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BERYLLIUM AND TUNGSTEN DEPOSITS OF THE IRON MOUNTAIN DISTRICT SIERRA AND SOCORRO COUNTIES NEW MEXICO

BY
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WITH A SECTION ON THE BERYLLIUM MINERALS

BY
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ABSTRACT

Beryllium and tungsten deposits of contact-metamorphic origin occur in the Iron Mountain district, in northwestern Sierra County and southwestern Socorro County, N. Mex. They are in irregular bodies of iron-rich silicate rock (tactite) formed by replacement of Paleozoic limestone and calcareous shale, generally at or near contacts with small intrusive masses of rhyolite, granite, and aplite, probably of mid-Tertiary age.

Most of the beryllium is in the complex silicate mineral helvite, but some occurs as a minor constituent of grossularite garnet, idocrase, and chlorite. All these minerals occur chiefly in a layered variety of tactite, to which the name "ribbon rock" has been given, but partly in strongly mineralized shear and breccia zones in earlier-formed, thick-bedded magnetite-garnet tactite. Fluorite and magnetite are the principal constituents of the beryllium-bearing rock, which forms thick pods, pipelike masses, and thin tabular bodies. The "ribbon rock" appears to have been formed through replacement of limestone by iron-rich solutions that entered along fractures, and the rhythmic layering is interpreted as a diffusion effect.

The amount of beryllium-bearing tactite that can actually be measured is small, but detailed mapping and preliminary sampling of the deposits by the Geological Survey, followed by extensive exploration and sampling by the Bureau of Mines, indicate a reserve of about 3,500 tons of higher-grade, magnetite-rich "ribbon rock" and 84,000 tons of lower-grade, silicate-rich "ribbon rock." The average BeO content of the magnetite-rich material, in which all or nearly all of the beryllium occurs in the mineral helvite, is probably about 0.7 percent, and that of the silicate-rich tactite, in which the beryllium is distributed among several

minerals, is about 0.2 percent. Indicated reserves of the two classes would thus correspond to approximately 204 and 1,400 tons, respectively, of beryl concentrates containing 12 percent BeO. In addition there are inferred reserves of roughly 1,000 tons of the higher-grade and 100,000 tons of the lower-grade "ribbon rock." These tonnages are thought to be near the maximum obtainable in the district, for the high-tonnage deposits of "ribbon rock" are cut off at shallow depth by igneous rock, and prospects for the discovery of new deposits are not good. The low grade of most of the Iron Mountain tactite and the difficulties involved in its metallurgical treatment appear to preclude its successful competition with beryl ores as a current source of beryllium, even though byproduct fluorite and magnetite might be recovered during its treatment.

"Ribbon rock" may be a useful guide in searching for beryllium-bearing contact deposits elsewhere. As beryllium occurs in "ribbon rock" but not, as a primary constituent, in typical massive tactite, beryllium compounds in contact deposits may be confined to rocks of dominantly hydrothermal origin. Close scrutiny of the hydrothermal portions of other contact deposits, particularly those of mid-Tertiary age in the southwestern states, may thus bring to light other occurrences of beryllium.

The tungsten minerals at Iron Mountain are scheelite and powellite, which occur most commonly as disseminations or fracture fillings in massive-bedded magnetite-garnet tactite. The ore bodies are generally small, but many contain relatively high-grade material. Most of them are adjacent to igneous contacts, at the intersections of two or more well-developed sets of joints or shear planes. Reserves of indicated and inferred ore are estimated as approximately 9,100 tons containing from 0.5 to 2.0 percent of WO_3. This total does not include some 9,500 tons of mineralized material in the Lucky Strike area that appears to be too low in grade to be regarded as ore. Even what is reckoned as ore is too low in grade, except for a few rich shoots in three deposits, to be shipped without milling; and construction of a small, carefully located mill in the district might be justified by the indicated tonnages and the possibility of developing additional ore. None of the tungsten-bearing tactite should present very serious milling problems.

INTRODUCTION

Beryllium and tungsten deposits of contact-metamorphic origin are numerous in the Iron Mountain district, an area that embraces about 15 square miles in northwestern Sierra County and southwestern Socorro County, N. Mex. (fig. 9). Mineralization appears to be chiefly confined to Iron Mountain itself, a narrow, elongated fault-block ridge that forms the northern end of the Sierra Cuchillo, and most of the deposits can be reached by trail or tractor road from a semipermanent camp, known as Brown City, at the base of this mountain. A 2-mile side road, which extends westward down a pediment slope, connects this camp with State Highway 52, a dirt and gravel road that leads 10 miles south to Winston, the nearest town. Hot Springs, on the Rio Grande 30 miles by airline southeast of Iron Mountain, is reached from Winston by way of 31 miles of fair gravel road and 9 miles of the paved U. S. Route 85; and Magdalena, 48 miles by airline to the north-northeast, by 54 miles of State Highway 52 and 21 miles of the oiled U. S. Route 60. Hatch is 40 miles south of Hot Springs by paved highway. Branch lines of the Atchison, Topeka, & Santa Fe Railway serve Magdalena and Hatch. Engle, a small station on the Albuquerque-El Paso line of the same system, lies 19 miles east of Hot Springs, but much of the intervening road is in poor condition.

Despite its altitude of 7,000 to 8,000 feet; the district rarely has winter weather severe enough to interfere with mining activity. Transportation is impeded only for brief periods immediately following the few heavy downpours characteristic of the

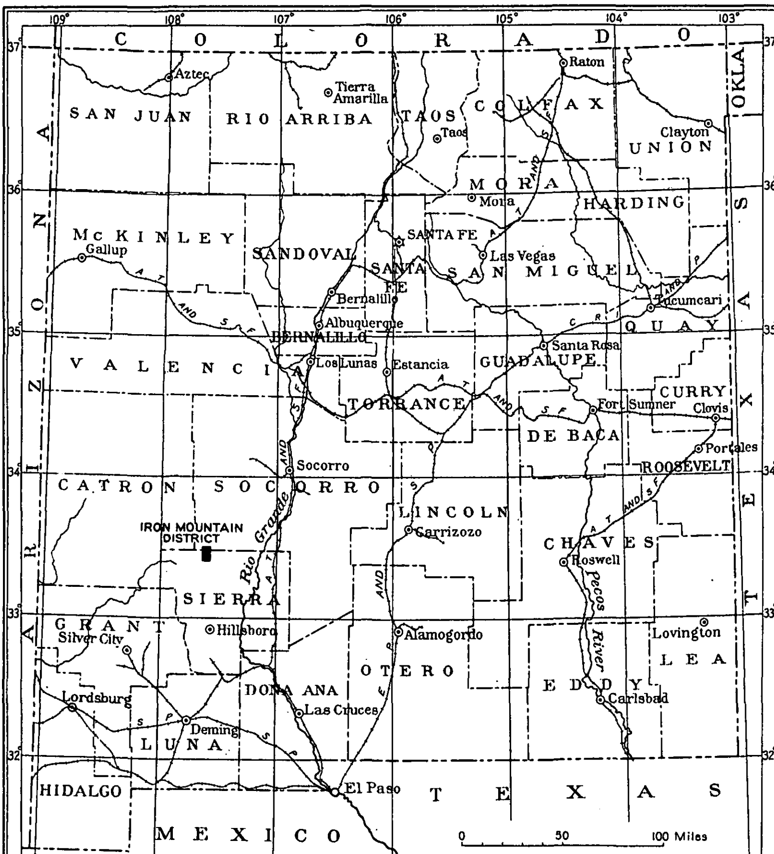

Figure 9.—Index map of New Mexico showing location of Iron Mountain district.

late summer and fall months. Owing to the general dryness of the region, all water must be obtained from relatively deep wells or hauled for distances of 7 miles or more. Whether such wells can supply sufficient water for mining and milling operations is not known.

The magnetite deposits of the northern Sierra Cuchillo have attracted the attention of prospectors for almost a century; and the late T. K. Scales of Winston spent many years in repeated attempts to exploit the area for its iron, gold, and base metals. A few tons of oxidized lead-copper ore is said to have been shipped by Scales and his associates from small deposits in the southern part of the district during the period 1880-1925, but this is the only production recorded up to the present time. About 20 years ago T. C. Parker relocated several old claims that had been permitted to lapse, and in searching these for zinc, gold, and fluorspar he noted with interest a peculiar garnetlike mineral that he was unable to identify. In November 1941 L. W. Strock,1/ during an examination of ores from claims held under option by the Saratoga Mining Corporation of Saratoga Springs, N. Y., determined the mineral, with the aid of the spectrograph, as helvite, a complex silicate-sulfide species containing beryllium, manganese, iron, and zinc. It was not until then that the potentialities of the district as a source of beryllium were first suspected.

Interest in the district was quickened in June 1942, when Parker discovered promising occurrences of tungsten ore. Five claims were sold outright to Continental Machines, Inc., of Minneapolis, Minn., and control of additional ground was acquired by several groups (see pl. 16). Since July 1942, Continental Machines, Inc., has been engaged in exploratory work, and from one deposit it has shipped several hundred tons of tungsten ore to a small mill recently erected near El Paso. Blanchard Hanson, discoverer and owner of a tungsten deposit in the southern part of the district, has done some exploring, but none of the other claim owners has been very active.

The Geological Survey was engaged in detailed examination and mapping of the deposits from May 5, 1942, to May 1, 1943, and thus has been able to follow closely the development of the district and to participate in the discovery of several ore bodies. A topographic and geologic map of the district was made on a scale of 1 inch = 1,000 feet with use of a barometer, hand level, and aerial photographs obtained from the Soil Conservation Service; several larger-scale maps were made with plane table and telescopic alidade. Forty-one systematic samples and 23 specimen samples collected by the writer and his assistants were examined petrographically in the field and analysed for beryllium and tungsten by chemical or spectrographic methods in the laboratories of the Geological Survey. Jewell J. Glass has studied the mineralogy of the ore bodies in detail, and has identified many of the minerals in the surrounding rocks. The writer has made only preliminary petrographic examinations of the rocks. The Federal Bureau of Mines explored and sampled the deposits during the period from June 1942 to May 1943.

Cordial hospitality was shown by several claim owners and their representatives, including Messrs. Blanchard Hanson, A. H. Gunnell, and L. A. Wilkie, and L. A. Wilke of Continental Machines, Inc., and especially by Mr. T. C. Parker. Many courtesies were received from Mr. and Mrs. H. R. Johnson of Winston and from other local residents too numerous to mention. Profs. S. B. Talmage and A. C. Walter, of the New Mexico School of Mines, and Ian Campbell and J. P. Buwalda, of the California Institute of Technology, kindly provided facilities for laboratory and library work. The cooperation of Mr. F. A. Rutledge, engineer in charge of exploration by the Federal Bureau of Mines, and the many courtesies received from all members of the Bureau party are greatly appreciated. W. Porter Irwin served ably as field assistant during the summer of 1942. L. A. Wright, who was assigned to the project through the winter of 1942-43, was in charge of the geological field work during the course of the diamond drilling by the Bureau of Mines. S. G. Lasky of the Geological Survey

1/ Strock, L. W., A new helvite locality—a possible beryllium deposit: Econ. Geology, vol. 36, pp. 748-751, 1941.

contributed stimulating discussion in the field and F. C. Calkins examined and criticized the manuscript.

GEOLOGY

Iron Mountain has been briefly described by Smythe,2/ Lasky,3/ and Harley.4/ Together with its extensions it forms a narrow, north-trending block of the basin and range type, 3½ miles long and 1,000 to 3,000 feet wide, rising 300 to 700 feet above the adjacent valleys (pl. 17). It is delimited from a valley on the west and north by a well marked fault zone, and from a rugged region to the east and south by a more irregular group of faults. These fault zones, along which the Iron Mountain block has been uplifted, converge to the north, meeting near the end of the range, and they also converge to the south and meet near Goat Canyon (pl. 17).

The distribution of the rocks in the district is shown in plate 17. Although the northern part of the Sierra Cuchillo is shown on all published maps as a great mass of volcanic rocks, the Iron Mountain block and the area immediately adjacent on the east present a rather complete section of eastward-dipping upper Paleozoic sedimentary beds, as well as local Mesozoic strata. The oldest rocks in the district are limestones, quartzites, and shaly beds of the Magdalena group, which is of Pennsylvanian and Permian age. These are successively overlain by red beds and limestones of Permian age, sandstones and conglomerate of Cretaceous age, and shale that is probably Cretaceous. Unconformably upon the sedimentary rocks lies a thick Tertiary volcanic series, which consists, in ascending order, of andesitic breccia, andesitic and latitic lavas and tuffs, felsite, and rhyolite with associated pyroclastics. Sills, dikes, and pluglike bodies of Tertiary monzonite, rhyolite, fine-grained granite, and aplite cut all the sedimentary units and at least the lower members of the volcanic series. The valley area west and north of the range is underlain by coarse, poorly consolidated sediments of late-Tertiary and Quaternary age.

Sedimentary rocks

Magdalena group.—Beds of the Magdalena group (chiefly of Pennsylvanian age) are exposed in the western part of Iron Mountain along a belt half a mile wide, where they dip rather uniformly at moderate angles to the east and east-northeast (pl. 17). The eastern face of the mountain is thus essentially a dip slope, and the edges of the Magdalena beds appear on the bold western face of the Iron Mountain block. The sedimentary series, which is about 1,400 feet thick, is best exposed in the southern part of the district, where it is least affected by metamorphism. It consists predominantly of slabby to thick-bedded non-magnesian limestone, much of which is cherty. At the base of the series, however, is 120 feet of white to brownish vitreous feldspathic quartzite and quartz-rich conglomerate, which is overlain by

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2/ Smythe, D. D., A contact metamorphic iron-ore deposit near Fairview, N. Mex.: Econ. Geology, vol. 16, pp. 410-418, 1921.

