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ABSTRACT

The Red Rose mine was British Columbia's largest producer of tungsten during World War II.

Scheelite occurs in a shear-zone that cuts Mesozoic Coast Range intrusives and hornfelsed tuff within 750 feet of the Rocher Déboulé batholith.

The minerals include scheelite, some ferberite, and, in order of abundance: quartz, orthoclase, oligoclase, apatite, biotite, hornchlorite, ankeritic carbonate, blende, chalcopyrite, and molybdenite. Cobaltian arsenopyrite, pyrrhotite, chalcopyrite, quartz, and tourmaline occur in the shear beyond the scheelite.

The scheelite ore occurs in two shoots where the shear cuts a 400-foot diorite sill but is not found where the shear cuts hornfelsed tuff. The stress diagram of the vein-shear and related breaks shows that the two ore shoots pitch in the same direction as the pitch of the intersection of potential tension openings with the vein.

Spectro-chemical analyses of 28 specimens of wall-rock and nearby rocks and of 14 specimens of vein- and rock-minerals showed variations of the trace elements in groups in which the range in atomic radii was within the 15 per cent. limit allowed by Goldschmidt in his rule for isomorphism of elements. Tungsten was absent in all the rock analyses; apparently it did not wander as a trace element into the wall-rocks.

The lenticular form, coarse to pegmatitic texture, and mineralogy of the tungsten vein, imply formation at high pressure and temperature (the hypothermal class of veins). As a producing property,

the Red Rose is unique in a class of scheelite deposits that does not
ordinarily include commercial deposits of tungsten.

INTRODUCTION

The Red Rose mine is in northern British Columbia, 12 miles
in an air-line southerly from the town of Hazelton (Fig. 1). The work-
ings (Fig. 2), between elevations of 5,650 and 6,400 feet, are above
timberline on the western slopes of the Rocher Déboulé mountains. These
mountains are 50 miles northeast of the main Coast Range.

The property was staked in 1913 and the early work was done
on outcrops of the vein where it carried small amounts of copper, gold
and silver. These workings have been described by Kindle.[1] It was not

[1]Kindle, E.D., Mineral resources, Hazelton and Smithers areas, Cassiar
and Coast districts, B.C. Geol. Surv. of Canada, Mem. 223, p. 57, 1940.

until 1923 that scheelite was found in outcrops of the same vein 700
feet above the copper-gold-silver showings. However, little work was
done on these until the summer of 1940 when the Consolidated Mining and
Smelting Co., Ltd., drilled 12 diamond-drill holes, ranging from 70 to
250 feet in length, that cut the vein from 80 to 325 feet below the
outcrop. Shortly afterwards, this company started underground work,
built a 75-ton mill, and started milling in October 1942. Milling con-
tinued until November 1943, when the property was closed down because
of lack of markets and shortage of labor. During this period "600 tons
of high- (73.8 per cent.) and low- (14 per cent.) grade concentrates,
(344 tons of WO_3) were shipped, the average grade of the ore treated
being 1.64 per cent. WO_3"[2], making the mine the largest producer of

[2]Wilmot, V. Eardley, Tungsten in 1944, p. 2, in the Canadian Mineral Industry in 1944. Dept. of Mines and Resources, Ottawa, Canada, No. 815, 1945.

tungsten in the province during World War II.

The writer examined the property in 1939 and 1942 and in 1943 published a short report on it.[3] He examined it in greater detail in

[3]Stevenson, J.S., Tungsten deposits of British Columbia. B.C. Department of Mines, Bull. 10 (Revised), pp. 60-71, 1943.

1943, when the more extensive underground workings permitted better correlation of the surface and underground geology than had been possible on previous examinations.

GEOLOGY

The rocks on the property include hornfelsed tuff, andesite porphyry, diorite, feldspar porphyry and granodiorite. The distribution of these rocks is shown in Fig. 3. The geologic setting of the property in the Hazelton area is shown on the Hazelton Sheet, Preliminary Map 44-24 of the Geological Survey of Canada. On this map the intrusive rocks near the Red Rose are shown as Upper Cretaceous or later in age and the nearby intruded rocks as Upper Jurassic or Lower Cretaceous.

Hornfelsed tuff. - The hornfelsed tuff is a massive, very fine-grained rock that breaks with a sharp conchoidal fracture. It is dark brownish-grey in color, definitely brownish because of an abundance of fine biotite. The rock consists of 6- to 12-inch beds of massive, brown tuff separated by 1/8- to 1/4-inch partings of shaly, black argillaceous material. The finely laminated bedding characteristic of otherwise

massive tuff, may be seen only in well-weathered material where weathering has differentially etched the beds. Because of the severe action of snow and ice, and the frequency of rock slides, the outcrops on the hillside near the workings are of freshly broken rock and only slightly weathered. However, the writer did fine some material in old talus-slides sufficiently well-weathered to bring out the finely laminated bedding characteristic of tuff.

In the absence of banding either in outcrops or underground, the structure of the tuff was determined from the attitude of shaly partings intercalated between the more blocky tuff. In general these shaly partings strike N.N.E. and dip 45° - 60° N.W.

Under the microscope the hornfelsed tuff is seen to consist of unoriented flakes and clusters of biotite in a fine-grained mosaic of quartz and untwinned oligoclase. Small amounts of widely scattered sericite comprise the only alteration product. Tourmaline that is probably hydrothermal occurs in vein-like clusters of grains.

