Chromite Deposits in Central Part Stillwater Complex, Sweet Grass County, Montana

GEOLOGICAL SURVEY BULLETIN 1015-D

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By A. L. HOWLAND

A CONTRIBUTION TO ECONOMIC GEOLOGY

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A description of layered deposits of chromite in the ultramafic rocks, and an estimate of their commercial importance

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1955

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.50 (paper cover)

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A CONTRIBUTION TO ECONOMIC GEOLOGY

CHROMITE DEPOSITS IN THE CENTRAL PART OF THE STILLWATER COMPLEX, MONTANA

By A. L. Howland

ABSTRACT

The chromite deposits of the central part of the Stillwater complex lie in a belt 9 miles long between the valleys of Boulder River and the West Fork of the Stillwater River in Sweet Grass County, Mont. The chromite occurs as layers near the middle part of the ultramafic zone in the lower part of the complex. The layers, originally horizontal, have been tilted so that they dip northeastwards at angles ranging from nearly horizontal to nearly vertical, and are cut by many cross faults, the largest with a horizontal offset of 3,000 feet. Investigations by the United States Geological Survey and the United States Bureau of Mines have shown that in this belt there are 5 sections ranging in length from 850 to 3,800 feet along the strike where the continuity and grade of the chromite can be reasonably inferred. In these sections the higher grade part (30 to 40 percent Cr_2O_3) of the main chromite layer averages about 1 foot in thickness. A zone of disseminated chromite (0.5 to 30 percent Cr_2O_3) adjacent to the higher grade layer ranges in thickness from a few inches to 8 feet. Analyses indicate that the cleaned chromite contains 43 to 48 percent Cr_2O_3 and has a chromium to iron ratio ranging from 1.46 : 1 to 2.20 : 1. The geologic factors are unfavorable for obtaining any large tonnage of chromite, and the inaccessibility of the area and the rigorous winter climate would make development both expensive and difficult.

INTRODUCTION

The occurrence of chromite deposits of possible economic interest in Stillwater and Sweet Grass Counties, Mont., has been known since the time of the First World War. The deposits occur in the Stillwater complex, a belt of layered noritic and ultramafic rocks 1 to 5 miles wide, that extends for about 27 miles along the northeastern margin of the Beartooth Mountains. Chromite occurs as layers near the middle of the ultramafic zone throughout most of the length of the belt.

In 1939 the United States Geological Survey, in cooperation with the United States Bureau of Mines, began a detailed study of the geology of the chromite deposits. Reports dealing with the deposits of the eastern part of the complex and with those of the Boulder River area have been published (Peoples and Howland, 1940; Howland, Garrels, and Jones, 1949). The present report describes the results of the geologic work in the area between that described in the Boulder River report and the West Fork of the Stillwater River.

Between the valleys of the Boulder River and the West Fork of the Stillwater River, which are 9 miles apart, the chromite-bearing belt crosses a rolling plateau, in part wooded and in part above timberline (fig. 17 and pl. 8). The chromite-bearing rock reaches an altitude of 10,000 feet on East Boulder Plateau between the Boulder and the East Boulder Rivers, descends to 8,700 feet at the East Boulder River, rises to nearly 10,000 feet again on Iron Mountain, and slopes off on the east to 8,700 feet at the edge of the deep valley of the West Fork of the Stillwater River. The highest point on the plateau, Chrome Mountain, is more than 10,150 feet high. This part of the complex is accessible only over steep pack trails from the road in the Boulder River valley and from the United States Forest Service road in the valley of the West Fork of the Stillwater River, which connects with the Mouat mine road. Both junctions of trail and road are nearly 45 miles from the nearest railroad. The West Fork road ends at an altitude of 6,500 feet, and the altitude of the Boulder River road is about 5,000 feet. Good grazing is available in the summer, but snow can be expected on the plateau from September to June.

Claims were staked over much of this area during the First World War, but none were patented, and many were restaked during the Second World War. The claims on East Boulder Plateau were held in 1944 by Dewey Whittaker and by the Montana Chrome Corporation, which also held all the claims in the Iron Mountain area. The Fry-Taylor claims lie in the valley of the West Fork of the Stillwater River and extend westward on the plateau about a mile.

In 1940 the east slope of Iron Mountain was mapped geologically by A. L. Howland and J. W. Peoples, assisted by W. R. Jones and M. G. Bennett. This map was revised and extended in 1942 by Howland (pl. 10). In 1941 Howland, assisted by Jones and R. M. Garrels, mapped the East Boulder Plateau (pl. 9), and in 1942 Howland assisted by J. S. Shelton, D. C. Cox, J. L. Weitz, and George Sendon, mapped the western side of the valley of the West Fork of the Stillwater River in detail (pl. 11). During 1942 the U. S. Bureau of Mines sampled the deposits. The topography of the area is shown on the Mount Douglas and Mount Wood 15-minute quadrangles, but these maps were not of sufficiently large scale to meet the requirements of the chromite work. In 1943, therefore, a topographic map on the scale

