed to cut the normal tactite. Owing to the greater tendency of some minerals than of others to take on crystal form and also owing to readjustments of circulation the relative ages of the minerals are not everywhere clear.

### CAUSES OF THE METAMORPHISM.

*Scope of discussion.*—Some details of the causes of metamorphism have already been given, and no general discussion of the causes of contact metamorphism or of other purely theoretical considerations will be undertaken here, but some of the results of the field and office study that bear especially on this type of contact metamorphism and on the tungsten deposits in particular require a brief discussion. The relative importance of the heat from the magma and of moving solutions, the source and character of those solutions, and the movement of the solutions are important scientifically and especially economically, for they influence the character and distribution of the ore deposition.

*Relative importance of heat from the magma and the movement of solutions.*—The mineral assemblage in these deposits and their close association with the contacts of large intrusive bodies show clearly that a fairly high temperature must have prevailed at the time of their formation. While magmatic heat is a necessary condition for the formation of the contact tungsten deposits, it is not of itself adequate, and solutions emanating from the magma but with additions from the heated rocks next to the magma must also be postulated to explain the large change in the composition of the rock on metamorphism, the erratic distribution of the deposits about the contacts, and the thin tabular bodies that extend for hundreds or even thousands of feet from the contact along certain beds or along fractures that cut across the bedding. Indeed, the movement of solutions through the rocks is clearly the dominant factor that determined the distribution of the deposits, and mere transference of heat by conduction was relatively unimportant. The chief work of the moving solutions was (1) to carry the heat from the magma into the adjoining rock and thus raise the temperature of the rocks adjacent to the passageway for the solution, (2) to remove material from the contact zone, (3) to carry mineral material from the magma or adjacent rock to the contact bodies and there deposit it, and (4) to bring about a recrystallization and rearrangement of the materials in the contact zones.

*Origin and character of the moving solutions.*—The solutions were originally squeezed from the molten magma during the process of cooling and crystallization. As they moved through the invaded rocks they exchanged part of their load for other molecules, and thus great quantities of lime and carbon dioxide were removed, and new minerals replaced the carbonates and other materials of the sediments. The temperature of formation of some garnets was probably below 800° C., for the garnets are generally birefringent, and H. E. Merwin [3c] has shown that if heated to 800° C. for a few hours the birefringent garnets from Kasaan Peninsula become isotropic. The temperature of the solutions was possibly above the critical temperature of water, and the solutions may have been very different from ordinary aqueous solutions.

The solutions that caused the first stage in the metamorphism and changed comparatively pure limestones to rocks made up mostly of garnet and epidote (including clinozoisite) or garnet and diopside-hedenbergite, all with moderate iron content, together with some quartz, calcite, muscovite, scheelite, apatite, titanite, fluorite, and other minerals, must have carried much silica, considerable iron and alumina, some tungsten, titanium, phosphorus, potash, and in places fluorine, chlorine, and other elements, and possibly considerable carbon dioxide.

On Pine Creek, near Bishop, Calif., the later stages of the metamorphism are especially well shown. Here during the stage represented by veinlets of feldspar and vesuvianite the solutions must have carried more alkalies than during the earlier stages. The lenses of scheelite and quartz represent a third stage during which silica and tungsten trioxide were deposited together. The next stage recognized included the decomposition of the diopside to quartz and calcite, with the deposition of molybdenite, pyrite, and pyrrhotite. It represents a period during which conditions were decidedly different, as the change tended to be in the opposite direction from that of the first stage, and carbon dioxide was the chief constituent added. There was also an addition of sulphur, molybdenum, copper, and probably of silica. The zeolitization of the marble represents an addition of silica and water. During these later stages the changes probably took place at considerably lower temperatures, and it seems probable that in the deep zone carbon dioxide was being freed during the garnetization of limestone, and this carbon dioxide, rising to the upper, cooler rocks, broke down the earlier-formed minerals.

*Movement of solutions.*—The metamorphosing solutions were able to pass along the contact zone of the granitic rock and the sediments, along certain limestone beds, or along cross fractures in the sediments. Clearly the granitic rock next to the contact zone had

[3c] Quoted by Wright, C. W., Geology and ore deposits of Kasaan Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 87, p. 108, 1915.

solidified at the time of the metamorphism, and the solutions could not have come directly from that rock and caused the metamorphism of the adjoining rock, for the metamorphism of the granitic rock and of the sediments has such a relation to the contact as to require solutions rising along the contact. The contact zone would probably offer a favorable place for shattering during the adjustment of the rocks to their new positions and to differences in temperature between the magma and the comparatively cool sediments, and the recrystallization of the sediments and readjustments within them may have added to the shattering. During the later periods of mineral deposition the earlier tactite and adjoining granitic rock were in places much shattered, and the solutions flowed along the fractures. That the solutions altered certain thin beds in the limestones and not others may have been due to the chemical composition, texture, or porosity of the rock, to protective mud coatings, or to other conditions that can be determined only by special study.

## ECONOMIC FEATURES.

### GENERAL FORM AND TENOR.

In most of the deposits the ore bodies are comparatively short and wide and do not extend to any great depth. They are therefore cheaply mined by means of "glory holes." The deposits at Mill City, Nev., however, are beds between nearly vertical walls of slate, and they are therefore tabular and resemble vein deposits, but their extension both vertically and horizontally is closely connected with that of the granitic bodies. They have been explored to a depth of more than 500 feet. In the deposits near Bishop, Calif., the ore as mined and milled averages about or somewhat less than 0.5 per cent of $WO_3$; ore mined in the Mill City district averaged about 2 per cent of $WO_3$.

### MILLING PRACTICE.

Several of the mills built to treat the contact-metamorphic ores were hastily constructed to meet the special conditions arising from the high price of tungsten during the World War, and they consequently lacked economy of operation, and their recovery was not much over 50 per cent. Others were well built and well operated. Milling practice was gradually improved, and in the fall of 1919 most of the mills were being operated with a much larger recovery. The ores are mostly hard, though some are friable. The scheelite grains are generally of fair size, usually one thirty-second of an inch or more in thickness; here and there they are as much as 2 or 3 inches thick, but in other places they are almost or quite invisible in the rock. The scheelite easily breaks free from the gangue, but its tendency to slime causes considerable loss, and one of the problems in milling is to make as small a proportion of fines as possible.

The crushing is usually done with rolls, though ball mills are used. Most of the ore is crushed to 6 to 12 mesh, but some ore is crushed to 40 mesh. Careful sizing before concentration increases the recovery materially. The concentration is done mostly on shaking tables and vanners.

Probably the best practice and one that leads to a high recovery—reported to be 85 per cent or more—is that used at the mill at Toulon, Nev., and at the new mills near Mill City, Nev. In these mills a low-grade concentrate is made on the tables, and this is dried and raised to a high-grade concentrate by passing it under an electromagnet that removes the garnet. Some of the Mill City ores are high in sulphides, and these are removed by giving the concentrates a light roast before passing them under the electromagnet. Flotation was tried unsuccessfully.

## HINTS FOR PROSPECTING.

With tungsten at the present prices in the United States little prospecting for it is likely, but when the price again reaches a point where ore running from 0.5 to 1 per cent of $WO_3$ can be profitably mined systematic prospecting for bodies of contact-metamorphic tungsten ore will probably be again undertaken and should result in the discovery of new deposits in the California-Nevada area, and probably also in some of the adjoining States.

In prospecting for such deposits it should be remembered

1. That the deposits are at or near the contact between a granitic rock and a sedimentary rock, generally limestone.

2. That the zone about a rather small outcrop of granitic rock is especially favorable for ore, particularly where several small outcrops are close together and separated by sediments, indicating a large granitic body barely exposed by erosion.

3. That the ore may occur in small outcrops of sediments surrounded by granitic rock where erosion has probably removed a large part of the deposit, as in the Bishop type; or along an extended granite-limestone contact, as in the Pine Creek type; or in a thin bed between barren slates, as in the Mill City type, in which the deposit simulates a bedded vein and has a tabular form. Some of the tactites are resistant rocks and crop out conspicuously, as near Bishop; others are not so conspicuous and require more systematic search for their discovery.

The contact-metamorphic tungsten deposits are very different from vein deposits, and their location, size, form, and extent are determined by details of the geology of the district. A thorough knowledge of the geology of the deposits is thus of the greatest value in all stages of their development—in the location of the prospects, the opening up and estimation of the size and grade of the ore, and the taking out of the ore. Indeed, any large operator not himself a geologist would be well repaid by obtaining the regular advice of a competent geologist, whose judgment as to the probable location, size, and form of the ore bodies might save many times the cost of his services by the avoidance of useless work.

### ENRICHMENT.

No evidence of any solution and redeposition of tungsten has been seen in the contact deposits, and the scheelite is generally not altered even at the surface, though tungstite stains the scheelite in a few places. However, at the outcrops of a deposit considerable calcite and some other minerals have commonly been leached out, thus raising the grade of the surface ore. Leaching of any considerable degree extends only for a short distance from the surface.

### THE DEPOSITS.

The following brief preliminary description of the contact-metamorphic scheelite deposits in the western United States is based largely on long contemplated reconnaissance examinations made by the writers during 1917 and 1918, at a time that made them fit in with the investigations of the important war minerals conducted by the United States Geological Survey. The office study of the data and specimens collected is only partly completed. The districts are described in approximate geographic order, beginning at the southeast and going west and then north and east.

### HACHITA, N. MEX.

According to Lindgren,[4] scheelite occurs in "considerable quantities" in a typical contact-metamorphic deposit in the Apache No. 2 district, 6 miles south-southwest of Hachita, N. Mex. Here quartz monzonite porphyry has intruded bluish-gray limestones of gentle dip that are evidently of Paleozoic age. The limestone is metamorphosed irregularly for 200 or 300 feet from the contact through the series. In places the limestone is replaced by extremely coarse grained calcite, quartz, garnet, epidote, and hedenbergite. Locally magnetite, pyrite, and zinc blende appear in large masses, also chalcopyrite. One of the garnet masses was worked for silver chloride (cerargyrite) in earlier days, and the deposit has also been

[4] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 52, 55, 343–344, 1910.

worked for copper. Nothing is said by Lindgren about the mode of occurrence of the scheelite, and so far as is known no attempt to mine it has been made.

### JOHNSON, ARIZ.

The copper deposits of Johnson, Cochise County, Ariz., though apparently not closely related to any body of granitic rock, have the characteristics of the contact-metamorphic deposits and are no doubt of similar origin. They are associated with large bodies of tactite that replace beds of limestone. The geologic section of the district appears to be similar to that at Bisbee and Tombstone.[5] The structure appears to be rather simple and the beds dip about 30°-40° NE.

The tactite bodies are of large size and have been opened up for copper for more than 2 miles along the strike. Many of them are as much as 50 feet thick, and some are reported to be 300 feet across. They have been found at more than one horizon in the limestone beds and appear to replace thin beds of impure limestone. The chief mineral of the tactite is a brown garnet; vesuvianite is locally abundant; quartz and calcite occur in moderate amount; and actinolite, chlorite, apatite, epidote, titanite, biotite, albite, orthoclase, muscovite, magnetite, scheelite, and the sulphides sphalerite, pyrite, chalcopyrite, bornite, and chalcocite are less abundant. Molybdenite is rare. Between the tactite zone and the marble there is a few inches of rock made up of colorless diopside, more or less altered to tremolite.

Scheelite was first recognized in these deposits by Mr. Larsen in the summer of 1918 and was found in all parts of the camp. Tactite from the dumps of the mines commonly pans a trace of scheelite. The scheelite appears to be especially abundant in some of the rock carrying sphalerite.

In the short time at Mr. Larsen's disposal no large body of the tactite of sufficient scheelite content to be worked profitably was recognized, but the examination justifies some systematic sampling and panning for scheelite and warrants the recommendation that other bodies of tactite in Arizona be carefully examined for scheelite.

### AGUANGA, CALIF.

Bert Simmons, of Aguanga, Calif., has located several claims on contact-metamorphic deposits at the head of Chihuahua Creek, about 9 miles east of Aguanga post office, in Riverside and San Diego counties. The claims are readily accessible by road and trail from Oak Grove Valley, about 7 miles distant.

[5] Ransome, F. L., Some Paleozoic sections in Arizona and their correlation: U. S. Geol. Survey Prof. Paper 98, p. 134, pl. 25, 1916.

A considerable number of small bodies of more or less metamorphosed limestone included in a fine-textured granite have been located in an area of about a square mile, in the midst of a great area of granitic rocks. Some of these bodies are only a few feet across and of short but uncertain length; others are as much as 40 feet across and 200 feet long. Most of the smaller bodies are completely changed to lime silicate rock carrying scheelite, and the larger bodies have irregular cores of marble. The chief minerals of the tactite are quartz, brown garnet, calcite, epidote, and amphibole, with a little scheelite. The less metamorphosed limestone of the zone of light-colored silicates is made up of wollastonite, colorless garnet, diopside, calcite, titanite, and quartz. The surface rock is more or less porous and iron stained from the leaching of calcite and sulphides. Much of the best scheelite ore is in quartz-actinolite rock, some of which carries several per cent of scheelite.

The deposits have been only slightly prospected, and the natural exposures are not of the best. So far as can be judged from a hasty examination, however, there are some small bodies of ore of good grade, but as yet no ore bodies of large size are indicated. The claims certainly justify some surface trenching, sampling, and panning, and careful search may reveal larger bodies in this part of California.

## VICTORVILLE, CALIF.

### AREA NORTHWEST OF VICTORVILLE.

The earliest known description of an American contact-metamorphic tungsten deposit was that of Surr,[6] who described a deposit 15 miles northwest of Victorville, San Bernardino County, Calif. Here scheelite occurs with copper minerals in a limestone replaced by quartz, hornblende, and other minerals. The limestone is in contact with schists, which are cut by pegmatite dikes, but no granite was seen cutting the limestone. More than 1 per cent of $WO_3$ was found in some of the rock, but no exploitation for scheelite is known to have been undertaken.

### AREA SOUTHEAST OF VICTORVILLE.

In 1916 claims were located on contact-metamorphic scheelite deposits on the east side of the San Bernardino Range, 45 miles by road southeast of Victorville. The claims were acquired by the United Tungsten-Copper Mines, and stock was sold widely.

Over most of the distance the road to the deposits is good and can be traversed by automobiles without trouble. The deposits are on

[6] Surr, Gordon, Tungsten at Victorville: Am. Mining Rev. (Los Angeles), vol. 24, pp. 8–9, July 11, 1908.

the desert side of the range but are well up toward the top, and the hills are covered with a good growth of piñon. Water is scarce, however, and the camp is supplied by a small spring 100 or 200 yards away. The deposits are in a flat-topped spur jutting out toward the valley from the main range.

The country rock is fine-grained biotite granodiorite, in places gneissoid, intruded into limestone that had previously been marbleized by regional metamorphism. Close to the granite intrusions small volumes of the marble have been highly metamorphosed, and in places the granite also has been highly altered. The greatest thickness of metamorphosed rocks seen was not over 10 feet. The minerals are quartz, a gray mica, epidote, garnet, actinolite, clinozoisite, and calcite, with accessory apatite, titanite, pyrite, a bismuth mineral (now oxidized), and scheelite. In places the mass is a soft aggregate of minerals that are difficult to determine by visual examination alone, and these spots are apt to be the richest. There are masses of brownish or reddish garnet, but they carry almost no scheelite. The quartz in places carries scheelite grains half an inch in diameter. When examined (October 11 and 12, 1917, by F. L. Hess) the known ore bodies were very small. Some of the scheelite is almost clear, pure white, and is in rough crystals a quarter of an inch through. At a number of places were found greenish needles of bismuth carbonate, as much as three-quarters of an inch long and one-eighth of an inch thick.

On top of the hill, 1,000 feet above the camp, the granite along the contact is metamorphosed to a depth of 1 foot. It is almost wholly altered to dense dark yellowish-green epidote close to the contact; a few inches back it contains more quartz than epidote; and still farther back is merges gradually into unaltered granite. This rock contains no scheelite. At another point a small volume of the granodiorite is altered to a rock that is 75 per cent red garnet.

## GREENHORN MOUNTAINS, CALIF.

### GENERAL FEATURES.

The Greenhorn Mountains form a short range on the west side of the Sierra Nevada in Kern County, Calif. Contact-metamorphic deposits, two of which were described by Storms,[7] were found on the west side of the range in 1916, and some work has been done on several of them. They are peculiar in that in one deposit a mass of pyrrhotite 6 to 8 feet thick was encountered. The metamorphism is probably of the same age as the mass of granodiorite of the Sierra Nevada, which is presumably early Cretaceous.

[7] Storms, W. H., New scheelite discovery: Min. and Sci. Press, vol. 113, p. 768, Nov. 25, 1916.

## CLAIMS.

### JUNE IONE AND SWEET MARIE CLAIMS.

The June Ione and Sweet Marie claims, now known as the Rand group, in secs. 19 and 20, T. 25 S., R. 32 E., on Cedar Creek, contain contact-metamorphic scheelite. The claims are only a few hundred feet south of the main road. The Rand Mining Co. erected a small mill and worked the property until July 1, 1917, when it was transferred to Gus Schamblin, of Bakersfield. When visited in October, 1917, it was being worked under lease by Charles Guzman and associates.

