TUNGSTEN DEPOSITS OF NORTHWESTERN INYO COUNTY, CALIFORNIA.

By ADOLPH KNOPF.

INTRODUCTION.

The tungsten deposits of northwestern Inyo County, Cal., are west of Bishop, the largest town in Owens Valley. The mining industry centers at Deep Canyon, 8 miles from Bishop, where two mines opened on notable deposits of contact-metamorphic ore have recently been brought to the producing stage.

Deep Canyon traverses an isolated group of hills that project through the glacial and alluvial deposits at the base of the Sierra Nevada. Similar groups of hills farther south in Owens Valley are known by distinctive names, such as the Alabama Hills, and the name Tungsten Hills is here suggested for the group in which the principal tungsten deposits have been found. The average altitude of the hills is 6,000 feet, about 1,500 feet above the floor of Owens Valley, but they are dwarfed into insignificance by the mighty range behind them, which towers to altitudes of 13,000 feet.

Tungsten has been found also in the Sierra Nevada itself, southwest of Bishop. The tungsten-bearing area, so far as now known, extends from the north slope of the Tungsten Hills to the mouth of Shannon Canyon, 11 miles south of Bishop. The topography of the area is shown in figure 23, which is based on the maps of the Bishop and Mount Goddard quadrangles, both of which are on a scale of 1:125,000, or approximately 2 miles to the inch.

The mining conditions are favorable: the climate is good, water is easily obtained, transportation facilities are adequate, and an electric transmission line traverses the belt, so that power is readily available. Timber, however, is lacking. The tungsten area adjoins a rich agricultural district.

The tungsten deposits were briefly examined by me in June, 1916. To Mr. L. E. Porter I am especially indebted for courtesies during this examination. In preparing the present report I have drawn in part upon information obtained by me in 1913 during a reconnaissance of the Sierra Nevada slope between McGee and Haiwee creeks, west of Owens Valley, the results of which are now being prepared for publication by the Geological Survey.

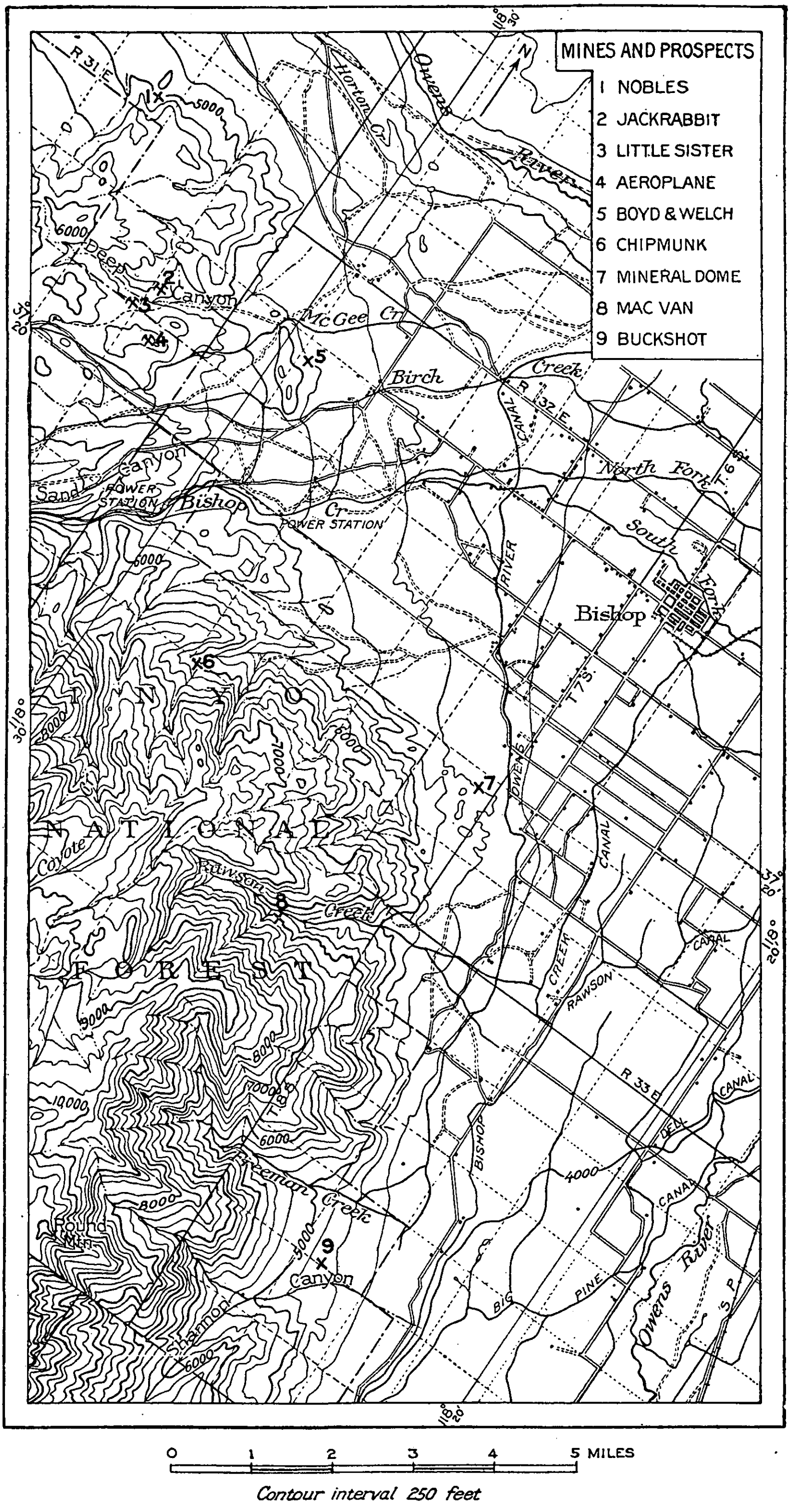

FIGURE 23.—Map of the tungsten-bearing area in northwestern Inyo County, Cal., and vicinity.

DISCOVERY AND DEVELOPMENT.