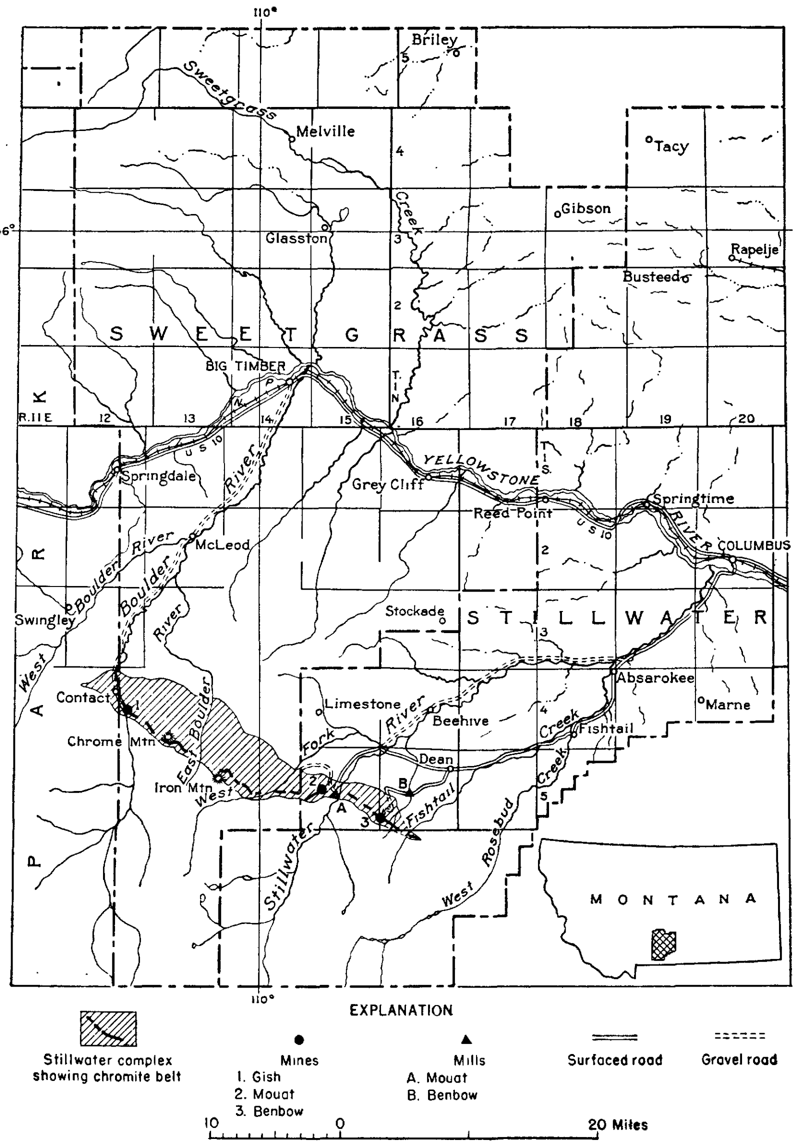

FIGURE 17.—Index map of the chromite deposits of the Stillwater complex, Montana.

of 1:12,000 was compiled from aerial photographs by stereophotogrammetric methods for the purposes of the detailed geologic mapping (pl. 8).

OUTLINE OF GEOLOGY

The igneous Stillwater complex forms the northern part of the pre-Cambrian crystalline core of the Beartooth Range in this area. To the south of the complex are metamorphosed sedimentary strata, which have been intruded by the complex and by granite that is believed to be younger than the complex. To the north are Paleozoic and younger sediments which rest on the eroded surface of the complex. The complex and the overlying younger sediments have been tilted and in most places dip steeply northward. Patches of Cambrian sedimentary rocks lying on the rocks of the Stillwater complex have been preserved by downfaulting.

The complex trends about N. 60° W. and is a remnant of a once far larger mass. Erosion removed the upper layers before Middle Cambrian time and the maximum thickness of about 16,000 feet is found on East Boulder Plateau. The complex has been divided for convenience into 3 zones. A thin, basal, noritic zone at the south is succeeded upward by a zone of ultramafic rocks containing layers of chromite; and that in turn by a banded zone in which norite, anorthosite, and gabbro are the dominant rocks.

PRE-CAMBRIAN ROCKS

METAMORPHOSED SEDIMENTS

Underlying the complex is a series of metamorphosed sediments that consist chiefly of hornfels but also contain quartzite and iron-bearing beds. On East Boulder Plateau this series extends several miles to the south. The hornfels is typically a fine-grained rock, dark-gray on fresh surfaces and brown where weathered. It is very similar in hand specimen to the norite of the basal zone of the Stillwater complex, but it can be distinguished from the norite by its granular texture and by the absence of laths of feldspar. The quartzite is commonly pale blue and so coarse grained that it resembles vein quartz. The iron-bearing member consists of alternating layers of quartz, magnetite, and iron silicate, from a fraction of an inch to several inches thick.

IGNEOUS ROCKS OF THE STILLWATER COMPLEX

The rocks of the Stillwater complex in this area are similar to those found elsewhere in its three zones: diabasic norite in the basal zone; bronzitite, poikilitic harzburgite, granular harzburgite, dunite, basic pegmatite, and chromitite in the ultramafic zone; and gabbro, norite, and anorthosite in the banded zone. Most of these occur as well-defined layers. Their general character has been described (Peoples and Howland, 1940) and the present discussion is confined to their particular features in the area between East Boulder Plateau and the West Fork of the Stillwater River.

BASAL ZONE

Norite.—Fine-grained generally dibasic norite occurs as a layer 50 to 200 feet thick nearly everywhere along the southern side or base of the complex. It consists of plagioclase, bronzite, and a monoclinic pyroxene. It closely resembles in texture and grain size the hornfels that forms the floor of the complex, and, as already noted, in many places the two are hard to distinguish. The norite grades rather rapidly upward into the ultramafic rocks of the overlying zone.

ULTRAMAFIC ZONE

The ultramafic zone averages about 4,000 feet in thickness in this area and consists chiefly of layers of bronzitite and harzburgite, with minor amounts of dunite, basic pegmatite, and chromitite. The chromitite will be described separately under the heading Chromite deposits.

Bronzitite.—Layers of bronzitite, a rock that consists essentially of the orthorhombic pyroxene bronzite, occur at many horizons in the ultramafic zone. Most of the bronzitite is medium grained, with crystals averaging a fourth of an inch in diameter, although in some layers grain sizes of from 2 to 4 inches occur. Interstitial feldspar and from 1- to 2-inch poikilitic crystals of a green monoclinic pyroxene are common, the latter especially in the bronzitite above the main chromite horizon. In the upper part of the ultramafic zone, the bronzitite contains 10 to 15 percent feldspar. In the area above timberline on East Boulder Plateau and Iron Mountain, the outcrops of the bronzitite are distinguished from those of harzburgite by being a somewhat lighter brown, and by a more distinct jointing and more blocky weathering. On the east slope of Iron Mountain, where the streams follow the trend of the layering, glaciers formed valleys in the well-jointed bronzitite by plucking. On Chrome Mountain the blocks of bronzitite resist weathering, remain angular, and show faintly as steps on the southern slopes of the south peak.

The thickest layer of bronzitite lies above the main chromite horizon and immediately beneath the norite of the banded zone. This layer, which will be called the upper bronzitite, is from 1,000 to 1,500 feet thick in the central part of the complex, and reaches a thickness of 2,800 feet in the vicinity of the Stillwater River.

