Tungsten Reserves Discovered in the Cottonwood-American Fork Mining Districts, Utah

With a Discussion of

The Influence of Scheelite on the Character of Secondary Molybdenum Minerals

BY

ARTHUR L. CRAWFORD
ALFRED M. BURANEK

ORIGINALLY PUBLISHED IN 1944 AS BULLETIN 24
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(UTAH ENGINEERING EXPERIMENT STATION)

IN COOPERATION WITH THE

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ARTHUR L. CRAWFORD, *Director*
UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
College of Mines and Mineral Industries
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Salt Lake City, Utah

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FOREWORD

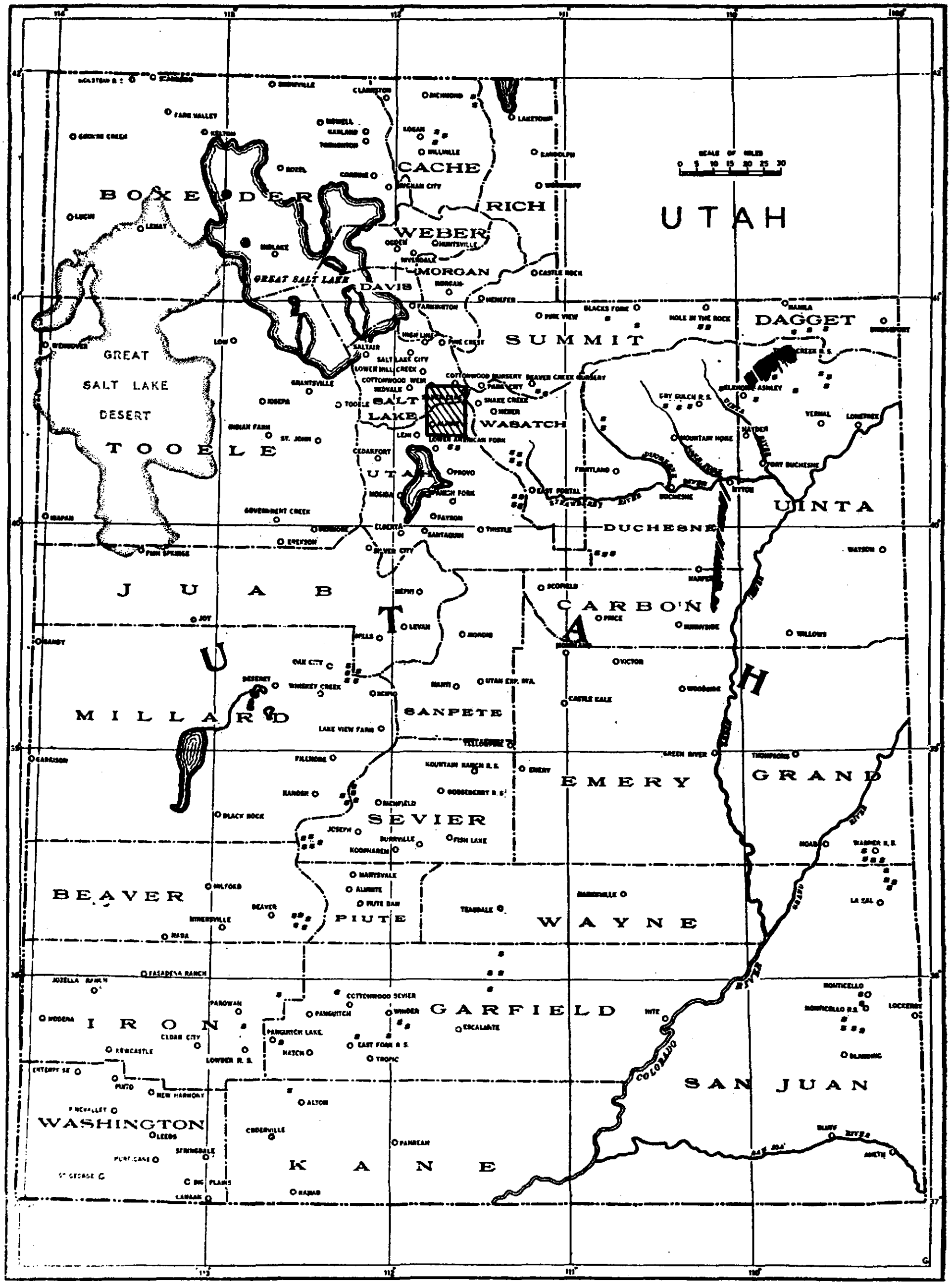
To the Reprints RS-55 and RS-56, 1957

To date no adequate discussion has been published on all of the tungsten deposits of Utah. The bulletins here reprinted (separately) on "Tungsten Reserves Discovered in the Cottonwood-American Fork Mining Districts, Utah" and on the "Tungsten Deposits of the Mineral Range, Beaver County, Utah" have, since their release in 1944 and 1945, respectively, served as preliminary studies of two areas of considerable promise. All of the copies of both of these original reports have now been sold.

Consequently, permission has been obtained from the Utah Engineering Experiment Station to have these respective bulletins reprinted as RS-55 and RS-56 by the Utah Geological and Mineralogical Survey, so that they can continue to be available to those interested in the tungsten deposits of Salt Lake and Beaver Counties.

The preliminary studies by the same authors on tungsten deposits in the Gold Hill district of Tooele County, in the Lucin district of Box Elder County, and in other districts of the state, were cut short by other assignments resulting from World War II. (See Dr. Center's Foreword to RS-56, "The Tungsten Deposits of the Mineral Range, Beaver County, Utah"). These unfinished studies have thus far not been resumed. However, as with the manganese studies and other strategic mineral investigations begun by the same authors during the incubation of the Utah Geological and Mineralogical Survey, it is hoped that time and facilities will ultimately be available for their completion and for the publication of the results so that the people of Utah may profit from a better knowledge of their mineral resources.

Arthur L. Crawford
Utah Geological and Mineralogical Survey



INDEX MAP SHOWING THE COTTONWOOD-AMERICAN FORK AREA

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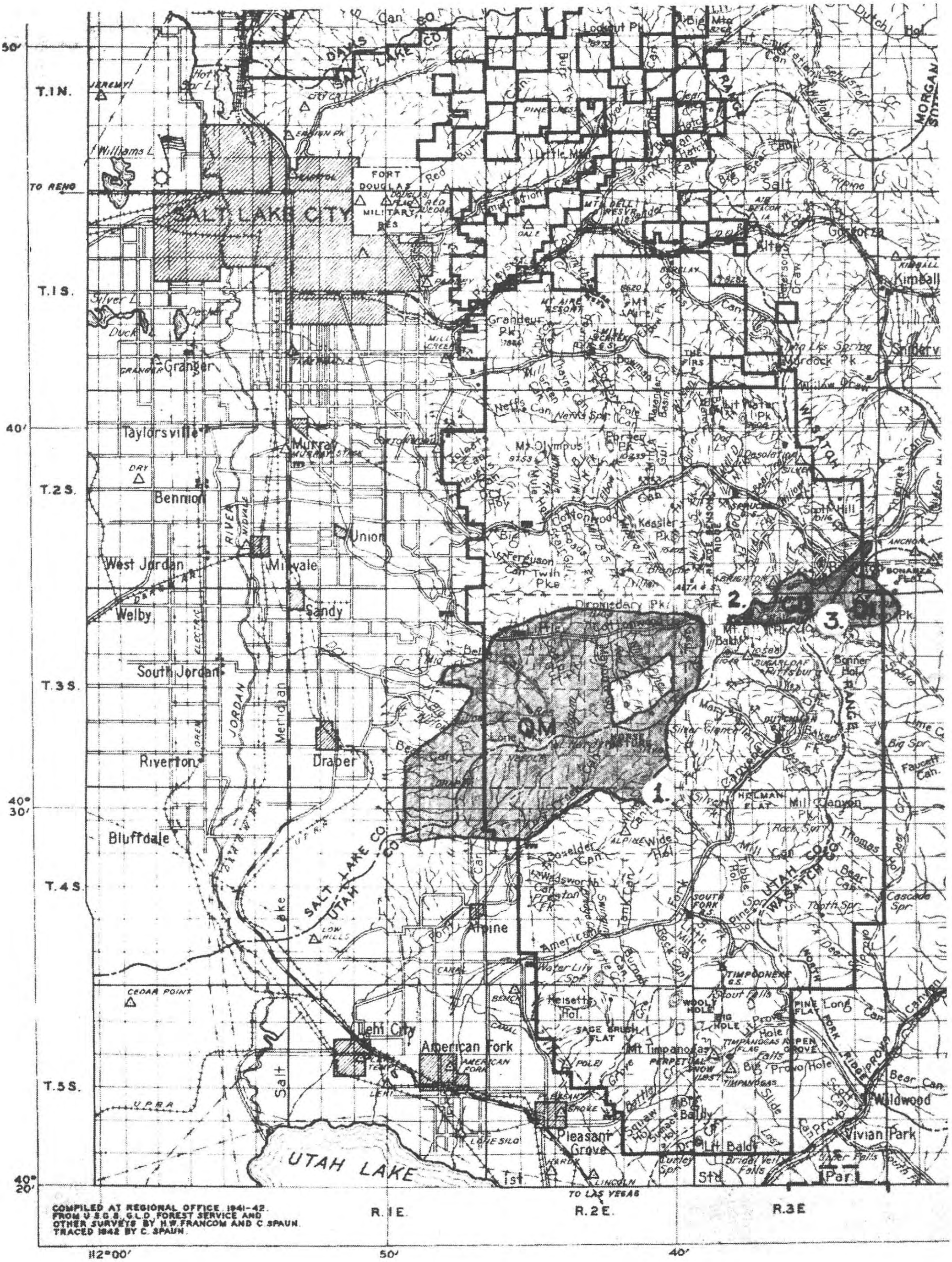
ABSTRACT

With the exception of the rare tungsten sulphide, tungstenite (WS_2), discovered in the Emma mine in Little Cottonwood Canyon, and stolzite ($PbWO_4$) also associated with the Emma ore body, no tungsten minerals had been discovered in the Wasatch Range prior to 1939. The introduction of ultra violet light to prospect for fluorescent minerals and the advent of World War II, with its demands for strategic materials resulted in the discovery of the three scheelite deposits described in this bulletin. The presence of hydrozincite, powellite, and other fluorescent minerals, together with the prevalent confusion in the methods for assaying tungsten in 1939 greatly retarded preliminary prospecting. The perfection of both visual and chemical methods for quantitatively separating tungsten from molybdenum has resulted in a better understanding of the role of scheelite in determining the character of secondary molybdenum minerals. It now appears that ferrimolybdite is the usual oxidation product of molybdenite wherever tungsten is not associated, but that in the presence of tungsten and the absence of lead, powellite is almost invariably the molybdate formed.

The discovery, occurrence, grade, extent, and origin of the three deposits are considered. Like similar Utah occurrences in Box Elder, Tooele, Juab, Millard and Beaver Counties, investigated by the writers, all are low grade marginal deposits occurring in tactite bodies and in mineralized breccia zones adjacent to igneous intrusives. The intrusives in the Wasatch Range, and the tungsten deposits resulting therefrom, are believed to be genetically associated with extensive Laramide thrusting and to be localized within a triangle forming the prow-shaped western end of the Uinta uplift. The authors find little evidence in support of Beeson's hypothesis of a laccolithic core for the Uinta Mountains. To them it appears more probable that a deep under-thrust, buttressed against the resistant quartzite of the old Uinta Highland, and focused on what is now the Bingham stock, granitized the "hot spots" within this comparatively local triangle, produced vulcanism, and generated deep-seated magmatic fluids containing mineralizers and metallizing solutions that gave birth to the famous "Bingham-Park City Ore zone", of which these tungsten deposits are a part.

The Mountain Lake Mine and the South Hecla Mine, near Brighton and Alta, respectively, contain copper and other metal values associated with the scheelite. The ultimate utilization of the tungsten may, therefore, depend to a large extent upon the perfection of metallurgical processes for the differential recovery of these associated metals in the complex ores. Accessibility, indicated reserves, and prior development favor the Alta deposits. The deposits of the Metals Coalition Mines Company in Deer Creek of American Fork Canyon are the least developed of the three occurrences; but they present the possibility of large low grade ore bodies which could be easily tested by shallow core drilling, trenching, etc. Conditions are favorable for further prospecting which might successfully develop sufficient tonnage with little over-burden to permit cheap open-cut methods of extraction so that in any future national emergency this, like the deposits near Brighton and Alta, might become a valuable reserve of this strategic metal.



(Adapted from map of U. S. Forest Servi

FIGURE 2.

Location map of the tungsten deposits discussed with reference to the intrusive bodies (shaded) of Cottonwood-American Fork area. 1. Metals Coalition Mine, 2. South Hecla Mine, 3. Mountain Lake M

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WITH A DISCUSSION OF

The Influence of Scheelite on the Character of Secondary Molybdenum Minerals

By

ARTHUR L. CRAWFORD[1]
ALFRED M. BURANEK[2]

INTRODUCTION

Tungstenite, the sulphide of tungsten (WS_2), was first discovered and described[3] from the Emma mine of the Little Cottonwood District. However, this new mineral was only a curiosity and no one appears to have suspected that scheelite ($CaWO_4$) or other tungsten minerals of possible economic value occurred in this region. If any thought was given to this subject nothing was done about it until World War II made tungsten a strategic metal. The possible tungsten ore reserves now known to exist in the Cottonwood-American Fork area have been discovered since 1939. They have not been reported hitherto except briefly in U. S. Geological Survey Professional Paper 201, on the Geology and Ore Deposits of the Cottonwood-American Fork Area, Utah, just released, after the original manuscript had been brought up to date to include the tungsten discoveries.

The properties herein described contain three tungsten occurrences of the Wasatch Range, one in Big Cottonwood Canyon, one in Little Cottonwood Canyon, and one in Deer Creek Canyon, a tributary of American Fork Canyon. This paper does not cover all of the tungsten occurrences of the Wasatch Range nor does it attempt to discuss in detail all of those in the Cottonwood-American Fork area. Scheelite has also been found to exist in the mineralized zones of the Milkmaid Mine of American Fork Canyon, in the contact rocks of Alpine Canyon, and has been reported from other properties of Little Cottonwood and Big Cottonwood Canyons[4] which are noted but not described in this report. Recently, farther north in the Wasatch Range, scheelite has been found by the junior author in Farmington Canyon and elsewhere in pegmatitic veinlets in the Archean schists and gneisses north of City Creek and south of Ogden Canyon.

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[1] Geologist and Mineral Technologist, Department of Mining and Metallurgical Research, University of Utah.

[2] Geologist, Utah State Department of Publicity and Industrial Development.

[3] Wells, R. C., and Butler, B. S., "Tungstenite, a New Mineral", Washington Acad. Sci. Jour. Vol. 7, (1917) pp. 596-599.

[4] High Grade samples were submitted to Buranek by Thomas H. Southworth of Salt Lake City, from an undisclosed property located in Big Cottonwood Canyon.

DISCOVERY AND OCCURRENCE OF SCHEELITE IN THE COTTONWOOD-AMERICAN FORK MINING DISTRICTS, UTAH

The known occurrence of tungstenite in the Emma Mine of the Little Cottonwood District prompted Buranek to "lamp" a number of the contact metamorphic ore-bodies in this area. The Mountain Lake Mine (also known as the Great Western Mine) in Big Cottonwood Canyon was first "lamped" during the fall of 1939, and scheelite, having a creamy-yellow fluorescence in ultra violet light, was found associated with the tactite rocks. Encouraged by this discovery, other trips were conducted into American Fork and Little Cottonwood Canyons in the spring and summer of 1941. These were made in conjunction with a night school prospecting class at the American Fork High School of which the junior author was instructor[1]. As a result, scheelite was found in the "contact" rocks of the Milkmaid and adjacent properties, American Fork Canyon, and in an old mine dump of Alpine Canyon. In each case the scheelite was associated with the periphery of the Little Cottonwood Stock of quartz monzonite. Scheelite was also found in the several out-crops of garnet rock and epidosite around the margins of the southwestern tongue of the Alta Stock of granodiorite and in the South Hecla Mine workings some 1500 feet below.

Other areas prospected for scheelite with ultra violet light were in Mary Ellen Gulch and in the various mines and prospects of the northeast fork of American Fork Canyon, such as the Pacific, Bay State, Pittsburg, Bog, and Silver Dipper mines and adjacent prospects at the extreme northwestern head of the canyon. However, no scheelite was found at any of these latter mines and prospects. The absence of scheelite in these areas is attributed to the lack of granitic masses penetrating the sedimentaries in the immediate neighborhood. The only granitic exposure in this vicinity is an elliptical outcrop from 400 to 800 feet in diameter located in the saddle crossed by the trail which connects Mineral Flat, at the head of American Fork Canyon, with Alta. The actual contact with this exposure is a mile or more away from most of the mines and prospects examined. Basic intrusive rocks such as the dioritic dikes at the Bog mine were carefully "lamped" but failed to show the presence of scheelite.

In the Silver Lake area of the western part of the American Fork district, in close proximity to the low-angle contact zone of the Little Cottonwood stock, small amounts of scheelite were noted at the Milkmaid claim and in the quartz-suphide rocks on the dumps of several prospects to the east. The tungsten from the original mineralizing "juices" appears to have been precipitated fairly close to the margins of the various granitic stocks.

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[1] Trade extension course in Prospecting, Provo Board of Education cooperating with the State Board for Vocational Education.

COMPARISON WITH OTHER UTAH TUNGSTEN DEPOSITS

The scheelite occurrences of the South Hecla Mine, Little Cottonwood Canyon, and the Metals Coalition property, American Fork Canyon, are typical of most tungsten deposits intimately associated with contact metamorphism. There is no striking difference between these deposits and those present in the House Range[1], Mineral Range[2], Deep Creek Range[3], Grouse Creek Range[4], and other Utah localities where the tungsten exists chiefly as scheelite disseminated throughout tactite rocks. Most of them have certain features in common:

1. The scheelite is found where granitic masses have been intruded into sedimentary rocks with the development of an aureola of tactite bodies around the intrusive, or at least the development of such bodies along part of the contact zone. So-called dry contacts are seldom productive. With few exceptions[5] tungsten has been found in significant amounts only in those "contact zones" rich in garnet, diopside, epidote, tremolite, wollastonite, etc. In such zones scheelite, as one of the early minerals, is also associated with tourmaline, titanite, apatite, or other minerals normally regarded as pneumatolytic products formed by "mineralizers".

