CHROMITE IN THE KLAMATH MOUNTAINS, CALIFORNIA AND OREGON.[1]

By J. S. Diller.

THE KLAMATH MOUNTAINS.

The Klamath Mountains of northwestern California and southwestern Oregon extend north and south for 260 miles—170 miles in California and 90 miles in Oregon. Their average width is about 80 miles. Their general outline and drainage features are shown in figure 1.

The eastern boundary of the Klamath Mountains is irregularly sinuous against the lavas of the Cascade Range. The western border is a long, shallow curve whose middle portion lies along the coast between Rogue and Klamath rivers. The northeastern limb of the curved border, overlapped by the Coast Range of Oregon, trends toward the Blue Mountains; the southeastern limb, overlapped by the Coast Range of California, trends toward the Sierra Nevada. These are the ranges to which the Klamath Mountains are most closely allied.

The geologic survey of the Klamath Mountains is not yet complete. Only the Redding and Weaverville quadrangles of California and the Roseburg, Port Orford, and Riddle quadrangles and general outlines in the Grants Pass quadrangle of Oregon have yet been surveyed. Much of the middle portion of the Klamath Mountains has been traversed in considerable detail, however, so that the prevailing formations are known and their general distribution can be outlined.

The Klamath Mountains are composed of rocks that are older and more complicated in structure than those of the Coast Ranges of California and Oregon and are closely related in materials and structure to the Sierra Nevada and the Blue Mountains.

The Klamath Mountains consist of two broad belts of closely related rocks, of which the most ancient are pre-Cambrian crystalline rocks, mica and hornblende schists, that in the western belt form the South Fork Mountains and in the eastern belt the bulk of the Salmon Mountains. In a general way these two belts show broad stretches of Paleozoic rocks, including many areas of slates, sandstones, and limestones apparently of Silurian and Car-

[1] Diller, J. S., Recent studies of domestic chromite deposits in the Klamath Mountains: Am. Inst. Min. and Met. Eng. Trans., September, 1919.

boniferous age, besides great volumes of Paleozoic volcanic rocks and later intrusive rocks of both acidic and basic types. The acidic types are represented by various forms of granitic and dioritic rocks; the basic intrusive rocks are gabbros and peridotites or serpentines.

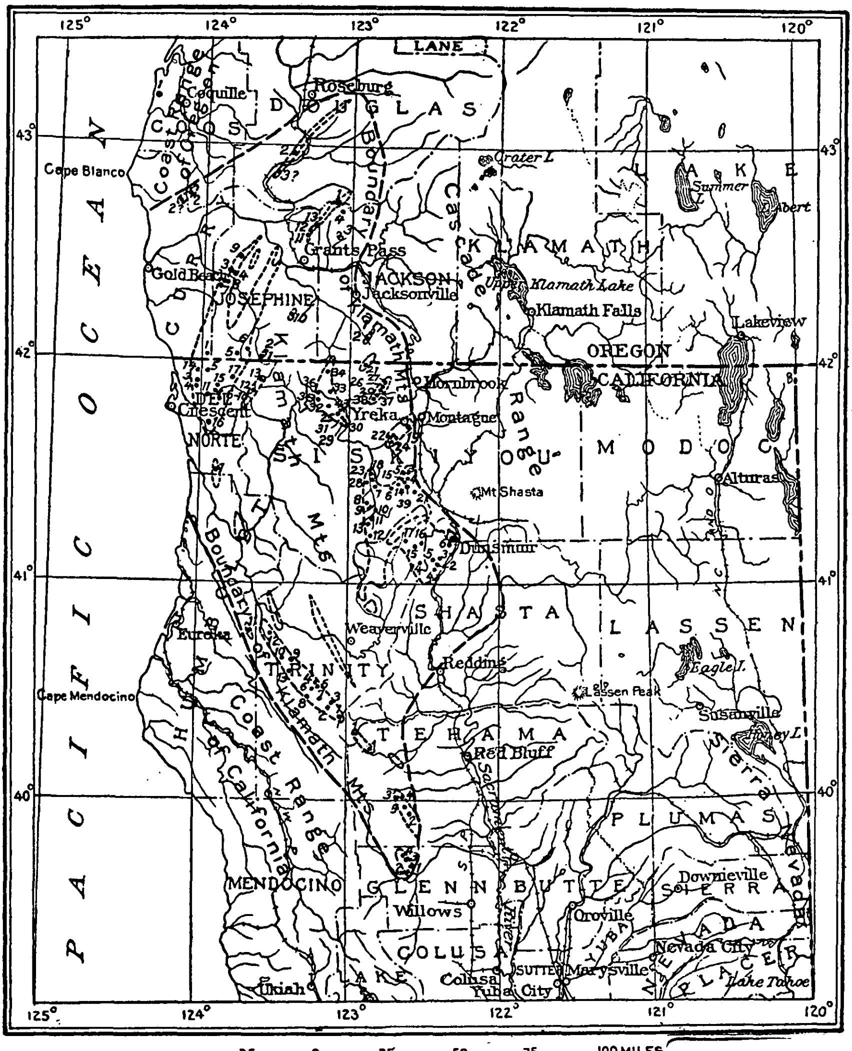


FIGURE 1.—Map of the Klamath Mountains, California and Oregon, showing by dots, numbers, and outlines the location of deposits of chromite in areas of serpentine.

The subjoined list includes the principal chrome mines and prospects in the Klamath Mountains in 1918. In figure 1 many of the deposits of chrome ore are shown by dots and numbered serially in each county. The numbers are given in the list. Mines that shipped ore in 1918 are designated by "S," those mining but not shipping by "M," and prospects by "P."

OREGON.

Coos County.

1.	Black Sand (Suffern Co.)	P
2.	White Rock (Krome Co.)	S

Douglas County.

1.	Starveout (Grants Pass Chrome Co.)	S
2.	Oregon Nickel Mining Co	S
3.	Cow Creek	M

Curry County.

1.	Bald Face	S
2.	C. & O. Lumber Co	S
	Meservey	M

Jackson County.

1.	Applegate group	S
2.	Horseshoe group	M
3.	Stray Dog	S
4.	G. H. Pease	P

Josephine County.

1.	Joseph Sowell	S
2.	Golconda	S
3.	Illinois River (California Chrome Co.)	S
4.	Grants Pass Chrome Co	S
5.	J. B. Harvey (?)	S
6.	Logan	S
7.	Casey & Daley	M
8.	Anderson	M
9.	Sordy & Noble	M
10.	Mungers Peak	M
11.	Sexton Peak	S
12.	Epperly	S
13.	Coyote Creek	S

CALIFORNIA.

Del Norte County.

1.	Red Mountain		S
2.	New Moon		S
3.	Rowdy Creek		S
4.	Mountain View		S
5.	High Plateau		S
6.	Zinc Saddle	Gordon Mountain group.	S
7.	No. 7	Gordon Mountain group.	S
8.	No. 8	Gordon Mountain group.	S
9.	Rowen	Gordon Mountain group.	S
10.	Madron	Gordon Mountain group.	S
11.	French Hill		S
12.	White Feather		M
13.	Alice and Blue Jay		S
14.	Black Prince		P
15.	Gasquets		S
16.	Rattlesnake		S
17.	Cedar Camp		M
	Boutz		S
	Sowers		S
	Zaar		M
	Morrell		M
	Moody		M

Siskiyou County.

1.	A. L. Coggins	S
2.	Scott Bros	S
3.	Chastain & Bowen	S
4.	F. Chastain	S
5.	Hayden & Hitt	S
6.	Walker	S
7.	Facey	S
8.	E. E. Taylor	S
9.	W. Taylor	S
10.	W. Bingham	S
11.	A. Bingham	S
12.	McKeen Bros	S
13.	Hugh Martin	S
14.	Siskiyou Syndicate	S
15.	G. J. Masterson	S
16.	Chastain & Archibald	S
17.	J. Gould	S
18.	Masterson & McBride	S
19.	Shebley	S
20.	Portuguese Gulch	S
21.	Lucky Haul	S
22.	Allison	S
23.	Grant	S
24.	Law	S
25.	Slide	S
26.	Blanton	S
27.	Indian Land	S
28.	Keppler	S
29.	Red Butte	S
30.	Octopus	S
31.	Liberty	S
32.	Reddy	S
33.	Dolbear	S
34.	Reddy	S

CALIFORNIA—continued.

Siskiyou County—Continued.

35. Reddy	S
36. Barton	S
37. P. S. Matthewson	S
38. Black Cap group	S
39. W. J. Chastain	S
40. Dietz	S
41. Dietz	S
42. Doe Flat	M
43. Jumbo	S

Trinity County.

1. Hart, Turner, and Adams	P
2. Drake	P
3. Old Bones (Shock)	S
4. Lost Horse	P
5. Foggarty & King	P
6. Pee Wee	S
7. Foster & Cuff	S
8. Big Stake (Scurlock)	S
9. Pallestreau	M
10. Schules	S
11. Lehmann (Humboldt Co.)	M
12. Upper Eltapom	P
13. McKay & Abbott	M
14. Copper King	S
15. Crow Creek group (Neely Bros.)	S
16. Integral Quicksilver Mining Co	P
17. Maltos, Green & Volente	S
M. Z. Samon	M
Luddy & Neilson	M
Larsen	M
Dubakella	S

Shasta County.

1. Beegum (Western Rock Properties Co.)	S
2. Forest Queen	S
3. Bull Dog	M
4. Noble Electric Steel Co	S
5. Hoy	S
6. Castle Crag	S
G. B. Allison	S
J. Q. Dick	M
George Williams	M
Chas. A. Wilson	S
Morton & Rogers	M
C. J. Shank	S
J. A. Heslewood	M
Hulse	M

Tehama County.

1. Tedoc	S
2. Adams & Maltby	S
3. Dolbear (American Refractories Co.)	S
4. Hillside (Noble Electric Steel Co.)	S
5. Kleinsorge	S
H. H. True	M
Zachary	M
Moore & Robinson	M
G. A. Eaton	M

Glenn County.

1. Grindstone Creek (California Chrome Co.)	S
2. Vanderford	S
3. Avery & Son	S
4. Adams & Maltby	S
Daisy	S

CHROMIUM-BEARING MINERALS.

Of the chromium-bearing minerals listed below the oxide, chromite, is the most abundant and the only one of economic importance as a source of chromium, and it is found in considerable quantities only in peridotite and serpentine.

The silicates are next in abundance. They are usually found in connection with deposits of chromite, where they were the latest chrome-bearing minerals to form. Chrome garnet occurs as minute bright-green dodecahedral crystals along joint planes cutting chromite, and the joint planes are in many places slickensided by later movements, as is well illustrated by some of the ore kindly sent to me by Mr. Musgrave, superintendent of the Selukwe mines in Rhodesia, for comparison with American ore. Crystals of chrome chlorite line cavities in the outer portions of many chromite deposits. This mineral was noted especially at the Castle Crag mine, Shasta County, Calif., and at the Deer Creek mine, in Wyoming, where an amorphous green clayey deposit like wolchonskoite rests on chrome chlorite in some of the cavities. It is interesting to note that wolchonskoite has recently been identified in this country for the first time by W. T. Schaller, of the Geological Survey, in a specimen from a vein near Ely, Nev. These silicates appear to originate largely if not wholly in the final hot gaseous emanations from the cooling though more or less solid deposit of chromite.

The sulphates have a somewhat similar origin. Knoxvillite occurs in the Redington mercury mine, and as pointed out by Becker it is due to the action of hot solfataric gases on chromite. The same may be true of the redingtonite that is associated with the knoxvillite.

Chromate of lead prepared artificially is extensively used for its yellow color.

This subject will be considered later in connection with the origin of the oxides chromite and picotite.

Chromium-bearing minerals.

Oxides:
- Chromite (chromic iron ore), $FeO.Cr_2O_3$.
- Picotite (chromic iron ore), $(Mg,Fe)O.(Al,Cr)_2O_3$.

Chromates:
- Crocoite (lead chromate), $PbCrO_4$.
- Phoenicochroite (basic lead chromate), $3PbO.2Cr_2O_3$.
- Vauquelinite (phospho-chromate of lead), $2(Pb,Cu)CrO_4.(Pb,Cu)_3.P_2O_8$.

Sulphates:
- Redingtonite (hydrous chromium sulphate).
- Knoxvillite[2] (basic hydrous chromium sulphate).
- Daubreelite (iron-chromium sulphide, known in meteorites only), $FeS.Cr_2S_3$.

Silicates:
- Chrome diopside, $CaMg(SiO_3)_2.nCr_2O_3$.
- Emerald (chrome beryl), $3BeO.Al_2O_3.6SiO_2.nCrO_3$.
- Uvarovite (chrome garnet), $3CaO.(Al,Cr)_2O_3.3SiO_2$.
- Fuchsite (chrome mica), $2H_2O.K_2O.3(Al,Fe,Cr)_2O_3.6SiO_2$.
- Kämmererite (chrome chlorite), kotschubeite, $4H_2O.5MgO.(Al,Cr)_2O_3.3SiO_2$.
- Wolchonskoite (a chrome-bearing clay).

PERIDOTITE AND SERPENTINE.

DISTRIBUTION.

Peridotite alters to serpentine, and whether fresh or altered it is generally called serpentine by miners. Peridotite and serpentine are the only rocks that contain commercial bodies of chrome ore, and

[2] Becker, G. F., U. S. Geol. Survey Mon. 13, pp. 279, 389, 1888.

they are the only ones of which the areas are outlined on the accompanying map of the Klamath Mountains (fig. 1).

Serpentine occurs in the Coast Ranges and in the Sierra Nevada, but considering the extent of the mountainous areas serpentine appears to be more abundant in the Klamath Mountains than anywhere else in California. The serpentine masses of the Klamath Mountains are very irregular, but to illustrate their relations most clearly on a map the outlines have to be generalized. Their forms vary in different portions of the mountain mass. Those of the western half are long and narrow and are parallel to the great curve of the Klamath Mountains on the west. In Trinity County, Calif., they trend southeast and their larger structural features point toward the Sierra Nevada. In Del Norte County, Calif., and the adjacent portion of Oregon they trend northeast, toward the Blue Mountains of Oregon. But between these two arms of the curve, especially east of the Salmon Mountains, which appear to be the solid core of the Klamath Mountains, the masses of serpentine are not only large and very irregular but more nearly equal in length and breadth.

PERIDOTITE AND ITS RELATIONS.

The term peridotite is applied to a basic igneous rock and in its broad sense includes the extremes dunite and pyroxenite and the intermediate more or less aberrant forms. In that sense peridotite is by alteration the source of practically all the serpentine in the Klamath Mountains. Peridotite consists chiefly of olivine, with which may be associated more or less pyroxene, generally enstatite but in many places diallage, rarely chrome diopside, and subordinate grains of magnetite and chromite. The relative proportion of these minerals varies greatly in different parts of the rock mass. Peridotite composed almost wholly of olivine is dunite; that composed mainly of pyroxene is pyroxenite. Both these extreme types of peridotite are abundant in the Klamath Mountains, where they are connected by intermediate grades, and appear to be unlike products of differentiation during the cooling and crystallization (solidification) of the same original magma. Special names, such as saxonite, lherzolite, and wehrlite, have been given to certain of the intermediate forms of peridotite. Perhaps the most common form in California and Oregon is saxonite, a rock which is rich in olivine and contains a considerable quantity of rhombic pyroxene, enstatite. The enstatite on a weathered surface of the rock gives rise to bright fibrous spots of bastite serpentine, which are generally characteristic of saxonite. Saxonite is dominant in Nickel Mountain,[3] 3 miles northwest of

[3] Nickel Mountain is named from the occurrence there of an interesting nickel silicate which has been described with the igneous rocks by George F. Kay in the text of the Riddle folio of the Geologic Atlas, not yet published.

Riddle, Douglas County, Oreg., where it contains bodies of high-grade chromite that are being mined.

Olivine and pyroxene both alter to serpentine, but the pyroxenes, except enstatite, generally alter less readily than olivine. Thus it happens that weathered saxonite shows patches of bastite, and peridotites rich in diallage have a very rough surface, owing to the projecting crystal grains of unaltered pyroxene left exposed when the wasted olivine has been changed to hydrous silicates and washed away. On the other hand, the surface of weathered dunite is comparatively smooth. Fresh rocks of all these types are well exposed in the higher parts of most of the large serpentine areas of the Klamath Mountains, where they have been laid bare by erosion.

The result of surface weathering upon fresh peridotite is to produce a hydrous alteration of the olivine and pyroxene, liberating oxide of iron, which colors the rock surface and soil a strong yellowish red, but beneath this red coating the fresh rock has the dark grayish-green color and vitreous luster of granular olivine and pyroxene. The red surface characteristic of weathered peridotite has caused many portions of the serpentine areas to be called "Red Mountain."

OCCURRENCE OF THE SERPENTINE.

Serpentine is always a secondary mineral and is formed by the hydrothermal alteration of olivine and pyroxene in peridotitic rocks. In some places the peridotites are fresh or but little altered; in others they may be largely or completely altered to serpentine, and as all intermediate degrees of alteration occur it is not possible to map the altered and unaltered parts separately. However, it is certain that by far the greater parts of the masses outlined on the map are serpentine. In general, where the rock is massive, the peridotite is unaltered, but where it is crushed so as to facilitate the circulation of the water it has been altered to serpentine. The outcrops of serpentine are for the most part highly fissured, rough, jointed, and sheared, and the fragments are slickensided as a result of the movement within the mass consequent not only upon stresses arising from mountain-making forces but also upon the increase of volume as the rock changes to serpentine. On a gentle slope serpentine generally decomposes to a reddish sterile soil, on which there is, as a rule, scanty vegetation, but on a slope where erosion is rapid the fresh serpentine crops out and has a yellowish-green color and a dull to waxy luster.

A thin section of this rock examined under a microscope shows that the chief mineral is serpentine, some of which is derived from olivine and some from pyroxene. Remnants of both minerals may occur in the serpentine and thus prove its source.

Many dustlike particles and grains of magnetite are present in the serpentine, and some of them show an irregular meshlike or gratelike arrangement determined by the lines of fracture in the altering olivine and pyroxene from which the magnetite in serpentine was chiefly derived. Grains or crystals of chromite are usually more or less abundant. In a thin section they are generally opaque, but where sufficiently thin in transmitted light they are seen to have a coffee-brown color. Locally the chromite is so abundant as to form a deposit of economic importance.

ORIGIN AND AGE OF THE PERIDOTITE.

The igneous origin of peridotites, including pyroxenites and dunites, is so widely accepted by geologists and petrographers that their origin in the Klamath Mountains and elsewhere on the Pacific coast needs no special consideration, as they are no exception to the general rule.

The peridotites of the Klamath Mountains penetrate not only the Paleozoic rocks that form the bulk of the central part of the mountains but also the Mesozoic rocks which, although they extend into portions of the Klamath Mountains, constitute under the general name of Franciscan formation a larger part of the Coast Range. The peridotites may not all have been erupted during the same epoch, but it seems most likely they were erupted mainly about the end of the Jurassic period. Those associated with the gneiss in the middle part of the Klamath Mountains may be older.

CHROMITE.

PROPERTIES.

Chromite is iron chromate represented by the theoretical formula $FeO.Cr_2O_3$, with 68 per cent chromic oxide (Cr_2O_3) and 32 per cent ferrous oxide (FeO). The iron may be replaced by magnesium and the chromium by aluminum and ferric iron, producing apparently all gradations in composition from spinel ($MgO.Al_2O_3$), which contains no chromium, and picotite [$(Mg,Fe)O.(Al,Cr)_2O_3$], which contains as much as 10 per cent of chromic oxide, to chromite proper. This gradation in composition was emphasized years ago by Wadsworth,[4] and it should be borne in mind in considering the concentration of chrome ore, for much of the ore is chemically of low grade

[4] Wadsworth, M. E., Lithological studies: Harvard Coll. Mus. Comp. Zoology Mem., vol. 11, pp. 1–208, 1884.

and can not be concentrated to a rich chrome ore by any mechanical process.

The color of chromite is between iron-black and brownish black. In very thin sections it is coffee-brown or yellowish red. It has a brown streak, a submetallic to metallic luster, an uneven fracture, and a hardness of 5.5. Its specific gravity is 4.32 to 4.57, and it is therefore not quite as heavy as magnetite, with which it may be associated and from which it may be distinguished by its brown streak and by being generally nonmagnetic.

Chromite crystallizes in the isometric system, usually in octahedrons, which may be modified by the dodecahedron. Complete crystals are not common. Large crystals are rare. The largest I have seen was given to me by Mr. Samuel H. Dolbear. It is nearly half of a regular octahedron found by W. H. Clary on F. M. Stockwell's property, 1½ miles west of Canyon City, Oreg., and its octahedral edge is 2 centimeters in length. Crystals of chromite are generally microscopic and are most commonly included in the olivine and pyroxene of peridotites, where, among other more or less regular forms, they have the diamond-shaped, square, and triangular cross sections of euhedral crystals shown in *a*, figure 2. Here and there a grain of chromite may show free crystallization upon one side, where it is bounded by crystal faces, but be irregular on the other side. As a whole the grain is subhedral, as shown in *b*, figure 2. Interferent crystallization prevented the development of a complete regular crystal form.

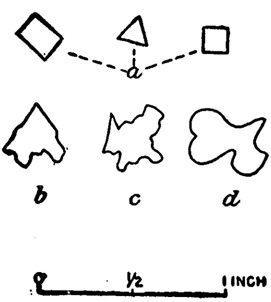


FIGURE 2.—Forms of chromite grains in peridotite. *a*, Euhedral; *b*, subhedral; *c*, anhedral angular; *d*, anhedral rounded.

The most abundant form of separate grains of chromite in peridotite, as seen under a microscope in a thin section of the rock, is anhedral, completely irregular (*c*, figure 2), angular, without a definite trace of crystallographic boundary.

In contrast to the angular outline just noted, which is most common in low-grade spotted or disseminated ore, there is another anhedral form characterized by curves, as represented in *d*, figure 2. In some places this is the most abundant form and occurs in connection with ore bodies that have more or less distinct nodular-concretionary structure. It suggests spherulitic forms of early crystallization, from which it is readily distinguished, however, by being wholly crystalline.

DEPOSITS OF CHROMITE.

FORM.

Grains of chromite that are abundant and closely aggregated or compact form a deposit. The simplest form, illustrated in figure 3, is a sharply defined body of chrome ore inclosed in serpentine. Most of the chromite bodies are more or less lenticular but very much longer than broad. They are, in fact, bands, layers, or sheets and are sometimes spoken of as tabular bodies or tables rather than lenses. Their distinctness of outline varies either by abrupt change or by perfect gradation from solid chromite with scarcely a trace of serpentine through all grades of intermixture to serpentine with only a few grains of chromite. The ore bodies are most sharply defined along the planes of greatest extent—that is, along their flat sides—though many of them send off inclined projections into the peridotite. Their edges are generally less sharply marked, and the gradation is accompanied by much irregular interfingering of ore and country rock.

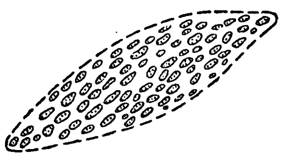


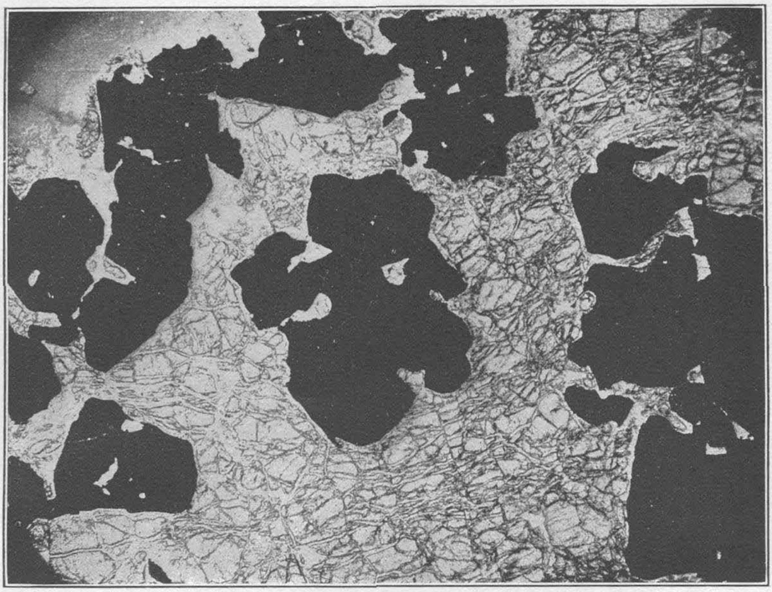
FIGURE 3.—Lens of nodular chromite in Coggins mine, near Dunsmuir, Calif. Length about 4 feet.

SIZE.