Poikilitic harzburgite.—Harzburgite is a variety of peridotite that consists of olivine and bronzite. In the Stillwater complex it commonly has a poikilitic texture, in which grains of bronzite from 1 to 5 inches in diameter enclose many small grains of olivine; but there is considerable variation in the degree to which this texture is developed and in the relative proportions of the olivine and bronzite. The poikilitic texture is most easily recognized where the bronzite crystals are large. Rocks in which the bronzite crystals, though poikilitic, are small and poorly developed grade into granular harzburgite, and in a number of places the harzburgite is neither typically granular nor typically poikilitic. In many places, particularly near the main chromite horizon, olivine-rich poikilitic harzburgite grades into the olivine rock dunite. Plagioclase is a common accessory mineral and may form as much as 15 percent of the rock by volume. Because of their greater resistance to weathering, the bronzite crystals stand out on weathered surfaces. Weathered surfaces of olivine-rich varieties of harzburgite are smooth and vary in color from red brown to grayish yellow, in contrast to the nearly black of fresh surfaces.

Chromite is a common accessory mineral in the poikilitic harzburgite. There are all gradations between harzburgite containing scattered grains of chromite and ore consisting chiefly of chromite.

Granular harzburgite.—In the granular harzburgite the olivine and bronzite grains average about a fourth of an inch in diameter and poikilitic texture is not shown. Weathered surfaces of this rock are rougher than those of the bronzitite, owing to the rapid weathering of the olivine. Faint regular layers from 1 to 6 inches thick, which differ chiefly in olivine content, are visible on some smooth glaciated surfaces. With a decrease in olivine content, granular harzburgite grades into bronzitite. Chromite occurs locally as an accessory mineral in the granular harzburgite, but is not so abundant as in the poikilitic variety.

Dunite.—Dunite consists essentially of the mineral olivine. This rock is much less abundant in the Stillwater complex than harzburgite or bronzitite. It contains scattered grains of bronzite in most occurrences, and it grades into both poikilitic and granular harzburgite. Low, rounded outcrops or fine rubble mark its surface exposures. Like the olivine-rich poikilitic harzburgite, it weathers to a smooth surface, and its color ranges from grayish yellow through greenish tan to dark red-brown.

Pegmatite.—Coarse pegmatites composed of olivine and pyroxene, of feldspar and pyroxene, or of all three minerals are of widespread occurrence but small volume. The pyroxene is chiefly bronzite, although green monoclinic pyroxene is also present. Most of the pegmatite bodies are irregular in shape, but a coarse bronzite-feldspar pegmatite forms a regular layer from 5 to 10 feet thick in the upper part of the ultramafic zone on Iron Mountain. Chromite is a common accessory mineral of the pegmatites; it characteristically occurs in the feldspar, or in the bronzite if feldspar is not present.

Serpentinization.—The harzburgite and dunite of the ultramafic zone have been partly serpentinized everywhere in the central part of the complex; the olivine-rich rocks were serpentinized more completely than those poor in olivine. Locally, near some faults, serpentinization is complete. The differences in color of the weathered olivine-rich rocks are probably due to differences in degree of serpentinization. The bronzitite is unaltered except near dikes and faults.

BANDED ZONE

Norite, anorthosite, and gabbro form well-defined layers in the banded zone overlying the ultramafic zone, but have not been mapped in detail. Only the southern or lower part of this zone is shown on the accompanying maps (pls. 8 and 9). The actual contact of the ultramafic and banded zones has been seen only in one place, on East Boulder Plateau, where it is sharp and clearly igneous, like the layer contacts throughout the complex. It is possible, however, that the boundary between the two zones may be a fault in some places.

DIKES

Dikes of gabbroic composition from 1 to 50 feet wide cut the ultramafic zone at a number of places. They are gray and fine grained and have several well-developed sets of joints which cause them to break into small angular fragments. Their presence can be detected in many places by the characteristic alteration of the ultramafic rocks that border them. The weathered surfaces of the altered harzburgite become a pinkish white to pinkish brown. Bronzitite, which appears to alter much less readily than harzburgite, has a purplish tinge under these conditions. A felsite dike similar to Cretaceous intrusions elsewhere in the Beartooth Mountains occurs a mile east of Iron Mountain (pl. 8).

GRANITE

Granite intrudes the metamorphosed sedimentary series on both sides of the valley of the West Fork of the Stillwater River, and east of the West Fork it crops out near the base of the complex. It is believed to be younger than the complex. Where the metamorphic series extends for several miles to the south of the complex on East Boulder Plateau, the hornfels is clearly related to the base of the complex and was produced by the thermal metamorphism associated with that intrusion. The intrusion of granite into the metamorphosed sediments, which are several thousand feet from the complex, has formed granitized schists. Where there are only small remnants of the old sediments between the complex and the granite, they are hornfels rather than schist, and it is concluded that the thermal metamorphism that altered the sedimentary rock to hornfels preceded the intrusion of the granite.

CAMBRIAN ROCKS

Gray shales and thin-bedded limestones of Cambrian age overlie the rocks of the banded zone in a belt 4 miles long between the West Fork of the Stillwater River and Iron Mountain. A small area of Cambrian limestone has been mapped at the headwaters of Brownlee Creek (Howland, Garrels, and Jones, 1949), 500 feet west of the East Boulder Plateau map area.

STRUCTURAL FEATURES

PRIMARY STRUCTURE OR LAYERING

Originally the layers of the rocks of the complex were essentially horizontal and later were tilted to their present position. Mapping on a scale of 500 feet to the inch, such as has been done on East Boulder Plateau (pl. 9), demonstrates that many of the thinner layers of bronzitite and harzburgite are not continuous throughout the complex, but are long lenses. The major features of the layering, however, can be traced throughout the area. The presence of fine-grained norite at most places along the base of the complex has already been mentioned. The upper two-fifths of the ultramafic zone is feldspathic bronzitite, showing little or no layering, and is in sharp contact with the noritic rocks of the banded zone above. Below the thick upper bronzitite are alternating layers, from 5 to 200 feet thick, of granular harzburgite, bronzitite, and poikilitic harzburgite. Generally the boundaries between layers are clearly defined and regular, although there are important exceptions. The dunite has irregular boundaries, and a few crosscutting dikelike bodies have been observed. The upper contacts of some layers of the poikilitic harzburgite are also irregular and project into the overlying granular harzburgite.