The original character of the rock near the workings has been entirely destroyed by recrystallization. However, about 1,500 feet from the workings, it grades into finely laminated, argillaceous rock that, because of the fineness and extreme angularity of the quartz grains, is though to be an argillaceous tuff. The recrystallized rock near the workings is therefore referred to as a hornfelsed tuff.

Andesite porphyry. - Andesite porphyry outcrops on the hillside northeast and southeast of the workings but it is not found underground. It occurs as tabular bodies conformable with the sediments, but because of folding between diorite sills, and variations in thickness of the bodies, the outcrops are very irregular in shape (Fig. 3).

Although flow structures have not been identified, a markedly por-
phyritic texture and the lack of any intrusive features, suggest that
the andesite porphyry is a flow-rock, interbedded with the hornfelsed
tuff.

The andesite porphyry is dark brownish-grey in color, massive
in structure and is strikingly porphyritic in texture. Under the micro-
scope it is seen to consist of andesine (Ab_{50}) phenocrysts, measuring
1 mm. by 0.8 mm., and a few, smaller, relict areas of light green horn-
blende phenocrysts, set in a fine-grained ground-mass of andesine and
biotite. The plagioclase laths in the ground-mass range from 0.7 mm.
by 0.2 mm. to 0.1 mm. to 0.03 mm.; the biotite is of a similar size and
occurs as scattered flakes or clusters that are pseudomorphic after
hornblende cyrstals. A small amount of hornblende is still present in
much of the biotite. The accessory minerals are quartz and apatite
and the secondary minerals, sericite and leucoxene. The mode of a
typical specimen of andesite porphyry is given in Table 1, column 1.

TABLE 1. - MODAL ANALYSES OF ROCKS

	1	2	3	4
	percent	percent	percent	percent
Quartz	8	3	5.4	20
Orthoclase	-	-	-	19
Plagioclase	46	60	74.5	47
Apatite	-	0.4	-	trace
Biotite	42	12	-	3
Hornblende	3	24	19.1	9
Ilmenite-Magnetite	-	1.6	1.8	2

1. Andesite porphyry; phenocrysts 62 per cent. and groundmass 38 per cent.
2. Diorite.
3. Feldspar porphyry dyke; phenocrysts 40 per cent. and groundmass 17 per cent.
4. Granodiorite.

Diorite. - Diorite is found in two large sills, an upper and lower (Fig..3) which strike N 30° - 45° E and dip 50° - 60° N.W. Although the upper sill outcrops over widths which range from 300 to 500 feet, it has a true width of only about 275 feet. The narrower, lower sill, has a true width of about 175 feet. The upper sill is important because the tungsten ore-body has been found only in this sill and neither in the adjacent hornfelsed tuff nor in the lower sill.

The diorite is massive in structure, greenish grey in color and possesses a fine, even-grained texture. Under the microscope it is seen to consist of clusters of brown biotite and green hornblende

in a felted mass of andesine laths. The plagioclase crystals range in size from 0.07 mm. by 0.3 mm. to 0.7 mm. by 2 mm.; the hornblende crystals are uniformly about 0.4 by 0.6 mm. and the biotite crystals usually 0.1 mm. by 0.05 mm. The plagioclase is andesine of composition Ab_{55}. The hornblende has alpha index 1.644 and gamma index 1.673, an extinction angle against Z of 20°; and a 2 V of 72° (as measured on a Universal Stage). It is therefore termed "ordinary hornblende". The biotite has a gamma index 1.667.

The accessory minerals include quartz, apatite, zircon, sphene and iron oxides. Zircon is found surrounded by pleochroic halos in the biotite and usually only remnants are present, but occasionally whole, perfectly-shaped crystals are found. The secondary minerals include leucoxene, sericite and carbonate.

The mode of typical material is shown in Table 1, column 2 and a chemical analysis and calculated norm are given in column 1 of Tables 2 and 3. Mineralogically and chemically the rock is a typical diorite, very similar to diorites found elsewhere in the western Cordillera.

Feldspar porphyry. - Several dikes of light colored feldspar porphyry, ranging from 1 foot to 50 feet thick, are found both underground and on the surface. The feldspar porphyry is a massive, light grey rock consisting of feldspar phenocrysts set in a medium-grained, grey ground-mass. This rock lacks the greenish color and the even-grained texture of the diorite and although porphyritic, lacks the contrasting fine-grained ground-mass and dark brownish-color of the andesite porphyry.

Under the microscope the feldspar porphyry is seen to consist of feldspar phenocrysts, from 2 mm. by 1 mm. to 5 mm. by 1 mm. set in a medium grained ground-mass of plagioclase, the grain size of which

ranges from 0.1 mm. to 0.6 mm. Both the phenocryst plagioclase and the ground-mass plagioclase are andesine of composition Ab_{60}. In addition to andesine, small amounts of quartz, green hornblende, biotite with included zircon, iron oxides, sphene and leucoxene are found in the ground-mass. Hydrothermal apatite is found as blebs and short veinlets in the feldspar porphyry where cut by the tungsten vein. The mode of typical material is shown in Table 1, column 3.

Granodiorite. - A large area of granodiorite is found on the mountain side east of the workings where it forms part of a larger area that extends for about 2 miles farther east. Granodiorite is also found northwest across Armagosa Creek beyond the area mapped by the writer. The granodiorite body east of the workings appears to plunge 25° - 50° W. towards the body across Armagosa Creek, and it is probable that this body connects with that across Armagosa Creek at no great depth below the Red Rose workings.

