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GENESIS OF THE TUNGSTEN DEPOSITS OF THE UNITED STATES

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(concluded)

Introduction

A short but general survey of the genesis of the tungsten deposits in the United States, such as this, might at first glance be expected to be entirely comprehensive, in view of the newness of discovery and development of the metal, and consequent probable scarcity of reference material. But tungsten has had an almost phenomenal growth as an industrial requirement in the past twenty-five years, and along with its growth an extensive bibliography has accumulated. Therefore, this survey, based on many references, must necessarily treat most of them briefly.

In discussing the tungsten deposits, a scientific classification rather than a commercial one is used.

Main tungsten deposits of the United States have been selected for illustration, with no attempt to describe deposits in detail, nor to present a multitude of examples. However, all facts vital to a particular point are given. Effort has been made to arrange in fairly systematic fashion data concerning location and distribution, classification of deposits, general features, characteristics of the ores, structural relation of the ore deposits, and to present practical conclusions.

Location and Distribution

Most of the tungsten deposits of the United States occur only in states that lie in and west of the Rocky Mountains--South Dakota, Montana, Colorado, New Mexico, Idaho, Utah, Arizona, Nevada, California, Oregon, and Washington--where there are areas of quartzose granitoid rocks. (See map of distribution on the page between 4-5)

In the Rocky Mountain and Great Basin States, the largest deposits of ferberite, wolframite, and hübnerite occur in the gold and silver producing areas. In the Sierra Nevada, the greatest known scheelite deposits are found at Atolia, at the south end of the range near important silver and gold deposits.

A large quantity of the tungsten produced in the United States prior to 1931 was taken from the vein deposits of two districts, the Boulder County district, Colorado, and the Atolia district, Southern California, and at the present time, a large production is from contact-metamorphic deposits. Most of the known contact-metamorphic tungsten deposits are in the Great Basin region in California and Nevada and Northwestern Utah, but Oregon, Arizona, and New Mexico are known to contain one deposit each. The chief producing districts are on the eastern slope of the Sierra Nevada near Bishop, California; in the Eugene Mountains near Mill City, Nevada; and in several ranges near Lovelocks, Nevada.

In the granites and related rocks exposed from Maine southward to Georgia, very little tungsten has been found. Scheelite has been mined on a small scale at Blue Hill Bay, Maine, and Trumbull, Connecticut; sporadic occurrences have been noted at several places in the Appalachian States including Flowe, North Carolina, Missouri, and the Old Irish Creek tin mine, in Rockbridge County, Virginia, 5 miles east of Vesuvius. At no other points in this whole eastern area have tungsten minerals been exploited.

The distribution of the four important ores of tungsten is given below. (Pages 4 -5)

Ferberite has been found in the United States principally in the Boulder field in Colorado. The Boulder field centers around Nederland, Boulder County from which it extends about ten miles northeast, and scattered deposits have been reported from points through a distance of ten or twelve miles to the south. The main belt is four or five miles wide. The Boulder district has been by far the most important ferberite mined in Colorado furnished between one-tenth and one-tenth and one-eighth of the world's tungsten production.

Hübnerite has been mined at Tungsten, Nevada in the Snake Range, twelve miles south of Osceola, at Tungstenia, thirty-five miles north of Osceola, Nevada; near Columbus, Mina, Spanish Springs and Round Mountain, Nevada; on Patterson Creek, in the Blue Wing district, Idaho; near Silverton, Colorado; at White Oaks, New Mexico; and at Dragoon, Arizona.

Wolframite is found in Arizona near Yucca, Columbia (Tip Top), Nogales, Hillside (Eureka district), and Benson (Whitstone Mountains), in the Clark Mountains, California; Penasco, New Mexico; Hill City, South Dakota; near Cathedral Peak, Okanogan County, and Cedar Canyon, Stevens County, Washington.

Scheelite occurs in commercially valuable quantities at the places indicated below: In Alaska, fifteen miles north of Fairbanks and placers near Nome; in Arizona, at Aracle, Pinal County, four miles north of Dragoon and near Duquesne; California, at Atolia and Randsburg, San Bernardino County; with wolframite in the Clark Mountains, San Bernardino County, eighteen miles south of the Inyo County Line and nine to ten miles from the Nevada boundary at Amalie, in Jawbone Canyon, and near Weldon, Kern County; Grass Valley, Nevada County; and at several places near Bishop, Inyo County, in Connecticut, at Trumbull, in Idaho, at Murray, Shoehorn County, Nevada, at Scraments Pass, ten miles north of Osceola; at Camp Bonita, on the opposite side of the Snake Range and south-east of Osceola; at Scheelite, six miles south; and in the Minerva district, twenty-five miles south of Osceola, White Pine County; in Utah, in the Deep Creek Mountains, Tooele County, and in the Grouse Creek Mountains, Box Elder County, fifteen miles north of Lucin.

Tungsten minerals have been reported from about eighty localities in the United States. In the following list the numbers referring to the accompanying map are combined together from the reports of R. D. George[6] and F. L. Hess and E. S. Larsen[9]. The dots mark places which have produced ore; the circles indicate the presence of tungsten minerals--rarely in commercial quantity; and the red dots indicate the contact-metamorphic tungsten deposits.

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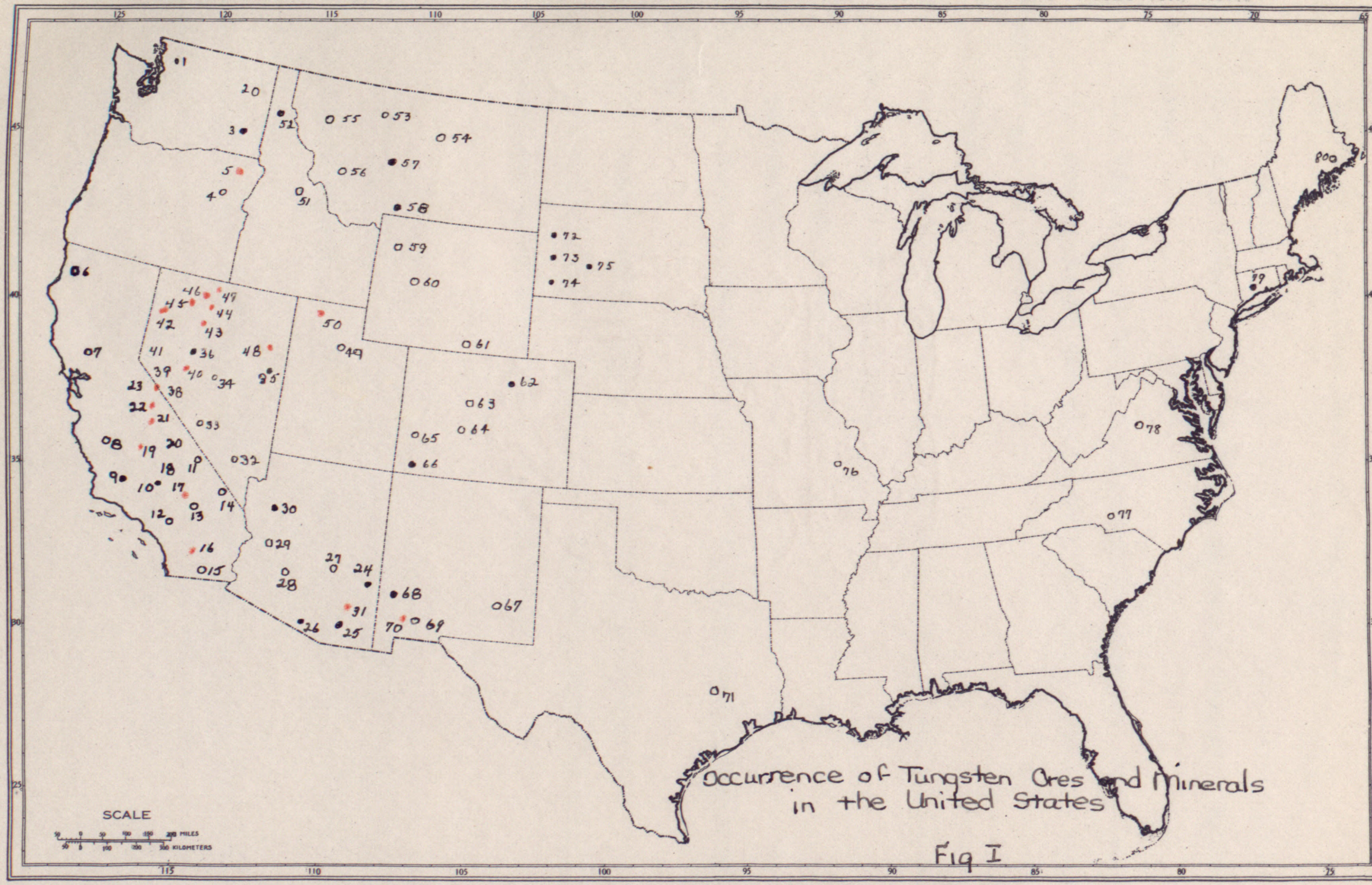

