

RED ROSE MINEUNDERGROUND DIAMOND DRILL HOLE LOGS

Logged by R. G. McEachern

Note: - The division of the diorite into three separate types was established during the study of the underground cores. Therefore logs made earlier in the study did not originally show the division. Later the logs were rewritten and division made on the basis of the rock descriptions with only a very limited recheck of the core. Therefore inconsistencies may exist in the diorite divisions in these logs, particularly those of holes U2, U3, U4, and U5.

Hole U1

Footage		Description
From	To	
0	- 5	No core "casing"
5	- 131	S.E.Di. - Distinctly porphyritic in first 40' then variably mottled to near end, where it is even textured similar to M.Di.
131	- 140	F. P. Dyke
<u>END</u>		

Hole U2

0	- 53	Sed. - Bi rich
53	- 56.5	Di. Dyke
56.5	- 58.5	Sed. -
58.5	- 60	Di. Dyke
60	- 135.5	Sed. - Bi rich, bleached along fractures
135.5	- 184.5	N.W. Di.
184.5	- 186	Sed. - dark gray, little Bi.
186	- 269	M. Di. - some variations similar to N. W. Di., could be dykes of latter?
259	- 261	rusty, shattered, some hornblendization, shear?
269	- 286.5	F.P. Dyke - considerable core lost, no apparent reason.
286.5	- 291	V. Dyke
291	- 294	F.P. Dyke - most of core lost
294	- 319	M. Di.
<u>END</u>		

Hole U3

0	- 53.5	Sed. - Bi rich, altered, bleached.
53.5	- 58	Di. Dyke
58	- 123	Sed. - only moderate amount of Bi.
123	- 175	N. W. Di.
175	- 209	Box of core missing
209	- 301	M. Di - very uniform texture, variable biotite replacement of hornblende. Increasing hornblendization over last few feet to a completely hornblende rock at end.
301	- 306	Vein - quartz with chalcopyrite, molybdenite and scheelite. Relatively unaltered Di. 303-4

Hole U3 - Cont'd

Footage		Description
From	To	
306	- 311	V. Dyke
311	-312	Vein as 306
312	- 316	Vein quartz with considerable hornblende - largely replaced Di.?
316	- 324	Core mixed and most lost. Vein qtz, hornblendite, and F.P. Dyke.
324	- 335	F.P. Dyke
<u>END</u>		

Hole U4

0	- 5	No core - "Casing"
5	- 181	Sed. - Bi rich in most. Considerable fracturing and associated bleaching in last part.
181	- 203	Much shattered and considerable core lost. Probably N.W. Di. but could be altered Sed.?
203	- 218	N.W. Di.
218	- 221	Di. Pegmatite Dyke. Uniform, moderately coarse textured rock of dioritic composition similar in appearance to more uniform parts of N.W. Di. However, is present here and in several other places as a definite dyke. Not fine grained at contacts, hence considerable pegmatitic.
221	- 277	M. Di.
277	-279	Dyke - dark greenish gray, now largely chloritized.
279	- 428	M. Di.
428	- 430.5	Di. Pegmatite Dyke.
430.5	- 435	M. Di.
435	- 438.5	Dyke - dark, fine grained.
438.5	-466.5	M. Di.
466.5	- 491	Sed. - Bi. rich, much bleaching and alteration associated with fractures³ Associated with fractures.
491	- 492	V. Dyke
492	- 495	Sed.,
495	- 496	Quartz Vein - barren. Core broken just beyond vein - shear ?
496	- 514	F.P. Dyke.
514	-522	Sed. - sheared, altered.
522	- 530	F.P. Dyke.
530	- 540	Sed. - Bi. rich
540	- 544	Di. Dyke - similar to M. Di.
544	- 546	Sed. - relatively little Bi. in much of it. Several small F.P. dykes
665	- 674	Di. Pegmatite dyke
674	- 716	Sed. Bi. and bleaching locally. Several small Di. Pegmatite dykes