The granodiorite is a massive, medium-grained rock, light grey in color and speckled with glistening black biotite and hornblende. Under the microscope it is seen to be hypidiomorphic in texture and to consist mainly of quartz, andesine (Ab_{65}), orthoclase, hornblende and biotite. Accessory minerals include apatite, zircon, titanite and iron oxides. Secondary constituents include leucoxene, sericite and carbonate. The general grain size of the rock ranges from 0.5 mm. to 1.0 mm.

The mode of typical material is given in Table 1, column 4 and a chemical analysis and calculated norm are given in column 2 of Tables 2 and 3. The rock would be called a biotite-bearing hornblende-grano-

diorite, according to Johannsen[4] or simply a granodiorite, according to

[4]Johannsen, Albert, A descriptive petrography of the igneous rocks.
Univ. of Chicago Press, Vol. I, p. 149, 1932.

Lindgren[5]. The chemical analyses and norms of granodiorite from Calif-

[5]Lindgren, W., Granodiorite and other intermediate rocks. Am. Jour.
Sc. 4th Series, Vol. 9, p. 279, 1900.

fornia, south-eastern Alaska and Nevada are also given in Tables 2 and
3 for comparison. The similarity of the Red Rose granodiorite with
other Cordilleran granodiorites is very striking, and indicates the
widespread occurrence of this type of rock in the western Cordillera.
The similarity of the Red Rose granodiorite to the granodiorite (column
5, Table 2) associated with the contact metamorphic scheelite deposits
of Mill City, Nevada is in support of Kerr's observation[6] that grano-

[6]Kerr, P.F., Tungsten mineralization in the United States. Geol. Soc.,
Am., Mem. 15, p. 23, 1946.

diorite and granite are the two types of intrusives most commonly
associated with tungsten mineralization.

Table 2--Chemical analyses of diorite and granodiorite; Red Rose
granodiorite compared with Alaska and California grano-
diorites. (Modes of Red Rose diorite and granodiorite
are given in Table 1)

	1	2	3	4	5
SiO_2	53.74	64.58	63.85	64.87	64.18
Al_2O_3	17.65	15.74	15.84	16.26	17.02
Fe_2O_3	0.27	1.67	1.91	1.51	0.79
FeO	6.98	2.43	2.75	2.89	2.43
MgO	4.69	1.97	2.07	1.72	1.69
CaO	8.18	4.48	4.76	4.72	4.32
Na_2O	3.69	3.73	3.29	3.62	3.87
K_2O	1.66	2.81	3.08	3.30	2.84
H_2O (-105°)	0.11	0.10	.28	0.00	0.03
H_2O (+105°)	1.12	1.49	1.65	0.28	0.85
TiO_2	1.25	0.57	.58	0.70	0.53
P_2O_5	0.33	0.20	.13	0.19	0.08
MnO	0.096	0.056	.07	–	0.06
BaO	0.09	0.10	.06	–	0.15
CO_2	–	–	–	–	0.21
SO_3	–	–	–	–	0.91

1. Diorite, Red Rose. G.C.B. Cave, analyst.
2. Granodiorite, Red Rose. G.C.B. Cave, analyst.
3. Granodiorite, Grass Valley, California, W.F. Hillebrand, analyst.
   Lindgren, W., Granodiorite and other intermediate rocks. Am.
   Jour. Sc., 4th Series, Vol. 9, p. 273, 1900. Norm as calculated
   by Washington, H.S., Chemical analyses of igneous rocks. U.S.G.S.,
   Prof. Paper 99, p. 361, 1917.
4. Granodiorite, core of Coast Range Batholith. J.G. Fairchild,
   analyst. Buddington, A.F., Coast range intrusives of south-
   eastern Alaska. Jour. Geol., Vol. 35, p. 245, 1927.
5. Granodiorite, Mill City, Nevada. F.A. Gonyer, analyst. Kerr,
   P.F., Tungsten mineralization in the United States. Geol. Soc.
   Am., Mem. 15, p. 24, 1946.

Table 3--Norms calculated from analyses in Table 2

Normative minerals	1	2	3	4	5
Quartz	2.58	20.46	19.44	16.98	18.78
Orthoclase	10.01	16.68	18.35	19.46	16.68
Albite	30.92	31.44	27.77	32.49	33.01
Anorthite	26.69	17.79	19.18	17.24	19.46
Diopside	10.95	3.15	2.94		-
Hypersthene	16.86	5.63	6.54	9.53	6.44
Olivine	-	-	-		-
Titanite	-	-	-	1.78	-
Ilmenite	2.28	1.06	1.06	-	0.91
Magnetite	0.46	2.55	2.76	2.09	1.16
Apatite	0.34	0.34	0.34	0.45	0.34

Column numbers refer to same rocks and references as in Table 2

Spessartite dike. - The youngest rock seen is a spessartite

dike, a strike N.W. and dip 65° S.W., and from a few inches to 2 feet

underground
wide, that is found ˄towards the south-eastern end of the 200, 300 and

600 levels. The dike cuts across the vein at a small angle, but does

a
not noticeably displace it. The rock consists of ˄felted mass of

basaltic hornblende and andesine, with a little chlorite and epidote.

Thermal metamorphism. - Thermal metamorphism by the nearby

granodiorite has produced mineralogical and textural changes in the

intruded rocks, particularly in the hornfelsed tuff, for a distance up

to 2,000 feet from the granodiorite.

The diorite and andesite porphyry contain very little primary

hornblende; most of it has recrystallized to new hornblende or has

altered to biotite. Recrystallization of the large crystals of primary

hornblende to smaller crystals of new hornblende takes place outwards

from fractures in the original crystal, and eventually results in a

pseudomorph that consists of a felted mass of small hornblende crystals.