3/ Lasky, S. G., The ore deposits of Socorro County, N. Mex.: New Mexico School of Mines Bull. 8, pp. 138-139, 1932.

4/ Harley, G. T., The geology and ore deposits of Sierra County, N. Mex.: New Mexico School of Mines Bull. 10, p. 118, 1934.

about the same thickness of tan to dark-brown shaly strata. Local interbeds of quartzite and calcareous shale occur higher in the section.

Younger pre-Tertiary rocks.—The Magdalena group is overlain with slight unconformity by the Abo sandstone, of Pennsylvanian or Permian age, which in turn is overlain conformably by limestones and red beds of the Yeso and San Andres formations, of Permian age. These rocks are well exposed east and southeast of the Iron Mountain block, and, like the Magdalena, they dip in general to the east and east-northeast. Their total thickness is at least 2,400 feet. The Abo consists mainly of tan to maroon sandstone and shaly sandstone, and the younger formations chiefly of fine-grained, dark-gray limestone and reddish sandstone. Resting with distinct unconformity on these rocks is a thin series of shale, sandstone, and conglomerate beds of probable Upper Cretaceous age; 50 feet of reddish shale lies on these beds 1.7 miles southeast of Brown City (pl. 17).

Tertiary and Quaternary deposits.—The coarse-grained, poorly consolidated sedimentary beds that underlie the valley area west and north of Iron Mountain are probably equivalent to the Santa Fe formation, exposed in the Rio Grande Valley to the east. They are generally in fault contact with the older rocks; immediately east of Iron Mountain, for example, they are preserved in a downfaulted block (pl. 17). These upper Miocene and Pliocene beds have been veneered with coarse, loose Quaternary gravel. Narrow strips of Recent alluvium lie along the bottoms of arroyos and washes that have been cut into the pediment surfaces.

Igneous rocks

Volcanic rocks.—A great eastward-dipping series of Tertiary volcanic rocks several thousand feet in thickness flanks the sedimentary belt on the east. In the area shown in plate 17 the series consists of andesitic breccia, andesite, latite, and tuffaceous beds of andesitic and latitic composition. These volcanics are cut by dikes of intrusive rocks with which the mineral deposits in the Iron Mountain block to the west are genetically associated, and hence are older than the mineralization.

Intrusive rocks.—The oldest intrusive rock in the district is an extremely fine grained, homogeneous, white to pearl-gray monzonite, in which the component mineral grains are not readily discernible without the aid of a microscope. It consists chiefly of lathlike plagioclase feldspar (andesine to labradorite), stubby grains of orthoclase feldspar, and much accessory diopside and clinozoisite; its composition over large areas indicates that it has digested considerable quantities of limestone. This rock is resistant to weathering and forms Reilly Peak, one of the highest mountains in the district. The Reilly Peak mass is a large, irregular intrusion that has split apart and engulfed several hundred feet of Magdalena strata, and it is traceable northward into a thick sill (see pl. 17). Elsewhere the monzonite forms much thinner sills and dikes, most of them not shown on the map.

Rhyolite, some of it coarsely porphyritic, occurs throughout the district as plugs and dikes, which generally cut across the bedding of the enclosing rocks. Most of the dikes dip steeply to the west or southwest. The rhyolite is dark gray to greenish gray where fresh, but weathers to a striking pink or reddish brown. It commonly forms ridges and irregular crags that stand distinctly above the surrounding areas. The larger intrusive bodies consist chiefly of very coarsely porphyritic rhyolite, in which numerous half-inch phenocrysts of orthoclase and smaller rounded masses of quartz occur in a fine-grained groundmass. The rock forming most of the smaller dikes is very fine grained and homogeneous; its few phenocrysts are mostly of quartz.

Most of the dikes and elongate plugs occupy fracture or fault zones, but are themselves little sheared. Primary flow structures, marked by layers of differing texture or color or by a crude orientation of feldspar phenocrysts, are common in the dikes, but are faint or unrecognizable in the larger bodies. The rhyolite cuts monzonite along the east slope of Reilly Peak and on the ridge between Goat and Campsite Canyons.

Large irregular sill-like masses of light-gray to flesh-colored, fine-grained granite and thin sills and dikes of aplite are common in the Iron Mountain block, but appear nowhere else in the area. They occur along the west face and at the extreme north end of the range, where the granite forms many small cliffs. This rock, which is almost wholly an even-grained intergrowth of quartz and orthoclase with subordinate biotite, is coarsest in the North End area, where its average grain size is a millimeter or more. It is cut by numerous irregular dikelike masses of bluish to milk-white quartz, but few pegmatite bodies have been observed. Faint flow structures are indicated by the orientation of biotite flakes and feldspar crystals; those near the borders of the intrusions tend to conform to the adjacent contacts. Dikes of granite and aplite cut the rhyolites and locally contain inclusions of them.

Local zones of fracturing and brecciation in the monzonite, rhyolite, and granite and in the Paleozoic rocks are cemented with a reddish-brown felsite that is mineralogically similar to the groundmass of the rhyolite. Several of these zones are shown in plate 18. The youngest intrusive bodies are numerous thin dikes of dark green to black lamprophyre, andesite, and basalt, none of them large enough to be shown on the maps.

Structure

The pre-Tertiary sedimentary rocks in and near the Iron Mountain block dip eastward at moderate angles, and appear to represent the west flank of a syncline that pitches gently to the south and south-southeast. The nose of this syncline, partly covered by younger volcanic rocks and much disturbed by faulting, is obscurely shown near the northeast corner of the geologic map (pl. 17). Conspicuous cross faults of slight displacement are common. Many are filled with dikes of rhyolite or monzonite and have experienced little postintrusion movement; considerable post-rhyolite movement has occurred, on the other hand, along the steeply dipping fault zone that bounds the range on the west. Total vertical displacement along this zone amounts to several thousand feet.

A strikingly consistent pattern of fractures that appear in igneous and sedimentary rocks alike is traceable throughout the area. Two prominent sets of steep joints trend northwest and east-northeast, and it is evident from an inspection of plate 17 that they conform in orientation to numerous faults, some of which are occupied by dikes. A third set of fractures, trending north-northwest and dipping steeply westward, is most strongly developed along the western edge of the range, where it makes an acute angle with the trace of the fault zone bordering the range.

Fracturing appears to have begun before the intrusion of the monzonite and to have continued intermittently and with little reorientation throughout the ensuing period of igneous activity, metamorphism, and mineralization. The relations of the rocks to structural features suggest the following general sequence of events in the district:

1. Broad folding of the pre-Tertiary rocks.
2. Faulting and long-continued volcanic activity, involving a gradual change from intermediate to silicic rocks.
3. Strong faulting and fracturing, accompanied by eastward tilting.
4. Intrusion of monzonite, chiefly as sills and laccolithic masses.
5. Fracturing and minor faulting.
6. Intrusion of rhyolite as dikes and plugs.
7. Fracturing and renewed movement along a few major faults.
8. Intrusion of granite and aplite, chiefly in concordant bodies.
9. Fracturing and local faulting, especially along the western range-border fault.

Even though adjacent stages in the above sequence must have overlapped, the injection of monzonite and younger igneous rocks clearly occurred later than most of the large-scale structural adjustments. Metamorphism and mineralization, being genetically related to the intrusives, must have affected the sedimentary rocks after they had attained essentially their present inclination.

Contact metamorphism

Many of the beds in the Magdalena group, as well as certain strata near the base of the Abo sandstone, have been altered in appearance and composition at and near contacts with intrusive rocks. The most widespread and profound of these metamorphic effects are shown in the northern half of the Iron Mountain block, where large areas are underlain by fine-grained granite and porphyritic rhyolite. The character of these igneous masses suggests a shallow-seated origin, and their shapes and distribution further suggest that they merge at no great depth beneath the present surface. Thus many of the belts of altered sedimentary rocks can best be interpreted as pendants or septa within igneous bodies, or as downward-projecting remnants of a once continuous but relatively thin sedimentary cover. Southward the proportion of exposed igneous rock decreases, and the exposed altered zones in the sedimentary terrane become correspondingly smaller and more scattered.

As in many areas of contact metamorphism, the metamorphosed rocks in the Iron Mountain district are divisible into two zones. In the zone of simple recrystallization, which is the one farther away from the intrusive bodies, the original rock constituents have merely been rearranged to form new minerals and fresh crystals of certain pre-existing minerals, without appreciable addition of material from outside sources. In the zone generally nearer to the intrusive bodies, recrystallization is accompanied by metasomatism, and the newly formed minerals in the altered rock plainly reflect the introduction of material from outside sources. The rocks in this zone are characteristically rich in silicate minerals. They can themselves be subdivided, on the basis of their iron content, into two zones that correspond to the zones of light- and dark-colored silicates as defined by

Hess and Larsen.5/ Only the dark-colored silicate rocks contain beryllium and tungsten in noteworthy quantity.

Recrystallized rocks

The chief product of recrystallization is a coarse-grained, white to bluish-gray marble in which individual calcite crystals half an inch across are common. This rock appears to have formed preferentially from thick beds of rather pure crinoidal limestone, and much of it is interbedded with finer-grained, less altered carbonate rock. Calcite is the only constituent of note, although scattered masses of tremolite, pale yellow garnet, and iron-poor epidote, presumably formed from impurities originally present in the rock, appear as irregular, brownish-gray patches on weathered surfaces.

In the quartzite beds, recrystallization has had little effect other than a visible increase in grain size. The shaly strata, on the other hand, have been converted to platy, dense, brittle hornfels of tan to dark reddish-brown color. Quartz and mica are its chief constituents, and these are generally accompanied by diopside, andalusite, ottrelite, clinozoisite, and bytownite feldspar. No great change in the over-all composition of the rock appears to have resulted from the formation of these minerals, most of which reflect its aluminous character.

The recrystallized rocks, which commonly extend for considerable distances from igneous contacts, generally grade imperceptibly into beds not recognizably affected by the metamorphism, but they tend to be clearly delimited from the more strongly metamorphosed rocks.

Metasomatically altered rocks

Iron-poor silicate rocks

The earliest-formed rocks in the zone of metasomatism are extremely fine-grained, homogeneous granulites, composed predominantly of iron-poor silicate minerals. They are hard, compact, and brittle, in marked contrast to the calcareous beds from which they were formed, but in most places they are so thoroughly broken into small polygonal blocks that they are not prominently exposed. Their typical color is pale green, but some beds, which are buff-colored to pure white, are difficult to distinguish megascopically from the fine-grained monzonite. The chief minerals are quartz, diopside, clinozoisite, epidote, and lime-soda feldspars in the bytownite-anorthite range; their minor constituents are tremolite, wollastonite, grossularite, hedenbergite, chlorite, calcite, sericite, and thulite, some of which have developed along fractures as coarse crystal aggregates. The main mass of the rock, on the other hand, is generally so fine grained that its minerals are not easily distinguished.

Most of the iron-poor silicate rocks, or granulites, appear to have been formed by silication of the more sandy and shaly limestone beds, and their composition shows that large quantities of silicon and minor quantities of magnesium and aluminum have been added to them and much of their carbon dioxide driven off.

5/ Hess, F. L., and Larsen, E. S., Contact-metamorphic tungsten deposits of the United States: U. S. Geol. Survey Bull. 725-D, pp. 252-253, 1921.

The silication acted selectively on favorable beds. Granulites can be traced along the strike into unreplaced beds through transition zones that are hundreds of feet long, but their boundaries parallel to the strike are generally well defined.

Iron-rich silicate rocks: tactites

Massive tactite.—Much of the iron-rich silicate rock, or tactite,6/ is a massive-bedded, dark-greenish to black rock that consists chiefly of coarsely crystalline magnetite and yellowish-green to coffee-brown andradite garnet, with locally abundant hedenbergite and specular hematite. Minor constituents, most of which are distinctly later than the chief constituents, are fluorite, apatite, diopside, iron-rich amphibole, quartz, feldspar, spinels, idocrase, biotite, chlorite, scheelite, powellite, willemite, pyrite, pyrrhotite, sphalerite, and galena. Tactite is found in the zones of most intense metamorphism, and has been formed by replacement of recrystallized limestone and, to a lesser extent, of iron-poor silicate rocks. This process must have involved the addition of large quantities of iron and silicon, together with minor quantities of magnesium, sulfur, tungsten, molybdenum, and base metals. Great quantities of calcium and carbon dioxide must have been driven off.

The bodies of massive tactite range in size from inch-thick lenses to great masses containing millions of tons; the largest of these crop out boldly along the summit and high on the east and west slopes of Iron Mountain (pls. 17 and 18). The size, shape, and distribution of each appear to have been chiefly governed by the position and attitude of the nearby igneous contact, the size of the igneous mass, and the chemical composition and physical susceptibility of the sedimentary beds. Where other factors have been equal, tactite has formed immediately adjacent to igneous bodies rather than at a distance from them; it has formed in impure limestones rather than in pure limestone, quartzite, or shale; and it has formed preferentially in the more permeable, highly fractured parts of the contact zones.