2. The tactite zones are relatively massive and continuous, extremely tough as a rule, weathering less rapidly than either the associated granitic rocks or the altered sediments beyond the tactite bodies. Unless subject to surface oxidation of contained sulphide minerals, the tactites are usually dull brown to greenish gray in color.

3. Selective contact metamorphism is usually prominent. Certain sedimentary beds show greater susceptibility to change than others. Hence, the tactite bands frequently show marked parallelism to the original bedding planes of the intruded sediments. Variations from this occur where metamorphism has followed shear-zones, faults, or other structural lines of weakness, or entrapment of the mineralizers expelled by the intrusive.

4. Tungsten mineralization is seldom uniform throughout a tactite body, although the pipes and lenticular scheelite-bearing masses are usually linked together in general parallelism with the line of contact with the intrusive.

5. Tungsten is usually associated with molybdenum with which it is isomorphous in the scheelite-powellite series. All gradations from the relatively pure powellite, essentially the calcium molybdate ($CaMoO_4$) to scheelite, the calcium tungstate ($CaWO_4$) may exist.

6. The tungsten ore-zones are usually marginal or low-grade disseminated ores with occasional high-grade "shoots" or "pockets".

Even though the need of tungsten for World War II, after Chinese supplies were cut off from the United States, greatly stimu-

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[1] "Amazon Stone—A New Variety of Feldspar for Utah—With Notes on the Laccolithic Character of the House Range Intrusive", Arthur L. Crawford and Alfred M. Buranek, Proceedings of the Ut. Acad. of Sci., Arts, and Letters, Vol. 19-20, pp. 125-127.

[2] "Certain Tungsten Deposits of the Mineral Range, Beaver County, Utah", Arthur L. Crawford and Alfred M. Buranek. Circular 26, Utah State Department of Publicity and Industrial Development, 1943.

[3] "The Tungsten Pipe of the Reaper Mine", Arthur L. Crawford and Raymond Chorney, Proceedings of the Utah Acad. of Sci., Arts, and Letters, Vol. 19-20, pp. 143-9.

[4] Report of "Field Trip to Western Box Elder County, Utah, September 14 to 23, 1942, J. Stewart Williams, Arthur L. Crawford, and Alfred M. Buranek, Memorandum Reports to the Utah State Department of Publicity and Industrial Development.

[5] Notably on the Star-Dust claims and elsewhere on Dutch Mountain in the Gold Hill District where the authors have observed large "kidneys" and "pockets" of pure scheelite in marblized limestones beyond the zone of contact silicates.

lated prospecting for this metal, no one deposit thus far has been found in Utah which appears to be a potential tungsten producer of the first magnitude. The recent introduction of ultra-violet light as a ready tool of the prospector and its particular usefulness in finding scheelite, because of the brilliant fluorescence of this mineral, have resulted in the discovery of many tungsten prospects. However, as in World War I, Utah tungsten continues to come from a great number of small producers. The reserves in the Cottonwood-American Fork districts are of particular interest in view of their close proximity to the industrial centers of the state. Further, these reserves are easily accessible over established roads to the respective tungsten-bearing mines.

Of the three properties described, the South Hecla shows the most promise. It may prove to be one of the best tungsten reserves in Utah. As shown hereafter, considerable ore in the Kate Hayes ore shoot in this mine will assay 1.8 percent WO_3, and one dump sample taken by Calkins and Kasteler[1] from the South Columbus Tunnel, believed to be representative of a 40 foot by 8 foot face, averaged 0.7% WO_3. There are geological reasons for believing that this 40 by 8 foot face may be elongated in a third dimension for 500 feet. Unlike many other tungsten properties, the South Hecla Mine has a complex assemblage of many ore minerals. Copper, lead, zinc, bismuth, gold and silver exist in appreciable quantities. These will enhance the value of the tungsten ore provided the metallurgy of their separation and recovery can be sufficiently simplified to make the process economical with the grade and tonnages of ore available.

The Mountain Lake Mine also has a complex ore mineral assemblage. Much of the ore contains copper, tungsten, iron, gold and silver, although the latter two are relatively insignificant. Because of the intimate relationship, which generally exists between the magnetite and copper-tungsten minerals, and because of the low-grade quality of the ore, it is believed that the ore-bodies cannot be profitably exploited without beneficiation. One of the favorable aspects of the property, however, is the possibility of proving large tonnages of low-grade ore. For example, the cupriferous-magnetite zone from the level of the Mountain Lake (Great Western) tunnel to the surface contains an estimated 280,000 tons. Other similar mineralized areas are present which deserve more detailed study.

The Metals Coalition property of American Fork Canyon shows promise to a lesser degree, as only "marginal" tungsten ore (0.5 percent or less WO_3) has been shipped thus far.

THE POWELLITE PROBLEM IN EVALUATING SCHEELITE DEPOSITS

As previously pointed out most of the tungsten deposits in the state have more or less powellite isomorphously associated with the scheelite. If the powellite molecule present in the scheelite crystal

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[1] Calkins, F. C.—Geologist for the U. S. Geological Survey; Kasteler, J. I.—Mining Engineer for the U. S. Bureau of Mines, verbal communication from Mr. Kasteler.

lattice constitutes more than one part of $CaMoO_4$, to twenty to twenty-five parts of $CaWO_4$, the color of fluorescence of this molybdenum-bearing scheelite is indistinguishable from powellite containing little or none of the scheelite molecule.

R. S. Cannon, Jr. and other investigators of the U. S. Geological Survey have worked out a comparative fluorescence color chart for molybdenum-bearing scheelite in which the weight percentage of molybdenum constitutes less than 4.8 percent in the crystal lattice of the isomorphous mineral. By means of this chart quantitative estimates with a high degree of accuracy can be made of the molybdenum content. In the range between chemically pure $CaWO_4$ and molybdenum-bearing scheelite, $Ca(W,Mo)O_4$, assaying less than 4.8 percent molybdenum the fluorescence color change is rapid and varies in direct proportion to the Mo replacing the W in the crystal lattice. The economic significance of molybdenum in scheelite ores and the history of the standardization of determinative procedure is summarized in Press Notice 611 released July 16, 1942, by the U. S. Geological Survey, under the caption "New Methods for Determination of Molybdenum in Scheelite", from which we quote:

> "The intensive search for tungsten, begun by the Survey in 1938, has met with success, although considerable scheelite with undesirable molybdenum content has been encountered. Most of the scheelite in the contact-metamorphic deposits of the western states contains at least a trace of molybdenum, and at many localities the scheelite mineral contains as much as half a percent. As commercial scheelite concentrates containing more than 0.4 percent of molybdenum are subject to a price penalty, these methods of testing will be useful to persons engaged in developing, mining, or milling scheelite ores.
>
> "One of the methods, which is intended for use in the field, depends on fluorescence; the other, an improved assay method, depends on colorimetric chemical analysis.
>
> "By the fluorescence method, the molybdenum content of scheelite can be determined visually in the field by any good observer equipped with the customary ultra-violet lamp. This method is based on the discovery that the fluorescence color of scheelite is directly related to the proportion of molybdenum contained in the crystal lattice of the mineral. In general, concentrates that are not penalized for molybdenum can be made from any scheelite that fluoresces distinctly blue; those that fluoresce white are borderline cases containing roughly from 0:35 to 1.0 percent molybdenum; and scheelite that fluoresces distinctly yellow contains more than 1 percent. More exact quantitative determination of the molybdenum content of any scheelite containing less than 4 percent can quickly be made in the field by comparing the fluorescence color of the powdered mineral with the fluorescence colors of powders of known composition, which are permanently mounted on a card.
>
> "The first step in developing this method was made by R. S. Cannon, Jr., a geologist of the Survey, while studying tungsten deposits in the Seven Devils mining district of Idaho. Having observed that the fluorescence color of the scheelite varied considerably, Cannon conceived the idea that there might be a quantitative relationship between the fluorescence color and the molybdenum content. This idea was put to the test as soon as possible by studies carried out in the Chemical Laboratory of the Geological Survey. F. S. Grimaldi made complete chemical analyses of selected samples of scheelites and powellites from the Seven Devils and other western districts. K. J. Murata at the same time prepared a series of synthetic compounds ranging in composition from pure calcium tungstate to pure calcium molybdate. It was then found that the fluorescence color given by all these materials of known composition varied systematically, so that it could be used as a means of estimating molybdenum.

> "With the type of ultra-violet lamp commonly used in prospecting for scheelite, Murata found that the fluorescence colors of the finely powdered synthetic preparations are bright blue for pure calcium tungstate; paler blue for preparations containing traces of molybdenum, and neutral white when the molybdenum content is about 0.5 percent. As the molybdenum content rises above 0.5 percent, the fluorescence color becomes increasingly yellow. It is strongly yellow for a compound containing 4.8 percent molybdenum; but, strangely enough, it remains of the same shade for any compound containing a higher percentage. The method accordingly serves to determine quantitatively the proportion of molybdenum—in the tungsten mineral, not in the sample—up to a practical limit of about 4 percent. But if the material shows the yellowest possible hue, it may contain any percentage of molybdenum between 4.8 and 48, which is the percentage in pure powellite."

Unfortunately, at the time the preliminary investigations were made of the tungsten occurrences in the Cottonwood-American Fork districts, this determinative chart had not been developed nor had local assayers a quick reliable method for quantitative chemical determinations in the presence of molybdenum. As a consequence, considerable confusion resulted from some of the preliminary discoveries. Ore thought to be rich in scheelite, judged by its degree of fluorescence, gave disappointingly low assays for tungsten. Others, fluorescing cream to yellow, thought at first to be powellite, gave high tungsten assays with the molybdenum to tungsten ratio less than one to ten. Ore found in what is now called the Powellite Stope of the Dwyer Tunnel of the South Hecla Mine was particularly troublesome in this regard.

HYDROZINCITE MISTAKEN FOR SCHEELITE

Another source of confusion in the early stages of the investigation, before the fluorescence colors of the various minerals were thoroughly known, was the bluish-white fluorescence of the hydrous zinc carbonate mineral, hydrozincite, $7Zn0.3C0_2.4H_20$, noted in some of the mines and prospects near the Dutchman and the Pacific mines of the American Fork District. The fluorescence of this mineral greatly resembles that of scheelite. However, it is usually less intense and gives little difficulty to the experienced observer.

Many prospectors who have access to an ultra-violet lamp mistake hydrozincite for scheelite. Except for the fluorescence there is little similarity between the two minerals. They are totally unlike in their occurrence. Hydrozincite is a low-temperature secondary mineral of the oxidized zone resulting from the alteration of sphalerite or other primary zinc minerals. It is found typically as an encrustation along water courses, in old stopes, etc. Hydrozincite is soft, often friable and so fine-grained as to appear amorphous. Unlike scheelite it is never found in large crystals or as a primary mineral in tactites.

Like hydrozincite, powellite is frequently found as a soft, friable, secondary precipitate. In this respect they both differ from scheelite. They can be distinguished from each other by their natural color and by the color of their fluorescence. Hydrozincite is white and shows bluish-white fluorescence. Powellite is various shades of yellow and shows yellow to cream fluorescence.

THE INFLUENCE OF SCHEELITE ON THE CHARACTER OF SECONDARY MOLYBDENUM MINERALS

Observations of both writers in their study of tungsten deposits throughout the state seem to indicate that the nature of the secondary minerals of molybdenum is governed to a very large degree by the presence or absence of scheelite as a primary constituent of the orebody. This is well illustrated by the contrast in the character of alteration of molybdenite at the Reaper Mine in the Gold Hill District with that of the various molybdenite occurrences in White Pine Canyon, tributary of Little Cottonwood Canyon in the Cottonwood-American Fork Districts.

At the Reaper Mine[1], powellite, often beautifully pseudomorphic after molybdenite, is the chief secondary mineral of molybdenum. A study of this deposit seemed to indicate that although large primary crystals of scheelite frequently contained the powellite molecule in isomorphic combination, the original crystals had been deposited as relatively pure $CaW0_4$ and that the partial replacement of the tungsten by molybdenum in the crystal lattice had taken place by supergene processes of enrichment. It appears that most, if not all, of the molybdenum in the primary hypogene solutions had been precipitated as molybdenite and that only through oxidation had the molybdenum been converted to the powellite molecule. It is of significance to note that ferrimolybdite, the earthy, sulphur-yellow, hydrous ferric molybdate ($Fe_20_3.3Mo0_3.7\frac{1}{2}H_20$)[2] was not observed at the Reaper Mine, nor in close association with scheelite in any of the other mines in that area, or elsewhere in our studies of tungsten occurrences in Utah.

A recent investigation of the molybdenum occurrence of White Pine Canyon[3] showed abundant ferrimolybdite but no powellite in the oxidized zone of the prominent (low-grade) molybdenum mineralized area of the Little Cottonwood Stock. It seems significant that in this case no scheelite was found with either the molybdenite or the ferrimolybdite. High-grade samples of molybdenite and ferrimolybdite from the Whitmore property, near Alta, also tested negative for scheelite.

The small amount of molybdenite present in the ore deposits of the Metals Coalition property alter to powellite, as do likewise the disseminated molybdenite occurring in the mineralized granitic sills of the House Range, Millard County, Utah, and the molybdenite in the quartz veins present in some of the properties in the Mineral

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[1] "The Tungsten Pipe of the Reaper Mine", Arthur L. Crawford and Raymond Chorney, Proceedings of the Utah Acad. of Sci., Arts, and Letters; Vol. 19-20, pp. 143-9.

[2] This yellow molybdic ocher was originally regarded as being MoO_3 and was so described under the name of molybdite in Dana's SYSTEM and in many of the other older texts. W. T. Schaller (The Chemical Composition of Molybdic Ocher: Am. Jour. Sci., 4th ser., Vol. 23, pp. 297-303, 1907) showed that it contained ferric oxide, and suggested the formula $Fe_2O_3.3MoO_3.7\frac{1}{2}H_2O$. However, the term molybdite continues to be used by many authors. Dana's Textbook of Mineralogy, 4th Edition p. 774 (1932) uses the name ferrimolybdite and gives the formula $Fe_2O_3.3MoO_3.8H_2O$. It is quite possible that the composition is variable. Detailed analyses have not been made owing to the lack of pure mineral in sufficient quantity for adequate testing.

[3] Buranek, A. M., "The Molybdenum Deposits of White Pine Canyon, Near Alta, Salt Lake County, Utah". Circular 28, (February 1944) of the Utah State Department of Publicity and Industrial Development.

Range, Beaver County, Utah. In the last two cases, as in the Reaper Mine already discussed, the powellite still retains the external form of the molybdenite crystals. Without exception, where powellite was found scheelite had been associated with the original molybdenite.

In view of these observations it would seem that the presence of tungsten, if not the actual existence of the scheelite molecule, may be necessary for the formation of powellite, particularly in the presence of ferric iron which is usually abundant in the supergene solutions around oxidizing ore-bodies. In the absence of scheelite to induce the precipitation of the molybdic oxide as powellite it appears that ferrimolybdite is the mineral usually formed.

Vanderwilt[1], who has made an exhaustive study of molybdenum occurrences says that, "Powellite and molybdite have not been observed occurring together even though powellite occurrences as an oxidation product are probably as numerous as molybdite." However, he goes on to say that, "Since powellite forms as a primary mineral there seems to be no good reason why tungsten should be a prerequisite in its formation." Vanderwilt "had an analysis made of powellite pseudomorphic after molybdenite, and no tungsten was reported". What the present writers would like to know is whether the powellite pseudomorphs were associated with a scheelite-bearing ore-body. If so, the occurrence of this powellite parallels the situation at the Reaper Mine and might be interpreted as having been formed under the catalytic influence of scheelite molecules present in the solutions which altered the molybdenite to powellite.

Vanderwilt's citation of Knopf's[2] description of the occurrence in the Divide Silver District near Tonopah, Nevada, as an illustration of powellite oxidizing to molybdite (ferrimolybdite) is not entirely convincing, although the inference that can be drawn from Knopf's language is strong that oxidation of powellite to ferrimolybdite has taken place. Knopf does not say that powellite and ferrimolybdite were found together at any one point, but merely that, "The molybdite diminishes in depth, and at the corresponding position *on the next lower level*[3] powellite (calcium molybdate) occurs abundantly." It would be an interesting study if modern ultra-violet lamps could now be used to trace the powellite (which fluoresces brilliantly) toward the surface. This interesting occurrence should be reinvestigated with emphasis on the relationship of the molybdenum to the tungsten, if tungsten is actually present.

So far as we have been able to learn, no powellite, except pseudomorphs after molybdenite such as cited by Vanderwilt, has ever been found which failed to show some tungsten present. Even the type crystals described by Melville[4] analyzed 10.28% WO_3. A recent study by Cannon[5] and Grimaldi of the same occurrence established

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[1] Vanderwilt, John W., "The Occurrence and Production of Molybdenum," Colorado School of Mines Quarterly, Vol. 37, No. 4. (1942)., pp. 27-30, October.

[2] Knopf, Adolph, The Divide Silver District, Nevada. U. S. Geol. Survey. Bull. 715, pp. 159-160, 1921.

[3] This was not italicized in the original.

[4] Melville, W. H., A New Mineral Species: U. S. Geol. Survey Bull. 90, pp. 34-37, 1892.

[5] Cannon, R. S., Jr., and Grimaldi, F. S., Scheelite-Powellite Minerals of the Seven Devils District, Idaho, (Abstract by Authors): Econ. Geology Vol. 36, pp. 839-840. 1941.

13.6% $CaWO_4$ as the minimum amount of the scheelite molecule found in any of the "pyrometasomatic" powellite of this locality.

Until the advent of the modern ultra-violet lamp there was no ready means of recognizing powellite. Without detailed chemical analysis of a given crystal the Seven Devils "pyrometasomatic" type of powellite could not be distinguished from scheelite. Their crystallographic elements were so nearly identical as to fall within the limits of error for all but the most refined measurements. On the other hand the powdery secondary type of powellite derived from the alteration of molybdenite so resembles various other ocherous substances that its presence was suspected only when it occurred in well preserved pseudomorphs after molybdenite. Consequently, until the last few years, powellite has been practically an unknown mineral. Now, the ultra-violet lamp has made powellite seem very common. Much work is now being done and we may expect a great deal more information concerning this mineral in the near future.