Tungsten ore was found in place in August, 1913, on the Jackrabbit claim, near the present center of mining activity. The discovery was the result of careful prospecting, though it was eventually hastened by chance. Three partners, who were mining placer gold in Deep Canyon, found that the concentrates they obtained were difficult to clean because a heavy white mineral persistently accumulated in considerable amount with the gold. The troublesome material proved to be scheelite; and when its identity and value were known, search was soon begun to find it in bedrock. After all the quartz float in the area adjoining Deep Canyon, so it is reported, had been broken open in vain during the course of a year and a half, the scheelite was finally found in its rock matrix by J. G. Powning, who while out hunting recognized the long-sought mineral in an outcrop of garnet rock on which he had just shot a rabbit, an adventitious circumstance to which the discovery claim owes its name. The scheelite is here embedded in the blackish garnet rock as particles that are somewhat larger than are common in the ore bodies of the district, but it must be said that the scheelite is neither so prominent nor so obviously recognizable that it would have been found had it not been the special object of search. The discovery that the scheelite occurs in the garnet rock, however, reduced prospecting for tungsten to a very simple matter. The blackish garnet masses on the bare hills contrast noticeably with the prevailing gray and reddish granite and are therefore easily recognized; they were soon staked and then tested for tungsten. In this way ore was found at many places. As a rule the scheelite is so inconspicuous that the largest ore body, although it crops out prominently, was at first unfavorably reported on by competent engineers, from sheer failure to ascertain its trend and consequently its width and length.

Early in 1916, when the price of tungsten ore reached an extraordinary level, outside capitalists became interested in the development of the claims. The Standard Tungsten Co. acquired the Aeroplane group of six claims, work began on April 7, and by June 7 a mill having a daily capacity of 30 to 50 tons began crushing ore. During this short time roads were constructed, a tunnel and drifts were driven, a mill was built, and electric power was brought in from Bishop Creek. The Tungsten Mines Co., owning 14 claims, commenced development work on May 1 and by the middle of July had completed a 300-ton mill and had energetically explored its main ore body. About 125 men were being employed at these two mines at the time of visit. Below the mill of the Tungsten Mines Co. Deep Canyon widens out, and here the town site of "Tungsten City" has been laid out.

The development of the deposits on Deep Canyon has greatly stimulated prospecting for tungsten in the region west and southwest of Bishop. All garnetiferous rock is carefully examined and panned, with the result that scheelite-bearing rock has already been found at a considerable number of places. The development work done or in progress is small, however, except at the two producing mines.

OUTLINE OF GEOLOGY AND ORE DEPOSITS.

The prevailing rocks of the tungsten-bearing area are granitic. Two varieties occur in about equal amounts—the older a quartz monzonite and the younger a coarse, white granite practically barren of dark minerals. Both, however, belong to one epoch of intrusion and are parts of the great granitic masses that make up the east slope of the Sierra Nevada. They are of late Jurassic or early Cretaceous age. Besides these dominant granitic rocks there are basic modifications of them, such as quartz diorite, which are of small areal extent and commonly occur near the tungsten-bearing deposits. Narrow dikes of aplite also occur at some places.

Scattered through the granitic rocks are masses of sedimentary rocks ranging in size from a cubic yard to cubic acres. They are remnants of the roof that formerly extended as a continuous cover over the granites. Under this roof the molten granitic magmas came to place and cooled; the roof rocks became highly metamorphosed as a result of the high temperatures to which they were subjected and of the hot gases that permeated them. Strata of limestone occurring in these roof rocks were particularly susceptible to chemical reaction with the gaseous emanations, and where these emanations carried tungsten they fixed it as scheelite, together with garnet, epidote, amphibole, and quartz.

Erosion has since cut deeply into the region, destroying the continuity of the sedimentary roof and leaving as isolated remnants only those portions of it that projected down more deeply into the underlying granite.

The east slope of the Sierra Nevada, as has long been known, is a great fault escarpment whose main features were produced at the beginning of Quaternary time. West of Bishop it is extremely steep, being, in fact, surpassed at few places in height and precipitousness. A few miles to the south its general southeasterly alignment is offset 8 miles to the northeast. The Tungsten Hills are situated in the angle produced by this jog in the fault escarpment, and they appear to represent a fault block that has not been depressed as deeply as the remainder of the floor of Owens Valley. As the present summits of the Tungsten Hills probably coincide roughly with the general level of the batholithic contact of the granites and the rocks they invaded, this subsidence accounts for the fact that this contact surface is from 3,000 to 4,000 feet lower here than it is in the Sierra Nevada proper a few miles to the west and southwest. These relations, though important to an understanding of the geologic history of the region, are hardly germane to the immediate problems of the ore deposits and will not be further considered here.

GENERAL GEOLOGY.

PREGRANITIC ROCKS.

CHARACTER AND DISTRIBUTION.

Although granitic rocks prevail in the tungsten area, sedimentary strata are scattered throughout the area in small masses, which range in size from a cubic yard to cubic acres. Economically they are the most important rocks, for they are the repositories of the tungsten ores. They are highly metamorphic, and their sedimentary character is therefore obscure. Originally they comprised in the main limestones, sandstones, and calcareous rocks, but as a result of the action of the heat and vapors that accompanied the granitic intrusions they were recrystallized, and a great variety of "contact rocks" or hornfelses was produced. The metamorphosed sandstones have largely retained their siliceous appearance, though specked with innumerable minute flakes of shimmering mica; the metamorphosed calcareous rocks—the calc-hornfelses [1]—are light gray, fine grained, and notably heavy. Most of these metamorphic rocks require microscopic examination in order to determine their mineral make-up with certainty. Some of them have been thus examined and are here mentioned briefly. The rocks of main interest in connection with the tungsten deposits are the limestones, which have been either altered to garnet and allied silicates, with which accessory scheelite is associated, or rendered coarsely crystalline—marbleized, as it is termed. Such marbleized limestones occur in considerable volume in some of the masses. They still exhibit their stratification, and in all places examined they show that the rocks are standing on edge.

Scattered through some of the contact-metamorphic sandstone on the Aeroplane group of claims are conspicuous prisms of black tourmaline. Under the microscope the matrix of these prisms proves to consist of an intergrowth of quartz, muscovite, biotite, and graphite. This tourmaline, however, is the only occurrence of the kind noted in the district, and none is found in the tungsten ore bodies.

Sillimanite schist occurs in the western part of the sedimentary mass in which the largest tungsten deposit of the district is inclosed.

---

[1] Such rocks are commonly called "lime-silicate rocks," but J. S. Flett in a systematic account of the hornfels group (Encyclopedia Britannica, 11th ed., p. 711, 1910) terms them "calc-silicate-hornfelses." This term is here abbreviated to calc-hornfelses.