The country rock is a light-colored quartz diorite, in which is inclosed a large fragment of limestone standing on edge and running directly north across the creek. The diorite carries both hornblende and biotite, and near the contact these dark minerals increase in quantity. The limestone apparently does not reach beyond the top of the hill on the south and is exposed for only about 35 feet on the north side of the creek.

On the south side of the creek an open cut about 20 feet deep and 6 to 10 feet wide had been made. The limestone has been altered to dark fine-grained tactite containing quartz, biotite, garnet, epidote, lime feldspar, and a few feet below the surface slightly magnetic pyrrhotite, a little pyrite, and a very little chalcopyrite. A few flakes of molybdenite have been found. The inclosing diorite also has been metamorphosed at the contact, so that it is difficult to identify.

There is also some rock that may be either a silicified aplite or a fine-grained quartzite. No growth of the quartz grains can be detected, as in most quartzites, and in the short visit no quartzite was seen at other places. The rock contains a good deal of biotite in small flakes.

A shaft 50 feet deep was sunk near the edge of the creek. It is said that some of the ore at the top carried 30 per cent of $WO_3$, but it dwindled in value downward and at the bottom yielded only a fraction of 1 per cent. Just below the top the gangue changed to almost solid pyrrhotite, with a little pyrite and a very little chalcopyrite. At the top the scheelite was in particles a quarter of an inch thick, but at the bottom they were not over one-sixteenth of an inch thick. The ore shoot was 30 feet long and 6 to 8 feet thick. The ore was very hard and difficult to work.

On the opposite (north) side of the creek some work has been done on a mass containing considerable garnet and less epidote, but no ore rich enough to pay for mining and milling was found.

Beyond the tactite wollastonite has been formed, and beyond that the limestone has been marbleized.

The mill was finished about June 1, 1917. It contained a 12 by 16 inch Blake crusher; Allis & Chalmers style C rolls; a screen 4 feet long by 3 feet broad, with 20 meshes to the linear inch; a Wilfley No. 3 table; an elevator; and a Marathon 20-inch mill. The concentrates were roasted and shipped to San Francisco for electromagnetic separation.

About 500 pounds of concentrates were produced in hand jigs. No ore was being taken from the deposit when visited, but the mill was being operated on ore from the Why Not claim.

### WHY NOT CLAIM.

The Why Not claim is about a quarter of a mile north of the June Ione, and the workings on it are 220 feet up the hill from the main road. The rocks at this point are covered with soil, so that little can be seen of them. J. R. Rogers found the tungsten-bearing rocks in 1916 by panning the dirt of the hillside. The tungsten-bearing rock is a rusty, spongy, friable mass of tactite, which, from the meager outcrops, seems to be faulted and cut by granitic dikes. Some of the rock composed of quartz and orthoclase appears to be pegmatite but may conceivably be a part of the metamorphosed limestone. Quartz, epidote, brown-red garnet, hornblende, and calcite could be recognized in the mass, and many small vugs partly filled with brown iron oxides showed where iron sulphides had weathered out. In some of the ore, although only a few feet underground, sulphides still exist. Part of the garnets were somewhat altered. Although a few pieces nearly half an inch across were found, very little scheelite could be seen in the ore, and mining was guided by panning. The excavation was about 15 feet wide. The ore was thought to carry about 0.75 per cent of $WO_3$.

For transporting the ore from the mine to the road an aerial tram had been made from a wire cable, on which were two carriers made from steel wheelbarrow bodies. The ore was hauled to the mill on the June Ione claim in a truck made from a Ford automobile.

### HERSCHEL KELSO CLAIM.

R. A. Brown, A. M. Kidd, M. W. Pollock, and George S. Seib had a claim named the Herschel Kelso at the head of Cedar Creek, near the middle of the north side of sec. 17, T. 25 S., R. 32 E., in the Sequoia National Forest, only a few hundred feet from the Summit Trail, on the top of the Greenhorn Mountains.

The claim was originally located for gold on a small patch of tactite, but later scheelite was found in the rock. The tactite forms a small hummock in the shallow depression at the head of Cedar Creek and at the outside is probably not over 100 by 200 feet in outcrop, and probably is smaller. The rock is mostly friable and rather fine grained. It is composed largely of epidote, with quartz filling interstices. There is some red-brown garnet, and parts of the rock contain a great deal of biotite in small radial flakes about one-sixteenth of an inch across. The scheelite is in grains one-thirty-second to one-sixteenth inch in diameter and is greatly crushed. The débris from a short prospect tunnel had slacked to a smooth pile of fine-grained material.

The ore is said to carry 2 per cent of $WO_3$. It must be packed by trail more than a mile to the road. Some had been taken to the Rand Mining Co.'s mill, and a small quantity was sacked ready for shipment. There is a small spring close to the deposit.

### CADILLAC CLAIM.

The Cadillac claim, owned by Mr. and Mrs. O. G. Wood, of Glenville, is on the North Fork of Cedar Creek about 2½ miles above the county road and is reached over a fairly rough trail. A man can reach it by following the creek, but this route is too difficult for a horse. This is probably the property described by Storms[8] as on Slickrock Creek.

The deposits are in a bank on the south side of the creek, which in the dry season is a small, trickling stream, and a face extending 30 or 40 feet above the creek has been exposed. A bulkhead 6 to 8 feet high was erected next to the creek, and efforts had been made to sluice the fine material.

The rock is very unevenly metamorphosed to epidote, quartz, and garnet. One small opening shows considerable pyrite. Scheelite is difficult to find in the rock, and Mr. Walton Van Winkle stated that panning tests made by him upon the deposit had given from 0.25 to 0.5 per cent of $WO_3$, but Mr. Wood is understood to claim that several times as much is present.

### WELDON, CALIF.

A number of claims on tungsten deposits of the contact type in the area just south of Weldon, Kern County, Calif., were visited in November, 1917, by E. S. Larsen. The greater part of the deposits are in the basin of Kelso Creek and are scattered along a belt a number of miles long. Weldon is about 46 miles by an excellent auto road from Caliente, on the Southern Pacific Railroad, and an automobile can be taken within half a mile of most of the deposits.

The prospects are near the contact between a large body of granite and granodiorite on the east and sediments on the west. The contact has the general north-south course of the bedding of the sediments,

[8] Storms, W. H., New scheelite discovery: Min. and Sci. Press, Sept. 25, 1916, p. 768.

and there is a considerable thickness of limestones in contact with the granitic rock. However, none of the prospects are along the main contact, but all are on small bodies of sediments surrounded by the granitic rock and within a mile or so from the contact.

The tactite has been derived mainly from limestones, which were interbedded with more or less shale and some quartzite. The chief minerals of the contact ore are quartz, calcite, pyroxene, amphibole, epidote, brown garnet, and nontronite or chloropal. The ore contains also some titanite, apatite, mica, feldspar, scheelite, chrysocolla, pyrite, chalcopyrite, and molybdenite. In the zone of light-colored silicates the chief minerals are calcite, tremolite, colorless garnet, colorless pyroxene, scapolite, leverrierite (?), mica, and apatite.

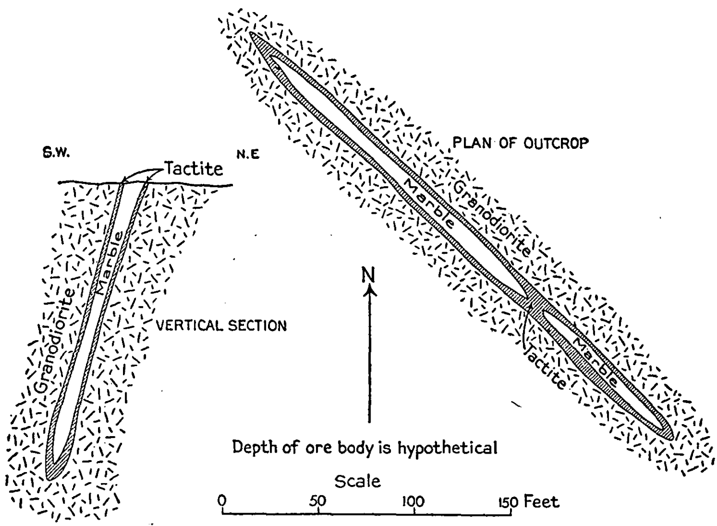



FIGURE 39.—Diagrammatic sections of the limestone inclusion and ore zone of the Tungsten King claim, near Weldon, Calif. The vertical section is hypothetical.

Most of the prospects are on very small included fragments of sediments, and the metamorphism has not usually extended far from the contact. Some of the bodies were dug out completely in prospecting and yielded only a few hundred tons of ore. Some bodies in the extreme northwestern part of the district, northwest of Weldon and west of the Kelso Creek drainage basin, appear to be rather small but of fair grade. One of these bodies, covered by the claim of A. B. Cohen, of Los Angeles, Calif., is a slab of limestone about 300 feet long and 12 feet across, which is changed to garnet tactite, some of it with a fair tungsten content, for a foot or two all around the contact, as shown in figure 39.

Just east of this are a number of claims owned by Joe Victor, of Isabella, Calif., located on a number of small bunches of garnet tactite ore of fair grade, mostly less than 20 feet across and a few times as long in outcrop, surrounded by granodiorite.

About 3 miles to the northeast are the claims of the Kelso Mining Co. They are equipped with a small mill and have made a small quantity of concentrates. The workings are scattered over an area about 300 feet in diameter and are on a number of rather small flat-lying inclusions in granite. The sediments are mostly hornfels derived from shales, with some metamorphosed limestone beds, and as they lie nearly flat their vertical extent is slight compared with their horizontal dimensions.

The largest body of tactite seen in the district is about 5 miles southeast of the claims of the Kelso Mining Co., and is covered by the claims of W. T. Stephens and Dave Creighton, of Mojave, Calif., and those of Citania Duarte and M. S. Hall. The inclusion is over 100 feet across and 1,000 feet in length and is mostly slates but carries a tactite layer that, where best exposed, is over 20 feet across. It appears to be of low grade but shows some scheelite.

On the whole, none of the prospects of this district are particularly promising, but larger bodies may be found, and the better-grade ore from a number of the prospects might be carried to a small, centrally located mill and treated at a profit under a war price for concentrates.

### KERNVILLE, CALIF.

Claims have been located about a mile and a half northeast of Kernville, Calif., on an included block of sediments, several hundred feet across, that consists mostly of schists and is intricately intruded by aplite, pegmatite, and granite. Some small beds of limestone are metamorphosed near the contact to material similar to that near Weldon. The bodies are of small size and show little scheelite, and nothing of promise was seen.

### AREA EAST OF OWENS VALLEY, CALIF.

The outcropping rocks of the mountains east of Owens Valley, Calif., are sediments ranging in age from pre-Cambrian to Triassic, with some volcanic rock and numerous bodies, comparatively small in outcrop, of granitic rocks intruding the sediments;[9] the conditions are therefore favorable for the development of contact-metamorphic tungsten deposits. However, little systematic prospecting has been done in the area for deposits of this type, and no valuable bodies have yet been opened up. In the course of other work during the summer of 1917 Mr. Larsen briefly examined tactite zones in this area about 2 miles southeast of Darwin; about 5 miles south of Darwin; near the head of Death Valley, about 13 miles southwest of

[9] Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, Calif.: U. S. Geol. Survey Prof. Paper 110, 1918.

Lida, Nev.; and about 18 miles northeast of Big Pine, Calif., a few miles north of Deep Springs Lake.

The deposit about 2 miles southeast of Darwin had been prospected a little and showed some small streaks of very good ore, but no large bodies had been exposed. The scheelite is in narrow, irregular seams cutting the rocks of the contact zone and is associated with pyrite, chalcopyrite, quartz, chalcedony, chrysocolla, calcite, calamine, and gypsum. Little scheelite was found disseminated in the contact rock itself, and the deposit is not a typical contact deposit.

The other deposits had not been prospected for scheelite, and in the hasty examination very little scheelite was found. They are along main contacts between granitic rocks and limestone, and some of the contact zones are of good size, but when tested they show only traces of scheelite.

## BISHOP, CALIF.

### GENERAL CONDITIONS.

The tungsten deposits near Bishop, Inyo County, Calif., are distributed along the eastern slope of the Sierra Nevada, mostly on the lower slopes and in the foothills called the Tungsten Hills, for a stretch of about 20 miles from a point near Big Pine to Round Valley. Similar deposits are known at the head of Pine Creek, about 10 miles to the west, and near Benton and Queens, respectively 30 and 40 miles to the north. The district contains three mines that are equipped with mills and have produced considerable quantities of concentrates. Two of these mines are on Deep Creek, and the third a few miles to the north, on the southern border of Round Valley.

The conditions for economical mining are very favorable, as the mines are on the border of a prosperous agricultural district, are reached by good roads, and are accessible to water and electric power. The relief at the mines is such that mining by open glory holes and short tunnels has been possible.

The tungsten deposits have been described by Adolph Knopf.[10] The following description is taken in part from his paper and in part is the result of later observations by E. S. Larsen in the summer of 1918, after the mines had been in active operation for two years.

### GEOLOGY.

The granitic rocks that make up the greater part of the district are chiefly an older quartz monzonite carrying both biotite and hornblende and a younger granite carrying only a little biotite. A quartz diorite that is a basic modification of the quartz monzonite commonly

[10] Knopf, Adolph, Tungsten deposits of northwestern Inyo County, Calif.: U. S. Geol. Survey Bull. 640, pp. 229–249, 1917.

borders the inclusions of sediments. According to Knopf,[11] "the present summits of the Tungsten Hills probably coincide roughly with the general levels of the batholithic contact of the granites and the rocks they invaded." Numerous bodies of older rocks ranging in size from small fragments to bodies 2,000 feet or more in length are scattered through the granitic rocks. These are probably in part included fragments and in part roof pendants—the remnants of irregular bodies that projected down into the granitic rock but were attached to the overlying roof, which has since been largely removed by erosion—and according to this interpretation, the Bishop deposits, in common with most of the other contact-metamorphic tungsten deposits, were formed at the apex or roof of the batholith rather than near the sides, in the deeper part of the batholith.

The included bodies are made up mostly of sedimentary rocks but in the northern part contain some andesitic volcanic rocks. The sediments were originally a series of interbedded limestones, sandstones, and shales. The limestones are now changed to marbles and lime silicate rock; the sandstones are changed to quartzites, carrying mica and in places sillimanite; and the shales are altered to hornfels and schists that locally carry andalusite.

### ORE DEPOSITS.

The greater part of the ore is the metamorphosed limestone or tactite, and the metamorphism is, as usual, irregular. Some of the larger bodies are completely changed to lime silicate rock, but some of the smaller bodies have only narrow, discontinuous borders of such rock. The chief rock of the lime silicate zone and by far the greater part of the ore is made up mostly of a dark-brown garnet, with more or less quartz, some epidote, and a little scheelite, apatite, and titanite. Locally epidote is the chief mineral, and while rock of this type has yielded some bunches of high-grade ore, it has furnished no important ore bodies. Some of the Deep Creek deposits contain an excellent ore made up mostly of quartz, epidote, green chlorite, and hornblende, but it is found only in small bodies. Some of the best ore in the Round Valley mine consists mostly of phlogopite mica, and ore at the Mineral Dome claim, to the south, carries much muscovite, biotite, and magnetite. Pyroxene, feldspar, vesuvianite, and the sulphides pyrite, pyrrhotite, chalcopyrite, sphalerite, and molybdenite are present. In places the scheelite appears to be associated with the sphalerite.

In the zone of light-colored silicates the chief minerals are quartz, calcite, colorless diopside, wollastonite, feldspar, colorless garnet, leverrierite (?), chlorite, vesuvianite, clinozoisite, and muscovite.

[11] Idem, pp. 232–233.

The granitic rock bordering the inclusions is commonly altered for a distance of 10 feet or less to a rock made up mainly of quartz, with pyroxene and epidote but apparently no scheelite.

There are some small bodies and bunches of ore that carry several per cent of $WO_3$, and it was the original plan of the operators to run their mills on ore averaging from 1 to 2 per cent, but it was soon found that the large bodies of ore averaged much less, and the average grade of the ore as milled was near 0.5 per cent.

## MINES.

### STANDARD TUNGSTEN CO.

The Standard Tungsten Co. milled about 37,000 tons of ore that carried an average of a little less than 0.5 per cent of $WO_3$. The greater part of this ore came from the Aeroplane mine, which is on the hill above and to the southeast of the mill. The ore came chiefly from a glory hole that is about 175 feet long at the outcrop and has an average width of 30 feet and a maximum width of 35 feet; its maximum depth is about 145 feet, and in vertical section it is rudely triangular with an apex of the triangle pointing down.