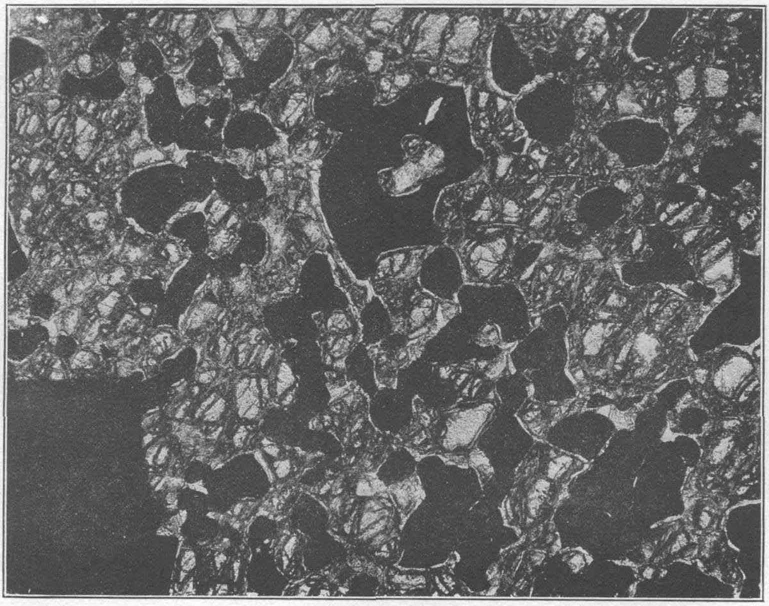
Chrome ore bodies range in size from a small nodule to a mass containing many thousand tons of chromite. The largest body of chrome ore mined recently[5] in the United States was 150 feet long, 40 feet in width, and 54 feet in depth. It occurred in the Castle Crag mine, on Little Castle Creek, in Shasta County, Calif., and yielded about 12,000 tons of merchantable ore, but as about one-third was lost in grading and washing it contained originally within the limits of the ore body about 18,000 tons of ore. The form of this large ore body is shown in plan and cross sections prepared by J. R. Van Fleet, the engineer in charge of the mine.[6] Sketches of chromite bodies in eastern Oregon by L. G. Westgate, in another paper in this bulletin (pp. 37–60, figs. 9–16) further illustrate the variability of the form and size of bodies of chromite. Other large bodies have been found in Fresno, San Luis Obispo, and Eldorado counties, Calif., and in Josephine and Grant counties, Oreg., although in some of these places the ore is contained in a series of adjacent overlapping lenses so near together as to be easily removed from one mine. The greater number of chrome ore bodies mined out in the United States within the last few

[5] According to Persifor Frazer (Pennsylvania Second Geol. Survey Rept. CCC, p. 192, 1880), 96,000 tons of chrome ore was removed from the Wood mine, in Lancaster County, Pa., about 1828.

[6] U. S. Geol. Survey Mineral Resources, 1916, pt. 1, pp. 29–30, figs. 1, 2, 3, 1917.



A.



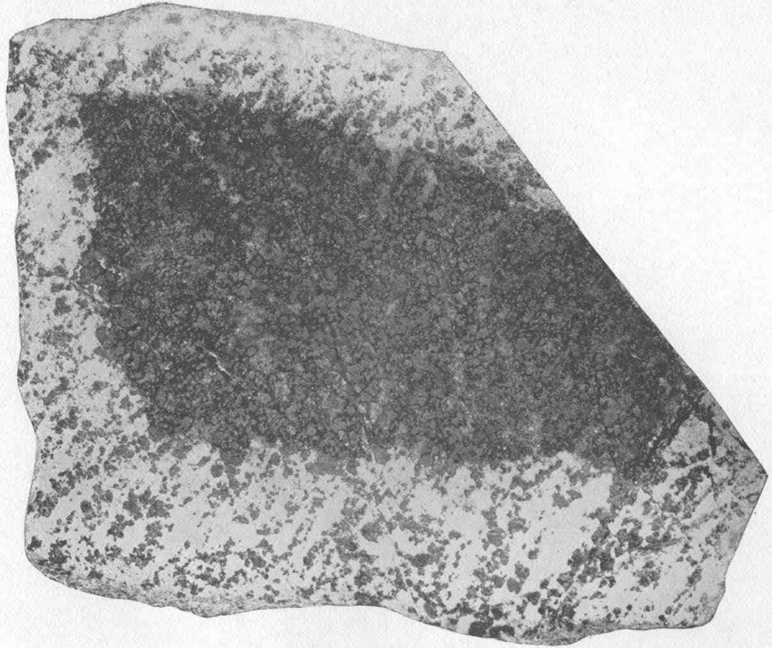
B.

EVEN-GRANULAR STRUCTURE OF CHROME ORE, CASTLE CRAG MINE, SHASTA COUNTY, CALIF.

A, Grains of chromite chiefly angular, enlarged 20 diameters; *B*, grains of chromite chiefly rounded, enlarged 25 diameters.

A. NODULAR STRUCTURE OF CHROME ORE, BRIGGS CREEK, JOSEPHINE COUNTY, OREG.

Enlarged $1\frac{1}{2}$ diameters.



B. BANDED STRUCTURE OF DISSEMINATED CHROME ORE, M. & L. CHROME MINE, NEVADA CITY, CALIF.

Enlarged 2 diameters.

years were relatively small. The chrome mines in the United States that contributed to the total output of ore in 1918 numbered about 240, and the average yield, calculated at 50 per cent grade, was about 260 tons. Very few mines worked upon the same body of ore throughout the year, and many mines included operations on five or more ore bodies. If it is assumed that each mine represented not less than five ore bodies the average content of an ore body would probably be 50 tons, or about a carload of ore. As compared with the extensive ore bodies of New Caledonia and Rhodesia, those of our Pacific coast appear small, but in other respects they are much alike.

STRUCTURE.

There are three varieties of structure common in deposits of chromite and the adjacent country rock—even granular, nodular, and banded.

Even-granular structure.—The even-granular structure is the most common and is best illustrated by disseminated or spotted ore in which the angular or rounded black grains of chromite are evenly scattered among the grains of olivine or pyroxene, as represented in Plate I. As the number and prominence of the grains of chromite decrease the disseminated ore grades into the inclosing country rock. On the other hand, with increase in the number or size of the chromite grains the disseminated ore finally becomes compact chromite with very little interstitial olivine, pyroxene, or serpentine. Even the best ores when examined microscopically are seldom found entirely free from small grains of one or more of the minerals named.

Nodular structure.—The structure of chromite is crystalline, but its crystallization, as already pointed out, may result in forming definite crystals, irregular angular grains, or rounded grains and nodules suggesting concretions. Nodular structure is characteristic of chromite deposits at many places. The nodules range from one-tenth to three-fourths of an inch in diameter and from spherical to lenticular in form. The lentils are generally in parallel position. Plate II, *A*, illustrates a specimen of nodular ore collected by H. R. Burritt in sec. 14, T. 16 S., R. 9 W., on Brush Creek, a tributary of Briggs Creek in Josephine County, Oreg. The wholly crystalline nodules of chromite are in a matrix of serpentine, most of it apparently derived from olivine, of which the meshlike structure outlined by oxide of iron still remains, surrounded by deep-green serpentine. The chromite is penetrated by many fractures visible to the naked eye. Most of them belong to one or the other of two sets that run approximately at right angles to each other. Those of the more abundant set extend nearly parallel to the length of the specimen and contain less serpentine than the minute transverse fissures, which generally show in the hand specimen bright reflecting surfaces of slickensides. The surfaces of the nodules are slightly indented and traversed by veins of serpentine. The original silicates, chiefly olivine, from which the serpentine is derived, appear to have enveloped the chromite nodules, as if the chromite had been formed before the silicates.

In the Placer Chrome mine, Eldorado County, Calif., there is a body of nodular ore in which the nodules of chromite, one-fifth to one-half inch in diameter, are wholly crystalline and apparently uniform throughout each nodule, although there is considerable variation in the luster of the grains that appear on the polished surfaces of the nodules. This may be due to differences in chemical composition or more probably to differences in the angle of the crystal section. The nodules are much fractured, and the fissures, as well as the internodular spaces, are filled with a greenish-white mineral whose acicular crystals locally have a radial fibrous arrangement and are regarded by W. T. Schaller as tremolite that readily alters to serpentine, with which it is intermingled. In a thin section the clear acicular crystals have the distinct cleavage of hornblende, and their occurrence in veins cutting the nodules of chromite shows that the tremolite is secondary. In this respect it is like the serpentine with which it is associated. Both form veins in the chromite. The original silicate from which the tremolite is derived, probably by hydrothermal action, is most likely pyroxene. To judge from the structure the primary silicates appear to have been younger than the chromite nodules which they inclose. In a near-by portion of the mine of the Placer Chrome Co. the nodular ore grades into compact ore. The groundmass of the internodular spaces is serpentine from altered tremolite. These nodular forms strongly suggest the chondrules of meteorites, described by Merrill[7] and others. It is a matter of surprise, however, that in meteorites the chondrules are commonly enstatite and olivine. Chromite, although present in many meteorites, is not reported as forming distinct chondrules.

The nodules of chromite, being granular, show no evident concentric or radial structure such as characterizes many concretions. The weathered surface of nodular ore is generally very rough, as shown in figure 3, which represents a lens of nodular ore 4 feet long and 1½ feet thick, projecting from an exposure on a steep slope of serpentine. The nodules are abundant in some portions of the Coggins mine and range from the size of a pea up to that of a hazel nut, although generally lenticular. They appear to contain about 45 per cent of chromic oxide but may be of higher grade, for C. B. Kinney,[8] chemist

[7] U. S. Nat. Mus. Bull. 94, pp. 18–20, 1916.
[8] Letter to the U. S. Geol. Survey dated Oct. 18, 1917.

of the Sawyer Tanning Co., of Napa County, Calif., found nodules of chrome ore from that region to contain 51.20 per cent.

Banded structure.—In many bodies of crude ore the chromite is arranged in parallel sheets or layers alternating with those of olivine, pyroxene, or serpentine, so as to produce more or less distinct banding on the exposed surface. In disseminated ore the bands are thin, irregular, and of small lateral extent, but there are all grades of accumulation to compact ore in bands or layers ranging from half an inch or less to several feet in thickness. Plate II, *B*, shows disseminated chrome ore with incipient banding. The rock is reported to contain about 15 per cent of ore and occurs in a belt 30 feet in width a few miles west of Nevada City, Calif., where it is crushed and concentrated, I am told, to about 36 per cent ore for market.

Banded chrome ore occurs on Sexton Peak, 12 miles north of Grants Pass, Oreg., where one of the largest and richest layers of ore contains many small particles of olivine and in the interfingering of the chromite and olivine illustrates the lateral passage of a layer of chrome ore into the country rock. In Plate III, *A*, the small bands are distinct. The same mine contains compact ore penetrated parallel to the banding by small cross-fiber veins of serpentine, which are also banded parallel to the banding of the ore.

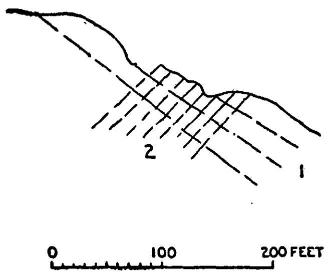


FIGURE 4.—Section from Octopus mine along slope of Red Butte, Siskiyou County, Calif., showing jointing (1) and banded structure (2) in peridotite.

The most remarkable bodies of banded chrome ore occur in Siskiyou County, Calif., in a mass of peridotite extending from Scott River above Scott Bar northwestward across Klamath River and Seiad Creek into Oregon. This area of peridotite is about 25 miles long and locally as much as 6 miles wide. It embraces many claims, of which half a dozen or more groups have contained active mines. The characteristic ores are illustrated by Plate III, *B*. The sample shown was taken from the Red Butte mine, operated by Reichman & Milne, 3 miles southwest of Scott Bar. At Red Mountain the belt of intermingled layers of chrome ore and olivine or serpentine is in places about 15 feet thick and has been traced north and south with a number of interruptions for several miles.

From the Octopus mine northward along the slope of Red Butte, as shown in figure 4, the jointed and banded structure of the peridotite is well illustrated. The jointed structure, dipping east, subdivides the rock so that it appears stratified. The fine banded belt is much less distinctly marked and contains relatively small bands of chrome ore.

There are several parallel ore belts in the Red Butte region, all of which have afforded promising prospects and in August, 1918, were undergoing rapid development. Exceptionally in the same region the structure of the ore is nodular.

The layers of country rock that alternate with those of chromite may be olivine, pyroxene, or serpentine, singly or intermingled. The olivine and pyroxene, like the chromite, are primary minerals, and the serpentine is secondary.

Another secondary mineral, magnesite, is associated with chromite in a few places. The simplest form of their association is illustrated in figure 5, which represents some banded ore of the Jumbo prospect, in the Red Butte region. The four solid layers of chromite are cross-jointed, and each joint is filled by a film of magnesite.

Veins of magnesite occur occasionally in deposits of chromite. The best I have seen are in the Red Mountain region of Fresno County, Calif., but the most interesting association of magnesite and chromite is in a banded specimen, illustrated in Plate III, *C*. This specimen was given to me by Mr. R. H. Farmer, of Newcastle, Placer County, Calif., and came from the chrome mine he was then operating 6 miles south of Newcastle, in Eldorado County, for the Placer Chrome Co. Chromite with a very small amount of magnetite forms the dark layers and magnesite the white layers. In a thin section the chromite is seen to be full of fractures which are filled with magnesite. The chromite is the oldest and only primary mineral of the specimen, and the magnesite appears to replace the peridotite with which the chromite was originally interbanded. The occurrence is of no economic importance but tends to show the primary character of the bands of chrome ore.

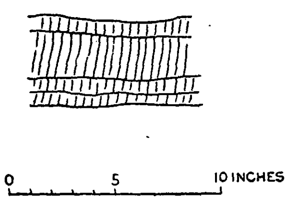


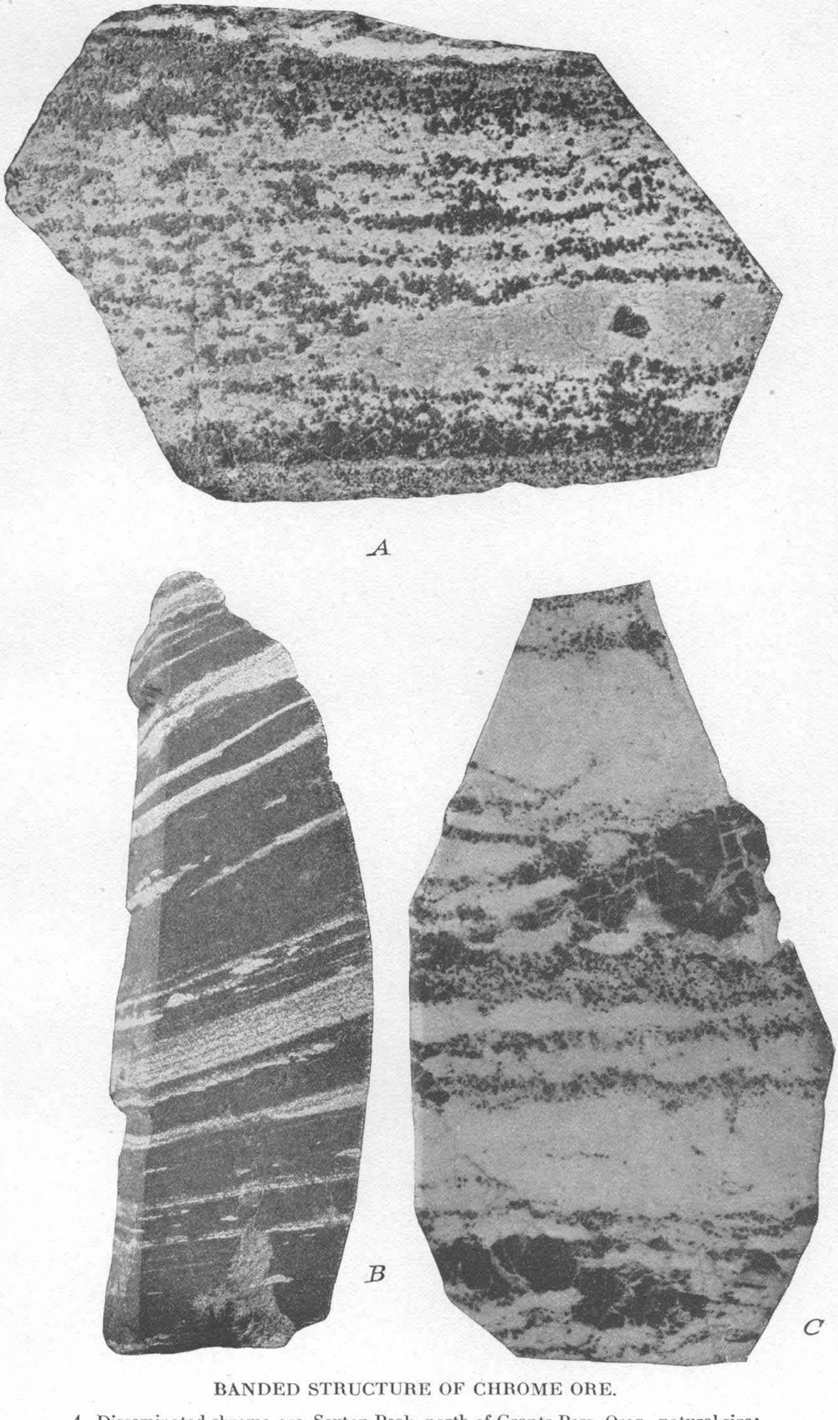
FIGURE 5.—Cross-jointed band of chrome ore containing films of magnesite in the joints, Jumbo prospect, Siskiyou County, Calif.

Vogt[9] has clearly illustrated and described various forms of banded structure in Norwegian chrome ores and calls attention to the fact that one set or type of chrome ore bands may transect another set formed at an earlier stage of development.

DEFORMATION.

There is abundant evidence that deformation, accompanied by more or less displacement, has occurred in the deposits of chromite since they were formed. In the solid massive peridotite, as shown by Van Fleet's sections of the Castle Crag ore body,[10] the displacement is relatively small, locally with distinct slickensides, yet without

[9] Zeitschr. prakt. Geologie, October, 1894, pp. 390–391.
[10] U. S. Geol. Survey Mineral Resources, 1916, pt. 1, p. 29, 1917.



BANDED STRUCTURE OF CHROME ORE.

A, Disseminated chrome ore, Sexton Peak, north of Grants Pass, Oreg., natural size; *B*, chrome ore, Red Butte, Siskiyou County, Calif., natural size; *C*, banded chromite and magnesite, Placer Chrome mine, Eldorado County, Calif.; enlarged 1½ diameters.

deformation; but where the rocks are altered into serpentine, which is particularly fissile, slippery, and readily susceptible to readjustment under earth stresses arising during its formation, the displacement may be large and result in the fragmentation and separation of deposits into distinct smaller bodies. Bands of solid ore raised to a nearly vertical position may have cross jointing well developed, so as to make the mass closely resemble an intrusive dike or vein.

Banded ores are in some places folded without fracture in a way to indicate plasticity of the rock matter at the time of deformation but subsequent to the development of the ore bands, which are bent and faulted. Joints and other fissures of the compact ores in northern Shasta County, Calif., and elsewhere are locally coated with green chrome garnet or purple to pink chrome chlorite, and subsequent rock movements have polished some of these brightly colored surfaces. It appears that the ore bodies have experienced folding or faulting during several epochs, and that the movement just referred to, which is so conspicuously recorded on some of the Rhodesian ore, was perhaps the smallest and latest earth movement. The earliest and greatest movement is considered below, in connection with the origin of chrome deposits.

ORIGIN.

The origin of chromite and its place in the order of mineral development of rock bodies received but little attention until microscopic petrographers discovered the mineral composition, structure, and history of rocks in which chromite occurs. The works of Rosenbusch (1873) are among the earliest of importance. He states[11] that "chromite is common in crystalline rocks rich in magnesia. In these it belongs to the oldest secretions, like magnetite, and is therefore usually inclosed in the next oldest constituents, especially in olivine. Chromite is also widely disseminated in the magnesian rocks of the Archean formation, particularly serpentine."

Chromite in crystalline grains is widely disseminated in peridotites and serpentine, and in addition to this distribution, which is regarded as practically uniform throughout the mass of peridotite or serpentine, there is a local irregular distribution in more or less well defined ore bodies that vary greatly in size, structure, and chemical composition. The widespread chromite grains are regarded by most observers as a product of earliest crystallization, preceding that of the olivine and pyroxene, in which many of them are clearly included. Perhaps this early crystallization of chromite may have been a fractional crystallization in an early stage of the differentiation of the peridotitic magma. The bodies of chrome ore, on the

[11] Rosenbusch, H., Microscopical physiography of rock-making minerals, translated by J. P. Iddings, p. 126, 1893.

other hand, may be regarded as products of more complete differentiation, having solidified later than the disseminated chromite of an earlier stage. In the Klamath Mountains the bodies of chromite, although in places associated with saxonite, which represents an early phase in the scale of magmatic differentiation, are commonly associated with dunite or pyroxenite of a later phase.

J. H. L. Vogt,[12] who was one of the first to give special consideration to the origin of chromite deposits, has shown that in the Norwegian deposits chromite in large masses for the most part represents purely magmatic separations in peridotite magmas, and that the chromite appears to be invariably the earlier consolidated constituent.

Lindgren,[13] though apparently approving the view of Vogt for many of the bodies of chrome ore, remarks that in part the ore may have a secondary origin, being developed together with magnetite during the process of serpentinization from primary chromite, picotite, and chrome diopside. In the Klamath Mountains the abundance and large size of the bodies of chrome ore associated with fresh dunite, pyroxenite, and saxonite show clearly that such bodies are primary and antedate the serpentinization. The same origin is ascribed to the bodies of chromite inclosed in serpentine, although it is clear that much of this ore has been fractured, sheared, and displaced by stresses developed in the formation of serpentine. How much, if any, of the primary chromite may have been dissolved in the process of serpentinization and redeposited as chromite is not easily determined. However, at most it appears to be of small quantity, even as compared with the secondary silicates developed.

Lindgren remarks: "It is noteworthy that during the weathering of chromite few chromium silicates are formed, while nickel silicates often develop." This might well be expected from the great chemical stability of chromite. Chromium, unlike iron, appears to have no hydrous oxide corresponding to limonite, which is so abundant in nature, especially among the products of weathering. Unlike copper, it has no carbonite readily formed under the influence of surface weathering; and unlike nickel, as noted by Lindgren, it does not commonly form silicates. The origin of chrome silicates generally, to be noted presently, appears to be deeper seated than ordinary weathering—a fact that aids in understanding the primary character of chromite.

Among the chrome silicates occasionally found with chromite are chrome diopside, chromiferous muscovite (fuchsite), chrome garnet (uvarovite), and chrome chlorites (kotschubeite and kämmererite). Chrome diopside is reported at only one locality in the Klamath

[12] Zeitschr. prakt. Geologie, 1894, pp. 384–394.
[13] Lindgren, Waldemar, Mineral deposits, p. 747, 1913.

Mountains,[14] where, to judge from the thin section, it appears to be associated with pink chrome chlorite of secondary origin derived from the alteration of the chrome diopside, which appears to be a primary constituent of the rock. The rare occurrence of chrome diopside with chromite is remarkable.

Uvarovite occurs in well-defined bright-green crystals at the Red Ledge mine, 2 miles southwest of Washington, in Nevada County, Calif. It occurs at many other localities as a thin chrome-green coating and is clearly of late secondary origin.

Chrome chlorite was abundant in the surface portions of the large body of chromite won at the Castle Crag mine, in Shasta County, Calif., and also in the Deer Creek mine, southwest of Glenrock, Wyo., where some good crystals line cavities in the ore and are evidently secondary. So also is the associated wolchonskoite.

The banded ores of the Hamburg region, Siskiyou County, Calif., throw an interesting light on the origin of chromite. A general section across Red Butte to Scott River (fig. 6) disclosed the relation of the banded chrome ore to the underlying gneiss,[15] which is well exposed along the Scott River road for 5 or 6 miles above Scott Bar. The general parallelism and structural similarity of the banded chrome ore and peridotite to the underlying gneiss are evident and strongly suggest that the banding of the ore is a gneissoid structure and has been determined by the same conditions that caused the gneissic structure in the underlying rocks. No definite contact was found between the hornblende gneiss and the gneissoid peridotite, but the presence of dark bands of hornblende-pyroxene material in both gneissic rocks is evidence of their similar and practically contemporaneous origin. It should be noted, however, that the gneissoid structure does not appear so prominent in the upper portion of Red Butte as it is in the underlying hornblende gneiss. It is least

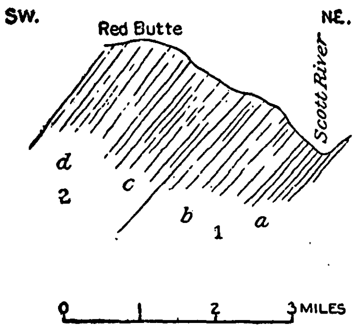


FIGURE 6.—Section across Red Butte, Siskiyou County, Calif., showing banded structure. 1, *a*, Hornblende gneiss—streaks of black hornblende mingled with a smaller amount of plagioclase and a little quartz; 1, *b*, hornblende-pyroxene rock forming bands in the hornblende gneiss; 2, gneissoid peridotite, in the basal portion of which there are thin layers of hornblende-pyroxene rock (*c*) in more or less massive schistose olivine rock (*d*) that contains the belts of banded chrome ore.

[14] The specimen was handed to me by Mr. J. F. Dwyer, of Yreka, Calif., who said that it came from the Ewing property, southwest of Yreka, in sec. 24, T. 44 N., R. 8 W., Siskiyou County.

[15] The term gneiss is here used as defined by Van Hise (U. S. Geol. Survey Mon. 47, pp. 782–783, 1894), "to apply to a banded rock the bands of which are petrographically unlike one another and consist of interlocking mineral particles."

conspicuous in the dunite, but this may be due to the predominance of olivine, for in small bands of pyroxene traversing dunite the elongation and alinement of the interlocking grains of pyroxene is decidedly more conspicuous than that of the adjoining olivine.