Although many stratigraphic details have been obscured by faulting prior to the metamorphism and by the metamorphism itself, most of the tactite bodies are not confined to one or a few horizons, but are irregularly distributed over the exposed calcareous terrane. Despite many complexities of detail, they are generally tabular and rudely conformable to the bedding of the enclosing rock. They range in thickness from an inch to more than 100 feet, and are traceable along the strike for distances as great as two miles (pl. 17). They do not everywhere lie immediately adjacent to the igneous intrusions, but may be separated from them by a few feet or tens of feet of less metamorphosed sedimentary rocks. Masses of tactite along concordant igneous bodies are much more continuous than those along cross-cutting contacts; the latter tend to feather out along favorable beds and hence are extremely irregular in pattern.

"Ribbon rock" tactite.—The "ribbon rock" variety of tactite, which contains most of the noteworthy beryllium deposits in the district, has been named 7/ for a peculiar rhythmically layered structure that sharply distinguishes it from the massive tactite.

6/ Hess, F. L., Tactite, the product of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 48, pp. 377-378, 1919.

7/ Jahns, R. H., "Ribbon rock," an unusual beryllium-bearing tactite: Econ. Geology, vol. 39, no. 3, pp. 173-205, 1944.

It consists of thin, minutely crenulated layers, each contrasting mineralogically with the adjacent layers. In section the layers appear as wavy ribbons 0.05 to 3 millimeters wide, with an average of about 0.2 millimeter (pl. 19). Layers consisting chiefly of magnetite, which is intimately associated in places with specular hematite, generally alternate with somewhat thinner layers composed of crystalline fluorite or silicate minerals or both. Many ellipsoidal pods rich in crystalline fluorite are enclosed by concentric shells; the shells nearest the pods are generally the thickest.

Magnetite, hematite, and fluorite are the chief minerals in the "ribbon rock," but sericite, green biotite and chlorite, pale yellowish-green idocrase, and brown helvite are locally abundant. Grossularite, diopside, clinozoisite, spinel, quartz, adularia, opal, and finely divided alteration products are common minor constituents of the fluorite-rich zones. Carbonate-zeolite veinlets, which cut layers and crystalline pods alike, represent a later stage of mineralization. They ordinarily contain small amounts of graphite, carbonate and oxides of manganese, sulfides, quartz, and chalcedony.

The "ribbon rock" forms thick pods, pipelike masses, and thin, tabular bodies whose length and breadth are measurable in tens of feet. Elongated bodies, and fingerlike projections of other bodies, tend to conform roughly to the bedding of adjacent sediments. The "ribbon rock" has sharp contacts with the earlier-formed massive tactite and granulite but generally grades into recrystallized limestone. The transition zones plainly show that iron-rich fluids entered the limestone along fractures and penetrated outward from each fracture with replacement of the calcite (pl. 20). Irregular, isolated carbonate masses in partly formed "ribbon rock," completely analogous in position to many of the fluorite-rich pods and druses in the end product, calcite-free "ribbon rock," evidently represent unreplaced cores of original limestone fracture blocks. Where similar late-stage, iron-rich fluids acted upon massive garnet-magnetite tactite along zones of fracturing and brecciation, ribboned structures are inconspicuous or absent.

The rhythmic layering is probably best interpreted as a diffusion effect, since it clearly is related to fractures in limestone, rather than to any original structures such as bedding, ripple mark, or cross-lamination.8/

Wherever both kinds of tactite are present, the massive tactite tends to occur between the "ribbon rock" and the nearest intrusive contact. The "ribbon rock" thus occurs on the limestone side of the contact zone, like most pyrometasomatic ores.9/ In the North End area it evidently was formed through replacement of limestone bodies that lay alongside massive tactite or extended into it at the close of an earlier stage of metamorphism (pls. 26 and 27).

Metamorphosed igneous rocks

The igneous rocks in the Iron Mountain district are relatively free from endomorphic effects. The sill-like body of granite immediately east of North Peak is altered to a quartz-

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8/ For a more detailed discussion see Jahns, R. H., op. cit., 1944.

9/ Umpleby, J. B., The occurrence of ore on the limestone side of garnet zones: California Univ. Dept. Geol., Bull. 10, pp. 25-37, 1916.

augite-epidote rock near its borders, but the alteration is confined to fracture-controlled zones rarely more than an inch wide. Somewhat similar zones of pyroxene-rich rhyolite and granite occur on the north side of Discovery Gulch, but they are too poorly exposed to permit detailed study. Although a few smears of scheelite have been noted along fracture surfaces in the rhyolite dike west of South Peak, no significant amounts of tungsten- or beryllium-bearing minerals are known to occur in any of the exposed igneous rocks.

ORE DEPOSITS

The beryllium minerals

By Jewell J. Glass

The chief source of beryllium in the Iron Mountain deposits is the mineral helvite, a complex silicate-sulfide that contains 13.6 percent of BeO and also contains iron, manganese, and zinc. In addition, beryllium occurs as a minor constituent in idocrase, in grossularite garnet, and in at least one variety of chlorite. The Iron Mountain deposits are the first in which helvite and associated beryllium-bearing minerals have been found in sufficient quantities to warrant consideration as sources of beryllium, and since there is reason to suspect the presence of similar deposits elsewhere in North America, the following brief mineralogic descriptions are included in the record. More detailed descriptions are being published elsewhere.10/

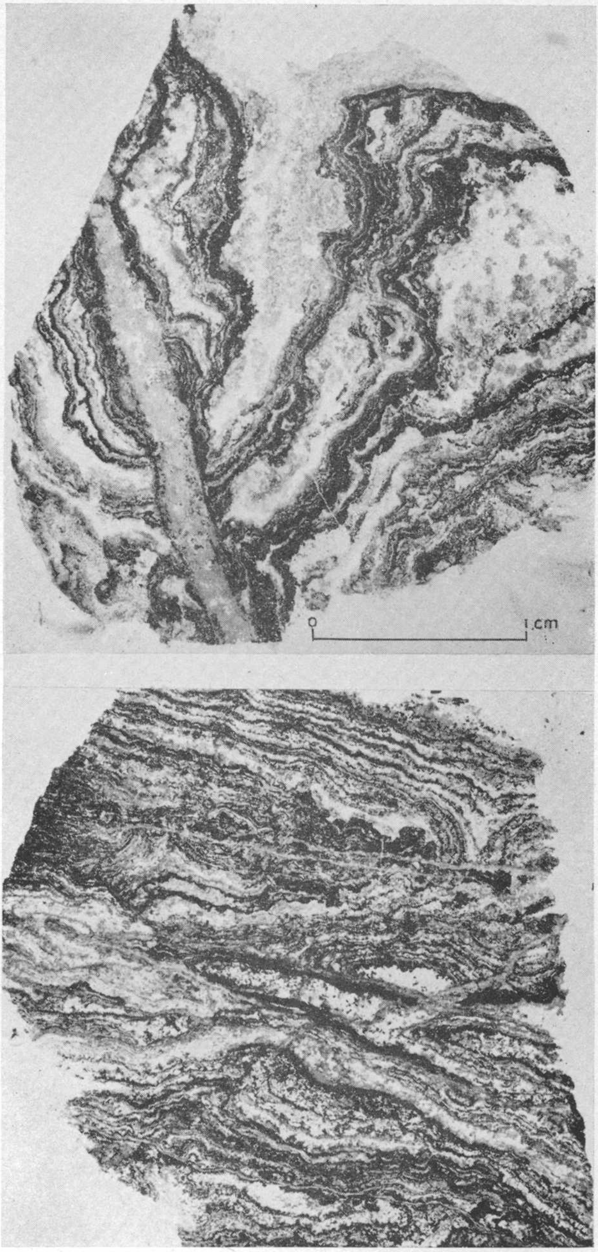
Helvite

Most of the helvite occurs in a coarsely layered, magnetite-rich variety of "ribbon rock," and is intimately associated with fluorite and quartz. Its color ranges from amber brown to mahogany red (Ridgway's color standards), but much of it is stained to a darker color by oxides of iron and manganese. It is transparent to subtransparent, with a vitreous to resinous luster, and occurs typically in crystalline masses or, together with fluorite, in crystalline aggregates. Well formed crystals, commonly associated with comb quartz, fluorite, and zeolites, are found in vugs; they are simple tetrahedra and combinations of positive and negative tetrahedra, generally less than 4 millimeters in diameter. Fine, evenly spaced striations appear on some of the crystal faces. Octahedral cleavage is poorly developed and seldom seen.

The Iron Mountain helvite so closely resembles garnet that its having been called garnet, not only by prospectors but by geologists, for many years is not surprising. Because of this striking similarity to garnet, moreover, it seems entirely possible that helvite has been overlooked in other contact-metamorphic deposits.

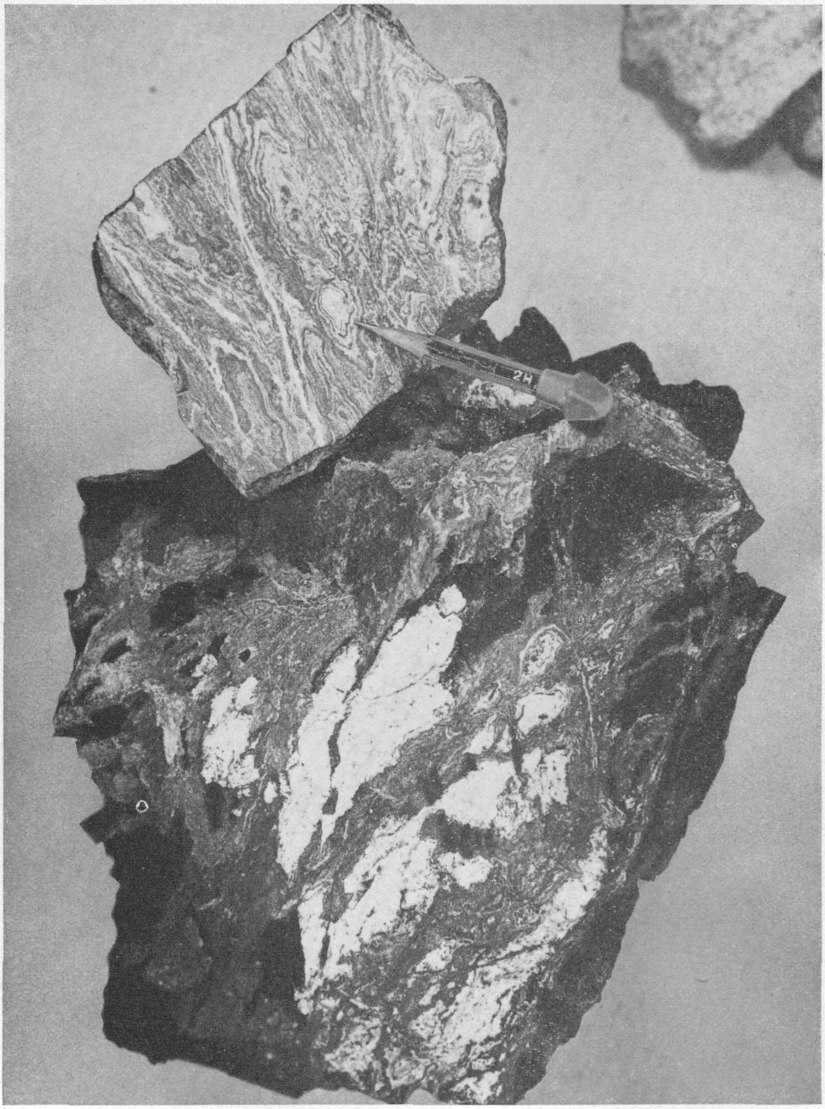
The properties that distinguish helvite from garnet in the Iron Mountain district are as follows:

10/ Glass, J. J., Jahns, R. H., and Stevens, R. E., Helvite and danalite from New Mexico, and the helvite group: Am. Mineralogist, vol. 29, pp. 163-191, 1944.



TYPICAL SPECIMENS OF "RIBBON ROCK" FROM THE NORTH END AREA, IRON MOUNTAIN.

Black bands are magnetite with subordinate specular hematite; dark-gray bands and masses are chiefly silicate minerals, and white to light-gray bands and podlike masses are fluorite. Note the late-stage, fluorite-rich veinlet in the upper section.



SPECIMENS OF PARTIALLY AND COMPLETELY FORMED "RIBBON ROCK" TACTITE.

Partially formed "ribbon rock" (below) from Jackpot Extension body and completely formed "ribbon rock" from North End area. Note fracture control of the dark-colored ribboned veinlets in the lower specimen. White masses of residual carbonate rock and cavities from which similar material has been weathered out correspond in position to the light-colored, fluorite-rich crystalline pods in the completely formed "ribbon-rock" (see, for example, orbicular mass near pencil point).

Properties of garnet and helvite

Property	Garnet	Helvite
Hardness......................	6.5-7.5	6
Specific gravity..............	3.5-3.8	3.33
Color of powdered mineral......	Brownish gray	Brownish yellow
Crystal form..................	Dodecahedral	Tetrahedral
Refractive index..............	1.865-1.885	1.746

Helvite dissolves slowly in boiling 1:1 hydrochloric acid, releasing hydrogen sulfide and forming a silica gel, whereas garnet is very difficultly soluble, does not yield hydrogen sulfide, and does not gelatinize.