The workings are on an outcrop of sediments about 1,300 feet long, in the direction of the bedding, and 250 feet wide at its widest point, surrounded by granitic rock. The average strike of the beds is about southwest, but the strike is more to the south in the southern part near the glory hole; the dip is rather steep to the southeast. The inclusion is made up of interbedded quartzites and schists with limestone, now mostly metamorphosed to tactite. A generalized section near the glory hole from southeast to northwest gave 40 feet of quartzites and hornfels, 30 feet of tactite, 20 feet of quartzite and schist, 40 feet of tactite, and quartz diorite. The greater part of the limestone of this inclusion is altered to tactite, and some of the interbedded sandstones and shales are metamorphosed to similar fine-grained garnet-epidote rock. There are local bodies of marble. The intrusive rock to the west is the normal quartz diorite, but to the southeast is a body, rudely circular in outcrop and about 1,500 feet across, of a rather fine, sugary-textured soda-potash granite that appears to be distinctly older than the quartz diorite.

The glory hole is on the tactite bed near the southeast border of the body, and all the ore in sight has been removed, yet tactite similar to that of the ore but nearly barren continues below the workings and in both directions along the strike of the bed. The chances of finding more ore along this bed or in the tactite bed to the northwest do not seem unfavorable. Some small bunches of ore have been found a few hundred feet south of the glory hole. The ore of the Aeroplane was mostly a dense brown rock made up mostly of garnet, with scme quartz, calcite, and epidote, a little scheelite, apatite, and titanite, and a variable amount of amphibole, pyroxene, sphalerite, and pyrite.

Other workings of the Standard Tungsten Co. that furnished some ore are about 2,000 feet west of the Aeroplane, south of Deep Creek. This Deep Creek mine is on a body of sediments that is rudely lenticular in outcrop and is about 700 feet long and 300 feet across. It is made up mostly of quartzite and mica schist that strike about N. 60° E. and dip 50° SE. Two beds of limestone are present. One near the northwest contact is about 15 to 20 feet thick and furnished the ore; another, about 150 feet to the southeast, is somewhat thicker but is thin bedded and interbedded with micaceous schists. The limestone beds are marbleized but contain few introduced minerals. The ore was a body of tactite about 160 feet long, 100 feet deep, and 16 to 20 feet across, and nearly all of it was removed. It gave place along the bed to marble. It is reasonable to suppose that other parts of this bed and perhaps also of the bed to the southeast are altered to tactite ore; indeed, the lower part of the inclusion, where it breaks off in the granite, may be an especially favorable place for such ore.

About 1,000 feet southwest of the Deep Creek workings are those of the Greenhorn. These are on a body of sediments consisting mostly of quartzite and hornfels and less than 100 feet long. The ore body is small but of better grade than the average ore milled and is characterized by abundant quartz, amphibole, epidote, and chlorite. There is an unusually large body of the metamorphosed granite near these workings.

The Brockman workings are about 1,000 feet south of the Deep Creek mine and are on a small body of tactite about 100 feet long and 30 feet across.

A number of other inclusions of sediments are present in this area, but no large tactite bodies are exposed, and little ore has been produced from them.

### TUNGSTEN MINES CO.

The Tungsten Mines Co. milled more than 100,000 tons of ore averaging about 0.5 per cent of $WO_3$. Practically all of this came from the glory hole on the Little Sister claim, which is a few hundred feet west of the mill of the Standard Tungsten Co. This glory hole is about 280 feet long, nearly 100 feet across at its widest part, and about 150 feet deep; its west, northeast, and east walls are quartz diorite, and much of the southwest wall is barren tactite and marble. The bottom of the glory hole still shows ore. A photograph of the glory hole is shown in Plate XI. The ore body is in a mass of sediments about 250 feet across, surrounded by granite. (See fig. 40.) The northeast contact appears to be a fault contact, but elsewhere the contact is intrusive. The mass was originally mostly limestone, but it is now mostly tactite with some remnants of marble. The beds are about vertical and strike about northeast. A body of quartzite with much the same structure lies to the northwest. The ore body is tabular parallel to the bedding of the sediments. The ore is a compact brown tactite made up mostly of garnet with some quartz, calcite, and epidote and small amounts of other minerals; it rarely shows scheelite to the naked eye, and panning is necessary to distinguish ore from barren rock.

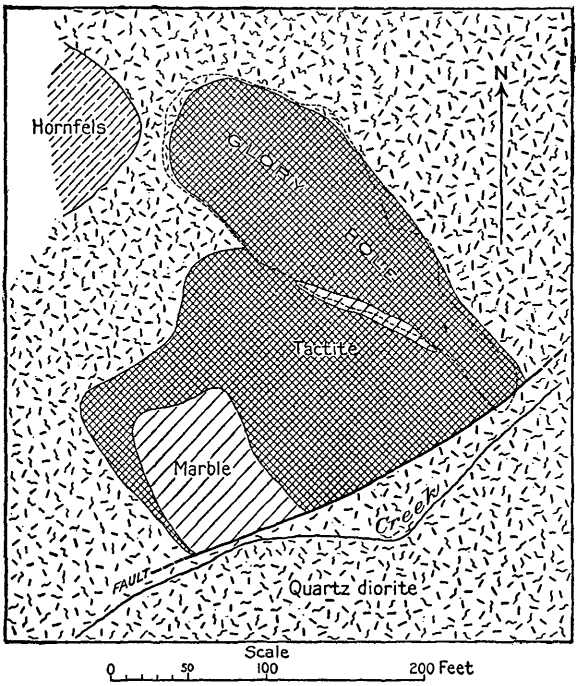
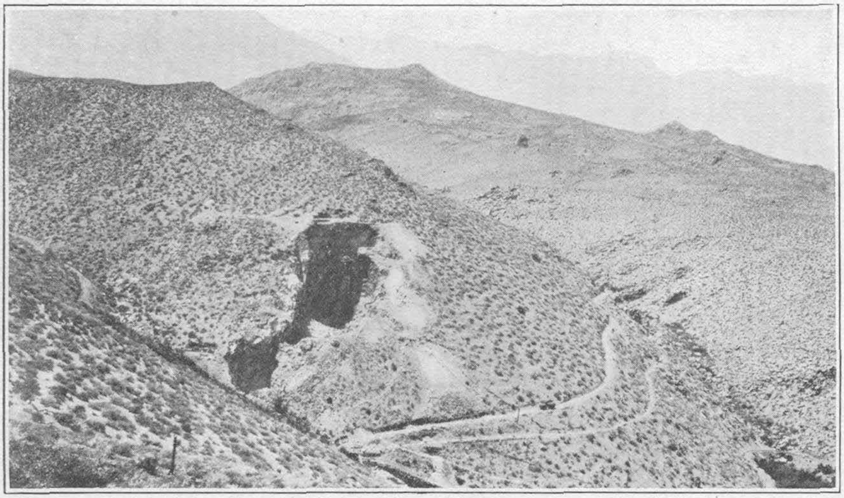



FIGURE 40.—Geologic map of area about Little Sister claim of Tungsten Mines Co., near Bishop, Calif. Shows the glory hole in July, 1918.

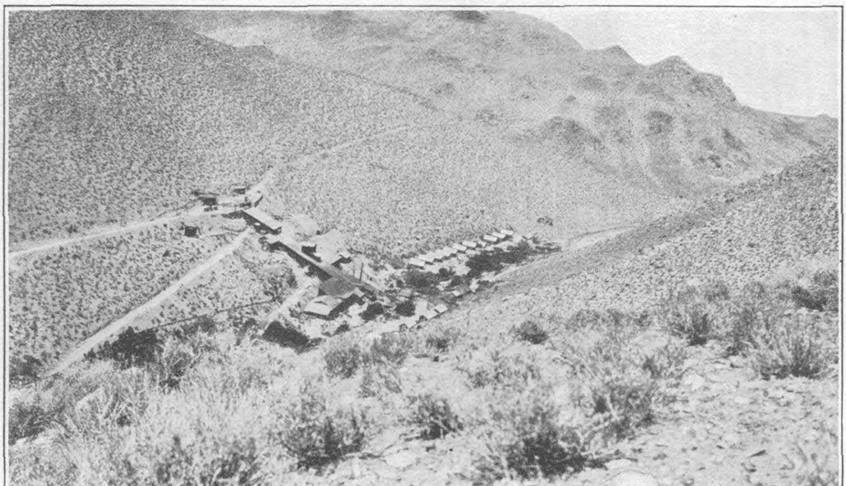
Southwest of the glory hole there are some smaller streaks that are of good tenor. At the time of Mr. Larsen's visit the company was planning to prospect the tactite body by diamond drilling, and the chances seemed good of finding more ore both along the present ore bed and in the large tactite body to the southwest. Of course, inclusions or roof pendants such as that carrying the ore body are not likely to go down to any great depth; indeed, they may end very abruptly, and the ore bodies will end with them.

The Tungsten Mines Co. has done some work on its Jack Rabbit claim, which is a short distance northeast of the Little Sister. The work is on a body of sediments whose outcrop is about 280 feet long and 80 feet in greatest width; it strikes nearly north and is about vertical. The rock carries more epidote than most of the ore; there is some good ore, but no large bodies have been found.

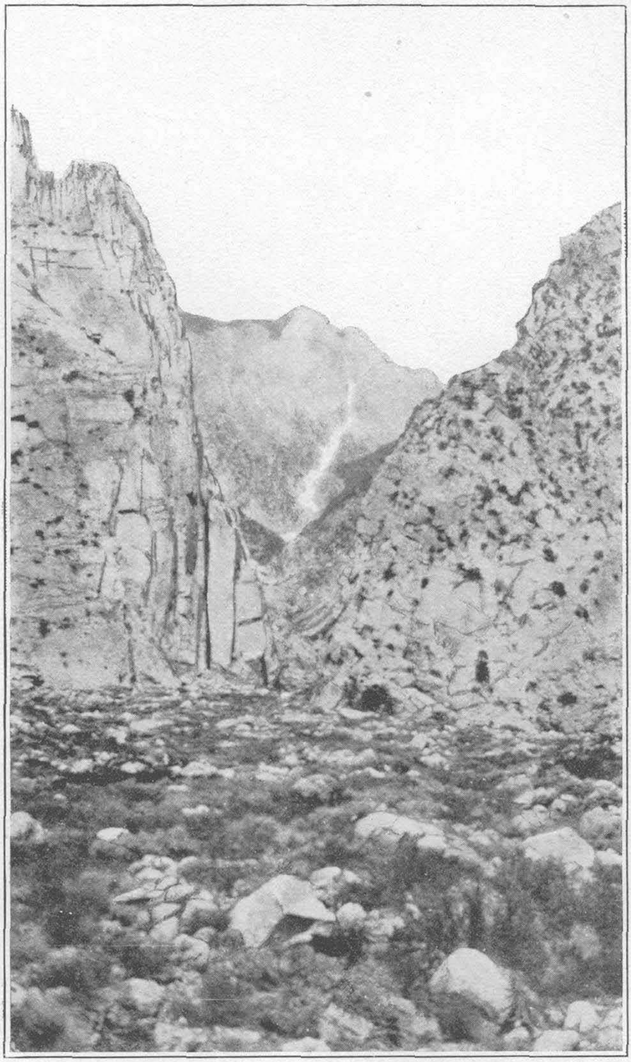
The Lookout workings of the Tungsten Mines Co. are in a tactite body that caps the hill a thousand feet or so north of the Aeroplane workings. They are in an inclusion of sediments that is about



*A*. GLORY HOLE OF TUNGSTEN MINES CO. NEAR BISHOP, CALIF.



*B*. MILL AND HOUSES OF TUNGSTEN MINES CO. NEAR BISHOP, CALIF.



VIEW IN CANYON OF PINE CREEK NEAR BISHOP, CALIF., SHOWING RUGGED TOPOGRAPHY IN THE GRANITE.

The Pine Creek tungsten deposit is just beyond the ridge in the center background.

circular in outcrop and 600 feet across. The bedding of the sediments is nearly flat, dipping 16° E. on the west side and 20° SE. on the north side, and the body appears to be a flat slab about 100 feet thick capping the hill. The main body is hard, nearly barren tactite banded and ribbed in outcrop; the lower beds are less banded and carry considerable epidote and in places considerable scheelite. Any ore found in this body would probably be in a nearly flat-lying bed.

### ROUND VALLEY TUNGSTEN CO.

The mine of the Round Valley Tungsten Co. is just south of Round Valley, on the northern border of the Tungsten Hills about 2½ miles northwest of the mines of the Tungsten Mines Co. The mine is in a body of sediments about 2,600 feet long and 1,000 feet across. The sediments dip 40°–60° W. A generalized section is as follows:

*Section at mine of Round Valley Tungsten Co., near Bishop, Calif.*

| | Feet. |
|---|---|
| Micaceous schists and quartzites | 200 |
| Thin-bedded, compact tactite | 100 |
| Micaceous schists | 100 |
| Tactite | 35 |
| Micaceous schists | 35 |
| Tactite | 40 |
| Marble | 200 |
| Tactite | 50 |
| Schist | 150 |
| Tactite | 50 |
| Schist | 100 |

The sediments are intruded by two dikes of andesitic rock, each a few feet wide, and by the later granite. A generalized geologic map of the inclusion is shown in figure 41. The slope of the hill is rather steep to the west.

The workings are near the northwest border of the inclusion, and most of the ore is in the upper part of the limestone layer. The main glory hole is over 100 feet across and extends from the granite to the marble. Other workings near by show ore, and there appears to be a considerable tonnage still available for mining.

Most of the ore is a tactite of rather coarser crystallization than the barren bands of tactite; it carries more quartz, epidote, and phlogopite mica than the ore of the mines to the south on Deep Creek. Some of the bodies of quartz are of high grade, and some irregular bodies of rock made up mostly of phlogopite, quartz, calcite, epidote, chlorite, and garnet are high-grade ore. Toward the marble this phlogopite ore gives place to a barren sand made up largely of vesuvianite.

The Round Valley Tungsten Co. has mined considerable ore, chiefly from a single glory hole. The average grade of the ore milled is about 0.5 per cent of $WO_3$. It is not possible to predict the presence of ore that is not exposed in deposits that are so irregular as the tactites, but it can be said that the zone favorable for ore deposition—the limestone near the granite—is more extensive at the Round Valley mine than in the other deposits of the district, the limestone body is of large size, and its structure indicates a continuation to considerable depth.

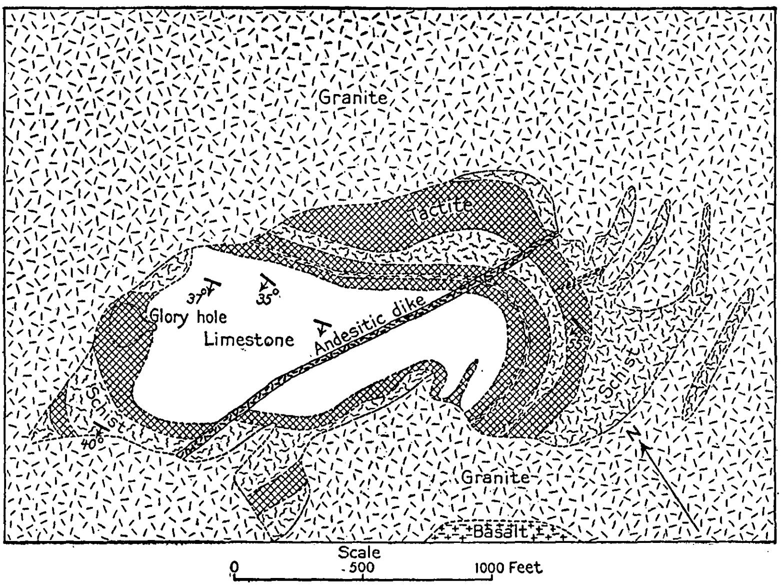



FIGURE 41.—Reconnaissance geologic map of the area about the Round Valley tungsten mine, near Bishop, Calif.

## PINE CREEK, WEST OF BISHOP, CALIF.

### GENERAL FEATURES.

The Pine Creek Tungsten Co., of Bishop, Calif., has a large tactite body near the crest of the Sierra Nevada, at an elevation of more than 11,000 feet, near the head of Morgan Creek, a north fork of Pine Creek, and about 18 miles west of Bishop. A road up Pine Creek goes within 3 miles of the deposit, and the remaining 3 miles is over a difficult trail. The deposit can also be reached by a road up Rock Creek, but the distance from Bishop over this road is about 50 miles, and the road will be blocked by snow a considerable part of the year. Water is abundant near the mine, and some good timber is present below the mine. The rugged topography (see Pl. XII) and inaccessibility of the locality, however, have added materially to the cost of opening the deposit and will no doubt add to the cost of operation.

The deposit has been little developed but is well exposed by nature. A 200-ton mill was erected about half a mile below the mine in 1918 and was operated for a few months during the later part of the year.

### GEOLOGY.

The greater part of the mountains about the deposit is made up of granitic rock, in part a porphyritic granodiorite and in part a darker rock. A body of sediments several miles long and about a mile across, surrounded by granitic rocks, is made up mostly of quartzites and schists but includes marble several thousand feet thick in the western part. The beds strike rather uniformly a little west of north and dip rather steeply to the east. A reconnaissance geologic map of the deposit is shown in figure 42.