TILT

The layers of the complex have been tilted, and they now dip northward at angles that range from nearly horizontal to nearly vertical. The prevailing dips are between 40° and 80° to the north and the general strike of the layers is about N. 60° W. Locally the layers are overturned steeply to the south and the strike is irregular. Although some of these irregularities are related to drag along cross faults, in both the East Boulder map area (pls. 8 and 9) and the Iron Mountain map area (pls. 8 and 10) the departures from the regional trends are more extensive than can be accounted for by the cross faults with which they are associated. In the northeastern part of the Iron Mountain map area the chromite and associated layers from an arc, concave to the west, and strike nearly at right angles to the boundary between the ultramafic and banded zones within 1,000 feet of their contact. Small-scale twists and irregularities occur in the chromite. To the east the chromite layers conform to the general northwestward trend and are offset southward. These relations could be explained by doming and cross faulting in the ultramafic zone and truncation by a strike fault. There is no evidence for such a fault contact between the ultramafic and banded zones, and as an alternative it may be suggested that the complicated structures in the ultramafic zone were developed during or immediately after the consolidation of the ultramafic rocks, but before the crystallization of the banded zone. The complicated structures in the East Boulder map area may have a similar explanation. The low dips and irregular topography in these areas are additional factors in causing the irregular surface pattern of the layers.

FAULTS

The faults of the area are of two kinds: strike faults, roughly parallel to the strike of the layering in the complex; and cross faults, mostly striking north to northeast. Only a few strike faults are known, but there may be others that have not been identified because of the difficulty of recognizing them.

The Iron Creek fault is a large strike fault, which has been traced for 4 miles from near the mouth of Iron Creek westward to the saddle north of Iron Mountain (pl. 8). The Iron Creek fault is a thrust dipping northward about 50°, and the rocks of the banded zone have been thrust up against Cambrian sediments on the south side of the fault. The dip of the layers in the overthrust block is 15° to 20° steeper than on the south side of the fault, suggesting rotation during the thrusting. The Brownlee Creek fault on the west side of the East Boulder Plateau (p. 8) shows a similar relation of fault and Cambrian sediments, and is believed to be a continuation of the Iron Creek fault, although the faults have not been traced across the valley of the East Boulder River.

The Bluebird fault, a southward-dipping thrust, is well exposed on the east side of the valley of the West Fork of the Stillwater River, where for some distance the ultramafic zone is thrust over the banded zone. Its westward extension lies along or south of the West Fork valley and will not be discussed in detail in this report.

A strike fault, apparently with downthrow on the north side, extends eastward from the north end of the north peak of Chrome Mountain on the west side of the East Boulder Plateau map area and is marked by a strong shear zone (pls. 8 and 9). South of this fault the dips are low; north of it they are steep, in places vertical. A diabase dike in the saddle of Chrome Mountain marks another fault, which terminates against a cross fault along the east side of the mountain.

There are many cross faults, generally of steep dip. Detailed mapping on the East Boulder Plateau, on Iron Mountain, and in the West Fork valley (pls. 9, 10, and 11) has shown the presence of many small cross faults displacing the chromite layers for distances of a few tens to several hundreds of feet. Cross faults on a much larger scale are readily recognized by displacements of the base of the complex (pl. 8). Not all seem to displace the contact between the ultramafic and banded zones, and the possibility that this contact is a fault in some places has been considered. No evidence for such a relation has been found west of the West Fork of the Stillwater River, however, and it seems more likely that the cross faults, which are steep, have vertical or nearly vertical displacements, producing larger effects in the gently to moderately dipping base of the complex than in the steeper upper contact of the ultramafic zone. Generally the offset on the larger cross faults is to the right, although there are a few exceptions.

A major change in the structures of the Stillwater complex is approximately marked by the valley of the West Fork. To the east of the valley there are large southward dipping thrusts which have no counterpart in the central section of the complex. That part of the complex lying east of the West Fork will be discussed in a separate report.

CHROMITE DEPOSITS

MINERALOGY AND PETROGRAPHY

The chromite of this area contains from 42 to 48 percent of Cr_2O_3 and has a chromium to iron ratio ranging between 1.46 : 1 and 2.20 : 1. Analyses of chromite from this part of the complex are shown in tables 1 and 2. On the basis of the chemical analyses, the formulas of four samples have been calculated.

H–354	$(Cr_{57}Al_{35}Fe_8)_2O_3.(Mg_{45}Fe_{55})O$
H–306a	$(Cr_{58}Al_{36}Fe_6)_2O_3.(Mg_{51}Fe_{49})O$
P–387	$(Cr_{61}Al_{36}Fe_3)_2O_3.(Mg_{50}Fe_{50})O$
H–421	$(Cr_{52}Al_{39}Fe_9)_2O_3.(Mg_{51}Fe_{49})O$

The composition does not differ greatly from that of the chromite elsewhere in the complex, in most of which the Cr_2O_3 content is between 40 and 49 percent, and the chromium to iron ratio is between 1.2 : 1 and 2.0 : 1. As compared with other analysed specimens of Stillwater chromite these four samples show low to intermediate Fe_2O_3, high Al_2O_3, and intermediate to high Cr_2O_3 content. There is a wide range in magnetic susceptibility, the explanation for which is not known.

The composition of the pure chromite is important because it shows the highest Cr_2O_3 content attainable by mechanical concentration of the ore. Any concentrates produced by mechanical means would be low-grade by current metallurgical standards, which require 48 percent Cr_2O_3 content and a chromium to iron ratio of at least 3 : 1 to be of commercial grade.

TABLE 1.—*Chemical analyses of samples of cleaned chromite*

	H-354	H-306a	P-387	H-421
Cr_2O_3	43.84	45.62	47.72	41.55
Al_2O_3	18.36	19.16	19.11	20.92
Fe_2O_3	[1] 6.64	[1] 5.01	[1] 2.30	[1] 7.09
FeO	[1] 20.46	[1] 18.62	[1] 18.86	[1] 18.47
MgO	9.38	10.75	11.21	11.08
MnO	.21	.18	.15	.21
NiO	---------	---------	---------	.10
CaO	.08	.02	.02	None
TiO_2	.79	.44	.62	.49
V_2O_3	---------	---------	---------	.06
P_2O_5	---------	---------	None	None
S	---------	---------	None	None
SiO_2	.24	.20	.80	.29
H_2O+	.02	.06	.12	None
H_2O-	---------	---------	.08	.24
Total	100.02	100.06	100.99	100.50
Sp gr	4.35	4.46	4.43	4.44
Magnetic susceptibility $\times 10^6$	8.34	121.94	27.80	21.85
Cr .... percent	30.00	31.22	32.65	28.42
Fe .... do	20.55	17.99	16.27	19.38
Cr/Fe	1.46	1.74	2.00	1.47
Cr_2O_3 in raw sample .... percent	32.94	42.50	42.94	17.00
Chromite in raw sample .... do	75	93	90	41
Cr in raw sample .... do	---------	---------	---------	11.6
Fe in raw sample .... do	---------	---------	---------	12.7
Cr/Fe in raw sample	---------	---------	---------	.92

[1] Calculated from total iron on the assumption that $RO:R_2O_3=1:1$.