END

RED ROSE MINE

UNDERGROUND DIAMOND DRILL HOLE LOGS

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Hole U5 ✓

<u>Footage</u>		<u>Description</u>
<u>From</u>	<u>To</u>	
0	- 287	No core - plugged
227	- 285	M. Di.
285	- 287	Dyke - dark, fine grained.
287	- 359.5	M. Di.
359.5	- 360.5	Dyke, - dark, fine grained.
360.5	- 362	Shattered zone - fault
362	- 420.5	M. Di.
420.5	- 445	Sed.
445	- 505	M. Di. 502-502 Dyke - very similar to V. Dyke
505	- 510	Sed.
510	- 522	Di. Dyke - similar to N.W. Di.
522	- 538	F.P. Dyke
538	- 547	4' core lost - remainder fragments of sed. & F.P. Dyke
547	- 559	F.P. Dyke
559	- 779	Sed. Bi rich at beginning, but remainder gray colored with little or no B ₂ . Several small Di. Pegmatite Dykes and two small F.P. Dykes
779	- 786	F.P. Dyke

ENDHole U6

0	- 11	S.E. Di.
11	- 36	Sed. - Bi rich
36	- 46	S.E. Di.
46	- 80.5	Sed. Bi rich
80.5	- 85?	Sed. largely hornblendized with pyrite and a little chalcopyrite. Rusty and fractured some core lost.
85?	- 90	Sed. - Bi rich

ENDHole U7

0	- 26.5	S.E. Di
26.5	- 74	Sed. Bi rich

ENDHole U8

0	- 94	S.E. Di.
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ENDHole U9

0	- 61	S.E. Di.
61	- 74	Massive pyrite and Chalcopyrite replacement in sheared Di. Diorite largely hornblendized.
74	- 103	S. E. Di.

END

Hole U10

Footage		Description
From	To	
0	- 193	N.W. Di. variable. Fracture zone in places, but nothing to suggest presence of strong shear or fault.

ENDHole U11

0	- 34.5	M. Di.
34.5	- 38	M. Di and Sed. irregular contact
38	- 54	Sed. - Bi rich. Core much broken in last 5'
54	- 77	F.P. Dyke
77	- 91	Sed. - relatively little Bi. or alteration.
91	- 97	Dyke - variety of F.P.
97	- 155	Sed. from 148 to end shattered zone

Still drilling.

R. G. McE/rcb/ehb
 Prince Rupert Office/Red Rose Mine Office
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¹Presented at the annual meeting, Geological Society of America, Chicago, Ill., December 27, 1946. Published by permission of the Chief Mining Engineer, B.C. Department of Mines.

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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, horn-chlorite, *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 workings (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

¹Kindle, 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 continued 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

²Wilmot, V. Bardley, 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

³Stevenson, 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 find 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 thought 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. 4). 3

Although flow structures have not been identified, a markedly porphyritic 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 microscope 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 hornblende 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 crystals. 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. ³4) 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 (present) writer. The granodiorite body east of the workings appears to plunge $25^{\circ} - 50^{\circ}$ 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 Johannsen⁴ or simply a granodiorite, according to

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

Lindgren⁵. The chemical analyses and norms of granodiorite from Calif-

⁵Lindgren, 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 observation⁶ that grano-

⁶Kerr, 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 granodiorites. (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 ₂ O ₃	17.65	15.74	15.84	16.26	17.02
Fe ₂ O 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 ₂ O	3.69	3.73	3.29	3.82	3.87
K ₂ O	1.66	2.81	3.08	3.30	2.84
H ₂ O (-105°)	0.11	0.10	.28	0.00	0.03
H ₂ O (+105°)	1.12	1.49	1.65	0.28	0.85
TiO ₂	1.25	0.57	.58	0.70	0.53
P ₂ O ₅	0.33	0.20	.13	0.19	0.08
MnO	0.096	0.056	.07	-	0.06
BaO	0.09	0.10	.06	-	0.13
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, U.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 southeastern 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	9.53	-
Hypersthene	16.86	5.63	6.54		6.44
Olivine	-	-	-		-
Titanite	-	-	-	1.78	-
Ilmenite	2.28	1.06	1.06	-	0.91
Magnetite	0.46	2.55	2.78	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 in a spessartite dike, a strike N.W. and dip 65° S.W., and from a few inches to 2 feet wide, that is found ^{underground} towards the south-eastern end of the 200, 300 and 600 levels. The dike cuts across the vein at a small angle, but does not noticeably displace it. The rock consists of ^a felted mass of basaltic hornblende and andesine, with a little chlorite and epidote. 5/ a/

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 of quartz, untwinned plagioclase and biotite flakes.