A very satisfactory selective staining method for the recognition of helvite has been developed by the research staff of Continental Machines, Inc., of Minneapolis, Minn. The procedure begins with the crushing of a small sample of the material to be tested and its immersion in dilute (1:5) sulfuric acid. A small amount of arsenic trioxide is added, and the solution is then boiled for one to two minutes. The acid is then decanted and the sample washed with water. Any helvite present will be covered with an easily recognized canary yellow stain of arsenic sulfide. If metallic antimony is substituted for the arsenic trioxide, a red stain of antimony sulfide is formed. This staining method is very sensitive, and it is said that other sulfides, such as sphalerite, galena, and pyrite, will not interfere with it.

A spot test for detecting beryllium oxide 11/ has been used by chemists and geologists of the Brush Beryllium Co. of Cleveland, O., and gives excellent results on helvite-bearing material. The procedure is essentially as follows:

Crush a piece of the sample to a coarse powder and grind this powder in a mortar to a fineness of about 200 mesh. Melt 1.5 grams of NaOH by heating to a dark cherry red in a 30-ml. nickel crucible, then add 0.08 to 0.10 gram of the finely powdered sample. Heat to a dark cherry red for five minutes. Allow the melt to cool, stirring briskly as it solidifies. Place the bottom of the crucible in cold water and put into it 10 ml. of cold water. Leaving the crucible thus partly immersed, stir the water inside continually until the melt is completely dissolved.

With a stirring rod, put a large drop of paranitrobenzineazoorcinol solution on a double thickness of filter paper. On the spot thus made, put a similar drop of 25 percent KCN; then put a small drop of the unknown solution in the center of the large spot. A pink ring will develop within five minutes if the original sample contained 1 percent or more of BeO.

To make up 100 ml. of the paranitrobenzineazoorcinol solution, dissolve 0.025 grams of the reagent in 100 ml. of normal (4 percent) NaOH solution.

Danalite, a member of the helvite group, occurs as a minor constituent of a relatively light colored, fine-grained, silicate-rich "ribbon rock," in which it is intimately associated with fluorite and grossularite garnet. This danalite is pale creamy yellow to honey-yellow in color, and generally assumes a rounded, dodecahedral crystal form. Most of the crystals are 1 to 2 millimeters in diameter. Under the microscope the mineral shows optical anomalies like those found in garnets, and a

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11/ Kulcsar, Frank, How prospectors can detect beryllium in ores: Eng. and Min. Jour., vol. 144, p. 103, 1943.

refractive index of 1.750 to 1.759. It is commonly intergrown with the grossularite garnet, even in individual crystals, and then the two minerals cannot be distinguished megascopically; under the microscope, however, the garnet shows a slightly higher index of refraction. Selective staining of the danalite by the method described above reveals textures that suggest partial to complete replacement of garnet crystals by danalite. Spectrographic tests show that the danalite contains little or no zinc.

Other beryllium-bearing minerals

The grossularite garnet associated with helvite in the silicate-rich "ribbon rock" is itself beryllium-bearing. Spectrographic analyses of carefully purified samples indicate a BeO content of 0.07 percent to 0.30 percent for one group of samples, and 0.08 percent to 0.19 percent for another. A pale-green variety of idocrase that is locally abundant in the silicate-rich "ribbon rock" and in fluorite-rich mineralized zones in massive tactite has been found by spectroscopic analysis to contain 0.80 percent to 1.30 percent BeO, and also appreciable quantities of boron. A chemical analysis gave 1.09 percent BeO. This mineral generally forms radiating groups of fibers and thin blades; such groups are 1/8 to 1/2 inch in diameter. A green chlorite with pearly luster, intimately associated with the idocrase, appears to contain a comparable proportion of beryllium. None of these minerals can stand alone as a commercial source of beryllium, but the combination of all three with helvite helps to make the silicate-rich variety of "ribbon rock" a potential source of that element. This tactite, moreover, contains in considerable quantity an extremely fine grained, opaque, non-crystalline substance, not yet identified specifically, that may well include alteration products of these beryllium-bearing minerals, for it consistently contains beryllium in appreciable quantity.

Beryllium deposits

The helvite and associated beryllium-bearing minerals are restricted in their occurrence to three distinct varieties of tactite: (1) dark-colored magnetite-fluorite-helvite "ribbon rock"; (2) lighter-colored, silicate-rich "ribbon rock"; and (3) fluorite-rich massive tactite.

Rock of the first variety includes all the "high-grade" deposits, such as the Hot Spot (Discovery Gulch) and Jackpot No. 2 bodies. This rock is reddish brown to black, and consists almost entirely of magnetite, fluorite, and helvite, the magnetite being dominant. It contains no garnet. The characteristic "ribbon" structure, though indistinct on freshly broken faces, is readily recognizable on most weathered surfaces. The layers are unusually thick—about 2 millimeters on the average—in this type of "ribbon rock," and most of the helvite occurs in crystals or crystalline aggregates more than a millimeter in diameter. In the richer tactite there are elongate lenses and curved pods, some of them over an inch thick, containing granular or coarsely crystalline helvite. Small cavities lined with crystals of fluorite, helvite, and quartz are also found.

This dark-colored, coarsely ribboned tactite forms irregularly tabular to podlike masses, which are only a few feet or a few tens of feet in length and rarely contain more than a few hundred tons. Despite the occurrence of local helvite-rich pods, the grade of the rock appears to be rather uniform throughout many of the exposed surfaces. Its BeO content ranges from 0.5 percent to 3.5 percent, with a probable average of slightly less than 1.0 percent.

The second variety, the silicate-rich "ribbon rock," is mineralogically more complex and markedly lighter in color than the first, and it occurs in relatively large bodies of somewhat wider distribution. It is especially common in the northernmost part of the district. Its known beryllium-bearing constituents, chiefly helvite, danalite, idocrase, grossularite, and chlorite, are intimately associated with fluorite in finely crystalline layers and orbicular to ellipsoidal masses. As a rule the layered structure is very distinct (pl. 19). The concentration of beryllium in this type of "ribbon rock" varies in detail, but broadly considered it appears to be remarkably uniform over areas of several square feet. The average grades of different bodies ordinarily fall within the range 0.1 to 0.85 percent BeO; the probable over-all average grade is less than 0.3 percent BeO.

Material of the third category, fluorite-rich massive tactite, was formed by mineralization along narrow fractured and brecciated zones in massive tactite. It is most easily recognized by its high content of coarsely crystalline fluorite. The accompanying minerals, which clearly were formed later than the andradite and magnetite of the massive tactite, correspond to those found in the silicate-rich "ribbon rock" but are distinctly coarser-grained. The average BeO content of these mineralized zones is only about 0.2 to 0.3 percent, and the tonnage of minable material of such grade in each body is so low that tactite of this type may be dismissed from present consideration as a possible source of commercial beryllium.

Near-surface oxidation of helvite is observable in many tactite masses, but the effect of this process on ore tenor is negligible. No secondary enrichment has been noted, and variations in grade are not related to the present surface, to any assumed earlier surface, or to fractures within the "ribbon rock." An apparently systematic variation in grade does occur, however, in several of the bodies, the beryllium content tending to decrease toward the nearest igneous contact. This is particularly true of the dark-colored "ribbon rock," but the fact would be of limited application in the mining of such small bodies. A similar variation may well occur in the larger bodies of lighter-colored "ribbon rock," but that cannot be proved until some of these bodies are more fully tested.

Tungsten deposits

In marked contrast to the beryllium, the tungsten of Iron Mountain nowhere occurs in "ribbon rock"; all known concentrations having commercial promise are in massive magnetite- or garnet-rich tactite. On the basis of the distribution of the principal tungsten-bearing minerals, scheelite and powellite, the deposits can be classified as follows:

1. Coarse-grained disseminations in magnetite-rich tactite.
2. Medium- to coarse-grained disseminations and smears restricted to narrow zones of closely spaced fractures, either open or healed, in andradite-rich tactite.
3. Fine-grained, "pin-point" disseminations in magnetite-rich tactite.
4. Coarse-grained disseminations in strongly mineralized fluorite-rich tactite.

Very small quantities of these tungsten minerals also have been observed along fracture surfaces in rhyolite, granite, recrystallized limestone, and iron-poor silicate rocks.

Most of the disseminated deposits occur in heavily broken ground at and near the intersections of two or more sets of fractures or shear zones. The central, richer parts of such bodies generally contain large crystals of scheelite and powellite, scattered through the tactite with little apparent immediate structural control, but the tungsten minerals in their outer, leaner parts are characteristically grouped along fracture surfaces. The largest crystals are a quarter of an inch or more in diameter, and most of the scheelite and powellite in the rock can be freed by crushing to pass a 20-mesh screen. The fine "pinpoint" disseminations, on the other hand, which occur at some places in the Black Bed deposits 1.5 miles south of Brown City, consist of evenly scattered crystals and crystalline aggregates 0.01 inch or less in diameter. These masses of finely disseminated ore minerals are too small to be of economic interest.

The origin and age relations of the tungsten minerals are most clearly demonstrated in the deposits restricted to narrow, "sheeted" fracture zones, particularly those on the main ridge near North Peak. Evidently the brittle, massive-bedded tactite was repeatedly broken and sheared during the last stages of its formation, each fracture or other opening being promptly "healed" by andradite, magnetite, or tungsten minerals, or by combinations thereof. The resultant thin-layered zones (fig. 10), firm and solid where no postmineral shearing has occurred, contain many laminae and thin lenses rich in scheelite and powellite. These are 0.02 to 0.15 of an inch thick, and some can be traced for distances of several feet along their strike. Here the ore-bearing solutions plainly depended for their entry into the tactite upon the presence of open passageways, and possibly the absence of tungsten-bearing minerals from many bodies of massive tactite indicates that no open fractures or other avenues of ready access were available during this period of mineralization. In some deposits of coarsely and evenly disseminated scheelite and powellite, however, it cannot be demonstrated that mineralization was preceded by fracturing or shearing.

The deposits in fluorite-rich tactite, particularly those in the Scheelemite area (pl. 18), commonly contain appreciable quantities of beryllium. Textural relations of the minerals indicate that strong shearing occurred after the formation of the tungsten minerals, and that these movements were followed by fluorite-beryllium mineralization. Hence it appears that tungsten-bearing solutions were no longer active during the period of beryllium deposition, an age relation that may well explain the absence of tungsten from the beryllium-bearing "ribbon rock."

Other deposits

The fluorite-rich massive tactite in the Scheelemite and North End areas contains finely disseminated specularite and willemite. Although seven composite chip samples of this material (collected by persons not known to the writer) are said to have assayed 8 percent to 21 percent in zinc, prospects for ore bodies are not good. Several small bodies of mineralized tactite in the Goat Canyon area (pl. 17) contain smithsonite, willemite, hemimorphite, wulfenite, anglesite, cerussite, and oxides and carbonates of copper, but attempts to work them on a small scale have never been successful. All these deposits are too small to permit profitable handling of such low-grade material, even under war-time conditions.

Much of the massive tactite is acceptable iron ore, and the bodies on Iron Mountain constitute a reserve of several million tons. The material is reported to be consistently low in sulfur and phosphorus, but because of intimately intergrown andradite and hedenbergite much of it is markedly siliceous. Although they have been prospected and sampled many times, these deposits never have been worked, because of their great distance from centers of demand and the long haul to a railhead.

Little of the fluorite-rich tactite could be successfully worked for its fluorspar content alone, but this mineral should not be ignored as a possible byproduct from the treatment of "ribbon rock" and other beryllium-bearing tactite. In 1941 an attempt was made to produce optical and acid grades of fluorspar from a mineralized breccia zone in the Scheelemite area (pl. 28), but numerous inclusions of specular hematite made it difficult to obtain high-grade concentrates.

The andradite garnet that is so common in the massive tactite has been reported 12/ to contain "a constant and characteristic 0.3 percent" of tin, and several determinations made in the Chemical Laboratories of the Geological Survey tend to confirm this statement. It is interesting to note that the rhyolite and granite with which the garnet is genetically associated probably correspond very closely in age to the well-known tin-bearing rhyolites of the Black Range to the west, 13/ although the Iron Mountain tin appears in the contact zones rather than in the igneous rocks themselves. The actual mode of occurrence of the tin in the garnet is not known; it presents a problem that deserves investigation.

Several mineralized zones in massive tactite contain manganese minerals that appear to have been derived from rhodochrosite and manganiferous pyroxenes. A few tons of manganite-pyrolusite-wad ore have been stockpiled at a small fluorspar cut in the Scheelemite area (pl. 28), but the amount of ore available is very small.

DESCRIPTIONS OF AREAS

All the known beryllium deposits in the district lie in the northern third of the Iron Mountain block. More specifically, they occur along the bottom and high on the north side of Discovery Gulch—a steep-walled canyon that drains westward from the saddle between North and South Peaks—and on the west slope of the mountain between the gulch and the Sierra-Socorro County line (pl. 17). Low-grade deposits of considerable size are found in the North End area, a mile north-northeast of Brown City. Most of the tungsten occurrences, on the other hand, lie along the crest and high on both slopes of the mountain between North and South Peaks, though the Black Bed deposits lie farther south and near the west base of the range.

12/ Strock, L. W., A new helvite locality—a possible beryllium deposit: Econ. Geology, vol. 36, p. 750, 1941.

13/ Fries, Carl, Jr., Tin deposits of the Black Range, Catron and Sierra Counties, N. Mex.: U. S. Geol. Survey Bull. 922-M, 1940.