Because of the close similarity between tungsten and molybdenum (when in its 6-valent state) it seems entirely logical to assume that powellite occurs as the isomorphic equivalent of scheelite as a "pyrometasomatic" mineral of the contact zone. However, more investigation seems necessary to establish even this point. So far as our information goes the data available do not preclude the possibility that the so-called primary powellite of the Seven Devils variety occurring as measurable tetragonal crystals of the scheelite type, associated with garnet, was originally scheelite the lattice structure of which has become enriched in molybdenum from cold percolating waters. Molybdenum ions in dilute solutions leaching oxidized molybdenite may have replaced tungsten ions in scheelite crystals without any visible disturbance of the crystal structure other than to slightly change the axial elements to the degree observed by Melville and others.

Aware of the danger of carrying postulates too far with insufficient data, the writers venture to suggest, in the hope of stimulating further research, the following tentative theories:

1. Because of the preference of sulphide sulphur for molybdenum over tungsten, molybdenum in the primary hypogene solutions is always precipitated as MoS_2 (molybdite), rather than $CaMoO_4$ (powellite) if sufficient sulphide sulphur is available. As a consequence, WS_2 (tungstenite)[1] and powellite are incompatible minerals never precipiated from the same solutions. Molybdenite and scheelite, on the other hand, are compatible and do occur as associates precipitated from the same solutions.

2. When there is insufficient sulphide sulphur in the hypogene solutions, to satisfy all the molybdenum to form molybdenite, the residual molybdenum becomes isomorphously associated with tungsten in the scheelite-powellite crystals precipitated.

3. As weathering encroaches upon the ore body molybdenite is more readily attacked and converted into soluble oxides than is scheelite.

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[1] In this connection it is interesting to note that no powellite has yet been found in the Emma Mine in Little Cottonwood Canyon, the only place where tungstenite has been found, and that the reported wulfenite ($PbMoO_4$) from the oxidized zone is believed by F. C. Calkins to have been stolzite ($PbWO_4$), which has since been identified from this property.

4. As the more soluble oxides of molybdenum begin to migrate in the percolating waters and the dilute solutions of molybdenum come in contact with nearby or more deeply buried crystals of scheelite the greater concentration of tungsten at the crystal faces tend to drive tungsten ions into solution and to retain molybdenum ions in their stead. The degree of replacement and the relative concentration of molybdenum as compared with tungsten in the resulting crystals depend upon the interplay of many complex factors.

5. After a certain concentration of molybdenum is reached in the isomorphous scheelite-powellite crystals equilibrium will be established and any diminution in the amount of molybdenum in the percolating waters as compared with the tungsten dissolved in them will result in a reversal of the process so that tungsten will replace molybdenum. As a result, etched and partially dissolved scheelite crystals at a much-leached and weathered outcrop should have less molybdenum content than similar crystals just beneath which have not been excessively leached and etched after the molybdenum concentration of the passing solutions became too dilute to replace the molybdenum losses from leaching. Tungsten oxides being less soluble than molybdenum oxides, the scheelite molecule should remain behind in greater concentration than the powellite molecule in the isomorphous crystals. Also, since molybdenum oxides migrate more rapidly than do tungsten oxides, and since under hypogene conditions scheelite precipitation is favored over powellite deposition, it follows that leaching and secondary enrichment of molybdenum-bearing scheelite ore bodies should result eventually in a molybdenum-bearing scheelite zone at the surface which will gradually increase with depth to a zone of maximum powellite concentration beyond which the ratio of powellite to scheelite will diminish progressively as the primary zone is approached.

6. The presence of $CaWO_4$ (scheelite) even in relatively dilute concentrations in the solutions at the face of a molybdenite crystal undergoing oxidation is sufficient to "fix" by catalysis, or some other method not clearly understood, the molybdenum atoms in a crystal lattice of the isomorphous scheelite-powellite type. So little migration of the molybdenum takes place during this oxidation and rearrangement of the molecules that the thin platy macrostructure of the original molybdenite is intricately preserved even though the new substance (powellite) is made up of a fine-grained aggregate of minute granules having an entirely different microstructure and unit crystal form than the pre-existing molybdenite. In the presence of $CaWO_4$ powellite is precipitated preferentially over all other molybdates, with the possible exception of PbMoO4 (wulfenite).

7. Lime is so omnipresent in the waters of the earth's crust that the availability of CaO in either hypogene or supergene solutions is seldom a limiting factor in the precipitation of $CaMoO_4$ (powellite) in any ore body.

8. In the absence of tungsten to "catalyse" or "infect" the molybdenite undergoing oxidation, or to act as a "seed" for the precipitation of powellite crystals from oxidized molybdenum-bearing solutions, and in the absence of oxidized lead to form wulfenite, the molybdates find their greatest affinity in ferric oxide. Under these circumstances ferrimolybdite ($Fe_2O_3.3MoO_3.7\frac{1}{2}H_2O$), a needle-like mineral without fluorescence and having an entirely different structure from powellite, is precipitated.

So far as the writers have observed good pseudomorphs of powellite after molybdenite occur only at the surface. If these observations prove general, the explanation may lie in the fact that the conversion to powellite took place only after exposure to the atmosphere when there would be little opportunity for an appreciable number of scheelite molecules to come in contact with the newly-formed powellite. In this case there could be no interchange of tungsten for molybdenum as might be the case if the transformation had taken place at considerable depth where there would be time for the percolating waters to carry tungsten in dilute solutions past the crystal faces until equilibrium between tungsten and molybdenum had been reached. This would explain the absence of tungsten in the analyses of powellite pseudomorphs after molybdenite and the presence of tungsten in all other powellite yet analyzed.

Obviously further study is desirable. Until more is known concerning both the geochemistry and microstructure of powellite and ferrimolybdite in relation to scheelite and other kindred substances little can be said that is not highly speculative concerning the paragenesis of powellite.

THE MOUNTAIN LAKE MINE

The first discovery of scheelite in the Cottonwood-American Fork area was at the Mountain Lake Mine.[1] See Figures 2 and 3. The discovery was made by the junior author when he visited the property in the fall of 1939. At that time the workings of the Great Western Tunnel of the mine were examined for scheelite and by means of a portable ultra-violet lamp material having yellow fluorescence was found. Since then several days have been spent on the property during which examinations were made of the Great Western and Big Cottonwood Tunnels and other workings as shown on Figure 3. The results of these investigations form the basis of this report.

The property is controlled by the Great Western Mining Company, of which J. W. Knight of Provo, Utah, is president. No production is credited from the mine during recent years. In fact, the only ore shipments made were during the early "boom days" of the Cottonwood-American Fork region and later in 1907 when iron flux was sent to the Tintic Smelter.

The location of the mine is at the head of Big Cottonwood Canyon on the southwestern rim of the amphitheatre surrounding Dog Lake. It is two hundred yards above Dog Lake near the southeastern margin of the Alta Granodiorite stock (see Figure 2), and is on the "contact zone" which cuts across the finger-like ridge lying between the Dog Lake amphitheatre and the larger elongated cirque to the west occupied progressively by Lakes Catherine, Martha, and Mary, named in descending order of cascading basins. Brighton, situated approximately one mile to the north, at an elevation 1,000 feet lower than the portal of the mine adit, is one of the winter sport centers of the Wasatch. It is readily accessible over a hard surfaced road that connects it with Salt Lake Valley, and from it an old wagon road in very poor condition leads to the Mountain Lake Mine.

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[1] There is apparent confusion concerning the names of the various mines here designated collectively as the Mountain Lake Mine. This property now under lease by Richard Knight of Provo, Utah, from the Great Western Mining Company, embraces: (1) the Mountain Lake (the Great Western) tunnel, shown on Calkin's map as the Big Cottonwood Mine, (2) the Big Cottonwood Tunnel, indicated by Calkins as the Mountain Lake Mine, and (3) the various minor workings as shown on Figure 3 of this report. The above designations are those used on the maps of the Great Western Mining Company.

The Geologic setting for this mineralized area is unique. The "contact zone" in which it is found is a roof-segment of Deseret and Madison limestones occupying the notch between the Clayton Peak diorite stock on the northeast and the Alta granodiorite stock on the northwest. The intruded limestone has been thoroughly altered by metamorphic processes to typical beds of tactite and marble. A zone

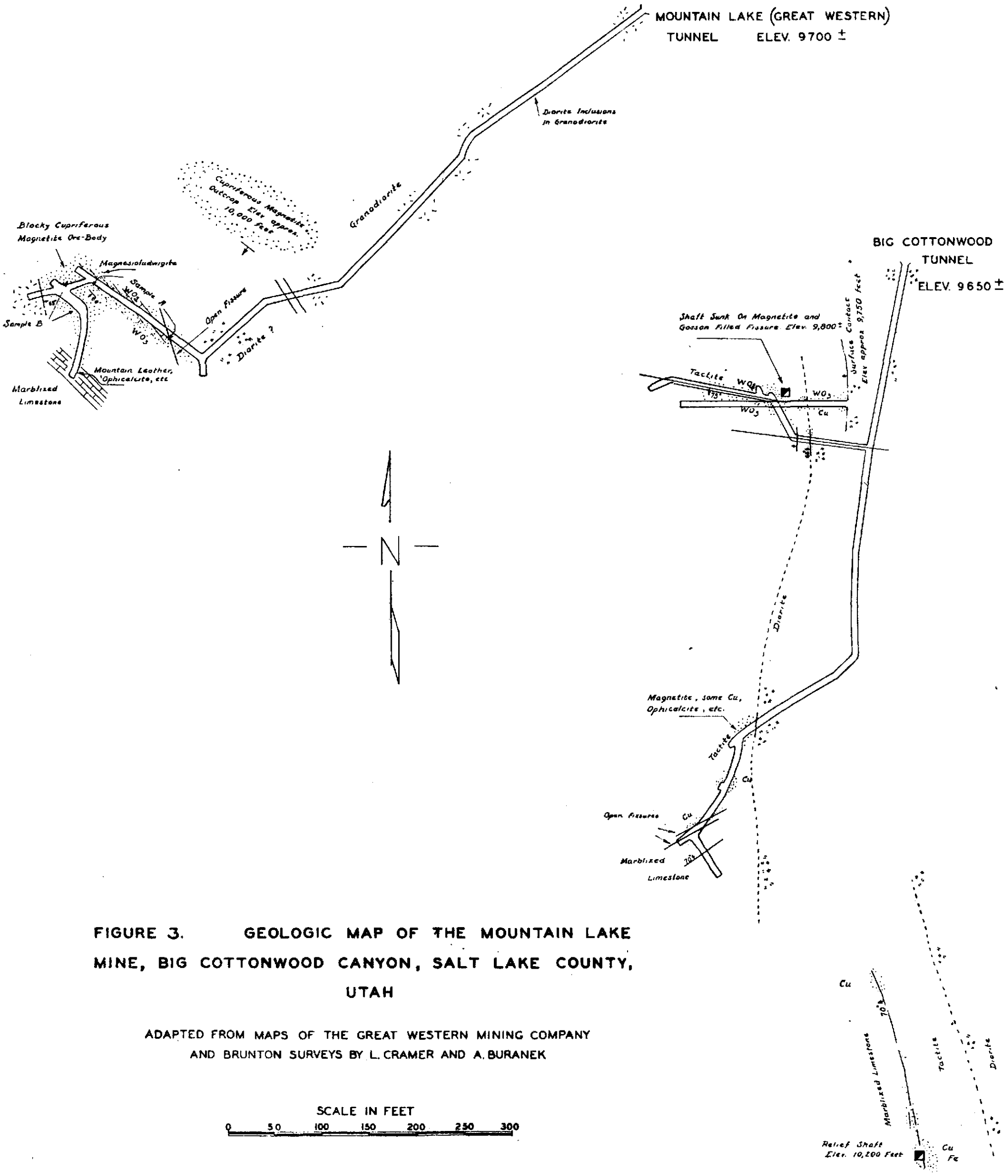

FIGURE 3. GEOLOGIC MAP OF THE MOUNTAIN LAKE MINE, BIG COTTONWOOD CANYON, SALT LAKE COUNTY, UTAH

ADAPTED FROM MAPS OF THE GREAT WESTERN MINING COMPANY AND BRUNTON SURVEYS BY L. CRAMER AND A. BURANEK of beautiful snow white marble is exposed at the head of the Dog Lake cirque for approximately 1,000 feet in length and 500 feet in height.

Both intrusive bodies appear to widen with depth in this vicinity. Outliers of the Clayton Peak stock are well exposed through "windows" in the roof of Paleozoic sediments overlapping its southwestern flank, and to the north of the principal line of junction with the sedimentaries numerous limestone roof pendants form islands within the main mass of the Clayton Peak intrusive. Extensive metamorphism at the head of Snake Creek, in the Provo drainage southeast of the divide, also indicates that the intrusive body is here not far beneath the surface and that the contact with the roof dips to the south at a comparatively low angle. That the Clayton Peak stock extends southward beneath the surface is further indicated by 1,000 feet of diorite penetrated in the southeastern portion of the adit known as the Steamboat Tunnel. This adit was driven by the late Jesse Knight from the head of Snake Creek northwestward with the hope of tapping the Mountain Lake Mine and adjacent properties. Financial difficulties and litigation over water developed in the tunnel are said to have prevented its completion. Beyond the 1,000 feet of diorite and several hundred feet of intervening limestone, fresh granodiorite to the extent of approximately 2,000 feet is alleged to have been transected. This granodiorite is believed to be the underground southeastward extension of the Alta stock.

Locally near the Mountain Lake Mine the strata dip at high angles and appear to have been subjected to pressure either by the invading magmas or by the thrustal movements from the west which preceded the igneous intrusions.

The Great Western Tunnel at an elevation of over 9700 feet has been driven in a southwesternly direction to intersect the downward projection of the large, cupriferous magnetite ore body exposed on the surface. (See Figure 3.) The showings are exposed for approximately 200 feet in length and 50 feet in width along the surface, but as this exposure crosses the rounded crest of a ridge, the actual dimensions of the ore zone are probably not more than 40 by 150 feet.

The portal of the Great Western Tunnel is approximately 700 feet northeast and 300 feet below the outcrop. The tunnel workings consist of a main adit with side drifts and stopes totaling approximately 900 feet. With the exception of the last 200 feet, the main adit lies entirely within the two intrusive bodies. The process of assimilation of the Clayton Peak diorite by the Alta granodiorite is plainly indicated in the tunnel walls where angular zenoliths of the diorite are included in the granodiorite. The intrusive rocks are non-metalliferous except for occasional shear-zones which are thinly coated with sulphides of iron and copper. That some of the mineralizing solutions penetrated beyond the thin walls of the fractures is apparent in dump samples of the granodiorite which contain disseminated sulphides throughout. It is not, however, until the sedimentary rocks are encountered in the tunnel that concentration of ore minerals is evident. From the point where the metamorphosed limestones abut against the intrusive rocks to the end of the underground workings, the iron-bearing zones become progressively richer in iron content. For example, (see Figure 3) the sedimentary rocks next to the intrusive consist chiefly of garnet, tremolite and other "contact silicates" with little or no visible magnetite, whereas westward from the contact the more inner workings are confined chiefly to a zone very rich in magnetite. The copper content, however, is surprisingly consistent over the entire area from the limestone contact with the intrusive, westward. It is interesting to note that the very end of a southwest drift, beyond the cupriferous magnetite in the Great Western Tunnel, has entered the white marble bed so prominently exposed on the surface. This white marble contains little or no minerals of economic consequence. The abrupt ending of ore minerals at the white marble also was noted both on the surface and in the Big Cottonwood Tunnel. Thus, from observation, the ore zone of the area appears to lie within the tactite rocks between the intrusives on the east and the marblized limestone on the west. Some of the marblized beds are mineralized but in no case was the ore zone any great distance from the tactite. In fact, the most prominent zone consists of malachite and is adjacent to the contact.

In the following analysis, Sample "A" represents the zone from the "Y" in the tunnel to approximately 100 feet to the northwest. Sample "B" consists of the "stoped" area of heavy massive magnetite beyond. (See Figure 3.)

	Gold ozs.	Silver ozs.	Wet Lead %	Copper %	Zinc %	Iron %
Sample A	0.01	0.25		2.32		10.40
Sample B[1]	0.03	0.50	0.1	1.67	0.05	35.0

	WO_3 %	Antimony %	Arsenic %	Sulphur %	SiO_2 %	Insol. %
Sample A	0.18					
Sample B[1]		0.30	0.02	0.96	18.2	23.8

From the above and from spectographic studies of split portions of the samples submitted for assay, it is apparent that the ore body is relatively complex, the minerals of probable value consisting of iron, copper and tungsten. The minor constitutents are compounds of arsenic, antimony, cobalt, nickel, boron, silver and gold.

The mineral assemblage is also complex, more so than is normally found in "contact metamorphic" ore bodies. Besides the usual "contact metamorphic" minerals, i.e., forsterite, tremolite, garnet, diopside, epidote, etc., magnesioludwigite (a rare iron magnesium borate) is present in abundance in certain portions of the ore body, particularly near the outer margins of the massive magnetite core. Sepiolite (mountain leather), spinel, serpentine and many other minerals are present. The mineralogic nature of the arsenic, antimony, cobalt and nickel has not been determined. A polished section of the ore

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[1] Bureau of Mines sample taken by S. R. Wilson, Mining Engineer, Bureau of Mines, Utah-Wyoming District Office, Salt Lake City, Utah.

studied by Crawford showed chalcopyrite and bornite to be the chief copper minerals, although small amounts of chalcocite and covellite are present as secondary constituents.

Tungsten in the form of scheelite was observed northwestward for approximately 50 feet from where an open fissure crosses the tunnel near the "Y". It is in the altered sedimentary beds which are immediately adjacent to the intrusive rock. It was not found within the massive magnetite ore body nor in the white marblized area at the end of the Great Western Tunnel. This affinity of scheelite for the tactite zones was noted elsewhere on the property, the tungsten apparently being confined to the brownish tactite rocks immediately adjacent to the intrusive and not being present in the white marble beds.

The individual scheelite crystals are small, less than one quarter of an inch over their greatest dimension. Under the ultra violet light they fluoresce a cream color and occur rather uniformly disseminated over the 50-foot zone in the Great Western Tunnel just described. Sample "A" consisted of a composite cutting from 100 feet, only 50 feet of which actually "lamped". In view of this fact the tungsten content of the 50-foot zone should be nearly twice the amount indicated for the over-all 100-foot zone. The tungsten-bearing zone should average about 0.25% to 0.30% WO_3 content. If the ore can be successfully beneficiated, tungsten may become an important by-product. Although the iron content of sample "A" is much lower than that of sample "B" taken from the massive magnetite zone, the copper, silver and gold content is somewhat higher. Thus the tactite zone between the diorite and the magnetite zone also should be considered as part of the ore body, and if the iron ore, the metallurgy of which is now under investigation by the U. S. Bureau of Mines, is made amenable to treatment, the combined mineralized zones might provide a tonnage that would permit the economies necessary to extract the values at a profit.