The hornfels texture which is so marked in the hornfelsed tuff and is spottily developed in other rocks older than the granodiorite, 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 $\frac{1}{2}$ 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. ^{in many deposits} Scheelite is usually older than any associated ferberite, ^{in the Red Rose vein is younger and} but Tweto⁷ has also described scheelite that is younger than

⁷Tweto, 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 $\frac{1}{4}$ inch by $\frac{1}{8}$ 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, and 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 oligoclase. The orthoclase is very coarse-grained and crystals up to $\frac{1}{2}$ 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 unreplaced 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 $\frac{1}{16}$ inch in size. Indices indicate a composition between Ab_{80} and Ab_{85} . The age relations of the plagioclase to the orthoclase 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 feldspars.

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 hornblende it has probably formed by direct precipitation from vein-solutions.

The vein-hornblende occurs in patches of euhedral crystals, some as large as $\frac{1}{2}$ 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.

were 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 *i/* 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 chalcopyrite 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, biotization 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 1/2 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 ₂ O	3.81	4.30	2.99	2.1
Na ₂ O	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 footwall strike southerly, and dip 68° W. toward the footwall. These contain 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. 3 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 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. 3.

Stress-diagram. - A stress-diagram similar to that constructed by McKinstry⁸, but based on the fracture-pattern of Fig. 3 has been

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

#5

drawn in the lower right-hand corner of Fig. 5. 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

⁹Op. cit. pp. 3-4.

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

¹⁰Op. 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 hornfelsed 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. ⁴5.

LOCALIZATION OF ORE

Localization of the ore-body by diorite sill. - Although the vein-shear cuts several rock types, the scheelite ore-body is found only where the shear cuts the upper diorite sill (Fig. 5). 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.

Localization of high-grade ore-shoots. - 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. ⁵ 7. Although no ~~4~~ actual tension breaks have formed, zones of tension pitching northwesterly 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. 2) and ³ 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 temperature 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 alkaline¹¹ rather than acid. Develop-

¹¹Lindgren, Waldemar, Mineral Deposits. McGraw Hill, p. 457, 1953.

ment work on the vein was not deep enough to determine whether an argillized zone of alteration, such as described by Lovering¹², lay be-

¹²Lovering, 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 Tweto¹³ in connection with

¹³Tweto, 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.

Lovering¹⁴ notes that a strong base such as calcium, is

¹⁴Lovering, 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 deposition 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.

SPECTROCHEMICAL ANALYSES OF MINERALS AND ROCKS

The tungsten vein contains several minerals that are found also as rock-forming minerals. An especially good opportunity therefore existed to study the variations of minor elements in two groups of minerals that originated from the same magma but which separated during different stages in the differentiation of the magma, the rock minerals early, during the magmatic stage, and the vein minerals later, during the hydrothermal stage. Spectro-chemical analyses were made of carefully cleaned samples of hornblende, biotite, plagioclase, and orthoclase, one group of minerals from the vein and one group from the nearby granodiorite; analyses were also made of wolframite, scheelite and quartz from the vein. The spectro-chemical analyses of minerals are given in Table 5.

Spectro-chemical analyses were also made of 28 samples of rock (see Tables 6-8) to study the variation of the minor elements in the different types of wall-rocks, and, as no tungsten minerals had been found by megascopic or microscopic study in the wall-rocks, to determine whether or not elemental tungsten had become trapped as a minor element in the crystal lattices of minerals, either hydrothermal or magmatic, in the wall-rocks. However, no tungsten was found in any of the wall-rock samples within the limit of spectro-chemical detection by the method used, so that not more than 0.02 % tungsten could be present.

The distribution of minor elements as given in Tables 5-8 agrees in general with that to be expected from the early studies of Goldschmidt¹⁵, who concluded that the distribu-

¹⁵ Goldschmidt, V.M., The principles of distribution of chemical elements in minerals. Jour. Chem. Soc., London, Pt. I, pp. 660-662, 1937.

tion of minor elements in rocks and minerals is mainly the result of isomorphous replacement of major elements by minor elements with closely similar ionic radii and the same or larger ionic charges or valence.

The variation of the minor elements in the mafic and felsic minerals, and in the different types of igneous rocks were similar in kind to those found by Bray¹⁶, in his studies

¹⁶ Bray, J.M., Spectroscopic distribution of minor elements in igneous rocks from Jamestown, Colorado. Bull. Geol. Soc. Am., Vol. 53, pp. 765-814, 1942.