H-354. 2-foot layer, "A" zone, Riverview B claim, southwest slope of Chrome Mountain. Montana (south) coordinates 526,750 N., 1,831,900 E. R. E. Stevens and M. K. Carron, analysts.
H-306a. Top of 1-foot layer, "G" zone, Champion no. 3 claim, East Boulder Plateau. Strongly magnetic. Montana (south) coordinates 527,000 N., 1,838,900 E. R. E. Stevens and M. K. Carron, analysts.
P-387. 8- to 12-inch layer, "G" zone, Chrome C claim, between Iron Mountain and West Fork of Stillwater River. Montana (south) coordinates 509,900 N., 1,863,800 E. M. K. Carron, analyst.
H-421. 2-inch layer, 350–400 feet stratigraphically above "G" zone, West Fork of Stillwater River. Montana (south) coordinates 504,550 N., 1,870,900 E. R. E. Stevens, analyst.

TABLE 2.—*Partial chemical analyses of samples of cleaned chromite*

	H-306c	P-284	P-278	P-281	P-282	P-321
			Concentrate			
Cr .... percent	32.09	32.23	31.62	30.05	31.48	31.06
Fe .... do	17.22	16.95	14.36	17.63	19.37	16.75
Cr/Fe	1.86	1.90	2.20	1.70	1.62	1.85
Cr_2O_3 .... percent	46.78	47.10	46.21	43.90	45.99	45.39
Sp. gr	4.46	4.44	---------	4.41	---------	---------
Magnetic susceptibility $\times 10^6$	55.61	---------	9.53	---------	10.33	---------
			Raw sample			
Cr_2O_3 .... percent	41.73	41.42	37.32	41.00	36.38	35.07
Chromite .... do	89	88	81	93	80	77

H-306c. Bottom of 1-foot layer, "G" zone, Champion no. 3 claim, East Boulder Plateau. Montana (south) coordinates 527,000 N., 1,838,900 E.
P-284. 1-foot layer, "G" zone, Apex 5 claim, Chrome Mountain. Montana (south) coordinates 527,750 N., 1,835,000 E. Magnetic in hand specimen.
P-278. Near middle of 2.3-foot layer, "G" zone, discovery pit, Sunshine claim, West Fork of Stillwater River. Montana (south) coordinates 504,200 N., 1,871,700 E.
P-281. 1-foot layer, "G" zone, about 120 feet southwest of P-278. Montana (south) coordinates 504,150 N., 1,871,580 E.
P-282. 1-foot layer, "G" zone, discovery pit, Ground Hog claim, West Fork of Stillwater River. Montana (south) coordinates 504,500 N., 1,872,200 E.
P-231. 2-inch layer, 275 feet stratigraphically above "G" zone, West Fork of Stillwater River. Montana (south) coordinates 505,200 N., 1,869,700 E. Grains are magnetic.

The chromite-bearing layers have a wide range in chromite content, and all gradations from a few percent to 90 percent of chromite have been observed. Where the rocks are unaltered, the gangue minerals are olivine and bronzite, and, in places, feldspar. The chromite characteristically occurs in the bronzite surrounding the olivine grains, but also in the feldspar where that mineral is present. Rounded olivine grains, surrounded by bronzite crowded with chromite grains, give a strikingly spotted texture to some of the disseminated ore. Alteration of the silicates is widespread, however, and much of the matrix of the chromite is serpentine.

The chromite has a granular texture and a grain size ranging from 0.005 to 0.1 inch (100 to 4 mesh); the coarser sizes are rare and restricted to small patches in the pegmatites.

The tops of the chromite layers are in most places distinguishable by the presence of a disseminated zone above the massive chromite layer. The thickness of the disseminated chromite zone may be several times that of the massive layer beneath it. Pegmatite sheets, irregular in thickness and extent, occur in many places on the lower sides of the chromite layers, and less commonly on the upper sides.

The chromite layers parallel the layered structure of other rocks of the ultramafic zone. Although some of the chromite layers are only an inch thick and their characteristics are not everywhere the same, they can be traced with remarkable continuity in some places for distances of several thousand feet, maintaining approximately the same position in the ultramafic zone. Thus the thin layers, though unimportant in themselves, are useful as markers to determine the concealed position of the more important known layers.

Only two chromite layers are of possible economic significance in the East Boulder Plateau-Iron Mountain area. One of these, which occurs somewhat below the middle of the ultramafic zone, is the more persistent and usually the thicker layer. It will be called the "G" zone or layer, the name originally applied to the main chromite layer of the Stillwater River area, of which this layer is the probable correlative. The other, which is from 300 to 500 feet above the base of the zone, will be called the "A" zone. Three or four layers, from 1 to 3 inches thick, occur between the "main" chromite layer and the thick bronzitite layer that makes up the upper part of the ultramafic zone, and in the West Fork area a persistent 1-inch layer occurs between the "A" and "G" zones.

DESCRIPTION OF DEPOSITS

EAST BOULDER PLATEAU AREA

An area of about 2 square miles on the East Boulder Plateau has been mapped on a scale of 500 feet to the inch (pl. 9). Included in the discussion of this area, however, are outcrops of the "A" zone layer as much as half a mile west of the map area.

Little is know of the chromite in the timbered country between the valley of the Blakely Creek to the west (Howland, Garrels, and Jones, 1949) and the East Boulder Plateau. The westernmost outcrops of the "G" zone on the plateau lie on the western slope of the north peak of Chrome Mountain (9,963 feet). The northward dip is only 20°, and the chromite outcrop swings to the south around the base of the peak. On the southeast side of the peak, the chromite layer is broken and interrupted by what is regarded as a deformation before complete consolidation. The chromite is believed to persist to the cross fault on the east side of the peak, but it probably is discontinuous. The lower part of the "G" zone here consists of massive ore averaging 1 foot in thickness, which is overlain by a foot-or-so of lean disseminated ore. Analysis of sample P–284 (see table 2), taken from the massive ore, shows 88 percent of chromite. The disseminated ore contains from 10 to 15 percent chromite. Two thin layers, 1 and 3 inches thick and about a foot apart, occur about 500 feet stratigraphically above the "G" zone and pass through the summit of the north peak, but owing to extensive alteration of the containing harzburgite they cannot be traced for more than a few feet.