The schist is associated with quartzite, siliceous grits and conglomerates, and limestones. It is a faintly schistose white rock, containing numerous particles of quartz; all in all it strongly resembles a dynamically altered rhyolite. Under the microscope it is found to consist of quartz, muscovite, and sillimanite. Some of the particles of quartz are much larger than the remainder, thus giving the schist its illusive porphyritic aspect. Sillimanite is scattered through the schist as a multitude of fibers in random orientation. From these determinations it is clear that the sillimanite schist was originally a siliceous grit. Its occurrence here is of some interest, inasmuch as the formation of sillimanite appears to require the highest temperature that prevails during contact metamorphism.

The calc-hornfelses include a number of varieties, ranging from dense fine-grained rocks resembling cherts or felsites to coarsely granular rocks. The fine-grained varieties consist of intergrowths of diopside, wollastonite, plagioclase, and garnet in various proportions; the coarsely granular varieties consist mainly of andradite garnet and epidote. An unusual variety, composed wholly of coarse vesuvianite, occurs near the Aeroplane ore body.

The age of these rocks is unknown, but they are believed to include strata ranging from Cambrian to Triassic. Cambrian fossils have been found in a small patch of limestones and sandstones, intruded by granite and aplite, west of the town of Big Pine and 4 miles south of the southernmost tungsten deposit yet known in the district. At the north end of the district considerable andesite, much altered by thermal metamorphism, occurs in a large remnant of pregranitic rocks. As andesites occur only with Triassic rocks in adjoining areas, where the stratigraphic record is unusually full, a Triassic age is suggested for this particular patch.

RELATION TO THE GRANITIC ROCKS.

The isolated bodies of limestone and associated contact-metamorphic rocks are remnants of a great mass of sedimentary rocks that once extended as a continuous roof over the granites. Under this cover the granites, working their way up into the lithosphere from unknown depths in the earth, came to place and, slowly cooling, assumed their characteristic coarsely crystalline state. The junction of the granites and roof rock is everywhere found to be of the kind peculiar to igneous contacts, and the position of the roof remnants in respect to the granites surrounding them is in nowise due to faulting.

The undersurface of the roof—that is, the contact of the sedimentary rocks and the underlying granite—was extremely irregular. It was angular in its local details, and in some places masses of sediments projected far downward in the granite, extending thus below the general level of the contact surface. Such masses, which have been called "roof pendants," generally extend down nearly vertically in this region, owing to the fact that in its intrusion the granite tended to rift off blocks of the sedimentary strata parallel to their bedding, which, as already mentioned, is vertical. Some of the smaller sedimentary masses may indeed be such blocks that were thus rifted off and partly sunk in the molten granite. Erosion has now cut down below the general level of the contact surface; it has destroyed the original continuity of the roof and has reduced the roof to a number of isolated remnants, which appear as if scattered through the district in a highly haphazard manner. Erosion has cut down so deep, in fact, that only the tips of the masses that projected farthest downward into the granites have been preserved. These general relations and their effect on the distribution of the ore bodies are shown diagrammatically in figure 24. The thickness of the rock cover under which the granites were intruded is of course unknown and consequently is not shown in diagram *A*; what this thickness was, however, is unessential to the present discussion.

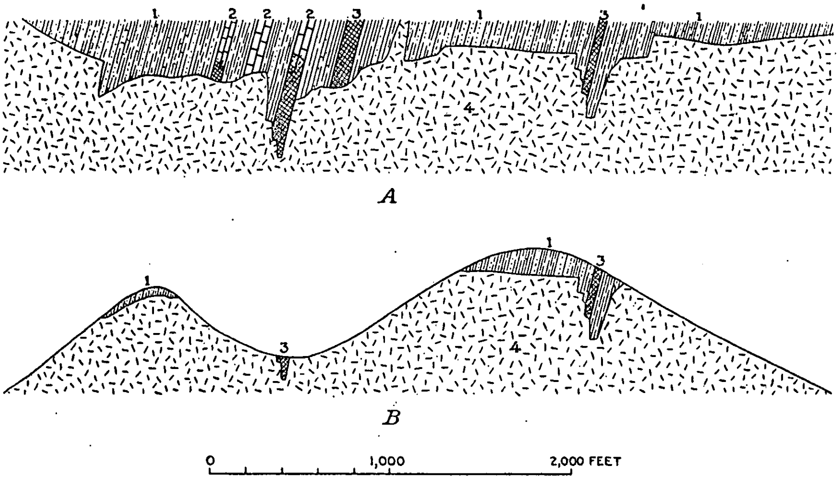

FIGURE 24.—Diagrammatic sections showing the relation of the metamorphic sedimentary rocks and ore bodies to the intrusive granitic rocks of the Tungsten Hills, Cal. *A*, At the time of intrusion; *B*, at the present time, when erosion has removed most of the rocks that formerly covered the granites and has evolved the existing topography. 1, Metamorphic sedimentary rocks; 2, limestone; 3, tungsten ore bodies; 4, granitic rock.

The depth to which the roof pendants extend in the granites that surround them is vital to the future prosperity of the tungsten-mining industry. Some of the masses, as indicated by their topographic relations, persist downward probably for at least 300 feet. As a rough generalization it is likely to prove true that the wider a roof pendant is at the surface the deeper it will be found to project into the granites.

Roof pendants are fairly abundant in the Sierra Nevada west of Owens Valley, especially in the higher parts of the range. Here their spatial relations to the granites are clearly revealed in the great canyons and deep glacial cirques, which show that they project deeply into the granites, some of them extending 1,000 feet or more vertically downward. The largest roof pendant in this part of the Sierra is that between Middle and South forks of Bishop Creek, a few miles west of the tungsten area; it is not only the largest but appears also to project the most deeply into the granite, extending downward at least 2,500 feet. North of Middle Fork it is abruptly constricted, becoming only a few hundred feet wide, but despite its narrowness it persists northwestward for several thousand feet. The Bishop Creek gold mine is in the constricted portion of this roof pendant, and the ore body consists of a narrow band of quartzite carrying disseminated sulphides, principally pyrrhotite but also arsenopyrite, sphalerite, chalcopyrite, pyrite, and molybdenite. The remarkable persistence of this narrow roof pendant, both in length and depth, is of much interest, inasmuch as it suggests by analogy that some of the roof pendants in which the tungsten deposits occur may extend to considerable depths.

GRANITIC ROCKS.