In addition to pseudomorphic replacement, some of the hornblende has

migrated in solution from the original crystal and recrystallized as

small crystals of hornblende either between crystals of plagioclase

or along fractures within individual crystals of plagioclase.

Secondary biotite after hornblende is found in the thermally

metamorphosed rocks where it is always inversely proportioned to the

hornblende. Some biotite has formed as rims around relict crystals

of primary hornblende and some has formed as clusters of flakes

pseudomorphic after the small crystals of secondary hornblende. Some

has migrated in solution from the site of the hornblende crystals and

recrystallized as flakes widely scattered through the rock. In this process biotite is dispersed from the larger clusters first as trailers of small crystals, some of which may rim or cut nearby plagioclase crystals, and then as widely scattered small clusters or single, un-oriented flakes that in places impart a decussate texture to the rock.

In the hornfelsed tuff the original felsic and ferromagnesian minerals have recrystallized to a mosaic or quartz, untwinned plagio-clase and biotite flakes.

The hornfels texture which is so marked in the hornfelsed tuff and is spottily developed in other rocks older than the grano-diorite, suggests recrystallization at elevated temperatures in a stress-free environment. This metamorphism appears to have been caused by the heat of the granodiorite intrusion.

Structure. - The hornfelsed tuff, andesite porphyry and diorite sills strike N.E. and in general dip N.W. However, this simple structure is complicated by a drag-fold in the andesite porphyry and hornfelsed tuff between the two diorite sills. This is shown in the structure section along the line A-A' in Fig. 3 and in Fig. 4.

SCHEELITE VEIN

The main tungsten mineral is scheelite, found in a vein that occupies a shear-zone, strike N. 30° W. and dip 60° S.W. The scheelite ore-body (Fig. 4) extends for about 500 feet along the strike of the vein and is known to extend for 580 feet down the dip, but the lower limit of the ore has not been reached by the present workings. A new low-level cross-cut, the 800 cross-cut, was being driven in August 1942,

160 feet below the lowest drift, to give approximately 190 feet more depth on the vein, but the results of this work are not known to the writer.

Form. - The scheelite vein is markedly lenticular, widening from a few inches to several feet in less than 25 feet of drift-length. Although a maximum width of 16 feet has been noted, a range from 3 feet to 6 feet is more common.

Texture. - The vein is massive and lacks banding or crustification. In places it has a slightly schistose appearance caused by unreplaced wisps of biotite that follow the plane of the vein. Some of the vein-matter consists of a coarse-grained intergrowth of minerals that, because of the development of large crystals, results in a pegmatitic texture. The pegmatitic material is found as small lenses, up to 3 feet long by 2 feet thick on the walls of, and within the vein. The contacts between the pegmatitic material and the wall-rock are gradational and irregular, typical of replacement. The pegmatitic material seeps into the biotized wall-rock and first isolates small slabs of wall-rock and then finally replaces them completely.

Besides pegmatitic material much of the vein consists of fine-grained, sugary quartz, from 0.03 mm. to 0.3 mm. in grain size, that has replaced much of the earlier, pegmatitic vein-matter and nearly all the other vein-minerals.

Mineralogy. - The ore-minerals include scheelite and ferberite and the gangue minerals include in order of abundance: quartz, orthoclase, plagioclase, apatite, biotite, hornblende, chlorite, ankeritic carbonate, chalcopyrite and molybdenite.

Scheelite is the main ore-mineral. It occurs as well-shaped crystals up to ½ inch by 1 inch, in the spaces between the ends of quartz crystals in pegmatitic quartz and as smaller remnants of partly replaced crystals in orthoclase and the fine-grained quartz, (Figs. 6, 7 and 8). It is therefore later than the pegmatitic quartz and earlier than the fine-grained quartz. In thin-section the scheelite is seen to contain unreplaced patches of ferberite and is therefore younger. Scheelite in many deposits is usually older than any associated ferberite, but Tweto[7] in the Red Rose vein is younger and has also described scheelite that is younger than

[7]Tweto, O., Scheelite in the Boulder district, Colorado. Econ. Geol. 42, p. 49, 1947.

ferberite.

Ferberite is not an abundant mineral in the vein and most of that seen was with pegmatitic quartz. Some of it is well-crystallized, in crystals up to ¼ inch by ½ inch, but much of it is moulded around the ends of quartz crystals and wedged between quartz and scheelite. Some occurs as remnant islands in scheelite crystals. The ferberite is therefore younger than the pegmatitic quartz but older than the scheelite. Chemically, the ferberite is very low in manganese, an analysis of typical material yielding only 0.2 per cent manganese.

Quartz in the pegmatitic lenses occurs as large, water-clear crystals up to 2 inches in length, surrounded by minerals of later formation. The fine-grained, sugary quartz is massive, without crystal outlines, and in thin-section is seen to consist of anhedral grains filling the interstices between earlier formed minerals. One quarter-inch stringers of quartz cut the two main types of vein-quartz and probably formed during the latest stage of mineralization.

The feldspars include abundant orthoclase and some oligo-
clase. The orthoclase is very coarse-grained and crystals up to
½ inch by 1 inch are common. It contains fine stringers and blebs
of albite and is therefore perthite. It is later than the crystalline
quartz as some of it is moulded around the ends of quartz crystals,
but it is earlier than the fine-grained quartz, as it is cut by hair-
like stringers of fine-grained quartz (Fig. 9) and occurs as unre-
placed islands in the quartz. The orthoclase is also cut by stringers
of biotite, and in places, large crystals of it are embayed and surrounded
by a felted mass of biotite flakes (Fig. 10). Oligoclase occurs with
orthoclase, but it is much finer-grained, the crystals being rarely
more than 1/16 inch in size. Indices indicate a composition between
Ab_{80} and Ab_{85}. The age relations of the plagioclase to the ortho-
clase are unknown.