South of the strike fault, which is believed to be downthrown on the north side (see pl. 9, cross section *A–A′*), the "G" zone is shown as extending in circuitous outcrop on the western and southern sides of the south peak of Chrome Mountain. Its position can be determined within narrow limits from the position of the layer of poikilitic harzburgite in which it occurs and from a few fragments of chromite float on the west side of the peak, but nothing is known of its thickness or grade. The only place where it crops out west of the cross fault is on the southern side of the south peak where it consists of three 1-inch layers in a zone about 6 feet thick, the rock between the layers containing a small amount of disseminated chromite.

From the cross fault on the south peak of Chrome Mountain, the "G" zone chromite can be followed northeastward with fair continuity to the eastward extension of the strike fault described above. In the basin at the headwaters of Brownlee Creek the chromite is broken by several small faults and has an irregular outcrop because of low dips and the presence of a shallow syncline in the basin. On the east slope of the south peak the chromite zone consists of two or three 1-inch layers, but in the bottom of the basin the zone ranges from 3 to 8 feet in thickness and contains, on the average, about 20 percent of chromite. The massive layer at the bottom is 6 inches to a foot thick and is overlain by banded disseminated material. Comparison of the analyses of the two samples H–306a and H–306c (tables 1 and 2) shows a slight decrease in chromium and an increase in iron in the chromite in the upper part of the layer. Sample H–306c, although collected at the bottom of the layer, contains 4 percent less chromium than sample H–306a, which was taken from the top of the layer. The increase of iron in the chromite of the upper part of the layer does not seem to be great enough to account for the much stronger magnetic property of this part, and information concerning the proportions of ferric and ferrous iron is not available.

Between the headwaters of Brownlee Creek and the east edge of the East Boulder Plateau (pl. 9) the structure is obscured by overburden and complicated by faults. In the southern part of the mapped area east of the trail, the structure appears to be complicated by intrusions of dunite too small to be placed on the map. There the massive layer of chromite is about 3 inches thick where exposed.

The "A" zone chromite is not exposed in the area shown in plate 9, but crops out and has been prospected west and southwest of the limits of the map. On the north side of the valley of Bobcat Creek about half a mile west of the mapped area (Howland, Garrels, and Jones, 1949, pl. 34), a layer 2 to 3 feet thick is exposed more or less continuously for 500 feet along the strike. This layer is also found, though poorly exposed, on the talus slope southwest of the south peak of Chrome Mountain (pl. 8, 525,800 N., 1,833,500 E.), but there it is only from 3 to 4 inches thick. Wherever the "A" zone has been observed in the complex, it has proved to be irregular and of uneven thickness, but its average thickness is probably 3 or 4 inches. The chromite of the "A" zone has also a lower Cr_2O_3 content and a smaller chromium to iron ratio than that of the "G" zone. Analysis of sample H–354 (table 1), collected from the "A" zone, indicates a Cr_2O_3 content of 43.84 percent and a chromium to iron ratio of 1.46 : 1.

EAST BOULDER PLATEAU TO EAST BOULDER RIVER

Between the East Boulder Plateau map area and the East Boulder River, the "G" zone crosses timbered country. Chromite crops out at a number of places and has been proved for about 1,000 feet along the strike on the Chrome Queen no. 9 claim, about a mile west of the East Boulder River (pl. 8, 521,300 N., 1,845,000 E.). (Locations of many of the claims in this area are shown by Wimmler, 1948.) It is not certain that all the outcrops represent the same layer. The thickness of the massive "G" layer ranges from 4 to 15 inches; the disseminated zone is not always present, but in places it is as much as 5 feet thick and contains from 10 to 20 percent of chromite. The "A" zone has been found by prospecting in two places, one close to the trail in the flat on the west side of East Boulder River (pl. 8, 519,000 N., 1,849,000 E.), and the other more than a mile to the west

(521,850 N., 1,843,600 E.), north of the Montana Chrome Corp. cabin. Though not clearly exposed at the time of examination, the chromite zone at these two localities apparently is about 2 feet thick and dips from 15° to 20° northward. Disseminated chromite is scattered through dunite over an area of 2,000 square feet or more on the Bonanza King claim, which is on the east side of the trail and 1,000 feet southeast of the East Boulder Plateau map area (pl. 8, 533,900 N., 1,842,800 E.). This is the approximate horizon of the "A" zone and illustrates its irregular character.

IRON MOUNTAIN AREA

Between the East Boulder River and the crest of Iron Mountain no chromite has been found. Timber covers the lower part of the valley that heads on the west flank of Iron Mountain, and above timberline there are few outcrops in the chromite-bearing part of the ultramafic zone. A cross fault about 1,600 feet east of the river, marked by a strong shear zone and a 3- to 4-foot quartz vein, displaces the base of the complex more than 3,000 feet southward on the east side. This is the largest displacement along this type of fault that has been noted anywhere in the complex.

The first exposures of chromite east of the river are in the basin on the east side of Iron Mountain. Good exposures below an altitude of 9,500 feet show that the "G" zone strikes from north to east and dips from 20° to 45° westward and northward. The trend of the outcrops forms a large arc in the basin, but the chromite is unknown beyond the area of small cross faults in the northeast part of the Iron Mountain map area (pl. 10). A major cross fault apparently displaces the chromite to the right. The chromite layer on the Chrome F and Chrome H claims, on the ridge south of Iron Mountain basin (pl. 8, 513,000 N., 1,860,150 E.) may be the continuation of the "G" zone beyond the fault, but it has the characteristics of the "A" zone, which is exposed on the Chrome D claim at triangulation station 9,344 (510,000 N., 1,862,750 E.), nearly a mile to the east.

The "G" zone in the northeast part of the Iron Mountain map area consists of a layer of massive ore 0.6 to 1.2 feet thick, and a 1.5- to 3-foot zone of disseminated chromite above it. Southwestward, however, it becomes a faintly layered, disseminated zone, which has a maximum thickness of 120 feet and is estimated to average from 6 to 8 percent of chromite.