Granitic rocks predominate throughout the tungsten-bearing area. Two varieties—quartz monzonite and granite—occur in about equal amounts. They differ notably in appearance and composition and are easily distinguishable. They are deeply weathered, especially in the main part of the tungsten area—the group of foothills west of Bishop. They have taken on a dull red or rusty orange color and in consequence contrast markedly with the brilliant white granites of the lofty Sierra high above the foothills. As the granitic rocks of the foothills and of the Sierra are portions of the same intrusive masses, this difference in appearance is manifestly due to differences in climatic environment and in the erosion to which they are subjected. In Owens Valley they are in a region whose rainfall is less than 5 inches a year and erosion is nearly at a standstill, whereas in the Sierra they are ceaselessly attacked by erosion. As a result the foothill granites suggest by their appearance that they are far more ancient than those of the Sierra; and to this illusive difference, it may be mentioned in passing, is doubtless due the belief, widely held in Owens Valley, that the foothills of the Sierra Nevada are the "oldest hills in the world."

The quartz monzonite is the oldest of the granitic rocks. It is a coarsely granular aggregate of quartz, orthoclase and andesine in equal amounts, hornblende, and biotite. Rock of this kind, locally more or less modified, makes up a large part of the Sierra Nevada slope west of Owens Valley.

The younger of the two principal igneous rocks of the tungsten area is a coarse white granite. In the Tungsten Hills it occurs in about the same amount as the quartz monzonite, and to the south, in the Sierra

Nevada, as is excellently shown in Rawson Canyon, it occurs in large volume. It is composed almost wholly of albite, quartz, and orthoclase. Biotite in scattered flakes is the only dark mineral and makes up not more than 1 per cent of the granite. A specimen of the granite from Rawson Creek at an altitude of 6,000 feet was analyzed in part in the laboratory of the Geological Survey, with the following results:

Partial analysis of granite from Rawson Creek, Cal.

[R. C. Wells, analyst.]

SiO_2	76.28
CaO	.47
Na_2O	4.72
K_2O	4.73

Specific gravity, 2.615.

Although quartz monzonite and granite predominate throughout the tungsten-bearing area considered as a whole, yet in the immediate vicinity of the main productive deposits—the Aeroplane and Little Sister—the prevailing igneous rock is quartz diorite. It is a rather dark variety, rich in biotite and hornblende, and is of medium to coarse grain. Under the microscope it is found that the component feldspar is andesine ($Ab_{60}An_{40}$) and that quartz occurs interstitially in moderate amount; hence the rock is termed quartz diorite.

The quartz diorite is clearly a local modification of the prevailing quartz monzonite, occurring only in proximity to the sedimentary rocks in which the tungsten deposits are inclosed. It is a basic contact facies, probably due to differentiation induced by the absorption of lime from limestones in the sedimentary roof rocks. Such contact facies do not occur near all the roof pendants, nor, on the other hand, are they in all places so homogeneous and so like normal plutonic rocks as is the quartz diorite on Deep Canyon. Adjoining some of the roof pendants, for example, are coarse hornblende-rich facies, which are irregular in grain and composition.

That the dioritic bodies surrounding inclosed masses of sedimentary rocks have resulted from the absorption of limestone is strongly suggested by the occurrence of similar dioritic fringes around inclusions in the orthoclase-albite granite of Rawson Canyon. Cubic miles of homogeneous granite are exposed in this profound canyon, but a few blebs of diorite, as they may be called, occur in the granite. When examined closely nearly every one of these bodies of diorite is found to inclose a core of garnet-epidote rock; aplite also occurs. It is manifest that the inclusions acted as centers that caused local differentiation of the surrounding granitic magma.

A few narrow dikes of aplite cut the sedimentary rocks of the tungsten-bearing area. They are fine-grained white rocks nearly barren of black minerals and are composed of quartz, microcline, albite, and scattered biotite or hornblende.

ORE DEPOSITS.

OCCURRENCE AND CHARACTER.

Tungsten deposits have so far been found in a belt 20 miles long extending from the north end of the Tungsten Hills to a locality within a few miles of the town of Big Pine. All the deposits are restricted to the isolated masses of metamorphic sediments embedded in the granitic rocks; and they are further restricted within these masses to the intercalated limestones.

The ores are of two main types, garnetiferous and micaceous. Those of the garnetiferous type strongly predominate and form the ore bodies now being worked. They consist largely of garnet, with which, however, some epidote is everywhere associated, and they carry scheelite as a subordinate constituent. Other minerals occur in minor quantities, and from place to place one or another of these is sufficiently abundant to be locally prominent. They include quartz, calcite, hornblende, pyroxene, and, as microscopic constituents, apatite and titanite. In one of the deposits, the largest yet found, quartz is somewhat more abundant than the associated garnet and epidote. Metallic minerals are extraordinarily rare in all the ore bodies: magnetite occurs sporadically in minute quantities, and the sulphides (pyrite, zinc blende, pyrrhotite, chalcopyrite, and molybdenite) occur in traces.

The garnet ranges from amber to dark brown in color, the deeper shades predominating. Under the microscope it generally shows complex birefringent patterns. It evidently varies in chemical composition, the refractive indices of different garnets ranging from 1.79 to 1.82, so that the average garnet may be considered as a variety about halfway between grossularite and andradite. As a rule the epidote is distinguishable from the associated garnet by its characteristic yellowish-green color and by its prismatic form. It appears to be generally a variety high in ferric iron; a specimen from the Aeroplane ore body gave $\gamma = 1.765$, corresponding to a variety containing approximately 15 per cent of ferric oxide. The amphibole, which as a whole is a subordinate component of the ores, is a fibrous variety of grayish-green color; under the microscope it proves to be deeply pleochroic in brown and green, and it is therefore referred to in this report as hornblende. The quartz, generally a very minor constituent, but in the Little Sister ore body highly abundant, is as a rule coarse grained and glassy. Under the microscope it resembles vein quartz, differing, however, in not uncommonly inclosing idiomorphic hornblende and pyroxene. It also incloses crystals of garnet and epidote. Calcite is generally a minor interstitial component, though in some ores it is fairly common and poikilitically incloses all the other constituents. All these minerals, including the scheelite, are of essentially contemporaneous origin, and no definite sequence of crystallization is ascertainable.