Lower part of Discovery Gulch

Several small bodies of beryllium-bearing tactite in the lower part of Discovery Gulch lie within a claim owned by the Saratoga Mining Corporation, and can be reached from Brown City over an abandoned tractor trail (1, pl. 18). The overburden was stripped from three of these bodies by the Geological Survey and the Bureau of Mines in 1942, and a fourth, larger mass was explored by trenching and underground workings, including a 225-foot adit, a 42-foot crosscut, and two raises (pls. 21 and 22). The tactite appears to have been formed by replacement of susceptible beds in an eastward-dipping limestone series exposed on the south side of the gulch, and several of the masses are in contact with coarsely porphyritic rhyolite, which crops out on the north side. To one ascending the gulch, therefore, the tactite appears as a series of irregular pods in successively higher strata (pl. 21).

The largest and most heterogeneous of these podlike deposits is the Old Adit body, which contains massive tactite, "ribbon rock," and strongly sheared tactite with a little granulite. It is bounded on the north and northeast by porphyritic rhyolite, on the south by recrystallized limestone, and on the west by pale-green bytownite-diopside granulite and fine-grained aplitic granite. The bedding dips gently eastward, and the cross-cutting rhyolite contact dips to the south-southwest, as shown in the fence diagram (pl. 22).

Although the contacts between the tactite of the Old Adit body and the adjacent rocks are everywhere sharp, the distribution of different varieties of tactite within that body is so complex that its ore-bearing parts cannot be outlined with assurance. Most of the beryllium-poor material seems to be adjacent to the rhyolite and granite, and much of the northwestern part of the tactite is barren or nearly so. The rock richest in beryllium is a medium- to fine-, even-grained, dark-greenish tactite that consists chiefly of magnetite, fluorite, biotite, chlorite, and diopside. Helvite, chlorite, and idocrase are the principal beryllium-bearing minerals; the idocrase commonly occurs as prismatic crystals in radiating groups a quarter of an inch or more in diameter. Ribboned structure is apparent in much of the rock, but in some places it is not recognizable. Abundant fluorite is a reliable guide to beryllium mineralization, although some of it is so finely disseminated that it may escape recognition.

Four systematic chip samples taken from an old trench and a short adit were found to contain 0.4 percent to 0.72 percent BeO, with an average of 0.55 percent. A fifth systematic sample, taken near the intersection of the Bureau of Mines adit and crosscut, contained 0.5 percent BeO. The results of subsequent, more detailed sampling by the Bureau of Mines have not been published. The irregular distribution of beryllium-bearing zones within the Old Adit body, together with the lack of detailed data on grade, make any estimate of reserves subject to serious error. It seems likely, however, that at least 1,500 tons of minable tactite with a BeO content of 0.3 percent or more is indicated on the basis of assumed continuity to a depth of 20 feet, and in addition to this a much larger tonnage of lower-grade material may well be present.

The Hot Spot, Hot Spot Extension, and Little Hot Spot bodies, which lie farther up Discovery Gulch (pl. 21), consist chiefly of the dark-colored, helvite-rich "ribbon rock" previously described, although lighter-colored silicate-rich "ribbon rock" forms the long projection of the Hot Spot Extension body. The Hot Spot body, from which the material first identified by Strock as helvite was collected, appears to be flanked by two poorly exposed masses of intrusive rhyolite. The attitudes of faint primary flow structures in these intrusive bodies suggest that the one on the south is a thin steeply dipping dike, but that the other may be the exposed tip of a stocklike or pluglike mass. At least the eastern part of the Hot Spot Extension body is bottomed in igneous rock, for a shallow test pit (pl. 21) revealed porphyritic rhyolite and aplite at a depth of only 5 feet.

Seven systematic chip samples were cut from 8-inch grids on the stripped surfaces of these three high-grade bodies. All were examined under the microscope and their helvite content determined, and the BeO content of four was determined chemically. The results are shown in the following table:

Determinations on samples from Discovery Gulch

Area sampled	Percent helvite (determined microscopically)	Percent BeO (calculated from helvite)	Percent BeO (determined chemically)
East third of Hot Spot	9.0	1.2	1.4
Central third of Hot Spot.	10.3	1.4	1.3
West third of Hot Spot	6.0	.8	.7
West half of Hot Spot Extension.	3.8	.5	.6
East half of Hot Spot Extension.	11.9	1.6	...
East half of Little Hot Spot.	3.4	.5	...
West half of Little Hot Spot.	5.7	.8	...

The close correspondence between the results of the chemical and mineralogic determinations indicates, as expected, that most of the beryllium is present in helvite. It also confirms the impression, gained from field observations, that the richest tactite occurs in the Hot Spot body and in the eastern part of the Hot Spot Extension body. The tonnage of such material is evidently small, since only the Little Hot Spot body appears to extend to any considerable depth. The other bodies, which presumably pitch eastward along the igneous contacts, may be cut off at relatively shallow depths by bulges or projections of rhyolite. It seems unwise, therefore, to assume that more than 2,500 tons of ore, containing 0.8 percent BeO, is indicated by present known relations. This would be the equivalent of about 170 tons of beryl concentrates containing 12 percent BeO.

West Slope area

Four small bodies of tactite crop out on the west slope of the mountain, about 1,400 feet north-northeast of Brown City, and are reached from that camp by two trails (2, pl. 18). These deposits, which are owned by Continental Machines, Inc., were trenched and sampled in 1942 by the Federal Bureau of Mines, but they have not been otherwise explored.

The tactite lenses form an irregular, discontinuous fringe around a large septum of recrystallized limestone that is bounded on three sides by fine-grained granite (pls. 18 and 23). Faint primary flow structure in the granite, best shown by alined small flakes of biotite, suggests that the igneous rock dips eastward beneath the western part of the septum and northeastward beneath its southern part. Two of the tactite masses are separated from the granite by narrow belts of recrystallized limestone, but the others are in immediate contact with the granite (pl. 23).

The Jackpot No. 2 body is an irregular lens, the outcrop of which is 200 feet long and 5 to 25 feet wide. It appears to dip eastward, in rough conformity with the adjacent limestone beds, and is probably less than 10 feet thick for most of its length. It consists of a strongly banded, dark-colored, helvite-rich "ribbon rock" that differs from the tactite of the Hot Spot body only in containing abundant chlorite. A large chip sample taken from the thickest part of the lens was found by chemical tests to contain 0.7 percent BeO. Chip samples representing respectively the north, central, and south thirds of the exposed tactite mass were found microscopically to contain 9.6, 4.2, and 10.1 percent helvite, or about 1.3, 0.6, and 1.4 percent BeO. Analyses showing as much as 2.2 percent BeO have been reported by the owners. This thin lens, with a possible over-all BeO content of 0.6 percent or more, should continue to a depth of at least 10 feet, and the indicated tonnage to this depth is about 1,000 tons. If two or three vertical drill holes were put down east of the outcrop, they might well prove a far greater depth for this body, and therefore justify upward revision of reserve estimates.

The somewhat smaller Little Jackpot and Lower Talus bodies contain intimately mixed helvite-rich "ribbon rock" and barren massive tactite. Since their beryllium-bearing parts could not be selectively mined and their average BeO content is undoubtedly lower than 0.6 percent, these masses offer little promise commercially. The much larger Upper Talus body consists chiefly of massive tactite, but two poorly defined zones of silicate-rich "ribbon rock" occur in its northern, broader half. The "ribbon rock" probably covers a total area of about 700 square feet, but its attitude and distribution beneath the surface are not known, and it is, moreover, distinctly lower in grade than the darker-colored, helvite-rich "ribbon rock" of the other bodies.

Brown ore body

The Brown ore body lies 1,100 feet east-northeast of Brown City, within a claim owned by the Saratoga Mining Corporation, and is accessible by trail (3, pl. 18). The tactite in this body forms the thick western border of a limestone septum that extends northward into fine-grained granite (pl. 24). At least three thin aplitic sills cut the coarsely recrystallized limestone, and they appear to be younger than some of the enclosing tactite, into which they extend. One small mass of silicate-rich "ribbon rock," 18 feet long and 4 feet thick, is the only clearly defined beryllium-bearing body. The remainder of the tactite is mostly massive-bedded, with only local ribboned zones. Although it could be regarded as an ore of iron, much of it is virtually barren of beryllium. Microscopic examination of 22 samples from the Brown body, together with chemical analyses of an even greater number by the Bureau of Mines, did much to demonstrate empirically that the typical massive, unmineralized magnetite-andradite tactite on Iron Mountain cannot be regarded as a possible commercial source of beryllium.

Jackpot No. 1 and Jackpot Extension areas

Several small bodies of tactite are exposed on the west slope of the mountain, 2,200 feet north-northeast of Brown City, from which most of them can be reached by trail (4, pl. 18). They are in claims owned by Continental Machines, Inc.

The Jackpot No. 1 body, which lies near the mouth of a narrow gulch, is a thick, curved, podlike tactite mass 180 feet long and about 70 feet in maximum width (pl. 25). It was trenched during the summer of 1942 by the Bureau of Mines, and shortly thereafter the owners explored it further by means of subsurface workings. On its northeast side it is separated from a tongue of fine-grained granite by 15 to 20 feet of massive magnetite-rich tactite; elsewhere it is in sharp contact with recrystallized limestone, which has been altered along favorable zones to a dense, buff-colored granulite. Except for a narrow belt of typical silicate-rich "ribbon rock" along its southeastern edge, the Jackpot No. 1 body is composed of massive tactite with many small lenses and irregular, poorly-defined masses of "ribbon rock." A 20-foot test pit near the southwest end of the "ribbon rock" belt passes through 2 feet of "ribbon rock" and 17 feet of strongly silicated limestone, and is bottomed in massive tactite (pl. 25). The "ribbon rock," like the altered rocks exposed west of the pit, probably dips eastward. A 30-foot adit in the northern part of the body follows the contact between massive tactite and a 4-foot aplite dike for several feet, then bends slightly and extends eastward through massive tactite with minor ribboned zones for the remainder of the distance. Similar material was encountered in a short crosscut, but the "ribbon rock" belt was struck in the top 2 feet of a 24-foot raise to the surface. A general chip sample and a systematic grid-chip sample of the "ribbon rock" contained 0.3 percent and 0.4 percent BeO, respectively. These should be representative of the entire belt, from which about 500 tons of "ribbon rock" could be obtained for each 10 feet of depth. The other material in the Jackpot No. 1 body is undoubtedly too low in grade to be profitably worked.

West of the Jackpot No. 1 body and separated from it by a small, poorly exposed complex of aplite, rhyolite, tactite, and vein quartz is another lens of beryllium-bearing tactite, but this lens, which is probably no richer than that of other "ribbon rock" in the area, is discouragingly small.

Similar material, associated with coarsely recrystallized limestone, massive tactite, and large masses of manganiferous pyroxene, occurs in the Jackpot Extension body, 350 feet up the slope to the east of the lens last mentioned (4a, pl. 18). These rocks lie near the north end of a large inclusion or pendant in fine-grained granite. Exposed in a deep exploratory trench is a very instructive 2-foot contact zone between "ribbon rock" and limestone (pl. 20), in which the mode of formation of this peculiar tactite at the expense of the carbonate rock is plainly shown. So little beryllium-bearing rock is present, however, that the deposit is of little commercial value.

North End area

The largest known bodies of "ribbon rock" tactite in the district crop out in the North End area, about a mile north-northeast of Brown City. They are held under option at present by the Saratoga Mining Corporation. They can be reached from Brown City over a good trail, or from State Route 52, to the northwest, over a poor road and a short, steep trail (pl. 17). The Federal Bureau of Mines explored these deposits thoroughly during the fall and winter of 1942-43 by means of 31 trenches, 8 test pits and shafts, and 11 diamond-drill holes; this work represents, in the aggregate, 2,850 linear feet of trenching, 275 feet of pit and shaft sinking, and 875 feet of diamond drilling.

Both "ribbon rock" and massive tactites, associated with feldspathic quartzite and quartz-plagioclase-diopside-clinozoisite granulite, occur in a large mass of altered limestone, which is underlain and flanked by fine-grained biotite granite (pl. 26). In the beryllium-bearing areas this igneous rock underlies the eastward-dipping limestone and associated contact rocks at depths that nowhere exceed 100 feet. The exposed bodies of "ribbon rock" appear to be remnants of large lenses whose upper parts have been removed by erosion. They are almost everywhere separated, both laterally and at depth, from the igneous rock by earlier-formed granulite or massive tactite, and along their strike they commonly pass rather abruptly into recrystallized limestone. They tend to be concordant with the bedding of adjacent rocks, and appear to have replaced limestone septa or pendants that formerly extended into or alongside massive tactite or granulite. Thus most of the beryllium-bearing rock extends to no more than a few tens of feet beneath the present surface.

The Beryllium Reef area, on the ridge about 900 feet south-southeast of North End Peak (pl. 26), contains at least ten large eastward-dipping lenses of "ribbon rock" tactite. These lenses, shown in detail in plate 27, are 50 to 350 feet long and 5 to 30 feet in exposed width. Many smaller lenses also have been observed. As seen in a few low outcrops and in the exploratory workings, the rock is rather uniformly a tactite of the silicate-rich variety, dense and fine-grained, of dark-reddish to greenish-gray color, and made up of thin, sharply defined layers. Only in local crystalline pods and layers are its constituent minerals readily recognizable. Composite samples of the two "ribbon rock" masses near test pits 1 and 2 (pl. 27) were found by chemical analysis to contain 0.1 percent and 0.4 percent BeO respectively. Carefully prepared composite samples of "ribbon rock" from all the exploratory workings in the area were later submitted to several analysts for quantitative spectrographic and chemical determination, the results of which indicate that the average BeO content of Beryllium Reef "ribbon rock" is probably 0.3 percent or less. These results are further discussed in the section on reserves (p. 77). Since most of the "ribbon rock" lenses contain many stringers and irregular masses of granulite and other relatively barren material, the BeO content of the minable rock would scarcely exceed 0.2 percent.