IRON MOUNTAIN TO THE WEST FORK OF STILLWATER RIVER

The "G" zone is exposed at a number of places between Iron Mountain and the edge of the plateau on the north side of the valley of the West Fork. On the Chrome group of claims about a mile east of the

Iron Mountain map area (pl. 8, 510,000 N., 1,862,700 E. to 508,700 N., 1,864,800 E.) prospecting has revealed two segments of the "G" zone totaling about 400 feet in a distance of 1,700 feet along the strike. A massive layer 0.8 to 1.0 feet thick is overlain by 1.0 to 3.5 feet of disseminated material containing from 5 to 15 percent of chromite. The analyzed chromite from the Chrome C claim (P–387, table 1) is strongly magnetic. The dip is 65° to 75° N. Several small outcrops show the "A" zone to be 1 to 2 inches thick on the east slope of Iron Mountain. On the Chrome D claim (pl. 8, 510,000 N., 1,862,700 E.), however, it ranges from 0.5 to 1.0 feet in thickness and is almost entirely massive, with little disseminated chromite. The chromite layer of the Chrome H and F claims on the ridge south of Iron Mountain basin (pl. 8, 513,000 N., 1,860,150 E.), 0.8 to 0.9 feet thick, probably is also a part of the "A" zone.

On the Fry-Taylor claims on the north side of Crescent Creek valley (pl. 8, 507,800 N., 1,865,500 E. to 506,300 N., 1,867,700 E.) the "G" zone is intermittently exposed for a distance of 2,700 feet along the strike. The massive chromite layer ranges from 0.5 to 1.7 feet, but does not average more than 1 foot in thickness. The disseminated chromite zone above the massive layer ranges from 0.7 to 2.8 feet in thickness and disseminations also occur beneath the massive layer. In places the dip of the chromite layer is irregular, but in general it dips 50° to 60° northward. There is a distance of about 1,500 feet between the most easterly exposures on the plateau and the outcrops on the north slope of the valley of the West Fork of the Stillwater River.

WEST FORK OF THE STILLWATER RIVER

On the north slope of the West Fork of the Stillwater River, the "A" and "G" zones, as well as a number of thin layers at other horizons, have been mapped in detail (pl. 11) for a distance of 3,800 feet along the strike, and at altitudes ranging from 7,100 feet at the eastern end to 8,600 feet near the edge of the plateau on the west.

Exposures are abundant in this area, and the relationships of the chromite and other layers for a stratigraphic distance of about 1,500 feet are clear. Stratigraphic sections at the position of the cross sections on plate 11 are shown in plate 8. Here, as on the East Boulder Plateau, it can be seen that although some of the layers are actually lenses, the major features of the layering are remarkably continuous. Examples are the occurrence of both the "A" and "G" zones within continuous layers of poikilitic harzburgite—a relationship true throughout the complex—and a 1-inch layer of chromite approximately midway between the "A" and "G" zones. Everywhere it has been found this midway layer marks the boundary between bronzitite and an overlying layer of poikilitic harzburgite. Some variations in the sequence of rock from one section to another are less real than apparent, for it is difficult to place the boundary between bronzitite and granular harzburgite; the relationship is in places a gradational one and the determination in the field is not based on accurate quantitative data concerning the relative proportions of olivine and bronzite. The thin layers of chromite both above and below the "G" zone make possible the approximate location of the main chromite even though it is not continuously exposed.

Cross faults which offset the layers from a few to 200 feet occur throughout the West Fork area, the longest section of unfaulted chromite being a little more than 500 feet. Cross faulting is, indeed, an important feature of every area in the complex that has been mapped in detail. The little evidence that is available in the shear zones and closely spaced joints near faults, indicates that most of the cross faults are steep.

The "A" zone has been followed for 1,900 feet along the strike to where it disappears beneath talus at the lower end. The containing rock is olivine-rich harzburgite, which usually has poorly developed poikilitic texture. The chromite is irregular, ranging from an inch to more than 3 feet in thickness; no consistent stratigraphic sequence of chromite layers and lenses exists. In one place chromite is disseminated through a stratigraphic thickness of more than 25 feet with some layers of massive chromite occurring within the zone. Elsewhere a 1-foot "layer" is known to be a lens only 6 feet long at the surface, and several layers shown on the map are only 1 or 2 inches thick.

In contrast, the "G" zone is remarkably uniform throughout the mapped area. It consists of from 0.5 to 2 feet of massive chromite overlain by from 0.5 to 2 feet of disseminated chromite. In a few places the main layer is approximately half silicate and at others there is a foot or so of disseminated chromite below the main layer. Nevertheless, the massive chromite averages 0.9 foot in thickness throughout, and the zone as a whole, including both massive and disseminated chromite, averages 1.8 feet.

The layer between the "A" and "G" zones and those above it average only an inch in thickness and have significance only as horizon markers.

MINING POSSIBILITIES

The possibilities of mining the chromite deposits of the central part of the Stillwater complex depend on: (1) the composition of the chromite mineral, (2) the grade of the chromite-bearing rock, (3) and the thickness and continuity of the chromite-bearing layers.

COMPOSITION OF THE ORE MINERAL

The Cr_2O_3 content of the pure mineral ranges from 43 to 48 percent and probably averages close to 46 percent. The chromium to iron ratio ranges from 1.46:1 to 2.00:1 and averages about 1.75:1. This composition is similar to that of the chromite that has been mined in other parts of the complex.

GRADE OF CHROMITE-BEARING ROCK

The grade of the chromite-bearing layers is also similar to that in the layers at the Gish, Mouat, and Benbow mines. So-called massive chromite contains between 70 and 94 percent of chromite (approximately 30 to 42 percent of Cr_2O_3), and could possibly be handsorted to give a material containing 35 percent Cr_2O_3 and having a chromium to iron ratio of 1:1.2. Disseminated material ranges from 1 to 70 percent of chromite (0.5 to 30 percent of Cr_2O_3) and would have to be concentrated. Channel assays across the chromite, most of them made on the "G" zone, have been reported by Wimmler (1948). Experience with the milling of the Stillwater chromite ores shows that even where the olivine and bronzite gangue minerals are serpentized, as they are in this area, and break away easily from the chromite, it is difficult to produce concentrates consistently containing more than 40 percent of Cr_2O_3. A high-grade metallurgical ore cannot be obtained, therefore, by even the best mechanical concentration.