The scheelite, a pure milk-white variety, is generally inconspicuous; in fact, in much of the best ore it is not certainly recognizable by the unaided eye. It has a fair cleavage, which distinguishes it from the milk-white quartz that occurs in some of the ore but which heightens its resemblance to the associated calcite. It is true that the trained eye can readily discriminate it from quartz and calcite by the refined distinctions of color, luster, and cleavage, but where the minerals occur in small particles this discrimination becomes impossible and it is necessary to pan the rock to determine its content of scheelite. Unlike the calcite in the ore, the scheelite rarely occurs interstitially between the garnet and epidote of the gangue, but it tends to form well-defined crystals; where it occurs in larger particles this tendency is readily apparent, and the scheelite at one prospect forms fairly good crystals as much as 1½ inches in diameter.

The micaceous tungsten ores are not common, having been found in two prospects only. The magnesian mica phlogopite is the chief gangue mineral in the principal ore body at Nobles camp (see p. 247); and biotite and muscovite, together with magnetite, make up the gangue at the Mineral Dome prospect (see p. 248).

The ore bodies now being worked carry from 1.5 to 2 per cent of tungsten trioxide (WO_3). They range from 20 to 60 feet in width and from 150 to 260 feet in length. The greatest depth at which an ore body has so far been undercut is 200 feet. The vertical range of scheelite mineralization, as exposed by the erosion of Deep Canyon, is at least 700 feet; this range, although determined by the difference in altitude between two deposits, indicates that individual ore bodies may persist to depths of at least 700 feet, provided that the other necessary conditions hold good.

The ore bodies trend parallel to the strike of the inclosing strata. Where metamorphosed sandstone adjoins an ore body, as in the Aeroplane deposit, well-defined walls result and the ore breaks clean from the barren country rock.

Irregular masses of milk-white quartz, in places several feet thick, occur in some of the ore bodies, evidently as the final phase of mineralization. They contain sporadic prisms of epidote but no scheelite.

ORIGIN.

The tungsten ore bodies are clearly of contact-metamorphic origin. As is well known, deposits of the contact-metamorphic group result from the replacement of limestone, which supplies the calcium needed for the growth of the garnet and epidote. That the tungsten deposits of Inyo County originated in this way is not obvious at the larger bodies, inasmuch as no limestone remains; if the deposits resulted from replacement, the limestone strata have been so thoroughly replaced that only a little calcite is left as an interstitial filling in the garnet rock. Some of the smaller deposits, however, give clear evidence as to the nature of the replacement. Near these deposits much marbleized limestone remains, and at the edges of the deposits the garnet and epidote can be seen irregularly interfingering the surrounding white marble. Thin sections cut from marble adjoining these peripheral stringers of garnet show some wollastonite, a mineral nowhere found in the scheelite deposits themselves, and this development of wollastonite is probably due to the fact that at the edge of the deposits the metamorphosing solutions had become depleted in ferric iron.

The granitic rocks adjoin some of the ore bodies and have been profoundly altered along some of these contacts. The most notable alteration is that shown near the southeast end of the Little Sister ore body, where the adjoining diorite has been thoroughly altered to a distance of 5 feet from the contact. The transition from altered to unaltered diorite is abrupt. The altered rock differs conspicuously from the normal diorite, and the most obvious megascopic difference is perhaps its coarsely quartzose composition. Under the microscope it is found to be composed of quartz, monoclinic pyroxene, epidote, and a little residual hornblende. No scheelite appears to have been introduced during this alteration.

The orthoclase-albite granite adjoining the Mineral Dome tungsten deposit, which consists of biotite, muscovite, magnetite, and scheelite, has been altered by the development through it of silvery plates of muscovite at the expense of the potassium feldspar; in short, the granite has been transformed to a moderately micaceous greisen.

These metasomatic alterations of the granitic rocks adjoining the ore bodies show that the ores were formed at some time after the surrounding granites had consolidated. That tungsten mineralization followed the intrusion both of the quartz monzonite and of the granite is shown by the fact that the limestones embedded in the quartz monzonite and those in the granite are similarly mineralized. If the mineralization had followed only the later intrusion, fissures should be found leading to the limestones embedded in the earlier quartz monzonite, but such fissures have not been detected.

The minerals formed in the ore deposits indicate that the mineralizing solutions were active at high temperatures, probably so high that the solutions were in the gaseous state; and they show further that the solutions were rich in silicon, aluminum, and ferric iron, were poor in sulphur, and carried tungsten, which was fixed by the calcite in the limestones as calcium tungstate (scheelite).

COMPARISON WITH OTHER DEPOSITS.

The contact-metamorphic group of ore deposits has become well known in recent years. Lindgren[1] classifies the group into seven principal types, all of which, except the chalcopyrite and magnetite deposits, are distinctly rare. Tungsten deposits are not recognized in this classification.

Scheelite has been known for some time to occur as a minor constituent of contact-metamorphic rocks in Finland,[2] Japan,[3] Alaska,[4] New Mexico,[5] and probably other localities. The scheelite deposit at Trumbull, Conn.,[6] should probably be mentioned here. The scheelite occurs in a quartz-zoisite-epidote-hornblende rock, but the mine has never been commercially productive. In some of the Japanese deposits the scheelite, which is associated with garnet and chalcopyrite, forms crystals as much as 4 inches in diameter.

Only in recent years, however, have deposits of contact-metamorphic origin been found that carry sufficient scheelite to make them commercially valuable as tungsten ores. The earliest recognized ore body of this type appears to be that near Toy (formerly Browns), Humboldt County, Nev.[7] This deposit became commercially productive late in 1915.[8] Similar ore bodies have lately been found in the same county, and the Ragged Top mine commenced to produce ore in 1916. The field occurrence of these deposits has unfortunately not yet been described.

The tungsten ore bodies of northwestern Inyo County, Cal., are, as will be seen from the foregoing statements, important additions to the number of recognized contact-metamorphic scheelite deposits; and they appear destined to contribute notably to the tungsten production of the United States.

PRACTICAL DEDUCTIONS.

The persistence of the tungsten deposits in depth is the problem most vital to the future of the district. Because the deposits are restricted to limestones jutting down into the embedding granites and because of the mode of origin sketched in the preceding pages it is clear that in no deposit can ore be assumed with much confidence to extend below the deepest level opened. I do not mean to say

---

[1] Lindgren, Waldemar, Mineral deposits, p. 682, 1913.

[2] Trüstedt, Otto, Die Erzlagerstätten von Pitkäranta: Comm. Geol. Finlande Bull. 19, p. 327, 1907.