Although the Hamburg serpentine area contains the most extensive and conspicuous banded chrome ore yet reported, there are other serpentine masses in the Klamath Mountains and elsewhere that contain banded ore. It is well developed at the chrome mine on Sexton Peak, north of Grants Pass, Oreg., and about Red Mountain, near the head of Swift Creek, in Siskiyou County, Calif. The grains of chromite in the ore bands alternating with bands of olivine or pyroxene in the Swift Creek region are scarcely longer parallel to the banding than in other directions. In the olivine, however, the grains are longest parallel to the banding and the granular structure is in general the same as that of the gneissoid banded ore of the Hamburg region.

The relation of the banded chrome ore to the associated gneiss indicates that many of the deposits of chrome ore originated under the same conditions that induced the development of the associated gneiss.

Van Hise considers that gneissic structure may be developed in rocks of igneous origin as well as in rocks of sedimentary origin and ascribes it to crystallization under differential stress, which may be so great as to control the direction of crystal growth. In metamorphosed sedimentary rocks gneissic structure is a secondary development to recrystallization, but, as pointed out by Van Hise, in original gneisses formed from magmas the structure is due to differential stress during the primary crystallization of the rocks. No distinct evidence has yet been observed in the banded chrome ore of the Klamath Mountains to indicate that it is not primary. Furthermore, slight change of stress during the progress of development may fracture ore bands formed during an early stage and permit them to be cut by bands intruded during a later stage of development.

The views considered thus far are those that grew mainly from the work of the German petrographers, but within the last decade the views of French investigators, especially those of De Launay [16] as stated by Singewald,[17] have attracted more attention. Singewald refers to the work of Tolman and Rogers[18] and emphasizes the effect of mineralizers in the later stages of magmatic or subsequent hydrothermal segregation, especially of ore deposits. Although many authors consider that there is a sharp distinction between magmatic

[16] De Launay, L., Gites minéraux et métallifères, 1913.

[17] Singewald, J. T., jr., Magmatic segregation and ore genesis: Min. and Sci. Press, vol. 114, pp. 733–736, 1917.

[18] Tolman, C. F., jr., and Rogers, A. F., Characteristics of magmatic sulphide ores: Min. and Sci. Press, vol. 114, p. 550, 1917.

and hydrothermal deposits, those of the French school, represented by De Launay, recognize a complete gradation or transition from purely igneous deposits to hydrothermal veins and ascribe a large influence to mineralizers.

The segregation of oxidic ores, especially of chromite, though most common near the borders of their enveloping igneous rock, occurs throughout its body but is rarely found on its contact. Daly[19] notes a body of chrome ore on the lower contact of a laccolith, as if differentiated by gravitation, and Bowen,[20] after a special study of the causes of the differentiation, says: "The decision is reached that this differentiation is controlled entirely by crystallization. The sinking of crystals and the squeezing out of residual liquid are considered the all-important instruments of differentiation, and experimental evidence is adduced to show that under the action of these processes typical igneous-rock series would be formed from basaltic magma if it crystallized (cooled) slowly enough."

As remarked by Singewald,[21] "There are so many admirable illustrations of gradation from rock with feeble concentrations of metalliferous minerals to important ore bodies (and this is true of chromite as well as other ores) that no particular significance has been attached to the observation that ore minerals are often later than the silicates." In many places this sequence appears certain, especially with reference to sulphide ores. A thorough study with reference to chromite is now being made by Tolman and Rogers, and further results are eagerly awaited. Singewald suggests studying the genesis of chrome-ore deposits with the possible influence of mineralizers in mind and apparently believes that they will finally be found in harmony with the deposits of other ores. However, he recognizes[22] that deposits of chromite "now seem to be an exception and to represent a direct segregation as the first product of crystallization from a molten magma."

In considering the genesis of chromite as compared with that of the sulphide ores, as set forth by De Launay, it should be borne in mind that terrestrial sulphides of chromium are unknown, although daubreelite, iron-chromium sulphide, occurs in meteorites. Clarke has estimated that chromium constitutes about 0.01 per cent of the lithosphere,[23] and most of it is in chromite, which, as Clarke remarks,[24] occurs almost exclusively in subsilicic rocks and is distinctly a magmatic mineral. Chromite is one of the most refractory and in-

[19] Daly, R. A., Igneous rocks and their origin, p. 455, 1914.

[20] Bowen, N. L., The later stages of the evolution of the igneous rocks: Jour. Geology, vol. 23, No. 8, suppl., p. 90, 1915.

[21] Singewald, J. T., jr., Magmatic segregation and ore genesis: Min. and Sci. Press, vol. 114, pp. 733–736, 1917.

[22] Op. cit., p. 736.

[23] Clarke, F. W., U. S. Geol. Survey Bull. 168, p. 15, 1900.

[24] Clarke, F. W., U. S. Geol. Survey Bull. 616, p, 697, 1916.

soluble of minerals, and the process of producing it artificially, as noted by Clarke, appears to throw little if any light upon its genesis in nature.

It has lately been stated by J. B. Platts [25] that there are many commercial bodies of chromite in Del Norte and Siskiyou counties that "are undoubtedly fissure fillings in the ordinary sense." He is of the opinion that some of the ore bodies are of magmatic origin but believes that those referred to are exceptional. This view I have not been able to confirm, possibly because I may not have seen these particular deposits, although I saw nearly all the deposits operated in 1918 within the counties mentioned.

It is evidently a matter of prime importance to determine the relative order of crystallization of chromite and the ferromagnesian silicates, olivine or pyroxene, in the ore bodies. For this purpose a microscopic study has been made of a number of thin rock sections from various parts of California and Oregon.

The body of chromite mined by the California Chrome Co. at the Castle Crag mine, on Little Castle Creek, 3 miles south of Dunsmuir, Calif., is the largest single body of chrome ore yet discovered on the Pacific coast. It occurs chiefly in pyroxenite and dunite, the two extreme differentiation products of peridotite, which occupy a large area in that region. Much of the peridotite has been changed to serpentine, but a large part of it, chiefly pyroxenite and dunite but with considerable saxonite, is still fresh in contact with the body of chromite. J. R. Van Fleet, who had charge of mining the chromite for the California Chrome Co., prepared sections of the ore body for the Geological Survey and calls attention to intrusions of the country rock into the ore body.[26] Plates II and IV show thin sections of ore from that body and illustrate the relation of chromite to olivine and pyroxene.

In attempting to apply to the problem in hand the conclusions of N. L. Bowen as to crystallization in igneous rocks, we appear to be met at the outset by the fact that the rock masses inclosing the larger bodies of chrome ore are all of plutonic origin. A corresponding type of effusive rock is lacking unless it is represented by a portion of those basalts which carry a small amount of chromite, either as single regular crystals or as groups of crystals included in the silicates, chiefly olivine.

Some information concerning the order of crystallization may be gained by a study of the lines of contact between the grains, especially with reference to the crystallization lines, the euhedrism of one mineral against another, the indentation of one mineral by

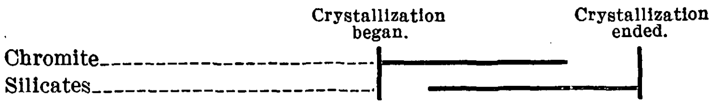
[25] Min. and Sci. Press, vol. 114, p. 872, June 23, 1917.

[26] Diller, J. S., Chromite in 1916: U. S. Geol. Survey Mineral Resources, 1916, pt. 1, pp. 29–30, 1917.

another, and the complete inclusion of one mineral by another, but the only safe conclusion, as pointed out by Bowen,[27] relates to the order in which the minerals ceased to crystallize.

A section of chromite from the Castle Crag mine of the California Chrome Co., in Shasta County, Calif., is shown in Plate IV. The net of serpentine that includes the chromite was derived from pyroxene, which was the last mineral to crystallize. The chromite includes many minute particles of serpentine that locally have a more or less well-defined zonal arrangement with reference to the outline of the including grain, which as it grew enveloped the inclusion. That the included particles were crystallizing at the same time as the chromite is suggested by the fact that some of the grains of chromite have no inclusions about the center but many inclusions nearer the border. The included particles are generally anhedral, but many of the larger ones, about 0.006 millimeter long and 0.002 millimeter broad, have straight sides as if euhedral and are arranged with their longer axes parallel to the zonal structure. These inclusions are now serpentine, apparently derived from original pyroxene of early crystallization. These early silicate particles included in the larger grains of chromite themselves inclose many smaller particles of chromite and dustlike particles that appear to be chromite, perhaps the first products of crystallization.

The crystallization of the chrome ore of this section may be represented according to the graphic method suggested by Bowen, as follows:



The chromite began to crystallize first and continued nearly to the end. The silicates began to crystallize soon after the chromite began and continued until the rock was completely consolidated. Although a part of the chromite crystallized before the silicates and some of the silicates crystallized after the chromite, most of the chromite and a smaller proportion of the silicates were practically contemporaneous in crystallization.

A sample of disseminated ore from the Castle Crag mine, near Dunsmuir, in Shasta County, Calif., is represented in Plate I, *A* (p. 10). The grain of chromite shown near the middle of the figure is decidedly roundish and deeply indented by projections of the olivine groundmass, of which one portion containing a grain of olivine in serpentine looks as if wholly surrounded by chromite, but the particles are anhedral and the lines from the indenting olivine

[27] Bowen, N. L., The order of crystallization in igneous rocks: Jour. Geology, vol. 20, pp. 455–468, 1912.

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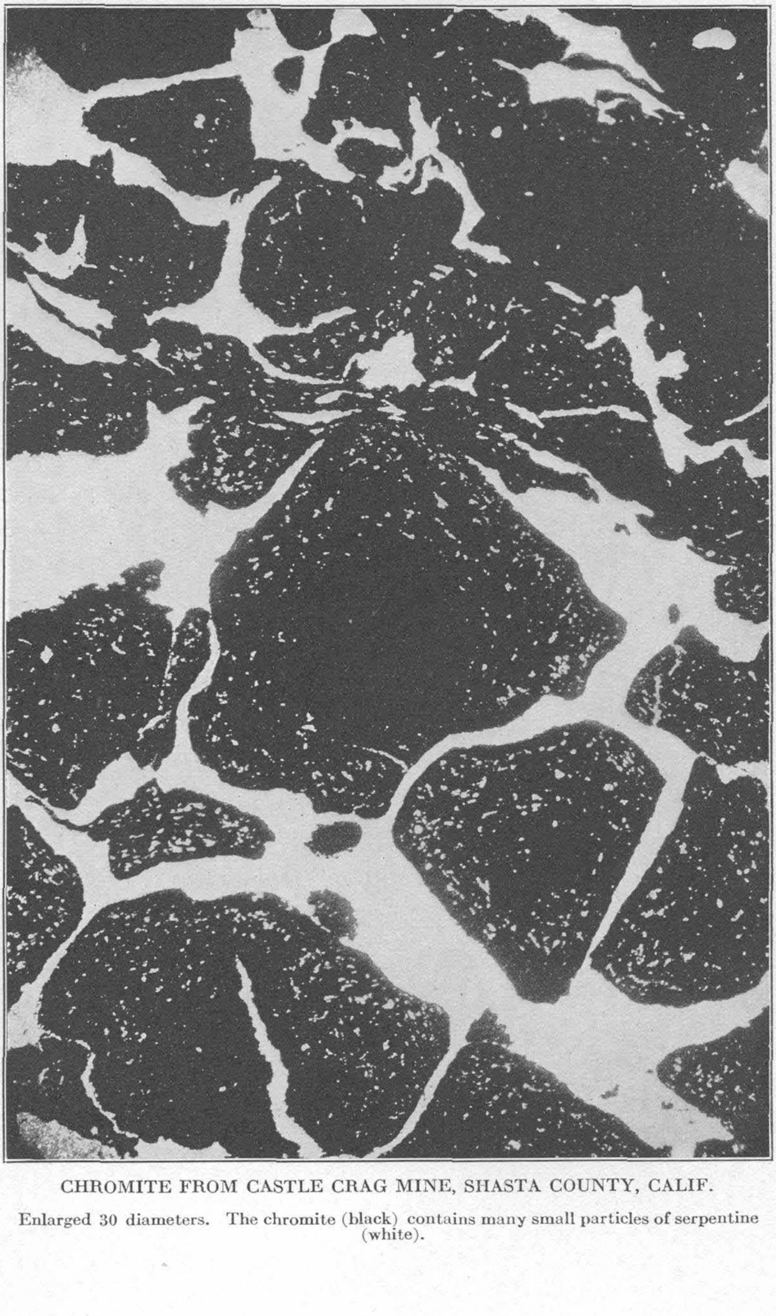
indicate that it is connected with a projection of olivine from a point outside the plane of the section. There are some small included particles in the chromite similar to those of Plate IV, but much less abundant. The fractures in the olivine (Pl. I, *A*) are locally curved about the chromite grains, suggesting flow structure. The general relations here appear to be essentially the same as those of the section shown in Plate IV.

At another point the disseminated ore in the Castle Crag mine contains a roundish grain of chromite. The chromite is indented by projections from the surrounding groundmass of pyroxene and olivine, which near by contains euhedral crystals of chromite. The crystals of chromite afford strong evidence that they are of early crystallization, perhaps antedating most of the particles of silicates by which they are inclosed. The small particles of silicates, now serpentine, inclosed in the larger grains of chromite show that the crystallization of silicates began early and apparently continued after the crystallization of the chromite was completed. The crystallization of much of both the chromite and the silicates may have advanced together so as to be practically contemporaneous.

The grains of disseminated chromite of the section shown in Plate V, *A*, are largely euhedral [28] and inclosed in olivine, which is partly altered to serpentine. The greater portion of the chromite crystallized before the olivine in which it is included. The small irregular particles of original silicates (now serpentine) included in chromite may have crystallized slowly, while that of the chromite proceeded more rapidly to completion. which was followed by the crystallization of most of the silicates.

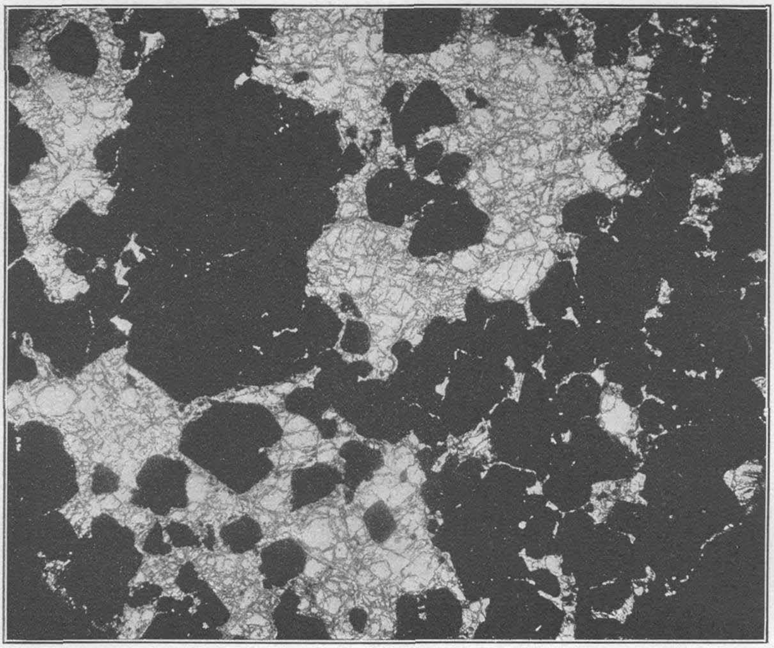
About 6 miles southwest of Yreka, Calif., toward Fort Jones, there is a remarkable disseminated chrome-ore body, of which a sample said to come from Mr. Ewing's property, in sec. 24, T. 44 N., R. 8 W., was given to me by Mr. J. F. Dwyer, of Yreka. The thickly set grains of lustrous black chromite form about 60 per cent of the rock, and the interspaces are filled with brilliant green chrome diopside tinged here and there by a pink chrome chlorite derived from the alteration of the diopside. In the thin section (Pl. V, *B*) the chromite is seen to be limited at a number of places by straight lines—crystal boundaries—and to that extent is euhedral, but the interferent crystallization of the chromite itself prevented the development of perfect crystals. The crystallographic planes of the chro-

[28] This general relation of the silicates and euhedral chromite is well illustrated by others. See Vogt, J. H. L. Zeitschr. prakt. Geologie, vol. 22, p. 389, 1914; Beck, R., The nature of ore deposits, translated by W. H. Weed, p. 29, 1905; Wyssotzky, N., Die Platinseifengebiete von Iss- und Nischny-Tagil im Ural: Com. géol. Mém., new ser., vol. 62, pl. 8, Nos. 3, 4, pl. 9, No. 3, pl. 10, No. 1, 1913. In plate 9 Wyssotzky shows euhedral chromite that includes anhedral platinum and is itself included in a groundmass of anhedral platinum.



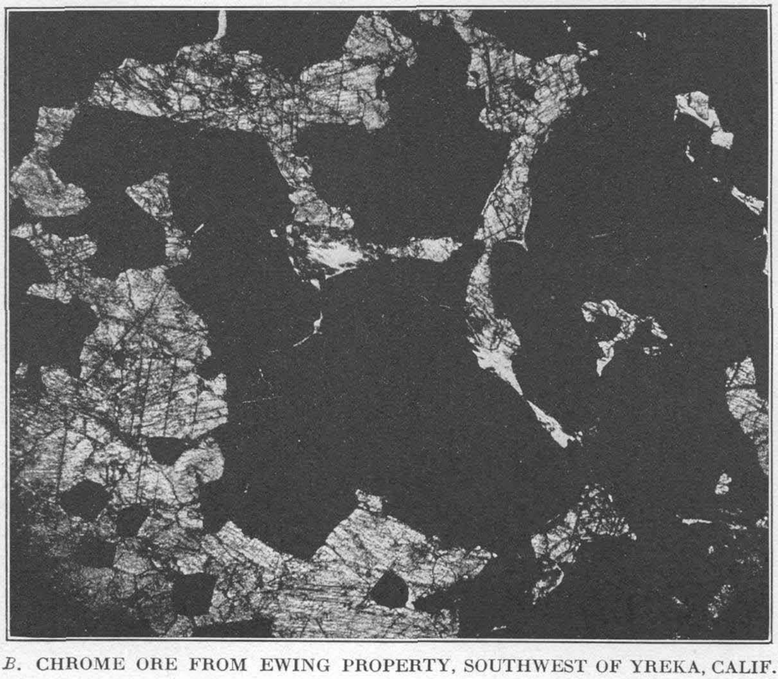
CHROMITE FROM CASTLE CRAG MINE, SHASTA COUNTY, CALIF.

Enlarged 30 diameters. The chromite (black) contains many small particles of serpentine (white).



A. CHROME ORE FROM DOLBEAR MINE, SISKIYOU COUNTY, CALIF.

Enlarged 20 diameters. Some of the chromite grains are euhedral.



B. CHROME ORE FROM EWING PROPERTY, SOUTHWEST OF YREKA, CALIF.

Enlarged 20 diameters.

mite appear to indent and limit the pyroxene, which was, at least in part, the last mineral to crystallize. The diopside is fresh and appears to be of primary origin. If so, it seems strange that chrome diopside is not a more common pyroxenic associate of chromite.

The veins of chrome chlorite, tremolite, and chrome garnet, which appear to be of hydrothermal origin, cutting fresh unaltered masses of chromite, show that the chromite they penetrate belongs to an earlier stage of development—that is, to the magmatic stage.

SUMMARY.

1. In the Klamath Mountains areas of peridotite and serpentine are numerous, and the serpentine is derived wholly from the alteration of the peridotite.

2. The several phases of peridotitic rocks are products of differentiation from a common magma and range from normal peridotite, made up of olivine and pyroxene with accessory chromite and magnetite, to pyroxenite, in which the silicate is pyroxene, on the one hand, and to dunite, in which the silicate is wholly olivine, on the other.

3. Both peridotite and serpentine contain not only separate grains of chromite scattered throughout them but segregated bodies of commercial interest as a source of chromite. These ore bodies may result from the differentiation of the magmatic mass in a tendency toward unification in mineral composition.

4. Grains of chromite, whether singly or in aggregates, may be euhedral, bounded wholly or partly by crystallographic lines, but most of them are anhedral, having crystallized under conditions of interference that prevented the development of crystal faces.

5. The original form of chromite bodies is in some deposits irregular, lens-shaped, short, and thick; in others relatively thin, long, broad, and like sheets or layers.

6. The structure of these deposits may be even granular, nodular, or banded, according to the distribution of the ore with reference to associated silicates.

7. In even-granular structure the grains of a segregated body of chromite are distributed throughout the associated silicates with approximate uniformity. In nodular ore the grains are segregated in nodules resembling concretions. In banded ore they are arranged in bands alternating with bands of silicates.

8. The magmatic origin of chromite is generally conceded, but its exact place in the scale of events from the beginning of crystallization in the magma to the mergence of this process into the formation of hydrothermal deposits, which are conceived to form with magmatic products a continuous thermal series, may be a matter of doubt.

9. Evidence concerning the proportion of crystallographic forms shows that the generally accepted view regarding chromite as one of the earliest minerals to begin to crystallize in the magma is probably correct.

10. The earliest crystallization of chromite was soon followed by the crystallization of small particles of silicates.

11. The crystallization of chromite and silicates proceeded at the same time, but that of the chromite more rapidly than that of the silicates, which it enveloped, and thus the chromite generally completed its crystallization before the silicates.

12. The final crystallization of silicates took place after that of the chromite was completed and filled the remaining spaces.

13. Although chromite is the earliest product of crystallization and the silicates, olivine and pyroxene, are the later products, it must be remembered that they are largely contemporaneous, as shown by their mutually interlocking anhedral boundaries.

14. Bowen [29] has reached the conclusion that differentiation is controlled entirely by crystallization and states that "the sinking of crystals and the squeezing out of residual liquids are considered the all-important instruments of differentiation."

15. The chromite deposits resulting from magmatic differentiation under the controlling factors noted above, which may be considered as producing even-granular bodies, may be greatly modified by the operation of other concurrent or subsequent factors that cause variations of original form as well as later deformation or displacement.

16. The nodular ore appears to be simply concretionary, but the special forms of serpentine and of tremolite associated with the nodules suggest unusual local conditions different from those which generally prevail. However, the order of development of chromite and silicates appears to be the same as elsewhere.

17. The banded ore where best developed is closely related to gneiss, and the structure of both has the same origin.

18. As urged by Van Hise [30] the gneissic structure may be developed by differential stress during the slow cooling and crystallization of an intruding magma.

19. The variations in the differential stress may fracture a crystallized mass of ore and intrude into it ore which in the process of differentiation has not yet fully solidified.

20. No conclusive evidence has been seen by me anywhere of the secondary origin and deposition of chromite. It is in places residual but appears to be everywhere of primary magmatic origin.

21. The magmatic origin of the sulphide ores and also of the ores of ilmenite and magnetite, advocated by Tolman and Rogers,[31] ably

[29] Bowen, N. L., The later stages of the evolution of the igneous rocks: Jour. Geology, vol. 23, No. 8, suppl., p. 90, 1915.

[30] Van Hise, C. R., U. S. Geol. Survey Mon. 47, p. 1002, 1894.

[31] Op. cit., p. 68.

seconded by Singewald,[32] has been regarded by these authors as indicating that chromite belongs in the same category—that is, that the chromite was generally formed later than the associated silicates and that its development was rendered possible by mineralizers of a late magmatic stage.

22. The widespread and common occurrence of veins of chrome silicates in chromite appears to show approximately the limit of the magmatic and hydrothermal phenomena and to demonstrate that the chromite is of magmatic origin.

23. Although much of the chromite and silicates crystallized about the same time, some of the chromite appears to be earlier than the earliest silicates, and much of the silicates is later than all the chromite, thus essentially confirming the views of Vogt, Beck, and Wyssotzky.[33]

TRANSPORTATION OF CHROMITE IN THE KLAMATH MOUNTAINS.

There are two principal lines of transportation to carry the chromite of the Klamath Mountains to market—the railroad on the east and the ocean steamers on the west. The main line (Shasta Route) of the Southern Pacific Railroad receives the ore from the eastern slope of the Klamath Mountains between Roseburg, Oreg., and Willows, Calif. Branch roads west of the main line from Grants Pass to Waters Creek, from Montague to Yreka, and from Willows to Fruto greatly facilitate the shipment of chrome ore. The principal shipping points are indicated on figure 1 (p. 2). The short branch railroads, truck roads, ordinary wagon roads, and trails enable the miner to reach back into the Klamath Mountains locally more than 50 miles from the railroad, but his expenses are greatly augmented by increase of distance from the shipping point. Thus the cost of transportation sharply limits the possibility of profitable mining.

The Klamath Mountains are deeply cut by lines of drainage, and the canyons are so rugged that the roads commonly follow the gentle slopes of the even-crested uplands rather than the stream courses. Although the Klamath Mountains are about 260 miles in length, they are crossed by only two wagon roads, one from Red Bluff to Eureka and the other from Grants Pass to Crescent City. Both are autostage roads and afford good transportation for ore that lies within easy reach of them. The ore is trucked on both roads from all points within 60 miles of the Southern Pacific Railroad, and a truck haul of 60 miles costs nearly $26 a ton. As the other expenses are proportional it is evident that the miner must have good prices for his ore f. o. b. railroad, or he can not afford to mine it.

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[32] Op. cit., p. 733.

[33] Wyssotzky, N., op. cit., pl. 8, Nos. 3, 4, pl. 11, Nos. 3, 4, pl. 10, No. 1.

The ore from the western slope of the Klamath Mountains is shipped mainly from Crescent City by boat to Eureka and to San Francisco, where it reaches railroad transportation for distribution to consumers. Small quantities are also shipped by boat from Smith River, from the mouth of Klamath River, and perhaps from other points along the coast, but these routes apparently afford less favorable opportunity for shipment to eastern markets.