Two hundred and fifty feet southeast of North End Peak is the small, poorly exposed Reef Extension body of "ribbon rock" (pl. 26). This lies near the northwest end of a long tactite-limestone septum that is bounded on three sides by fine-grained granite. Primary flow structures in the igneous rock indicate that it probably extends beneath the altered sediments and cuts them off at no great depth, and a test pit sunk in tactite near the north end of the septum exposes granite at a depth of only 18 feet. The "ribbon rock," which at the surface is flanked on the east and west by recrystallized limestone, appears to dip eastward; in two Bureau of Mines test pits (pl. 26) it is underlain at depths of 2 to 8 feet by massive tactite. Where best exposed it is fine-grained, has narrow, sharply defined bands, and is unusually greenish in color. Much of the green is due to abundant chlorite and idocrase, both of which contain a little beryllium. Analyses of a carefully taken composite sample of this "ribbon rock" are not in close agreement, but its BeO content does not appear to exceed 0.25 percent, and that of the minable material is probably less than 0.2 percent.

In the Beryllium Chief area, which lies athwart Gunnell Gulch 600 feet east of North End Peak (pl. 26), there are large outcrops of beryllium-bearing tactite. "Ribbon rock," with intercalated lenses of granulite, massive tactite, and recrystallized limestone, forms a mass whose outcrop is more than 400 feet long and 5 to 100 feet wide; it dips steeply to the east-northeast, and is overlain by coarsely recrystallized limestone. To the west it is separated from a large body of granite by massive magnetite-rich tactite, and drill holes consistently demonstrate that most of it is underlain by massive tactite, granulite, or granite at depths not more than 30 feet below the surface. Much of this "ribbon rock," especially north of the gulch, is extremely dark colored, dense, and fine-grained, with a thin-layered structure that is not readily apparent. It is relatively rich in magnetite and poor in beryllium-bearing minerals. More normal silicate-rich "ribbon rock" also is present, but its relations to the beryllium-poor variety are not clear. Chemical and spectrographic analyses of the two varieties indicate that they respectively contain, on the average, about 0.1 percent BeO and 0.2 to 0.3 percent BeO. The average tenor of minable material from the Beryllium Chief area as a whole is probably less than 0.15 percent BeO.

The Beryllium Queen area, which lies low on the east slope 450 feet southeast of Gunnell Gulch, contains relatively short, thick lenses of strikingly banded "ribbon rock" tactite. These lenses are about 100 feet long and 5 to 30 feet broad, dip steeply to the east-northeast, and are bounded by strongly fractured and brecciated granulite and recrystallized limestone on the east, and by massive tactite and diopside-rich granulite on the west (pl. 26). Between the "ribbon rock" bodies are thin layers of limestone, granulite, and massive tactite. Much of the silicate-rich beryllium-bearing tactite is an unusually coarse grained and light colored rock, in which broad layers and podlike masses of crystalline fluorite and silicate minerals contrast boldly with dark layers of magnetite and associated specular hematite. Many of the helvite and grossularite crystals are a millimeter or more in diameter, and the fluorite is even coarser grained. This coarse-grained, light-colored "ribbon rock" appears to contain about 0.3 percent BeO, but the BeO content of minable rock would be nearer 0.2 percent.

Immediately southwest of the Beryllium Queen area are the Beryllium King deposits (pl. 26)—three small, poorly exposed lenses of "ribbon rock" similar in composition and appearance to that in the Beryllium Reef area. These lenses lie along an extremely irregular contact zone between limestone on the north and massive tactite on the south. Their total tonnage is so small that they can have no commercial importance.

Still higher on the slope, about midway between the Beryllium King and Beryllium Reef deposits, are the Upper and Lower Star bodies (pls. 26 and 27). These contain thin, elongate lenses of typical silicate-rich "ribbon rock" tactite and shorter, broader masses of massive tactite, which has been brecciated and cemented with fluorite and minor quantities of beryllium-bearing idocrase and chlorite. This fluorite-rich rock also contains a little scheelite and tungstite, these tungsten-bearing minerals being particularly well exposed in three shallow cuts (pl. 27). The beryllium content of both varieties of tactite in the Star bodies, as indicated by chemical and spectrographic analyses on composite samples, is very low—probably 0.2 percent BeO or less. The tungsten mineralization appears to be so restricted that it is of no commercial interest.

The approximate amount of beryllium-bearing tactite exposed in large enough masses to permit its removal by mining or quarrying in each of the North End deposits is as follows:

Deposit	Exposed area of beryllium-bearing tactite (square feet)	Tonnage per 10 feet of assumed depth continuity*
Beryllium Reef.....	15,000	18,750
Reef Extension.....	1,500	1,900
Beryllium Chief....	22,500	28,100
Beryllium Queen....	4,000	5,000
Beryllium King.....	1,200	1,500
Upper Star.........	1,100	1,400
Lower Star.........	750	900
Total..........	46,050	57,550

* Figures roughly approximate because of unpredictable variations in subsurface form of tactite bodies.

That the "ribbon rock" lenses tend to be conformable with the adjacent altered sedimentary rocks is clearly shown in the walls of test pits and shafts, as well as by correlation between drill records and surface geology (pls. 26 and 27). The lateral or downward continuation of such lenses, on the other hand, cannot be predicted with any assurance in advance of exploration; even where drill holes are rather closely spaced it is rarely possible to determine the forms of the lenses with any precision. For this reason, the amount of actually measurable ore 14/ in such low-grade material is very small. Exploratory workings are sufficiently numerous, however, to block out about 80,000 tons of indicated ore having an average grade between 0.15 percent and 0.2 percent BeO. The total amount of indicated and inferred ore in the North End area cannot be more than about 150,000 tons. Other bodies of "ribbon rock" tactite may be discovered, but that is not considered probable.

Scheelemite area

The Scheelemite area lies high on the west slope of the mountain, about 600 feet west-southwest of North Peak (5, pl. 18). It is included in claims owned by the Saratoga Mining Corporation, and can be reached over a steep tractor trail that extends up Discovery Gulch from Brown City. As shown in plate 28, this area contains a large, irregular body of massive magnetite-rich tactite, which is in contact on the west with coarsely porphyritic rhyolite. About 200 feet up the slope east of this contact the tactite is overlain by a series of diopside-rich granulite beds, which dip gently eastward. To the north the tactite mass is split by a large septum, trending south to south-southeast, of recrystallized limestone about 100 feet wide. Small, poorly exposed sills and dikes of aplitic granite and an irregular body of fine-grained rhyolite also lie within the tactite belt (pl. 28).

A strongly sheared and brecciated zone at least 25 feet wide extends along the tactite-rhyolite contact in the southern part

14/ The term "ore" is here used in its broadest sense, and does not necessarily mean that the material contains enough beryllium to currently permit its mining at a profit. Cut-off values for this unusual rock cannot be determined until the final results of beneficiation and extraction tests become available.

of the area, and, as traced for 220 feet from an old open cut to a larger and more recent cut near the center of the area, it strikes N. 10°-20° W. and has a steep dip to the west. A second, somewhat similar brecciated zone, at least 180 feet long and with a more northwesterly strike, appears in the narrow belt of tactite between the two rhyolite masses in the northwestern part of the area (pl. 28). Both zones have been mineralized with coarsely crystalline fluorite, together with subordinate specular hematite, idocrase, chlorite, grossularite, manganese carbonate and silicates, willemite, and chalcedony. This mineralization, some of which is shown in plate 28, appears to die out in a southerly direction near the old iron cut.

The helvite, together with the beryllium-bearing idocrase, chlorite, and grossularite contained in the fluorite-rich massive tactite, make it a potential ore of beryllium, but one of very low grade. The concentration of these minerals appears to vary, in general, with that of the fluorite. Several systematic chip samples of the mineralized tactite were analysed chemically with the following results:

BeO content of samples from Scheelemite area

Sample and location	Percent BeO
1. Large fluorspar cut in center of area..............	0.6
2. Small cut 110 feet west-northwest of fluorspar cut..	.05
3. Small cut 140 feet northwest of fluorspar cut.......	.22 and .08*
4. Two trenches 180 feet northwest of fluorspar cut....	.3
5. Two trenches immediately southeast of fluorspar cut.	.1

*** Duplicate determination by Brush Beryllium Co.; other determinations by U. S. Geological Survey.**

Subsequent examination of material from the fluorspar cut with the spectrograph and the petrographic microscope indicates that its average grade is much lower than that shown by sample No. 1 above. The four beryllium-bearing minerals, which are generally too fine grained to be readily recognized with the unaided eye, are so irregularly distributed through the shear and breccia zones of the Scheelemite area that estimates of tenor made in advance of detailed sampling are no more than rough approximations. The indicated ore blocked out by the present shallow openings amounts to only a few tons of material containing about 0.2 percent BeO, together with some 2,000 tons containing 0.05 percent to 0.1 percent.

Also present in the mineralized tactite are the tungsten and molybdenum minerals scheelite and powellite. A few large crystals were observed with the fluorescent lamp near the mouth of an old 50-foot adit and in low outcrops immediately south of the fluorspar cut (pl. 28), but the only occurrence having commercial promise lies in a narrow tactite belt northwest of the fluorspar cut, where stripping by the Bureau of Mines has revealed an area of irregular tungsten mineralization 135 feet long and 8 to 18 feet wide. The chief tungsten mineral is a molybdenian scheelite that appears to contain 5 percent to 12 percent of MoO_3; its color under the fluorescent lamp is a rich, creamy white. Large crystals of it, many of them at least a quarter of an inch in diameter, are disseminated through the tactite, their distribution being chiefly controlled by two sets of fractures, which trend north-northwest and northeast and dip steeply to the west and southeast respectively. There has been much postmineral shearing, and the scheelite appears to be distinctly older than the fluorite and the beryllium-bearing minerals present in the same zone of mineralization.

Three composite samples were cut from shallow trenches and analysed by representatives of Continental Machines, Inc., prior to the stripping of the deposit. These were found to contain 0.41 percent, 1.15 percent, and 1.64 percent WO_3. A carefully prepared composite sample from all trenches and outcrops, which was analysed in the laboratories of the Geological Survey, contained 0.94 percent WO_3. The Bureau of Mines sampling indicates that the average tenor over an area of approximately 220 square feet is about 0.5 percent of WO_3. About 275 tons of this ore would be available for each 10 feet of depth in the deposit. As the tactite forms a pendant in rhyolite (pl. 28), the ore may well be cut off at no great depth, but the rhyolite contacts are so steep that they may go down for at least a few tens of feet before coming together.

Parker Strike area

In the Parker Strike area, which lies on the ridge midway between North and South Peaks (6, pl. 18), is exposed a small but rather high-grade tungsten deposit, owned by Continental Machines, Inc., which can be reached from Brown City over a steep automobile road. It was worked intermittently from July 1942 to April 1943. No production of concentrates is yet recorded, but approximately 400 tons of ore and waste, estimated to average 0.5 percent WO_3, has been shipped to a mill near El Paso, Tex.

The area is traversed by a thick dike of porphyritic rhyolite, which trends north-northwest and dips westward at moderate angles (pl. 29). Flanking this dike is an eastward-dipping series of beds and lenses of coarsely recrystallized limestone, pale-green to gray diopside-clinozoisite granulite, vitreous quartzite, and massive tactite. The tactite forms irregular pods and thin, concordant, lenticular masses that are generally many tens of feet long (see pl. 29). At least two pre-rhyolite faults, which trend east-northeast and dip vertically or nearly so, are readily recognizable by their truncation of thin but prominent quartzite beds. A set of strong joints and shear planes lies parallel to these faults, and a second set conforms to the dike in trend but dips more steeply west. At the intersections of particularly well marked zones in these two sets, the brittle contact rocks are severely shattered, and scheelite is relatively abundant at two of these intersections, both of them west of the dike.

The scheelite crystals, which contain 3 to 10 percent of MoO_3 and are creamy white to pale golden yellow under the fluorescent lamp, are disseminated in the richer parts of the ore bodies and smeared along fractures in the outer, leaner parts of the bodies. The distribution of the mineralization is shown diagrammatically in plate 29. A low knob in the southern part of the area consists of massive tactite that is irregularly impregnated with scheelite crystals, an eighth of an inch or more in diameter, throughout an exposed surface of about 500 square feet. The average WO_3 content of this material, as estimated by inspection with the fluorescent lamp, is slightly less than 0.5 percent. As the tactite is conformably underlain at little depth by an eastward-dipping bed of limestone, the total indicated amount of tungsten-bearing rock is no more than 200 tons. Numerous exploratory trenches, spaced on 25-foot centers and extending at right angles to the rhyolite dike, reveal no other ore zones on either side of this body.

The upper Adele workings, which partly expose the most promising deposit in the area, consist of a shallow cut 60 feet long and 30 feet wide, a 12-foot test pit (now filled with broken ore), and about 35 feet of diamond-drill hole (pl. 29). Several chip samples cut on 8-inch grids at different stages of the operations in the cut were analysed chemically; two of the samples, consisting of lean material near the margins of the ore body, contained 0.34 percent and 0.53 percent WO_3; three samples of ore whose grade could be maintained by careful mining contained 0.91 percent, 1.9 percent, and 2.62 percent; and two from rich shoots containing a few tens of tons of ore assayed 3.3 percent and 4.03 percent in WO_3. About 1,000 tons of 1.5 percent to 2.0 percent ore, including that already mined, is indicated by existing workings, and it seems reasonable to infer that 500 tons in addition is available.