Fig I

For class use in Geography, History, Civics, Economics, etc. Prepared by J. Paul Goode. Published by The University of Chicago Press, Chicago, Ill.

Index of Localities Shown on Map, Fig. I

Washington:

1. Near Loomis, Casade Mts., Okanogan County. Wolframite. Shipping

2. Vicinity of Deer Trail, Stevens County. Two localities.

3. Cedar Canyon and Springdale District, Stevens County. Opened up.

Oregon:

4. Virtue district, east of Baker City. Scheelite in placer gravels of Cliff mine.

5. Joseph. Scheelite.

California:

6. Eureka, Humboldt County. Tungsten mineral not specified.

7. Howard Hill, Grass Valley, Nevada County.

8. Twelve miles northeast of Raymond, Mader County, and in southern Mariposa County. Scheelite.

9. Caliente, Amalie and Paris, Kern County. Scheelite in a lead silver mine at Caliente. Producing.

10. Randsburg and Johannesburg district in Kern and San Bernardino Counties. The Atolia Mining Company. Scheelite. Producing.

11.Ivanpah district. Wolframite occurs. No production reported.

12. Sierra Madre, Los Angeles County. Tungsten--minerals not specified.

13. Near Kelso, on the Salt Lake Road. Scheelite.

14. Manvel and Signal. Scheelite. Producing.

15. Julian, San Diego County. Tungsten--minerals not specified.

16. Aguanga. Scheelite.

17. Marango district. Scheelite.

18. Weldon. Scheelite.

19. Glendale. Scheelite.

20. Darwin. Scheelite.

21. Bishop. Scheelite.

22. Pine Creek. Scheelite.

23. Benton. Scheelite.

Arizona:

24. Cochise County, six miles north of Dragoon, on the A. T. & S. F. Produced.

25. Whetstone Mts. Euclid Mining So. Operated wolframite mine in 1906.

26. Near Arivaca, in Santa Cruz County. Hübnerite has been mined.

27. Santa Catalina Mts., near Southern Bell Gold Mine. Scheelite.

28. On Buffalo-Arizona Company's property, near Phoenix. Ore reported.

29. Sixty miles south of Hackberry, in Aquarius Mts., Mohave County.

30. Near Owens, 80 miles south of Kingman and 12 miles east of Big Sandy River. Wolframite. Small shipment in 1905.

31. Johnson. Scheelite.

Nevada:

32. Mammoth District; Hübnerite. This is the place of the

original discovery of hübnerite.

33. Lander County. Ore reported.

34 Near Atwood, Nye County. Tungsten ore.

35 Tungsten Mining District, 12 miles south of Osceola, in White Pine County. Producing.

36. Round Mountain. Hübnerite. Producing, 1907.

37. Forty miles south of Lovelocks, Humboldt County. Wolframite. Considerable development. Shipped 1908.

38. Queens. Scheelite.

39. Hawthorne. Scheelite.

40. Mina. Scheelite.

41. Churchill Butte. Scheelite.

42. Nightingale Mountains. Scheelite.

43. Toy. Scheelite.

44. Toulon. Scheelite.

45. Lava Beds. Scheelite.

46. Mill City. Scheelite.

47. Golconda. Scheelite.

48. Ruby Range. Scheelite.

Utah:

49. Little Cottonwood. Tungsten ore. No shipment in 1905.

50 Lucin. Scheelite.

Idaho:

51. Patterson Creek, Lemhi County. Hübnerite and wolframite.

52. Near Murray, Wallace and Mullan, Coeur d'Alene district. Producing.

53. Near Helena. Scheelite.

54. Near Neihart. Scheelite.

55. Missoula County, western part. Scheelite. Shipped in 1905.

56. Near Phillipsburg. Hübnerite.

57. Birdie Mine, east of Butte. Hübnerite.

58. Near Jardine and Crevasse, Park County. Scheelite. Producing.

Wyoming:

59. Jackson Hole region, near Elk. Wolframite.

60. Fremont County, near Shoshone. Tungsten ore.

61. Holmes (near). Wolframite.

Colorado:

62. Boulder County, and adjacent parts of Gilpin County.

63. Leadville. Several mines report wolframite and hübnerite.

64. Near Salida. Hübnerite in a vein worked for copper. Scheelite also occurs in Chaffe County. (Personal correspondence)

65. Ouray County, Uncompahgre District, Royal Albert vein.

66. Red Mountain and Gladstone, in San Juan region. Hübnerite. Produced.

New Mexico:

67. Bonito. Hübnerite occurs.

68. Steins Pass, Lordsburg and Separ. Hübnerite and wolframite shipped in 1895-6.

69. Victorio district, 18 miles west of Deming. Hübnerite and Scheelite.

70. Hachita. Scheelite.

Texas:

71. Falls County. Ore reported.

South Dakota:

72. Lawrence County, Durango, Sula, Harrison, Golden, Summit and Two Strike mines produced 106 tons wolframite concentrates, carrying 38-50% tungstic oxide.

73. Near Hill City, Pennington County. Producing.

74. Custer County. Producing.

75. Keystone, Pennington County. Wolframite. Producing (?).

Missouri:

76. Madison and St. Francois County, in vicinity of Mine La Motte. Wolframite.

North Carolina:

77. Flowe, Cosby and Cullen mines of Cabarrus County. Scheelite with a little wolframite.

Virginia:

78. Rockbridge County.

Connecticut:

79. Long Hill station. (Monroe and Trumbull are included in the reference)

Maine:

80. Blue Hill Bay.

TYPES OF DEPOSITS

According to Lindgeen[21], and Lovering[23], nearly all the tungsten ore of commercial importance, relatea to igneous rocks is found in the four types of deposits below: 1. Pyrometasomatic deposits. 2. Hypothermal deposits. 3. Mesothermal deposits. 4. Epithermal deposits. In addition to these, non-commereial tungsten ores occur in pegmatite and in magmatic segregations, and a little commercial ore is found in placers.