The chrome ore already mined in the Klamath Mountains is that which was nearest and most conveniently located for transportation to market. It is only a small portion of the whole, but that which is still available can be won only at greater cost. The problem of producing chromite in the Klamath Mountains now hinges largely on transportation, and the operators require high prices to mine and market the ore at a fair profit.

PRODUCTION OF CHROMITE IN THE KLAMATH MOUNTAINS IN 1918.

In the Klamath Mountains there were 147 producers of chrome ore in 1918—120 in the six counties in California and 27 in the five counties in Oregon—and the total shipments amounted to 27,185 short tons of all grades—21,021 tons from California and 6,164 tons from Oregon. The total amount of ore reported as mined in the Klamath Mountains in 1918 was 48,571 short tons, of which 21,386 tons was left in the hands of the producers either at the railroad stations or at the mines. The reports of shipments furnished independently by the railroad agents and the producers of the same region approximately agree, and this gives confidence in the returns, which are summarized in the following table:

Chromite produced in the Klamath Mountains, 1918.

[Subject to revision.]

County.	Shipments[a] (short tons).	Stocks on hand Dec. 31, 1918 (short tons).	Value of ore sold.	Average value per ton.
California:				
Glenn County	1,466	520	$72,046.17	$45.72
Tehama County	1,952	4,790	95,610.54	48.27
Shasta County	2,019	1,045	89,327.84	43.37
Trinity County	1,556	2,729	57,021.14	40.79
Siskiyou County	6,125	2,917	261,962.03	45.13
Del Norte County	7,903	4,345	380,536.34	42.00
	21,021	16,346	956,504.06	45.50
Oregon:				
Jackson County	168	50	6,718.95	42.63
Josephine County	5,396	3,663	263,191.62	48.77
Curry, Coos, and Douglas counties	600	1,327	32,575.58	51.16
	6,164	5,040	302,486.15	49.07
Grand total	27,185	21,386	1,258,990.21	46.31

[a] As the shipments are weighed their record is more accurate than that of stocks on hand, which are generally estimated.

The total shipments of 27,185 short tons are equivalent to 24,272 long tons.

The ore shipped from the Klamath Mountains varied widely in richness, its content of chromic oxide ranging from more than 45 per cent to less than 35 per cent; the average content was 41 per cent. This ore is of much lower grade than the best imported ore, which is generally estimated on a basis of 50 per cent chromic oxide. The 27,185 short tons of 41 per cent ore marketed in the Klamath Mountains in 1918 is equivalent to 19,903 long tons of 50 per cent ore, or 6,809 tons of the metal chromium.

The relative importance of the Klamath Mountains as a source of chromite in 1918 appears by a comparison of their output with that of other mountain ranges of the Pacific coast, as well as the total output of the United States and the imports of chromite during 1918. For this comparison the figures of production used thus far will be changed from short tons (2,000 pounds) to long tons (2,240 pounds), in which the record of imports is published.

Chromite produced in the United States and imported, 1918.

	All grades (long tons).	Per cent of Cr_2O_3.	Equivalent in 50 per cent grade (long tons).	Chromium (long tons).
Total shipments:				
Klamath Mountains, California and Oregon	24,272	41	19,903	6,809
Coast Range of California	16,790	40	13,432	4,595
Sierra Nevada of California	27,580	40	22,064	7,548
Blue Mountains, eastern Oregon	12,950	40	10,360	3,544
California	63,064	40	50,451	17,259
Oregon	18,455	40	14,764	5,051
Other States (Maryland, North Carolina, Washington, and Wyoming [a])	831	40	665	227
United States	82,350	40	65,880	22,538
Produced in the United States but not shipped (estimated)	42,650			
Total output of the United States	125,000			
Imports [b]	100,142			

[a] Georgia, Montana, and Pennsylvania each produced a small amount but made no shipments in 1918.
[b] Bureau of Foreign and Domestic Commerce.

The Klamath Mountains produced more than 29 per cent of the total quantity shipped in the United States in 1918, or, if the estimated stocks remaining unshipped December 31, 1918, are included, the Klamath Mountains yielded about 39 per cent of the total output.

RESOURCES OF CHROMITE BY COUNTIES.

CALIFORNIA.

GLENN COUNTY.

The chrome mines of Glenn County, Calif., are in an area of serpentine that forms the southern terminus of the Klamath Mountains opposite Millsaps and Newville. This mass of serpentine belongs to an interrupted belt extending through the western part of Tehama County into Trinity County. Chrome mining began here years ago, and up to 1893 more than 3,000 tons had been mined and shipped around Cape Horn to Philadelphia or Baltimore. Operations then ceased until 1915, when the California Chrome Co. began to operate, and for three years this company continued to produce a large quantity of high-grade ore. The ore came from a number of small bodies and was hauled by truck 15 miles to Fruto for railroad shipment. When I visited the mines in 1916 operations were in progress on four bodies, none of which were 100 feet in length. The bodies were irregularly lenticular in crushed serpentine with their greatest extent approximately northeast. From the mines farther north the ore is hauled by wagon 6 miles to a point near Newville and thence trucked about 23 miles to the main line of the Southern Pacific at Orland.

Of the nine producers of chrome ore in Glenn County in 1918 the California Chrome Co. on Grindstone Creek (1[34]), Adams & Maltby at the Pinto and High Point mines (4), and Avery & Son at the Hill mine (3) shipped the largest quantities. Only two other producers shipped their output. The total production of the county in 1918 was 1,986 tons, of which 1,466 tons was shipped and 520 tons remained on hand. There is clearly enough ore in sight at the mines and prospects of Glenn County to warrant the expectation of 1,500 tons of ore as yet unmined, and when the results of more searching prospecting over the western portion of the county are considered, in view of the fact that Glenn County has already been a large producer, it is evident that the possibly available ore may well reach 6,000 tons. The greater part of the ore shipped averaged 40 per cent of chromic oxide; over 100 tons carried above 45 per cent, and 600 tons below 35 per cent. Nearly all the stock remaining unsold at the end of the year was of the 35 per cent grade.

TEHAMA COUNTY.

The mines in the southwestern part of Tehama County, west and southwest of Lowrey, in the drainage basin of Elder Creek, ship their ores by wagon about 3 miles and by truck 30 miles farther, to Red Bluff, at a total cost of about $9 a ton. The Noble Electric Steel Co. began mining here at the Hillside mine (4) some years ago and had a large output in 1917. In the same region are mines operated by the American Refractory Co. (3), Adams & Maltby (2), and W. E. Kleinsorge (5), all of which were considerable producers in 1918. The Kleinsorge mine has a concentrating mill, and these mines yield much ore for concentration.

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[34] The mine numbers refer to the county lists and map (fig. 1).

The mode of occurrence of chromite along the western border of Sacramento Valley is favorable for mining. The peneplain that rims Sacramento Valley at the foot of the Klamath Mountains forms the flat tops of the ridges between the deep canyons of the mountain streams that flow into the Sacramento. The serpentine exposed on the peneplain appears also in the canyon, near water power, where the bodies of chrome ore, generally lenticular and steeply inclined, are most readily taken out in open pits, prepared for market, and hauled into the valley for shipment.

In the northwestern part of the county, within and about the drainage basin of Beegum Creek, the owners of the Tedoc (1) and Beegum mines (1 in Shasta County) have built well-graded truck roads 11 and 5 miles, respectively, from the mines to the State highway near Beegum and thence about 50 miles to Red Bluff. At the Tedoc mine lenticular masses of chromite containing as much as 47 per cent of chromic oxide are in sheared serpentine. Many small bodies have been found. One large body over 100 feet long, 30 feet wide, and 5 to 10 feet thick yielded about 1,500 tons. The same mass of serpentine extends northwestward across the drainage basin of Beegum Creek into Shasta County and includes many bodies of chromite, of which that of the Western Rock Properties Co. in Red Mountain has attracted most attention. One very irregular, cross-jointed dikelike body in sheared serpentine yielded about 250 tons. Some other bodies appear to be large, but owing to lack of cooperative action in that region much of the available ore failed to reach market.

The total ore shipped from Tehama County in 1918, not including that of the Western Rock Properties Co., whose mine is really in Shasta County, was 1,952 short tons. The quantity remaining unshipped in the hands of the producers at the end of the year was 4,790 tons.

SHASTA COUNTY.

Shasta County has been for many years a large producer of chromite, not only on account of the chrome deposits which it contains, but largely because of its excellent facilities for transportation. The main line of the Southern Pacific follows Sacramento River across the western part of the county, which is occupied by a large mass of serpentine in which many deposits of chromite have been found. North of Red Bluff and Redding the railroad shipping points for the chromite of the county are La Moine, Castella, and Dunsmuir. There were 14 producers of chrome ore in Shasta County in 1918, and they mined 3,064 tons. Only 7 of the producers shipped ore, of which the total quantity was 2,019 tons. The three chief producers were the Western Rock Properties Co. at Red Mountain (1), the Union Chrome Co. at Forest Queen (2), and the Noble

Electric Steel Co. near Chromite (4). More than 1,000 tons of mined ore, chiefly at the mines, remained unsold at the end of the year. From what is known of the production and the deposits it is believed that under favorable conditions Shasta County may yet yield a large supply of chrome ore.

TRINITY COUNTY.

Trinity County contains large areas of serpentine in two belts—one in the southern part of the county, west of Weaverville, and the other in the northern part, southwest of Dunsmuir. Both belts contain many deposits of chromite. The State highway from Red Bluff to Eureka, 169 miles long, crosses the Klamath Mountains and affords a convenient outlet for the ore of the southern part of Trinity County. For many miles between Wildwood and Autorest the highway traverses a large area of serpentine which contains numerous bodies of chrome ore. About a dozen of them near the road have been opened and have yielded a considerable amount of ore carying from 40 to 50 per cent of chromic oxide, although the larger proportion is of low grade. The mines are shallow open quarries, and the cost of mining the ore is reported to be from $4 to $5 a ton. Transportation by autotruck to the railroad costs 35 cents a ton-mile, and as some of the ore is trucked 72 miles to Red Bluff the transportation amounts to $25.20 a ton. By an approximately equal haul some of the ore from deposits near the State highway in Trinity County goes to Redding for shipment.

There were 14 producers reporting from Trinity County in 1918, of which the three largest shippers were Neely Bros. (15), O. W. Kay, and Maltos, Green & Volente (17). The total quantity of ore shipped from the county during the year was 1,556 short tons, and at the end of the year 2,729 tons of mined ore remained unshipped, almost wholly at the mines. This large proportion of unshipped ore is due chiefly to the long haul and the fact that the ore bodies were not reached until late in the year.

SISKIYOU COUNTY.

The large irregular area of serpentine that has proved so rich in chromite in Shasta and Trinity counties is more extensively developed in Siskiyou County opposite Edgewood and farther north at many points near the road leading west from Gazelle to Callahan. Beyond Callahan some ore has been packed out of the Cecilville country, the very heart of the Klamath Mountains. The total railroad shipments at Gazelle in 1918 from about 20 mines in the southern part of Siskiyou County amounted to more than 1,200 short tons of crude ore gathered by truck, wagon, and pack train at the mines, some of which are not less than 50 miles from the railroad.

In the northern part of Siskiyou County, however, in the Klamath River region, a greater quantity of chrome ore is produced in the three serpentine areas of Yreka, Gottville, and Hamburg, the ore from which reaches the railroad at Montague and Hornbrook.

The country rock of the chromite is generally dunite, and much of it is altered to serpentine, which has been much sheared. The bodies of chromite are lenticular and commonly vertical, running northeast or northwest. They are of moderate size, few of them containing more than a few hundred tons. Much of the ore is black and compact, ready for market. With it there is much spotted ore that could be concentrated, but concentration has not yet been undertaken.

The Hamburg area, which extends northwestward from the mouth of Scott River, is remarkable for its banded ore, which is well exposed in the Red Mountain mines. The banding in this ore is parallel to the banding in the underlying gneiss, a fact that appears to throw light on the conditions under which the chrome ore was formed. The Klamath River road to Hornbrook, on the main line of the Southern Pacific Railroad, affords an outlet for this ore, and some of it is hauled by trucks nearly 70 miles, at a cost of about 35 cents a ton-mile.

In Siskiyou County there were 71 active chrome prospects in 1918, of which the greater number shown on the map were producers, with total shipments of 6,125 short tons of all grades. Nearly 3,000 tons of mined ore remained unshipped at the end of the year. The three principal shippers were S. H. Dolbear, Milne & Reichman, and the California Chrome Co. The ore ranged in chromic oxide content from 35 to 55 per cent and averaged nearly 45 per cent.

DEL NORTE COUNTY.

In Del Norte County serpentine is one of the most abundant surface rocks, and it contains many bodies of chrome ore that are sufficiently accessible to transportation facilities to warrant mining. The ore bodies are rather large and attracted the attention of the Tyson Mining Co., of Baltimore, many years ago. The company still holds the Rowdy Creek (3), Mountain View (4), and French Hill (11) mines, which are operated under lease by the American Exploration & Contracting Co., and the ore is sold to Adams & Maltby. The ore from these three mines is sent by truck to Crescent City, whence it is shipped by boat to the railroads at Eureka and San Francisco. The ore bodies are among the largest on the Pacific coast, and although they have already yielded much ore they are far from being exhausted. The ore in carload lots carries about 42 per cent of chromic oxide, but much of it is richer.

The High Plateau mine (5), owned by E. J. Hawkins, of Crescent City, is operated under lease by Adams & Maltby, who haul the ore by truck 60 miles to Waters Creek for shipment by rail through Grants Pass. Some of the ore contains 56 per cent of chromic oxide, which is probably much better than average carload lots. The same firm operates the Rattlesnake mine (16). Much ore was extracted in 1918, but owing to the lateness of the season and the decline in demand only a part of the ore mined was shipped. Some of it contained 55 per cent of chromic oxide, and the remainder contained 45 per cent.

A notable group of chrome mines on Gordon Mountain was acquired from George Barton and others in the spring of 1918 by the California Chrome Co. It consists of the Zinc Saddle (6), No. 7 (7), No. 8 (8), Rowen (9), and Madron (10) mines. About 2,300 tons of ore was mined here in 1918, while 18 miles of truck road was being built to get the ore out to the stage road, on which it is 15 miles farther to Crescent City. In the early part of September the truck road was nearly completed, and the removal of the ore commenced, when the demand ceased and no more ore was taken out. Nearly all the ore mined still remains at the mines. It is of good quality and contains not less than 45 per cent of chromic oxide. The mines show much more ore in sight.

At the Red Mountain mine, 14 miles southeast of Requa, near the mouth of Klamath River, more than 500 tons of 40 per cent ore was mined in 1918 and was packed and hauled to the mouth of Klamath River and thence taken by boat to Eureka, but only two carloads were shipped.

Developments thus far indicate large deposits of chromite in the country about Weitchpec and the lower Klamath River.

The total production of chrome ore in Del Norte County in 1918 was 7,903 tons shipped and 4,345 tons not shipped. Del Norte was the premier county of the Klamath Mountains in the production of chrome ore in 1918.

OREGON.

JACKSON COUNTY.

About 10 miles northwest of Ashland, Oreg., in the drainage basin of Applegate Creek, the Applegate (1) and Horseshoe (2) chrome claims were worked by L. H. Van Horn and others. The ore was packed 4 miles and hauled 5 miles by a truck and delivered at Talent for railroad shipment. The ore is reported to contain 45 per cent of chromic oxide. The total shipment was small. Other claims have been reported farther south, near the California line, but they did not reach the producing stage.

A few miles beyond the north end of Pleasant Valley a body of chromite was located by Savage & Robinson and operated in 1918 as the Stray Dog mine (3) by E. Vaughan. The ore contains about

41 per cent of chromic oxide. It lies among small mountains, and by a gentle down-grade haul of 15 miles its ore reached the main line of the Southern Pacific at Rogue River. The production of nearly 100 tons exhausted the deposit.

Farther north, on upper Grave Creek, Cole & Thrasher and G. H. Pease report a small quantity of ore shipped on the main line of the Southern Pacific at Leland.

The total chrome ore shipped from Jackson County in 1918 was only 168 tons, and the reported amount of stock on hand was small.

JOSEPHINE COUNTY.

Josephine County embraces most of the large area of peridotite in southwestern Oregon. It contains many bodies of chrome ore and as a producer ranks next to Grant County in Oregon. Of the active mines, 13 are shown on the map. The three largest shippers in 1918 were the California Chrome Co., the Grants Pass Chrome Co., and the Union Chrome Co. The largest body of chrome ore found in the county was on Illinois River (3), and the mining of this body was begun in 1917 and completed in 1918, yielding a total of about 4,600 tons of shipping ore. The ore body was made up of a number of parallel lenses, one of which was 65 feet in length N. 10° W. and 20 feet thick and dipped about 45° E. The ore generally contained 50 per cent or more of chromic oxide, and but little low-grade ore was found. No purple chrome chlorites or green chrome garnet, such as are commonly seen elsewhere, were noted at this locality. The country rock, dunite, is completely changed to serpentine. Other deposits of value occur in the same region, especially one controlled by the Grants Pass Chrome Co. (8), others by Casey & Daley (7), and one opened by Sordy & Noble on Briggs Creek (9), which is especially remarkable for its concretionary structure.

The Sexton Peak deposits, operated by the Grants Pass Chrome Co., yielded in 1918 several hundred tons of more or less distinctly banded ore that contained about 33 per cent of chromic oxide. A large deposit is reported on Mungers Peak (10), about 15 miles south of Grants Pass, but although much ore is said to have been mined from it little was shipped. The total quantity of ore shipped from Josephine County in 1918 was 5,396 short tons. The estimated stock on hand at the end of the year was about 3,600 tons, and there is a large amount of unmined ore in sight.

CURRY COUNTY.

In Curry County, which lies along the coast, chromite occurs in deposits of beach sand as well as in masses of peridotite. At Port Orford and Gold Beach the sands have been tested but not yet successfully worked for chromite.

In the great mass of dunite that forms Iron Mountain, in the northern part of the county, there are many scattered grains of chromite, but commercial deposits of chrome ore are exceptional. The C. & O. Lumber Co. (2) reports a small production in that locality.

The largest mass of peridotite in the Klamath Mountains lies in Del Norte County, Calif., and Josephine and Curry counties, Oreg. It contains a number of large deposits of chromite. One of them, at the Bald Face mine (1), is in the southeast corner of Curry County. The deposit was located by Costelloe & Keaton and has been leased to Seagrave & Gazzam, who operated the mine in the later part of 1918, but the work of completing a road to the stage road for the long haul of nearly 60 miles to a Southern Pacific Railroad shipping point at Waters Creek long delayed production. I did not visit this property, but it is reported to have been traced for nearly 3,000 feet and to have shown a large tonnage of 42 to 45 per cent ore available.

The total shipments of chrome ore from Coos, Curry, and Douglas counties in 1918 are reported to have been 600 tons, and at the end of the year 1,327 tons of mined ore remained unshipped. The chromic oxide content of the ore ranged from 42 to 50 per cent, with an average apparently of about 45 per cent, and the cost of production and transportation in the longest haul to the railroad is reported to have been $35.70 a ton.

DOUGLAS COUNTY.

Chromite has been produced at three localities in Douglas County—one at the head of Starveout Creek and two west and southwest of Riddle. A considerable quantity of ore shipped from Glendale was mined by the Grants Pass Chrome Co. on the slope of Green Mountain. It had to be hauled 19 miles to the railroad, and nearly half the output remains unshipped. On Nickel Mountain, west of Riddle, a large quantity of high-grade chromite has been mined by the Oregon Nickel Mining Co. The chromite occurs irregularly in small bodies scattered through saxonite. An ore of nickel occurs in the same rock and suggests the similar occurrence which is of great importance as a source of chromite and nickel in New Caledonia.

In 1917 considerable chromite was mined about 10 miles south of Nickel Mountain. In 1918 some ore was mined but none shipped from the Kate C mine.

COOS COUNTY.

Coos County lies on the coast, and ore mined in this county could be shipped by boat from Coos Bay or by railroad from that point to Eugene, on the main line of the Southern Pacific.

The White Rock chrome deposit, on Johnson Mountain, about 25 miles south of Myrtle Point, has been operated by the Krome Co., of Portland, Oreg. There are several bodies reported by S. H. Dolbear, and the ore is said to run as high as 50 per cent of chromic oxide and 5 to 6 per cent of silica. Several hundred tons was mined, and a part of it packed 9 miles to the end of the railroad at Powers. The Johnson Mountain deposits are near the north end of Iron Mountain, in Curry County, where the peridotite is rich in grains of chromite.

The black sands of the Oregon coast, especially in Coos and Curry counties, have long attracted attention and years ago were worked for gold, the chromite being left in the dumps, both along the beach and inland on the shore terrace. These dumps have been recently investigated by the Suffern Co., of New York, with a view to concentration and found to promise a commercial yield of 40 per cent of chrome ore. The successful concentration of the black sands of the Oregon coast would mean much to the State, in providing an output not only of gold and chromite but of platinum, garnet, and other valuable minerals.

DEPOSITS OF CHROMITE IN EASTERN OREGON.

By Lewis G. Westgate.

INTRODUCTION.

The chromite mines and prospects in Grant and Baker counties, in eastern Oregon, are in three areas. One in Grant County, mainly on the south side of John Day River between Prairie and Dayville, will be referred to as the John Day area. Another comprises several

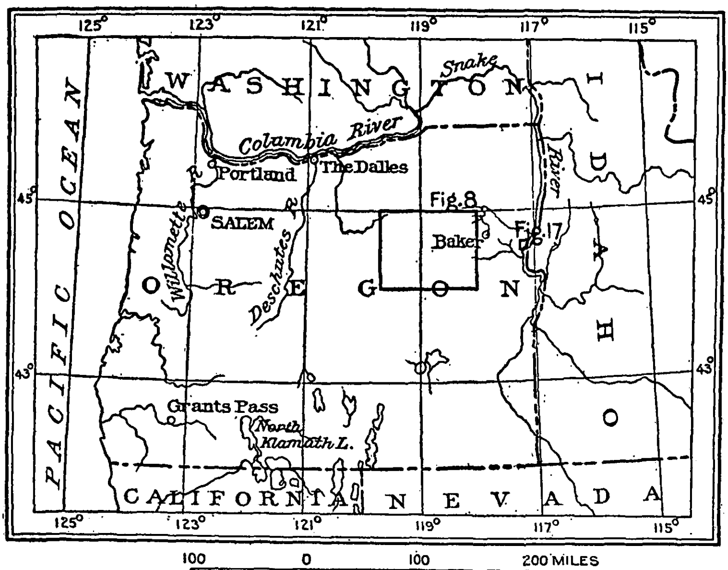

Figure 7.—Index map showing location of areas in eastern Oregon in which chromite deposits occur. (For detailed maps, see figs. 8 and 17.)

groups of prospects near Sumpter, Granite, and Greenhorn, not far from the Baker-Grant county line. As all the prospects, except the one at Sumpter, lie in the basin of Granite Creek and its tributaries, this will be referred to as the Granite Creek area. A small isolated deposit occurs on Connor Creek, a small stream entering Snake River from the west about 12 miles north of Huntington. (See fig. 7.)

The field work in these areas was done from July 31 to August 23, 1918. All the mines and prospects that showed any promise of production were visited, with the purpose of finding out the probable output, particularly in view of the need of chrome ore for the war.

The special purpose of the visit and the limited time allowed for the work did not permit as detailed a study of the general geology and petrography of the serpentine belts and of the ore bodies as would have been necessary if the main purpose had been the study of the genesis of the serpentines and ores; yet the data obtained are helpful toward this larger aim.

The writer wishes to record his cordial appreciation of the uniform courtesy and help given to him by the miners and prospectors of the region and by the members of the United States Forest Service. In particular he would acknowledge his indebtedness to Mr. Percy Swink, of Canyon City, in charge of the mines of the Blue Mountain Chrome Co., the chief operator of the region.

BIBLIOGRAPHY.

The following references to the literature cover the geology of the area and the character and origin both of the chrome ore and of the serpentine rock in which it is found. This list is not intended to be complete, but it will point one who is interested in chrome-ore mining in eastern Oregon to the nearest sources of information, and these first references will suggest others on special aspects of the subject.

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TOPOGRAPHY.

The line between Grant and Baker counties follows the divide between the headwaters of Burnt and Powder rivers, which flow southeastward to Snake River, and the headwaters of different members of the John Day system, which flow northwestward to the Columbia. The largest chromite area, the John Day, lies wholly within the drainage basin of the main John Day River.

Topographically this region is one of high relief, a part of the Blue Mountains of eastern Oregon. North and west of Sumpter are the Elkhorn and Greenhorn mountains, which rise over 9,000 and 8,000 feet, respectively, above sea level and which have many peaks 3,000 and 4,000 feet above the larger valleys. South of the John Day Valley lies the Strawberry Range, its north flank largely serpentine, which has an east-west trend and parallels the course of the river for nearly 50 miles. The only level tracts are in the broader valleys. The mountains are steep and rise to peaks or rounded shoulders, nowhere to upland plateaus.

GENERAL GEOLOGY.

There are in this region two main series of rocks—an older series of sedimentary rocks with some interbedded lavas, cut by igneous intrusives, and a younger series of lavas with associated sedimentary beds.

The sedimentary rocks of the older series are slates and shales with a small amount of limestone, which are believed to be of late Paleozoic and early Mesozoic age (Carboniferous and Triassic). Interbedded with the sediments are lavas. The whole series has been closely folded and to-day shows an east-west strike and a prevailing southward dip between 40° and 70°. The rocks are so monotonous in character and so lacking in fossils and have been so greatly disturbed by folding and faulting that it has not yet been possible to work out their structure in detail.