The Big Cottonwood Tunnel. The portal of the Big Cottonwood Tunnel lies approximately 400 feet east and 50 feet below that of the Great Western Tunnel. The aggregate total of the underground workings is slightly greater than that of the Great Western Tunnel. (See Figure 3.) It consists chiefly of one main adit driven nearly south and a side drift which has been driven westwardly for about 275 feet from a point approximately 200 feet from the portal. As indicated on the map, most of the underground workings lie in the Clayton Peak diorite. In the westward trending drift the contact of the diorite with the sedimentary rocks is exposed. It has a strike nearly north-south and a 65° dip to the west.

Tungsten is present as scheelite in a 12-inch quartz vein at the contact. Some tungsten was also noted in small fractures near the contact but within the intrusive rock. The sedimentary beds consist almost entirely of garnet rock which in some places shows an abundance of scheelite. A composite sample cut for 15 feet obliquely across the bedding (see Figure 3) averaged 0.78% WO_3; 0.22% Mo.;

0.11 ozs. silver; and 0.01 ozs. gold. Scheelite was noted from the intrusive-sedimentary contact westward to a point nearly 75 feet from the end of the drift. Over this entire length the scheelite is present although in some areas it is much richer than in others. Several lenses from 2 to 4 feet across would constitute high grade ore and scheelite crystals in these "hot spots" are relatively large, but as a rule most of the crystals are small, similar to those in the Great Western Tunnel. As is shown on Figure 3, the side drift for about 100 feet follows a shear in the diorite trending slightly north of west. The drift then follows a course to the northwest for over 50 feet to the intersection of another fault paralleling the first. Movement along the north fault was sufficient to produce crushing in the hard, massive garnet rock. The entire width of the tunnel is now crushed and altered material, chiefly fault gouge. If this faulted crushed zone is projected to the west it will be seen to intersect the center of the ore body exposed in the Great Western Tunnel, but whether both deposits are on the same ore channel is not yet known.

As shown on Figure 3[1], the main adit of the Big Cottonwood Tunnel roughly parallels the contact of the sedimentary rocks with the Clayton Peak diorite. The adit is continued in the diorite for a distance of nearly 300 feet beyond the first main drift to the west. Turning southward, the adit tunnel then crosses the contact and penetrates the metamorphic limestones.

In many cases it has been the observation of the writers that invading magmas have paralleled the bedding, but in this instance the intrusive has cut obliquely across the bedding. Because of this oblique contact the metamorphic beds exposed near the end of the Big Cottonwood Tunnel are quite different from those of the west drift. Instead of being garnet rocks they consist almost entirely of pure crystalline limestones (beautiful white marble). Near the contact, bands of granular magnetite, alternating with tremolite, and partially serpentinized forsterite, form a pleasing display. At the elbow in the tunnel, a few feet from the contact, a minor amount of "vuggy" garnet rock is present. The remainder of the tunnel is almost devoid of this type of material. Near the end of the Big Cottonwood Tunnel, strong open fissures in the white limestone are intersected. The largest of the open fissures is lined with stalagtitic aragonite. Although this south area of the Big Cottonwood Tunnel was "lamped" for scheelite, no fluorescence was found other than a few specks noted relatively near the contact. However, apparently associated with the open fissures are masses of dove-colored limestone which give a pale blue fluorescence somewhat similar to hydrozincite although not so intense. Samples of this material submitted for analysis showed 0.45% zinc but no tungsten. From the contact southwestward to the open fissures described, copper minerals, chiefly in the form of chalcopyrite and malachite, occur associated

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[1] The Big Cottonwood tunnel and adjacent workings and geology as plotted on Fig. 3 are the result of a Brunton survey by Louis Cramer, Mining Engineer, Salt Lake City, Utah, and Buranek, the junior author of this bulletin. This survey was tied to the Mountain Lake tunnel and the Relief Shaft as shown on a large plat claim map submitted by the Great Western Mining Co.

with minor amounts of magnetite and pyrite. As shown on Figure 3, the mineralized area associated with the open fissure and that immediately to the north assayed as follows: copper—2.76% and 3.15%; oxide copper—0.48% and 0.49%; tungsten—0.08% and nil%; iron —1.4% and 10.8%; gold—0.01 ozs. and 0.02 ozs.; and silver 0.40 ozs. and 1.20 ozs., respectively.[1]

Other workings of the Mountain Lake Mine consist of incline shafts, tunnels, and surface prospects. The largest of these is a tunnel approximately 175 feet in length which has been driven roughly parallel to the fault zone containing the scheelite exposed in the Big Cottonwood Tunnel. The portal of this 175-foot tunnel, as shown on Figure 3, lies roughly 175 feet southwest and 100 feet above the portal of the Big Cottonwood Tunnel. It was begun at the contact of the diorite with the metamorphic sediments and continues westward for its entire length in the altered sedimentary beds. Apparently the purpose of this work was to develop the cupriferous magnetite body which is exposed on the surface from this point to the site of the shaft some 100 feet to the west and 40 or 50 feet higher in elevation. However, because of the strike and dip of the replaced beds only the first 10 feet of the tunnel is in this magnetite body. Westward from the magnetite only brownish to greenish-gray tactite rock is encountered. However, as in the Big Cottonwood Tunnel, this brownish tactite also carries gold, silver, copper and tungsten. For approximately 50 feet from the point where the magnetite became a negligible constituent, the garnet rock showed varying amounts of cream fluorescing scheelite. Although a portion of this zone "lamped" very well the scheelite crystals had a tendency to occur in lenticular zones with barren areas between. A composite sample taken over a distance of more than 30 feet contained the following: copper—0.76%; tungsten—0.08%; gold—0.02 ozs.; silver—0.21 ozs.

The shaft mentioned previously was sunk on the massive magnetite outcrop at its intersection with a strong nearly vertical gossan-filled vein approximately 12 inches in thickness. Unaltered portions of this vein contain pyrite in abundance. Samples collected of the gossan material and of the magnetite contained gold, silver and copper in similar percentages to those of samples taken elsewhere in the mineralized areas.

High on the ridge of the Snake Creek-Big Cottonwood Divide, approximately 1000 feet south and 550 feet above the portal of the Big Cottonwood Tunnel, a shaft (now caved) has been sunk on a shear zone trending northwest and paralleling the contact of the diorite with the metamorphic sediments. The ore consists of magnetite containing malachite, chalcopyrite, etc., similar to that shown by the oxidized portions of the other ore bodies. The mineralized zone extends from the garnet rock into the white marble. The latter has in places been leached and the resultant cavities, either as open cracks, or elliptical depressions, have been filled with malachite. It is not believed, however, that oxidation zones at this altitude and

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[1] Samples taken by Cramer during a joint investigation of the property by Cramer and Buranek.

latitude are strong enough to go to any appreciable depth. Here again it is very evident that mineralization has followed the tactite zone between the diorite and the replaced limestone. The contact was followed from this shaft to the surface outcrops of the Great Western Tunnel. Magnetite and copper minerals were observed in varying amounts over the entire distance. The spots showing the greatest concentration of ore values are those developed by the three tunnels previously described.

A theory of origin for these unusual pyrometasomatic ore bodies is suggested by the unique geologic setting outlined in a previous paragraph. Occurring as they do at the south end of the line of junction between two great igneous intrusives, the eastern magma of which is now believed to have been emplaced and largely stabilized prior to the advent of the magma to the west, this may be a twice-concentrated ore zone. It would appear that the Alta magma from the west may have advanced toward the east in this vicinity along the southern margin of the Clayton Peak stock, re-dissolving and re-distilling the mineralizers "locked" in the contact zone of this pre-existing intrusive the cooling of which first precipitated these mineralizing constituents about the periphery of the Clayton Peak stock. As the magma of the Alta intrusive stoped its way upward, progressively widening its base to the southeast, it appears to have progressively encrouched upon the southeastward trending contact zone of the pre-existing Clayton Peak stock re-concentrating the precipitated mineralizers of this zone at right angles to the previous line of contact. Thus, the minerals, that were once distributed along the southwestern margin of the Clayton Peak stock may have been "bunched" by the shortening of this line nearly at right angles to its length. It seems quite possible that when the zone was invaded by the Alta intrusive, these volatile and soluble compounds were "pushed" upward and southeastward so as to reconcentrate the distillates and entrap them in the limestone roof segment between the main bodes of the respective intrusives. Boron, now found abundantly present in the ludwigite minerals of the Great Western Tunnel, is an active "mineralizer" and might be expected to facilitate the distillation and reconcentration of the ore mineral compounds along the tongue of the roof segment in the notch between the intrusives, as already suggested. Additional supporting field evidence is necessary to substantiate the above theory which is offered only as a plausible explanation for the interesting location of these unique ore bodies with reference to the two intrusive stocks.

Suggestions for future prospecting for tungsten in this area should be based upon observations already made concerning the occurrence of tungsten minerals. Since most of the tungsten deposits of Utah are confined to tactite zones or to lenticular veins in marblized limestone roof pendants the relatively low-angled south wall of the Clayton Peak stock at the head of Snake Creek Canyon and vicinity offers a favorable area to prospect for tungsten. Here wide exposures of tactite and several large roof pendants are well displayed.

It is one thing to have favorable conditions for the expulsion, entrappment and precipitation of tungsten minerals, and quite another to have the tungsten present in sufficient quantities in a given magma, or in a segment of the earth's crust invaded by a given magma, to permit the accumulation and deposition of significant ore bodies of this metal. It has not been determined whether the tungsten values of the Mountain Lake Mine were brought in by the Alta magma or were reconcentrated from deposits originally brought in by the Clayton Peak magma or whether they have resulted from contributions from each of the two separate magmas the products of which have been intermingled and blended into a single deposit. If the Clayton Peak magma carried appreciable tungsten, then the Snake Creek tactite zones would be a favorable area to prospect for tungsten. If, on the other hand the tungsten of the Mountain Lake Mine was brought in by the Alta magma as it appears to have been brought in by this magma at the South Hecla mine, the Clayton Peak magma may have been barren of tungsten and the Snake Creek area would then be unproductive of this metal.

The strength of mineralization and the known occurrence of scheelite at the Mountain Lake Mine plus the well exposed contact zone in the immediate vicinity, would seem to justify prospecting the general area for other tungsten ore bodies. So far as the writers have been informed this has not been done prior to the publication of this report.

THE SCHEELITE OCCURRENCES NEAR ALTA, LITTLE COTTONWOOD CANYON, UTAH

Alta, now a famous "Winter Sport" recreational center, is a small but historic mining settlement in the Little Cottonwood Mining District, near the head of Little Cottonwood Canyon. It is connected with Salt Lake City, to the northwest, by 28 miles of paved highway, which, because of the winter playground at Alta, is kept open throughout the year.

The mineralized area in which the tungsten was found lies south of the old town site. The occurrences here described consist of those present on Rustler Ridge (See Figure 5) and those exposed in the underground workings of the South Hecla Mine (See Figure 4). All are located on property owned by the Alta United Mines Company, a consolidation of 34 old mining corporations, controlling approximately 2,100 acres covered by 164 mining claims. George H. Watson, of Salt Lake City, is President, General Manager and principal stockholder of the company.

Only silver-lead-bismuth and copper-silver ores of smelting grade have been shipped thus far. The South Hecla group is reported[1] to have produced 44,302 tons of dry ore during the period from 1911 to the end of 1919, and the old Rustler workings, now owned by the

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[1] Calkins, F. C., and Butler, B. S., Geology and Ore Deposits of the Cottonwood-American Fork Area, Utah, with Sections on History and Production by V. C. Heikes: U. S. Geol. Survey Prof. Paper 201, 1943, p. 125.

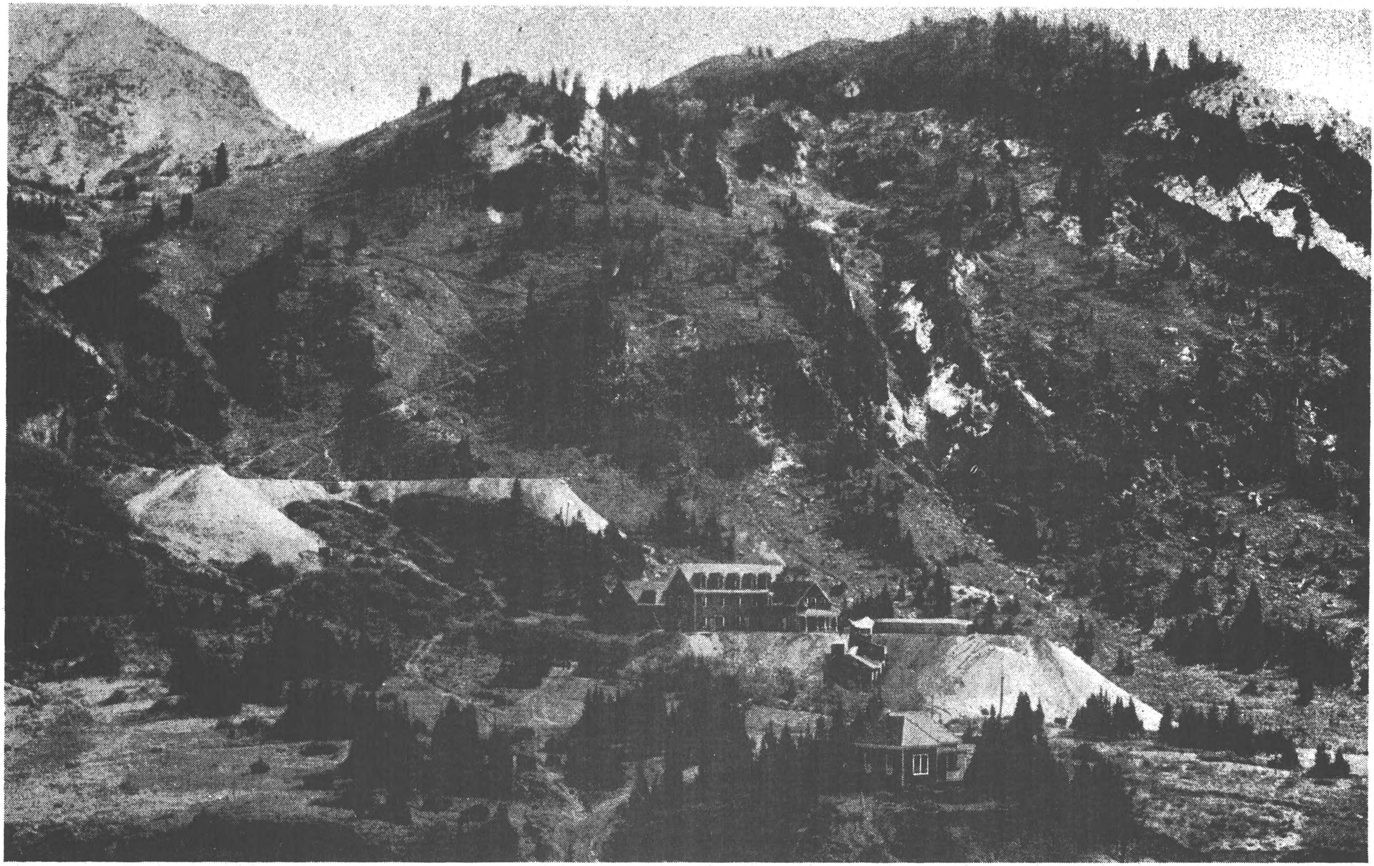

FIGURE 4.

Looking south from Alta, immediately west of Figure 5, at the Quincy and Dwyer tunnels of the South Hecla Mine of the Alta United Mines Company. Collins Gulch, now famous as a winter sports recreational area, is at upper left of picture. Picture taken 1919.

Alta United Mines Company, is estimated to have shipped ore amounting to $900,000 prior to 1885.

The geology and development of the South Hecla Mine is discussed in detail by Calkins and Butler in their recent comprehensive U. S. Geological Survey Professional Paper 201. To this the reader is referred. The area owned by the Alta United Mines Company lies at the extreme southwestern tip of the Alta granodiorite stock and approximately one mile distant from the northeastern border of the exposed portion of the Little Cottonwood quartz monzonite stock (See Figure 2). Plate 44 of the Calkins and Butler report shows the underground geology as revealed by the thousands of feet of drifts and crosscuts of the Sells, Dwyer, Alta-Quincy, South Columbus and less extensive tunnels belonging to the Alta United Mines Company.

The Sells tunnel is driven eastward from a point in Peruvian Gulch 8,753 feet above sea level. It is connected with the southwest branch of the Dwyer tunnel, the elevation of which is 8,601 feet at its portal, on the southern rim of Little Cottonwood Canyon, opposite Alta. The South Columbus tunnel is driven southeastward. Its portal, 8,533 feet above sea-level, is approximately 600 feet to the northeast of that of the Dwyer tunnel. Other tunnels on the property of the Alta United Mines Company south of Alta which enter from Little Cottonwood Canyon, include, the Rustler and the Alta-Quincy, at an elevation of 9,307 feet and 8,711 feet, respectively. The Alta-Quincy is driven almost due south with a long branch to the southeast under Rustler Ridge. It explores the area to the south and southeast of the Dwyer tunnel. The total length of the Alta-Quincy is approximately 6,000 feet. On what is called the East Four drift of this tunnel the Kate Hayes mineralized fissure, striking slightly north of east, is shown on plate 44 of the Calkins and Butler report. The Kate Hayes fissure has been an important producer in this area and, as noted elsewhere, is tungsteniferous throughout a considerable zone. In the *East Four* drift of the Alta-Quincy the ore is mapped as occurring in Deseret limestone, a short distance west of the projected position of the lower thrust plane of the Alta overthrust. This plane here dips about 50° to the east. Above this thrust plane is a blanket of Ophir shales which may have impeded the progress of the mineralizing solutions and thus formed a trap for the deposition of the ore.

Recent work by the U. S. Bureau of Mines, not shown on the Calkins map, has explored what is assumed to be the western continuation of the Kate Hayes fissure at the southwestern extremity of the Dwyer tunnel. The mineralized zone was traced westward, down the geologic section to the Ophir shales. Here the ore pinched out; but it is planned to continue the drift westward with the hope of encountering an ore body where the Kate Hayes fissure intersects the 80-foot Ophir limestone. The latter separates the upper from the lower Ophir shales.