Distribution and General Character of Pyrometasomatic Deposits (Contact-Metamorphism)

Pyrometasomatic deposits are metalliferous deposits formed at high temperatures by emanations issuing from the intrusive rocks causing replacement of the enclosing rock with addition of substance.

General Distribution: Many scheelite deposits of contact-metamorphic origin occur in roof pendants along the eastern flank of the Sierra Nevada west of Bishop, California. One of them--the Pine Creek deposit is the largest of its kind in the world.[23] Scheelite the usual ore mineral--Contact metamorphism deposites have characteristic mineral assemblage and special relation to intrusive rock. It is found in replaceable rock, usually limestone. The scheelite is associated with garnet, calcite, hornblends and pyroxene. The intrusive rock is usually a granodiorite; the replaced rock always a limesone or a dolomite. The succession is in general garnet, diopside, epidote; scheelite was apparently formed with the silicates the scant sulphides were later. The granitic rock adjoining the contact had solidified at the time of ore formation.

Mill City, Nevada[21]--The district seven miles northwest of Mill City, Humboldt, County, Nevada, is one of the most important tungsten producers in the United States. The ore has averaged 2% of WO_3 --much higher in grade than that of any of the other contact-metamorphic deposits.

The ore bodies consist of replaced layers of limestone enclosed in hornhelsed slates near their contact with granodiorite. The ore is made up of a garnet and epidote in variable proportions, with much quartz and calcite and some sulphides, zeolites, and scheelite.

Other districts[21]--Many other pyrometasomatic tungsten deposits in the United States. Chiefly in the Great Basin region, have been described by Hess and Larsen. Those authors recognize a zonal arrangement:

Adjacent to the intrusive a zone of dark silicates (garnet, epidote and diopside-hedenbergite, together with uralitic hornblende, sulphides quartz, calcite, and scheelite); next a zone of light-colored silicates mainly tremolite and wallastonite, with some diopside, scapalite, alkali field-spar, quartz, and vesuvianite, but pyrite is rare and scheelite is absent; and beyond this zone comes marble. In general garnet is one of the earliest minerals to form.

Distribution and General Character of Hypothermal Deposits

Hypothermal deposits are veins and replacement deposits (excepting contact-metamorphic deposits) formed at high temperature and pressure and in genetic connection with intrusive rocks.

Many hypothermal tungsten veins are found in the United States. In the Deer Trace district[23] , Washington, lenticular deposits of wolframite occur in quartz veins containing fluorite and tourmaline, locally scheelite, pyrite, chalcopyrite, molybdenite, arsenopyrite, galenobismutite, and cosalite are also present.

In the Jardine district [23] a few miles northeast of Gardner, Montana, wolframite and auriferous arsenopyrite are contained in quartz veins.

In the Tungsten and Kern Mining district of eastern Nevada, in Arizona, and at several other localities that are commonly, but less certainly, classed in the group, tungsten-bearing quartz veins occur.

Distribution and General Character of Mesothermal Deposits

Mesothermal deposits are metalliferous deposits formed at intermediate temperatures by ascending thermal waters and are genetically related to intrusive rocks.

Mesothermal deposits of Boulder County, Colorado [21] -- Some wolframite occurs in the gold-bearing veins of Boulder County, but there is a fairly well-defined area near Nederland which is characterized by tungsten ores alone. In 1918, 5,020 tons of tungsten concentrate were produced in the United States of which the largest part came from the deposits of Boulder County. The present production is small. The domestic production at present comes in part from Atolia, Kern County, California where scheelite occurs in gold-bearing quartz veins of the mesothermal type; but briefly, from contact-metamorphic deposits in Nevada and California.

At Butte, Montana, hüberite is a minor constituent of many of the copper veins and gold-silver veins of mesothermal types, but only in the gold-silver veins is it abundant enough to be of commercial importance. It is associated with pyrite, marcasite, galena, sphalerite silver, and some copper minerals in quartz gangue. [23]

Mesothermal tungsten-bearing veins also occur in the Patterson Creek district, fifty miles south of Salmon, Idaho where veins of coarsely crystalline quartz contain sphalerite, hübnerite, tetrahedrite with some molyodenite and galena and near Murray, Idaho, where scheelite occurs in gold, it is associated with a variety of sulphide minerals such as pyrite, chalcopyrite, galena, sphalerite, and tetrahedrite in a coarse-grained quartz gangue.[23]

Epithermal Deposits

Distribution and General Character

Epithermal deposits are metalliferous deposits formed near the surface by ascending thermal waters and in genetic connection with igneous rocks.

Epithermal veins[23]--The most important tungsten deposit in the United States that belongs to the epithermal vein group is in the San Juan Mountains of Colorado, epithermal veins carrying hübnerite are found in a district about nine miles long, extending from Silver to Gladstone.

Epithermal replacement deposits[23]--In the Black Hills most of the tungsten production has come from replacement deposits near Lead. The wolframite is locally associated with barite, stibnite, scheelite, and gold, and is probably an epigenetic deposit of early Tertiary age.

Most of the general features ofthe tungsten deposits of the United States are given under each type of deposit for illustrations. Some characteristics of a few of the commercially important deposits are as follows:[27]

Those of Boulder County, Colorado[6], the principal source of tungsten in the United States lie on the eastern slope of the Front range of the Rocky Mountains, about thirty miles north-west of Denver. The veins are narrow fissures in granite and in porphyry dikes, accompanied in places by breccia. The ore-mineral is ferberite, finely disseminated through quartz or lining cavities. A few deposits have been opened to a depth of 600 feet but most were impoverished at much shallower depths.

Second in importance among American occurrences are the deposits at Atolia[27], in San Bernardino County, California. Here the ore-mineral is scheelite, in seams and veins varying from thin stringer to widths of four feet, in grano-diorite and schist. The gangue consists of quartz, calcite, and crushed country rock.

In the Dragoons Mountains[26] of Arizona, hubnerite occurs in vertical quartz veins in granite with a little muscovite and fluorite. The hübnerite occurs distributed through the quartz in tabular masses and blade like crystals in gold bearing quartz veins.

In White Pine County[27], Nevada, hübnerite and scheelite occur in quartz veins occupying fault-fissures associated with fluorite, pyrite, muscovite, and minerals of copper, lead, zinc, and silver. The veins range from thin stringers to thickness of eleven or twelve feet; some are very rich.

In the northern Black Hills[16] of South Dakota, deposits of wolframite lie in the Cambrian dolomite, associated with the flat-dying masses of refractory silicious ores, north of Lead. The wolframite appears in flat, horizontal but irregular masses, and in many places seems to form a rim around the siliceous ore-shoots, except on the under side.

Near the granitic area of Harney Peak in the southern Black Hills[16], wolframite exists in pegmatite. In the southern hills also, quartz veins bearing wolframite, tourmaline, muscovite, and graphite are being worked for their tungsten content. The veins dip steeply and are, for the most part, in lenticular masses from a few inches to two or three feet wide. The wolframite is intergrown with quartz in tabular masses. Many of the veins show a banding parallel with the walls.

GEOLOGY

General Features

Tungsten minerals occur in rocks from Pre-Cambrian[30] to Tertiary[29] age. They are found usually in quartz veins in granite; in contact-metamorphic deposits which are near or at the contact between a body of granular quartzose intrusive rock and other rocks, chiefly limestone, and also in pegmatite. As a rule, the vèins cut the igneous rocks, but they are also found penetrating adjacent sedimentary or metamorphic rocks.