An adit driven 125 feet east-northeastward from a point 240 feet down slope from the upper Adele workings (section, pl. 29) crosses a succession of eastward-dipping limestone and dense granulite beds for 94 feet, then passes into porphyritic rhyolite. An irregular raise from this adit to the surface exposes a 60-foot section of slabby to thick-bedded granulite. Whether or not tactite is present along the hanging wall of the rhyolite mass between this raise and the surface workings to the east-northeast is not known, but the tactite exposed immediately east of the raise collar probably extends downward to the rhyolite. This tactite offers the greatest promise of additional ore bodies.

Lucky Strike-Tungsten Reef area

Several masses of tungsten-bearing tactite are exposed immediately south and southeast of North Peak (7 and 8, pl. 18), on ground controlled by the Saratoga Mining Corporation. The area is connected with the automobile road of Continental Machines, Inc., by a truck trail. It was explored by the Federal Bureau of Mines during the spring of 1943, chiefly by means of shallow trenches. Most of the scheelite occurs in a thick-bedded garnet-magnetite tactite, which is underlain conformably by dense, pale-green, diopside-rich granulite. These rocks dip gently east, together with a thin, sill-like body of fine-grained granite intruded into them. The granite crops out along the ridge (pl. 30).

In the Lucky Strike body scheelite and powellite occur in and immediately adjacent to thin, straight, closely spaced stringers of magnetite and andradite garnet. These stringers are 0.5 to 8 millimeters thick and lie 1 millimeter to several centimeters apart (fig. 10). Though individually somewhat discontinuous, they form "sheeted" zones that are several inches or more in width and traceable for distances as great as 100 feet. These zones, which trend northeast to east-northeast and dip very steeply southeastward, cut across the edges of the massive beds of garnet-rich tactite exposed west of the ridge, and at least two can be traced into thin strongly endomorphosed zones in the fine-grained granite.

The tungsten minerals form crystals and crystalline aggregates whose minimum dimensions are generally a millimeter or more. In the richer veinlet zones, scheelite stringers 2 millimeters thick are common, but they rarely persist for more than a few feet along the strike. Grab samples of tactite from these veinlet zones have been reported to contain as much as 5.7 percent WO_3, but the average WO_3 content of the minable ore is probably less than 1 percent. Three systematic samples cut from channels normal to the strike of the veinlets were found to contain 0.32 percent, 0.94 percent, and 4.34 percent WO_3, and from

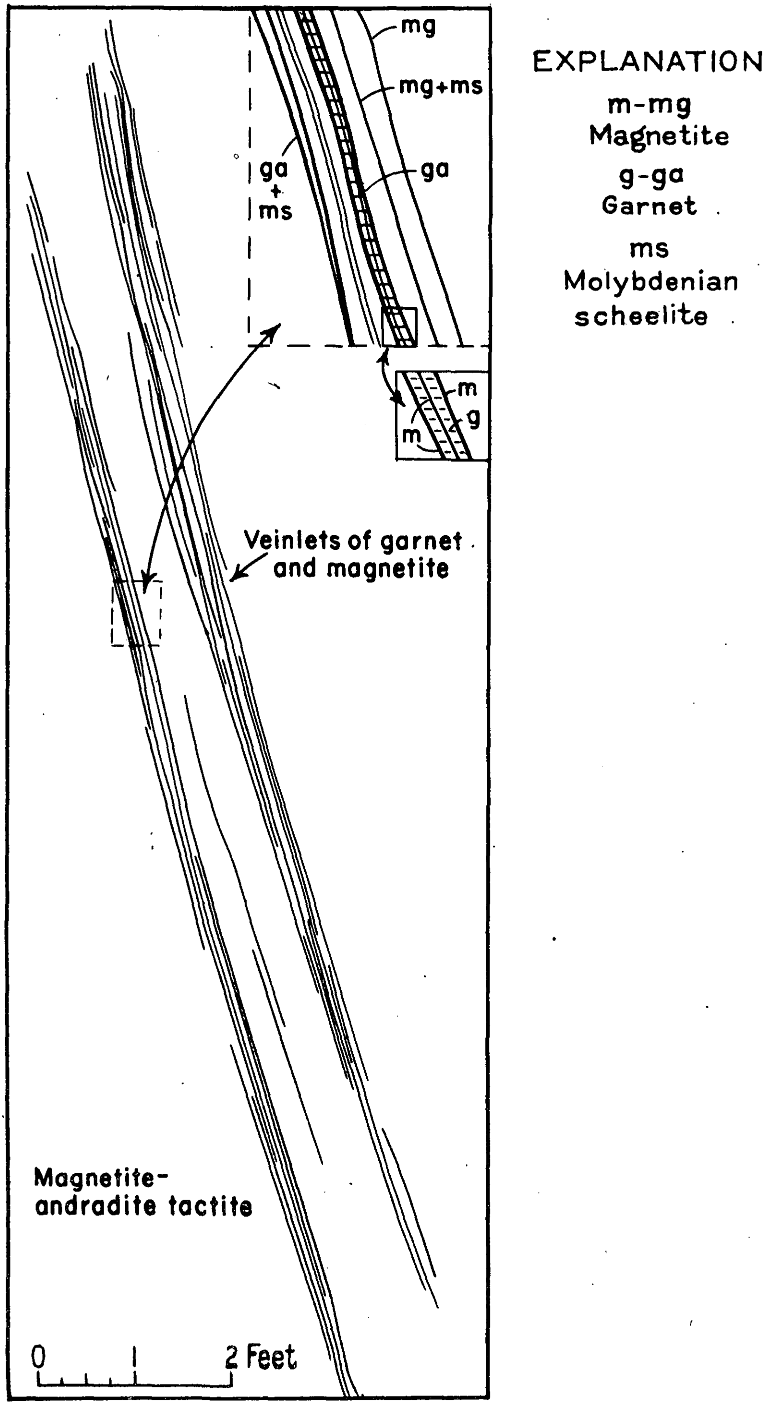

Figure 10.—Sketch of tungsten-bearing veinlet zones in massive garnet-magnetite tactite, Lucky Strike deposit.

inspection with the fluorescent lamp it seemed probable that efficient mining should produce ore having a WO_3 content between 0.5 and 0.8 percent. On the other hand, analyses made for the Bureau of Mines 15/ indicate a much lower tenor in WO_3 possibly because of a relatively high powellite content. A considerable tonnage of such mineralized material has been outlined by 11 exploratory trenches and several small stripped areas, and, in view of the known persistence of veinlet zones across tactite beds along the present exposed surface, it seems likely that this material may persist downward nearly to the underlying granulite. The results of the Bureau of Mines analyses indicate, however, that the material may be of too low grade to be regarded as ore.

Immediately south of the Lucky Strike body is a small, ill-defined area of tungsten mineralization (pl. 31). Large crystals of molybdenian scheelite, some of them a half inch in diameter, occur sparingly in massive-bedded tactite, without apparent structural control. One composite sample representing 400 square feet of exposed tactite near the west edge of the granite dike was found to contain 0.13 percent WO_3, and the other mineralized zones are probably a little richer. Nothing is known of the distribution of the scheelite beneath the surface.

Farther southeast, on the opposite side of the granite, is a somewhat larger area in which coarse-grained scheelite is sparsely and irregularly disseminated through massive tactite, large blocks of which have moved southward from their place of origin for some yards down the slope. Since the tactite that lies in place is bottomed at depths of 1 to 6 feet by barren granulite, as demonstrated by outcrops and two shallow test pits, the tonnage of mineralized rock is small compared with its exposed area, which is about 25,000 square feet. The average WO_3 content of this material, as estimated by inspection with the fluorescent lamp, is about 0.1 percent, but the outcrops and workings indicated that approximately 1,500 tons of 0.5 percent ore could be produced by selective mining. Additional tungsten-bearing tactite might be found beneath the granulite, which appears to be only a few feet thick; at the present time, however, no exploratory workings on the east side of the mountain—which is a dip slope—are deep enough to prove that scheelite mineralization continues downward beyond barren interbeds of limestone, granulite, or quartzite.

Scheelite Gem deposits

The Scheelite Gem deposits, on the steep east slope of the mountain, 1,000 feet southeast of North Peak (9, pl. 18), are held under option by the Saratoga Mining Corporation. They are reached by a steep trail from the road on the ridge to the west, and by a shorter trail from an old road, in bad condition, that enters the area from the south. The tungsten-bearing rock is a thick-bedded, coarse, magnetite-rich tactite, which dips eastward in rough conformity with the slope; it is overlain and underlain by barren beds of recrystallized limestone associated with a little hornfels and granulite. Two mineralized zones, exposed by small cuts 6 to 8 feet deep, appear to extend along a prominent set of fractures that trends east-northeast and dips very steeply south. This may well be the eastward continuation of the shear and fracture zone exposed in the upper Adele workings in the Parker Strike area.

15/ Information furnished by F. A. Rutledge, Bureau of Mines Project Engineer, June 1943.

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The chief tungsten mineral is coarsely crystalline molybdenian scheelite, in which the ratio of MoO_3 to WO_3 is about 1:8. Near the surface it is accompanied by orange to canary-yellow crusts of tungstite and molybdic ocher, and finely disseminated willemite is common throughout the workings. The deposits appear to be small but of high grade, assays of 5 percent and 6 percent WO_3 having been reported from grab samples. Two systematic chip samples were analyzed by the Geological Survey. One of them, consisting of lean material near the margins of ore bodies, was found to contain 0.94 percent WO_3; the other, consisting of typical ore from the central parts of ore bodies, contained 4.34 percent WO_3. As the tactite in both cuts is underlain by nearly barren iron-poor contact rocks, the amount of indicated ore does not exceed 200 tons; it should average at least 1 percent WO_3. It is possible, however, since the fracture zone that may have controlled the mineralization probably persists to depths of some tens of feet, that additional ore occurs in other tactite layers beneath the present shallow workings, and this possibility should be tested.

South Peak-Backslope area

The South Peak-Backslope area (10 and 11, pl. 18), which contains several small tungsten deposits owned by Continental Machines, Inc., can be reached by trail from the end of the road at the Adele workings, which lie 1,000 feet to the north-northwest. Garnet-magnetite tactite in which large and small crystals of scheelite and powellite are disseminated forms irregular bodies adjacent to two rhyolite dikes, which dip steeply to the west and southwest. These dikes are offset by a steep fault that appears to be genetically associated with the tungsten mineralization.

The mineralized areas have been thoroughly prospected by the owners. At South Peak, two test pits and several hundred feet of trenching have demonstrated that the scheelite-bearing tactite, though locally rich, contains so much waste that the minable material probably contains no more than 0.5 percent WO_3. The tactite bodies appear moreover to be small, and their subsurface distribution is uncertain. A shaft that is being sunk from the summit of South Peak may furnish useful data as to the form of the deposits. The Backslope deposits, farther to the northeast, lie in a tactite body whose outcrop is triangular and has an area of about 25,000 square feet, but as it lies on a dip slope it may be underlain at shallow depth by barren limestone or granulite. This body has been explored by means of a 10-foot pit and five cuts, none of which is more than 3 feet deep. As these openings show the distribution of tungsten minerals to be very irregular and outcrops in the intervening area are poor, no estimate of grade or tonnage can be made without further exploration.

Black Bed area

The Black Bed area, which lies low on the west slope of Iron Mountain, a mile south of Brown City (pl. 17), is connected with State Route 52, to the west, by a poor dirt road. The tungsten deposits in this area are controlled by Mr. Blanchard Hanson of Hot Springs, and they have been trenched and sampled by him, by Continental Machines, Inc., and by the Bureau of Mines. As shown in plates 17 and 31, the deposits occur in a thin, remarkably continuous bedlike mass of tactite, which occupies a definite stratigraphic position in a series of metamorphosed sedimentary rocks. On the west, this series is bounded by an intrusive mass of fine-grained, dark-gray to reddish-brown, distinctly porphyritic rhyolite, which is well exposed near the mouth of Last Chance Canyon (pl. 31). East of the rhyolite are exposed, in ascending order, 105 feet of dark-brown, platy to thick-bedded vitreous quartzite, 45 feet of dense, brittle, pale-green, diopside-rich granulite in 1- to 4-foot beds, a thin layer of magnetite-garnet-pyroxene tactite (the "black bed"), and a great thickness of white to bluish recrystallized limestone with minor silicated zones. This series can be traced northward along the strike for 5,000 feet, and southward for 1,000 feet.

The tactite ranges in thickness from a knife edge to 12 feet, with an average of 2 or 3 feet. It is coarse-grained and contains more pyroxene than the other tungsten-bearing rocks in the district. Scheelite and powellite, in fairly large to minute grains, are disseminated in the tactite of the "black bed" and also, locally, in the granulite and in small light-colored lenses of garnet-rich tactite that lie entirely within the limestone areas. Mineralization of the "black bed" is very irregular: in some places rich ore zones that are traceable for as much as 30 feet along the strike pass abruptly into barren tactite; elsewhere the ore occurs in much smaller, podlike masses. No immediate structural control for the positions of these ore bodies is apparent, although the richest part of a given body is commonly nearest the top of the tactite mass. As shown in plate 31, most of the ore occurs on the slopes of Last Chance Canyon.