The main ore body is tactite and lies along the west border of the inclusion, east of Morgan Creek. It follows the contact rather regularly, with some offshoots, for nearly a mile and locally is 70 feet across. It ends rather abruptly at the south, but farther south there are some bunches of tactite along the contact between granitic rock and marble; in most places, however, the marble is not replaced along the contact. In form the tactite zone in the outcrop is much like a vein, and the form and size of the contact zone and the size and structure of the marble beds

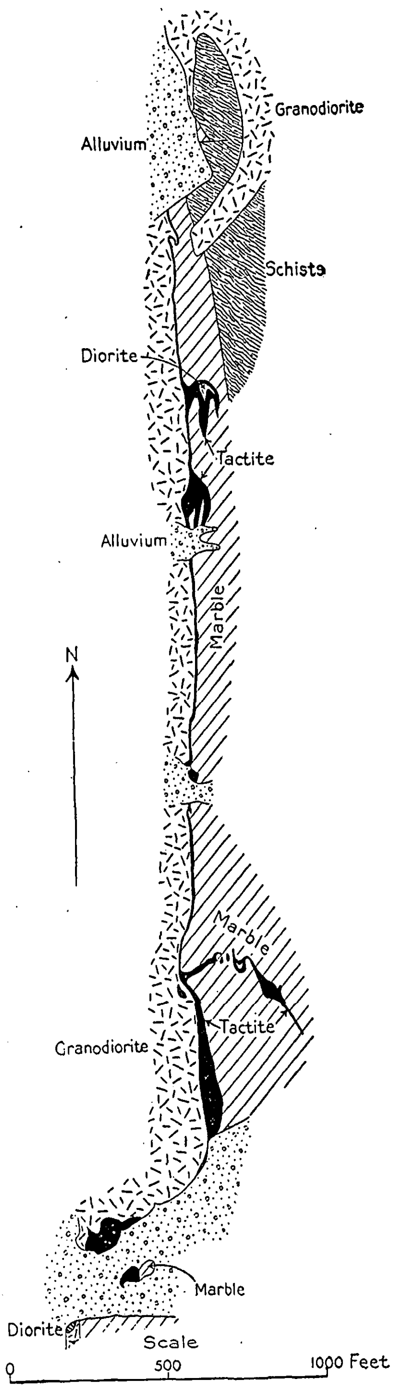



FIGURE 42.—Reconnaissance geologic map of the Pine Creek tungsten deposit, near Bishop, Calif.

make it seem probable that this tactite body is likely to continue to a greater depth than many of the other contact deposits.

### CONTACT METAMORPHISM.

The tactite is for the most part a rather dark green medium-grained rock, made up chiefly of red-brown garnet and dark-green diopside-hedenbergite, with more or less fluorite, apatite, and titanite. Several periods of metamorphism are clearly shown in this deposit. After the garnet-diopside rock was formed it was shattered, and the fractures were healed by a feldspar-vesuvianite rock; later quartz lenses, carrying scheelite, were deposited; and still later the sulphides pyrite, chalcopyrite, and molybdenite were deposited along fractures associated with alteration of the diopside-hedenbergite to quartz and calcite. Veinlets of prehnite and epidote, lenses of coarsely crystalline calcite associated with sulphides, and a large body of laumontite appear to represent late periods in the metamorphism.

The zones of metamorphism are also well marked in the deposit. The zone of automorphosed granodiorite is narrow, and the rock is mostly quartz with some diopside. This altered granodiorite appears to grade into the main zone of garnet-diopside rock. Rather sharply separated from the garnet-diopside zone is a narrow zone of light-colored silicates made up of scapolite, colorless diopside, feldspar, vesuvianite, wollastonite, and titanite, with considerable calcite. The light-colored silicates grade into the main body of marble.

### ECONOMIC FEATURES.

The surface features indicate a large tonnage of tactite. Data are not available for an accurate estimate, but a rough approximation is about half a million tons of tactite for each hundred feet of depth. Not all of this material is ore, but sampling by the operators indicates that a considerable part pans well in scheelite, and samples carefully tested by engineers for the company over 15-foot squares to cover the large body at the south end of the deposit is said to have run from 0.5 to 1.5 per cent and rarely up to 5 per cent of $WO_3$, and to have averaged a little over 1 per cent. There is no reason to expect a systematic change in either the size of the ore body or the grade of the ore within moderate depth, except that the grade may be a little higher at the surface owing to the leaching out of some calcite and sulphides.

## BENTON, CALIF.

Some contact-metamorphic tungsten deposits occur in Mono County, Calif., about 8 miles south of Benton and a few miles west of Yellow Jacket Spring. In this area the relations between sediments and intrusive granitic rocks are complex; the tactite deposits lie about a rudely circular outcrop of biotite-quartz monzonite, less than half a mile across, surrounded by sediments. Larger bodies of granitic rock can be seen a few miles to the north, south, and east. The ore is near the east border of the monzonite. The sediments are chiefly thin-bedded quartzites and schists derived from sandstones and shales, with some beds of marble; the general strike is about S. 30° E. and the dip steep to the east. In the area of the deposits there are several beds of more or less garnetized marble 50 feet or more in thickness. The tactite is made up mostly of brown garnet with more or less quartz, calcite, epidote, amphibole, fluorite, chlorite, scheelite, apatite, and titanite.

The mineralized zone is prospected for probably half a mile along the strike of the beds, and there appears to be a very large amount of tactite exposed. Some parts of the tactite appear to be fair ore, but much of it is nearly barren.

An automobile road connects the deposits with Benton. There are some scattered piñon trees on the hills, but water is scarce, there being only small springs near the deposit. The showings justify more systematic surface trenching and sampling.

## QUEENS, NEV.

About 3 miles northeast of Queens, Mineral County, Nev., claims have been located on contact-metamorphic deposits in an area in which the main rocks are thin beds of quartzite, slaty rocks, and hornfels with some interbedded marble, intruded by a considerable body of dark biotite-pyroxene-quartz diorite and by small dikes of granite porphyry. The whole series is covered here and there by remnants of later volcanic rocks that filled in great irregularities in the older rocks. Locally the rocks are much altered and mineralized, and there has been considerable prospecting for gold and silver. The scheelite deposits are in the sediments near their contact with the diorite. Natural exposures are poor, and there has been no systematic prospecting, but scattered over an area covered by several claims are outcrops and pits that show layers of tactite that are in places several feet across. The tactite is made up mostly of garnet, with epidote, calcite, vesuvianite, quartz, fluorite, chlorite, molybdenite, pyrite, and scheelite. There is some ore of good grade, but at the time of Mr. Larsen's visit in August, 1917, no large body of ore had been found. There is some piñon timber near the deposits, but the nearest adequate supply of water is several miles away, across the valley.

## MINA, NEV.

### GENERAL CONDITIONS.

Claims owned by Nick Ableman, J. C. McKay, J. A. Jordan, and H. C. Trapman, all of Tonopah, Nev., and bonded and leased to S. M. Summerfield, of Mina, Nev., are located on the east slope of the Pilot Mountains near Graham Spring, about 23 miles by road from Mina. An automobile can be driven to the deposits. The hills are covered with a scattered growth of cedar. There is a small spring at the deposits, Graham Spring is only half a mile away, and a spring said to flow 4 miner's inches is about 2 miles to the west, about 250 feet higher than the base of the deposits. The relief about the deposits is moderate.

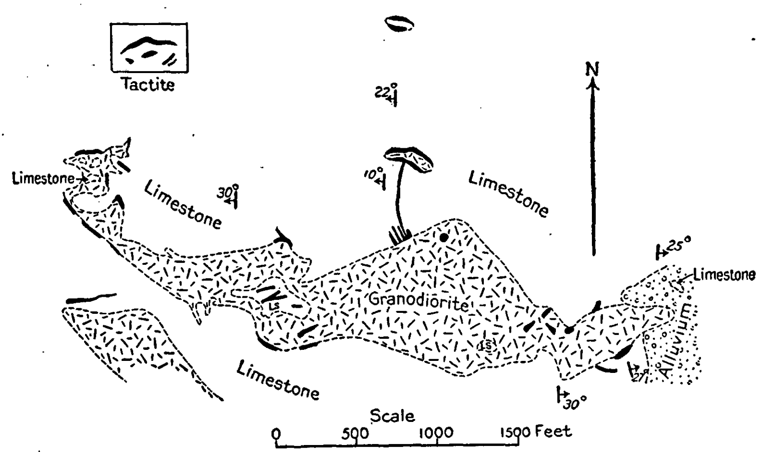



FIGURE 43.—Geologic map of the Summerfield lease and adjoining area, near Mina, Nev.

### GEOLOGY.

The district is made up mostly of sediments intruded by granodiorite porphyry and overlain by gravels, which are in turn capped by a flow of basalt. Erosion has barely cut down to the apex of the granodiorite, as within a few miles of the deposit there are three irregular areas of granodiorite each several hundred feet across and some smaller areas, while no other outcrops of granitic rock are known within a number of miles. The granodiorite bodies are all small and irregular in outcrop, and the scheelite ores occur around the largest. A generalized geologic map of this granodiorite body and its vicinity, showing its form and the distribution of the larger ore and tactite bodies, is given in figure 43.

The deposits are in a thick series of limestones that is overlain and underlain by dark outcropping slate, hornfels, and thin-bedded quartzite. At the deposit the structure is that of a gentle anticline whose axis is across the elongation of the granodiorite body, and there is no evidence of doming or distortion of the sediments by the intrusion.

ECONOMIC FEATURES.

The ore bodies are at or near the contact of the granodiorite and limestone, but along much of the contact there is little ore or tactite. Three types of ore are present—tactite ore, a quartz-calcite-scheelite vein, and bunches of quartz, calcite, galena, and scheelite, rich in silver. The tactite ore is the only type that appears to occur in large bodies. This ore is made up mostly of dark-brown garnet, with some quartz, calcite, and diopside, the last partly altered to chlorite and amphibole. The tactite is found at many places near the contact, and it replaces some small inclusions in the granodiorite. In part it forms a strip or less regular bunches along the contact; in part it is in veinlike bodies a foot or two wide that cut across the bedding of the sediments and are clearly replacement deposits along fractures in the sediments; but the larger bodies have been formed by the replacement of limestone beds extending out from the contact. The largest body exposed is of this type and is on the northeast contact of the granodiorite at about the center of the mass. Here there are five distinct beds, each from 4 to 6 feet thick, separated by about 10 feet of barren, impure limestone. Three of these beds extend only 40 or 50 feet from the contact, but one is continuous for about 500 feet to another small granodiorite outcrop. The beds here dip about 10° W. A diagrammatic vertical section of these beds across the contact is shown in figure 44. Separating the tactite body from the granodiorite, which is much crushed and altered near the contact, is a rather regular, nearly vertical vein that has slickensided walls and is from a few inches to 3 feet across, made up mostly of quartz and calcium-iron carbonate and carrying some apatite, which is in part, at least, high-grade scheelite ore. It weathers to a porous iron-stained rock. The vein has been followed by a tunnel for about 185 feet, and both the vein and the adjoining tactite continue to the face.

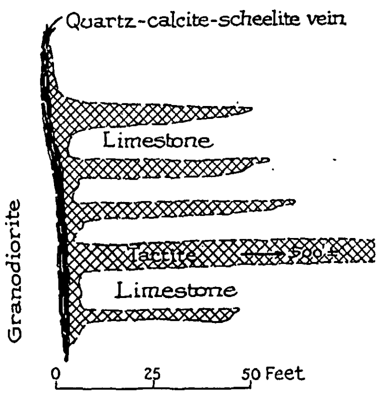



FIGURE 44.—Vertical section across contact zone at main tunnel on Summerfield lease, near Mina, Nev. Shows nearly flat beds altered to tactite and vein separating granodiorite from tactite.

At a number of places in the sediments adjoining the contact, and especially in the eastern and western parts, there are irregular bodies, mostly only a few feet long, of quartz that carries some galena and considerable scheelite and some wulfenite and that is reported to be high-grade silver ore.

On the whole, the quartz-galena silver ore appears to be in small, irregular bodies; the quartz-calcite-scheelite vein along the contact is small but of good grade; and tactite bodies are the only bodies that are likely to yield any considerable tonnage of ore. No accurate estimate of tonnage can be made, but the five tactite beds near the tunnel contain roughly 300 tons of tactite for each foot along the beds. How much of this tactite is ore is uncertain, but most of it carries some scheelite, and much of it is reported to carry nearly 1 per cent.

## HAWTHORNE, NEV.

A number of deposits have been prospected along the east slope of the Wassuk Range about 7 miles south of Hawthorne, Mineral County, Nev. The deposits are distributed from North Canyon nearly to Cottonwood Canyon, a distance of about 4 miles. The chief rock of the district is a granodiorite. The lower slopes are on older greenstone, and the granodiorite carries inclusions of the greenstone and some of limestone and other sediments. Considerable parts of the granodiorite, especially about inclusions, have been greatly sericitized, and there is much widely distributed mineralized rock. The water in nearly all the gulches is very high in sulphates and is called alum water. In former years there was considerable prospecting for gold, silver, copper, and other metals in this region.

The scheelite is in the contact-metamorphosed sediments and has not been much prospected; about most of the marble-granodiorite contact there is little tactite, and most of it pans only a trace of scheelite. The bodies in North and Alum canyons consist mostly of massive garnet, with some quartz, calcite, epidote, diopside, and hornblende. Some streaks of the ore are of very good grade, but no large bodies have yet been found. South of Alum Canyon there are, in or near the contact zone, bodies of sulphide ores with silver, gold, molybdenite, galena, pyrite, and chalcopyrite.

Probably the most promising tungsten claims of the district are those owned by Senator Oddie and Siri Giovanni, on the crest of the ridge south of Willow Canyon, at an elevation of about 7,600 feet. The ridge is high, and the deposits are rather difficult of access. The main ore body caps the ridge and dips from the crest toward Willow Creek at an angle of about 30°. It stands out prominently, with steep walls, like a capping of basalt. In outcrop it is rudely elliptical, about 200 by 130 feet; its thickness, as estimated from the outcrop and from a single tunnel that cuts through it into the granodiorite near the center, is approximately 10 to 20 feet. An estimate from these approximate figures indicates that this body contains 25,000 tons of tactite. It is said to average 0.5 per cent of $WO_3$. A sketch of the outcrop and a vertical section across the body are shown in figure 45.

The tactite is hard and compact and is made up mostly of brown garnet, with some quartz, hornblende, and calcite and a little diopside and scheelite. The tactite was shattered after it was formed, and the fractures were healed by veinlets of new garnet with much quartz and some diopside, amphibole, and scheelite. Most of the scheelite appears to be in these veinlets, and, as the rock tends to break along them, the fragments of tactite show much scheelite and give, on superficial examination, an impression of high-grade ore; but most of the scheelite is in the thin surface shell.

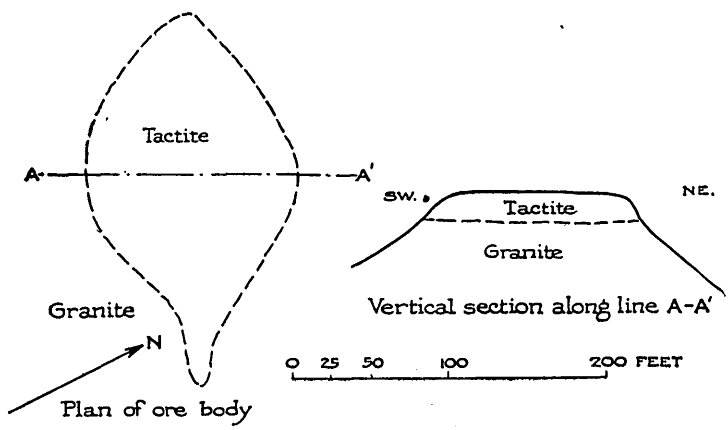



FIGURE 45.—Tactite body south of Hawthorne, Nev. Shows a cap of ore over the granite.

On the opposite side of the ridge from the body described in the preceding paragraph there is a considerable mass of detrital material, as much as 20 feet thick, that is made up of blocks of tactite of the type found in place, with interstitial granite sand. This detrital body contains a considerable tonnage of tactite, possibly as much as the body in place. It has been prospected by shafts and tunnels.

## CHURCHILL, NEV.

Tungsten deposits occur in Lyon County, Nev., a few miles north of Churchill, in the basin on the southeast slope of Churchill Butte. Churchill Butte is made up mostly of comparatively young, unaltered volcanic rocks, which are underlain very irregularly on the lower eastern slopes by a series of older volcanic rocks and a body of granitic rock about 2 miles long that intrudes the older volcanics. About the granitic rock the older andesitic rocks have undergone more or less metamorphism, with the development of considerable epidote, chlorite, and in places quartz and scheelite. No large bodies that appeared to be ore were seen, but some small bunches of good scheelite ore were found.