The stratigraphy and structure of the area are extremely complex. The sedimentary rocks involved originally constituted a normal sequence of strata beginning with pre-Cambrian quartzites and

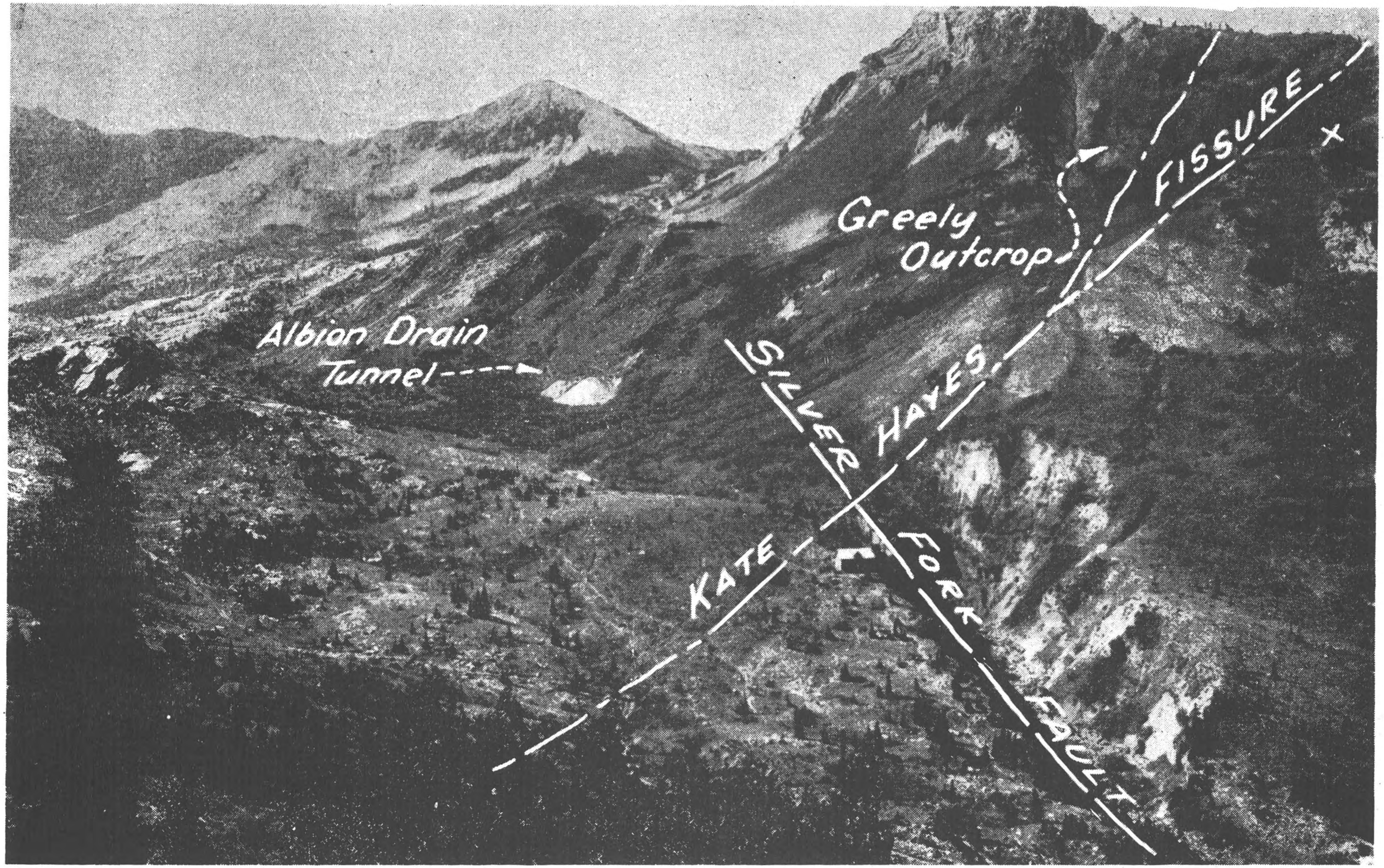

FIGURE 5.

Looking south from north side of Little Cottonwood Canyon near Alta. (Albion Basin, middle and Rustler Ridge, right). Discovery outcrop of scheelite, the calcium tungstate, indicated by X on Rustler Ridge. Sky-line at middle of photograph is the divide between Little Cottonwood and American Fork Canyons. Picture taken 1919.

ascending through basal Cambrian tillite, Tintic quartzite, Ophir shale, Maxfield limestone–all of Cambrian age; Jefferson (?) dolomite of Devonion age; and a thick series of Mississippian limestones including the Madison, Deseret and Humbug formations. However, prior to the advent of the intrusives these strata were sliced and jumbled by the great Alta thrust zone which passes through the property and which is believed to have carried the upper thrust plates a minimum of six miles[1] east of their former positions.

Although the original thrust planes dipped gently to the west, most of those exposed on the property of the Alta United Mines Company, now dip steeply to the east. They steepen progressively eastward until finally, on the extreme east, adjacent to the Alta stock, they are actually overturned so that they here dip steeply to the west. Likewise the original bedding planes, which were nearly parallel to the Alta thrust planes, also dip to the east except where they too, have been overturned. As a consequence of the thrusting some formations have been cut out while others have been repeated.

The largest of the post mineral faults which cut the property is a north-trending, nearly vertical, displacement with the downthrow to the east. It is known as the Howland fault and can be seen near the portal of the Dwyer tunnel. West of the Howland fault, the workings of the Sells tunnel and those of the west branch of the Dwyer tunnel are below the Alta thrust zone. The strata are in their normal position, but dip eastward around 35° so that in going eastward into the Sells tunnel and out through the Dwyer one passes upward through the stratigraphic column from Tintic quartzite to Deseret Limestone.

East of the Howland Fault much of the Dwyer Tunnel is in the great Alta thrust zone and, as noted by Calkins, "A striking change in the aspect of the walls occurs a little east of the portal, where the No. 1 East drift crosses the lowest over-thrust of the Alta thrust zone. The thrust here brings Cambrian shale over the Deseret limestone instead of quartzite as at the surface. East of this great fault the dominant country rock is Ophir shale."[2]

Granodiorite porphyry dikes having a general northeasterly strike cut the strata both east and west of the Howland fault. Numerous pre-mineral fissures of small displacement, which dip steeply to the northwest and have a northeasterly strike, roughly parallel the granodiorite dikes. The latter are regarded by Calkins and Butler as apophyses of the Alta granodiorite stock to the east. The dikes are near their parent intrusive as is indicated by the metamorphism of the country rock adjacent to the dikes, where extensive tactite bodies in the limestones and shales have been developed. The Wedge and the Kate Hayes fissures striking more easterly than the dikes and being more nearly parallel to the principal axis of the Alta stock, have produced the best ore bodies—chiefly of lead, silver, bismuth and copper.

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[1] Beeson, J. J., Mining Districts and Their Relation to Structural Geology: Transactions A.I.M.M.E. Reprint (Sept. 1925) p. 10.

[2] Calkins, F. C., Butler, B. S., Geology and Ore Deposits of Cottonwood-American Fork Area, Utah, With Sections on History and Production by V. C. Heikes: U. S. Geological Survey Prof. Paper 201, 1943, p. 126.

The high bismuth content characteristic of the complex ores associated with some of the Alta tungsten deposits is unique among the tungsten deposits of the West. Most of the ore shipped has been oxidized but it seems to have been derived from bismuthinite and one or more complex argentiferous sulpho-salts, probably associated with chalcopyrite, galena, and native gold. Bismuthinite and aikinite, a rare copper-lead-bismuth sulphide ($Cu_2S.2PbS.Bi_2S_3$), found in the Sells tunnel have been oxidized to bismite, plumbojarosite, covellite and copper carbonates. According to M. N. Short, quoted by Calkins and Butler, this is the only American occurrence for aikinite thus far reported. Hitherto it has been reported only from Beregov, in the Ural Mountains of Russia.

Scheelite was first discovered in Little Cottonwood Canyon when Buranek and members of a prospecting class "lamped" the area during the Spring of 1941. This discovery was in an old prospect pit on the northeast brow of Rustler Ridge (See Figure 5) about one mile southeast of the new Rock Shelter Lodge. The scheelite was shown to Watson of the Alta United Mines Company and by him drawn to the attention of Calkins of the U. S. Geological Survey in time to have the occurrences included in U. S. Professional Paper 201, then in process of being edited. Later, the U. S. Bureau of Mines, prospecting for copper and bismuth in the Dwyer, *West One*, discovered a new occurrence on the Kate Hayes fissure and began research on ways and means of recovering the various constituents in the complex ore associated with the scheelite.

Rustler Ridge is the long finger-like spur projecting northward between the two cirques known as Albion Basin on the east, and Collins Gulch on the west. The latter is the glacial "hanging" valley occupied by the two ski lifts and the slaloms that have made Alta famous in recent years as a recreation center for winter sports. The outcrop, where the discovery was made, is at an elevation of approximately 9,500 feet and is at the intrusive contact with a marblized limestone, apparently a roof segment in the Alta Stock.

The scheelite-bearing zone of the discovery prospect, is on the southeastern edge of the roof segment. It is approximately 3 feet thick, is relatively flat, and dips slightly to the northwest as if controlled by the relation of the intrusive to the floor of the limestone roof segment. In this prospect euhedral scheelite crystals occur, up to three quarters of an inch in length. Under the ultra violet lamp some show bluish white fluorescence. Others show mottled bluish white and creamy yellow fluorescence.

Gangue minerals associated with the scheelite are diopside, garnet, and other contact silicates. A thin section of the scheelite-bearing gangue rock failed to show any scheelite included within the section. Garnet and diopside, occurring in about equal amounts were the main two constituents. Anhedral diopside grains about 0.1 millimeter in size, form a matrix surrounding skeletal residuals of garnet, the average diameter of which is about one millimeter. The garnet residuals are often interconnected but because of their isotropic character it is impossible to determine the original size of the crystals by observing the extent of their optical continuity. None of the original outlines of the garnet crystals remain. Small brown goethite-stained cavities 0.1 to 0.2 millimeters in diameter appear to mark the leached-out loci of former pyrite crystals. The diopside appears to have replaced the garnet.

Additional exploration, using a portable ultra-violet lamp, traced the scheelite zone to the northwest brow of Rustler Ridge where it is again exposed in a number of old workings along the contact zone. The "Emerald Dike", at an elevation of approximately 9,500 feet, on the northwest point of Rustler Ridge and about 1,000 feet east of the portal of the old Rustler tunnel, was subsequently "lamped" by the writers. In the mouth of the prospect incline, a nearly vertical scheelite-bearing zone, striking N. 50° W. was observed. This zone, approximately 18 inches in thickness, contained finely disseminated scheelite with occasional large crystals embedded in a groundmass of the typical contact metamorphic minerals. The fluorescence of the scheelite under the ultra violet lamp was here observed to be white to bluish white. The scheelite is thus relatively free from molybdenum. An assay of a trench sample taken across the 18-inch zone showed 0.30% $W0_3$. The presence of scheelite here, as elsewhere in the Cottonwood-American Fork area, was not suspected by the early prospectors. They sunk the incline in search for gold, silver, copper and lead values which do occur in the Emerald Dike.

The presence of scheelite on Rustler Ridge gave promise of its extension underground into some of the old workings below. In the same thrust block, the South Columbus tunnel of the South Hecla Mine is located a thousand feet lower in elevation and is driven in similar rocks to those exposed in the surface prospects on Rustler Ridge. The overturned beds, indicated on the mine maps of the South Columbus tunnel, strike to the northwest and dip steeply to the southwest. Hence, there seemed a good chance that favorable scheelite bearing zones near the margin of the Alta stock might be encountered at depth and be found to carry through to the surface. The projection of the scheelite zone downward to the level of the South Columbus tunnel (provided the scheelite-bearing zone of the surface outcrops extend continuously to such depths) would thus give approximately 1,000 feet of "backs" that might be developed from the underground workings. The extensive drifts and crosscuts of the Dwyer tunnel, farther to the southwest, offered other interesting possibilities.

In view of the foregoing, arrangements were made with Mr. Watson to investigate these tunnels, their associated workings, and their dumps (See Figure 4). They were examined in the spring of 1941, and a number of promising scheelite-bearing zones were discovered. The following year, in the autumn of 1942, the writers again visited the area and re-examined the tungsten occurrences.

The South Columbus Tunnel was found to have several scheelite showings. A 2-inch quartz-pyrite vein containing scheelite, which under the ultra violet light fluoresces white, crosses the tunnel in a short stub drift approximately 900 feet from the portal. The strike is N. 35° E. The dip is about 50° to the northwest. About 100 feet farther in, where another short stub drift is driven to the northeast, a series of joint planes parallel to the scheelite-bearing vein mentioned above contain finely disseminated specks most of which show a creamy fluorescence under the ultra violet lamp. However, occasional seams show specks with white fluorescence.

A third showing is exposed at the southernmost extremity of these workings, in the face of the 230-foot righthand drift which branches southward from a point some 50 feet short of the end of the straight portion of the tunnel. Near the end of this righthand fork of the tunnel what is assumed to be the Maxfield limestone-Ophir shale contact crosses the tunnel obliquely from west to east, revealing a bedding fissure with a strike of N. 15° W. and a dip of about 75° to the southwest. Dark serpentinized streaks are evident in the limestone east of this contact near the end of the tunnel. The base of the overturned Maxfield limestone has been metamorphosed into tactite much of which carries disseminated scheelite exposed along the west wall of the tunnel throughout much of the 230-foot length of the righthand drift paralleling the contact.

None of the three occurrences in the South Columbus Tunnel thus far described is sufficiently wide and rich to indicate more than a "lead" that might connect with something of possible commercial importance. However, between the second and third of the showings just mentioned are two other northeast "breaks" where the scheelite mineralization has been much stronger. The best of these has since become known as the Scheelite Fissure.

The Scheelite Fissure crosses the tunnel less than 200 feet from the end of its straight portion, and is paralleled by a northeast drift which eventually arcs around to the east and then to the southeast. The Scheelite Fissure occurs adjacent to and on the southeast (footwall) side of a lamprophyre dike and near the junction of the Ophir shales with what Calkins regards as the Maxfield limestone. The strata appear to be overturned so that the shales occur above the limestone, dipping to the southwest around 55°. The scheelite is exposed from the entrance of the drift to where the lamprophyre dike crosses the drift obliquely about 50 feet in from the tunnel. The scheelite is also well exposed in the southwest wall of the main tunnel opposite the drift where it forms a face 8 to 10 feet wide on the south side of the lamprophyre dike. To the north, beyond the dike in the main tunnel, scheelite is not apparent except for the minor disseminated specks in the veinlets that form a continuous zone in the Ophir shales northwestward to the area described under the second of the occurrences mentioned in the South Columbus Tunnel.

The evidence seems to indicate that the lamprophyre dike served as a dam that helped to precipitate the ore minerals beneath it to the south along the Maxfield-Ophir contact. This hypothesis is in harmony with the theory advanced elsewhere that in general the tungsten-bearing solutions which formed these deposits ascended from a southwesterly direction. The lamprophyre dike which forms the hanging-wall of the Scheelite Fissure strikes N. 35° E. and dips about 80° to the northwest. There appears to have been some movement on a minor fault near the contact of the Ophir shales and the Maxfield limestone, so that this fault (if it is a pre-mineral fault) may have formed the obstruction that was, in part, responsible for the ore-shoot or (if it is a post-mineral fault) it may have cut off the ore body and removed the northeast segment of the dike so that it is not evident in the curved extension of the drift where it otherwise again ought to have been intersected. A small amount of work in this area would do much to clarify the questions thus indicated. Calkins has plotted the relationships without noting the existence of scheelite at this point. As shown on his plate 44, the Ophir-Maxfield contact makes an "X" with the lamprophyre dike which crosses the drift at or near the east boundary of the scheelite exposure, the "X" being astride the plane of the Scheelite Fissure.

The scheelite-bearing rock is pale grayish-green in coler with large splotches of poikilitic calcite intergrown with the garnet, epidote and scheelite. Euhedral crystal faces are not prominent on any of the constituents. The scheelite crystals occur up to nearly one and a half inches across, and are quite uniformly disseminated throughout the scheelite-bearing zone.

The scheelite crystals from the Scheelite Fissure were examined in thin sections. Large crystals were found to be skeletal in character. Areas an inch or more across consist chiefly of the mineral scheelite in optical continuity, showing that the "islands" and skeletal masses all belong to a single crystal.

The scheelite seems to have grown around and partially replaced dodecahedral crystals of garnet. The scheelite, in turn, appears to have been corroded and replaced by diopside, epidote, quartz, calcite and a clear mineral resembling quartz but with an index of refraction less than Canada balsam. This mineral is too fine grained in the sections studied to be identified with certainty. It is probably albite or cordierite. The garnet crystals are usually from 1 to 2 millimeters in diameter and unlike the garnet of the scheelite-bearing tactite on Rustler Ridge these are not isotropic. They show strong birefringence approximately equal to that of adjacent quartz. Sector divisions and zoning are both prominent.

The garnet is, therefore, probably grossularite, since birefringence is much more common in this variety than in other garnets. The abundance of associated calcite and the occurrence of the garnet in the limestone-shale contact zone, where both lime and alumina are abundant, would also lead one to suspect grossularite in this association. The presence of diopside inclusions in both the garnet and the scheelite suggests the possibility that diopside may be the oldest mineral present. However, judging from the paragenesis of the minerals examined from Rustler Ridge where the diopside-garnet relationship is much clearer, it is believed that the diopside is younger than the garnet and probably younger than the scheelite[1] as well. Possibly the factor that determines whether scheelite will form before or after garnet is the ease with which $C0_2$ can escape from the heated contact zone. With a high concentration of $C0_2$ vapor pressure it is possible that scheelite will precipitate first. With lower $C0_2$ vapor pressure the lime may be more easily converted into the complex silicate than precipitated as a tungstate.

The grade of the ore from the Scheelite Fissure has not been thoroughly established. However, the U. S. Bureau of Mines[2] sampled a portion of the South Columbus dump and found it to assay 0.7% $W0_3$. The sample was carefully taken and is believed to be representative of the scheelite-bearing portion of the drift developed along the Scheelite Fissure. The scheelite crystals and the gangue are characteristic of those in the drift. The material[3] had laid on the dump for over 40 years and was about the last portion mined from the workings of the South Columbus Tunnel. The size of the drift opened in ore of this character is approximately 8x8x40 feet, or 2560 cubic feet. However, since the most heavily mineralized portion of this zone is confined to about 4 feet in width, the grade of this portion may have averaged near 1.4% $W0_3$. Considering the relatively high specific gravity of this ore it is reasonable to assume that five 50-ton cars of scheelite ore averaging 0.7% $W0_3$ have been taken from this drift and thrown on the dump before the rock was known to contain tungsten.