¹⁷ ----- Distribution of minor chemical elements in Tertiary dike rocks of the Front Range, Colorado. Am. Min., Vol. 27, pp. 425-440, 1942.

of igneous rocks in Colorado, and to those found by Shimer¹⁸ in his

¹⁸ Shimer, J.A., Spectrographic analysis of New England granites and pegmatites. Bull. Geol. Soc. Am., Vol. 54, pp. 1049-1066, 1943.

study of New England granites and pegmatites.

The spectre-chemical analyses were made by the Chief Analyst of the Department of Mines on an A.R.L. Dietert spectrograph using an aluminized grating with a dispersion in the first order of seven Angströms per mm.; only the ultra-violet spectra

were obtained. "Super-pure" grade graphite electrodes, one-quarter inch diameter, were used, operating on ⁹/10 ampere- 220 volt direct-current source. Each analysis was run in duplicate and a satisfactory check obtained. The results are given in Tables 5-8, and the figure for each element is the average of the two checks.

The figures for the spectro-chemical analyses are semi-quantitative. The relative concentrations of any one element are expressed numerically by figures which are approximately proportional to the spectral line densities, which in turn are functions of the metal present. A plus sign (+) after a figure in the tables indicates a spectral line density that may be any value above that figure. The figures may be used in comparing the concentration of a single element but may not be used in comparing the concentrations of the different elements with each other.

MINERALS

Elements detected.- The minor element content of the minerals is given in Table 5. The following elements, both minor and essential, were detected in one or more samples: Na, K, Mg, Ca, Sr, Ba, B, Al, Sc, Yt, La, Yb, Si, Ti, Zr, Sn, Pb, Ga, V, Zn, Cr, W, Cu, Ag, Mn, Ni, Co, Fe. Table 5 does not include Na, K, Mg, Ca, Al, Si, and Fe, because these elements are major constituents of the hornblendes, biotites and feldspars, and are not found in the tungsten minerals, and therefore were of no value in comparative studies. The other elements detected were used in comparison studies.

Comparison of mineral species.- In comparing the variation in total number of minor elements it may be seen from Table 5 that the hornblendes and biotites contain some of all the 19 minor elements listed in the table, whereas the feldspars and the tungsten minerals contain only 12 or less of these 19 minor elements. In explanation of a variation in number of minor elements, Bray¹⁹ has shown that biotite and hornblende permit

¹⁹ Bray, J.M., Bull. Geol. Soc. Am., p. 782.

substitution for a greater number of major elements than the feldspars, and may therefore contain a greater number of minor elements.

There does not seem to be any correlation between the amount or variety of minor elements in the minerals of Table 5 and the packing index²⁰ of the minerals. All the minerals in

²⁰ Fairbairn, H.W., ~~Packing in ionic minerals.~~ Bull. Geol. Soc. Am., Vol. 54, pp. 1305-1374, 1943.

this table have a relatively high packing index²¹, and compared

²¹ Fairbairn, H.W., *idem.*, pp. 1317-1319.

to minerals with a much lower packing index, would tend to be relatively free from minor elements, but compared to each other, the variation in index may not be sufficient to account for the variation in minor element content.

In comparing the kinds of minor elements found in the different minerals it may be seen from Table 5 that the hornblendes and biotites are high in the minor elements of relatively small ionic radii, such as V^{3+} (0.75Å); Ni^{2+} (0.78Å);

²² V^{3+} (0.75Å); ionic charge and ionic radius respectively for vanadium, data from Wyckoff, R.W., The structure of crystals. Reinhold; pp. 192-193, 1931; and Stillwell, C.W., Crystal chemistry. McGraw-Hill; pp. 417-419, 1938.