## NIGHTINGALE RANGE, NEV.

The Nightingale Range lies on the east side of Lake Winnemucca, Nev., and runs due north. It is a part of what was mapped by the Fortieth Parallel Survey[12] as the Truckee Range. The range is mainly granitic, but the south end is covered by lava and fine-grained, thinly bedded quartzite and black shale (commonly called slate), with interbedded limestone. On the Fortieth Parallel Survey map the sediments are shown on the west side of the range as Triassic and on the east side as Archean, but the rocks resemble each other and the limestone beds resemble those near Fanning and Toulon (Karnak of King) and in the Eugene Mountains, all of which are mapped as Jurassic. The writers' examination (east side by Frank L. Hess; west side by Frank L. Hess and E. S. Larsen) was brief, and the only fossils found were in the Eugene Mountains.

On the east side of the range the sediments stand on edge and strike north parallel to the range. The valley on the east is floored with quartz monzonite and the top of the ridge is quartz monzonite, so that the sediments probably form only a narrow belt of no great depth on the side of the mountains. A limestone bed 16 feet thick forms the ore host and had been located for about 2 miles by Barrow, Butcher, Frazier, and Ransom. It lies along the southern part of the east side of T. 25 N., R. 24 E., and is at least partly in sec. 25, which is thought to be owned by the Southern Pacific Railroad.

The limestone lies just above the foot of the steep slope of the mountain and has been cut at several places by quartz monzonite dikes. The metamorphism considerably resembles that in the Grouse Creek Mountains, Utah; and here, as there, the silicate minerals carry little iron. The limestone is largely altered to light-colored or even colorless epidote (clinozoisite), quartz, and pure-white laumontite (calcium-aluminum silicate), with smaller quantities of calcite and a little actinolite. Garnet is absent or very scarce. The scheelite is in particles that range in size from those of microscopic dimensions to some as large as a walnut and is generally beautifully white, but in places it is stained a rich yellow or orange by tungstite. It is said to be most abundant with the quartz.

At the time the deposit was visited (July 7, 1917) only a few prospect holes had been dug and one small lot of ore had been taken out. The largest opening, in which the best ore had been found, was near the south end of the claims and was an open cut 20 feet long, 4½ feet

[12] U. S. Geol. Expl. 40th Par. Atlas, map 5, 1876.

wide, and 10 feet deep at the face. Clinozoisite crystals, loosely cemented, reached a length of 3 inches and were three-sixteenths of an inch thick. Considerable laumontite is found between the clinozoisite crystals and in part looks like albite.

In another cut the ore was a peculiarly dense rock carrying scheelite in very small particles with epidote, hornblende, quartz, and calcite stained by iron and manganese oxides.

There is no timber in this region, but fortunately Linton's well, which yields excellent water in sufficient quantity for domestic purposes, is on the flat only about a mile east of the deposit. The nearest water for milling is at the Peacock ranch, on Truckee River, at the south end of Lake Winnemucca, 7 miles southwest. The haul would be downhill all the way. The nearest railroad point is on the branch line of the Southern Pacific Railroad running north from Fernley and is 17 miles to the southwest.

Joe Bean and associates mined some ore from the deposit before the signing of the armistice in 1918 and shipped it to Toulon for treatment. The Humboldt County Tungsten Mines & Mills Co. also did some work on the property, and is said to have cut ore carrying considerable pyrite at a comparatively shallow depth. North of this group of claims Temney and others have claims on the same beds. A specimen sent by Mr. Temney to the United States Geological Survey shows beautifully white pieces of scheelite, an inch in diameter, buried in quartz.

On the west side of the Nightingale Range, opposite the north end of the claims on the east slope, are a group of claims owned by C. R. Cowles, sr., and associates. They were visited by the writers on July 20, 1917. The claims are 3 miles back from the lake in Cowles Canyon, in front of which a large alluvial fan juts out into the lake. The place is best reached from Fernley, on the main line of the Southern Pacific Railroad, or from Wadsworth, 3 miles north on the branch of the Southern Pacific that runs to Susanville, Calif. The claims are about 35 miles by road from Wadsworth. For 15 miles to the Piute Indian agency on the Piute Reservation the road is good, but between the agency and the foot of the lake the road runs for several miles over sandy hills and hauling for teams is heavy. Along the lake shore the road is not only sandy but treacherous, and the traveler may unexpectedly find that his vehicle has sunk to the hubs in slick, oozy mud that on top looks like the harder sand some feet away. The road follows the beach for possibly 9 miles and could be improved at comparatively small expense. The bare hills along the last 3 or 4 miles before the deposit is reached are formed of nearly black shale in thin beds 1 to 2 inches thick, with here and there a limy layer. The west face is steep and is probably a fault face. Above the present beach are the hardened shore lines of ancient Lake Lahontan, running like remnants of old railroad grades along the steep hillsides. Cowles Canyon practically marks the northern limit of the sediments, and beyond it the hills are made up of yellowish quartz monzonite, contrasting strongly in the bright sunlight with the somber hills of dark shale.

The claims cover a considerable number of outcrops of metamorphosed limestone, mostly jagged pieces that have stuck down into the monzonite when they were floated upward and ruptured by the rising molten mass. The contact is exceedingly irregular, and dikes of the monzonite extend half a mile or more into the sediments. Along the canyon are places where it would be difficult to tell whether monzonite or shale predominates. At other places the shale and the limestone are certainly blocks floated in the monzonite. For example, 3 miles from the mouth of the canyon there is a limestone block 110 feet thick and somewhat less than 100 feet long. The metamorphism of the limestone is just as irregular as the contact of the igneous and sedimentary rocks.

Most of the metamorphosed masses of limestone lie on the steep north hillside, which rises more than 400 feet above the canyon floor. Work had been done here and there where the deposits were richest, and 1,500 sacks of ore were piled in the canyon. The deposits resemble those on the east side of the range in containing little iron but differ in that they carry considerable garnet. The garnets are light colored, usually brown-red, though some are colorless. The garnet is very irregularly distributed and is most abundant near the channels from which metamorphism spread. Some masses are 2 to 10 feet in diameter. Epidote is not as prominent as garnet but forms light grayish-green streaks 6 inches thick. Calcite is in part of the same age as the garnets and forms concentric layers in them. Sphene, diopside, and albite are also present. Farther away the limestone is largely altered to fibrous radial wollastonite, with which occur diopside and a peculiarly glistening calcite that may be easily mistaken for scheelite.

The quartz monzonite everywhere shows some metamorphism along the contact, and in one place the altered rock is 10 feet thick. Quartz is by far the most abundant introduced mineral, but hornblende and epidote are also present. The scheelite is mostly confined to the tactite, which is made up chiefly of light-colored garnets and is largely in irregular masses of quartz. The quartz carrying visible scheelite was greenish; in clear quartz close by, as much as 14 inches thick, no scheelite was seen, but this does not mean that it was absent. None could be seen in the altered granite, but at one place Mr. Larsen found as much as 6.5 per cent of scheelite by panning. The particles of scheelite seen were pure white and less than a quarter of an inch thick. Mr. Cowles, however, had one piece with poor crystal boundaries that was about 2 inches long. About 80 tons of ore milled in 1918 gave approximately 1.28 per cent of $WO_3$.

Little can be told about the depth of the deposits without drilling or driving prospect tunnels or shafts. The limestone remnants are surely irregular in shape.

Up the canyon from the main deposit are several lesser deposits, and in a branch canyon there are said to be still others that were not seen by the writers.

## JUNIPER RANGE, NEV.

### GENERAL FEATURES.

The Juniper Range is a small range parallel to the Nightingale Mountains, to which it is joined by a broad neck. It is separated from the Trinity Range on the east by Granite Spring Valley, a broad desert flat 16 to 25 miles wide. The Fortieth Parallel Survey called the range the Sahwave Mountains. Only the south end of the range was seen. It is made up of intrusive quartz diorite in which are caught fragments of rocks that may be a few hundred feet long and that, so far as may be judged from their lithology, are apparently the same as those carrying scheelite tactites in the Trinity Range, the Eugene Mountains, and the Nightingale Range. At the northeast edge of the range the Fortieth Parallel Survey mapped two patches of Jurassic rocks 4 and 8 miles long, and it seems probable that the little patches at the south end are from the same original beds.

### CLAIMS.

#### ROOP & ALLEN CLAIMS.

Deb Roop and H. J. Allen located a group of claims in sec. 21, T. 25 N., R. 26 E., near the south end of the range. The claims are reached by a poor trail over which, however, an automobile was driven. By way of Jessup, they are 21 miles from the railroad and 41 miles from Lovelocks. The hills are well rounded with easy slopes. The quartz diorite, being near the original surface, is variable in appearance and composition, and some parts might be classed as biotite granite.

Only a little work has been done on the claims, and, as shown by outcrops and prospect pits, the deposits are not large. The contact metamorphism is very similar to that at Ragged Top. (See p. 289.) Light and dark garnets, quartz, calcite, epidote, and muscovite are the chief minerals. In hand specimens from most of the outcrops scheelite is almost indistinguishable, but specimens panned seemed to show 3 or 4 per cent of scheelite. In places the beds are silicified and iron stained, and at these places they seem to carry no scheelite. The openings gave no adequate idea of the thickness of the limestone, but in general they gave an impression of greater thickness than that of one bed which was plainly 3 feet across. On one claim, known as the Wild Bill, limy, shaly beds have been only partly replaced by other minerals, but Mr. Roop said that from any part of a cut 15 feet long scheelite could be pannel. In a few places the granitic rock is replaced in spots 2 or 3 feet across by minerals almost like those replacing the limestone. No timber grows near by, though there is some juniper on the hills. The nearest water is at Granite Spring, 6 or 8 miles northwest.

### ANDERSON CLAIMS.

F. A. Anderson has a group of claims covering tactite scheelite deposits on the south end of the main ridge of the Juniper Range, in secs. 19 and 30, T. 25 N., R. 26 E. The point overlooks the valley between the Juniper and Nightingale ranges, and the workings on the east side of the Nightingale Range, about 6 miles away, are in plain sight. The claims were formerly located for copper, and a shaft was sunk in the diorite, in which, to judge from the dump, several hundred feet of workings must have been driven. A couple of good cabins have been erected. The scheelite deposit is in vertical thin-bedded limestone and hardened shale, probably the same rocks as were elsewhere called Jurassic by the Fortieth Parallel Survey. It crops out for about half a mile, striking N. 50° E. At the southwest end, nearest the cabins, the ore body is about 6 feet wide and the sediments are wholly altered to a mass of dark red-brown garnet, dark-green epidote, iron oxide formed by the weathering of chalcopyrite, finely acicular actinolite, quartz, calcite, and scheelite. The metamorphism lessens toward the northeast, and at the northeast end, where the limestone bed is thinner, only about one-half of it is thoroughly metamorphosed. At the southwest end the ore is at least as rich as any tactite seen elsewhere by the writers. The scheelite is in pieces as much as 2½ inches or possibly more in longest dimension, and some of it shows fair crystal form, with a tendency to form crystals, whose cross sections are rectangles. The scheelite is naturally pure white but is largely stained green by malachite. Toward the northeast end it occurs in very small particles. The scheelite follows the bedding planes, and a piece of tactite 2 inches thick may have a good crust of scheelite on one side and very little on the other. Several holes from 6 to 50 feet deep have been dug at different places, and probably 30 tons of ore had been mined when the deposit was visited (July 7, 1917). The nearest water is at Linton's well, 5 miles west.

## TRINITY RANGE, NEV.

### GENERAL FEATURES.

By the Trinity Range is here meant the range of mountains in the northwest quarter of Nevada that forms the northwest side of the Humboldt River valley and stretches in a northeasterly by northerly direction from Humboldt Lake for 50 miles or more. A pass near Lovelocks is used as a basis for a division of the range, so that on many maps only the north end is referred to as the Trinity Mountains, the southwest end being unnamed. The Fortieth Parallel Survey mapped the whole range as the Montezuma Range.

The southwestern part of the range is the more important so far as tungsten mining is concerned, and contains the Ragged Top and St. Anthony deposits, for which mills were built, and a number of smaller deposits. In the northeastern part of the range only one small deposit, that in Black Canyon, is known. The St. Anthony contact-metamorphic deposit was the first tactite worked in this country for tungsten.

### MINES AND PROSPECTS.

#### ST. ANTHONY MINES.

The St. Anthony Mines Co. has a group of claims 2 miles southwest of Toy, a section house and siding formerly known as Browns, 18 miles southwest of Lovelocks. They are 3½ miles southwest of Fanning, a siding that was put in for the company when it built its mill.

The deposits are in an area of hardened limy shales, largely black, and fine-grained quartzites, in which is a thin-bedded limestone. The beds dip 40°–60° S. 20° E. The series is well exposed in an arroyo through which the road runs between the mill and the mine. The rocks are mapped as Jurassic by the Fortieth Parallel Survey and are apparently the same as the beds in the Nightingale, Eugene, and other adjacent ranges. The limestone is possibly somewhat less than 20 feet thick. The road from the flat to the claims crosses the old terraces of Lake Lahontan, and the workings are perhaps 200 feet above the highest terrace.[12a]

The beds have been intruded by a granitic rock, probably a granodiorite, of medium grain, carrying biotite. This rock is now badly disintegrated. The ore is found where the limestone lies against the granodiorite, along the tops of rounded hills of small relief. The deposits show little individualism. The limestone for 2 or 3 feet,

[12a] Lake Lahontan was a large irregular Pleistocene lake that filled the Humboldt Valley and adjacent valleys but is now dry. It had a depth of 500 feet near this point. See Russell I. C., Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada: U. S. Geol. Survey Mon. 11, 288 pp., 1885.

or, in places, through its whole width, is altered to what at first appears to be characterless rusty quartzose mass in which particular minerals or structure are difficult to discern. On careful examination it is seen that part of the rock is made up mostly of brownish-red garnet with individual form and that other parts carry considerable hornblende. Scheelite is rarely found in visible particles. Ordinarily the ore shows a remarkable lack of dark garnets exhibiting crystal form, and epidote is scarce. Outside of the zone of introduced minerals the limestone is marbleized. Near the end of the workings some of the quartz appears chalcedonic. Under the microscope the rock shows garnet, diopside, quartz, hornblende, clinozoisite, scheelite, calcite, pyrite, chloropal, and iron oxide formed from the oxidation of pyrite. In the sections cut the scheelite is in particles less than 1 millimeter (0.04 inch) across, and as the particles are all broken, the pieces obtained by crushing would be considerably smaller.

The property was purchased by the St. Anthony Mines Co. in 1908, and prospecting of the deposits was carried on slowly until 1916, when tungsten prices reached a high figure; then a mill was built and the production of scheelite was actively prosecuted, so that the company received a maximum return upon its investment.

For a contact deposit in this area the workings are extensive. They follow the contact for 600 feet or more, and stopes from 2 to 25 feet across are taken out through most of the distance. One stope was at least 100 feet high. Most of the ore was taken from the limestone, but in places it seemed to have been taken almost wholly from the granite. The granite carries ore only next to the contact. Exploration tunnels were driven 300 or 400 feet into the granite, and though the granite is sheeted parallel to the bedding no ore was found until a crosscut was run to the contact.

In workings near the east end of the deposits the granodiorite passes under the limestone and cuts it off. Here the alteration of the limestone to dark minerals may be distinctly seen to follow joint and bedding planes. The deepest working was less than 200 feet along the incline. The ore is said to have yielded about 1 per cent of $WO_3$

The mill was built on the flat surrounding Humboldt Lake and close to the railroad. Water for milling was obtained from a well said to be about 40 feet deep. Drinking water was brought in tank cars from Humboldt House, 56 miles to the northeast, on the Southern Pacific Railroad.

The company ceased operations at the mine early in 1917, the ore bodies seeming to have been exhausted. Afterward lessees developed ore in the bottom of the shaft that is said to have carried 2 per cent of $WO_3$.

### BONANZA KING GROUP.

About 2 miles north of the St. Anthony Mines Co.'s mill, on the highest beach of Lake Lahontan, are some small workings on claims known as the Bonanza King tungsten group. The claims are probably 2 miles about east of the St. Anthony Mines Co.'s workings.

The limestone is considerably broken and may be a different bed from that worked at the St. Anthony mine. It is on the ridge of a narrow promontory that jutted into the old lake. The altered limestone is a peculiarly nondescript mass, yellow and brown from iron oxides, and about the only distinct minerals are gypsum in cross fibers filling thin veinlets, chloropal, and dendrites of manganese dioxide. Scheelite in very small grains is found in a rock that looks like decomposed, fine-grained diorite. The ore also carries some pyrite. Under the microscope considerable garnet in small grains is seen.

An inclined shaft about 25 feet deep cuts through a contact between limestone and biotite granodiorite, containing only minute quantities of apatite, sphene, and zircon. A drift makes a spiral so that it turns under itself.