[3] Fukuchi, Nobuyo, Mineral parageneses in the contact-metamorphic ore deposits found in Japan: Beitr. Mineralogie Japan, No. 3, pp. 87, 89, 93, 94, 1907.

[4] Knopf, Adolph, Geology of the Seward Peninsula tin deposits, Alaska: U. S. Geol. Survey Bull. 358, p. 38, 1908.

[5] Lindgren, Waldemar, The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 47, 52, 1910.

[6] Hobbs, W. H., The old tungsten mine at Trumbull, Conn.: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 13-22, 1901.

[7] Hess, F. L., Tungsten [etc.]: U. S. Geol. Survey Mineral Resources, 1908, pt. 1, p. 724, 1909.

[8] Hess, F. L., Tungsten minerals and deposits: U. S. Geol. Survey Bull. 652 (in press).

that individual ore bodies may not persist to depths of 700 feet or more, but until the continuity in depth is proved by exploration the uncertainty is great. This may sound axiomatic, inasmuch as the persistence of any ore body is more or less uncertain, but for the deposits here described the uncertainty is peculiarly great. The persistence of these deposits in depth depends on two factors—(1) the persistence of the limestone, the indispensable receptacle of the ores, and (2) the range through which the mineralization took place. Erosion has evaluated the second of these factors: it has disclosed the fact that the vertical range of mineralization was at least 700 feet, and there is no reason why the range may not have been considerably greater, although contact-metamorphic deposits, as must be recognized, are characteristically bunchy and irregular. The other factor is highly uncertain: the limestone originally necessary to form the ore may be cut off abruptly at any level below that now seen, owing to the unpredictable irregular nature of intrusive contacts. It is possible, however, that some sedimentary masses may project to considerable depths into the granite, as was pointed out on page 236. The conclusion that inevitably flows from these considerations is that it is not advisable to attempt to undercut the tungsten deposits by tunnels driven much below the lowest level on which ore has been proved to occur; in short, it is not advisable to drive the successively lower tunnels at vertical intervals greater than, say, 100 or 200 feet. It follows also that tungsten prospects situated in small, narrow roof pendants, however rich at the surface, are of very doubtful value; until they have been proved by actual exploration and an adequate amount of ore has been put in sight they will not justify the erection of mills.

Although the recent high prices of tungsten ores were the incentive for the rapid development of the district, nevertheless the principal operators believe that the mines can be profitably worked, even should the prices fall back to the levels prevailing before the European war—about $6 a unit—a possibility that must of course be kept steadily in mind, in view of the enormous world-wide stimulation of the tungsten-mining industry. This confidence in the district is justified by the favorable mining conditions and the amount of ore indicated.

The milling capacity of the district is sufficient, if utilized in full on ore of the grade now worked, to make the annual output of the district equal that of the whole annual output of the United States before the war. Manifestly this rate of production would speedily deplete the known ore bodies, and it appears doubtful whether so large an output could be maintained for a number of years unless other ore deposits in addition to those now worked were found and developed extensively.

Geologic conditions similar to those at Deep Canyon prevail over a wide area along the east slope of the Sierra Nevada. The bodies of garnet rock scattered through the great granite masses that make up this slope are being carefully examined and panned for scheelite by the prospector, and as a result other ore bodies will doubtless be found.

MINES AND PROSPECTS.

The two operating mines and the prospects that were examined during the time at my disposal are described in the following pages, but these descriptions by no means include all the prospects in the district. The locations of the mines and prospects here described are shown in figure 23.

AEROPLANE GROUP.

The Aeroplane group of six claims is owned by the Standard Tungsten Co., the pioneer company in the district. The claims are on the south side of Deep Canyon, and the principal ore deposit is near the top of the hill on which is situated the 6,045-foot bench mark of the United States Geological Survey. The mill is in the canyon about 600 feet below the ore body. It is equipped with a jaw crusher and rolls, and its capacity at the time of visit was from 30 to 50 tons a day, but this is now being increased to 100 tons. During the initial operation of the mill the ore was crushed to 8-mesh and concentrated upon an Isbell table. By this procedure, however, about 35 per cent of the scheelite was lost in the tailings, and the concentrates were not clean, as it proved to be difficult to separate the heavy garnet, whose specific gravity is near 3.8, from the scheelite (specific gravity 6). The ore was then crushed to 14-mesh in order to set free all the scheelite contained in it, and the operation of the table was also changed.

The main tungsten deposit is cut at a depth of 30 to 40 feet by a tunnel 100 feet long. The ore is quarried at the surface and dumped through a grizzly into a chute extending down to the tunnel; from the mouth of the tunnel the ore is dragged in two-wheeled sleds to the mill. It is proposed, however, to build eventually a tramway 1,700 feet long, from the tunnel to the mill.

The prevailing country rock is a medium-grained dark-gray quartz diorite containing much hornblende and biotite. Embedded in this, between the mill and the main ore body, are masses of sedimentary rocks, which were originally sandstones and limestones but are now highly recrystallized as a result of the metamorphic action of the intrusive diorite. Some of these rocks—contact rocks or hornfelses—have been examined microscopically in order to determine their mineral composition. For example, one of the metamorphosed sandstones, occurring on the lower slope of the hill shows conspicuous prisms of black tourmaline and under the microscope is found to consist of abundant muscovite together with biotite and graphite, in addition to the original detrital quartz. The rocks at the summit of the hill, which inclose the main ore body, are mainly calc-hornfelses and limestones. They strike north as a rule and stand on edge. They are cut by a few dikes of aplite, and on the south they are intruded by coarse white granite.

The main ore body is 150 feet long and ranges from 20 to 30 feet in thickness; it averages 1.5 per cent of tungsten trioxide. The ore is scheelite inclosed in a gangue consisting mainly of garnet and epidote. The scheelite appears to be evenly scattered throughout the ore in small particles, few of which exceed a quarter of an inch in size and most of which are much smaller. Although garnet and epidote predominate in the gangue, hornblende is present subordinately, and calcite, quartz, pyroxene, apatite, and titanite occur in minor quantities. The only metallic minerals in the ore are black zinc blende and pyrite; they occur in insignificant amounts only, but as the ore at the surface is somewhat oxidized they may become slightly more abundant in depth.