The Powellite Fissure is the name here given to the fifth scheelite occurrence in the South Columbus Tunnel. It appears to be second in importance only to the Scheelite Fissure and appears to be intimately associated with the Ophir-Maxfield contact zone containing the scheelite in the third occurrence described in the foregoing discussion. However, the Ophir Maxfield contact strikes N. about 15° W., whereas, the Powellite Fissure where it intersects the tunnel appears to be roughly parallel to the Scheelite Fissure, striking N. about 35° E. The Powellite Fissure is so called because of the abundance along it of powdery material showing from cream to yellowish fluorescence with ultra-violet lamp. This northeast fissure crosses the west branch of the South Columbus Tunnel just south of the "V" made by the junction of the south drift extention with the main tunnel. This "V" is about 50 feet northwest from the end of the main South Columbus Tunnel. For some unexplained reason the Powellite Fissure does not extend across the "V" so that it shows in the main (east) branch of the tunnel. Where exposed in the west branch,

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[1] For a more detailed study of scheelite preceding diopside in the paragenetic series see "The Tungsten Pipe of the Reaper Mine" by Arthur L. Crawford and Raymond Chorney: **Proceedings** of the Utah Academy of Sciences, Arts and Letters, Volumes XIX, XX, pp. 143-149.

[2] Oral communication from J. I. Kasteler, Mining Engineer, U. S. Bureau of Mines, Salt Lake City, Utah.

[3] Part of this scheelite-bearing tactite on the dump of the South Columbus Tunnel may have come from the south drift where similar scheelite occurs along the west wall for nearly 230 feet. If so, the ore on the dump may be much more than the 250 tons here estimated.

the Powellite Fissure appears to have a mineralized zone about 4½ feet wide but in the Dwyer *East One,* approximately 70 feet above, where it is again well exposed, it is about 4 feet across. The Powellite Fissure dips steeply to the northwest and shows, in addition to occasional large crystals of scheelite, similar in size to those in the Scheelite Fissure, minutely disseminated specks that under the ultraviolet lamp are more yellowish in color. The latter are believed to be powellite-enriched material, part of which is supergene in origin.

The ratio of molybdenum to tungsten in the Powellite Fissure is indicated from an assay made by the Union Assay Company of Salt Lake City on a sample of "fines" collected by the writers. The assay was reported as 0.92 percent $W0_3$ and 0.093 percent Mo. In terms of pure scheelite and pure powellite these percentages are equivalent to approximately 1.07 percent and 0.19 percent, respectively. In terms of their molecular proportions these equal 0.0037 for scheelite as compared with 0.00096 for powellite. In other words, there is present, according to this assay, 3.85 molecules of $CaW0_4$ for every molecule of $CaMo0_4$ in this mineralized zone. Hence, while this mineral has a yellowish fluorescence and has been called powellite only about one fifth of the scheelite molecules have been replaced by $CaMo0_4$.

An interesting characteristic of the area immediately east of the Powellite Fissure in the South Columbus Tunnel is the presence of the rare iron-magnesium borate, ludwigite, as a metamorphic constituent associated with the marblized and partially serpentinized limestones. This is noted by Calkins on his plate 44 as occurring "in white and grey dolomite and limestone." No attempt was made by the writers to determine whether this is ordinary ludwigite or the magnesio-ludwigite such as found at the Mountain Lake Mine in Big Cottonwood Canyon already discussed.

The Dwyer *East One* Tunnel was found to contain several scheelite occurrences. Some of them can be quite definitely correlated with those in the South Columbus Tunnel already described. This is true for the upward and southwestward projection of the Scheelite Fissure and of the Powellite Fissure. However, several scheelite exposures were found which have no counterparts in the South Columbus workings. These were in or near the Sulphide Stope some 600 to 700 feet east of where the *East One* branches off from the main Dwyer Tunnel.

The Sulphide Stope occurs just below one of the prominent thrust planes of the Alta thrust zone where this and a number of other structural and stratigraphic features have combined to produce a favorable trap for impounding mineralizing solutions rising from the intrusive below.

Most of the Sulphide Stope lies within a downfaulted block between two northeast fissures, and north of what Calkins has mapped as a minor thrust having an east strike and a northerly dip. Part of the Sulphide Stope extends to the south of the downfaulted block, but this portion is also north of the minor thrust just referred to.

Several minor fissures converge in this area. The mineralized zone is at, or near, a shale-limestone contact. The formations are plotted by Calkins as Ophir and Maxfield, respectively. Scheelite is exposed in numerous places throughout this stoped area but is most abundant around the southern margin of the stope. A 30-pound grab sample taken of the whole ore zone assayed 0.33 percent $W0_3$. This is in remarkably close agreement with the assay computed from a test shipment of 0.501 tons made by the U. S. Bureau of Mines to the Salt Lake Chemical Tungsten Plant. This 0.501 tons contained 0.64 units of $W0_3$, equivalent to 0.32 percent $W0_3$. The disseminated scheelite under the ultra-violet lamp shows a yellowish to cream fluorescence indicating the presence of an appreciable amount of isomorphous powellite.

A small amount of scheelite was noted in a drift north 50 feet from the Sulphide Stope. At this locality disseminated scheelite is associated with sulphides in a contact zone in the wall of a fissure along an old caved drift. Here, in the northeast edge of the Sulphide Stope, scheelite was found associated with black copper oxide, apparently derived from pre-existing chalcopyrite. In the wall northwest of the Sulphide Stope finely disseminated scheelite was also noted.

In the angle made by a short drift 40 feet southeast of the entrance to the Sulphide Stope a 4-foot face exposes relatively rich disseminated scheelite in contact metamorphic siliceous limestone. This massive zone of disseminated scheelite is also exposed on both sides of the drift. The zone dips 15° to 20° to the north. A sheared, much stained, relatively barren zone caps the scheelite. This appears to be the minor thrust plane above referred to, which Calkins plots with a question mark.

The complex faulting in this vicinity seems to have brecciated the country rock permitting ready access of mineralizing solutions along the northeast fault at the southeast boundary of the main downfaulted block. The old Alta thrust plane above probably dammed off the solutions forcing them to permeate the fractured and jumbled calcareous shales which provided a favorable chemical and physical environment to precipitate scheelite and other ore minerals from the hot solutions rising from the intrusive below.

The Scheelite Fissure noted in the South Columbus Tunnel to the east, where it is associated with a lamprophyre dike, is tentatively correlated with a similar exposure, but having a more easterly strike, about 450 feet to the southwest on the Dwyer *East One* level. This occurrence which is also associated with a lamprophyre dike, is some 500 feet southeast of the Sulphide Stope and is at the southern end of the 300-foot segment of the Dwyer *East One,* driven along the Ophir-Maxfield contact. This segment of the Dwyer *East One* is offset about 50 feet to the southwest from another 300-foot segment driven to the southeast but following the trace of the fault plane of the Alta overthrust. The 50-foot offset was probably occasioned by a desire to explore the lamprophyre dike with its parallel mineralized zone northeastward to the plane of the Alta overthrust. However, the scheelite along this zone was not recognized prior to its discovery by the junior author in the spring of 1941.

The 3-foot lamprophyre dike is prospected by a stub raise driven along the north side of the dike at an angle of about 33° up into the Ophir shales a short distance under the contact with the overlying Maxfield limestone. Opposite this raise, following the dike to the northeast, is the 50-foot offset drift to which reference has been made. The offset drift is continued northeastward by the main northeast drift of the *East One* (Dwyer Tunnel). It follows the dike for another 50 feet before turning to the right and leaving the dike and the scheelite zone.

Since the raise is on the north side of the lamprophyre dike the scheelite zone is not opened to best advantage—assuming the same relationship here, between the dike and the Scheelite Fissure, as is shown in the South Columbus Tunnel. Only traces of scheelite are evident on the northwest wall of the dike. On the southeast side of the dike is the main scheelite zone which here strikes N. approximately 50° E. and dips about 70° northwest. The scheelite occurs in disseminated one-half inch crystals which give a cream to white fluorescence under the ultra violet lamp. The scheelite zone is about 4 feet wide, within the Maxfield limestone segment between the Ophir shales and the Alta overthrust.

The Powellite Fissure in the Dwyer Tunnel is exposed in a sheeted zone striking N. 75° E. and dipping 80° northwest near station 522, in the *East One* branch, where it passes some 70 feet above the exposure of this zone in the South Columbus workings. Here, across a 4-foot zone scheelite specks, which show cream to yellowish fluorescence, occur along with occasional one-half inch scheelite crystals, the fluorescence of which is bluish white. Vug-like cavities are common, and it appears that water courses have facilitated the isomorphous replacement of secondary powellite for primary scheelite to bring about an enrichment of molybdenum.

The Dwyer *West One* workings revealed no scheelite ore at the time they were first "lamped". However, recent exploration by the U. S. Bureau of Mines on an extension of the southernmost drift of this tunnel has opened one of the most promising scheelite occurrences in this area.

During recent years the Alta United Mines Company extended the Dwyer *West One* approximately 50 feet south of the southern extremity of the tunnel as shown on plate 44 of the Calkins report. Here a prominent northeast fissure was encountered striking N. about 65° E. and dipping approximately 80° to the northwest. This is believed to be the Kate Hayes Fissure developed on the old Rustler property to the east. Drifts along the fissure 30 feet to the northeast and 50 feet to the southwest, of where it was intersected, failed to discover a commercial ore body.

Later, the help of the U. S. Bureau of Mines was enlisted in a search for strategic metals to aid in national defense. After considerable study of the geology and the pattern of mineralization, the Bureau extended the southwest drift nearly 250 feet along the fissure. The end of this extension is, at this writing, in Ophir shale and from it diamond drilling is being done with the hope of locating an ore body in the 80-foot Ophir limestone which separates the upper from the lower Ophir shale.

The strata here are below the lower thrust plane of the Alta overthrust. They dip about 35° northeast so that the drift to the southwest passed downward through the section from lower Jefferson limestone through the Maxfield limestone into upper Ophir shale.

The Kate Hayes Fissure was very productive of silver-lead-bismuth ores in a stope some 2,000 feet to the northeast that was developed through the Alta-Quincy Tunnel on the old Rustler property. There was a pronounced mineralized zone where the Kate Hayes Fissure was first encountered by the southern extension of the Dwyer *West One* Tunnel. The strength of mineralization gradually increased until, 54 feet from the beginning of the U. S. Bureau of Mines drift, an oreshoot of shipping grade was encountered. This oreshoot in the Maxfield limestone is of mineable width and grade for 70 feet along the drift to the top of the Ophir shale. After passing into the shale the ore is no longer oxidized and the oreshoot pinches down to a vein of less than 4 inches.

A 2-foot lamprophyre dike, striking more northerly than the Kate Hayes Fissure, and dipping steeply to the northwest, crosses the fissure near the center of the oreshoot on the drift level. The area most heavily mineralized is on the hanging wall side of the dike in the Maxfield limestone, between the dike and Ophir shale. The intersection of the dike with the fissure is about 135 feet southwest of where the Kate Hayes Fissure was first encountered in the Dwyer workings. The same dike is cut by the southern extension of the Dwyer *West One* tunnel approximately 65 feet north of where the tunnel intersects the Kate Hayes Fissure. In this latter exposure there are no evident ore minerals associated with the dike. Consequently, the position of the dike, near the center of the oreshoot, on the Kate Hayes Fissure, may have no special significance. Its association with the ore may be purely coincidental. It is possible, however, that this may be the same lamprophyre dike associated with the Scheelite Fissure in the Dwyer *East One* and in the South Columbus Tunnels. Very few lamprophyre dikes have been noted in this area and is may be significant that three of the best scheelite exposures on the Alta United Mines property are adjacent to the intersection of a lamprophyre dike with a mineralized east-northeast fissure, that in each case the best scheelite is found in Maxfield limestone at or near its contact with the Ophir shale, and that the oreshoots are so situated as to have been most easily nourished by mineralizing solutions rising from the southwest, assuming the lamprophyre dikes to have dammed and precipitated the minerals from these solutions.

Assays from the oreshoot on the Kate Hayes Fissure vary, but the following is a weighted average[1] of the samples taken by the U. S. Bureau of Mines:

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[1] Over-all estimate based upon numerous assays of trench samples taken by the U. S. Bureau of Mines during its exploration program. Courtesy of J. A. Marsh, District Engineer, U. S. Bureau of Mines, Salt Lake City, Utah.

Bi—0.60%; Cu—2%; Ag—18 ozs. Au—0.03 ozs.
WO_3—1.80%; Pb—3%; Zn—1%

The oxidized ocherous material in the brecciated Maxfield limestone, examined by the writers in hand specimens, seems to be composed chiefly of limonite and jarosite, probably with bismite, plumbojarosite, and possibly some argentojarosite, associated with quartz, calcite, and scheelite.

Scheelite, in the *West One* workings, just described, is not evident in the mine walls until after the ore samples have been washed. It occurs in disseminated fine grains, which give a bluish white fluorescence under the ultra-violet lamp after the scheelite surfaces have been cleaned from mine dust and from films deposited during the oxidation of the ore body.

Scheelite is most pronounced where the other ore minerals have been deposited in greatest abundance, indicating that it was deposited as a part of the same process and was derived from the same general source. No appreciable scheelite has been noted under the ultra-violet light by "lamping" the ore from the sulphide streak along the Kate Hayes Fissure in the Ophir shale, notwithstanding the fact that WO_3 assays have been reported as high as 0.5 percent. It is not known whether this apparent discrepancy is due to faulty exploration and sampling, to shale dust obscuring the scheelite fluorescence, or to the existence of the rare tungsten sulphide, tungstenite, within the sulphide streak. The latter possibility is of interest because of the close proximity of this deposit to the Emma oreshoot across the canyon to the northeast about 4,000 feet along the line of strike of this fissure system. The Emma oreshoot contained what is believed to be the only tungstenite occurrence thus far of record.

The grade and size of the scheelite ore body along the Kate Hayes Fissure has not been fully established. One channel sample taken by the U. S. Bureau of Mines across a 3½-foot face is reported to have assayed 7 percent WO_3. Others taken at intervals along the drift across the oreshoot were much lower but gave an average of 3 percent WO_3 for a thickness of 2½ feet, along the 35 feet in the Maxfield limestone between the Ophir shale and the 2-foot lamprophyre dike. This oreshoot appears to be tabular and to average about 2½ feet thick. As already noted, when the assays were averaged over this thickness, for the full 70 feet of ore exposed along the drift on the Kate Hayes Fissure, they gave the value of 1.8 percent WO_3.

The origin of the metallizing solutions which deposited the tungsten ores of the Alta district is almost certainly connected with the intrusion of either the Alta granodiorite stock to the east, or with the Little Cottonwood quartz monzonite stock to the west. Calkins and others tacitly assume that most of the granodiorite porphyry dikes in this area are apophyses of the Alta intrusive body, since they are nearer to it and are more nearly like it in composition than they are to the quartz monzonite. The ore channels are roughly parallel to the dominant direction of these dikes and otherwise show that they are related in origin. Hence, they too, are generally assumed to have been formed by the Alta intrusive.

Since the various intrusives in the Cottonwood-Park City area followed closely in the wake of, and were probably aided if not generated by, the great overthrusts that came from the west at the close of the Cretaceous period, it seems probable that the intrusives were directed eastward as they progressed upward along the lines of least resistance.

However, as noted by Calkins, the intrusive become more silicic from east to west from the Clayton Peak diorite through the Alta granodiorite to the Little Cottonwood quartz monzonite. It is now known that the Alta intrusive is younger than the Clayton Peak body, part of which it has replaced. Since silicic stocks are usually intruded later than less silicic stocks from the same parent magma, it is assumed that the Little Cottonwood quartz monzonite is younger than the Alta granodiorite, part of which it is assumed to have replaced at depth.

Crawford[1] and Jacobson have shown that the Little Cottonwood stock, was originally less silicic and contained much less potash feldspar than does the present rock type.[2] Hence, it is entirely reasonable to assume that the granodiorite dikes, and possibly the Alta stock, represent an earlier less deep-seated phases which is replaced downward and southwestward by the Little Cottonwood quartz monzonite. The structural pattern, the position of the respective intrusives, the grain size and character of the respective rock types, and the metasomatic changes evident from a paragenetic study of the rock-forming minerals in what is assumed to be the most deep-seated phase yet exposed of these intrusives, all indicate a fluctuating process of common origin by which the more mobile constituents diffusing from a deep-seated source to the southwest, metasomatically replaced hornblende, plagioclase, etc., of an earlier fine-grained diorite to produce a coarse-grained, more silicic rock type richer in potash feldspar.

The iron and magnesia released through such a process is evident in the higher northeastern portions of the intrusive area, as already noted in the minerals characteristic of the Mountain Lake Mine. Similar mineral assemblages are present on Rustler Ridge, in the South Hecla mine, and elsewhere, in the Alta district.

It, therefore, is believed that progressive waves of metasomatism (the chemical replacement of earlier minerals) caused by the expulsion of mobile constituents from the deep-seated magma reservoir, produced different rock facies depending upon the depth of the rocks affected and the time of contact of these rocks with emanations

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[1] Crawford, Arthur L., and Jacobson, Frank E., Feldspar Phenocrysts in the Cottonwood Granodiorite, Replacements of Their Fine-grained Associates: Utah Academy of Sciences, Arts and Letters, Volume X, p. 55, (1933).

[2] In this connection it is pertinent to note that a thin section of a mineralized border facies from near the contact of the Clayton Peak stock with the Alta stock and adjacent to the Mountain Lake Mine showed a syenitic type presumably caused by the pyrometasomatic replacement of pre-existing minerals by orthoclase, during the late "magmatic" stage, just prior to the introduction of the ore minerals.

from the intrusive source[1]. According to the foregoing assumptions the resulting rock facies would in general be as we have found them, more silicic and potassic with depth, or with nearness to strong regional fissures (like the one near the Mountain Lake Mine) which tapped the source of magmatic emanations at great depth. Likewise, silica and potash would increase from the northeastern extremity toward the center of what was the final wave of metasomatism.