According to Emmon[3], ferberite, wolframite, and hübnerite are probably everywhere primary. Tungsten and tungstic ocher are alteration products. Scheelite is primary in the main, butt some is secondary. The tungsten minerals are not very soluble in ground water and at many plaaers accumulate in placers, along with cassiterite and other minerals that are relatively stable in the oxidizing zone.

Although the tungsten minerals are very common in pegmatites and in lodes formed at considerable depths, the most valuable deposits in the United States are lodes formed by ascending hot waters at moderate or shallow depth.

Among rocks[27], granite, granitic gneiss such as slate, schist, quartzite, or crystalline limestone, and metamorphic rocks, are by far the most common associates of tungsten deposits.

The mineral associates of tungsten also are well defined and characteristic. It is commonly accompanied by one or more of the following: [27] quartz, muscovite, cassiterite, topaz, tourmaline, fluorite, beryl, biotite, bismubh, molybdenite, pyrite, arsenopyrite, chalcopyrite, galena, sphalerite, gold, silver and graphite. In the orebodies the tungsten minerals may occur finely disseminated and scattered through the gangue; irregularly distributed throughout the orebody or they may appear as crystals lining cavities. Many veins exhibit a banded structure with the tungsten minerals concentrated in definite layers, especially along the veinwalls.

Mineralogy

Tungsten never occurs in the native state. The known minerals of tungsten are as follows:

Commercial Importance of Tuhgsten Ore

1. Wolframite...Iron manganese tungstate (Fe, Mn) WO_4 (76,4% of WO_3).
2. Scheelite....Calcium tungstate ($CaWO_4$) (80.6% of WO_3).
3. Ferberite....Tungstate of iron and manganese ($Fe(Mn)WO_4$).
4. Hübnerite....Manganese tungsten oxide ($Mn(Fe)WO_4$) (76.6% of WO_3).

Non-commercial Importance of Tungsten Ore

5. Stolzite, lead tungstate ($PbWO_4$)
6. Raspite, lead tungstate ($PbWO_4$), differs from stolzite only in crystal form.
7. Cuprotungstite, hydrous copper tungstate ($CuWO_4 \cdot 2H_2O$)
8. Tungstite, hydrous tungsten trioxide ($WO_3 \cdot H_2O$). It is also known as tungsten ocher.
9. Ferritungstite, hydrous iron-tungsten oxide ($Fe_2O_3 \cdot WO_3 \cdot 6H_2O$).
10. Tungstenite (WS_2).

Wolframite;--This mineral is a frequent companion of tin ores, the cassiterite and the tungsten minerals having developed in much the same way. It is also often associated with quartz, native bismuth, scheelite, pyrite, galena, and sphalerite. Wolframite occurs in heavy dark-gray to black sub-metallic crystals, orthorhombic, and also in coarse divergent columnar and granular masses. It is a brittle mineral with an uneven fracture and submetallic luster, and is generally of dark brown to black in color. The streak is greenish gray to black; the hardness is 5.5; and the specific gravity is 7.5.

Scheelite;--The chief mineral of contact-metamorphic deposits is found with casiterite, topaz, fluorite, apatite, molybdenite, or worlframite in quartz, and associated with gold, Molybdenum is often present and may replace a considerable amount of the tungsten. Didymium, cerium, lanthanum, and tantalum may also be present.

Scheelite occurs in heavy brownish white or white masses square pyramids, and in crusts of yellowish or brown crystals. It is a brittle mineral, having a vitreous luster inclining to adamantine, and may be found in a variety of colors--white, pale yellow, yellowish white, brown, green, or red; it is sometimes almost orange-yellow. The streak is white; the hardness is 4.5-5.0 and the specific gravity is 5.9-6.1.

Ferberite;--This mineral is found usually in tabular and in crested aggregates and also in compact and granular masses. The streak is brown to black; the hardness is 5; the specific gravity is 7.5.

Hübnerite;--This mineral is found usually in bladed forms, rarely in distinct crystals. The color is brownish red to hair brown to nearly black, and the streak is greenish gray to yellowish brown; the hardness is 4.5 to 5.5; the specific gravity is 6.7 to 7.3.

The commercially important deposits of tungsten of the United States are almost wholly confined to the following six modes of occurrence: [27-7]

(1) Segregation deposits
(2) Pegmatite dikes
(3) Contact-metamorphic deposits
(4) Veins
(5) Replacement deposits
(6) Placers

Segregation Deposits

At some places igneous rocks, such as granite, contain a much larger proportion of certain minerals than at other places in the same body of rock, and such masses are known as segregations. Many of them contain the heavier minerals, among which may be tungsten minerals.[7]

Only one such occurrence of wolframite is known--a deposit in the Whetstone Mountains[8], Cochise County, Arizona, twelve miles south-southwest of Benson. Here wolframite, in small flat crystals, is distributed through a very pure potash granite in irregular masses that lie close to small, irregular gash quartz veins.[9]

Pegmatite Dikes[7]

When masses of molten (igneous) rocks, such as granite, diorite, and related rocks, are forced toward the surface of the earth, they cool and freeze. In cooling, the rocks shrink, new adjustments of position are made, and the mass is cracked. By the shrinkage of the mass, or by other forces, parts of the rock which are still molten, and which may contain large quantities of water, are forced up into the cracks, forming dikes.

A crust is formed that shrinks and cracks, and the pasty central mass if forced up into the cracks. In a general way, the minerals of the dikes resemble those of the surrounding rock mass. Thus most of the rocks that form dikes in the less siliceous rocks contain soda or lime feldspars. Part of the dikes are coarse, unevenly grained, and generally not homogeneous in composition, and these are known as permatites. Many permatites carry numerous rare minerals among which may be tungsten minerals.

Near Oreville and Hill City, South Dakota, wolframite is found in pegmatite. Scheelite has been found in pegmatite on the north side of Tunk Pond, near Cheeryfield, Maine.

Many quartz veins that carry tungsten minerals appear to be pegmatites from which most of the minerals have been precipitated at lower levels. Such are the veins at Hill City, South Dakota. On Irish Creek, Rockbridge County, Va., there is a deposit, generally called a vein, which shows some of the characteristics of a pegmatite. A vein system near Pony, Montana, that carries hubnerite grades into pegmatite.

So far no large production has been made in the United States from deposits that are essentially pegmatitic.

Minerals Found in Tungsten-bearing Pegmatites

The minerals of the pegmatities are ordinarily those of the parent rock mass. The commonest minerals are quartz, feldspar, and muscovite mica, and in the United States, tungsten occurs in dikes composed of these minerals, especially in dikes that contain quantities of quartz so large that the dikes approach quartz veins in composition. Some pegmatites, however, carry a great variety of minerals, many of them rare. The following list of minerals[7] found in the Etta dike, one and one-half miles south of Keystone, South Dakota, shows how many minerals may be contained in a complex pegmatite. The minerals indicated by capital letters occur in large quantity.

ALBITE
Andulusite
Apatite
Arsenopyrite
Autunite
Barite
BEREL
Biotite
Bismuth
Cassiterite
Chalcocite
Columbite
Corundum
Epidote
Graphite
Griphite
Grossularite
Heterosite
Ilmenite
Lepidolite
Lithiophilite
Lollingite

Melanite (andradite
MICROCLINE
Molybdenite
Monazite
MUSCOVITE
ORTHOCLASE
Petalite
QUARTZ
Rutile
Scheelite
Scorodite
Sphene
Spinel
SPODUMENE
Stannite
Struverite
Tourmaline
Triphylite
Triplite
Wolframite
Zircon

Wolframite is the tungsten mineral most commonly found in pegmatites. In many dikes it is accompanied by small quantities of scheelite, and in a few pegmatites scheelite is the only tungsten mineral present. Like cassiterite (tin-oxide), the tungsten minerals seem not to have crystallized in quantity in such rocks, until after most of the mica, feldspar, and other minerals crystalized even where they were in the solutions that accompanied the injected pegmatite.