Into this series of sedimentary rocks were intruded different kinds of igneous rocks, which came to rest far beneath the land surface of that time. The most abundant igneous rock is a granodiorite, which occupies considerable areas in the Elkhorn Range north of Sumpter, west of Greenhorn, and farther southwest, both north and south of John Day River. In places more basic igneous rocks, gabbro and peridotite (or their alteration product, serpentine), cut the sedimentary beds. The serpentine is the rock with which the chrome-ore deposits of the district here considered are almost exclusively associated. Lindgren[1] says:

> This rock, which is rarely found in Idaho and Montana, begins to appear in force as the Pacific province of intrusive rocks is reached. It forms large areas in the vicinity of Robinsonville and Bonanza, in the eastern part of the Greenhorn Mountains, at Susanville, and in the Strawberry Range south of Prairie and Canyon. At all these places it is closely associated with gabbros and allied rocks. This is so constant that one is forced to believe that the serpentine is an altered form of gabbro, perhaps also of peridotite, and that in its original state it was intruded simultaneously with the gabbros, diorites, and granodiorites into the sedimentary series.

The younger of the two series of rocks of eastern Oregon is a succession of lava flows, mostly basalts, with beds of gravel, sand, or clay, the finer of which have been considered lake beds—deposits in lakes that were made by the damming of river valleys by lava flows. Through a large part of the region these lavas conceal the older rocks.

After the folding and the invasion of the older sedimentary series by igneous rocks, the surface of eastern Oregon was of mountainous character. Then followed a long period of erosion, during which the country was brought to a condition of broad, open valleys with low mountain groups rising above them. Then in mid-Tertiary (Miocene) time began a great outpouring of lavas. Flow after flow filled the valleys and rose against the flanks of the mountains, which stood as islands above a sea of lava. After the flows of lava ceased mountain-making forces became active and the lavas were folded and faulted. Streams began carving the surface to its present form. The present areas of older rocks, in which the serpentines and their chrome-ore deposits occur, were either islands never covered by the sea of basalts or were bared by the erosion of the flows.

MODE OF OCCURRENCE OF THE ORE.

There are two main modes of occurrence of the ore. On most of the properties the chromite is in veinlike, lenslike, or kidney-like masses in shattered serpentine. The original rock has usually altered wholly to serpentine, and its earlier character is a matter of inference. On other properties, especially those that include the larger mines, the chromite occurs in veinlike or dikelike masses or in irregular bodies of considerable size, in a more or less serpentinized rock of basic character. This country rock, though jointed, is much less shattered and serpentinized than that of the other class. Practically all the chromite deposits of eastern Oregon belong to the first class, except some of those in the John Day area between Prairie and Canyon City.

[1] Lindgren, Waldemar, The gold belt of the Blue Mountains of Oregon: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, p. 589, 1901.

The eastern Oregon chromite deposits agree with like deposits elsewhere in that they lie in serpentine country rock, and the serpentine is derived from basic rocks of the pyroxenite-peridotite series. The basic igneous rocks in which the Oregon chromite is found were intruded into the slate series probably in mid-Mesozoic time, possibly near the end of the Jurassic period.

THE MINES.

JOHN DAY AREA.

SUBDIVISIONS.

The mines of the John Day area occur in several east-west belts of serpentine, all of which, except two, lie south of John Day River. (See fig. 8.)

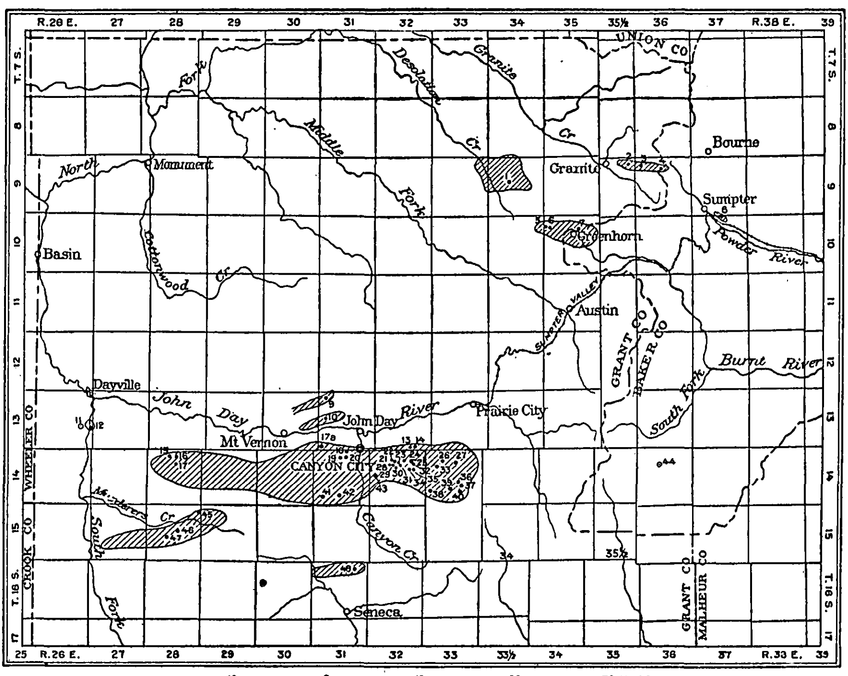


FIGURE 8.—Map of the chrome-bearing serpentine belts of Grant and Baker counties, Oreg. The numbers indicate deposits described in the text.

1. The largest body extends for 30 miles along the Strawberry Range, from a point west of Strawberry Peak to a point about 7 miles east of the South Fork of John Day River. Its average width is 4 to 5 miles, its maximum width 7 miles. On the north it disappears beneath the lavas and outwash of the valley; its south boundary lies roughly along the crest of the range, where the serpentine again disappears beneath the lavas. It makes, then, the north slope of the range.

2. A belt 14 miles long by 2 to 3 miles broad lies southwest of the main belt, on Murderers Creek.

3. A small area about 1 by 6 miles occurs in Bear Valley, north of Seneca.

4. There are two small masses on either side of South Fork of John Day River, 4 miles south of Dayville.

5. Two narrow serpentine bodies, each 1 by 4 miles, lie north of John Day River, east of Mount Vernon.

The third of the belts listed above is an independent belt and is separated from the main area to the north by older slates. The other smaller areas are separated from the main belt by Tertiary lavas and may very well be continuous with the main belt beneath the lavas.

Most of the mines of the John Day area are working lenses in shattered serpentine. Others, especially the larger mines between Prairie and Canyon City, are within vein-shaped or irregular bodies of larger size and different type. These will be described first.

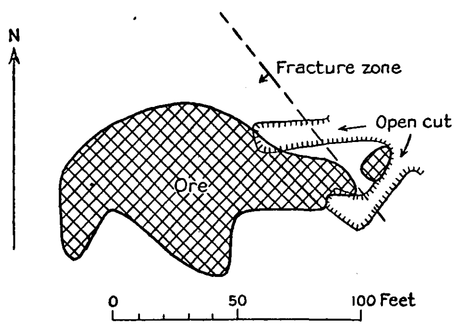


FIGURE 9.—Plan of ore body at Ray mine, Grant County, Oreg.

MAIN SERPENTINE BELT.

RAY (39).[2]

The Ray mine is near the east end of Bald Mountain, at an altitude of 6,900 feet. The country rock is massive serpentinized peridotite, irregularly jointed to good-sized blocks and weathering red-brown. The plan of the ore body, which has sharp contacts against the peridotite, is shown in figure 9. As it is practically undeveloped, its surface outline alone is known. The ore is a medium-grained black rock, consisting chiefly of shining chromite, with small amounts of white or light-green interstitial matter. It assays 32 to 44.70 per cent of chromic oxide. Under the microscope irregular grains of chromite are seen to make up perhaps three-fourths of the rock. The border of the chromite, even against the interspaces, shows only rarely the straight edges of crystal faces. The interstitial matter consists of olivine and monoclinic pyroxene[3] (diopside), of which the olivine is perhaps somewhat the more abundant. A little serpentine shows about the borders or in cracks in the olivine. The ore

[2] Numbers in parentheses refer to corresponding numbers on the map (fig. 8).

[3] The monoclinic pyroxene of this region is apple-green or grass-green in the hand specimens and colorless under the microscope in thin sections, with an oblique extinction in the plane 010 up to 39°. There is no means of knowing the proportions of lime, magnesia, and iron. The mineral is referred to as diopside throughout this paper.

is almost perfectly fresh and unfractured. The chromite may be a result of immediate solidification from a magma, or it may have been introduced by later solutions. The absence of crystal outlines suggests the latter alternative.

SHEEP ROCK (36, 37, 40).

There are three prospects on Sheep Rock, on the east side of Indian Creek.

At Hanenkrat's (40) the rock is identical with that of the Ray mine. The country rock is a black serpentine. The ore body, which has been practically worked out, was wedge shaped, 4 feet wide at the top, narrowing to 1 foot at a depth of 15 feet, below which it was not followed. The ore carried 30 to 40 per cent of chromic oxide.

At Morgan's claim (36) thin sheets and irregular bands of chromite, aggregating 2 feet, occur through a width of 10 feet. The bands bear N. 30° E. and can be followed along the hillside for 250 feet. The adjoining rock is more or less sheeted parallel to the ore bands. The ore bands show to a depth of 10 feet, below which they have not been followed. Besides the bands there are some larger irregular masses. The country rock here is a dull dark-green aphanitic rock. The microscope shows it to be largely serpentine, within which lie cores of unaltered olivine. The original grains of olivine reached 1 centimeter in diameter. A few grains of chromite, the largest 1 millimeter across, with crystal outline, and a very few irregular grains of diopside of about the same size, are the only other original minerals. Besides the serpentine secondary magnetite occurs in minute grains, a few of which show crystal form. The original rock was composed of olivine, with a little diopside and chromite, and was a dunite.

Campbell's claim (37) contains a shallow lens or half lens of spotted ore in black serpentine rock. The bands of ore that make up the lens are clearly defined from the serpentine, and the two are in sharp contact. No change is seen in the ore near the contact.

MARKS & THOMPSON (27).

A large body of low-grade ore occurs on the west side of Indian Creek, and its form and dimensions are shown in figure 10. A smaller body lies 170 feet to the northeast. The main body has been worked in the Marks & Thompson mine to a depth of 25 feet. The country rock is a dark serpentine, in large part massive though jointed and in places broken and crushed. The ore body is of low grade (26 to 34 per cent of chromic oxide, averaging 30 per cent) and fairly uniform, though some parts of it seem thoroughly crushed.

The low-grade ore is medium grained, the grains averaging 2 millimeters, with black chromite scattered uniformly through a matrix of green and brown iron-stained serpentine and making up about half the rock. The microscope shows chromite in irregular to subhedral grains, 2 millimeters or less in diameter. One or two grains only seem to have crystal faces against the serpentine. Magnetite is absent, but a considerable amount of the yellow-brown iron oxide is present. Though none of the original minerals from which

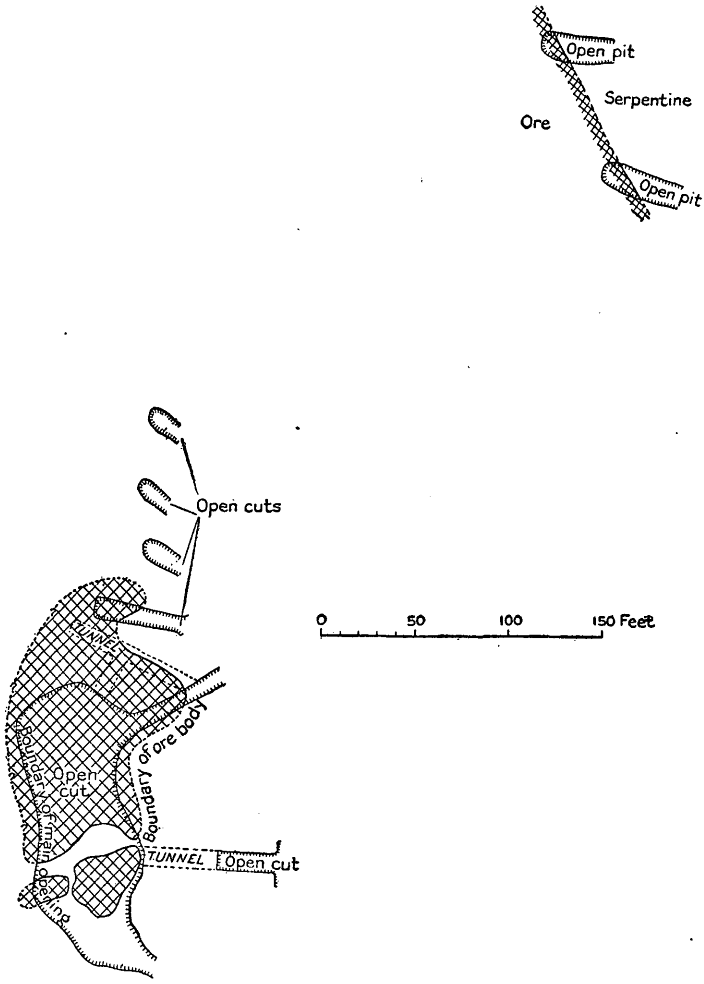


FIGURE 10.—Plan of ore body at Marks & Thompson mine, Grant County, Oreg.

the serpentine was derived are present, the well-developed mesh structure in the serpentine suggests olivine.

Specimens of more broken ore show black medium to fine grained chromite containing small brown or green irregular areas of other minerals. Narrow cracks in the rock are filled with chalcedony. The microscope shows that about 60 per cent of the rock is chromite.

Olivine occurs in polygonal grains 0.5 to 1.5 millimeters in diameter, making irregular aggregates in the chromite. Perhaps half of it has altered to serpentine. Little or no secondary magnetite is to be seen, though there is some staining with iron oxide.

DRY CAMP (33).

The Dry Camp mine is 700 yards east of Little Indian Creek. A plan and section of the openings are shown in figure 11. The ore occurs in bands in serpentine. In the south opening these bands total about 6 feet in a width of 25 feet and dip 80° E. to 90°. In the open cut of the north opening the ore is in bands dipping 70° E. Just at the entrance to the open cut there is a belt of banded ore and rock. Farther in four well-marked bands of ore show thicknesses of 2, 2, 4, and 4 feet, respectively. The band on the right ("black ore") curves down and then up into the roof of the tunnel. Other ore bands in the tunnel probably represent the bands of the open cut. In the glory hole black ore and ribbon ore show. A possible interpretation of the structure is given in the section (fig. 11).

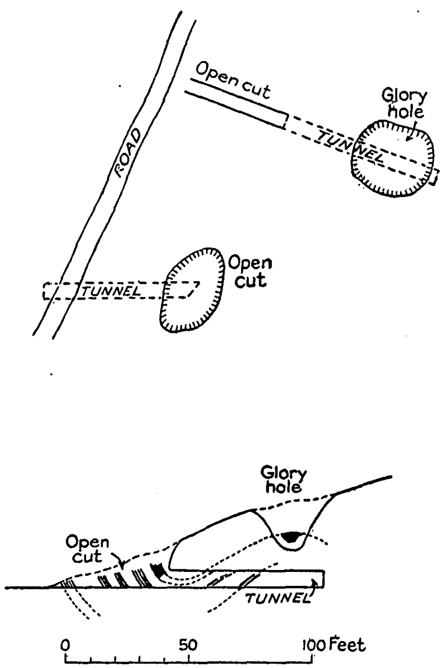


FIGURE 11.—Plan of openings and section of ore body at Dry Camp mine, Grant County, Oreg.

The country rock is a brown serpentine. At the back of the north tunnel it is a dense, fine-grained brown serpentine with fine dark veinlets and shows minute scattered grains of shining chromite. Nearer the ore bands it is the same, except for the absence of the veinlets and for a greater abundance of scattered chromite in irregular grains. Hand specimens of banded ore show bands of chromite which seem to have sharp contact with the serpentine but which under the hand lens show a rather abrupt transition to the rock. The rock contains abundant chromite, and the ore bands show smaller masses of serpentine. The difference between ore and rock lies in the proportion of chromite and serpentine. At the contact there is within a short distance a gradual transition from an aggregate composed chiefly of chromite to one composed chiefly of serpentine.

A hand specimen of the richer ore is black and shows small scattered irregular masses of greenish-white serpentine lying in the chromite. The microscope shows serpentine and chromite, the latter making up nine-tenths of the rock. None of the original material from which the serpentine came is left. The chromite grains nowhere show crystal boundaries against the serpentine.

HOWARD (26).

The Howard mine includes several openings about a mile northeast of the Dry Camp mine. The ore occurs in irregular masses in very much jointed and in places finely broken serpentine. It runs 30 to 40 per cent of chromic oxide.

Two specimens of country rock were taken, one from the lower opening on the Howard property and one along the road to the Dry Camp mine. The first is a green-black fine-grained rock, with grains of green platy enstatite scattered through it. The microscope shows serpentine as the most abundant mineral, but the serpentinization has not gone so far that the original minerals are completely destroyed. These are, in order of abundance, olivine, enstatite, diopside, and chromite. The olivine is much the most abundant and occurs as cores in the meshes of serpentine. The slide shows one large grain (2 millimeters) of enstatite and a few irregular grains of diopside measuring 0.6 millimeter or less. Chromite occurs in subhedral to irregular grains, and some of the latter hook around the serpentine areas in a manner to suggest that the chromite is one of the late minerals of the rock. Besides the serpentine, much fine magnetite (averaging 0.001 millimeter in diameter), some of it with crystal outlines, has resulted from the alteration of the silicates. The rock is a peridotite-saxonite.

The specimen obtained between the Howard property and the Dry Camp mine is an aphanitic dark gray-green rock. The microscope shows it to be mainly an aggregate of olivine (maximum 3 millimeters), altered along cracks to serpentine, which is stained with iron and carries minute magnetite grains. A number of areas of fibrous hornblende are present, possibly altered from pyroxene. A few grains of chromite, the largest 0.4 millimeter in diameter, occur, all anhedral or subhedral. The rock is a dunite.

A specimen of completely serpentinized rock was taken west of the Howard property on Little Indian Creek. It is a greenish-black dense rock that shows slickensided surfaces and breaks with a dull-black fracture surface.

The microscope discloses only a few fragments of monoclinic pyroxene left, but this may not have been the main original constituent. A few scattered irregular grains of chromite are present. The chief mineral is serpentine, in part platy serpentine (antigorite), in part seams of fibrous serpentine (chrysotile). These seams cut the pyroxene and are in turn cut by later seams, which also cut the fractured and locally faulted chromite grains. The serpentinization was a continuing process, and seams made by the expansion of the rock during the earlier stages were filled by later serpentine. Secondary magnetite accompanies the serpentine in grains as much as 0.04 millimeter across, some of which have crystal form.

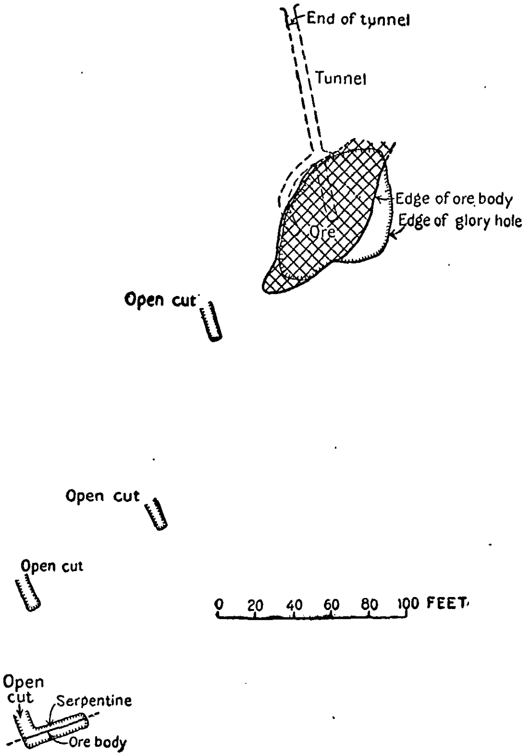


FIGURE 12.—Plan of openings and ore body at Chambers mine, Grant County, Oreg.

The ore from the upper mine of the Howard property is a dense fine-grained dull-black ore, which has been fractured and the seams filled with films of white or rusty serpentine. Under the microscope chromite is seen to make up almost the whole rock, with serpentine in cracks and irregular spaces. The chromite shows no crystal outline against the serpentine.

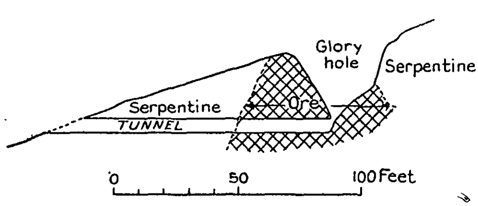


FIGURE 13.—Section of ore body at Chambers mine, Grant County, Oreg.

CHAMBERS (38).

The Chambers mine is on the south slope of Bald Mountain, at the head of Pine Creek. The country rock is a broken serpentine, which usually shows specks of chromite. The map (fig. 12) and section (fig. 13) show the general outline of the body, so far as present workings permit it to be seen. The chromite occurs as a large body of low-grade ore which was first worked in an open cut, now turned into a glory hole. At the surface it is 100 by 40 feet; it has been followed to a depth of 40 feet and is wider at that depth than at the surface. About a quarter of the ore is of too low grade to work and is thrown out. The remainder runs about 31 to 32 per cent of chromic oxide, and the best ore reaches 36 per cent. The large body can not be followed to any great distance east or west. A smaller body has been struck southwest of the main body, and float is found along the hillside for 100 feet farther southwest.

WARD (28).

The Ward mine, southeast of Canyon City, started as an open cut 80 feet long, on a veinlike body that bears N. 70° W. and dips 70°–80° S. Mining has been carried to a depth of 71 feet, and the ore is now reached by a tunnel. The country rock is serpentine and near the ore is hard. The ore is banded; in places the bands are thick and massive; elsewhere they are narrower and lie parallel in the serpentine matrix. Near the surface at the west end of the property banded ore 2 feet thick narrows to nothing at the top. Here several narrow vertical chromite stringers pass off into the serpentine at an angle of 20°, as if following cracks in the serpentine. At the east end the body is cut out at the surface by a fault. At a depth of 50 feet it is slightly displaced by a horizontal fault, and it may be faulted at the bottom. Most of the ore is spotted, though in this spotted ore lie masses of black ore. The ore assays from 31 to 47 per cent of chromic oxide; the best ore shipped contained a little over 40 per cent, and large amounts of 31 to 32 per cent ore have been shipped.

The Ward mine and the McIntyre mine (19) are the only mines in the district that reach any considerable depth (both about 70 feet). The McIntyre goes down on lenses, stringers, and kidneys of ore in crushed serpentine rock. Both mines are on the point of being abandoned.

HAGGARD & NEW (31).

There are two mines and some smaller prospects on Little Dog Creek. The Haggard & New mine consists of a series of openings for 100 feet on a veinlike body that bears N. 55° W. and dips 50°–60° NE. At the lower opening a spotted ore shows through a width of 8 feet, in sharp contact with the inclosing and locally included serpentine. Chromite, in irregular stringers, occurs in the adjoining serpentine and in places connects with the main body. At 15 feet to the northeast a second veinlike body of spotted ore, 2½ feet thick, parallels the larger body. Some ball ore is found, in which the chromite occurs in spheres as large as half an inch. The serpentine is a black fine-grained shattered rock and shows specks of chromite. The ore assays 35 to 45 per cent of chromic oxide.

BLUE GROUSE (23).

The Blue Grouse prospect is below the Haggard & New mine, on the same side of Little Dog Creek. The ore body is in the form of a vein or series of lenses, 2 feet in greatest width, along a broken zone in the serpentine. The strike of the lenses is east, and the dip is 70°–80° N. Two veinlike bodies 8 to 10 feet apart have been followed for 100 feet up the hill. Both spotted and black ore occur. In places along the lower side of the south body is ball ore with spheres of chromite as much as half an inch in diameter.

NORWAY (20).

At the Norway mine, 2 miles west of Canyon City, mining consists in recovering float from the surface dirt. The cover, which is about 2 feet thick, is all moved, and the float is saved. Spotted ore running less than 30 per cent of chromic oxide is thrown aside; only the black ore, averaging 45 per cent, is kept. Over 1,000 tons of float has been recovered from the 3 acres worked; some 30 acres of promising territory remains unworked. The method in use has been locally termed "digging potatoes."

As the loose mantle rock is worked, the outcrops of veinlike bodies at the surface of the bedrock are noted and saved for later mining. These lie in two belts, which make a V opening to the north. The west limb, followed for 600 feet, bears N. 30°–35° W. and dips steeply west; the east limb, half a mile long, bears N. 20°–40° E. and is vertical. The adjacent rock is a shattered serpentine, though the outside barren rock, both within and without the V, is solid, basic, and less serpentinized. The ore in the serpentine occurs in veinlike or lenslike bodies, which contain from 26 to 47 per cent of chromic oxide; the average of the better lenses is about 42 per cent. Veins of aragonite cut the serpentine.

About 1,800 feet north of the Norway workings is a vein-shaped body of chromite, which bears N. 45° E. and dips 60° S. The south wall is a massive coarse-grained serpentine; the north wall a crushed serpentine. The body has been followed for 200 feet and is 2 feet in maximum thickness but averages between 8 and 10 inches. Some side stringers of chromite occur in each wall, particularly in the south wall.

IRON KING (43).