It is believed that the metallizing solutions are in general slightly younger than any of the intrusives with which they are directly associated. This is necessarily true since the process of granitization, whether it is assumed to occur by direct crystallization from a rock melt or by metasomatic replacement of sediments and other pre-existing solid rock mineral aggregates, is a higher temperature process than that required for ordinary ore deposition. Thus, even though ore deposition and granitization may occur simultaneously, they do so in different zones, the ore deposition out in front beyond the zone of intense granitization, so that by all the criteria of geologic diagnosis the ore deposits appear younger than the intrusive from which they were derived.

If the intrusive continues to advance, the ore deposits already formed are re-dissolved and forced outward to the cooler zones beyond. When the intrusive begins to cool down tension cracks develop through which emanations from the deeper and hotter interior ascend. These react with the walls of the fissures leaving part of their mineral burden behind forming within the cooler portions of the intrusive the "roots" of veins which may extend to the sedimentaries far above. Thus, since part of the veins always form within the intrusive, itself, the veins are said to be younger. Therefore, since it is assumed that the core of the Little Cottonwood quartz monzonite is the youngest phase of the deep-seated magmatic rock derivitives in this area, it seems probable that this igneous body a short distance to the west acted as the last source of heat which kept the metals in solution during the pre-mineral stages of subsiding igneous activity. Hence, the source of the metallizing solutions may be more closely connected with the quartz monzonite than with the Alta granodiorite. The chief ore channels are roughly parallel to the common major axis of the Little Cottonwood and the Alta stocks; but the solutions appear to have risen towards the northeast from a deep-seated source common to both of these stocks.

The tungsten may have been deposited and redissolved several times during the advance and retreat of the heat waves associated

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[1] In the foregoing connection it is interesting to note the late 2-inch "veins" of potash feldspar observed by A. C. Peale of the Hayden Survey and to compare the early concepts of "metamorphic" granite implicit in Peale's description and that of Professor W. P. Blake for the Little Cottonwood igneous body (1) with the hypotheses of Butler, Calkins, Beeson and other workers in the district who are followers of the prevalent theory of deep-seated up-welling liquid magma as the source of the Little Cottonwood stock, and (2) with the modern version of the metamorphic theory for the origin of certain batholiths and their appendages as revised and defended by Locke and others. See—

Peale, A. C., (1873) P. 106, in Sixth Annual Report, U. S. Geological Survey of the Territories, Embracing Portions of Montana, Idaho, Wyoming and Utah; Being a Report of Progress of the Explorations for the year 1872, By F. V. Hayden, Geologist.

Locke, Augustus, "Granite and Ore": Economic Geology, Vol. 36, pp. 448-454, 1941.

with the processes of metasomatism. Some of the oreshoots in this area may owe their origin first to the solutions which emanated from the advance intrusion of the Alta stock and then finally to solutions, derived from the later phases of the Little Cottonwood intrusive, which redissolved or redistilled and reprecipitated the metals. The probability of finding deposits reconcentrated from earlier deposits or formed by the comingling of emanations from both sources in this manner would be expected to increase as the convergence of the contact zones between these intrusives is approached at depth.

Since scheelite is a high temperature mineral[1] which is usually precipitated at the contact zone, and is redissolved and redistilled with difficulty, any tungsten expelled by the advancing magma might be expected to linger near, or "hug" closely, the "front" of its parent intrusive. Given, a series of waves of metasomatism so intense as to produce a succession of "metamorphic" intrusive shells one might expect that wherever the periphery of the last frontal wave pushed to or beyond the lime-silicate zone of the outer shell established by the strongest of the preceding waves, that zone should be a favored place to hunt for scheelite since all of the cumulative scheelite mineralization of preceding magmatic derivitives would be reconcentrated and made a part of the products of this last surge of magmatic emanations. Such ideal conditions are seldom found, where all favorable factors are superimposed. Had the northeastern front of the Little Cottonwood stock advanced farther so as to "sweep up" and combine the minor deposits between it and the Alta stock it might have produced such a zone, had there existed a trap through which all of the emanations would have had to be focused.

The minor details that determined the exact position of such Scheelite oreshoots as now exist must be sought in the relationships of major ore channels with respect to porous breccias, to dikes, thrust planes, shale cappings, and to replaceable limestones. That all of these are important contributing factors in producing limited ore traps is readily apparent from a close study of the scheelite occurrences in the workings of the Alta United Mines Company.

Where to prospect for more scheelite is indicated by the character of the occurrences already discovered. The recommended steps to be followed in locating the most favored traps for scheelite ore deposition in the area covered by the holdings of the Alta United Mines Company are here listed in what seems to us the most logical sequence:

1. Search the lime-silicate contact zone near the intrusive or its apophyses for fluorescence or other evidences of scheelite.

2. Search for well-established ore channels, (such as the Kate Hayes Fissure, the Wedge, the Powellite Fissure or the Scheelite Fissure). The most favored fissures in this locality are not parallel to

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[1] See "The Tungsten Pipe of the Reaper Mine" by Arthur L. Crawford and Raymond Chorney: PROCEEDINGS of the Utah Academy of Sciences, Arts and Letters, Volumes XIX, XX, pp. 142-149.

the Uintah axis (N. 78° E.) but as pointed out by Beeson[1] for ore-bearing channels that have yielded other mineral wealth, they "apparently form a system in the northeast quadrant with the major fissures striking about 65° East and the minor fissures striking N. 35° E." Where such fissures parallel or intersect a lime-silicate contact zone an accumulation of scheelite is likely to be found.

3. Search for evidence of pre-mineral brecciation along a mineralized fissure in or near a lime-silicate zone. Breccation provides vugs and other open spaces so that mineralizing solutions have an opportunity to slow down under reduced pressure that will permit the precipitation of the scheelite and other ore minerals.

4. Look for an area where the foregoing features can be correlated with a parallel or intersecting dike—preferably a lamprophyre dike, which in this area seems to have favored precipitation of the scheelite.

5. If possible project the features described in the four preceding paragraphs to a position where they will pass under a flat, or eastward dipping, thrust plane having a shale hanging wall which may have served to empound or dam the upward, and presumably northeastward, flow of the mineralizing solutions.

6. Trace as many of the foregoing features as possible to a zone where they will be superimposed upon the Maxfield limestone-Ophir shale contact. This particular stratigraphic horizon has proved to be the most prolific yet explored in this area. Other limestones, in favored spots, have precipitated scheelite, but less consistently and in less quantity.

7. Seek for an elongated projection of the foregoing features so correlated with depth, accessibility, dip, strike, and freedom from post-mineral faulting, that there will be a reasonable chance of having preserved intact an ore body of sufficient size and so located that it may be extracted with profit.

THE METALS COALITION TUNGSTEN MINE

American Fork Canyon

The third tungsten locality in the Wasatch Range, discussed in this paper, definitely belongs to the zone of mineralization of the Little Cottonwood quartz monzonite stock. It is situated on the southeastern periphery of this intrusive (See Figure 2). Scheelite was here discovered in September, 1941 by J. S. Larsen and D. V. Farnsworth on claims leased from the Metails Coalition Mining Company of Salt Lake City, Utah.

The location is in the Silver Lake Mining District on the north side of Deer Creek Canyon, a western tributary of the North Fork of American Fork Canyon. This is about 4 miles beyond the south-

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[1] Beeson, J. J., Mining Districts and Their Relation to Structural Geology: Transactions A.I.M.M.E. Reprint (Sept. 1925) p. 25.

western margin of the area mapped by Calkins for his U. S. Geological Survey Professional Paper 201. However, shortly after the discovery, Calkins, in company with J. S. Larsen and D. V. Farnsworth, visited this occurence and briefly described it in his report.

From U. S. Highway 91, or from either of the three railroads passing the Jordan Narrows, there are vantage points near the Utah County-Salt Lake County boundary from which can be seen a low place in the Wasatch Range just south of "The Narrows" on the high eastern skyline. To the north of this gap stands Lone Peak, the high point of the Little Cottonwood stock. To the south is Box Elder Peak, a tepee-shaped prominence of resistant Pennsylvanian strata. A saddle north of Box Elder Peak is formed by the heads of two canyons draining in opposite directions. That draining to the west is one of the upper right-hand forks of Dry Creek above the town of Alpine. That draining to the east is the Deer Creek branch of the North Fork of American Fork Creek. The heads of these two streams have etched out the east-west Deer Creek fault zone, which here follows roughly the southern margin of the Little Cottonwood quartz monzonite intrusive. The scheelite property here discussed is down Deer Creek Canyon more than a mile east of the divide and is in the contact zone where metamorphic limestones of Mississippian age form a relatively thin blanket over the southeastward-dipping body of quartz monzonite. The trace of the Deer Creek fault appears to lie near the bed of Deer Creek, south of the scheelite exposures, and to mark the southern boundary of the zone where contact metamorphism is evident on the surface.

Judging from the wide exposures of wollastonite, garnet, and other contact silicates over most of this area and from the actual exposures of the quartz monzonite contact near the head of Deer Creek and in Silver Fork Canyon to the north, it appears that the intrusive here has a relatively low angle contact with the limestone beds, almost parallel to the dip slope of the present erosion surface. None of the scheelite exposures found were especially high grade, but the character of their occurrence is such as to suggest that detailed investigations involving core drilling of the scheelite-bearing zones might develop a tonnage of low grade tungsten ore that could be stripped from the dip slope by inexpensive surface methods.

The examination by the writers was made in 1943 with S. D. Pack, then lessee of the property. The method of investigation consisted of daylight examinations of the tungsten outcrops and prospects, a reconnaissance hike up Deer Creek Canyon to its head to ascertain the magnitude of the contact metamorphism with which the tungsten deposition is correlated, and night lamping of the tungsten ore. Samples were taken of the more promising ore-bodies.

Mr. Pack has since relinquished his lease and his rights have reverted to the Metals Coalition Mining Company. This corporation has three patented claims (see Figure 6) under lease and option from R. D. Wadley, of Pleasant Grove, Utah. In addition, it now owns 21 unpatented claims which have been added to the group. All are located in Townships 3 and 4 South, Range 2 East, SLB&M.

Officers of the Corporation at the time of this writing are: Leo Peterson, Salt Lake City, President; Edward H. McCauley, Salt Lake City, Vice President; John M. Calderwood, Salt Lake City, Secretary-Treasurer; and Thomas E. McCauley, Director.

The approach to the property is via the town of American Fork situated approximately 10 miles by air line to the southeast and about 17 miles by road. From American Fork City up American Fork Canyon the road is paved for approximately 10 miles to the South Fork of American Fork Canyon. Up the main branch the road is well graded and graveled for the first 2 miles, beyond which the Deer Creek Road forks to the left and continues as a steep mountain road in poor condition for approximately 2½ miles to the tungsten mine.

During the winter season, snow would prevent shipments with present facilities. The main canyon road, including the lower part of the Deer Creek branch, probably could be traveled most of the year, but the last mile would undoubtedly be difficult to keep open during heavy snows, as the elevation of the claims is between 7,000 and 9,000 feet. The Wadley patented claims from which trial shipments have been made are at the lower southeastern edge of the series.

The geology of the northern American Fork area has been described by Butler[1] and Loughlin, by Hintze[2], and by Calkins and Butler.[3] However, the area where the scheelite occurs, was only touched upon by most of these studies. Unfortunately, the best treatise on Deer Creek and vicinity is not yet available to the general reader. This is a thesis presented in May, 1928, by A. Lee Christensen to Stanford University, in partial fulfillment of the requirements for a Masters Degree in Geology. The present writers are indebted to Dr. Christensen for his courtesy in loaning the use of his personal copy. It was most helpful in providing background for this report.

The beds on the northeastern side of Deer Creek Canyon strike in a northeasterly direction, so that their crenulated, obliquely beveled edges point up-canyon at a narrow angle. They dip to the southeast (down the canyon) forming alternate bands of dip slopes and emerging ribs. The sedimentary rocks of the south side of the canyon as viewed from the mine appear to strike northwestward and to dip steeply to the northeast, so that both the dips and the strikes on the opposite sides of Deer Creek form angles with each other approaching 90°. This peculiar anomaly has resulted from differential movement along the great Deer Creek fault. Concerning this fault Christensen[4] has the following to say:

"The large E-W fault which follows the south side of Deer Creek will be called the Deer Creek fault. The Intercalated Series (Pennsyl-

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[1] Butler, B. S., and Loughlin, G. F., A reconnaissance of the Cottonwood-American Fork Mining Region, Utah with notes on History and Production by V. C. Heikes: U. S. Geological Survey Bulletin 620, 1915.

[2] Hintze, F. F., Jr., A contribution to the Geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, Vol. 23, pp. 85-143, pls. 1-6, 1913.

[3] Calkins, F. C., and Butler, B. S.,—op. cit.

[4] Christensen, A. Lee, Geology and Physiography of Deer Creek and Silver Fork: Masters Thesis, Stanford 1928, pp. 54-56.

vania) has been faulted down against the limestone contact zone (near the base of the Mississippian), giving a stratigraphic throw of over 3,000 feet, and it is probable that the actual displacement is much more. The beds on both sides dip into the fault at high angles and their strikes are almost at right angles to each other, so the fault must have been one with a large amount of rotation or else one with a very large horizontal component, bringing the limbs of the two different folds together. The dip and strike at right angles cannot be explained by any relations of folding and the beds continue their dip without change within 50 yards of each other. The actual fault plane was not seen because of the heavy growth of brush and timber, but it could easily be traced by the relations of the beds on both sides. The fault was not traced west of the divide because of the poor exposures, but it appears to bend toward the southwest. It was not traced east of Deer Creek; it passes under morainic material and could not be picked up east of American Fork Canyon. The fault is thought to be later than the intrusion for the following reasons:

"1. Toward the head of Deer Creek the granite intruded into the Mississippian is in contact with the Intercalated Series but stops in line with the fault plane, although west of the divide it goes more to the south and gives the appearance of cutting the fault plane. The actual contact was seen at the divide and was not intrusive, no dikes cutting into the Intercalated Series.

"2. The Mississippian limestone has been completely altered to marble, tremolite, wollastonite and other silicates, while the Pennsylvanian beds, which are of a very similar nature and dipping into the granite at 70°, giving the most favorable position for passage of hot gases, have not been altered at all ,not even a coarsening of grain being noticeable."

The writers of this report do not feel as certain as does Christensen that the Deer Creek fault is younger than the Little Cottonwood stock. Nor is it at all certain that the general fault surface is as nearly vertical as it is indicated by the exposure where it crosses the divide. The apparent deflection to the south of the western extension of the fault trace beyond the Wasatch divide has not been fully explained.[1] In addition to Christensen's theory concerning the fault, three possibilities which seem to suggest themselves may be indicated:

1. The Deer Creek fault may be a normal post-intrusive fault as Christensen suspects, but with the fault plane less nearly vertical than is indicated by his diagramatic cross-section. Where the fault is exposed at the divide it does appear that the plane is nearly vertical, but this segment may be a minor irregularity and the total surface

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[1] One possible explanation is indicated by A. J. Eardley on his map, Plate 1, in his paper "Structure of the Wasatch-Great Basin Region", (Bull. Geol. Soc. Am., Vol. 50, pp. 1277-1310, 1939). His hypothetical extension of the Uinta Axis in a wide arc to the southwest through the Cottonwood uplift, the Ophir dome and the Sheeprock uplift would make this south-curving contact fault in Alpine Canyon roughly parallel to, and presumably genetically connected with the Uinta-Sheeprock axis.

may be far from a plane. Thus the fault may dip southward and follow the margin of the quartz monzonite southwestward along Dry Creek.

2. The Deer Creek fault may be a nearly vertical tear representing a horizontal thrust fault of the same general age as the Alta overthrust. In this case the north block may have ridden high over the western end of the Uinta buttress and so relieved the pressure on the mass at depth as to facilitate fusion and intrusion. The latter may have been confined in general to the north block except west of the present divide.[1] Here, opposite the greatest mass of the intrusive and presumably near the zone of most prolonged stoping, the south wall of the fault may have been invaded and local assimilation taken place without the marked development of contact silicates. It is well known that contact metamorphism is not always evenly distributed around the periphery of an intrusive.

3. It may be a thrust plane younger than the Alta overthrust and belong to "a much later episode of thrust faulting"[2] from the southwest, belonging to the series of thrusts traced by A. A. Baker in Provo Canyon and referred to by Calkins in his report.[3]

The quartz monzonite of the Little Cottonwood stock does not outcrop in the immediate vicinity of the principal scheelite prospects, but its nearness to the surface is suggested by the intensity of the metamorphism. Apparently during the invasion of the sedimentaries the intrusion not only altered them, but also arched them, so that their remnants now lie steeply inclined upon its southeastern flank. Erosion has stripped off the upper beds down to the contact zone, most of which is still preserved as a "blanket" dipping steeply to the southeast. The stock is unroofed near the head of Deer Creek, where intrusive rocks form the north half of the saddle. The quartz monzonite, here exposed represents the southernmost extension of the Little Cottonwood stock east of the Wasatch divide. West of the longitude of the Metals Coalition property and north of Dry Creek this intrusive forms the mountain mass as far north as the north rim of Little Cottonwood Canyon and as far west as the middle slopes of the Wasatch front. (See Figure 2). Except for a few roof embayments the intrusive is continuously exposed throughout this area.

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[1] If the relationships should prove to be those postulated by A. J. Eardley in Figure 4 of his paper, "Slotted Templet for Resolving Crustal Movements" (Jour. Geol., Vol. XLVII, No. 5, July-August, 1939, pp. 546-554), the intrusive west of the Wasatch divide would probably be confined to the north block. In Eardley's diagram his resolution of forces indicate a northwestward movement of the Cottonwood uplift during the Laramide Orogeny a total distance of approximately 10 miles with respect to the west end of the Uinta Mountains.

[2] This later thrusting may have been contemporaneous with the Oligocene deformation of Beeson (op. cit. p. 11) which hitherto has been thought to be confined chiefly to the northern Cordillera. However the relationships of the Duchesne River formation along the south flank of the Uinta Mountains show that this area underwent extensive adjustments in Oligocene time. (See Walton, Paul T., "Geology of the Cretaceous of the Uinta Basin, Utah", Bull. Geol. Soc. Am., Vol. 55, pp. 91-130, 1944; also, papers by Kay, J. L., Spieker, E. M., and Forrester, J. D., referred to by Walton).

[3] Calkins, F. C., and Butler, B. S., op. cit. p. 60.