Co^{2+} (0.82Å); Zn^{2+} (0.83Å); Sc^{3+} (0.83Å); Zr^{4+} (0.87Å); Mn^{2+} (0.91Å). These elements, because of the same or larger ionic charge and similar ionic radii, can proxy for the major elements Fe^{3+} (0.67Å); Mg^{2+} (0.78Å) and Fe^{2+} (0.83Å). The feldspars and scheelite are lacking or low in minor elements of small ionic radii because the major elements of these minerals, Na^{+} (0.98Å); Ca^{2+} (1.06) and K^{+} (1.33Å) have relatively large ionic radii and are therefore replaceable only by the minor elements of large ionic radii, such as Sr^{2+} (1.27Å) and Ba^{2+} (1.43Å). Ferberite is relatively low in minor elements although its two major constituents Fe^{2+} (0.83Å) and W^{6+} (0.65Å) possess small ionic radii, but this may be due to the relatively high ionic charge, 6+, of tungsten, and the consequent resistance to replacement offered by tungsten to minor elements of lower ionic charge.

²³ Goldschmidt, V.M., op. cit., p. 661.

Comparison of vein-minerals with rock-minerals.-

The vein-minerals have as great a variety of minor elements as the rock-minerals, but they have a lesser amount of each of ^{ten} ~~the~~ elements, Sc, Zr, Sr, Pb, Ga, Zn, Cr, Ag, Mn, and Ni, and a larger

amount of only six elements, Sr, Yt, La, Ti, V, and Ni. This indicates a greater purity for the vein-minerals in respect of amount of minor elements. In explanation of this Bray²⁴ reports

²⁴ Bray, J.M., Bull. Geol. Soc. Am., p. 783.

Buerger as suggesting that in minerals which are genetically related to the same parent source, the minerals formed at higher temperatures, such as rock minerals, are more tolerant to minor elements than the minerals formed at lower temperatures, such as the vein-minerals.

Comparison of early vein-minerals with late vein-minerals.- If the vein-minerals are compared on the basis of their paragenesis, which is, from oldest to youngest, hornblende and biotite, plagioclase, orthoclase, ferberite, and scheelite, it is seen from Table 5 that, with the exception of wolframite, not only the number of minor elements, but also the amounts of minor elements, are less in the minerals of later formation. The number of minor elements in the minerals, in order of age from oldest to youngest is: hornblende and biotite 19, plagioclase 12, orthoclase 7, ferberite 10, and scheelite 4. The more ordered and intolerant structures of later minerals formed at lower temperatures may, as suggested by Buerger, explain the relative "purity" of the later minerals.

Rocks

The minor element content of the rocks is shown in Tables 6-8. The variation in minor element content of all the rocks has been studied in relation to the distance from the vein-shear and for the hornfelsed tuff, also in relation to distance from the granodiorite, the heat from the intrusion of which appears to be responsible for the thermal metamorphism of the hornfelsed tuff.

No tungsten was found in any of the rocks either distant from or close to the vein-shear. Although of relatively small ionic radius, tungsten apparently possesses too high an ionic charge ($6+$) to enter into the crystal lattices of any of the magmatic or hydrothermal minerals.

Hornfelsed tuff.- The hornfelsed tuff shows no mineralogical changes as the vein is reached, and correspondingly shows no change in minor element content in that direction. However, towards the granodiorite it shows a slight increase in biotite and shows a corresponding increase in the following minor elements (Table 6); Ga³⁺(0.62Å); Tl³⁺(0.64Å); Cu¹⁺(0.96Å); V⁵⁺(0.75Å); Ni²⁺(0.78Å); Mn²⁺(0.91Å) and Ag¹⁺(0.97Å). Excepting Ag, these are elements with relatively small ionic radii which were seen in Table 5 to occur commonly as minor elements in the biotite, and their increase toward the granodiorite would correspond to an increase in biotite content in that direction. The hornfelsed tuff contains more boron than the other rocks. This is due to occasional veinlets and scattered blebs of tourmaline crystals found only in the hornfelsed tuff.

Diorite.- The silicified diorite contains less V, Ga, Ti, Cr, Zn, Zr, Sr, and Ba than the biotized diorite. This may be explained by the absence in the silicified diorite of biotite, hornblende and feldspars, minerals which were found (Table 5) to contain these minor elements. In comparing the biotized diorite with the unaltered diorite it is found to contain larger amounts of Sn, Pb, Ga, Cu and Ni and lesser amounts of Sr, Ba, Ti, Zr, V, Zn, Cr, Ag, and Mn than the unaltered rock. This change implies that the biotization of the diorite

involves not only the recrystallization of the hornblende but also the addition and subtraction of material represented by additions and subtractions of minor elements to the rock as a whole, and it is most probable that this material was supplied by hydrothermal solutions from the vein-shears.