Apatite occurs in small clusters of grains commonly associated
with scheelite. It is veined by and therefore earlier than the fine-
grained quartz (Fig. 11) and also appears to be earlier than the feld-
spars.

Biotite is found as thick patches of fine, black flakes
wrapping around and embaying crystals of earlier formed minerals
(Figs. 9 and 12). It is commonly seen as unreplaced wisps in fine-grained
quartz. The wisps of biotite are parallel to the plane of the vein
and where abundant, they impart a schistose texture to the vein-matter.
Some of the biotite may be an alteration product from hornblende but
where very abundant and in parts of the vein entirely free from horn-
blende it has probably formed by direct precipitation from vein-solutions.

The vein-hornblende occurs in patches of euhedral cyrstals,
some as large as ½ inch by 1 inch. The indices of the hornblende are,
$\alpha = 1.644$ and $\gamma = 1.673$, and the extinction angle is 20 degrees; and,

although hydrothermal, it is optically and therefore probably chemically similar to the magmatic hornblende found in the diorite and andesite porphyry.

Rosettes and irregular clusters of chlorite, showing anomalous interference colors, were seen in a few sections of the vein-minerals. The chlorite did not replace hornblende and biotite and appears to have been precipitated as chlorite directly from the vein-solutions.

Ankeritic carbonate in small amounts occurs as veinlets cutting many of the vein-minerals.

Sulphides are rare in the ore. Short stringers of chalcopyrite follow the cleavages of some of the hornblende crystals and scattered clusters of grains are found elsewhere in the same crystals. Similar stringers are found occasionally in the orthoclase crystals. Larger blebs of chalcopyrite up to 1 inch in diameter have been found in the vuggy quartz. Molybdenite is present but very scarce; it occurs as thin stringers in the quartz.

The paragenesis of the minerals in the scheelite ore-body is; pegmatitic quartz, hornblende, ferberite, scheelite, apatite, perthite, oligoclase, biotite, chlorite, ankeritic carbonate and fine-grained quartz. The position of the small amount of chalcopyrite and molybdenite in the mineral sequence is uncertain.

Sulphides, rare in the ore, are found in veins up to 6 inches thick elsewhere along the vein-shear and in branch veins. These veins consist of cobaltian arsenopyrite, pyrrhotite, and chalcopyrite in a gangue of quartz or occasionally of quartz with tourmaline, but never with any scheelite. The cobaltian arsenopyrite contains about 4 per cent. cobalt. The sulphide veins have not been found cutting the main scheelite vein and are thought to be earlier than the scheelite vein.

Oxidation. - Oxidation of the vein-minerals has not been
pronounced. In the vein-outcrop a small amount of the scheelite has
altered to a canary-yellow oxidation-product, probably tungstite, which
occurs as a dust-film coating quartz crystals, and where protected
from surface erosion, occurs as small, 0.5 mm. tabular crystals.
The total amount of tungstite present is very small, probably because
most of it has been carried away by the violent rains, snow and ice
characteristic of the mountain slopes at the attitude of the vein-
outcrops. Ferberite from the surface is always oxidized to earthy,
limonitic masses that frequently possess a cellular or lattice-work
texture. It is apparent that the tungsten of the ferberite was
carried away by the ground water and the iron left as limonitic
material with a lattice-work texture. Underground, oxidation has
occurred only where chalcopyrite is found. Limonite replaces chal-
copyrite and any nearby iron-bearing vein-minerals such as biotite
and ankeritic carbonate. Very little oxidation occurred more than
300 feet below the surface.

WALL-ROCK ALTERATION

Metasomatic action by vein-solutions on the adjacent wall-rock
has been intense in all the rock types except the rather refractory
hornfels. Biotization, sericitization and silicification have been
the dominant types of wall-rock alteration.

At several places along the vein, biotiz/ation of the diorite,
the principal wall-rock of the scheelite ore-body, has been complete
for widths up to one foot from the vein. The biotized rock consists
of a mass of coarse biotite crystals arranged with a flow-like orientation
developed under the influence of stresses present near the vein-shear.
Some biotite has migrated from the vein along joints in the diorite
for several tens of feet from the vein-shear and is found in sharp-
edged veinlets 1/16 in. to ¼ in. thick in the diorite. The amount of
biotite in the completely biotized diorite and even in the diorite cut
by biotite veinlets is far in excess of the amount that would form by
the alteration of the rock-hornblende during thermal metamorphism of
the diorite. It is therefore most probable that much of the biotite
has been contributed by vein-solutions and its formation is the result
of wall-rock alteration by these solutions. In many places, the diorite
is cut by veinlets of green hornblende, also contributed by vein-
solutions from the main vein-shear, and therefore hydrothermal.

Sericitization by vein-solutions has been strong for about
50 feet from the vein-shear, but beyond this distance, its effects have
been very weak. The plagioclase in rocks near the shear has been
completely altered to closely-packed sericite that forms bundles
pseudomorphic after plagioclase crystals, whereas plagioclase in the
same rocks at some distance from the shear is entirely free from sericite.

Silicification of the wall-rock is found at several places along the vein. Where intense it has produced a rock that consists of a mosaic of unstrained, anhedral quartz grains, which, with biotite, produces a typical hornfels texture. This silicified rock differs from the hornfelsed tuff, which is not visibly affected by silicification, only in having a larger grain size. Where silicification has been slight, it has added only a few widely scattered, anhedral grains of quartz to the rocks.