The Iron King mine is the largest property that works isolated lenses in the serpentine. It has produced over 6,000 tons of ore averaging 32 per cent of chromic oxide. The mine is 3½ miles southeast of Canyon City, just below the crest of the east side of Canyon Creek valley. The ore occurs in lenses in shattered serpentine and is worked by a large open cut. One lens on the back face of the cut showed dimensions of 10 by 4 feet. The whole rock is quarried, the ore being taken out as the lenses are reached, and the low-grade ore and serpentine are thrown into the dump below the quarry. No vein or lead is followed.

The shattered serpentine is separated from the firmer rock on the north by a curving slickensided fault face striking N. 70° W. and dipping 55° S. About 50 feet to the south the southern boundary appears to be a fault face. Float has been found eastward up the

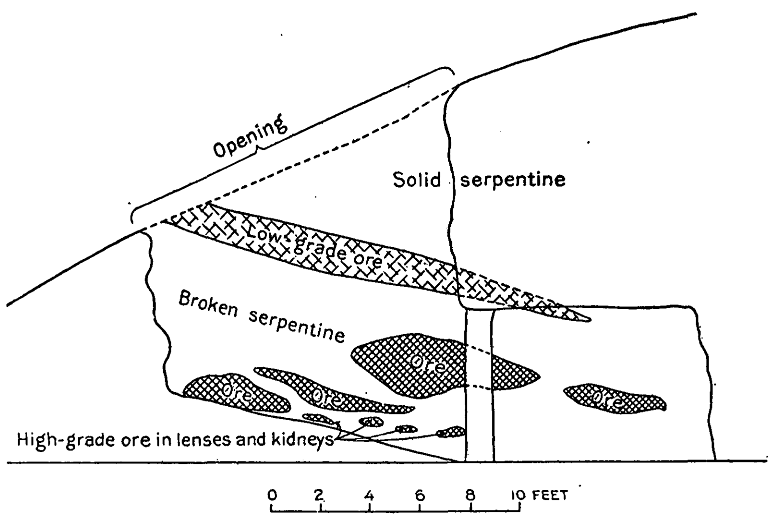


FIGURE 14.—Vertical section showing lenses of chromite at Smith & Geitsfield opening, Grant County, Oreg.

hill as far as a belt of coarser, massive serpentine, which makes a series of outcrops bearing N. 25° W. Between the massive serpentine and the shattered serpentine is serpentine breccia, cemented to a resistant rock. Some aragonite is found in veins and crystals in cavities in the serpentine.

SMALL PROPERTIES ON LENSES.

The small properties described below are working lenses of chromite in shattered serpentine.

Lyon (41).—The Lyon prospect consists of lenses and kidneys of chromite 2 or 3 feet in greatest thickness, which have no recognized general trend. The ore is black and assays 31, 33, and 35.7 per cent of chromic oxide; the average is 35 per cent.

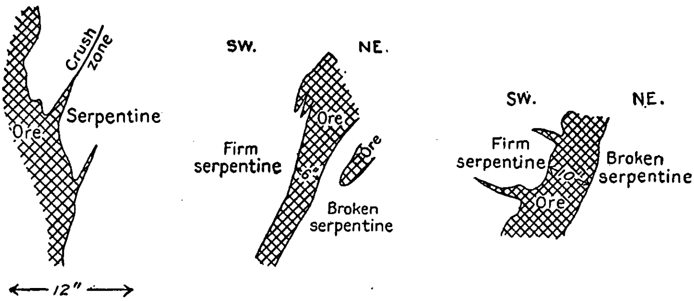
Patterson & George (42).—The Patterson & George prospect has lenses and kidneys similar to those on the Lyon prospect. The ore assays 42 and 47 per cent of chromic oxide and averages about 45 per cent.

Kingsley (30).—The Kingsley prospect consists of lenses of chromite in sharp contact with serpentine. The shattered serpentine, with no well-marked wall, is in contact with more massive basic rock.

Smith & Geitsfield (18).—The form and size of the lenses in the Smith & Geitsfield prospect are shown in figure 14.

Reed (13).—At the Reed prospect there is a veinlike body 2 feet in maximum thickness, extending 100 feet along a crushed zone in serpentine. The strike of the body is N. 60° W., and the dip is 50° NE. Black ore occurs in the thinner parts and spotted ore in the thicker parts.

Campbell (14).—A vein-shaped body on the Campbell claim extends for 40 feet and has a greatest thickness of 1½ feet. It strikes



A B C

FIGURE 15.—Sections of chromite veins on Louie (A) and Campbell (B, C) claims, Grant County, Oreg.

N. 60°–65° W. and dips 65° S. The south or hanging wall is shattered serpentine; the north wall is firmer. Both contain specks of chromite. A detail of the edge of the body is shown in figure 15.

Powers (21).—At the Powers mine lenses and irregular masses of both spotted and black ore are found for 250 feet along a zone of crushed serpentine. The crushed zone is between 1 foot and 8 feet in thickness and lies between walls of solid serpentine. Some of the ore assays 50 per cent of chromic oxide, and carload lots averaging 42 per cent have been shipped.

Louie (32).—Lenses, stringers, and irregular bodies of rich soft chrome ore, constituting what is called the Louie lode, occur in a black fine-grained broken serpentine, which weathers buff. The rock is thoroughly jointed and is cut in many places into large blocks by 1-inch seams of crushed serpentine. Along the line of the ore bodies it is generally completely shattered. Veinlike and irregular masses of ore occur in the serpentine, apart from the main body. Figure 15 shows a detail of the edge of the ore against the serpentine. The ore assays 50 to 52 per cent of chromic oxide. The silica content is about 4 per cent.

Accident (35).—Spotted and black ore occurs in irregular masses and lenses, without any general trend, in black fine-grained serpentine, over an area 80 by 80 feet on the Accident claim. Fine grains of chromite are found in the serpentine. The ore carries from 39 to 57 per cent of chromic oxide.

Anderson (34).—At the Anderson mine, up the hill from the Accident, black ore occurs in lenses and bands as much as 8 inches thick, in hard serpentine.

DUNN (17a).

The Dunn mine is on Fall Creek 4 miles west of Canyon City. A large mass of ore 20 feet long, 3 to 4 feet wide, and showing 6 feet in height along the side of the hill lies in shattered serpentine and has a smooth and curving contact against the serpentine. It carries 35 per cent of chromic oxide.

PROPERTIES NEAR WEST END OF BELT.

Several properties toward the west end of the main area, on Fields Creek, are described below.

Queen of the May (16).—Irregular lenses in crushed serpentine are found at the Queen of the May mine. The ore carries 36 to 41 per cent of chromic oxide.

Uncle Sam (15).—The Uncle Sam mine has ore similar to that at the Queen of the May.

Stone & Hawkins (17).—The ore and inclosing rock at the Stone & Hawkins mine are similar to those in the Queen of the May. The ores runs 38 to 42 per cent of chromic oxide. The ore body in the pit is part of a large lens that bears N. 50° E. At a depth of 12 feet it is 12 feet wide; 2 feet lower, at the bottom of the pit, it has narrowed to 8 feet.

MOUNT VERNON SERPENTINE BELTS.

Two belts of serpentine lie within the lava area north of John Day River, between Mount Vernon and John Day. A few small prospects have been opened on small lenses, and one mine of larger size has been operated.

The ore at the Silver Lease mine (10) occurs as shoots that pitch 50° or more to the east. The inclosing rock is a thoroughly broken serpentine, along certain zones very finely broken. The contacts between ore and serpentine are sharp and show movement. The content of chromic oxide in the ore varies between 25 and 34 per cent, and carloads averaging 28 per cent have been shipped. Two different igneous rocks cut the serpentine and ore. One near the entrance to the tunnel is an acidic dike rock. The other is very much weathered and broken, as if it had shared in the fracturing of the serpentine.

MURDERERS CREEK BELT.

The Murderers Creek serpentine belt is about 13 miles long and 2 to 3 miles wide and bears a little south of west. Three prospects were seen, and in all three the ore occurs as lenses or kidneys in broken serpentine.

At the Hankins mine (45), 1 mile north of the creek, two large lenses and a number of smaller ones are well exposed. The inclosing rock is a broken green-black serpentine, waxy in many places. The ore is black, not spotted, and is separated from the inclosing rock by sharp contacts, marked by movement surfaces. The larger of the two lenses is shown in A, figure 16, where the directions of dip of the walls are indicated. This lens was reported to have stood originally 8 feet above the surface of the ground. The other lens is shown in B, figure 16.

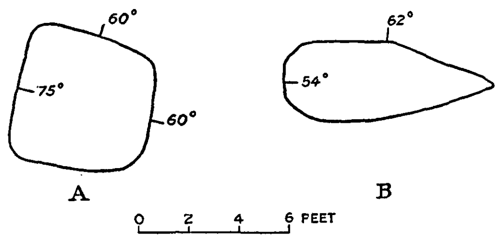


FIGURE 16.—Ore bodies at Hankins mine, Grant County, Oreg.

Two prospects on the south side of the creek, the Shelby & Hamer (46) and Delore (47), show a similar method of occurrence.

SENECA.

About 5 miles north of Seneca there is a small belt of serpentine. At Vancils (48) 124 tons has been mined from float; the largest mass found weighed 10 tons. The assays averaged 45 per cent of chromic oxide. No ore has yet been found in the bedrock.

SOUTH FORK OF JOHN DAY RIVER.

On the South Fork of John Day River 4 miles south of Dayville two areas of serpentine emerge from beneath the lavas. On the east side of the river (12) 10 tons of black chrome ore containing 45 per cent of chromic oxide has been produced, but the deposit is now exhausted. About 1,000 feet above the river, on its west bank, on the O. R. Mascall claims (11), chromite occurs in small narrow lenses and masses, connected by narrower stringers, in a serpentine so much broken that it can be easily dug with a hand pick. Very little ore is in sight, and there seems to be little promise of production in this area.

GRANITE CREEK AREA.

Several belts of serpentine lie near the Baker-Grant County line, between Sumpter and Olive Lake.

SUMPTER BELT.

A small belt, a quarter of a mile across, centers 2 miles southeast of Sumpter and bears north of west. It has not been traced to its west end, and on the east it runs beneath the alluvial floor of Sumpter Valley. The rock is a talc or carbonate-talc rock of variable character. A common type is a fine-grained massive light-brown rock, mottled with gray. The microscope shows that about nine-tenths of it is an aggregate of talc scales, and most of the remainder consists of irregular grains and aggregates of dolomite, as much as 0.3 millimeter in diameter. A few grains of magnetite, both with and without crystal outlines, the largest 0.4 millimeter across, a little scaly serpentine, and rusty-brown translucent iron oxides make the small remaining portion. Other specimens consist of a greener talc rock.

The ore at the Gardner mine (8), 2 miles southeast of Sumpter, shows shining black grains of chromite in a black aphanitic base. It assays 37.60 to 51 per cent of chromic oxide, and carload lots averaging 43.46 per cent have been shipped.

The ore occurs in lenses and kidneys in crushed talcose rocks and is most abundant in the more shattered seams or zones. These vary in position; one seam strikes N. 50° W. and dips steeply northeast; another strikes N. 40° E. and dips southeast. Little ore was in sight at the time of the writer's visit.

GRANITE BELT.

A nearly east-west belt, somewhat over 5 miles long, lies east of Granite. Several properties in this belt were examined.

MEADOWS & DUCKWORTH (2).

The country rock adjacent to the ore on the Meadows & Duckworth property is soapstone. It is a fine-grained massive rock of light-brown color, mottled with gray. The microscope shows that over two-thirds of it is an aggregate of talc scales; the remainder is mainly dolomite. The dolomite occurs in irregular grains and aggregates 1.5 millimeters in maximum diameter. Some of the dolomite grains show partial development of crystal faces. One irregular and broken grain of chromite is present in the thin section examined. Black dust (iron oxide) is scattered through it.

The ore is dark, fine grained, and speckled and carries chromite in irregular grains in a cement that appears to the eye like the adjacent country rock. A single assay gave 35 per cent of chromic oxide. The ore occurs in lenses and bands 2 to 3 feet thick, through a breadth of 10 feet. Green serpentine shows as float north of the prospect but is not present at the mine.

FORD & MYERS (3).

At the Ford & Myers mine the ore is found in a series of openings on a zone of broken serpentine that strikes east and dips 70°–80° N. The broken zone is from 4 to 8 feet wide and is clearly separated from the adjoining more massive serpentine. The ore is a low-grade spotted material, which has been followed down to a depth of 22 feet, where the body is 6 feet wide and 8 feet long and pinches out at the east end.

OLIVE LAKE (1).

The Olive Lake mine consists of a series of openings in shattered green serpentine. The largest opening has gone down 30 feet on a line of lenses that runs N. 30° E. and pitches 70° E. The ore occurs as kidneys or lenses, the largest weighing a ton, and follows a line of broken serpentine which has firm serpentine on the hanging wall. Similar openings have been made for half a mile in a northwesterly direction. The ore runs from 42 to 58 per cent of chromic oxide, and lots averaging 44.20 per cent have been shipped. West of the mine, across North Fork, an outcrop of low-grade spotted ore 6 feet wide has been opened to a depth of 10 feet.

GREENHORN BELT.

In the Greenhorn belt several small prospects are found in serpentine. One of these, the Campbell prospect (6), is just above the Bimetallic mine, on a branch of Salmon Creek, where perhaps 15 tons of ore is in sight. The Combs prospect (5) is on the Clear Creek side of the divide, at the head of Salmon Creek, where a lens of ore 5 feet in maximum width follows a seam in solid serpentine.

CONNOR CREEK AREA.

Chromite is found on Connor Creek, a small stream entering Snake River from the northwest some 13 miles north of Huntington. The rocks of the region are mapped by Lindgren[4] as limestones and

[4] Lindgren, Waldemar, op. cit., pl. 64.

shales of probable " Jura-Trias " age. The ore is found in a belt of talc-carbonate rock, which crosses the creek in a N. 50° E. direction. The property of the Kromite Mining Co is west of the creek; that of Lambert & Flick east of it. (See fig. 17.)

KROMITE MINING CO. (49).

On the Kromite property the ore lies in a band of gray or white rock resembling crystalline limestone. It is in part nearly massive, in part well though somewhat unevenly banded or schistose. The band is 200 feet across at Connor Creek but wedges out before reaching the Fox Creek divide, to the west. It strikes N. 50° E. and dips 70° NW. The surrounding rock is a blue limestone.

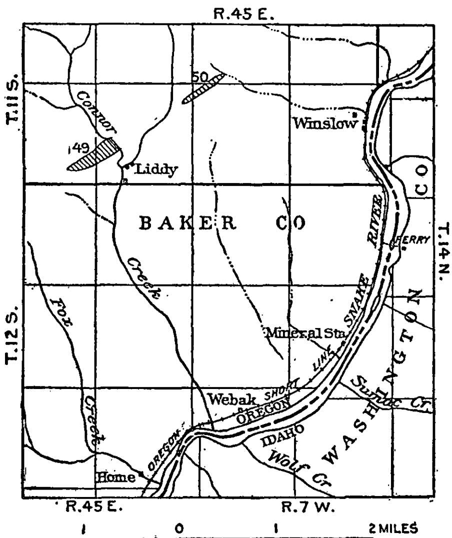


FIGURE 17.—Map showing location of chromite properties on Connor Creek, Baker County, Oreg.

A hand specimen of the rock is light gray, irregularly banded and streaked with shades of lighter and darker gray. The microscope shows talc, dolomite, a little serpentine, and minute amounts of pyrite and iron oxide. Three-quarters of the rock is an aggregate of talc scales. Dolomite in irregular grains and aggregates, with a few grains showing a tendency to rhombic outlines, makes up about a quarter of the rock. A single grain of chromite shows in the section examined. Chromite in scattered grains is common in the talc-dolomite rock near the ore. The talc-dolomite rock is probably a product of alteration from serpentine and represents an intrusive mass in the blue limestone.

Chromite occurs as a spotted ore in small irregular masses, with sharp contacts, usually against solid rock. Single hand specimens can be gathered showing ore and rock firmly united. The largest body seen was an irregular seam or compound seam, 8 feet long by 1½ feet wide, at the bottom of an opening 5 to 10 feet in depth. It is said that the ore assays as much as 50 per cent of chromic oxide and that two car lots of 32 and 35 per cent ore have been shipped.

Serpentine was reported to occur to the southwest along the strike, toward Fox Creek, but was not seen by the writer.

LAMBERT & FLICK (50).

The ore on the Lambert & Flick property occurs in a belt of crystalline talc-dolomite rock (perhaps altered serpentine) 200 feet or more wide, which strikes N. 60° E. and dips 70°–80° E. The talc-dolomite rock here and that across Connor Creek bear toward each other, but it is not known that they are actually connected.

The talc-dolomite rock is thoroughly crystalline, is broken, and contains a large amount of silica, both quartz and chalcedony, filling fractures and in places making flinty masses of considerable size. It is locally cut by dikes of a dark rock (diabase?), 5 feet or less in width. No serpentine was noted, unless some greenish parts of the talc-dolomite rock contained it. Grains of chromite are common. Two specimens of the talc-dolomite rock were sectioned. One in the hand specimen is a gray fine-grained rock, showing small grains of dolomite embedded in an aphanitic base.

The microscope shows that dolomite makes up over three-fourths of the rock. Aggregates of talc scales constitute most of the remainder, but much of the area between the dolomite grains is an opaque white fibrous aggregate. A little serpentine is present. Pyrite occurs in small irregular grains and in the hand specimen in small veinlets. Magnetite is abundant. One grain is 1 millimeter square, but most of the magnetite is in fine grains, usually with crystal outlines. Opal and chalcedony fill cavities and veinlets in the section.

The second specimen was taken near the basic dikes. The hand specimen is a gray fine-grained rock, spotted with grains and aggregates of chromite that average 1 millimeter in diameter. Under the microscope this rock is seen to consist of dolomite, chromite, and talc, in the order named. The dolomite occurs in irregular grains and aggregates, the largest over 1 millimeter across. The talc is in fibrous aggregates. Chromite occurs in irregular grains 1 millimeter or less in diameter and does not show crystal outlines. Its grains are cracked, and the cracks are filled with talc.

The ore is a mixture of dark chromite and green or white filling and assays from 24 to 42.85 per cent of chromic oxide; the average is perhaps 30 per cent. It occurs in lenses sharply separated from the talc-dolomite rock, which next to the contact is solid. Crushed and schistose talc-dolomite rock is present but is independent of the ore bodies. Several lenses, the largest 8 or 10 feet long by 2 to 3 feet thick, lie parallel to the banding of the talc-dolomite rock.

ORIGIN OF THE SERPENTINE.

The serpentine is derived from the alteration of basic igneous rocks belonging to the peridotite family. The chief mineral and in some places the only mineral of the original rock is olivine; it may therefore be named dunite. The accessory minerals are orthorhombic pyroxene (enstatite) or monoclinic pyroxene (diopside). Chromite is also a constant accessory mineral.

The peridotites and associated coarse-grained igneous rocks are shown by earlier field work in the region to be intrusive into the slate series, probably in late Jurassic or early Cretaceous time. The folding of the slates belongs to the same general period.

No light is thrown on the question whether the waters that caused the serpentinization were deeply descending surface waters or magmatic waters originating either in the peridotite itself or in the parent magma from which it was derived.

In several areas there are soapstones and talc-dolomite rocks which in places contain remnants of serpentine. These rocks represent a further stage in the alteration of the original basic intrusives.

ORIGIN OF THE CHROMITE.[4a]

The constant occurrence of chromite in small masses throughout the serpentine and the peridotites from which the serpentine is derived makes it certain that the origin of the chromite is to be sought in the molten peridotite magma. The concentration of the chromite in workable masses in the serpentine may have come about in three ways:

1. It may have been due to an early crystallization of the more basic minerals at the time of the original solidification of the rock, the chromite masses being analogous to the darker " schlieren " with more abundant biotite and hornblende found in granites.

2. The chromite may have been introduced toward the end of the period of solidification, after the main body of the rock was substantially solid. In that case masses of the more basic rock were forced into cracks in the already solidified yet possibly pasty peridotite.

3. The chromite may have been introduced by circulating waters into the serpentine or peridotite after they had solidified, replacing to that extent the earlier substance of the rock.

It is not thought that the last method played any part in the formation of the ore bodies. The chromite and originally associated silicates appear to belong to the same general period of mineral formation. The attempt will not be made to decide between the first two methods of origin. It is likely that each had its part in the concentration of the chromite, and that the relative share of each differed in the different ore bodies. The kidneys and lenses in the

[4a] Diller, J. S., Recent studies of domestic chromite deposits: Am. Inst. Min. and Met. Eng. Trans., vol. 63, pp. 120–129, 1919.

thoroughly serpentinized rock have been affected by the movements due to change of volume in serpentinization.

The occurrence of chromite in a country rock consisting largely of talc, between Granite and Sumpter, seems not different from the occurrences already described. Serpentine is found near by, and both are probably derived from some member of the peridotite series.

The Connor Creek chromite, associated with talc-dolomite rock, is also similar in general method of occurrence to the other chromites in eastern Oregon. The talc-dolomite rock lies within an area of limestone and locally contains remnants of serpentine, although in the field it shows many characteristics of an impure marble. It is probably a dolomitized serpentine or soapstone.

CHROMITE MINING.

QUALITY AND AMOUNT OF ORE.

Chemically pure chromite is $FeO.Cr_2O_3$, and chromite with that composition should yield 68 per cent of Cr_2O_3. As a matter of fact no ores actually reach this grade, partly because of the presence in almost all chrome ore of more or less of the gangue rock and partly because Al_2O_3 and Fe_2O_3 may have replaced the Cr_2O_3 in varying amounts and MgO may have replaced the FeO. At but three mines in eastern Oregon is the average composition of the ore reported at or above 50 per cent of chromic oxide. More mines are shipping ore running 30 to 40 per cent than over 40 per cent. None are shipping ore of lower grade than 30 per cent.

It is impossible to make any close estimate of the total amount of chrome ore remaining in eastern Oregon, for two reasons—many of the mines are working lenses of no large size and the amount of ore in sight is small, and at the mines opened on larger bodies development work has not been carried ahead of actual mining operations so as to show the full possibilities of production. The bodies of low-grade ore are the larger. An estimate of the amount of ore in sight in the summer of 1918 gives 4,000 tons of ore running 40 per cent or more of chromic oxide and 25,000 tons running from 30 to 40 per cent. The total quantity of chromite in the ground in this region is doubtless much greater than this, hidden ore bodies probably occurring both at the mines now being operated and in other serpentine areas where chromite is not now known.

PROSPECTING AND MINING.

Chromite is a black, opaque mineral occurring in disseminated grains and in compact masses. Its crystals are octahedral, but crystals were not seen at any of the localities in eastern Oregon. Its hardness is 5½—that is, it can fairly readily be scratched with a knife—and its specific gravity is 4.4. A constant characteristic is its brown streak or powder, which can be obtained by scratching with a knife. Chromite closely resembles magnetite in color and crystal form. Magnetite differs in that it is harder—it can not easily be scratched with a knife—has a black streak, and can be attracted by a magnet.

As chromite weathers less readily than the serpentine in which it is contained, masses of chromite are found in the loose residual rock above the bedrock. Many of these masses are large, one near Seneca (p. 53) having furnished 10 tons of ore. Prospecting consists in a search for the fragments of chromite (float) on or in the soil and an attempt to locate the body from which they were derived. As the chromite is almost invariably associated with pyroxenite or peridotite, or the serpentine or talcose rocks derived from them, search in areas of other rocks is not worth while.

The mining of the ore is a very simple matter. In most of the mines it consists merely in digging out the lenses or masses that are exposed at the surface. Other lenses doubtless exist below the surface, but they are not connected in such a way that their presence can be known, and exploratory work under such conditions is very expensive.

In a few of the mines the ore body is more veinlike or dikelike, and mining can be carried to a greater depth. At two mines, the Ward and McIntyre, which have reached a depth of 70 feet, the ore bodies are of this type, and a few others of similar character may ultimately be worked to as great or even greater depths.

PRODUCTION.

Most of the mines in eastern Oregon were not in operation before 1917. As all the ore shipped from the region, except that from Connor Creek, passes out to Baker over the Sumpter Valley Railway, the following figures will give the production for 1917 and 1918.

Chrome ore shipped over the Sumpter Valley Railway in 1917 and 1918, in long tons.

	1917	1918		1917	1918
January	226	354.9	August	402.6	1,857.1
February	163.2	349	September	476.8	2,033.0
March	254.4	267.7	October	236.3	1,362.5
April	48.4	712.2	November	333.6	1,420.5
May	89.1	1,281.8	December	587.6	1,133.9
June	303.9	1,307.1			
July	575.2	1,486.9		3,697.1	13,566.6

Shipments from Connor Creek will add 80 tons to the total for 1917 and perhaps 100 tons to that for 1918.

CHROMITE ORES IN WASHINGTON.

By J. T. Pardee.

INTRODUCTION.

Deposits of chromite in serpentine on Cypress Island, Skagit County, and near Mount Hawkins, Kittitas County, Wash., were developed during 1917 and 1918. A total production of about 200 tons is reported, most of which contained between 45 and 50 per cent of chromic oxide. One lot from Cypress Island that contained 25.5 per cent was milled in the Faust Concentrating Co.'s plant at Seattle, yielding coarse and fine concentrates that contained in round numbers respectively 44 and 50 per cent of chromic oxide. Samples from the deposits near Mount Hawkins are said to assay as much as 51 per cent of chromic oxide. These high percentages indicate that in composition the chromite approaches the theoretically pure mineral as represented by the formula $FeO.Cr_2O_3$ and contains no great amount of ferric oxide or other substance capable of replacing the chromic oxide. It is therefore probable that the Washington deposits will yield material suitable for use in industrial chemistry as well as for the manufacture of ferrochrome and chrome bricks.