Contact-Metamorphic Deposits[9]

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

Distribution: Most of the known contact-metamorphic tungsten deposits in the United States are in the Great Basin region in California and Nevada and northwestern Utah, but Oregon, Arizona, and New Mexico are known to contain one deposite each, and it is probable that other such deposits will be found in widely different parts of the county.

The distribution in the western United States of the known tungsten deposits of this type is shown on the map (see map of distribution). (The red dots indicate the contact-metamorphic tungsten deposits.) The chief producing districts are on the eastern slope of the Sierra Nevada near Bishop, California; in the Eugene Mountains near Mill City, Nevada; and in several ranges near Lovelocks, Nevada.

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

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

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

The Process of Contact-Metamorphism: The most pronounced changes of this type are ordinarily those which take place close to the contact of the invaded and the invading rock, and so the process is commonly called "contact-metamorphism". The metamorphism proceeds in zones, which show less noticeable alteration as they are farther removed from the contact or the channels along which the solutions move. The process is one of solution, the formation and deposition of new minerals, and the emigration of some old minerals, carried on by moving gases or liquids, the heat from the molten magma greatly increasing the solvent power of the solutions and consequently the interchange of minerals, and the degree of heat probably largely determining the kind of minerals deposited. The solutions naturally follow along cracks or other open spaces in the igneous rock, in the sediments, and between the two, and not uncommonly tabular or less regular bodies thus deposited extend along a certain bed of limestone or along a fracture that cuts across the beds for several hundred feet or even several thousand feet from the contact. Some deposits of the same character show no visibly close relation to any granitic body. At the same time the solutions may form veins and the metamorphism may spread from them.

The chief minerals of the contact-metamorphic scheelite deposits are different from those of most other mineral deposits, comprising the silicates garnet, diopside, epidote, vesuvianite, and hornblends. Quartz, calcite, and both potash and magnesian micas are common; and pyrite, chalcopyrite, pyrrhotite, molybdenite, sphalerite, magnetite, hematite, flurorite, zeolites, and a large number of other minerals are present in some deposits. It is noteworthy that in the many scheelite-bearing contact-metamorphic deposits examined[7] no boron minerals and, except in one, little original hematite or magnetite have been found.

Size and Form of the Deposits: The size and form of the contact-metamorphic deposits depend chiefly on the size and form of the sedimentary and intrusive bodies, the quantity and character of the solutions accompanying the intrusive, the fractures in both the sedimentary and the intrusive rock at the time of the metamorphism, the relative susceptibility of certain beds or bodies to metamorphism, and the structure of the sedimentary rocks. Owing to the presence of fractures, which afford channels for the emanations, the metamorphism is not uniformly distributed about the intnusive contact; large bodies of metamorphic rock may occur near one part of the contact, while only a few yards away there may be none. Likewise chunks of limestone may be wholly immersed in the intrusive mass and be only slightly metamorphosed.

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

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

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

In general, garnet was one of the first minerals to be deposited, diopside was in part contemporaneous with the garnet and in part a little later. Epidote was somewhat later. The sulphides were still later and are associated with quartz and calcite or with the decomposition of the diopside and epidote. Hornblende was formed later than the epidote and is in large part derived from the pyroxene. Quartz and calcite were deposited throughout the period of metamorphism and fill spaces around the garnet, diopside, and epidote and occur as veinlets cutting the other minerals. Scheelite was also deposited throughout except possibly in the latest stages of the metamorphism.

Veins[7]

Veins are relatively thin bodies that fill cracks in rocks and have been deposited from solution. Most of them are different from the rocks that form their walls. Such are the familiar quartz and calcite veins.

All the tungsten minerals have been found in veins and most tungsten deposits are of this form. The tungsten minerals are accompanied by a considerable variety of others, though as a rule not many of them occur in any one vein.

General Form of Veins

A tungsten vein may show all the vagaries of other veins. It may be a single veinlet of "knife-edge" thickness, or a single vein many feet wide, or it may consist of compound veins with many anastomosing (interlacing) veinlets of criss-crossing veins, some of them several inches wide, or it may consist of short "stepped" veins that form one series which is not yet continuous. It may swell or pinch to a stringer, or it may disappear entirely for a distance. The minerals in a vein are generally in shoots of more or less good ore alternating with barren parts.

Most tungsten veins have a quartz filling in which the tungsten minerals are embedded, but some, such as the thin veins in the Boulder field carry comparatively little quartz; most of the vein is ferberite. In the deposits at Atolia, California, also, there is comparatively little quartz; calcite carrying some iron is the principal gangue mineral.

Minerals

In known veins the following minerals are associated with tungsten minerals. The minerals are in general grouped after the plan of Dana's, "System of Mineralogy".

Native Elements

Bismuth--In this country bismuth is found in wolframite deposits in the Eureka district, forty-five miles west of Prescott, Arizona. Oxidized bismuth minerals are found with scheelite three miles north of the Dona Ana County line, thirty-seven miles west of Tularosa, New Mexico; in the Ruby Mountains, ten miles south-southwest of Ruby Valley post office, Elko County, Nevada; and with wolframite in the Hachita district near Gage, New Mexico.

Gold:--Gold is found in many tungsten-bearing veins, but seems to be associated with scheelite more commonly than with the worlframites. Gold is found with scheelite in the Uninn Hill and Empire mines at Grass Valley, California. At Randsburg, California, scheelite is found in many of the gold veins;

at Murray, Idaho, and Amalie, California, scheelite has been mined with gold-bearing galena and pyrite. At Leadville scheelite and less worlframite are found in a quartz-pyrite. vein carrying 0.8 ounce of gold and 0.5 ounce of silver to the short ton or ore. Gold is found in scheelite-bearing quartz veins in the Sheepeater district, near Jardine, Park County, Montana; near Baker City, Oregon; at Oracle, Arizona, where the veins are worked for both gold and scheelite; and in other places.

Graphite--Graphite is found in wolframite-bearing quartz veins on the May Day and Vida May claims near Hill City, South Dakota.

Sulphides, Arsenides, Antimonides, and Tellurides

Arsenopyrite (FeAsS)--It occurs with wolframite on Irish Creek, Rockbridge County, Virginia; in small quantity with the wolframite at Lead, South Dakota; and in the Etta dike at Keystone, South Dakota.

Chalcocite (Cu_2S)--It has been noted at Patterson in Blue Wing district, Lemhi County, Idaho, and with wolframite in Powers Gulch eighteen miles west of Globe, Arizona. At Butte, Montana, hübnerite is found in copper deposits that carry great quantities of chalcocite, and at Woody, California, a wolframite that is possibly ferberite is found in gold-bearing copper deposits that carry chalcocite.

Chalcopyrite ($CuFeS_2$)--It is generally found in many tungsten deposits.

Cosalite--(bismuth-lead sulphide)--It has been found in hübnerite deposits five or six miles northeast of Loon Lake, Steven County, Washington, in the S. E. ¼ section 16, T. 30N., R. 42 E.

Covellite--The copper sulphide, covellite (CuS) is found in the oxidized and in the enriched parts of deposits that carry chalcopyrite.