Small blebs and short gashes of hydrothermal apatite are found in the diorite near the vein. This apatite is in addition to the magmatic apatite common as small grains throughout the diorite.

The hornfelsed tuff is the only rock in which marked textural and mineralogical changes have not been brought about by the vein-solutions. However, chemical analyses (Table 4) show a marked increase in the soda content of hornfelsed tuff as the vein is approached. Analyses of argillaceous tuff 500 feet from the vein-shear showed a soda content of 2.35 per cent, hornfelsed tuff 150 feet from the vein showed a soda content of 4.3 per cent whereas analyses of material adjacent to the vein showed a soda content of 7.34 per cent. As blebs or veinlets of albite are not apparent in either hand specimens or thin-sections of the high-soda rock, the increase in soda-content as the vein is reached must be attributed to an increase in the content of albite molecule of the oligoclase of the hornfelsed tuff. Analyses of hornfelsed tuff at the contact of the granodiorite do not show any increase in soda and it is most probable that the albitization described above is a hydrothermal alteration directly related to vein solutions.

TABLE 4. — PARTIAL ANALYSES OF TUFF TO SHOW ALBITIZATION BY VEIN-SOLUTIONS

G.C.B. Cave, Analyst

	1	2	3	4
SiO_2	61.0	58.9	60.0	67.6
CaO	1.3	2.9	2.3	3.4
K_2O	3.81	4.30	2.99	2.1
Na_2O	2.35	4.30	7.34	3.68

1. Argillaceous tuff, 500 feet from vein-shear.

2. Hornfelsed tuff, 150 feet from vein-shear.

3. Hornfelsed tuff, adjacent to vein-shear.

4. Hornfelsed tuff at immediate contact with granodiorite.

STRUCTURAL ANALYSIS OF VEIN-SHEAR AND BRANCH SHEARS

Direction of movement along the vein-shear. - The scheelite ore-body occupies a shear that strikes N. 30° W. and dips 60° S.W. The shear is a normal fault in which the hanging-wall has moved down 50 feet and about 150 feet southeasterly with respect to the footwall. The amount and direction of movement were determined by offsets of rock-contacts and by the direction of fluting or grooves in the vein-quartz. Well-defined grooves are very noticeable in an outcrop of vein-quartz above the 200 level, where the grooves are seen to pitch to the south at an angle of 35 degrees from the horizontal.

Branch shears. - Several breaks, some mineralized and some unmineralized, branch from the vein-shear, some into the hanging and

some into the footwall. On the 600 level, two breaks in the foot-wall strike southerly, and dip 68° W. toward the footwall. These con-tain quartz, pyrrhotite and cobaltian arsenopyrite. A shear in the hanging-wall outcrops 500 feet east of the ore-body, strikes N. 10° E. and dips 45° N.W. towards the hanging-wall. On the 300 and 600 levels a strong, and unmineralized shear in the hanging-wall strikes N. 6° W. and dips 55° S.W. towards the hanging-wall. These breaks are shown in Fig. 5 in a cross-section perpendicular to their common line of intersection.

Fracture-pattern. - The elements of the fracture-pattern include the vein-shear, the branch shears from it, and the plane of potential tension openings within the vein-shear as ~~shown~~ given by a plane perpendicular to the relative direction of movement of the vein-walls.

The line of intersection of the vein-shear, branch-shears and plane of potential tension openings within the vein plunges about 45° N.W. For the sake of simplicity, the precise direction of plunge, N. 65° W. at 45°, of the vein-shear and potential tension openings, is used in the following discussion. A plane perpendicular to this line strikes N. 65° E. and dips 45° S.E. Because of the several orientations of these different planes, they can only be represented in true cross-section on a plane perpendicular to their common line of intersection. This has been done in Fig. 5.

Stress-diagram. - A stress-diagram similar to that constructed by McKinstry[8], but based on the fracture-pattern of Fig. 4 has been

[8]McKinstry, H.E., Structural control of ore deposition in fissure veins. Trans. A.I.M.E. T.P. 1267, 23 pp., 1941.

drawn in the lower right-hand corner of Fig. 4. In this type of diagram
the traces of the four planes of maximum stress "on the plane of the
paper are as a figure resembling a cross superimposed on an X, the
plane of maximum normal stress being indicated by the tail of an arrow
without implication as to whether it represents maximum tension or
compression."[9] It is impossible to assign directions to the external

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[9] Op. cit. pp. 3-4.

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force because any one of the four possible types of external force,
compression, tension, and two directions of shear-couples, will pro-
duce identical orientation of the resultant planes of maximum stress
(McKinstry, Fig. 2).[10]

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[10] Op. cit. p. 3.

The diagram indicates that during the structural history of
the vein the shears that formed followed only one major direction of
shearing, the direction followed by the vein-shear and its branch-
shears. The directions followed by the pyrrhotite-arsenopyrite and the
arsenopyrite veins do not correspond exactly to the direction of the
vein-shear but the deviations may be because they are wholly in horn-
felsed tuff beyond the uniform diorite. It is possible that in passing
from diorite to hornfelsed tuff the stress conditions changed sufficiently
to account for the deviation from the theoretical direction as defined
by the main vein-shear. No reason is evident for the deviation of
the unmineralized shear.

Although no tension-breaks paralleling the direction of
maximum compression have been formed, they are implied, or potential,
in a plane perpendicular to the relative direction of movement of
the vein-walls, and their direction is shown as a dashed line in the

fracture-pattern of Fig. 4.