### RAGGED TOP CLAIMS.

Among other claims located through the prospecting brought about by the great rise in prices for tungsten ores late in 1915 was a group on the west side of a mountain known as Ragged Top, about 10 miles west of Toulon, a siding on the Southern Pacific Railroad 14 miles southwest of Lovelocks. The mountain is made up largely of latites, which at the top are columnar and give it somewhat the appearance of ruins, so that it was called Karnak by Hague.[13] Inconspicuous outcrops of contact-metamorphosed limestone, unnoted by members of the Fortieth Parallel Survey, were found by E. J. Mackedon and others at the west base of the range, in secs. 1 and 12, T. 25 N., R. 28 E., early in 1916. On April 18 the claims were sold to H. M. Byllesby & Co., of Chicago. Exploration, development, and the building of houses and a mill were quickly begun, and an excellent road about 10 miles long was built between the deposits and the mill, which was erected on the railroad. This site being on the edge of the Humboldt Lake flat, water for milling was obtained from a well about 80 feet deep.

On a low, flat ridge sloping from the base of Ragged Top into Granite Valley limestone crops out at a number of places. The largest outcrop is on the Sheepshead No. 2 claim and is on the south side of the road at the base of the main ridge. Masses of limestone more heavily bedded than that on the St. Anthony claims are included in a

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[13] Hague, Arnold, U. S. Geol. Expl. 40th Par. Rept., vol. 2, p. 761, pl. 23, 1877.

light-gray quartz diorite and cut by sodic aplite and other dikes connected with the quartz diorite and also by the latites that have welled up to form the south end of the range. The largest mass of limestone is at the foot of the steeper part of the range and is probably between 200 and 300 yards long in a north-south direction and very much narrower. Smaller masses representing several beds are exposed at half a dozen places along the ridge and one or two across a small gulch on the south.

The largest mass was exposed by an open cut at each end and two prospecting tunnels. A shaft 167 feet deep was sunk a little way west of the open cut, but the dump shows only granite. Apparently no metamorphosed limestone was found. From the north open cut several thousand tons of ore was taken. On one side of the cut about 50 feet of tactite was exposed, and on the other side about 30 feet. The most prominent minerals are brownish garnet, calcite, quartz, and scheelite. The rock contains also a little epidote, choropal, halloysite, pyrite, and chalcopyrite. Some of the rock is a very close textured mass of garnet with less quartz and calcite, which under the microscope is seen to be minutely fractured, and the garnet is altered along the cracks to chlorite. Quartz forms masses as much as 2 feet thick; the largest quantity lies along an aplite dike of irregular shape. Some of the quartz contains layers of yellowish-brown garnets.

The quartz diorite is silicified for 6 or 7 feet next to its contact with the highly metamorphosed limestone. The scheelite does not seem to be so closely associated with the quartz as at some other places, and Mr. Mackedon says that the richest ore is of loose texture. No scheelite was found in the very close textured garnet rock described. A lens 12 to 14 feet long, 12 to 14 inches thick, and 8 feet deep, is said to have carried 49 per cent of $WO_3$, but 3,600 tons of ore shipped to Eureka, Utah, for milling before the company's mill was built, averaged 1.25 per cent of $WO_3$. The visible scheelite at the time the deposit was visited was mostly in the garnet-rich parts of the rock.

In general the scheelite is in particles not more than a fiftieth of an inch in diameter, but pieces several inches in diameter have been found. Many of the small particles have a distinctly greenish tint, and Mr. Mackedon sent to the United States Geological Survey larger pieces that were almost black, and one was more than 2 inches in length.

At the south end of the limestone is a smaller open cut, about 20 by 30 feet and 20 feet deep, and in this the tactite contained considerable muscovite in minute radial plates. The alteration of the limestone is in places rather definitely bounded by joint planes. A prospect tunnel, 6 by 7½ feet at the smallest point and more than 300 feet long, was driven into the limestone below the cut but disclosed less tactite than limestone that was marbleized only.

Another prospect tunnel driven into the limestone from the west near the first open cut showed 30 feet of garnetized limestone and 110 feet of granodiorite between the limestone and latites. A lateral to the north in the tactite struck small caves and loose material, probably due to the solution of the limestone at the time of metamorphism. The ore is said to have been of good grade, carrying as much as 12 per cent of $WO_3$.

On the Sheephead No. 1 claim, west of the No. 2, a fragment 7 feet thick from a bed of limestone is caught in the quartz diorite. It dips 52° NW. and has been replaced by massive garnet and other minerals, including a black variety of calcite, but the mass is lean in scheelite.

On the Young Man No. 1 claim, about half a mile west of the deposits on the Sheephead No. 2 claim, an open cut of irregular outline, possibly 75 feet long, 30 feet broad, and less than 15 feet deep, was made and seems to have held a small block of soft tactite. Four shafts 50 to 100 feet deep on this and adjoining claims seem to have developed very little ore. The company built an excellent mill with a magnetic separator and hauled the ore to it with tractors. Operations ceased in April, 1917, the company not being able to make a profit from the small ore bodies.

Later in the year Mr. Mackedon and associates leased the property and worked it for a while. The mill was then operated as a custom mill and worked on ores from many points through 1918.

### GRANITE POINT.

Granite Point is a point of rock between 100 and 200 feet high that approaches within 400 or 500 yards of the Southern Pacific Railroad in sec. 21, T. 26 N., R. 30 E., 8 miles south of Lovelocks. It is about 200 yards west of the county road. The point has a flat top that was cut as a terrace in one of the lower stages of Lake Lahontan, and at a still lower stage it formed a promontory in the lake.

Most of the point is formed of dark flat-lying hardened shale, part of it limy. The shale is intruded by numerous small aplite dikes from underlying quartz diorite, and at one place a limy shale band cut by an aplite sill, in most places less than 4 inches thick, is metamorphosed to hornblende, garnet, brown mica, and scheelite in small grains to a maximum distance of 4 or 5 inches from the aplite but in the main for only about an inch. A prospect tunnel 20 feet long had been run at this point. Several other openings show even less scheelite-bearing material.

### BLACK CANYON.

Near the head of the north branch of Black Canyon, in the Trinity Range, in the NE. ¼ sec. 17, T. 29 N., R. 31 E., about 10 miles by road west of Oreana, a shaft has been sunk to a depth of probably 50 feet or more and a number of trenches dug on a contact-metamorphic deposit that has some unusual characteristics. A block of sediments, apparently less than 300 feet long and 50 or 60 feet broad, is included in the granite and has been highly altered. Garnet has formed in seams 2 to 6 inches thick along the bedding planes and is brown, of a rich wine color, nearly black, and green. Along some of the planes garnet crusts have formed, and as in the course of alteration the volume of garnet formed was less than that of the calcite removed crystal faces, some of which are an inch or more across, line flat vugs. Some garnets have green centers and red-brown exteriors; some have light brown-red centers and darker exteriors; and some are mottled. Between the garnet layers are layers of epidote. In one place is a bed of quartz 12 inches thick with garnets half an inch or less thick sprinkled through it. The rock shows some copper staining. No scheelite was visible in the rock, though some was said to be shown by crushing and panning.

### THE LAVA BEDS, NEV.

The Lava Beds is the strangely inappropriate name by which is now known the range south of the Black Rock Desert and 45 miles northwest of Lovelocks, called by the Fortieth Parallel Survey the Pahsupp Range. Pahsupp may not be a euphonious name, but so far as has been ascertained there is not a pebble of lava in the range. The Fortieth Parallel Survey shows the range, except for two small strips that it determined as Jurassic on the east side, to be made wholly of granite. The brief observations of Mr. Hess accord with this determination.

The mountain group consists of a steep-walled range running nearly due north and rising less than 1,000 feet above the plain. It presents a nearly straight line on the east but spreads out in rounded, gently sloping hills for 8 or 10 miles on the west. At its south end the eastern part of the range is separated by a valley from a western group of hills. The scheelite deposits examined are on the east side of this valley and are scattered from the base to the top of the range.

The locality is reached by automobile from Lovelocks by way of Seven Troughs. To Seven Troughs the road is good on account of the gold mines. Without climbing to the now nearly deserted town the road skirts the east side of the Seven Troughs Range, then rounds its north end, and thence goes west and south to Hannan's cabin and spring, on the east side of the Lava Beds. The automobile must be left there, and a dim trail is followed over the ridge, a steep climb of about 900 feet vertically. In a direct line the deposits are about 12 miles northwest of Seven Troughs, but the distance is estimated as 35 miles by road, most of which is poor. Seven Troughs is about 35 miles from Lovelocks.

On the summit and at several points a short distance down the west slope are patches of dark-green spongy epidote, with grayish quartz and slightly grayish scheelite, in biotite monzonite. These patches are evidently metamorphosed parts of the monzonite. Single epidote crystals are more than an inch thick, though most of them are much smaller. On both sides of a small valley, which from the shrubs surrounding a spring in it is called Willow Gulch, are other outcrops of tactite, most of which are altered limestone and contain a great deal of dark gray-green hornblende in small needles. Other spots are largely reddish-brown garnet. Visible scheelite is found only in the coarser-textured parts of the rock.

Scheelite has, in part at least, come into the deposits after the formation of the epidote and has formed in cracks in dark-green epidote masses that replace the granite. In one specimen a crystal with edges of about 1¼ inches and a breadth of more than 2 inches has a thickness of perhaps 0.02 inch. In some dark garnet rock scheelite in brilliant light honey-yellow crystals the size of peas is distributed along a plane that probably represents a bedding plane.

The largest deposits are on the south side of the gulch. Monzonite breaks through and surrounds patches of thin-bedded limestone and limy shales, which are very unevenly metamorphosed to quartz, garnet, actinolite, hornblende, and epidote. The garnet is mostly in streaks of dark brownish red at most a few inches thick, following bedding planes or cracks, and may show crystal form; some epidote also shows good terminations. Scheelite occurs in the tactite in pieces as much as 2 inches in diameter, but mostly much smaller, visibly following planes in the garnet or in quartz. The mass of the rock contains no visible scheelite, and probably mill runs alone can determine the average content.

The extent of the deposits is uncertain, as the rocks are partly covered by soil. There are apparently two principal inclusions of limestone on the south side of Willow Gulch, with a length of some hundreds of feet, interrupted by dikes of monzonite, and an exposed width of at least 25 feet. Part of the monzonite near the deposits is prominently sheeted in plates 2 to 6 feet thick, dipping 50° N. 40° W.

About a mile west-southwest of Willow Spring is a tactite mass on the point of a hill, 150 feet above the gulch into which Willow Gulch empties. Here brown garnet and epidote form streaks 1 to

12 inches wide and 1 to 2 feet apart in the less coarsely metamorphosed limestone. Very little scheelite is visible.

Less than a mile south along the same gulch, between $1\frac{1}{2}$ and 2 miles southwest of Willow Spring, a patch of tactite occupies the point of another hill and is surrounded by rotten monzonite. The patch may be a couple of hundred feet long but is narrower. The visible scheelite seemed to be confined to streaks of epidote and quartz.

Other deposits were said to exist farther west in the hills, but they were not visited by either of the writers.

Exploitation of the deposits would be difficult, but should the price of tungsten again reach more than $25 a unit they would be worthy of more careful examination.

Besides Willow Spring there is another small spring half a mile below in the same gulch. Sheephead Spring, $3\frac{1}{2}$ miles to the north, is said to be larger.

The Western Pacific Railroad may be reached at Cholona, 25 miles to the northwest. It is said that a road to Cholona can be cheaply and easily constructed, and the part of the country seen bears out this statement.

## HUMBOLDT RANGE, NEV.

There are numerous contact-metamorphic tungsten deposits in the Trinity, Eugene, and other mountains on the northwest side of Humboldt River, but in the Humboldt Range, directly opposite, only two small deposits are known, although the granular intrusives are apparently of the same general age and composition and the limestones are equally replaceable.

### CHALMERS & BEDFORD CLAIMS.

Near the mouth of a canyon 12 or 14 miles southwest of Lovelocks a group of claims were located by William Chalmers and J. S. Bedford on the contact between a fairly coarse crumbly granite with pink porphyritic orthoclase feldspars an inch long and a white limestone 30 or 40 feet thick. The granite is cut by numerous granitoid dikes, both light and dark colored. The limestone is fairly massive, is marbleized, and is cut by many faults. At several places garnet and other contact minerals have been developed in the limestone through a thickness of 1 to 7 or 8 feet, especially in the crushed material along faults. Most of the tactite is a mass of small garnets, quartz, and diopside, with a little scheelite in very small grains. Here and there are bunches of magnetite several inches thick—a unique occurrence in the contact-metamorphic scheelite deposits examined by the writers.

Prospect pits follow the contact about an eighth of a mile from the canyon onto a ridge. One lot of samples collected by Mr. Chalmers, cut across 2½ to 7 feet of metamorphosed rock, carried from 0.3 to 1.3 per cent of $WO_3$. Other samples are said to have carried from 2 to 5 per cent.

The nearest water is that in the irrigating ditches taken from Humboldt River and is several miles away. The nearest mills are those at Joy and Toulon, distant 20 miles or more.

#### WRIGHTS CANYON.

Wrights Canyon is a narrow steep-walled gash running west and southwest from the summit of the Humboldt Range and opening into the Humboldt River valley 5 or 6 miles northeast of Oreana. It contains a fine small stream that supplies Lovelocks with water under pressure, without the need of artificial power.

At its head the canyon cuts through granite; lower down it cuts through old lavas, partly crushed to schist, and through limestones and the thinly bedded materials common in the Eugene, Nightingale, and other adjacent ranges.

On the north side of the canyon in sec. 7, T. 29 N., R. 34 E., a prospect hole 10 feet deep exposed about 7 feet of contact-metamorphosed limestone. The block appeared to be small. Scheelite was difficult to find unless the rock was panned. An interesting feature was the presence of a vein of chloropal an inch thick. A good roadbed, but so steep that few automobiles can climb it, leads past the deposit. It is reported that some tungsten was produced from the deposit in 1918.

### MILL CITY, NEV.

#### GEOGRAPHY.

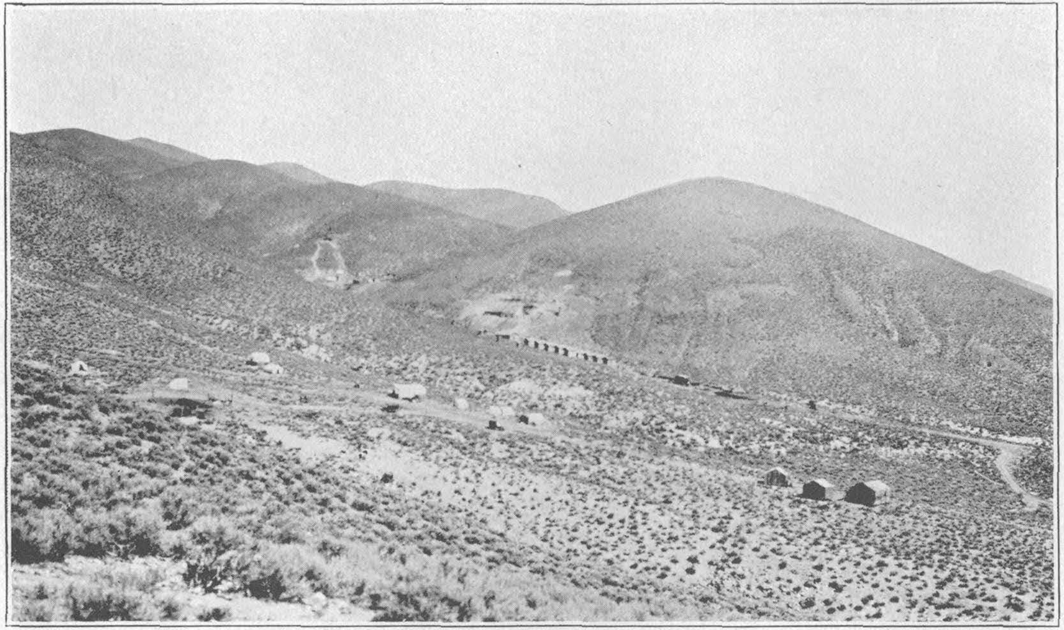
One of the most important scheelite-producing districts in the United States is in Humboldt County, Nev., on the southeast slopes of the Eugene Mountains, about 7 miles northwest of Mill City. The district is readily reached by automobile from Mill City or Imlay. The Eugene Mountains rise several thousand feet above Humboldt River, but the maximum relief in the vicinity of the main scheelite deposits is only a few hundred feet. The climate is arid; there is no timber, and only a scant growth of desert vegetation. Water is scarce, there are only a few springs near the deposits, and much of the water is too highly mineralized for domestic use. However, Humboldt River is only 5 miles away. The general character of the mountains is shown in Plate XIII.