The ore body trends north and stands nearly vertical, following the stratification of the inclosing rocks. The east boundary is well defined, being marked by a "wall," though it is not a wall in the usually accepted meaning of the term. The wall rock, locally known as porphyry, is a thermally metamorphosed sandstone, consisting largely of an aggregate of quartz grains, throughout which there is a new growth of muscovite and biotite. This siliceous rock was evidently not susceptible to replacement by garnet, epidote, and scheelite and hence now forms a wall to the ore body.

The ore zone ends on the north against fine-grained dense calc-hornfels, resembling chert or felsite. A variety of metamorphic rock made up chiefly of vesuvianite occurs here also. These rocks are cut by a granite dike interlaced with stringers of coarse white quartz. In places the quartz carries crystals of epidote and the granite is altered to a mass of epidote prisms. As exposed at the surface the ore-bearing zone extends farther south beyond the ore shoot, and in the drift on the tunnel level the ore extends somewhat farther south in this zone than it does on the surface. Considerable quartz occurs in the ore zone in places, swelling to masses several feet in size; it carries no scheelite, however.

In addition to the main tungsten deposit, 5 feet of rich ore was crosscut at the portal of the tunnel; in this the scheelite has a sort of porphyritic habit, owing to its occurrence in relatively large distinct crystals. Some isolated masses of scheelite-bearing contact rock have been found several hundred feet north of the main ore body, at an altitude 250 feet lower.

As exposed by erosion the sedimentary rocks that inclose the main ore body have an extreme vertical range of 250 feet; they may project down into the granite this much more in their whole bulk or only parts of the mass may project downward, and this downward-projecting portion may not include the ore-bearing zone. In view of these uncertainties, it is not advisable, in exploring the ore zone in depth, to drive the successive tunnels at vertical intervals greater than 250 feet. The relief between the mill and outcrop of the ore body makes it easy to attain a depth of 600 feet on the ore body by a tunnel, but in view of the origin of the deposit it would be highly incautious to attempt this until more development work in depth has been done.

TUNGSTEN MINES CO.'S CLAIMS.

The Tungsten Mines Co. owns 14 claims, which lie north of those of the Standard Tungsten Co. Development of the property began on May 1, 1916, and was pushed with great vigor, 90 men being employed. Mining work was centered on the Little Sister claim, on which the largest and most easily workable ore body is situated, and the construction of a mill of 300 tons daily capacity was begun. The mill, which was completed by the end of July, is equipped with jaw crushers, rolls, and tables and is planned to operate on a product crushed to 14-mesh. A tramway connects the lower tunnel on the Little Sister claim with the mill, and another tramway is being built to the workings on the Jackrabbit claim, where a body of ore is also indicated.

The main ore deposit on the Little Sister claim is 260 feet long on the surface. It is opened up by two tunnels, one at a depth of 60 feet and the other at 200 feet. A shaft has been sunk in ore from the surface and connects with the upper tunnel. The ore is not conspicuously different from the inclosing country rock, nor in general is its content of scheelite certainly recognizable without panning. The grain of the ore-bearing rock is somewhat coarser, however, than that of the barren rocks; this difference is well shown at the northwest end of the ore body, where dense aphanitic calc-hornfelses appear—rocks that, as Mr. Cooper Shapley, the superintendent, expresses it, are "too tight for ore to live in." A small horse of similar calc-hornfels occurs in the ore body 20 feet southeast of the shaft; it is a heavy fine-grained white rock, which in microscopic section is found to be made up of garnet, pyroxene, and wollastonite.

The upper tunnel at the time of visit had crosscut 60 feet of ore without reaching the farther limit of the ore body. The lower tunnel, according to a late report, has cut the ore body 390 feet from its portal. The ore across the 60-foot crosscut in the upper tunnel averages 2 per cent of tungsten trioxide, but in the last few feet it averages between 3 and 4 per cent.

The ore body is near the east margin of a relatively large mass of metamorphosed sedimentary rocks embedded in quartz diorite. These rocks consist of limestone, calc-hornfelses, sillimanitic quartzite, siliceous conglomerate, and metamorphic shale. They stand vertical. Some narrow dikes of aplite have been injected into them parallel to the stratification. On the summit of the knob, a few hundred feet west of the mine, an intrusion breccia of granite filled with sharply angular fragments of metamorphic sedimentary rock is well shown. The cover of sedimentary rocks has been stripped off the diorite in places, showing that locally it is very thin.

The ore body begins at the southeast corner of the roof remnant and extends 260 feet N. 55° W. At its southeast end it adjoins the diorite, which here has been intensely altered to a quartz-pyroxene-epidote rock, but as it extends northwestward it diverges from the contact, whose trend is slightly more northerly.

The ore crosscut in the upper tunnel consists of scheelite in a gangue of quartz, garnet, and epidote. Black zinc blende, pyrite, and molybdenite occur in minute amounts. The quartz, which is coarse and glassy, dominates in the gangue, giving the ore a characteristic siliceous appearance, and in this respect the ore differs from the other ores of the district. Minor constituents, recognizable as a rule only under the microscope, however, are hornblende, pyroxene, calcite, and apatite. The ore exposed in the upper tunnel is probably somewhat more coarsely granular than the general run of ore along the outcrop. The larger part of the outcropping ore is rather fine grained, and the scheelite it contains is extremely inconspicuous, even in ore rich in this mineral. Such ore resembles so much barren country rock—a resemblance that caused the deposit to be underrated earlier in the history of the district, as only by a systematic campaign of sampling and panning were its course and dimensions determined.

A body of good tungsten ore 10 feet wide crops out about 100 feet southwest of the main deposit but has not yet been prospected.

The company has also done some work on the Jackrabbit claim, where tungsten ore was first found in place in the district. The developments consist of a number of trenches, a shaft, and a short tunnel and drift. The ore differs widely from that on the Little Sister claim, being composed largely of garnet, with accessory scheelite. Minor components are hornblende, quartz, calcite, and pyroxene, any one of which in places may become prominent; at one of the lower trenches, for example, hornblende is a conspicuous component of the garnetiferous rock.

The scheelite-bearing garnet rock at the portal of the tunnel is coarse grained, and the garnets are particularly well crystallized. In the drift beds of garnet rock 8 to 12 inches thick alternate with white calc-hornfels; they strike N. 70° E. and dip 70° S.

The ore body on the Jackrabbit claim is in a mass of metamorphic sedimentary rocks, largely garnetized, separate and distinct from that containing the ore body on the Little Sister claim.

NOBLES CAMP.