Galena--Galena, lead sulphide (PbS) is found with hübnerite at Silverton, Coloradp; in small quantity with hübnerite at Tungsten, twelve miles south of Osceola, Nevada, and on Patterson Creek, Idaho; and with wolframite near Pioche, Nevada, and Silvermine, Missouri. In the ferberite veins on the edges of the Boulder field in Colorado a little galena is found. It occurs with scheelite in the Golden Chest mine at Murray, Idaho and at Covada, Washington.

Molybdenite--Molybdenite, molybdenum sulphide (MoS_2) has been found with wolframite near Daisy, Washington, with ferberite at Cave Creek, Arizona, and with scheelite in the Deep Creek Mountains, Utah.

Pyrite--The yellow iron sulphide, pyrite (FeS_2), is common in veins formed at all depths and, as would be expected, it is found in most tungsten veins, though in many of them it occurs only in small quantity. Some deposits, such as the scheelite veins of Atolia, California, and the ferberite veins of Boulder County, Colorado, are remarkably free from pyrite. The scheelite from Leadville is accompanied by large crystals of pyrite formed in a vug, but pyrite usually occurs in irregular masses.

Silver Minerals--The form in which silver occurs in most tungsten-bearing veins is obscure. It is probably never native except in the oxidized or enriched parts of veins or where it is alloyed with gold, and in most deposits it is probably combined with sulphur or other elements. In deposits at Loon Lake, Washington, it occurs in cosalite; at Silvermine, Missouri, in argentiferous galena; and in the contact-metamorphic deposits near Hachita, New Mexico, as horn silver.

Sphalerite--The zinc sulphide, sphalerite (ZnS), is found in only a few tungsten-bearing veins in the United States, It is found in hubnerite veins at Patterson, Idaho.

Stibnite--Stibnite, antimony sulphide (Sb_2S_3), occurs with scheelite at places, but has rarely been found with the wolframites, At Atolia, California, a little wolframite vein an inch wide in the Clark Mountains, San Bernardino County, California, and in the Black Hills.

Sylvanite--Sylvanite, gold-silver telluride ($(Au,Ag)Te_2$), is found in some of the ferberite veins in the Boulder field, in Colorado, mostly around the outer edges of the field, where the gold veins and ferberite veins come together.

Tetrahedrite--Tetrahedrite is a mineral of varible chemical composition. In its simplest form it is a copper sulphantimonide ($Cu_8Sb_2S_7$). It is found with hübnerite at Patterson, Lemhi County, Idaho, and at Spanish Springs, seven miles southeast of Manhattan, Nevada.

Fluorides

Fluorite, or fluorspar, the calcium fluoride (CaF_2). Hubnerite is found with colorless fluorite at White Oaks, New Mexico, and Silverton, Colorado: with lavender-colored fluorite on the west side of the Desatova Mountains, and deep amethyst colored fluorite at the old mining camp of Ellsworth, in northwestern Nye County, Nevada. Fluorite is of common occurrence with the wolframites, but it is known to occur with scheelite at only one locality, the El Porvenir district, eighteen miles northwest of Las Vegas, New Mexico, where green, white, and amethystine fluorite is found with scheelite.

Oxides

Cassiterite--Tin oxide (SnO_2) accompanies tungsten at very few places in the United States, but wolframite and, to a less extent, scheelite are common in tin veins. Cassiterite is found with wolframite and arsenopyrite on Irish Creek, Rockbridge County, Virginia.

Chalcedony--Quartz that appears to be chalcedonic is found in many parts of the Boulder area, in Colorado, at Silverton, Colorado, and at Atolia, California.

Opal--Opal is a variety of quartz or silica that is combined with water. Opal mixed with chalcedony forms a thin coating on ferberite crystals from the Boulder tungsten field.

Quartz--Silica, silcon dioxide (SiO_2). Quartz is the universal vein mineral. Nearly all waters that deposit vein materials deposit quartz with them, and it forms the large part of most metalliferous veins. In tungsten veins the quartz is usually colorless or milky, but a vein near Loon Lake, Stevens County, Washington, carries some smoky quartz. In the veins of the tungsten area in the Boulder field much of the quartz resembles chalcedony and is of a greenish-gray color. In some tungsten-bearing veins the quartz was deposited at the same time as the tungsten minerals; in others it was deposited without tungsten minerals; these were next laid down and then another deposit of quartz; and in the Clark Mountains, California, this deposit was in turn succeeded by that of another tungsten mineral, scheelite.

Hematite--The iron oxide known as hematite (Fe_2O_3). Hematite occurs in tungsten veins in two principal forms--in scales or thin plates and in massive form. All hematites give a reddish-brown to cherry-red streak or powder, which distinguishes them from the wolframite, for which they are frequently mistaken. Specularite, hematite in scaly forms occurs in parts of the ferberite veins of the Boulder tungsten field and greatly resembles fine-grained ferberite.

Carbonates

Calcite, dolomite, ankerite, and siderite--Carbonates are common in tungsten veins and grade into one another by imperceptable stages so that it is impracticable to distinguish them except by chemical analyses.

Siderite, iron carbonate ($FeCO_3$), is so similar to calcite that the molecules crystallize together as ferruginous calcite ($(Ca,Fe)CO_3$), which may contain a rather large proportion of iron, yet the mineral may be clear white, as it is in the gnague of the largest veins of scheelite at Atolia, California, or gray, as it is in other veins of the same region.

No dolomite has been certainly recognized in the tungsten deposits but is reported to occur in them, and a number of analyses of scheelite show the presence of magnesium which, however, may be contained in ankerite, the calcium-iron-magnesium carbonate ($(Ca,Fe,Mg)CO_3$).

Silicates

Feldspars--Adularia, a potassium-aluminum silicate ($K_2O.Al_2O_3.6SiO_2$) It is found in the ferberite veins of the Boulder tungsten field, but invariably in small quantity, and it is of little or no importance.

Beryl--Beryl, a silicate of aluminum and the rare metal glucinum (commonly known as beryllium) ($3GIO.Al_2O_3.6SiO_2$). Nearly opaque buff beryl is found in a tin-tungsten vein on Irish Creek, Rockbridge,County, Virginia.

Chlorite--Chlorite is a name for a group of mica-like minerals which is found in a few tungsten-bearing veins but is not common in such veins in this country.

Muscovite--Muscovite is the ordinary white mica, a hydrous potasium-aluminum silicate ($2H_2O.K_2O.3Al_2O_3.6SiO_2$). It is found in many quartz-tungsten veins near Hill City, South Dakota.

Lepidolite--Lepidolite is a lithium-bearing mica, in general appearance much like muscovite, but it may be pink, red, lilac, lavender, or other colors. It is known in only one tungsten vein, that at Silvermine, Madison County, Missouri.

Topaz--Topaz is a mineral containing aluminum, oxygen, flurorine, and silicon ($AlF_2.AlSiO_4$). It is found in fibrous masses an inch or more thick in the veins on Tin Creek, Lost River, 110 miles northwest of Nome, Alaska.

Tourmaline--Tourmaline is a complex silicate of boron and aluminum with fluorine, iron, magnesium, solium, potassium, or lithium, and in some specimens with other elements. Black tourmaline is found with wolframite in veins on the Black Metal claims, a mile northeast of Hill City, South Dakota, and on the Black Horse claims near Daisy, Stevens County, Washington.

Phosphates

Apatite--Apatite is one of two general varieties, one containing fluorine, a calcium fluoride and phosphate, $CaF.Ca_4(PO_4)$, and one containing chlorine, a calcium chloride and phosphate, $CaCl.Ca_4(PO_4)_3$. Small light-green masses are found in the veins of Hill City, South Dakota. Small brownish-yellow prisms and white irregular masses are found in and with scheelite in the Clifton district, Deep Creek Mountains, Tooele County, Utah.