While the zones of finely disseminated scheelite are not extensive enough to be of commercial value, the coarser ore is more promising; but, although assays of 2 to 4 percent WO_3 have been reported from samples representing several tons of ore, inspection with the fluorescent lamp indicates that the grade of any large quantity of ore would be much lower. On the basis of present exposures, and on the assumption that the ore will extend continuously downward for 10 feet, 1,800 tons of indicated ore averaging 0.5 to 0.8 percent WO_3 is estimated to occur in the "black bed" along the slopes of Last Chance Canyon. Other, more scattered occurrences might add 200 tons to this figure. The tactite may well extend, however, to depths greatly in excess of 10 feet, since it is very persistent along the strike and since there seems to be little chance of its being truncated by igneous rock or by a large fault. The tungsten mineralization must indeed be somewhat less persistent and may be irregular, yet some down-dip exploration along the part of the "black bed" that crops out in Last Chance Canyon seems desirable. Pending such exploratory work, an estimate of 3,000 tons of inferred ore seems consistent with what is now known concerning the deposit.

RESERVES AND OUTLOOK FOR THE DISTRICT

Beryllium deposits

Most of the "ribbon rock" bodies in the Iron Mountain district are so unpredictably irregular that accurate estimates of their tonnage cannot be made. Within 10 feet or less, a given body may undergo marked change in shape or size or may pass abruptly into barren material. But, although little ore can be measured, the exploratory work done by the Federal Bureau of Mines on most of the known deposits has furnished satisfactory data for the estimation of indicated ore. The amount of inferred ore, which is nowhere more than the amount of indicated ore, is relatively small, because the beryllium-bearing material in the larger deposits is bottomed by igneous rock at shallow depths and because its downward continuity in the smaller, less regular deposits cannot be predicted far beyond the limits of exploration.

Detailed mapping and preliminary sampling of the "ribbon rock" bodies by the Geological Survey, together with extensive exploration of these deposits by the Bureau of Mines, indicate a reserve, in the district as a whole, of about 3,500 tons of the higher-grade, magnetite-rich "ribbon rock" and 84,000 tons of the lower-grade, silicate-rich "ribbon rock." Inferred ore of the two classes amounts to approximately 1,000 tons and 100,000 tons, respectively. The higher-grade tactite contains 0.4 percent to 3.5 percent BeO, with a probable average of about 0.7 percent; hence the amount of this material indicated in the district (chiefly in the Discovery Gulch and West Slope areas) would correspond to approximately 25 tons of BeO or to 204 tons of beryl concentrates containing 12 percent BeO. The average BeO content of the silicate-rich "ribbon rock" has not been satisfactorily determined but is probably about 0.2 percent. On this assumption the indicated low-grade material would contain approximately 168 tons of BeO, and would be the equivalent of 1,400 tons of beryl concentrates containing 12 percent BeO.

Since most of the district has been thoroughly prospected for "ribbon rock," which is easily recognized in outcrops and in float, it seems likely that significant additions to its reserves must await the discovery of additional beryllium-bearing tactite that lies wholly beneath the present surface. In a few places the structural conditions and expectable grade of ore might be sufficiently favorable to justify subsurface prospecting for such tactite. For example, bodies of relatively high grade, magnetite-rich "ribbon rock," similar to the Hot Spot and Little Hot Spot bodies, might well occur within the limestone terrane on the south side of Discovery Gulch, presumably at or near the southward-dipping rhyolite contact. Other high-grade bodies might be found in the West Slope area in a down-dip (easterly) direction from the Jackpot No. 2 body. In most parts of the district, however, there is little to guide subsurface prospecting. No single stratigraphic horizon or zone has been shown to be especially likely to contain beryllium-bearing tactite, and there is no reason to assume that low-grade ore will pass downward into richer ore. Both types of "ribbon rock" occur in close proximity to either rhyolite or granite.

The future of the Iron Mountain district rests upon the satisfactory solution of three problems:

1. Development of a relatively low cost, high-recovery procedure for beneficiation of the beryllium-bearing rock.
2. Development of a reliable method for assaying the lower-grade, silicate-rich "ribbon rock."
3. Utilization of mining techniques that would minimize dilution of beryllium-bearing material by waste rock.

In the effort to establish a satisfactory method for beneficiating such low-grade material, the Bureau of Mines and other organizations have repeatedly tested large quantities of "ribbon rock." The silicate-rich "ribbon rock" has been particularly troublesome, largely because of its extreme fineness of grain and the dispersal of the beryllium it contains into several different mineral species. No metallurgical procedure has yet been developed that would permit the low-grade Iron Mountain tactite to compete successfully with the present sources of beryllium, even though its grade is comparable to that of the beryl-bearing portions of many pegmatites. It remains to be seen whether potential byproduct fluorite and magnetite will make it possible to mine the ore at a profit.

The beryllium content of "ribbon rock" tactite has been difficult to determine with accuracy. Although consistently close agreement has been attained between chemical, spectrographic, and mineralogic determinations made on the magnetite-rich variety, in which all or nearly all of the contained beryllium appears to occur in helvite, this has not been true of the lower-grade, silicate-rich variety. Characteristic discrepancies between methods and between analysts are shown in the following tabulation of analyses made on seven composite samples from the North End deposits:

Analyses of "ribbon rock" samples from North End area

Sample and location	Determinations in percent BeO						
	Spectrographic			Chemical			Mineralogic
	1	2	3	4	5	6	7
A. Beryllium Reef, trenches 1-3.	0.16	0.23	0.20	0.51	....	0.26	0.07
B. Beryllium Reef, trenches 4-8.	.15	.20	.16	.44	0.23	.20	.01
C. Reef Extension....	.11	.05 to .10	.15	.34	.30	.20	.02
D. Beryllium Chief, north of Gunnell Gulch.	.08	.05	.12	.15	....	.17	.01
E. Beryllium Chief, south of Gunnell Gulch.	.09	.05	.15	.53	....	.21	.04
F. Beryllium King and Queen.	.15	.22	.21	.47	....	.29	.03
G. Upper and Lower Star bodies.	.16	.19	.18	.43	....	.25	.09
Calculated average.	0.13	0.15	0.17	0.41	....	0.23	0.04

1. Spectrographic analyses by L. W. Strock, Saratoga Springs, N. Y.
2. Spectrographic analyses by Pennsylvania Salt Co. (Munter), Philadelphia, Pa.
3. Spectrographic analyses by Smith-Emery Co., Los Angeles, Calif.
4. Chemical analyses by Pennsylvania Salt Co. (Munter), Philadelphia, Pa.
5. Chemical analyses by Booth, Garrett, & Blair Co., Philadelphia, Pa.
6. Chemical analyses by Smith-Emery Co., Los Angeles, Calif.
7. Mineralogic analyses by J. J. Glass and R. W. Lemke, U. S. Geological Survey. Values are calculated from percentages of helvite, idocrase, and grossularite, determined in each sample by counting 2,000 to 14,000 grains of representative crushed material.

It is clear that chemical determinations of BeO in silicate-rich "ribbon rock" give consistently higher results than the corresponding spectrographic determinations; even the chemical determinations that are made with the greatest care, under the most closely controlled conditions, apparently give results considerably higher than those obtained with the spectrograph. Careful analytical work by chemists of the Geological Survey and of the Smith-Emery Co., Los Angeles, Calif., tends to indicate that the spectrographic method is the more dependable for this material; for it was found that, although appreciable quantities of beryllium are lost during the usual chemical analysis, the resulting error is considerably overcompensated by the presence, shown by spectrographic checks, of aluminum and iron as impurities in the final weighed precipitate. The mineralogic method is even less adapted to beryllium determinations on this type of material, since it appears evident that only a part of the beryllium is contained in helvite, idocrase, grossularite, and other species that can be recognized under the microscope. Thus the spectrographic method of analysis seems to give the most uniformly correct results, and it is fortunately the least difficult, provided the apparatus for applying it is available.

Should the Iron Mountain deposits ever be worked, the mining of "ribbon rock" with a minimum of dilution by waste will become a real problem. Small lenses and larger, more irregular masses of granulite, limestone, and massive tactite are common within bodies of "ribbon rock," many of which are themselves narrow and irregular. The mining of such bodies by any low-cost method will almost certainly reduce their grade by at least 20 percent.

Tungsten deposits

The tungsten deposits of the district have not been explored in sufficient detail to determine anything more than their general characteristics. Many of the deposits occur in gently dipping beds of massive tactite, underlain by, and in places interlayered with, barren granulite and recrystallized limestone. The limited vertical extent of the tactite masses and the lenticularity of the ore bodies within the tactite are only partly offset by the possibility that other tactite bodies may lie beneath the barren zones.

The individual deposits, though of good grade, are small, and probably few of them contain more than 1,000 tons of ore averaging from 0.5 to 1.5 percent of WO_3, though the aggregate tonnage of near-surface ore in the district may be many times that. Because of the limited exploration of the district, reserves of measured ore are very small. Reserves of indicated ore are estimated to be about 4,800 tons, and those of inferred ore about 4,300 tons; the ore of each class is assumed to contain from 0.5 to 2.0 percent of WO_3. There is also, in the Lucky Strike area, a considerable tonnage of mineralized material that is apparently too low in grade to constitute ore.

Although selective mining of high-grade ore on the Parker Strike, Scheelite Gem, and Lucky Strike deposits might well yield several carloads of 3- to 4-percent ore, the great bulk of the tungsten-bearing tactite is too low in grade to be shipped without milling. A small mill, so located and equipped that it could handle ore from all the deposits, might be justified by the indicated tonnage. Preliminary tests by engineers of Continental Machines, Inc., as well as by other investigators, indicate that few serious difficulties would arise in the milling of Iron Mountain tungsten ore. Most of the scheelite and powellite is freed from the associated magnetite, garnet, and fluorite by relatively coarse crushing (20-40 mesh), and the gangue minerals can be separated without resorting to unusually complex or expensive milling procedures.

Most of the area shown in plate 18 has been examined in detail with the fluorescent lamp, and it appears to contain no promising deposits other than those already mentioned. Additional deposits might be found outside this area, particularly in the massive tactite exposed along and near the main ridge between North Peak and the North End area. There also remains the possibility of down-dip continuation in the Black Bed deposits and of appreciable vertical persistence of mineralization—by "skipping" from one tactite bed to the next across intervening beds of unfavorable material—in the deposits of the North Peak-South Peak area.

PROSPECTING FOR OTHER CONTACT-METAMORPHIC BERYLLIUM DEPOSITS

The restriction of beryllium in the Iron Mountain district to the unusual "ribbon rock" tactite and closely allied zones of late-stage mineralization furnishes an immediate clue for recognition of similar deposits elsewhere. Knopf,16/ for example, has described an "orbicular contact-metamorphosed rock" from the Seward Peninsula, Alaska, that is remarkably like the Iron Mountain "ribbon rock" in appearance, composition, and origin. Dr. L. W. Strock of Saratoga Springs, N. Y., and Dr. George Steiger, of the Geological Survey, have recently made independent spectrographic examinations of this Alaskan rock, and their preliminary findings indicate a beryllium content comparable to that of the Iron Mountain material. Another occurrence, in Pitkäranta, Finland, of what is probably typical "ribbon rock" has been described by Trüstedt,17/ but no specimens have been available for analysis. This rock, and all other tactites that resemble "ribbon rock," should be carefully tested for beryllium.

The beryllium at Iron Mountain occurs in rocks of late-stage hydrothermal origin, and is absent from material deposited chiefly by magmatic vapors.18/ Theoretical considerations, moreover, indicate that little beryllium can be transferred from a magma in a vapor phase, and make it still more probable that beryllium minerals are to be sought in rocks of dominantly hydrothermal origin. It is therefore unlikely that beryllium ores will be found in deposits of massive magnetite or magnetite-garnet tactite, such as the "contact" iron ores in southwestern Utah 19/ and southeastern California,20/ unless these deposits present evidence of late-stage, typically hydrothermal mineralization. Recent examination of several such deposits in the southwestern states has failed to reveal any beryllium-bearing minerals. When such minerals are found, they may prove to be associated, as they are at Iron Mountain, with silicic intrusive rocks of mid-Tertiary age, and contacts of such rocks with limestone deserve special attention. But the main hope of increasing the non-pegmatite reserves of beryllium in the United States appears to lie in finding pyrometasomatic deposits with ribbon banding.

16/ Knopf, Adolph, Geology of the Seward Peninsula tin deposits: U. S. Geol. Survey Bull. 358, pp. 45-46, pl. 4, 1908.

17/ Trüstedt, O., Die erzlagerstätten von Pitkäranta am Ladoga-See: Bull. Comm. Geol. de Finlande, no. 19, p. 226, 1907.

18/ For a detailed discussion of the origin of Iron Mountain tactite rocks, see Jahns, R. H., "Ribbon rock," an unusual beryllium-bearing tactite: Econ. Geology, vol. 39, no. 3, pp. 173-205, 1944.

19/ Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, Utah: U. S. Geol. Survey Bull. 338, 1908.

Wells, F. G., The origin of the iron ore deposits in the Bull Valley and Iron Springs districts, Utah: Econ. Geology, vol. 33, pp. 477-507, 1938.

20/ Harder, E. C., Iron-ore deposits of the Eagle Mountains, Calif.: U. S. Geol. Survey Bull. 503, 1912.

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