#### GENERAL GEOLOGY.

The main production comes from contact-metamorphic deposits in an area of about a square mile, and the larger part has been made by three companies—the Mill City Tungsten Co., which operated chiefly in the southeastern part of the district, the Pacific Tungsten Co., whose workings were chiefly in the southwestern part, and the Nevada-Humboldt Tungsten Mines Co., which worked chiefly in the central part. The principal rocks in the vicinity of the scheelite deposits are a series of dark outcropping sediments made up mostly of hornfels grading into slates, some interbedded quartzite, and some comparatively thin layers of limestone. The beds strike rather uniformly a little east of north, coinciding with the general elongation of the range. They dip steeply for the most part to the west and into the slope of the range, but in the southeast corner of the producing district they dip to the east. The sediments have been intruded by several kinds of porphyritic rocks in small dikes or sills and later by a larger body of granodiorite with associated aplite, pegmatite, and porphyritic dikes. As shown on the geologic map (Pl. XIV) there are a number of these bodies of granodiorite in the vicinity of the mines, and the largest is about a mile and a half long. The long dimension of the bodies trends across the sedimentary bedding, and the intrusion does not seem to have greatly affected the structure of the sediments. There appear to be none of the larger granodiorite bodies for at least several miles north of the producing area, but in the next gulch to the south there is another large body. The larger granodiorite bodies occupy the gulches and basins, and the sediments form the intervening ridges, not so much because the gulches and basins have been eroded deep enough to expose the granite, but rather because the upper surface of the granodiorite was a succession of high peaks, east-west ridges, and deep gulches, and as the granodiorite is much more readily eroded by the streams than the hornfels, in the wearing away of the mountains, the position of the gulches and basins was determined by the position of the softer rocks on the surface, and these were the peaks and ridges at the top of the granodiorite. Wherever observed, the contact between granodiorite and sedimentary rock is very steep.

## ECONOMIC GEOLOGY.

The ore deposits are portions of the limestone beds that have been replaced, near the granodiorite contact, by a medium-fine, rather even-textured aggregate of pale-brown garnet and greenish epidote in variable proportions, with considerable quartz and calcite and some sulphides, zeolites, and scheelite. The ore from the deeper levels is rather hard and compact and carries considerable calcite and pyrite and small amounts of other sulphides; that from the surface is friable and carries little calcite or sulphides. Bodies of the soft ore project into the hard ore in chimneys or caverns, suggesting limestone caves. The friable surface ore is in part derived



TUNGSTEN DISTRICT NEAR MILL CITY, NEV.

View of the mill, in course of construction, and the workings of the Nevada-Humboldt Tungsten Mines Co.

from the hard ore in the deeper workings through the leaching out by surface water of the sulphides and carbonates. On the other hand, there has been a downward enrichment of the pyrite and calcite at and for some distance below water level. Locally there are bodies of hard, compact garnet rock, commonly low in scheelite.

In the southwest corner of the area included on the geologic map (Pl. XIV) there are a great number of beds of dark-colored crystalline limestone, many of them only a few feet thick, but some appear to be as much as 60 feet thick. Toward the north these beds become silicified and changed to a rock that is difficult to distinguish from the hornfels; at first the limestone becomes ribbed with lenses or layers of resistant siliceous rock alternating with layers of limestone, and finally the whole of the limestone is replaced. The relation of this alteration of the limestone to the deposition of the tactite was not positively established, but the available evidence indicates that it was earlier and that the ore bodies represent portions of the limestone that had not been silicified at the time of the ore deposition but were then altered to ore.

The scheelite-bearing garnet-epidote type of altered rock is confined to the immediate vicinity of the contact. Within a few hundred feet of the contact it changes rather abruptly to marble. Remnants of marble are surrounded by the ore rock, and bunches of the ore are present in the marble some distance from the main ore bodies. The width of the stoped ore beds is from 2 to 8 feet, and most of the beds are rather uniform in width. The form and extent of the ore bodies in depth are determined by the form of the contact between granodiorite and sedimentary rock, as the ore is in the sediments near the contact. No positive statement can be made in regard to the form of this contact, but wherever observed it is steep. The ore that has been mined averaged about 2 per cent of $WO_3$ and was therefore of considerably higher grade than that produced in quantity from any of the other contact-metamorphic deposits.

At least three of the limestone beds have produced ore, and some of the other beds, of which there are a number, may carry ore near the granodiorite. Some of the beds carry ore at a number of places—for example, the Sutton bed, on the eastern edge of the field—and it seems probable that the main ore of the Friedman mine is in the same bed as the ore of the Springer workings.

The structure of the beds is simple, in a broad way, but there are numerous small faults and local distortions. A detailed geologic map displaying clearly the structure should aid greatly in the mining and development work, and it would also aid in the search for new ore bodies, but such a map could not be prepared during the present reconnaissance.

## MINES.

### NEVADA-HUMBOLDT TUNGSTEN MINES CO.

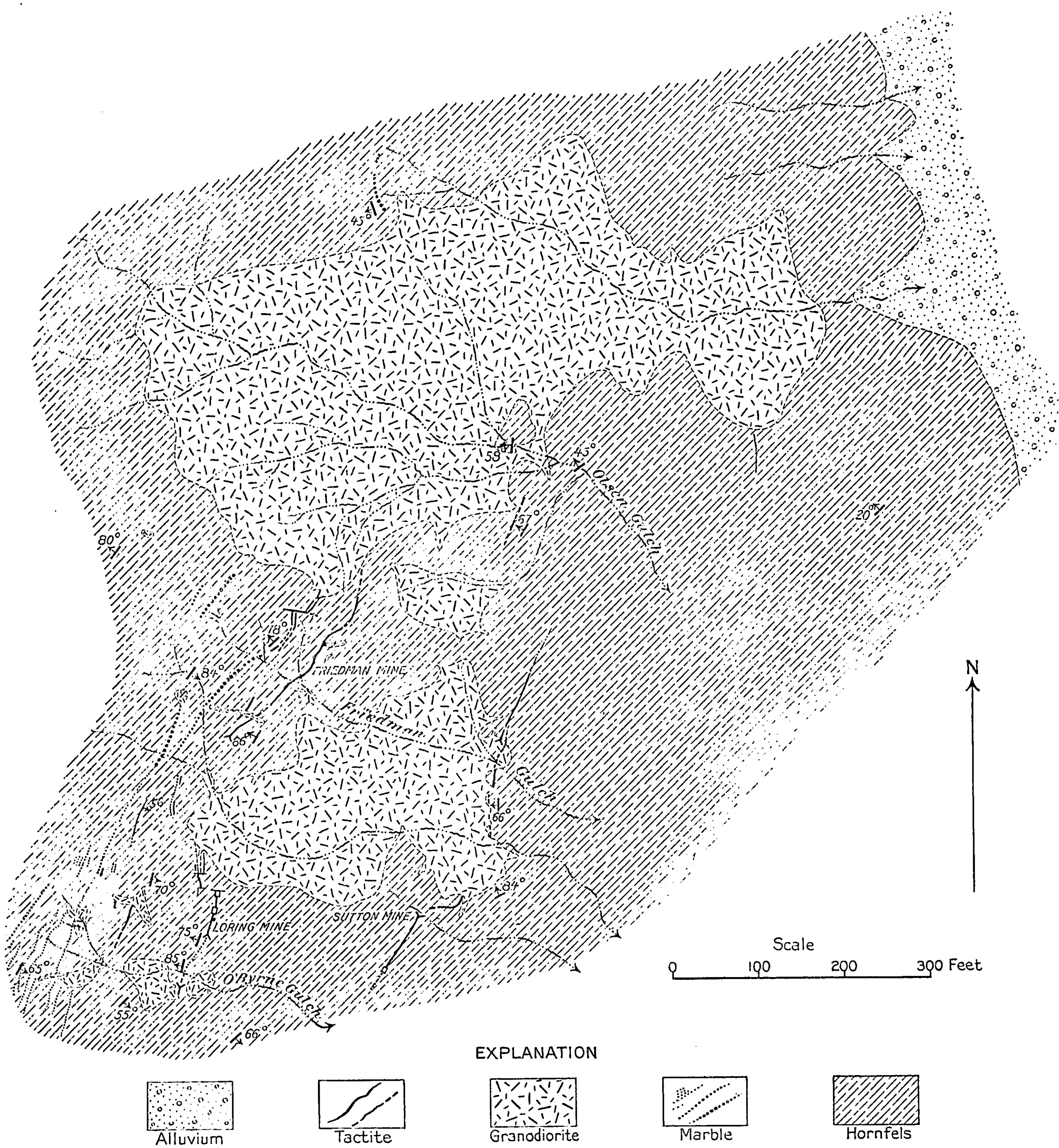
The property of the Nevada-Humboldt Tungsten Mines Co. is in the central part of the district, and the chief underground workings and the mill are in the upper part of Friedman Gulch. The mill has a capacity of 150 tons a day and was completed and operated in the fall of 1918. The main workings are a little west of the mill, along a bed that is about 6 feet thick and that can be followed for 2,500 feet along the outcrop. Along most of this outcrop the limestone has been replaced by garnet-epidote rock, although there are some remnants of marble. The main work has been done on a body that is mostly north of the gulch and is developed for 700 feet along the bed and to a depth of 650 feet. Practically all of this body is reported to be good ore, and a considerable quantity has been stoped.

About 500 feet to the northwest is a parallel bed that has produced some ore. Southwest of the main gulch this bed is mostly marble, in part silicified and in part changed to garnet-epidote rock. It appears to be from 30 to 40 feet thick, but in its northern part it is much silicified, part of it resembles the hornfels, and locally there appear to be two separate layers of tactite. There is some faulting in this bed, but the considerable width of the bed makes it difficult to distinguish irregularity in the alteration of the bed from small faults.

### MILL CITY TUNGSTEN CO.

The Mill City Tungsten Co., the pioneer in the district, began operations in August, 1917, and shipped its first lot of ore in the following November. The workings are mainly along the eastern ore bed of the district, the Sutton bed, and the ore has been taken chiefly from the southern part of the bed. South of the gulch the bed has been prospected by a tunnel that has been run about 500 feet to the south. The tunnel is in ore for the first 300 feet or so, and beyond this part the bed is mostly marble with some bunches of tactite, mostly garnet and epidote. On the surface this bed was followed for nearly 1,000 feet, and the southern part is mostly marble with some tactite. Beginning about 80 feet from the portal and continuing for about 150 feet the bed has been stoped from the tunnel level to the surface; the width of the bed was uniformly about 4 feet, and the walls are hornfels. Beyond the stope to the south the tactite continues for about 100 feet but is said to be of low grade. The ore continues below the tunnel level.

To the northeast across the gulch there are no exposures for several hundred feet, but a tunnel crosscuts to the bed and follows it for about 200 feet. The bed has been stoped from the surface to and below the tunnel level for about 150 feet in length, and low-grade




RECONNAISSANCE GEOLOGIC MAP OF THE TUNGSTEN DISTRICT NEAR MILL CITY, NEV.

ore continues to the north, probably to the granodiorite, which is only a short distance away. In this part of the vein there is a sharp local flexure and probably faulting. (See Pl. XIV.)

To the north this bed is cut out by the granodiorite for most of the distance to Friedman Gulch. North of Friedman Gulch it has been prospected by surface cuts and by a tunnel along the bed for about 240 feet. The tunnel exposes from 2 to 3 feet of tactite, said to be low-grade ore, nearly to the face, which is marble. On the surface this bed was followed for over 1,000 feet, and much of it is tactite, with marble more abundant in the northern part. Near the crest of the ridge there is about 25 feet of fine-textured green tactite, mostly epidote, that is reported to be good ore. It apparently represents local mineralization of the hornfels as well as of the limestone.

### PACIFIC TUNGSTEN CO.

The Pacific Tungsten Co. has produced most of its ore and done most of its work in the southwestern part of the district but has also prospected and produced some ore in the northern part. The chief workings are on a bed about 2½ feet wide, between walls of hornfels. The ore is opened up by two shafts near the crest of the ridge, about 200 feet apart, and a tunnel lower on the slopes whose portal is about 285 feet to the south of the southern shaft and which in August, 1918, ran to a point about midway between the two shafts and reached the southern shaft at a depth of 109 feet. The northern shaft starts in ore but reaches hornfels near the bottom, and the ore bed is probably faulted. The southern shaft is in ore throughout. The tunnel starts in marble with a little garnet-epidote rock, but the garnet-epidote rock becomes increasingly abundant and within a short distance replaces the whole of the limestone bed. All the ore between the walls has been stoped for much of the block above the tunnel and between the two shafts. Everything between the walls was good ore. The workings expose ore for about 400 feet along the bed, and the north shaft is about 200 feet from the granodiorite contact. To the south this bed is not well exposed, but it appears to be mostly marble to the bottom of O'Byrne Gulch. Just beyond O'Byrne Gulch the workings of the Page lease are probably on the same bed; some good ore and some low-grade tactite are exposed in the workings.

A number of other beds to the west have been prospected and show some ore. Only a few hundred feet to the west and southwest there are several beds of limestone that have not been changed to garnet-epidote rock.

To the north, toward the property of the Nevada-Humboldt Tungsten Mines Co., the Pacific Tungsten Co. has other workings along several beds, and some of these have produced some ore and show more. The company has also produced some ore from workings in the gulch north of Friedman Gulch and has ore exposed in a number of other places.

### OUTLYING PROSPECTS.

Near the head of Pole Canyon, a few miles north of the Mill City district, some small lenses of high-grade scheelite ore have been found. The ore appears to replace beds of the hornfels, and no large bodies of granite are exposed in the area.

Some prospects are located about the granite body to the south of the main mines, and, although no valuable ore bodies have yet been found, this area has much the same geologic features as prevail near the mines.

### CONCLUSION.

A carefully prepared large-scale geologic map showing in detail all the limestone beds and their various alteration products from which may be obtained a thorough and detailed knowledge of the geology of this district, and especially of its structure, is of the utmost importance to the systematic and economical mining of the ore, and especially to the development work and prospecting. To have such a study made would well repay the operators in locating faults and flexures in the ore beds and in aiding them to understand the nature of the ore bodies, thus enabling them to save dead work.

## GOLCONDA, NEV.

### GEOGRAPHY.

The Golconda tungsten district is in the Osgood Range, on the east and north slopes of Mount Osgood (also known as Adam Peak), about 20 miles northeast of Golconda, Humboldt County, Nev. The Osgood Range is a short but rather high, rugged range, and Mount Osgood rises about 4,000 feet above the floor of the valley. In common with the rest of Nevada the district has an arid climate, but a number of the gulches heading in Mount Osgood contain good springs, and some have enough flow to furnish water for irrigation on a small scale. The district is readily accessible by automobile from Golconda.

### GENERAL GEOLOGY.

Sediments make up the greater part of the Osgood Range, but on the east and north flanks a stock of quartz diorite intrudes the sediments and crops out in two lobes that are of about equal size and that are connected by a short, narrow neck. The total length of the intrusive mass from north to south is about 6 miles and its width about 2 miles. In the vicinity of the intrusive rock the sediments are mostly limestone and metamorphosed shale, with some quartzite, and some of the individual series made up chiefly of limestone are several hundred feet thick. In general the beds strike about north, with the elongation of the range, and dip steeply to the east. The eastern part of the range carries much limestone; the western part is chiefly shale and quartzite.

### ECONOMIC GEOLOGY.

The contact zones about the quartz diorite have been prospected for copper and silver for many years, and some of the properties are reported to have produced both metals. As long ago as 1883 the Richmond mine was patented by Joe Farrell. More or less contact-metamorphic rock carrying scheelite is found along a considerable part of the contact between the quartz diorite and the limestone, and the outcrops of some of the bodies are of large size. The average grade of the ore appears to be less than 1 per cent, but at the high prices for tungsten during the World War some of the bodies were well worth prospecting and sampling.

The tactite is made up mostly of brown garnet with considerable epidote and quartz, some calcite, and a little diopside, amphibole, chlorite, titanite, apatite, pyrite, chalcopyrite, molybdenite, and scheelite. Some irregular bodies of quartz, with much scheelite and galena, are said to be good silver ore, and they are similar to the silver ore of the deposit at Mina, Nev. In places the quartz diorite adjoining the metamorphosed limestone is changed to a quartz-epidote rock with more or less sericite and some scheelite.

### PROSPECTS.

#### CLAIMS OF GEORGE BLAINE.

At the time the district was visited George Blaine was prospecting three claims along the east border of the quartz diorite, from Granite Creek to the north. In this area the quartz diorite is in contact with limestone, and there appears to be a continuous layer of tactite from 2 to 10 feet across and averaging about 3 feet for a distance of 1,000 feet or more; beyond, to the north, the contact turns and the tactite does not appear to be so regular. The contact rock is said to average 1 per cent of $WO_3$.

#### CLAIMS OF FAYANT & BLAINE.

The claims of Fayant & Blaine are south of Ranch Creek. In the area prospected the contact between quartz diorite and limestone is rather irregular and appears to dip under the limestone. (See fig. 46.) The limestone bed dips 35°–50° E.; the slope of the hill is in the same direction but is not quite so steep. Along much of the diorite contact there is some tactite, but its width is very irregular and it tends to follow certain of the limestone layers. One of the largest outcrops of tactite is lenslike and measures 150 by 50 feet; for about 50 feet beyond this to the east there is little tactite, but for the next 200 feet the outcrop is from 15 to 50 feet across. The structure of the limestone beds, the slope of the hill, and the form of the diorite-limestone contact suggest that these large outcrops may represent comparatively flat bodies that have no great depth. However, if the grade of the tactite is satisfactory the deposits are well worth scientific prospecting and may yield a large tonnage.