In both the localities mentioned small bodies of high-grade ore remain, and on Cypress Island several thousand tons of material carrying from 10 to 25 per cent of chromic oxide and capable of concentration is estimated in reserve. Chromite is also reported in places in the serpentine areas surrounding the deposits already developed. Elsewhere in the northern Cascade Mountains there are areas of serpentine that probably will prove to be sources of chromite. That they contain more or less of this mineral is indicated by reports of considerable chromite sand in the stream deposits along tributaries of Skagit and Wenatchee rivers and in the Sultan Basin near Index. A serpentine dike near Okanogan is also reported to contain noteworthy amounts of disseminated chromite.

Some of the deposits on Cypress Island were visited by the writer in September, 1917, and the Burke prospect, near Mount Hawkins, was seen in July, 1918. Information about other deposits was obtained from the operators and from prospectors.

CYPRESS ISLAND.

HISTORY OF MINING.

Chromite ore was mined on Cypress Island in 1917 by the Bilrowe Alloys Co. for use in its smelter at Tacoma. Prior to this no production is reported, but a moderate amount of development work had been done on several claims that were located 15 or 20 years earlier. In 1918 development work was extended, several new bodies were found, and a moderate amount of ore was produced by the Cypress Chrome Co.

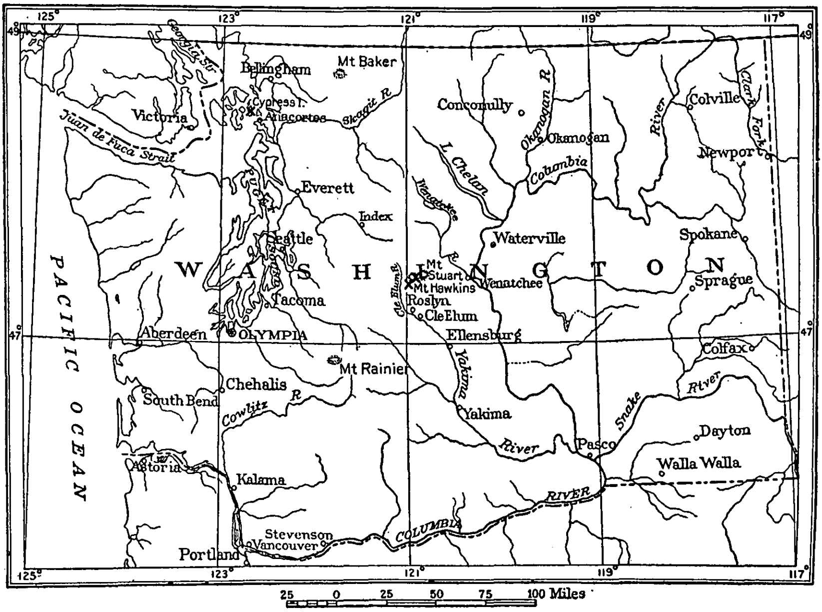


FIGURE 18.—Index map showing location of chromite deposits (×) in Washington.

GEOGRAPHY.

Cypress Island is a part of the hilly San Juan archipelago which separates Puget Sound and Juan de Fuca Strait from the waters of Georgia Strait. (See fig. 18.) It is about 10 miles due west of the mainland at Samish Bay, 4 miles northwest of Anacortes, the nearest railroad point, and about 80 miles by water from Seattle. The island is about 5 miles long from north to south and 3 miles wide in the middle. The surface is hilly throughout, and the main summit reaches an altitude of 1,530 feet. Many of the slopes are steep and cliff-like, and all projecting areas are well smoothed and rounded by Pleistocene glaciation. Most of the stream channels seen by the writer during a traverse across the island in September were dry, though it was evident that they carry more or less water in the rainy seasons. There are several small swampy meadows and a lake a quarter of a mile long near the center of the island, at an altitude of 900 feet.

GEOLOGY.

So far as known the island is underlain entirely by serpentine. Except a few patches of glacial drift no other rock was seen in a traverse from the east to the west shore or reported by persons familiar with the other parts of the island. The outcrops are numerous and extensive and are colored a deep brown on the roughened weathered surface. The weathered layer is very thin, however, and the fresh rock shows the smooth curved fractures and predominating dark-green shades characteristic of serpentine generally. The microscopic texture of several specimens examined suggests that the serpentine was derived from olivine. The rock is traversed by many persistent shear or joint planes of a general northerly direction, and fault planes that trend eastward are exposed by some of the workings.

PHYSIOGRAPHY.

A general northwesterly trend is shown by the main divides and by numerous steep scarplike slopes. Several valleys of uneven depth maintain a similar direction regardless of the general slope. These valleys are probably of structural origin, though they were excavated largely by the Pleistocene glacier, which moved from north to south. On Cypress Island, as well as on most of the other lands about Puget Sound, the general surface profile, which shows rather moderate slopes inland, becomes very steep as it approaches the shore and plunges beneath the water. Therefore boats and barges can approach the shore closely, and, as the water surface is generally smooth, cargoes can be taken on or off almost anywhere.

ORE BODIES.

Distribution and occurrence.—Chromite is scattered through the serpentine in many places, in several of which it is sufficiently abundant to form workable ore bodies. The largest body of this description observed by the writer is on the Ready Cash claim, on the steep west slope of the island, about 1,100 feet above sea level and three-quarters of a mile from the shore. It was developed by an open cut 10 feet wide, 15 feet long, and 6 feet deep, from which about 25 tons of ore was mined. The serpentine is traversed by persistent narrow veins or seams that trend N. 25° W. and are filled with a rather soft light-green claylike material, apparently a decomposition product of the rock itself. Locally the seams are accompanied by chromite, which forms irregular veinlets an inch or more thick and bunches or pockets a foot or more in diameter. The surrounding masses of serpentine also contain more or less chromite in the form of scattered grains. On the south side of the cut a face 6 feet high and 6 feet wide was estimated to be about half serpentine and half chromite. On the north a fault that strikes N. 75° E. and dips 60° S. cuts off the ore. In 1918 the Cypress Chrome Co. developed this body further, extending its known limits considerably and mining about 50 tons of ore.

On the southwest side of the island, on one of several claims belonging to the estate of George B. Smith and others, a short distance west of Mexican Bay, a small ore body is exposed by an open cut and short drifts. These workings are made along a fault plane that strikes N. 70° E., dips 80° N., and carries 2 or 3 feet of crushed and mixed serpentine and chromite. Small bunches and stringers of chromite are also scattered through the serpentine in the hanging wall. At a level 70 feet below the open cut an adit is driven N. 65° W. for 60 feet, following prominent joint planes that dip 45° SW. In this working small bunches and streaks of chromite occur sparingly.

At the lake near the center of the island an adit level is driven northward 120 feet into the serpentine without disclosing more than a few grains of chromite, but several small streaks of chromite are said to crop out on the hill above. Several other claims belonging to the Smith estate and reported to contain chromite were not examined.

Bodies made up of chromite grains thickly disseminated in serpentine were discovered a short distance south of the lake by the Cypress Chrome Co. while building a road from Strawberry Bay to the Ready Cash claim. A shipment from one of these bodies was milled at the Faust Concentrating Co.'s plant in Seattle. Other similar bodies are reported to occur short distances west and south of the Ready Cash claim.

Character and composition.—Ore from the Ready Cash body consists of rather coarse granular chromite intergrown with small amounts of a micaceous amethystine or rose-red mineral identified as the chrome chlorite kotschubeite. There is a little serpentine between the grains, and the aggregate is cut by veinlets of a rather coarse platy light-green chrome-bearing variety of hornblende. Most of the other deposits consist of serpentine more or less thickly peppered with fine grains of chromite. Ore shipped from the Ready Cash claim by the Cypress Chrome Co. averaged 47.5 per cent of chromic oxide. Ore from the Last Chance claim, south of the lake, that was milled in Seattle carried 25.5 per cent of chromic oxide. The coarse and fine concentrate made from it contained respectively 43.9 per cent and 49.6 per cent of chromic oxide.

Platinum is reported on good authority to occur in some of the chromite concentrate from Cypress Island in amounts ranging from 0.006 to 0.245 ounce to the ton. Although in view of the great scarcity and high price of platinum this fact is interesting, the amount of platinum present is much too small to make the chromite deposits valuable as an ore of that metal.

MOUNT HAWKINS.

Chromite ore was mined at several places near Mount Hawkins in the summer and fall of 1918 by Richard Denny, who shipped a carload by packing and hauling the ore from the mines to the railroad at Roslyn, a distance of 30 miles. The deposits are in the rugged mountains between Cle Elum and Teanaway rivers, of which Mount Hawkins, at an altitude of 7,000 feet, is one of the more prominent summits. Practically all the surface is steeply sloping, and the local relief is about 3,000 feet. From Camp Creek, on the wagon road up Cle Elum River, trails lead to the chromite deposits.

The known ore bodies are in the western part of a serpentine area 3 or 4 miles wide and 20 miles long that extends from Cle Elum River eastward around the south side of Mount Stuart. Most of the area is within the Mount Stuart and Snoqualmie quadrangles, the geology of which is described in detail by George Otis Smith and others.[1]

On the north side of Boulder Creek, half a mile east of the road up Cle Elum River, an open cut and short adit had been made on the Chromium claim at the time of the writer's visit (July 28, 1918). A tabular body of chromite 18 inches in maximum thickness was exposed for a depth and length of 6 feet, its limits not being shown. The body is sharply defined, pitches steeply, and is easily separated from the serpentine. Samples are reported to assay as much as 51 per cent of chromic oxide, and the ore appears to be practically unmixed chromite of moderately coarse texture. Further development work is said to have shown that the body is larger than was at first apparent, and a carload of mixed ore from this deposit and from another near the small lake east of Mount Hawkins, shipped by Richard Denny late in 1918, was reported to contain 44.6 per cent of chromic oxide.

[1] U. S. Geol. Survey Geol. Atlas, Mount Stuart folio (No. 106), 1904; Snoqualmie folio (No. 139), 1906.

DEPOSITS OF CHROMITE IN STILLWATER AND SWEET GRASS COUNTIES, MONTANA.

By Lewis G. Westgate.

POSITION AND TOPOGRAPHY.

Chromite is found in a belt of pyroxenites and peridotites near the south border of Montana, in Sweet Grass and Stillwater counties

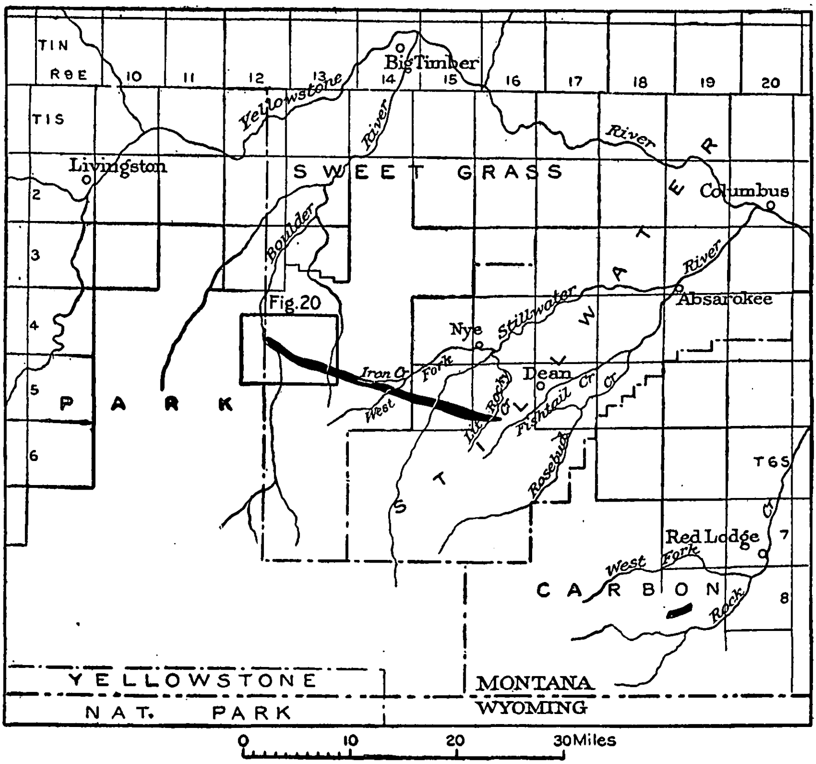


Figure 19.—Sketch map showing location of belt of chromite-bearing pyroxenite in Sweet Grass and Stillwater counties and of chromite deposit in Carbon County, Mont.

(fig. 19). The belt starts on Boulder River, in Sweet Grass County, 10 miles south of McLeod, and extends in a general direction 15°

south of east for 27 miles, to Fishtail Creek, in Stillwater County. The belt is convex to the south, and at its west end it bears 40° south of east. Where it crosses Boulder River it is 20 miles S. 55° E. of Livingston.

The eastern border of the northern Rocky Mountains here bears north of west, and the pyroxenite belt is roughly parallel to it, at a maximum distance of 6 miles on the south. The most conspicuous features of the mountain topography are the upland plateaus. East and west of Boulder River these stand between 9,000 and 10,000 feet above sea level. To the east, on the Stillwater, they reach 10,000 to 11,000 feet. These plateaus are fragments of what was once a gently rolling surface or peneplain. Hills (monadnocks) rise 1,000 to 2,000 feet above the plateau level, and their sides are in places steepened by glacial erosion. Below the upland level streams flowing northeastward to Yellowstone River have cut deep canyons. These, in order from west to east, are Boulder River, cut 3,500 feet below the plateau; West Fork of the Stillwater, 3,000 feet; Stillwater River, 4,500 feet. The chromite-bearing belt, which trends northwest, crosses these valleys and intervening plateaus and varies in altitude by nearly a mile.

A smaller deposit of chromite some 25 miles to the southeast, near Red Lodge, is not a part of this belt and is described separately.

GENERAL GEOLOGY.

The rocks of the region consist of a series of sedimentary formations ranging from Cambrian to Cretaceous in age, underlain unconformably by pre-Cambrian crystalline rocks. The mountain uplands are composed mostly of the pre-Cambrian rocks. The plains are underlain by Mesozoic rocks, mainly sandstones and shales. The Paleozoic rocks are bent up near the mountain border and form the foothills.

Pyroxenite occurs as an intrusive dike or sill 27 miles long and from half a mile to a mile wide. On Boulder River it is 5 miles south of the Paleozoic rim; on the Stillwater it is not over 2 miles south; and at the east end of the belt it is nearly if not quite in contact with the Paleozoic rocks. It invades the pre-Cambrian complex on Boulder River, but at the east end of the belt, on the north side of the Benbow properties, the pyroxenite and a gabbro associated with it show a contact with a somewhat metamorphosed but still clearly fossiliferous limestone. It is therefore at least post-Carboniferous, perhaps post-Mesozoic, and may have been intruded at the time of the mountain folding of the Laramide revolution. It may be noted in this connection that 13 miles south of the place where the pyroxenite crosses Boulder River, at the south edge of the pre-Cambrian belt, in Haystack Mountain,[1] gabbro cuts Tertiary andesite, as well as pre-Cambrian rocks.

FIELD WORK AND ACKNOWLEDGEMENTS.

The writer spent August 30 to September 9, 1918, inclusive, in visiting the Montana chrome-ore properties and wishes to acknowledge the very generous help he received in being taken to and shown over the properties by Messrs. J. H. Brophy, of Red Lodge; T. E. Benbow, of Columbus; and A. E. Fry and W. D. Dillon, of Limestone. He has also had the advantage of using the detailed manuscript report on the Boulder Creek properties prepared by Prof. C. H. Clapp, of the Montana School of Mines, at Butte, and a report on the same properties prepared by Mr. J. H. Warner, of Butte. The map of the part of the belt in Sweet Grass County is taken from Prof. Clapp's report. Unfortunately the visits to the Benbow properties and to those on Boulder River had to be made on days when clouds made it impossible, most of the time, to see more than a few hundred feet.

BOULDER RIVER.

LOCATION.

The best-known portion of the chromite belt is its west end, on Boulder River. The accompanying map of this area (fig. 20) was prepared by Prof. C. H. Clapp, of the Montana School of Mines. The west end of the pyroxenite belt begins on the lower slope of the west side of Boulder River. Thence it extends southeastward to East Fork of Boulder River. The difference in altitude between Boulder River and the summit of East Boulder Plateau is 4,500 feet. East of Boulder River the pyroxenite belt ranges from half a mile to a mile in width.

Prof. Clapp's map shows the pyroxenite lying between quartz-feldspar-mica schist on the south and gabbro-anorthosite gneiss on the north.

The chromite occurs in a veinlike body, which begins a little east of Boulder River and follows the pyroxenite belt near its middle almost if not quite continuously to East Fork of Boulder River. At several places short bodies of similar form parallel the main body. The bodies dip 60°–80° NE.

[1] Iddings, J. P., and Weed, W. H., U. S. Geol. Survey Geol. Atlas, Livingston folio (No. 1), 1894.

PETROGRAPHY OF THE COUNTRY ROCK.

The common rock of the belt is a greenish-gray medium-grained pyroxenite (enstatite rock, or enstatolite[2]). To the eye it is almost wholly an aggregate of yellow-brown grains of enstatite, averaging 5 millimeters in diameter, though exceptional grains reach 1 centimeter or more. A little plagioclase and a very little green monoclinic pyroxene show in the interstices of the enstatite.

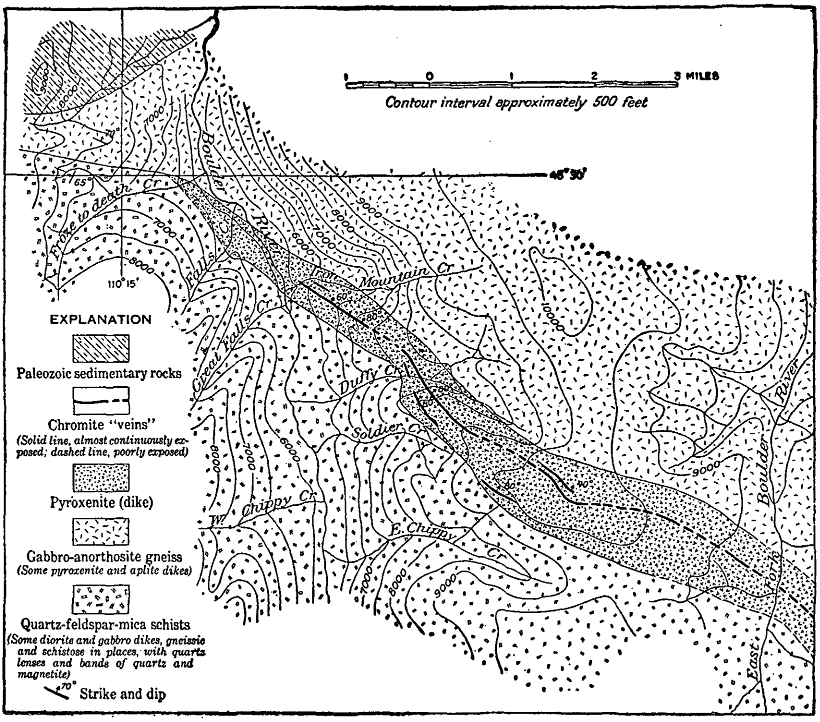


FIGURE 20.—Geologic sketch map of the west end of the pyroxenite belt in Sweet Grass County, Mont.

The microscope shows that the rock is composed of enstatite, plagioclase (labradorite), and a monoclinic pyroxene, in the order named. No magnetite or chromite was seen, and the rock is almost perfectly fresh. The enstatite is colorless and occurs as an aggregate of grains without crystal form. A fine multiple twinning is present in many grains. The monoclinic pyroxene is nearly or quite colorless and occurs as irregular grains between the enstatite grains and as irregular inclusions in the enstatite.

Near the chromite body the rock changes in mineral composition and in structure. Olivine in large part replaces enstatite, and the rock becomes a peridotite, in places even a dunite. Chromite be-

[2] Pratt, J. H., and Lewis, J. V., Corundum and the peridotites of western North Carolina: North Carolina Geol. Survey, vol. 1, p. 30, 1905.

comes an essential mineral. Structurally the most significant feature is a definite banding parallel to the chromite body, shown partly by the difference in mineral composition of the rock itself, partly by the presence of bands of chromite in the rock. A section (fig. 21) at right angles to the veinlike mass, at a point not far east of the openings at the west end of the belt, shows the following bands, in order, beginning with the footwall (south) side:

1. Pyroxenite (enstatolite), apparently identical with the rock already described as the common type of country rock. It is found to the south but was not followed in that direction.

2. Peridotite or dunite (50 feet). A rather fine grained greenish-gray rock, which in the ledge appears coarse grained by reason of patches of enstatite. The microscope shows it to be composed almost wholly of an aggregate of olivine grains, the largest 10 millimeters in diameter. A few grains of enstatite,

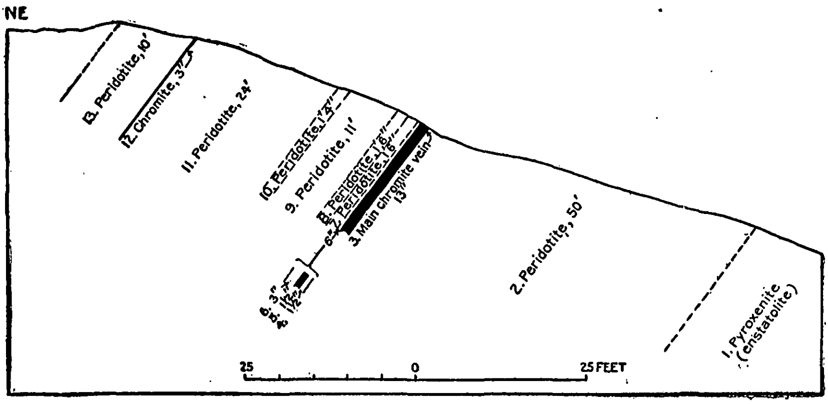


FIGURE 21.—Section of chromite vein and adjacent rock on Bonanza claim, near Boulder River, Sweet Grass County, Mont.

a very little plagioclase and monoclinic pyroxene, in irregular grains in the olivine, and a few grains of chromite, as much as 1 millimeter in diameter, are also present. Serpentinization, accompanied by the development of magnetite, has gone on along cracks, especially in the olivine, but as a whole the rock is fresh. A little secondary calcite, chlorite, and iron oxides are found.

3. The main veinlike mass of chromite (13 inches). In detail, the contact is irregular and the ore is "frozen" to the rock. In places small stringers of chromite are present in the adjacent footwall. The ore is a black, shining aggregate of chromite grains, many of which show octahedral faces where there is gangue in the ore body.

4. Granular mixture of rock and chromite (1½ inches).

5. Ore (1½ inches).

6. Mixed rock and chromite (3 inches), making a transition between Nos. 5 and 7. The passage of ore into rock is not sharp but gradual. In some bands the passage is sharper on the footwall side. Even here a close inspection shows that no sharp plane separates the two.

7. Peridotite with scattered grains of chromite the size of small shot and scattered patches of enstatite as much as 3 inches in diameter (1 foot 6 inches).

8. Peridotite with abundant chromite, much of it in bands (1 foot 6 inches).

9. Peridotite (11 feet). Chromite grains show, but no bands, except a few near the south margin. Patches of enstatite as much as 8 inches in diameter. The hand specimen is a medium-grained gray-green rock, showing in places skeleton grains of enstatite poikilitically inclosing the other constituents of the rock. In thin section under the microscope the rock is seen to consist of olivine and enstatite in about equal amounts. Contains many crystal sections of chromite measuring 0.5 millimeter or less. Serpentinization, accompanied by the separation of magnetite and iron oxides, has gone on to a slight extent along cracks, especially in the olivine, but the rock as a whole is fresh.

10. Rock like Nos. 9 and 11 but containing lines and bands of chromite (1 foot 4 inches).

11. Probably peridotite, containing scattered grains and a few fine bands of chromite about 8 feet from the footwall (24 feet).

12. Chromite (3 inches).

13. Coarse-grained rock, probably peridotite (10 feet). Northward for some distance there are belts of a coarse-grained rock (peridotite?) in the fine-grained country rock (enstatolite?).

To the west, at the tunnels, the rock within 4 feet of the ore body is peridotite (dunite) similar to the rock in bands 2 and 9 of figure 21. It is a greenish-yellow or dark-green, rather fine grained rock, showing in places rather large skeleton grains of cleavable enstatite. Olivine and enstatite are the main constituents, and olivine makes about three-fourths of the rock. Monoclinic pyroxene is present in one specimen, and another shows interstitial plagioclase (labradorite). Chromite occurs in varying amounts to a maximum of about one-tenth of the rock, in subhedral to octahedral grains 1 millimeter or less in diameter. Serpentine, with secondary magnetite, occurs along cracks, especially in the olivine, but nowhere to an amount that would make the rock a serpentine.

THE ORE.

The ore is an aggregate of black, shining grains of chromite, with an average diameter of 0.5 millimeter. Where the grains are crowded they do not commonly show crystal form; where there is a large amount of interstitial matter present, well-developed octahedral crystals are common. Thin sections of the ore for microscopic study were not made, but the matrix seems quite like that farther east in Stillwater County, where it is largely serpentine.