LOCALIZATION OF ORE

<u>Localization of the ore-body by diorite sill.</u> - Although
the vein-shear cuts several rock types, the scheelite ore-body is
found only where the shear cuts the upper diorite sill (Fig. 4). The
quartz vein is continuous where the shear is in diorite, but loses
its continuity where the shear leaves the diorite for hornfelsed tuff
or andesite porphyry, and quartz occurs in the vein-shear only as
a few, thick, disconnected lenses entirely lacking in scheelite.
Sulphide veins, not found with the scheelite ore-body, are common in
the vein-shear where it is not in diorite, but they lack scheelite.

The vein-shear is decidedly weaker outside the diorite.
In the hornfelsed tuff the break is less clean-cut and consists of only
a few narrow shears that die out and come in along the general plane
of the break. Although the vein-shear does not perceptibly change in
dip and strike in going from one rock to another, the deviation in
attitude though small, may have been sufficient to permit the formation
of openings along the vein-shear during pre-vein movements, openings
sufficient to receive the large amount of vein-matter that accompanied
and was part of the scheelite mineralization.

<u>Localization of high-grade ore-shoots.</u> - Two high-grade
ore-shoots separated by a lean section are found in the vein. The
lean section is 50 to 80 feet long and extends from near the surface
to the lowest drift as of the summer of 1942. In general, the pitch
of the ore-shoots is to the northwest although for a short distance above
and below the 500-foot level it is vertical.

This northwesterly pitch of the high-grade shoots is also the pitch of the potential tension openings within the vein as seen in the fracture pattern and stress diagram of Fig. 4. Although no actual tension breaks have formed, zones of tension pitching north-westerly in the plane of the vein-shear may have developed sufficiently to permit localization of high-grade ore within them.

Origin

Source of vein-solutions. - A large area of granodiorite lies only a few hundred east of the scheelite ore-body (Fig. 3) and another large area lies several hundred feet northwest of the ore-body. The contact of the easterly mass dips westward under the scheelite outcrop towards the northwest area and it is probable that the two masses connect at no great depth beneath the vein-outcrop. The plane of the vein-shear approximately parallels the southwestern slopes of this body of granodiorite and it is therefore unlikely that the vein-solutions came immediately from the granodiorite. However, as the vein is close to the granodiorite, and as the minerals are definitely of a high tem-perature assemblage of minerals, it is likely that the source was in the same magma chamber from which the granodiorite differentiated and which probably lay close to the vein. A similarity in optical properties and therefore in chemical composition of the hornblende found in the vein and the hornblende found in the diorite suggests that the diorite may also have come from the same magma-chamber as the vein-solutions and the granodiorite.

Nature of vein-solutions. - The nature of the vein-solutions is indicated by the wall-rock alteration, mineralogy of the vein and

paragenesis of the vein-minerals. The diorite wall-rock next to the vein has been silicified and biotized and the plagioclase largely sericitized. The sericitization of the diorite plagioclase shows that by the time the solutions reached the diorite in their passage upwards from the source-magma, they were alkaline[11] rather than acid. Develop-

[11]Lindgren, Waldemar, Mineral Deposits. McGraw Hill, p. 457, 1933.

ment work on the vein was not deep enough to determine whether an ar- gillized zone of alteration, such as described by Lovering[12], lay be-

[12]Lovering, T.S., Tungsten deposits of Boulder County, Colorado. Econ. Geol., 36, p. 236, 1941.

neath the sericitic zone of alteration and therefore to determine whether the solutions changed from acid to alkaline on their way up from the source magma or whether, as suggested by Tweto[13] in connection with

[13]Tweto, Ogden, op. cit. p. 53.

scheelite in Colorado, the solutions were alkaline when they left the magma, the change from acid to alkaline having taken place before the solutions left the magma.

Lovering[14] notes that a strong base such as calcium, is

[14]Lovering, T.S., Tungsten deposits of Boulder County, Colorado. Econ. Geol., 36, pp. 269-271, 1941.

necessary for the precipitation of scheelite from an alkaline solution. The silicification and sericitization of the diorite, a high-calcium rock (8.18% calcium oxide, see Table 2, column 1) and the early de- position of scheelite and closely related apatite, suggest that the necessary calcium was obtained by reaction of the vein-solutions with

the diorite wall-rock. The later plagioclase in the ore-body may represent the precipitation of excess calcium obtained in this manner. The paucity of calcium in the hornfels (1.3 to 2.3 per cent. calcium oxide, see Table 4, columns 1 to 3) and therefore the absence of a precipitating agent for the scheelite, apatite and plagioclase may be the chemical factor contributing to the total absence of those minerals in vein-quartz where the vein-shear cuts hornfelsed tuff.

Table 5.—<u>Analyses of rock- and vein-minerals</u>.

Sequence of elements according to Soddy's helical arrangement of the periodic system,
Figures refer to spectral line densities.