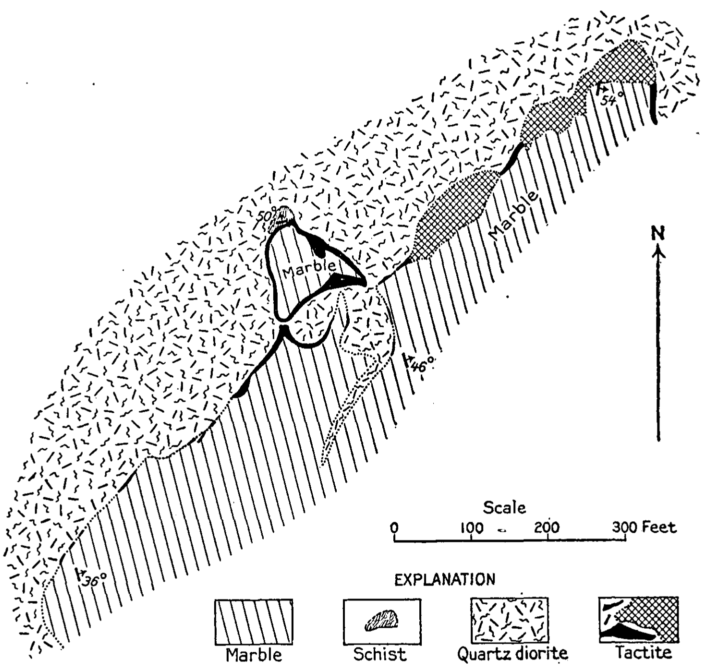



FIGURE 46.—Reconnaissance geologic map of the contact zone on the claims of Fayant & Blaine, north of Golconda, Nev.

RICHMOND MINE.

The Richmond mine is on the west side of the range, in Anderson Gulch, a mile or two northwest of the claims of Fayant & Blaine. The beds here strike about N. 20° W. (magnetic) and dip 70° E. The ore is along the contact of the diorite with a limestone series that is several hundred feet thick and lies between thick series of metamorphosed shale and quartzite. The contact is rather irregular near the mine, and the main body of tactite trends across the bedding. A sketch of the geology is shown in figure 47. The largest outcrop of tactite is on the west side of the gulch. It is not very well exposed but reaches a width of 100 feet and appears to be very wide for 400 feet along the contact to the point where it goes under the talus to the east. The structure and general character of this body indicate a considerable depth to the deposit. East of this outcrop, for about 450 feet, to the opposite side of the gulch, there are no exposures, but for 100 feet or so beyond about 10 feet of tactite lies between the limestone and the diorite. A tunnel was driven in the limestone from a point 275 feet northwest of the contact on the east side of the gulch and cuts the contact at a depth of about 140 feet. Where it crosses the contact there is a 20-foot dike of a porphyritic rock between the diorite and the limestone but no ore. The absence of ore along the contact in this tunnel is said to have led to the abandonment of the prospecting in 1917, but the tunnel gives little evi-

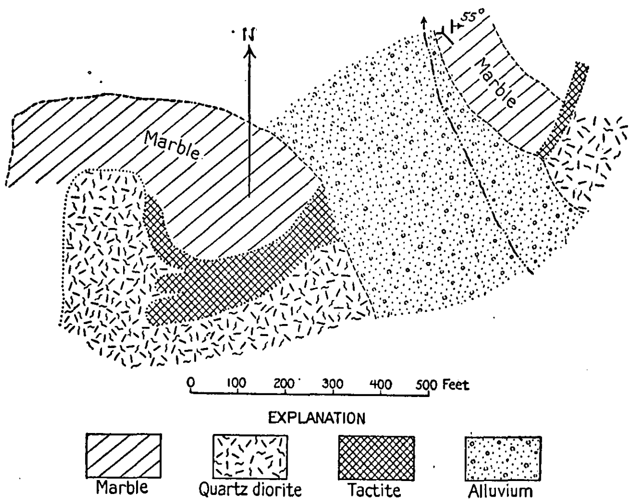



FIGURE 47.—Reconnaissance geologic map of the contact zone at the Richmond mine, near Golconda, Nev.

dence for or against the continuation of the ore in depth, as the dike would probably have cut out any ore present where the tunnel crosses the contact. This mine has been operated in a small way for many years as a silver mine, and small, irregular bunches and lenses of quartz carrying some galena and considerable scheelite are said to be good silver ore. This silver ore is in considerable part on the limestone side of the contact zone and is especially well shown on the east side of the gulch. It resembles the silver ore of the district east of Mina, Nev.

Although not enough work has been done on this property to warrant any estimate of the tonnage, there appears to be a large quantity of tactite present. The grade of the ore is uncertain, but samples from large exposures are reported to have assayed from a little less than 0.5 per cent to more than 1 per cent of $WO_3$, and some parts of the ore assayed as high as 8 per cent.

The large outcrop on the west side of the gulch seems to be the most promising for a large body of ore, but it has been little prospected.

### OTHER PROSPECTS.

Numerous other prospects have been located along the diorite-limestone contact and some of them appear to be on considerable bodies of tactite. Along the southern part of the contact, in the drainage basin of Granite Creek, there are some large outcrops of tactite that years ago were extensively prospected for copper and that have lately been located for tungsten. Contact zones near the head of Granite Creek have also been prospected for tungsten. Along the northeastern part of the contact the Jack mine has prospected a large body of tactite for copper and later for molybdenum, but the prospect seems to be about as promising for tungsten as for either copper or molybdenum. Prospects south of Osgood Creek have more or less tactite that carries scheelite and molybdenum. The claims of Fayant & Leonard on the divide between Ranch Creek and Anderson Gulch show in some old prospect shafts 10 feet or more of tactite with some bunches of high-grade tungsten ore.

### CONCLUSIONS.

There is an unusual amount of tactite about the quartz diorite of Mount Osgood, and, so far as available data go, it seems to average fairly well in scheelite. Careful, systematic sampling and surface prospecting may disclose one or more large bodies of low-grade scheelite ore in the district.

## RUBY RANGE, SOUTH OF ELKO, NEV.

### GENERAL CONDITIONS.

The Ruby Range, south and east of Elko, is one of the most rugged and highest ranges in Nevada. It is better watered than most of the Nevada ranges, as many of the gulches contain streams. The range is made up for the most part of biotite granite and quartz monzonite,[14] which intrude Paleozoic sediments, mostly limestones with considerable quartzite. Contact-metamorphic tungsten deposits are known in three districts in the range—(1) in the Valley View district, about 10 miles south-southwest of Ruby Valley post office; (2) a few miles southeast of Harrison Pass; and (3) in the Bald Mountain district, about Joy post office. All three districts are readily accessible by automobile from Elko.

[14] Hill, J. M., Notes on some mining districts in eastern Nevada: U. S. Geol. Survey Bull. 648, pp. 54–63, 1916.

### VALLEY VIEW DISTRICT.

The following description of the scheelite deposit in the Valley View district is taken from Hill's report:[15]

The deposit occurs in white crystalline limestone, a belt of which about 600 feet wide lies between quartzite to the west and north and dark contorted arenaceous limestone to the south. A number of small faults cut these formations, and locally the dark thin-bedded limestones show intricate contorted folds. The edge of the main mass of intrusive porphyritic quartz monzonite is nearly half a mile west of the prospect. Offshoots from this intrusive have invaded the sedimentary rocks, usually as narrow dikes parallel to the major structure. Most of the dikes are fine to medium grained porphyritic quartz monzonite containing few ferromagnesian minerals.

Small lenslike bodies of ore are exposed in a number of pits. Most of these bodies are near dikes and, like them, parallel the general structure. They usually consist of two more or less well-defined zones. The outer, which is frozen to the coarse calcite crystals of the walls, consists of an intergrowth of pod-shaped white crystals of scheelite, the largest half an inch in diameter, of large flat greenish-yellow crystals of epidote, and of quartz, chlorite, and calcite. Thin sections of this material studied under the microscope show that the scheelite at least is a metasomatic replacement of calcite. Near the center of the lens native bismuth and pyrite begin to appear. The central part of the lenses are usually fine-grained aggregates of quartz, phlogopite, and light-green to white pyroxene, in which there are small crystals of pyrite, bismuthinite ($Bi_2S_3$), and native bismuth. Whether these aggregates were originally dikes is not certain, though in one pit the suggestion was strong that an 8-inch highly altered dike formed the center of the vein. In another pit the center of the lens consisted of an aggregate of quartz, phlogopite, and pyroxene, with the metallic minerals sparingly distributed through it.

The development was not sufficient at any place to warrant a statement as to the probable continuance of these deposits with increase of depth, but the fact that any particular lens of ore does not extend for many feet on the surface would raise the question whether any large body of ore would be found.

Although Hill suggests that the deposit may have originally been a dike, there seems no doubt, after the writers' extended study of similar deposits, that this too is a contact-metamorphic deposit.

### HARRISON PASS AREA.

The granite-limestone contact east of Harrison Pass has been more or less prospected for a distance of a mile or so from Harrison Pass Creek southward beyond Limekiln Creek. The contact is very irregular and serrated, and numerous dikes of aplite cut the limestone. Along the main contact and the contacts of the aplite dikes there is more or less tactite that carries some scheelite and is reported to average about 2 per cent of $WO_3$. These contact bodies are rarely over 3 feet wide, and they appear also to be of small extent along the contact and vertically. At the time of Mr. Larsen's

[15] Idem, pp. 62–63.

visit no considerable ore body had been uncovered. The ore is made up mostly of quartz, garnet, and epidote, with more or less chlorite, calcite, scheelite, and sulphides.

### BALD MOUNTAIN DISTRICT.

The Bald Mountain district is in the south end of the Ruby Range, in White Pine County, about Joy post office. The district was described by Hill[16] before the discovery of tungsten, and the tungsten deposits were examined by E. S. Larsen in the summer of 1917. The following description is partly abstracted from Hill's report and partly the result of the later examination:

The rocks of the district are chiefly Paleozoic sediments, mostly limestones but with some quartzites. The sediments are intruded by a body of granite porphyry about 4 miles long and 1½ miles wide at its southern part but narrower to the north. The district has been prospected for many years, and veins of gold-bearing quartz carrying pyrite, stibnite, and chalcopyrite are present in the granite porphyry, replacement copper ores occur in the limestone, and copper and tungsten have been found in the contact-metamorphic zones.

The deposits a little north of Joy post office do not appear to be large or of high grade. They are irregular and in part lie along the contact and in part follow the bedding of the limestone. The contact rock is made up chiefly of garnet and diopside, with quartz, carbonates, mica, and amphibole. Limonite stains are abundant, and there are probably considerable quantities of sulphides in depth. The granite near the contact is also somewhat altered.

The prospects a little west of Joy, on the south side of Water Canyon, are along a part of the granite and limestone contact where there is on the limestone side about 15 feet of garnet-diopside-quartz tactite that is low in scheelite but on the granite side 7 feet of altered granite near the contact that carries more scheelite.

*Section at prospects west of Joy, Nev.*

| | Feet. |
|---|---|
| Granite, little altered but grading into next band. | |
| Altered granite, now mostly quartz; decomposed feldspar, chlorite, calcite, epidote, titanite, pyrite, actinolite, and scheelite | 1 |
| Dike of lamprophyre | 2 |
| Mostly albite, more or less decomposed, and diopside, more or less quartz, calcite, brown garnet, green hornblende, chlorite, titanite, and scheelite | 6 |
| Garnet-diopside rock. | |

This zone pans rather well in scheelite; a part of the scheelite is disseminated through the rock, but a part lies along seams and frac-

[16] Op. cit., pp. 152–161.

tures. There was nothing to show any considerable continuity for this ore.

### GROUSE CREEK MOUNTAINS, UTAH.

Tactite tungsten deposits have been worked in the Grouse Creek Mountains, in Boxelder County, Utah, 15 miles northeast of Lucin, a small station in the desert on the Southern Pacific Railroad, at the junction of the Lucin cut-off and the old line of track around the north end of Great Salt Lake, and 7 or 8 miles from Bovine, a side track on the old line. The road from Lucin follows in part the old emigrant trail of the "forty-niners," traversing the ancient bed of Lake Bonneville, the broad fresh-water ancestor of Great Salt Lake, crossing the Bonneville beach lines, and in part following its gravel bars, which run at different levels straight from one old promontory to another. The deposits are a few miles north of the highest shore line of the ancient lake. During rainy weather the road in the flat becomes muddy and difficult of passage.

The deposits lie near the south end of the range (shown on the Fortieth Parallel Survey maps as the Raft River Mountains), in the ridge between Emigrant Wash on the east and Willow Wash on the west, and on the west side of Willow Wash. A thick, rather heavily stratified limestone, mapped by the Fortieth Parallel Survey as of "Lower Coal Measures" age, has been lifted by great masses of a porphyritic granitic rock carrying considerable biotite. The granitic rock is of variable composition, and in places there are segregations of biotite and hornblende. Near the deposit it forms the base of the hills and gradually rises, so that less than a mile to the north the limestone gives way altogether on the rugged Citadel Peak, the upper 200 feet or more of which is granitic rock of a lighter variety carrying considerable gray quartz. It is possibly a monzonite.[17] The rough outline of this peak contrasts strongly with the rounded contours of the limestone hills. Dikes of a fine-grained biotite granite cut the limestones near the deposits and are mostly badly decayed.

The metamorphism seems to be due largely to the fluids attending the dikes at the time of their intrusion. The greater mineralization along joints and faults is noticeable, and the deposits are remarkable in having no visible garnet. The minerals are pale yellow-green epidote, the larger crystals of which have flesh-colored centers, quartz, calcite, chlorite, actinolite in minute radial masses, and gray mica. Accessory minerals are scheelite, galena rich in silver, vanadinite, wulfenite(?), and stolzite. Some bismuth is also reported to have been found. The scheelite is said to occur where the rock contains

[17] Unfortunately specimens, in the collection of which considerable effort was expended, were lost.—F. L. H.

most quartz. The largest workings were on the west side of Willow Creek and were comparatively small and irregular, being probably not over 75 feet in longest dimension and 35 to 40 feet deep, partly under cover. The scheelite particles are mostly smaller than peas, and the largest piece seen was less than an inch through, but pieces 4 to 5 inches through were said to have been shipped under the impression that they were cerusite. A few of the scheelite grains are stained yellow by tungstite ($WO_3+H_2O$).

Part of the claims were located by Frank Edison for gold and silver in 1904, but the presence of scheelite was not discovered until 1915. When visited June 1, 1917, a few hundred tons of ore, said to carry from 1.5 to 2 per cent of $WO_3$, had been run through a small mill put up by Mr. Edison and George W. Riter on the west side of Willow Wash. The mill was equipped with a small jaw-crusher, rolls, and a Wilfley table and was fed by hand. It was said to have a capacity of 7 tons in 12 hours. A small gasoline engine furnished power. Water was obtained from shallow wells in the bottom of Willow Wash. Mr. Edison said that when the wells were sunk into the granitic bedrock the supply of water decreased rather than increased.

Part of the claims on the west side of Emigrant Wash were in dispute. A number of prospect pits had been sunk and some ore had been taken out.

There is a long contact between the limestone and the granite in this area, and it seems possible that other deposits may be found.

## JOSEPH, OREG.

In the summer of 1917 Mr. Larsen examined the Frazer mine, in Wallowa County, about 18 miles south of Joseph, Oreg., as a molybdenum prospect and found it to be a deposit of the contact-metamorphic type and to carry scheelite. It lies at the head of the west fork of Wallowa River, in a very rugged country, and is difficult of access.

At the prospect a thick series of alternating marbles, quartzites, and schists are intruded by a large body of quartz diorite striking about N. 70° E. and dipping about 50° S. 20° W. Along much of the marble-diorite contact there is little tactite, but about a semicircular outcrop of marble a few hundred feet across that is nearly surrounded by diorite the tactite zone is from a few feet to 20 feet or more in width and the adjoining diorite has itself been considerably metamorphosed. The most abundant mineral of the tactite is a brown garnet with moderate iron content; green epidote, quartz, and calcite are less abundant; and green hornblende and chlorite are abundant locally. Titanite, apatite, scheelite, and the sulphides pyrite, chalcopyrite, and molybdenite occur in small amount. As usual, the minerals are irregularly distributed, and the sulphides which are later than the garnetization, are associated with fractures in the tactite and the adjoining granite and are especially abundant on the granite side of the contact.

The outcrop and geologic relations of the tactite indicate a body of moderate size. Along the borders of quartz lenses there are some bunches that are rich in scheelite. A picked sample from a bunch on the west side of the ridge panned 17 per cent of $WO_3$, and about as good material was seen at another point on the east side a few hundred feet away. However, two grab samples from the tactite rock panned only a trace of $WO_3$. On the whole this deposit appears to be at least as promising for scheelite as for copper or molybdenum, and a little surface prospecting for scheelite by trenching and constant panning would seem advisable. Bodies of tactite are not uncommon in northeastern Oregon and the adjoining parts of Idaho, and it would be surprising if some of these bodies did not carry scheelite. Such deposits justify a search for scheelite by panning.

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