A striking similarity in the minor element content of the three specimens of diorite farthest from the shear (Nos. 4, 5, and 6 in Table 7) suggests that the diorite at these distances has been unaffected by hydrothermal solutions and the minor element content of these specimens is that of relatively unaltered diorite.

The minor element content of the diorite of the lower sill (Nos. 8, 9, and 10 in Table 7) is very similar to that of the upper sill. This similarity suggests that the two sills differentiated from the same magma and at about the same stage of crystallization of the magma.

Andesite porphyry and feldspar porphyry.- Both the andesite porphyry and the feldspar porphyry fail to show any gradational change in minor element content as either the vein or the granodiorite were reached.

Comparison of rock types.- A comparison of the minor element content of the hornfelsed tuff, diorite, andesite porphyry, feldspar porphyry and granodiorite is shown in Table 8. Many of the variations may be explained by differences mainly in the hornblende, biotite, plagioclase, and orthoclase content of the rocks and the consequent differences in the kind and amount of proxying elements.

The greater amount of lead in the granodiorite may be explained by the similarity of ionic radii of lead (1.32Å)

and of potassium (1.33Å), a major constituent of orthoclase, which is found only in the granodiorite and not in the other rock types. Sandell and Goldich²⁵ have found that the lead con-

²⁵ Sandell, E.B., and Goldich, S.S., The rarer metallic constituents of some American igneous rocks. Jour. Geol., p. 183, 1943.

tent of igneous rocks is higher in the more silicic varieties.

The greater abundance of copper in the andesite porphyry and diorite as compared with the feldspar porphyry and granodiorite is probably due to a small amount of chalcopyrite in the more basic rocks. Sandell and Goldich²⁶ suggest that the

²⁶ Sandell, E.B., and Goldich, S.S., *idem.*, p. 175.

greater abundance of copper in the more basic varieties of igneous rocks may be due to a similarity in ionic radii of copper (0.75Å) and ferrous iron (0.83Å) and consequent proxying by copper in the more abundant mafic minerals of the basic rocks. However, this is not borne out by Table 5, where copper is as abundant in the felsic as in the mafic minerals.

SUMMARY AND CONCLUSIONS

The scheelite vein is found in a diorite sill close to a large body of granodiorite.

the The ore-body is found only where the vein-shear cuts a thick diorite sill and, although the shear continues into adjacent hornfelsed tuff, no scheelite, and only a little quartz, is found beyond the sill. The pitch of the two high grade ore-sheets in the vein corresponds to the pitch of potential openings within the vein-shear.

The vein
The lenticular form and coarse-grained to pegmatitic texture of the vein, the assemblage of high-temperature vein-minerals, and the iron-magnesia metasomatism of the wall-rock, suggest that therein is a typical hypothermal vein as defined by Lindgren.

The vein does not occur within the granodiorite and it is therefore improbable that the vein-solutions came from the granodiorite body itself. However, it is close to the granodiorite and it is probable that the vein-solutions came from the same deep-seated magma from which the granodiorite and probably the other igneous rocks differentiated.

Sericitization rather than clay-mineral alteration characterizes the wall-rock and the vein-solutions were therefore alkaline rather than acid; and the scheelite, forming early in the sequence of mineral deposition, was precipitated from alkaline solution, along with apatite, by reaction of the solutions with calcium from the diorite, a rock with 8.18 per cent calcium oxide. The absence of scheelite in the hornfelsed tuff may be ascribed to chemical as well as to structural causes, for the hornfelsed tuff is low in calcium and would therefore not have precipitated the scheelite and apatite.

— / Spectrochemical analyses provide data for generalizations concerning the distribution of minor elements in different minerals and rocks that are in accord with those of other investigators. In addition, the analyses provide data for

further conclusions: tungsten, possibly because of an ionic charge larger than that of the common major elements in minerals of the wall-rocks, was found only in the vein and not in any of the wall-rocks, either close to or distant from the vein; hornfelsed tuff showed a gradational change in minor element content as the granodiorite responsible for its thermal metamorphism was reached; the minor element content of the diorite varied directly with the hydrothermal alteration of the diorite as the vein was reached.

either/ Inasmuch as the most important deposits of tungsten are/epithermal or pyrometamorphic, the Red Rose deposit is unique in that it is one of the few hypothermal deposits of scheelite that has produced important amounts of tungsten.

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