THICKNESS AND CONTINUITY OF THE CHROMITE-BEARING LAYERS

The value of any particular layer of chromite as ore depends upon its thickness as well as upon its grade. The thickness of the massive part of the "G" zone does not exceed 2.5 feet and does not average more than 1.2 feet even in selected areas. The layer of disseminated ore above the massive ore ranges in thickness from a few inches to 8 feet and contains an average of 10 to 15 percent of chromite. The most favorable parts of the area for future mining, as indicated by both thickness and grade, are listed in table 3. Because the "A" zone is thought to have no commercial value, the "G" zone is alone considered.

TABLE 3.—*Surface extent, thickness, and grade of ore in the central part of the Stillwater complex*

Locality	Length (feet)	Average thickness (feet)	Percent Cr_2O_3
Chrome Mountain	850	3	15
East Boulder Plateau	2,000	5	15
Chrome A, B, and C claims	1,700	3	15–20
Crescent Creek area	2,700	2.2	15
West Fork	3,800	1.8	15

On the southwestern and southern sides of the north peak of Chrome Mountain, chromite crops out for a distance of about 1,000 feet along the strike of the "G" zone. Its extension to the west is unknown, but the eastern end appears to be interrupted and where it is next seen there are only two or three 1-inch layers of chromite. The massive layer averages 1 foot in thickness, and the disseminated layer above it, only 1 to 2 feet; the grade across the total 3-foot thickness is believed to be less than 15 percent of Cr_2O_3. The outcrop curves around the peak, in part because of the low dip of the layer (20° N.) and the topography. Therefore, although the distance along the outcrop is 1,000 feet, a measurement parallel to the strike would be only about 850 feet. The depth down the dip presumably is comparable to the true strike length of the layer.

In the basin at the headwaters of the south fork of Brownlee Creek, east of Chrome Mountain, the "G" zone is exposed for about 1,500 feet along the strike. The massive layer is from 0.7 to 0.9 foot thick, and there is a wide disseminated zone that averages 5 feet in thickness and reaches a maximum of 8 feet on the Champion no. 3 claim. To the southwest this zone is represented only by two or three 1-inch layers. To the north it is interrupted by a strike fault, and only thin layers and disseminations are seen in the eastern part of the East Boulder Plateau map area. Although at this place the chromite layer is thicker than anywhere else in the East Boulder Plateau-Iron Mountain area, an attempt to estimate tonnage would mean little as the chromite lies in a shallow syncline and its extension down the dip is buried on the downthrown north side of the strike fault (pl. 9, cross section *C–C′*).

The part of the "main" layer between East Boulder Plateau and East Boulder River has not been mapped in detail, but reconnaissance mapping (pl. 8) has indicated that it probably is continuous for several thousand feet. At least two important cross faults, marked at the surface by long open clearings in the timber, cut the ultramafic zone, and several minor cross faults are visible. The few exposures east of the eastern fault show only from 3 to 4 inches of massive chromite; to the west of the western fault the disseminated layer is either missing or is from 60 to 100 feet above the massive layer. The block between the two faults is about 2,000 feet long, and has a thickness of 0.5 to 1.9 feet of massive chromite and 3 to 5.8 feet of disseminated, which together might be equivalent to about 5 feet of ore averaging 15 percent Cr_2O_3. The dip of the chromite ranges from 70° southward to 65° northward.

The chromite exposure in the basin on the east side of Iron Mountain is about 1,200 feet long. The massive layer is 0.6 to 1.2 feet thick, the disseminated 0.9 to 3.5 feet. To the west the massive layer changes to a wide zone of low-grade disseminated chromite (2 to 5 percent Cr_2O_3), and to the east it is cut by many small cross faults.

On the Chrome A, B, and C claims, about a mile east of Iron Mountain, chromite is exposed sporadically for a distance of 1,700 feet, but the aggregate length of the exposures is only about 400 feet. The layer appears to be consistent wherever exposed, however, with an average thickness of 0.9 foot of massive ore and a little over 2 feet of disseminated, for an average Cr_2O_3 content of 15 to 20 percent. The layer dips from 65° to 75° northward. Nothing is known of its continuation to the west between the Chrome C claim and the Iron Mountain basin, but it apparently continues eastward onto the Fry-Taylor claims. There is probably a cross fault just west of the Chrome A discovery pit (508,800 N., 1,864,800 E.).

The section of the Fry-Taylor claims on the north side of Crescent Creek (Vega, Orion, New Deal, Venus, and Jupiter claims) shows interrupted exposures of the "G" zone averaging 2.2 feet thick, of which a little less than 1 foot is massive chromite, for a distance of 2,700 feet. The dip of the "G" zone is 50°–60° northward.

The section of the Fry-Taylor claims on the north slope of the valley of West Fork of the Stillwater River contains the longest and best known exposure of chromite in the central part of the complex. It is, furthermore, the most accessible part of the area. The eastern end of the outcrops is low on the slope of the valley, about 350 feet above the river. The U. S. Forest Service road along the West Fork reaches to within 2 miles of the lower end of the chromite. The "G" zone is believed to average about 1.8 feet thick, about 15 percent Cr_2O_3, and to be continuous for 3,800 feet along the strike between the altitudes of 7,100 and 8,600 feet. The many cross faults, which displace the chromite in this section, might be expected to cause difficulties and substantial losses of ore in mining.

SUMMARY

Although all the central part of the Stillwater complex has not been mapped in detail, the mapping of critical areas and careful reconnaissance of the remainder justifies a preliminary statement concerning its chromite reserves. The thin chromite layers are unfavorable for the production of a large tonnage of ore. Mining would be expensive and complicated, because of the presence of many faults and the occurrence of the chromite in gently to moderately dipping layers, and because of the inaccessibility of the plateau areas and the rigorous climate. The Fry-Taylor claims in the valley of the West Fork of the Stillwater River are the most favorable area.

LITERATURE CITED

Howland, A. L., Garrels, E. [R.] M., and Jones, W. R., 1949, Chromite deposits of Boulder River area, Sweet Grass County, Montana: U. S. Geol. Survey Bull. 948-C.

Peoples, J. W., and Howland, A. L., 1940, Chromite deposits of the eastern part of the Stillwater complex, Stillwater County, Montana: U. S. Geol. Survey Bull. 922-N.

Thayer, T. P., 1946, Preliminary chemical correlation of chromite with the containing rocks: Econ. Geology, v. 41, p. 202-217.

Wimmler, N. L., 1948, Investigation of chromite deposits of the Stillwater complex, Stillwater and Sweet Grass Counties, Montana: U. S. Bur. Mines Rpt. Inv. 436B.

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U S GOVERNMENT PRINTING OFFICE: 1954