At the north end of the Tungsten Hills is a group of claims owned by A. W. Nobles, one of the original three locators in the district. These claims cover one of the largest masses of metamorphosed sedimentary rocks in the hills. The rocks are of many kinds but include much limestone. Some andesite, altered by thermal metamorphism, is associated with the sedimentary rocks. To the southeast coarse white granite is the country rock.

Very peculiar tungsten ore is exposed at the lowermost open cut, where 8 feet of ore, averaging, it is reported on good authority, 4 per cent of tungsten trioxide, has been crosscut. The deposit is a few feet from the contact of the granite and the metamorphic sedimentary rocks in which it is inclosed. The scheelite occurs in a roughly banded rock composed chiefly of dark mica, which the microscope shows is the magnesian variety phlogopite. With the mica are associated a little epidote, quartz, and apatite. In the ore body are small horses of dense fine-grained calc-hornfels.

Southeast of the open cut just described a tunnel, which had been driven a number of years ago to prospect a supposed gold deposit, cuts another belt of scheelite-bearing rock. A drift has been driven on this deposit and some cupriferous tungsten ore, consisting of chrysocolla, quartz, and scheelite, has been taken out. Rock from a shallow pit above the tunnel, supposedly on the outcrop of the deposit cut in the tunnel, is stained by a yellow vanadium mineral.

CHIPMUNK PROSPECT.

The Chipmunk prospect was located in April, 1916. It is at an altitude of 6,000 feet in a nameless canyon in the Sierra Nevada slope, the second canyon south of Bishop Creek. The property consists of nine claims in two groups.

The rock of the lower part of the canyon is the coarse white granite, but that in the vicinity of the prospect is gray quartz monzonite, consisting of quartz, andesine, orthoclase, and biotite. The scheelite deposits occur in a block of sedimentary rocks, largely limestone, embedded in the quartz monzonite. The sedimentary mass is 200 feet wide at its widest part, is several hundred feet long, and as shown by the deep canyon on the northwest, extends downward at least several hundred feet. The limestone, which is marbleized, is cut by a few narrow dikes of aplite.

Scheelite occurs at the southeast end of the sedimentary mass in scattered shoots. The ore is as a rule highly garnetiferous but contains also epidote, hornblende, calcite, and quartz. Scheelite is irregularly distributed through this rock in comparatively large particles, which commonly show the double pyramidal form characteristic of the mineral. Crystals as much as 1½ inches long have been found.

In general the scheelite occurs in larger individuals in this prospect than in any other deposit in the district. Metallic minerals occur in trivial amount and include magnetite, pyrite, pyrrhotite, sphalerite, and chalcopyrite.

MINERAL DOME PROSPECT.

The Mineral Dome prospect is 3 miles south of Bishop. The ore-bearing zone here consists of a belt of garnetiferous rock 600 feet long and in places at least 50 feet wide. It lies at the foot of a granite ridge and extends along the edge of the alluvium and the granite. Granite sand and immense granite bowlders have slid over the ore-bearing zone and nearly conceal it.

The ore-bearing zone trends westward. Near its east end the zone is cut by a short tunnel, which penetrates the orthoclase-albite granite bounding it on the south. The granite has been somewhat altered by the growth of muscovite through it, and is slightly seamed with micaceous veinlets; such granite is said to pan gold. The tunnel shows, besides garnetiferous rock and limestone, a 4-foot layer of micaceous tungsten ore. The ore layer dips southward at a low angle, terminating against the granite. The ore consists of scheelite in an intergrowth of biotite, muscovite, magnetite, quartz, and epidote. Some chrysocolla and chalcopyrite occur in places in the ore.

The other development work done on the prospect consists of three trenches dug across the width of the ore-bearing zone. They expose garnetiferous rock locally rich in scheelite.

MACVAN CLAIM.

The MacVan claim, located in May, 1916, is 1½ miles up the canyon of Rawson Creek. The general country rock is coarse white granite, within which are some small bodies of diorite. In the heart of these diorite masses are small inclusions of metamorphosed limestones, most of them not over a few cubic yards in volume. The metamorphic rock consists of garnet and epidote and carries a little quartz and scheelite of sulphur-yellow color.

BUCKSHOT PROSPECT.

The Buckshot prospect, on the north side of the mouth of Shannon Canyon, is 11 miles south of Bishop. A knob of bedrock, about 300 square feet in areal extent and 30 feet high, projects here through the alluvium at the base of the Sierra. It had been slightly prospected for gold in years gone by.

The knob consists of a series of coarsely crystalline limestones standing on edge and abutting on the north against a rudely crescentic outcrop of granite. Along this contact there has been intense metamorphism, resulting in the formation of epidote-hornblende rocks. The granite is as a rule highly epidotized, and in places it is impossible to distinguish altered limestone from altered granite.

The ore, which in places is of extremely high grade, consists of scheelite, of rather idiomorphic habit, in a gangue composed principally of epidote, hornblende, calcite, and quartz. Under the microscope chlorite, pyroxene, garnet, magnetite, titanite, and apatite are found to occur subordinately. Pyrite is a rare constituent. Between the ore and the granite there are in places irregular masses of epidote-bearing quartz, which carry sporadic scheelite. Two shoots of ore are recognizable; they extend into the limestone for a distance of about 20 feet from the contact.

The Buckshot prospect is near the southernmost limit of the tungsten belt, so far as now known.

SUMMARY.

Tungsten deposits were found in northwestern Inyo County, Cal., in 1913 but remained practically unknown until the spring of 1916, when they began to be energetically developed. By midsummer two mills, having a total daily capacity of 400 tons, had been completed and were in active operation.

The ore consists of scheelite associated mainly with garnet, epidote, and quartz. The country rock is prevailingly granitic, but in it are isolated masses of limestone which became mineralized shortly after the granitic rocks were intruded. The limestones were altered to masses of garnet carrying subordinate scheelite by the metallic vapors then given off, and these altered rocks are the tungsten deposits now under exploration. The ore bodies that are being mined are from 20 to 60 feet wide and from 150 to 260 feet long. They carry from 1.5 to 2 per cent of tungsten trioxide (WO_3). The area in which scheelite-bearing deposits have been found roughly forms a belt 20 miles long, but it is likely that the prospecting now going on will extend the dimensions of the field.

These deposits, like those discovered in recent years in Humboldt County, Nev., belong to the contact-metamorphic class, a well-known source of copper and iron but not widely recognized as a possible source of tungsten.

INDEX.