Hamlinite (?)--Practically all the ferberite ores of the Boulder tungsten field carry traces of phosphorus, which apparently come from a mineral found particularly in the highly siliceous ores, but only in microscopic particles. It is probably the phosphorus-bearing mineral of the Boulder field. It has not been found in other tungsten ores.

Triplite--Triplite ($3MnO.P_2O_5MnF_2$), a manganese phosphate and fluoride, occurs as a flesh-pink mineral in small quantity with hübnerite in the Regan district, Nevada.

Minerals Containing Columbium and Tantalum

In this country, tungsten minerals containing columbium and tantalum oxides have been reported as follows:

Hübnerite from Ouray County, Colo., Cb_2O_5 (?)	0.05%
Hübnerite from White Oakes, N. Mex., $(Cb,Ta_2)O_5$ (?)	Trace
Wolframite from Irish Creek, Va., $(Cb,Ta_2)O_5$, etc.	.96%
Wolframite from Pioche, Nev., $(Cb,Ta_2)O_5$	.82%
Wolframite from Cave Creek, Ariz., $(Cb,Ta)_2O_5$	2.20%
Ferberite from Boulder County, Colo.	Trace

Outcrops of Tungsten Veins

The outcrops of tungsten veins resemble those of other veins and their character depends on the geologic history of the country, the minerals of the veins, the composition of the country rock, and the climate.

In general tungsten veins (among which are not classed pegmatite dikes or contact-metamorphic deposits) fall into three classes: quartz veins, carbonates, and thin veins carrying comparatively little gangue.

Granitoid rocks[7] such as granite, granodiorite, and diorite, waste under weathering slowly but faster than quartz.

Some such rocks, however, weather rapidly, especially where they have been altered by vein forming solutions. Schists usually weather faster than dolomite and limestone much faster than quartz veins. Thus at Patterson, Lemhi County, Idaho, quartz veins carrying hübnerite project as much as thirty feet above the schist surface on one side.

Downward Extent of Tungsten Veins

According to Hess[7], at White Oaks, New Mexico, hubnerite has been found at a depth of 1,350 feet. In the Boulder field, Colorado, no ferberite ores have been found at a depth greater than 900 feet, but the question of depth can not be considered as settled for the field. At the East Union mine, Atolia, Cali fornia, the greatest quantity of ore was found on the eight level (about 800 feet deep along the vein and about 400 feet below the surface vertically) and the mine still yields good ore at a depth of 1,000 feet along the vein which is equivalent to a vertical depth of about 510 feet.

Lindgren, in writing of the ferberite veins of Boulder County, Colorado, puts them in a class wholly different from veins closely related to the pegmatites. He says:[22] (page 462)

"Although the filling of these veins is very different from that of the telluride veins at Eldora, there is unquestionably a strong resemblance between them as far as the structure of the vein and sericitization of the country rock are concerned, and this leads to the belief that the tungsten veins are also a product of comparatively recent thermal activity, and that they are deposited at only a moderate depth below the original surface.

Wolframite is found in pegmatite veins, in company with cassiterite and other minerals of rare kind. More commonly it is found in quartz-filled veins similar to the ordinary gold quartz deposits of California. The tungsten deposits of Boulder County differ from both of these types."

In writing of the ferberite deposite of Boulder County, Colorado, George says[6]: (page 85)

"The ore is distributed along the veins in bunches and pockets or rarely shoots, and up to the present nothing has occurred to suggest that the downward distribution is less regular than the lateral. In fact, a considerable number of the best ore bodies have had greater vertical than lateral dimensions."

According to Hess'[7] opinion, this statement applies also to the scheelite deposits at Atolia, California.

Hess[7] concludes in a general way that the depths that are reached by gold-bearing veins are indicated by the length of their outcrops, but tungsten deposits whose outcrops are comparatively small seem to reach relatively greater depth, especially those that have pegmatitic characteristics.

Replacement Deposits[7]

The rock in an area where veins traverse easily soluble rocks is commonly replaced by the vein matter, and the replacement may be so complete and extensive as to obliterate all trace of the original opening through which the solutions passed, and such bodies are naturaly called replacement deposits.

Certain rocks are rather easily dissolved in the solutions from which tungsten and other minerals are deposited, particularly rocks that are largely or wholly made up of carbonates, such as limestone, which is more or less pure calcite, calcium carbonate; dolomite, the magnesium-calcium carbonate; and siderite, the iron carbonate.

At Lead, South Dakota, wolframite was apparently brought from the depths by solutions that flowed through thin cracks known as "verticals" where the solutions reached a bed of dolomite they spread out through the rock replacing it and depositing wolframite and small quantities of scheelite, gold, silver, pyrite, and other minerals.

The scheelite deposit at Long Hill near Trumbull, Connecticut, is in a place of greatly metamorphised limeston, lying between gneisses which are highly metamorphosed diorite or tuffs, and contains replacement bodies now composed of quartz, ziosite, epidote, and other minerals with which is associated nearly white scheelite.

The wider scheelite veins at Atolia,[27] California, are replacement bodies for the crevices which existed when the veins were formed were probably rather narrow, and much of the fine-grained quartz found in both sets of veins has probably replaced granite or granodiorite.

Placer Deposits

The heavier and less abundant minerals in the rocks are the most resistant to dedomposition and when the weathered rock is eroded and sorted by water they usually become concentrated in the lower parts of the sand and gravel beds. This class of deposits, which form an important source of supply of metals, were called placers.[21]

Alluvium is transported in three different ways [33], by traction, suspension and solution. In so far as economic minerals are concerned, the last factor does not apply here. Traction is the most important mechanism from the present standpoint, and it includes every process or combination of processes whereby mineral particles or pebbles are carried downstream by rolling, sliding or jumping.

Generally speaking, tungsten placers yield heavy minerals which have seldom travelled very far and are probably less than a mile away from the sites of the nuggets found. The comparatively short distance of transport is not always due to retardation or obstruction of currents so much as to oscillating conditions which cause a forward and backward movement of the particles.

Wolframite, that valuable associate of tungstone, is quickly at the mercy of the abrasive forces of the current unless protected by quartz; it suffers from being comparatively soft, and is therefore lost at an early stage (eluvial). It is often, if not invariably, absent from placers where, from a knowledge of its occurrence at head-waters, it might reasonable be expected.

The first scheelite produced at Atolia, California[7], was float material picked up in the desert sands. Some scheelite has been dug from Baltic Gulch, between Atolia and Randsburg.

In Boulder County, Colorado, a large quantity of float ferberite has been dug from the dirt near the outcrops of the tungsten veins. Some of the residual pieces of scheelite found near Atolia have been large. The residual pieces found near Atolia are covered with caliche-calcium carbonate, much like a spring deposit. Most of the pieces found in the watercourses, even in the infrequently wet stream beds of the desert are clean, and many of the scheelite pebbles from the Nome placers are crumbly showing that they are gradually bein dissolved. In the Atolia district considerable tungsten concentrate (scheelite) was recovered along with gold. This is considered as one of the commercial importance of this type of deposits.

SUMMARY AND CONCLUSIONS

Distribution:

Most of the tungsten deposits of the United States occur only in the states that lie west of the Rocky Mountains--South Dakota, Montana, Colorado, New Mexico, Idaho, Utah, Arizona, Nevada, California, Oregon, and Washington.