In thickness the main ore body varies between extremes of 5 inches and 3 feet 6 inches, but commonly it is between 12 inches and 2 feet thick. Assays of the ore show from 27.8 to 41.8 per cent of chromic oxide, and seven analyses average 36.5 per cent. On the northeast or hanging-wall side of the vein chromite is found in the peridotite country rock in bands, stringers, and grains, in sufficient amount to make a low-grade ore. The band of mixed ore and rock, which averages 4 feet in width, assays from 4.6 to 25.3 per cent of chromic oxide; ten assays give an average of 11.8 per cent.

Mr. Warner states that in a concentrating test on a small Wilfley table the low-grade ore, assaying 13.5 per cent of chromic oxide, after being crushed to 50-mesh size, was concentrated to a 39.8 per cent ore, with a saving of 53 per cent of the chromite. He concludes that "the ore will concentrate, giving a 40 per cent product, and by working out thorough methods there is little doubt but that a saving of 60 per cent or better can be made."

FRY-DILLON CLAIMS.

LOCATION AND CHARACTER.

The pyroxenite has been traced continuously from Boulder River 10 miles to East Fork of Boulder River. It reappears 2 miles farther east, on upper Iron Creek, on the east side of the Boulder-Stillwater divide. The writer has not followed the belt between the two localities but has no doubt as to its continuity. The Fry-Dillon claims follow the pyroxenite belt from a point near the head of Iron Creek in a direction S. 70° E. to the West Fork of Stillwater River, a distance of 4 or 5 miles. They are in secs. 15–18, T. 5 S., R. 14 E. The western claims are on the plateau level, at an altitude of 9,000 feet; the eastern claims are only a few hundred feet above the West Fork. The vertical difference in level is nearly 2,500 feet.

Toward the west end, where the ore body crosses the plateau level, it is largely covered by rock débris and its position is indicated only by float and scattered prospect openings. Eastward on the slopes to the Stillwater it crops out more continuously. More digging is necessary to demonstrate its continuity.

The ore body varies in width. At the west end it is 18 inches wide. Farther east it ranges in general from 9 to 11 inches but at one point (Climax claim) drops to 6 inches. At the Dixie Queen it is exceptionally wide, between 3 and 4 feet for an exposed distance of 20 feet; but this width has not been noted elsewhere and is probably not maintained here for any considerable distance. The average thickness, however, seems somewhat greater at the east end than in the middle of the property. The dip is north or northeast, at angles varying between 30° and 50°.

A good exposure of the chromite body is found on the Brannan claim, in the basin on the south side of Iron Creek, just west of the Fry-Dillon series of claims. Here an 8-inch seam of black ore, which bears N. 50° E. and dips 45° NW., can be followed for 60 feet. A second seam 1 inch wide is found about a foot north of the main seam and at one point is joined by an irregular cross seam to the main body. Small specks of chromite occur through the inclosing rock for 20 to 30 feet to the north. Farther southwest chromite is again found, bearing N. 35° W. The irregular form of the vein at this point is shown in figure 22.

PETROGRAPHY OF THE COUNTRY ROCK.

The country rock of the pyroxenite belt is in all essentials like that already described as the common type on Boulder River. It is a medium-grained dark rock consisting chiefly of enstatite. In the more basic specimens a very little plagioclase shows between the enstatite grains, and a small amount of green monoclinic pyroxene is present. In the more siliceous parts the plagioclase is more abundant and may make skeleton grains 1 or 2 centimeters in diameter, inclosing grains of enstatite. Chromite is not noticed in the hand specimen. The rock weathers a red-brown, owing chiefly to the discoloration of the enstatite. The enstatite is very much more abundant than the plagioclase, and the plagioclase is more abundant than the monoclinic pyroxene.

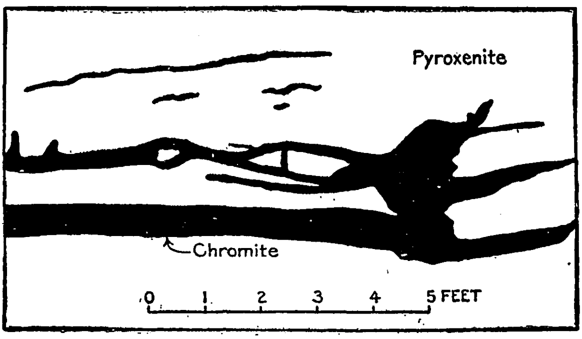


FIGURE 22.—Detail of chromite vein on Brannan claim, south of Iron Creek, Sweet Grass County, Mont.

Microscopic examination shows but little in addition to what has already been noted. The enstatite occurs in grains as much as 3 millimeters in diameter, which are rounded or euhedral, many of them in basal sections showing sharp crystal outlines. It ranges from nearly colorless to pleochroic in pink and green. Much of it shows fine multiple twinning. Minute grains of magnetite are common. Chromite was not recognized. There is almost no serpentinization. In places nearer the chromite vein the rock varies from the ordinary type, but this variation is not nearly as conspicuous as on Boulder River or farther east on the Benbow claims.

Serpentinized rock from the immediate contact with the vein is brownish black and fine grained and under the magnifying glass shows a resinous brown color where fractured translucent grains occur. Chromite grains are visible. The microscope shows large amounts of serpentine. Large plates of enstatite (?) with finely parallel parting have been altered to a yellow-brown serpentine; indeed, the whole section is part of a single grain, 15 by 17 millimeters. Rounded areas 3 millimeters in greatest diameter made up of a network of serpentine scales appear to represent olivine; they constitute about one-quarter of the section. Chromite is common in octahedral crystals, 0.7 millimeter or less in diameter, and many of the crystals are cracked and the cracks filled with serpentine. Chromite does not make one-twentieth of the section. The rock is intermediate between pyroxenite (enstatolite) and peridotite.

THE ORE.

The ore is a black, shining rock, almost completely a mosaic of grains of chromite, many of which show crystal outlines against the interspaces. These spaces are usually filled with serpentine, which here and there contains small residual masses of monoclinic pyroxene. Hand specimens of leaner varieties of ore show chromite in octahedral crystals measuring 1 millimeter or less, in a serpentine groundmass.

The main body on the Fry-Dillon claims closely resembles that on Boulder River, but chromite grains and stringers are very much less abundant in the adjoining country rock, and there is a less noticeable development of peridotitic facies adjacent to the ore body. Neither of these features is entirely lacking, but both are much less conspicuous than at either the west end or the east end of the belt.

BENBOW CLAIMS.

LOCATION AND CHARACTER.

The Benbow claims are near the east end of the pyroxenite belt, in secs. 28, 29, and 30, T. 5 S., R. 16 E. They begin near the Stillwater-Little Rocky divide and extend eastward for 2 miles to the west slope of Fishtail Creek valley. How far east of Fishtail Creek the pyroxenite belt can be traced is not known. Between the east end of the Fry-Dillon claims, on the West Fork of Stillwater River, and the Benbow claims is a stretch of 8 miles in which the belt has not been followed. In the section between the West Fork and the Stillwater Reeber & Hawk are reported to have three claims and Dillon one claim on the West Fork slope; M. W. Monat has claims on the Stillwater slope. For 2 miles east of the Stillwater no claims are held. It is clear that the pyroxenite belt continues through the interval between the Fry-Dillon and Benbow claims, but in the absence of any active mining work this part of the belt was not visited.

The chromite occurs as a nearly if not quite continuous band, which bears between west and N. 80° W. and has a nearly vertical dip. Dips of 80° and 65° N. were observed at some of the openings. The chromite band is near the middle of the pyroxenite belt, which is about half a mile across and shows a vertical difference of 700 feet in different parts of its course.

PETROGRAPHY OF THE COUNTRY ROCK.

The pyroxenite is in general similar to that of the belt farther west, being a dark-green medium-grained massive rock that consists mainly of enstatite in grains commonly reaching 5 millimeters and in places 1 centimeter in diameter. In the fresh rock the enstatite is yellowish brown and shows a platy or fibrous structure; on the weathered surface it is red-brown. Smaller amounts of plagioclase and green monoclinic pyroxene are present in the interspaces between the enstatite grains, and some of the plagioclase occurs in skeleton grains as much as 2 centimeters in diameter, in which lie variously oriented subhedral grains of enstatite, the rock thus showing poikilitic structure. In some specimens a few flakes of biotite are seen.

The microscope discloses enstatite in subhedral or euhedral grains from 1 to 5 millimeters in diameter. It is colorless or very pale red and slightly pleochroic. Some grains show in whole or in part a fine multiple twinning. Colorless to pale apple-green monoclinic pyroxene occurs here and there, but in much less amount than the enstatite. Plagioclase (labradorite) is also much less abundant than the enstatite. Both monoclinic pyroxene and plagioclase fill the spaces between the enstatite grains, and each of them, but particularly the plagioclase, may occur in large skeleton grains, inclosing the subhedral grains of enstatite. The order of abundance is enstatite, plagioclase, monoclinic pyroxene. The enstatite is probably five to ten times as abundant as the feldspar. Accessory minerals are biotite, pyrite, and in one section two or three small grains of chromite. Chromite and magnetite are not normally present, nor is olivine noted. The rocks are almost perfectly fresh, a little serpentinization being noticed in some places along cracks.

The pyroxenite near the ore band shows changes similar to those noted on Boulder River. Within a distance ranging from 20 to possibly 100 feet from the vein the pyroxenite changes notably in texture and in mineral composition. It shows both coarse and fine grained varieties, and poikilitic structure is developed in both. Plagioclase disappears, and olivine and chromite come in.

The coarser variety is greenish black and weathers brown. Its most conspicuous feature is the large cleavage areas of enstatite, 5 centimeters in size in the hand specimen and even larger in the field. The enstatite plates inclose dark-green masses of secondary minerals, as much as 10 millimeters in diameter. Some chromite and green monoclinic pyroxene also appear. Under the microscope the green areas in the enstatite are seen to be aggregates of serpentine containing grains of secondary magnetitite, stained by limonite. They may represent alteration products of olivine. The chromite is in rounded grains not over 1 millimeter in diameter.

The finer-grained rock is nearly black and is characterized by cleavage surfaces of enstatite as much as 4 centimeters across. Small rounded grains and octahedrons of chromite are very abundant. The microscope shows enstatite, nearly fresh, in large grains. Chromite occurs in crystal sections, many of them rounded; some of the grains are cracked, and the cracks are filled with veinlets of serpentine. The large crystals average 5 millimeters in diameter. The chromite may make between one-fifth and one-tenth of the rock. Olivine is abundant. It is largely altered to serpentine and now occurs only as cores in the mesh of serpentine. The serpentine is present to some extent in the enstatite but mainly in the olivine. A little secondary magnetite accompanies the serpentine. The enstatite is more abundant than the olivine, and the rock may be named a peridotite.

SERPENTINE.

The rock immediately adjacent to the ore body and occurring as horses within it is almost if not quite completely serpentinized. It is a fine-grained, nearly black rock, much broken. The hand lens shows a waxy luster that is resinous yellow where translucent, with scattered grains of shining chromite.

A specimen taken 30 feet from the ore body shows under the microscope an aggregate of serpentine, with a small amount of chromite in irregular grains and crystal sections, 5 millimeters in maximum diameter. The arrangement of the serpentine shows that the rock was originally almost wholly an aggregate of rounded grains and crystal sections of a mineral, probably enstatite, between which were small amounts of another mineral, not now recognizable. The chromite is almost wholly in the spaces between the enstatite. A specimen taken from a horse within the ore body shows considerable masses of platy enstatite in the serpentine. A little secondary magnetite and brown iron oxide are present in the rock.

THE ORE.

The ore on the Benbow property is soft, friable, and rather fine grained and consists of octahedrons and rounded grains of chromite about 1.5 millimeters in greatest diameter, held together by films of greenish-white serpentine and traversed by stringers of the same mineral. The largest chromite crystals are 3 millimeters across. The microscope shows chromite and serpentine, the latter a nearly colorless aggregate of fibers, in places so fine grained that the mass is nearly isotropic. Enstatite is recognized in the powder of some of the ores, and probably the serpentine is largely derived from it. No secondary magnetite was noticed.

The ore varies in the amount of serpentine present, the better material being almost entirely an aggregate of chromite grains and crystals but the leaner ore showing chromite crystals embedded in an abundant serpentine matrix.

The following assays, probably of selected ores, are reported:

Assays of ore from Benbow claims.

	Cr_2O_3.	Fe.
Eclipse	38.3	16.6
Bonanza	34.3	19.1
Lucky Strike	38.3	17.5
Titanic	38.4	19.4

The width of the ore band varies. On the Majestic claim, at the west end of the property, the ore body is 5 feet 6 inches thick and at its south side shows 3 feet of banded rock consisting of coarse-grained country rock that contains little chromite and rock that is richer in chromite yet too lean to make an ore. The next claim on the east showed 3 feet 4 inches of nearly solid ore, with 1 foot 8 inches of mixed banded ore and rock on the south side. About 200 feet north of this point is a parallel vein showing 7½ inches of good ore. The widths at openings farther east are 3 feet 6 inches, 4 feet 2 inches, 3 feet 8 inches (Eclipse), 4 feet 4 inches to 6 feet (Lucky Strike). The section of the veinlike ore body on the Eclipse claim is shown in figure 23. Near the east end of the property, on the War Eagle claim, 4 feet of banded granular ore and black serpentine is shown, and for 15 feet to the south masses of ore lie irregularly in the serpentine. The rock farther south, for 20 to 50 feet from the ore, is coarse country rock showing in places poikilitic structure; beyond that is the ordinary form of pyroxenite. The rock north of the ore body is broken but does not show chromite.

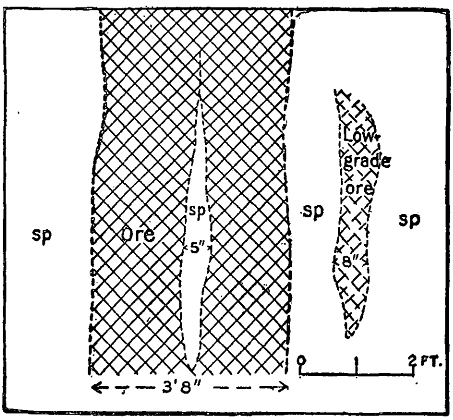


FIGURE 23.—Detail of chromite vein on Eclipse claim, Benbow property, Stillwater County, Mont. sp, Serpentine.

ORIGIN OF THE ORE.

The main ore body is a tabular, veinlike body that follows the middle of a pyroxenite dike and dips steeply north. The common type of this pyroxenite country rock is an enstatolite, chiefly enstatite, with minor amounts of labradorite and monoclinic pyroxene and very little or no chromite. Near the chromite body the rock becomes a peridotite of the variety saxonite (olivine and enstatite), or even a dunite (composed almost wholly of olivine). It contains abundant chromite, commonly in octahedral crystals. Bands of chromite parallel the main body in its immediate vicinity. It is clear that the origin of the chromite and that of the peridotite facies of the pyroxenite are parts of the same problem.

The following possible explanations of the chromite body suggest themselves:

1. The chromite may have been introduced by solutions from a deeper part of the magma, or from some other magmatic source. Against this hypothesis is its failure to account satisfactorily for the chromite crystals, which have every appearance of being the result of primary crystallization from an igneous magma, and its inability to account for the peridotite facies of the pyroxenite dike. Furthermore, the gangue of the ore, while mainly serpentine, seems to be altered from enstatite or augite and perhaps olivine, a fact which suggests that the ore body is a differentiate resulting from a continuation of the process that produced the peridotite.

2. The peridotite and chromite may be products of magmatic differentiation in place. This hypothesis seems better fitted to the facts than the one just given, but it can hardly explain the repeated banding in the vicinity of the ore body as shown in figure 21. Differentiation in place has probably occurred but was a minor factor in the production of the present ore body.

3. The chromite and adjoining peridotite may be more basic differentiation products intruded into the earlier-formed pyroxenite toward the end of the magmatic period. The differentiation took place well below the present surface, and the basic differentiate represented by the chromite and peridotite resulted from the splitting of the general magma and not from that of the magma represented by the pyroxenite. The pyroxenite was sufficiently solidified to permit fracturing, but the pyroxenite, peridotite, and chromite may all be considered events of a single magmatic period. This hypothesis would account for the peridotite facies of the pyroxenite. The chromite may have followed the peridotite, or it may have been the more basic part of the later magma dragged out into bands during intrusion. Some differentiation in place by gravity may have occurred in this later magma; it is suggested by the way in which some of the chromite bands grade out into the wall rock on the hanging-wall side, while transition is much more abrupt on the footwall side. Differentiation in place, however, is believed to have been a subordinate factor in the formation of the present ore body.

If this hypothesis of origin is correct, it implies that the chromite body has a very considerable extent downward, measured certainly in hundreds and perhaps in thousands of feet. All the field evidence corroborates this conclusion.

TONNAGE AND TRANSPORTATION.

BASIS OF ESTIMATES.

The tonnage of the ore body depends on its width, continuity, and depth. The mode of occurrence gives every reason to believe that the ore extends for considerable distances below the surface, perhaps 1,000 feet or more. This belief is borne out by the facts that on all the claims the character of the rock and of the ore body shows no evidence of being influenced in any way by surface conditions and is identical through a vertical range of 1,000 to several thousand feet. The lower limit to which the ore can be mined is much more likely to be determined by the expense of mining than by the disappearance of the ore. In making the tonnage calculations the very moderate depth of 100 feet was arbitrarily assumed. From these calculations anyone can easily estimate the tonnage on the basis of any greater depth. The width and continuity of the ore body vary along the belt and will be considered for the different parts separately.

BOULDER RIVER PROPERTIES.

The chromite body has been mapped by C. H. Clapp between Boulder River and East Fork of Boulder River, a distance of 7 miles, and for nearly 4 miles of this distance it is almost continuously exposed.

East of Boulder River there are four groups of claims. The Bonanza group, controlled by the Boulder River Chrome Co., covers about 3,600 feet of the main chromite belt. It rises from an altitude of 5,700 feet (200 feet above Boulder River) on Iron Mountain Creek to 6,500 feet on Iron Mountain Ridge. This is the most accessible part of the range. The M. & R. group, bonded to J. L. Bruce and associates, of Butte, extends southeastward from the Bonanza group nearly to Duffy Creek, at an altitude of 7,600 feet. In this section are two claims located by G. M. Kirwan, jr., of Contact, and associates. A third group, held by several persons, including Mr. Kirwan, extends for 12,000 feet from Duffy Creek southeastward to the crest of the plateau between Boulder River and East Fork. A fourth group includes five claims held by Edward Royal and others, two of which lie in part on the main ore body, the other three on parallel bands within that section of the belt covered in general by the third group.

From the data already given it is possible to estimate the tonnage. Assuming for the Bonanza claims a length of 3,600 feet, an average width of 14 inches for the layer of high-grade ore, and a depth of 100 feet, we would have approximately 47,000 tons of ore carrying about 40 per cent of chromic oxide. Taking an average width of 4 feet for the adjacent low-grade ore of the hanging wall, we would have nearly 150,000 tons of concentrating ore running about 12 per cent. This ore can be mined at the same time as the other ore. Whether it can be profitably taken out will depend on the cost of mining and the price of ore.

To the east, on the M. & R. group, though the development work done is slight, the ore body seems to be very similar in character to that on the Bonanza claims.

On the third group the main ore band varies between 6 and 32 inches in width, and by including the low-grade ore alongside the richer chromite mass an ore body between 4 and 12 feet thick is obtained. The narrower high-grade band of ore alone, with an average thickness of 1 foot and a length of 10,000 feet of the total 3 miles or more of ore-belt length, would yield 110,000 tons. With the amount of high-grade ore already estimated for the Bonanza claims, this makes 157,000 tons. An estimate of 150,000 to 200,000 tons for ore approaching 35 per cent between Boulder River and East Fork is believed to be very moderate. Development work along the outcrop and in depth is likely to show much more rather than less.

The above estimate omits the low-grade ores. It is concerned only with tonnage and not with the metallurgic character of the ore, nor with the problem of getting the ore to the railway. Unfortunately, all parts of the chromite belt are at a disadvantage when marketing is considered. The natural outlet for the west end of the belt is by Boulder River valley to Big Timber, on the Northern Pacific Railway, a distance of 34 miles. For the first 8 miles from the mines the roads are hilly and rough; for the rest of the distance the roads are good in fair weather but in large part clayey and impassable in wet weather. The properties at the west end would be able to get ore to the road without great difficulty, but the ore body rises rapidly in the hills to the southeast, and it will be increasingly expensive to get the ore out the farther the workings are from the river.

FRY-DILLON CLAIMS.

The development work on the Fry-Dillon property is less extensive than that on either the Boulder River or the Benbow properties. At the west, on the plateau, the ore body is not plainly visible. From the Iron Duke claim, near the middle of the property, to the east, especially on the slope down to Stillwater River, it crops out more continuously, and it is clearly a continuous or nearly continuous body like that on Boulder River. It is unlike the Boulder River body, however, in that there is not enough chromite in the rock adjacent to the ore body to form a low-grade ore. If a continuous vein is assumed for 4,000 feet, 1 foot in width, and extending 100 feet below the surface, approximately 50,000 tons would be indicated.

To get the ore out it must be taken down to the West Fork of the Stillwater, and this becomes increasingly difficult for those parts of the ore body distant from the river. From the point where the pyroxenite belt crosses the West Fork a road will have to be built down the Stillwater to the mouth of Iron Creek, a distance of 3 miles, with some steep grades. From Iron Creek a good autotruck road extends 40 miles to Columbus, where it meets the Northern Pacific Railway.

BENBOW PROPERTIES.

The ore body on the Benbow properties can be followed at intervals for 8,000 feet. Where opened it ranges in width from 3 feet 4 inches to 5 feet 6 inches. A width of 3 feet and a depth of 100 feet for 4,000 feet would give about 130,000 tons of ore. There is some chromite in the adjoining peridotite, but its value as an ore is doubtful, and it is not considered in estimating the tonnage.

The Benbow properties are at altitudes of 8,700 to 9,650 feet. To get out the ore it is proposed to construct a 2-mile tram to Rocky Fork, then 5 miles of roadway to Dean, not a difficult matter. From Dean to Columbus, 31 miles, there are already fairly good roads. The Benbow properties are nearer to the railway than any other properties along the belt.

SUMMARY STATEMENT.

In considering the estimates of tonnage in the chromite belt of Stillwater and Sweet Grass counties, it is well to keep in mind several facts. No careful survey of the belt as a whole has been made. Clapp has mapped the westernmost 7 miles, but the middle and eastern parts have not been mapped. Again, except for two 90-foot tunnels on Boulder River, the development work consists of shallow prospect holes at intervals, which seem to show a continuous body of ore but do not demonstrate its absolute continuity or thickness. The estimates of nearly 350,000 tons for the three areas considered cover only a part of the belt—19,000 feet in a total length of 27 miles. Chromite is found between the areas represented in the estimates and in places doubtless occurs in paying quantities. The depth of 100 feet is arbitrarily assumed: without doubt the ore goes beyond that depth to a considerable but unknown distance. Thus, although no approach to an accurate estimate is at present possible, it is the belief of the writer that the estimate of 375,000 tons is a low estimate for the belt as a whole. If that amount of ore is not ultimately recovered it will not be because the ore is not in the ground, but for other reasons which are not considered in detail here, such as inapplicability of ore of this particular composition to metallurgic purposes and distance from markets.

It should be noted that the form of occurrence of the chromite in this belt is radically different from that of deposits farther west, in California and Oregon, and that there is much stronger reason for counting on continuity in depth here than there.

To get the ore to the railway from the points where the belt crosses the valleys requires a haulage of 34 miles from the Boulder River properties, 43 miles from the Fry-Dillon claims, and 36 miles from the Benbow properties. From the Fry-Dillon and Benbow properties the roads go by the Stillwater and the Rosebud, meeting at Absarokee, and then by the lower Stillwater to Columbus. The transportation facilities would be improved were there a branch railway leading up the Stillwater. That possibility depends on the agricultural resources of the valleys, for they contain no known mineral resources except the chromite. There is much good farm land in the Stillwater Valley as far up as a point several miles above Absarokee, and along the lower Rosebud and lower Fishtail for 2 miles above Absarokee. Whether it would pay to construct a branch line to Absarokee, and if beyond Absarokee to a point nearer the mountains, and if the latter, whether by the Stillwater or by the Rosebud, are questions which can not be answered without a careful survey of all the resources of the area.

CHROMITE NEAR RED LODGE.

Chromite is found on claims belonging to J. F. Brophy, of Washoe, Mont., 10 miles southwest of Red Lodge, in secs. 20 and 21, T. 8 S., R. 19 E. (See fig. 19.) The prospects are on Silver Run Plateau, at an altitude of 9,500 feet, between Rock Creek and West Fork of Rock Creek. The main country rock is a coarse granite, almost like pegmatite, which cuts an older series of dark-brown hornblende gneiss, amphibolite, and biotite-hornblende schist. In the vicinity of the chromite the granite is much more abundant than the basic rocks, which occur as inclusions in the granite. Elsewhere the basic rock may be more abundant than the granite.

The chromite prospects are in the older basic rock, in a line bearing N. 80° E. At one point the country rock is a strip of dark gneiss 50 feet across, cut out within short distances in both directions by the granite. The ore body is a lens or band of this larger inclusion, 2 to 3 feet across. The ore is black and shows shining granules of chromite averaging 0.3 millimeter in diameter, set in a greenish-white groundmass, in part probably serpentine. No assay of the ore is available, but the amount of gangue even in the better ore suggests that it is not of very high grade. At several points within half a mile to the east other chromite masses occur, but they are not parts of a continuous body. No estimate of tonnage was made, but the occurrence of the chromite in scattered inclusions of the older rocks in granite indicates that it is not large.

The ore would have to be taken 3 miles downhill to the Laurel Creek road and then hauled 11 miles to Red Lodge.