Like other high regions of the central Wasatch, Deer Creek Canyon was scoured by glacial activity, during Pleistocene times. Much of the road leading from Deer Creek Canyon to the Metals Coalition cabin and the 1,500 foot section of road from the cabin to the lower tungsten ore body is located on a lateral moraine. The hanging valley on the north side of the head of Deer Creek Canyon, containing the rock fall described by Christensen[1], is believed by us to have been caused, in part at least, by glacial erosion. The rock fall, itself, is believed to have been the result of the over-steepening at the base of a segment of the intrusive contact. Joint cracks gave ground water access to the top of the comparatively shallow igneous body beneath the pre-glacial cap of contact silicates. The latter was tougher and more resistant to kaolinization than the feldspars of the igneous rock. Pre-glacial weathering due to percolating waters beneath the contact is believed to have produced incipient kaolinization along joint planes and thus to have "greased the skids" so that when glacial "plucking" of the bergschrund around the rim of the incipient cirque later over-steepened the base of the mass, a sudden rock fall took place some time after the close of the last glacial epoch. That it was not prior to this epoch is indicated by the manner in which the "felsenmeer" still covers the floor of the incipient cirque. If there had been any appreciable movement of a glacier after the rock fall occurred the loose rocks would have been swept out of this catchment area to the canyon below. This rock fall differs from a landslide in its absence of fine material. Christensen estimated an area one-half by one-quarter of a mile with an average thickness of 20 feet of rock debris, or, a volume of 2,500,000 cu. yards. Single blocks are as long as 20 feet. Most of the material is altered Mississippian limestone, but the floor of the scar is almost wholly quartz monzonite. The blocks of this debris-strewn area, are in such jumbled confusion that not even deer paths cross the center of the slide.

The tungsten deposits of Deer Creek Canyon are similar to many other tungsten ore bodies existing in contact metamorphic zones in which scheelite, is associated with the garnet, epidote, tremolite, wollastonite, and other typical "contact" minerals. There is little room for doubt that the metamorphism and mineralization of the original sedimentaries have resulted from the intrusion of the quartz monzonite, the "mineralizers" of which carried tungsten.

The lowest ore-body, located some 1,500 feet up the canyon from the cabin, is on the Mayday extension claim, owned by R. D. Wadley. This is developed by three prospect pits situated one above the other. The lowermost of these three consists of a pit, or short incline, approximately 20 by 10 by 6 feet, driven into the ridge in a northerly direction. A very tough and massive scheelite-bearing garnet rock has been followed as far as the face of the incline. A barren, marblized limestone apparently terminates the ore, although an eastward-dipping thin quartz vein cuts the garnet and limestone

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[1] Op. cit. pp. 98-100.

and may have controlled to some extent the tungsten mineralization. A dump sample selected by comparison with the fluorescence of the scheelite-bearing zone shown in the wall (because of the difficulty of cutting a channel sample in the tough tactite), contained 0.35 percent $W0_3$.

Approximately 40 feet above the short incline an open cut, roughly 15 feet in length and 5 feet in both width and depth, has been dug along the strike of beds. This tactite rock is more friable and more decomposed than that in the tunnel below, and it shows more fluorescence and assays higher in tungsten. A sample cut from this zone contained 2.26 percent $W0_3$ and 0.11 percent Mo. Some 15 feet above this open cut another shallow open trench has been started which also exposes scheelite ore.

The tungsten ore in all three prospects is similar, consisting of a soft to very hard and tough tactite containing scheelite disseminated throughout. The scheelite is relatively fine grained, individual crystals seldom exceed one-eighth of an inch in cross-section, the majority being about one half this size. As shown by the assay quoted, molybdenum is also present in the ore. Under the ultra-violet lamp the ore shows fluorescence which varies from cream color to bluish white. Some samples were noted to contain molybdenite, the sulphide of molybdenum. The amount of molybdenite is insignificant, but the alteration of it to the molybdate is believed to have caused the partial supergene replacement of scheelite crystals by powellite molecules.

From the creek level on the Glacier claim, owned by R. D. Wadley, an old tunnel is shown on Figure 5 running northwestward for 1,000 feet to a point almost beneath the pits on the Mayday Extension claim. The tunnel was reported to be caved and was not investigated by the writers.

Approximately 1400 feet up the canyon to the west of the workings on the Mayday Extension claim a similar tactite zone has been prospected by three small open pits on the Metals Coalition No. 2 claim (See Figure 6). These pits are arranged in step-like manner up the beveled edge of one of the southward-dipping scheelite-bearing bands. The two lower pits are approximately 40 feet apart, with the second lying northeast of the first. The third pit is above and about 200 feet north of the second. On Metals Coalition No. 1 claim, near the bed of the creek about 300 feet south of the first of the three pits, a tunnel has been driven through a diorite dike, into the side of the canyon for ore. Immediately southeast and adjacent to this tunnel, a body of partially altered pyrite is exposed which shows the presence of small amounts of scheelite and assays 7 percent titanium oxide (TiO_2).

Samples were taken from two of the three pits in the garnet ledges located on what is said to be Metals Coalition No. 4 claim on the slope approximately 1500 feet northwesterly above the altered pyrite zone, and although the WO_3 content appears insignificant, being 0.04 and 0.02 percent, respectively, the area deserves further prospecting. Samples containing from 2 percent to 4 percent WO_3 are reported to have been taken from this area but the exact exposures

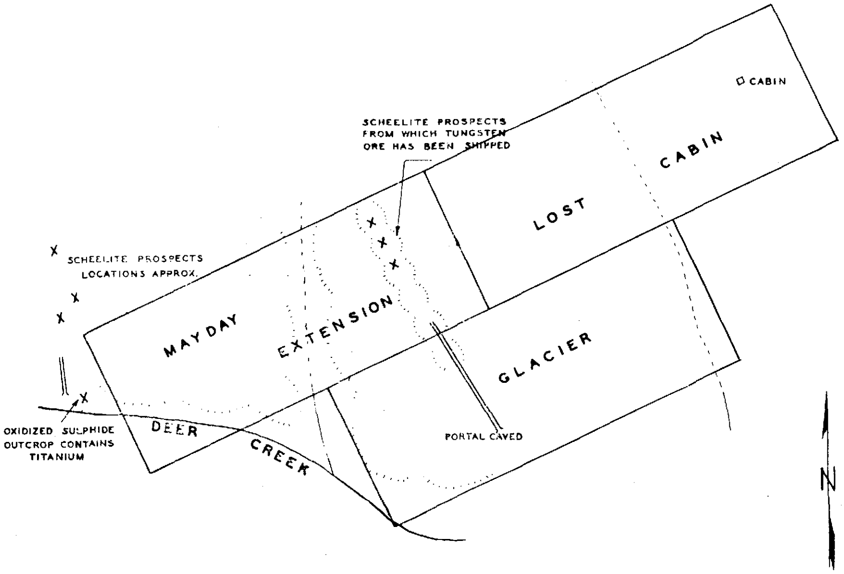

FIGURE 6. CLAIM MAP OF THE METALS COALITION MINING COMPANY

ADAPTED FROM U.S. GENERAL LAND OFFICE MAP OF THREE PATENTED CLAIMS – MAYDAY EXTENSION, LOST CABIN, AND GLACIER, LOCATED IN THE SILVER LAKE MINING DISTRICT, DEER CREEK CANYON, AMERICAN FORK AREA, UTAH COUNTY, UTAH

SCALE IN FEET
0 300 600 900

from which they were cut were not found by the writers. One of the samples collected showed considerable fluorescence under the ultra violet lamp, but apparently much of the fluorescence was due to powellite, as the assay was low in WO_3. High grade streaks of relatively coarse scheelite crystals were noted in this area, but no fluorescent zones observed by the writers on this claim appear to indicate commercial ore.

The distribution of the tungsten ore zones on Deer Creek is highly suggestive. The erosion surface of that part of the canyon containing the three pits on the Mayday Extension claim slopes steeply to the south, and the garnetiferous tungsten-bearing ore forms lenses in rib-like layers interbedded with contact metamorphic limestone strata which blanket the underlying intrusive. The three prospect pits on Metals Coalition No. 2 claim, some 1400 feet to the west, are similarly situated with reference to their geologic environment, as are also the outcrops of scheelite-bearing lenses in the garnetiferous ledges higher on the canyon side some 1500 feet still farther to the northwest. Whether all three of these zones are at or near the same stratigraphic horizon and are merely outcrops of a somewhat crenulated steeply southward-dipping tungsteniferous member, or whether the various prospects are in lenses scattered through an appreciable stratigraphic range, was not determined. Further development is needed to show the extent and character of these lenticular ore bodes. If the mineralized areas should prove to be comparatively continuous along the beds between these exposures, surface stripping may be all that is necessary to mine the scheelite cheaply, provided the tenor of the ore is proved sufficiently high to be profitable. Additional study may show that the garnetiferous tungsten-bearing beds have a schematic relationship to the intrusive contact. It is believed that the pattern of these beds will prove to be exactly similar to certain other garnetiferous tungsten-bearing zones investigated by the writers. Along the southeastern flank of the Mineral Range[1] intrusive in Beaver County and around the periphery of the House Range[2] intrusive in Millard County, Utah, the metasomatic garnetization of sedimentary beds, as well as the deposition of tungsten, was found to be highly selective, although in general the intensity of metasomatism was found to be progressively less as the distance from the intrusive becomes greater.

Tungsten production from the Metals Coalition property began with a carload shipment by S. D. Pack August 9, 1943. This was the first tungsten ore marketed from the American Fork district and with the exception of two sample lots of 0.345 and 0.156 tons, respectively, assaying 0.30 and 0.34 percent WO_3, respectively, which were shipped in January 1943 by the U. S. Bureau of Mines from the Alta United Mines property, Pack's car of scheelite ore was the first tungsten ore mined from the Wasatch Range since tungstenite was produced from the Emma Mine. Tungstenite, the tungsten sulphide, and (probably) stolzite[3], the lead tungstate, were mined and shipped along with silver-lead ore from the Emma property in Little Cottonwood Canyon prior to 1900. However, no substantial tonnage of tungsten ore has, thus far, been produced from any mine in the Cottonwood-American Fork area. Only two car-loads have been shipped[4] from the Metals Coalition property to date, both in 1943.

S. D. Pack (lessee) and associates sold:

41.247 tons, containing 13.20 WO_3 units, averaging 0.32 percent WO_3 per ton.

Metals Coalition Mining Company sold:

35.683 tons, containing 16.77 WO_3 units, averaging 0.47 percent WO_3 per ton.

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[1] Crawford, Arthur L. and Buranek, Alfred M., Certain Tungsten Deposits of the Mineral Range, Beaver County, Utah: Circular 26, Utah State Department of Publicity and Industrial Development, published in cooperation with the Engineering Experiment Station, University of Utah, October, 1943.

[2] Crawford, Arthur L. and Buranek, Alfred M., Amazon Stone—A New Variety of Feldspar for Utah—with Notes on the Laccolithic Character of the House Range Intrusive: PROCEEDINGS of the Utah Academy of Sciences, Arts and Letters, Vols. 19 and 20, pp. 125-127, 1943.

[3] Calkins, F. C., Butler, B. S., Geology and Ore Deposits of Cottonwood-American Fork Area, Utah, with sections on History and Production, by V. C. Heikes: U. S. Geological Survey Prof. Paper 201, pp. 96, 97, 1943.

[4] Production figures obtained through courtesy of D. D. Baker, Supt. in Charge, Salt Lake Chemical Tungsten Plant, U. S. Vanadium Corporation.

The origin of the tungsten deposits in the Deer Creek area is tied directly to the origin of the structural features and of the intrusion of the Little Cottonwood stock. It is safe to say that it was the expelled mineralizers from the hot intrusive that selectively garnetized and deposited scheelite in certain beds. What has been said of a general nature regarding the origin of scheelite in other deposits applies here. In addition there are certain other speculative considerations, which are suggestive when the American Fork mineralization is contemplated in relation to its broader geologic setting. The ultimate solution of many perplexing problems in economic geology has been furthered by such stimulating hypotheses as those proposed by Butler[1] for the formation of ore deposits about the apices of intrusive stocks, by Beeson[2] for the localization of mineral wealth along the "Bingham-Park City Ore Zone", by Billingsley[3] and Locke for the "Tectonic Position of Ore Districts in the Rocky Mountains", by Loughlin[4] for the relation of mineral deposits to the origin and structural control of igneous rocks, and by Willis[5] and Willis for the cyclic generation of continental thrusts from radioactive minerals in the earth's crust. This is not the time nor place to elaborate upon these profound and history making theories. However, since part of the Cottonwood-American Fork area lies within the "Bingham-Park City Ore Zone", and since, "Crossing as it does the great Uinta arch and occupying transition ground between the Laramide system on the east and the Great Basin system on the west, as well as between the Rocky Mountains on the north and Colorado Plateaus on the south, it is a critical tectonic point of the first rank and is likely to be one of the battle grounds of geologic science for many years to come,"[6] the present writers may be justified in closing this paper with some speculations of their own. If the reader is forewarned it is hoped the following may stimulate observation without adding further to existing confusion.

The prow-shaped counter thrust of the Uinta Mountains is believed by the writers to have generated the intrusives which, in turn, were responsible for the Bingham-Park City Ore zone. The writers have found no evidence that the Great Uinta arch has a laccolithic core.

The major mineralization of the Cottonwood-American Fork area appears to be limited roughly on the south by the Deer Creek fault. An east-west line extended in each direction from the Deer Creek fault would, on the east, be practically coincident with the

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[1] Butler, B. S., Relations of Ore Deposits to different types of intrusive bodies in Utah: Econ. Geology Vol. 10, pp. 101-122, 1915.

[2] Beeson, J. J., op. cit.

[3] Billingsley, Paul, and Locke, Augustus: Tectonic Position of Ore Districts in the Rocky Mountain Region: A.I.M.M.E. Technical Publication No. 501, 1933.

[4] Loughlin, G. F., Comments on the Origin and Major Structural Control of Igneous Rocks and Related Mineral Deposits: Econ. Geology, Vol. 36, pp. 671-697, 1941.

[5] Willis, Robin, and Willis, Bailey, Eruptivity and Mountain Building, Bull. Geol. Soc. of America, Vol. 52, pp. 1643-1684, 1941.

[6] Ransome, F. L., Tertiary Orogeny of the North American Cordillera and its Problems, (in) Problems of American Geology: p. 320, Yale Univ. Press, 1914.

southern boundary of the westward plunging "nose" of the great Uinta arch and, on the west, it would roughly frame the southern wall of the Little Cottonwood stock. With this line as the southern leg of an equilateral triangle based against the west end of the Uinta arch and having the Bingham stock for the apex, or point of focus, the same observational data used by Beeson[1] can be employed to construct a plausible hypothesis quite different from that devised by him for the origin of the "Bingham-Park City Ore Zone." This acute-angled prow of the westward plunging Uinta arch would inscribe all of the more important producing mines of the Bingham-Park City districts. Likewise it would include all of the intrusive bodies with which any of these mines is even remotely associated, and as noted by Beeson,[2] the mineral production coming from the Bingham-Park City uplifts have produced 70 percent of the gross value of the principal metals mined in Utah from 1875 to 1924.

Beeson believes that the intrusives along this zone consist of unroofed portions of an elongated laccolith extending eastward under the arch of the Uinta anticline. By inference he assumes that the axis of this intrusive laccolith may have been mineralized throughout most of its length—the preservation at mineable depths of valuable deposits at Bingham and Park City being due to the fact that the present erosion surface here coincides with the zone of optimum ore deposition. He points out that the Little Cottonwood stock has been so deeply truncated that most of the minerals deposited in this area have been planed off by erosion and lost, so far as the present evolutionary cycle is concerned.

No evidence of a floor has yet been found for any of the intrusives within this area; nor is there appreciable evidence along the axis of the deeply eroded Uinta arch that the Uinta Mountains may have a laccolithic core. Furthermore there are other cogent reasons for believing that the folds[3] flanking the Cottonwood intrusives antedate rather than result from them.

To the writers it seems more in keeping with all of the known evidence to assume (1) the pre-existence of a rigid elongated east-west buttress (the thick quartzite core of the present Uinta arch) at the time of the great Laramide thrusts, (2) that the nose of this buttress formed a prow-shaped mass that plowed deeply beneath the great overthrusts coming in from the west, (3) that the overthrust blocks above this "metallogenetic" prow, or angle of deep counterthrust, rode high upon the end of the Uinta buttress, (4) that the relief of pressure beneath these uplifted overthrust blocks, plus the intense friction generated by the deep underthrust buttressed by the elongated mass of resistant quartzite, generated the family of intrusives within this angle. So deep-seated were these intrusives as to tap the metalliferous zones which supplied the mineralizing solutions that deposited the metallic wealth for which this area is famous.

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[1] Beeson, J. J., op. cit.

[2] Beeson, J. J., op. cit. p. 19.

[3] Christensen, A. Lee, op. cit. p. 68.

If this picture has a counterpart in reality the principal rent along the southern margin[2] of this prow might be expected to provide a line of weakness in the over-riding roof-blocks along which mineralizing solutions might reach favorable beds where scheelite and other high temperature minerals might be deposited. At the southeastern corner of the Little Cottonwood intrusive, a Mississippian limestone remnant (between Deer Creek and Silver Fork) bounded by pre-mineral faults and wedged in between a block of Cambrian quartzite on the north and a block of siliceous Pennsylvania beds on the south was well situated to form a trap for intrusive-driven, "lime-loving", tungstic acid. Whether the lime tungstate was precipitated in economic concentrations, or whether it was disseminated so widely through this segment of the overlapping roof that it will never have economic value, only time and search will determine. If ever again a national emergency makes tungsten a critical metal, this, along with other possible reserves, should be carefully investigated.

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[2] Calkins, F. C., to whom the authors are greatly indebted for a critical reading of the manuscript on the Metals Coalition section of this bulletin and for many helpful suggestions connected therewith, believes (personal communication) that the authors have "given the Deer Creek fault a little too much importance." No doubt this is a valid criticism, since, as Calkins points out, "there are at least two other great east-west faults with down throw on the south between Deer Creek and the mouth of American Fork Canyon." These have not been studied by the authors of this bulletin but, following the general hypothesis of a prow-shaped underthrust from the Uinta block, these, too, might fit in as marginal down-drops resulting from tensional adjustments roughly parallel to the rent-zone produced along the southern rim of the uplifted thrust plate on the nose of the prow. It is conceivable that such border normal faults might be considerably later than the initial rent and the primary folding that accompanied the Laramide orogeny. Thus, unstable conditions created by the latter, might require a long period of adjustment. Tensions would continue to be relieved by relaxational movements long after events which gave them birth.

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