	Sr	Ba	Se	Yt	La	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	W	Cu	Ag	Mn	Ni	Co
Granodiorite hornblende	1	1+	5	2	1	3	3	5+	1	3	2+	4	3	2	-	4+	18	5	1	2
Vein Hornblende	1.5	4	3	2.5	-	2	2.5	2	1	.5	?	5	2	1	-	4+	6	4	5+	5.5
Granodiorite biotite	1	1+	1	-	-	-	tr	1	tr	2	4+	2	4	1+	-	3+	2	5	2	2
Vein biotite	.5	1+	.5	1	1.5	1	2.5	1.5	tr	.5	4+	3+	1.5	1+	-	5+	1.5	4	4+	3
Granodiorite plagioclase	1	1+	-	-	-	-	tr	tr	28	5+	2	tr	-	1	-	5+	5+	-	tr	5+
Vein plagioclase	1+	1+	-	-	-	-	tr	-	-	tr	3	tr	-	tr	-	5+	1	1	tr	1
Granodiorite orthoclase	1	2	-	-	-	-	tr	1	3	5+	1	1	-	1	-	4+	5+	1	tr	5+
Vein orthoclase	4+	4	-	-	-	-	tr	-	-	1	?	-	-		-	tr	-	tr	-	1
Ferberite	-	1.5	-	13.5	-	9	tr	1	2	*	-	-	-	*	5	2+	1.5	3	-	tr
Scheelite	4	-	-	-	-	-	-	-	1	*	-	-	-	*	3	1+	-	-	-	tr
Quartz	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-

SYMBOLS:
- Metal not detected.
* Tungsten line interferes.

NOTE:
Not completely confirmed but probably present: P, Ge, Mo, Nd, Ce.
Sb and Bi found only in granodiorite plagioclase.
No As detected; traces of B in some samples.

Table 6.--Analyses of hornfelsed tuff, according to distance from granodiorite.

	Sr	Ba	B	Sc	Yt	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	Cu	Ag	Mn	Co	Ni
25 ft. from granodiorite (700 ft. from vein)	4+	4+	2	3.5	1	1	3	3	tr	1	?	5	-	3.5	4.5	2	4.5	1.5	4
1030 ft. from granodiorite (150 ft. from vein)	4	4+	3+	2.5	1	1	2.5	2.5	tr	.5	4	4.5	.5	3.5	3.5	2	2	2.5	3.5
1120 ft. from granodiorite (Footwall of vein)	4	4+	1	2.5	tr	tr	1.5	2	tr	1	3	3.5	-	4	4	1	1.5	tr	1
1250 ft. from granodiorite (Hanging-wall of vein)	5	5	2	3.5	.5	tr?	1.5	1.5	2.5	.5	3.5	4	1	3.5	5	3	1	1	2.5
1400 ft. from granodiorite (180 ft. from vein)	4	4+	.5	3	1	tr	2	3	-	1	3	3.5	2.5	3	3.5	1	3	1	2
1700 ft. from granodiorite (550 ft. from vein)	4+	4+	5+	3	tr	tr	2	2.5	tr	1	?	3.5	.5	3	1	1	2.5	1	2
Average	4.1+	4.1+	2.2	3.0	.6	.3	2.1	2.4	.4	1	2.2	4	.6	3.4	3.6	1.3	2.4	1.1	2.5

Symbols as in Table 5.

NOTE:
    La, As, Sb, Bi, W not detected in any of the samples.

Table 7.--Analyses of diorite, upper and lower sills.

	Sr	Ba	B	Sc	Yt	Yb	Ti	Zr	Sn	Pb	Ga	V	Zn	Cr	Cu	Ag	Mn	Co	Ni
1	3.5	2	-	-	4	3.5	tr	-	-	3	-	2	-	tr	5+	1.5	4.5	3.5	4+
2	4+	4+	tr	1	1	tr	3	3.5	tr	1	5	2	-	tr	5+	3	2	4	3
3	2	2.5	tr	1	1	1	3	3	1	tr	4	4.5	.5	2.5	4	-	3	5	2.5
4	4+	4+	tr	3	1	1	4.5	4	tr	.5	3	5	1.5	2	4	1.5	5	2.5	2
5	4.5	4.5	tr	3	1?	tr	3	3	tr	1	3.5	4	1	3	4	3.5	4	tr	1
6	4+	4+	tr	3	1.5	2	3	4	.5	1	4	5	-	3.5	4	2.5	5	3	2
7	4.1	4.1	tr	3	1.2	1.5	3.5	3.6	.2	.8	3.5	4.6	.8	2.8	4	2.5	3.6	1.8	1.6
8	4+	4+	1	1.5	tr	tr	2.5	2.5	tr	1	3+	5	4.5	1	3	2	5	2.5	1
9	4+	4+	tr	1.5	1	1	3.5	3	tr	1	4+	5	-	3	4	2	3.5	1.5	2
10	4+	4+	tr	3	1	1	3	3	tr	1	3	5	1	4	3	4	4.5	2	2
11	4+	4+	.3	2	.6	.6	3	2.8	tr	1	3.3+	5	1.8	2.6	3.3	2.6	4.3	2	1.6
12	4+	4+	.2	2.5	.9	1	3.2	3.2	.1	.9	3.4+	4.8	1.3	2.7	3.6	2.5	3.9	1.9	1.6

Symbols as in Table 5.

1. Silicified diorite, foot-wall of vein-shear
2. Biotized diorite; biotite: hornblende = 100:0; hanging-wall of vein-shear
3. Biotized diorite; biotite: hornblende = 78:22; hanging-wall of vein-shear ⟩ Upper sill
4. Biotized diorite; biotite: hornblende = 36:64; 250 feet from vein
5. Biotized diorite; biotite: hornblende = 18:82; 50 feet from vein
6. Biotized diorite; biotite: hornblende = <10:90; 300 feet from vein
7. Average of 4, 5, and 6
8. Diorite 10 feet from vein
9. Diorite 100 feet from vein ⟩ Lower sill
10. Diorite 200 feet from vein
11. Average of 8, 9, and 10
12. Average of 7 and 11, i.e. average of the two diorite sills
La found only in 1

Sb, Bi, W not detected, for other notes see Table 6