A very little tungsten has been found in Maine, Connecticut, North Carolina, Missouri, and Virginia

The following distribution of four important tungsten ores are given below:

Scheelite: Fairbanks, Alaska; San Bernardino, Kern, Nevada, and Inyo Counties, California; Monroe and Trumbull, Connecticut; Cochise, Pinal and Santa Cruz Counties, Arizona; Jardine, Montana; White Pine and Humboldt Counties, Nevada; Tooele County, Utah; Murray and Shoehorn Counties, Idaho.

Ferberite: Boulder County, Colorado; Cave Creek, Arizona; Hill City, South Dakota.

Wolframite: Black Hills, South Dakota; Boulder County, Colorado; Monroe and Trumbull, Connecticut; Tip Top, Eurepa district, Whitstone Mountains, Arizona; Clark Mountains, California; Penasco, New Mexico; Cathedral Peak and Cedar Canyoh, Washington.

Hubnerite: Lemhi County, Idaho; White Pine County, Nevada; Arivaca, Pima County, Arizona; Ouray and San Juan Counties, Colorado; White Oakes, New Mexico.

Classification of Deposits:

All the tungsten ore of commercieal importance is found in the following types of deposits:

Commercial deposits:

1. Pyrometasomatic deposits. Chiefly in the Great Basin region: Northwestern Inyo County, California; Mill City, Nevada, etc.

2. Hypothermal deposits. Deer Trace district, Washington; Jardine district, Montana; Tungsten and Kern Mining district of eastern Nevada and in Arizona.

3. Mesothermal deposits: Boulder County, Colorado; Atolia Kern County, California, etc.

4. Epithermal deposits. Epithermal veins: San Juan Mountains, Colorado; epithermal replacement deposits: Black Hills, South Dakota.

Deposits of little commercial importance:

5. Placers

Non-commercial deposits:

6. Pegmatite

7. Magmatic segregation

Geology:

Tungsten minerals occur from pre-Cambrian to Tertiary.

Tungsten is found usually in quartz veins in granite; in contact-metamorphic deposits which are at or near the contact between a body of granular quartzose intrusive rock and other rocks, chiefly limestone, and also in pegmatite, often near and in contact with metamorphic rocks.

As a rule, the tungsten veins cut the igneous rocks, but they are also found penetrating adjacent sedimentary or metamorphic rocks.

As regards the deposition of tungsten minerals, ferberite-worframite, and hübnerite are probably everywhere primary. Tungsten and tungstic ocher are alteration products. Scheelite is primary in the main, but some is secondary.

The most valuable tungsten deposits in the United States are lodes formed by ascending hot waters at moderate or shallow depth.

Among rocks, granite, grantic gneiss, metamorphic rocks, such as slate, schist, quartzite, or crystalline limestone, are the most common associates of tungsten deposits.

The mineral associates of tungsten also are well defined and characteristic. It is commonly accompanied by one or more of the following: quartz, muscovite, cassiterite, topaz, tourmaline, fluorite, beryl, biotite, bismuth, molybdenite, pyrite, arsenopyrite, chalcopyrite, galena, sphalerite, gold, silver and graphite, etc.

Scheelite is usually found with quartz, cassiterite, fluorite, topaz, molybdenite, wolframite, and apatite, etc.

Ferberite occurs with quartz, hematite, limonite, molybdenite, pyrite, scheelite, wolframite, and sylvanite, etc.

Wolframite occurs with quartz, mica, fluorite, cassiterite, apatite, scheelite, molybdenite, hübnerite, ferberite, galena, and sphalerite, etc.

Hubnerite occurs in quartz veins with wolframite, fluorite, pyrite, scheelite, galena, tetrahedrite, and muscovite, etc.

Mineralogy:

Tungsten is never known to occur in the native state. The known minerals of tungsten are as follows:

Commercial important tungsten ores:

1. Wolframite
2. Scheelite
3. Ferberite
4. Hübnerite

Non-commercial important tungsten ores:

1. Stalzite
2. Raspite
3. Cuprotungstite
4. Tungstite
5. Ferritungstite

All the commercially important deposits of tungsten of the United States are almost wholly confined to the following six modes of occurrence:

1. Segregation deposits--Whetstone Mountains, Cochise County, Arizona.

2. Pegmatite dikes--No large production has been made in the United States from deposits that are essentially pegmatitic.

3. Contact-metamorphic deposits--Most of the known contact-metamorphic tungsten deposits in the United States are in the Great Basin region in California and Nevada and northwestern Utah, but Oregon, Arizona, and New Mexico are known to

contain one deposit each, and it is probably that other such deposits will be found in wisely different parts of the country.

The chief producing districts are on the eastern slope of the Sierra Nevada near Bishop, California; in the Eugene Mountains near Mill City, Nevada; and in several ranges near Lovelocks, Nevada.

4. Vein deposits--Boulder field, Colorado; White Oaks, New Mexico; East Union mine, Atolia, California, etc.

5. Replacement deposite--Lead, South Dakota; Long Hill near Trumbull, Connecticut; and the wider scheelite veins at Atolia, California, are replacement bodies.

6. Placer deposite--Atolia district, California.

Tungsten minerals are of widespread occurrence, but few deposits are rich enough to mine. The major tungsten deposits of the world are distributed in a great horseshoe about the Pacific.

In the United States, Colorado and California were formerly the major producers. Although tungsten minerals have been observed in the mines of the San Juan Mountains of Colorado, the most productive region of the state has been in Boulder County with its center in the neighborhood of Nederland, but extending into Gilpin County. Here, in an area approximately four miles in width and twelve miles in length, are located the richest ferberite deposits of the world. The United States is the only country where an important deposit of scheelite occurs. It is found at Atolia, Kern County, California. The principal California deposits extend from near Atolia in northern San Bernardina County to near Randsburg in eastern Kern County. Near Bishop, in Inyo County, lies a second very important area. First discovered in 1913, by midsummer of 1916, four hundred tons of ore were being milled daily. About 75% of the tungsten produced in United States prior to 1931 was taken from the vein deposits of above mentioned districts, and much of the remaining production is from scattered contact-metamorphic deposits.

The Boulder County veins have produced slightly more than one million units of WO_3, valued at approximately $19,000,000.

Atolia district in southern California is credited with a little more than half a million units of WO_3, valued at about $12,000,000.

Wolframite is mined at Lead, South Dakota, in the northern part of Black Hills. Deposits have been worked in the Dragoon Mountain, Cochise County at Oracle,Pinal County; and at Arivaca, Pima County, Arizona. Small amounts occur in Utah, Nevada, Missouri, and Washington.

Hübnerite is found at Lemhi County, Idaho; White Pine County, Nevada; Ouray and San Juan Counties, Colorado; White Oaks, New Mexico.

As regards the genesis of the tungsten minerals, they were formed under considerable pressure and at high temperatures. They were deposited by magmatic solutions most of which were rich in fluorine, for fluorite is a common gangue mineral. The tungsten minerals are genetically associated with granitic rocks. In a few places they are found in volcanic, sedimentary, or metamorphic formations, but ordinarily even these are not far from underlying granites. The form of the deposits varies widely. Thus, there are segregations, pegmatite dikes, contact-metamorphic deposits, vein deposits, replacements, and placers. Despite the normal occurrence in proximity to granites, there are large areas of such rock almost destitute of tungsten minerals. No important occurrences are known in the Eastern United States which is a region predominately granitic.

The ore bodies themselves are notoriously erratic, characterized by irregular swellings and pinchings, richly mineralized pockets frequently alternating with barren waste; sometimes of very limited extent both horizontally and vertically, yet again persisting over a considerable distance along the strike, and even to depths of one thousand to one thousand five hundred feet.

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