The Chromite Deposits of Stillwater and Sweetgrass Counties, Montana

Uuno Sahinen

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THE CHROMITE DEPOSITS OF STILLWATER
AND SWEETGRASS COUNTIES, MONTANA

By UUNO SAHINEN

MONTANA STATE SCHOOL OF MINES
JUNE 1929
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by

UUNO MATHIAS SAHINEN

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The Chromite Deposits of Stillwater and Sweetgrass counties, Montana

By Uuno M. Sahinen

Introduction

In writing this report, two objects were kept in mind, (1) to explain, if possible, the origin of the chromite deposits found in Sweetgrass and Stillwater Counties, and (2) to bring up to date all information on these deposits which has thus far been available.

The work done consisted of study of the rocks and ores of the area under the microscope, both as thin sections and as polished sections, practically all of which was done at the Montana State School of Mines, during the school year of 1928 - 1929.

The rock specimens and much information as to their locations and probable compositions were obtained from Mr. P. F. Minister, of the East Butte Copper Company. United States Geological Survey Bulletin 725-A, Deposits of Chromite in California, Oregon, Washington, and Montana, and the unpublished report on the Chromite deposits of the Boulder River, prepared by Prof. C. H. Clapp of the University of Montana, were frequently referred to and considerable material was drawn from them. The map of the Boulder River area is from Clapp's report.

Geography

The chromite deposits are associated with a narrow belt of pyroxenites and peridotites which extend from Boulder River at the eastern boundary of Sweetgrass county in a general direction S. 75° E., to Fishtail Creek in Stillwater county, a distance of
27 miles. The western end of the deposits is about 30 miles to the southwest of Big Timber, Sweetgrass county, and the eastern end, about 30 miles southwest of Columbus, Stillwater county. Another deposit of chromite occurs 12 miles southwest of Red Lodge, in Carbon county. The latter deposits are not associated with the former, and will not be described in this report.

The region is one of great relief. The northward flowing streams have cut canyons 3,000 to 4,000 feet deep in high upland plateaus, upon which there are a few isolated hills which rise 1,000 feet higher. The plateaus, remnants of an old peneplain, are in themselves, in general of moderate relief, their elevations being from 9,500 to 11,000 feet above sea level. The main Boulder Valley has been glaciated and its steep slopes have been cut by narrow "V" shaped valleys with steep gradients. These great variations in altitude, from the bottoms of the main valleys to the plateaus exposes the chromite dike through a vertical range of over 5,000 feet, and incidentally, makes the problem of transportation a vital ones in the development of these properties. At present, the roads from the nearest railroad stations to the depositis are not all that they could be and would require an investment of considerable money in order that they might be put into shape to serve as routes of transportation of the ores or concentrates to the railroads.
General Geology

In describing the general geology, Westgate* says, "The rocks of the region consist of a series of sedimentary formations ranging in age from Cambrian to Cretaceous, 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 borders of the mountains, forming the foothills.

"Pyroxenite occurs as an intrusive dike or sill 27 miles long and from half a mile to a mile wide. On the Boulder River, it is 5 miles south of the Paleozoic rim; on the Stillwater river, it is not over 2 miles south; and at the eastern 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, gabbro cuts Tertiary andesite, as well as pre-Cambrian rocks.

Sketch Map Showing Topography and Geology in the Vicinity of the Boulder River Chromite Deposits, Sweet Grass County, Mont.

**Legend**
- Paleozoic sediments
- Chromite "veins" (solid where almost continuously exposed, dotted where poorly exposed)
- Pyroxenite (dike)
- Gabbro-anorthosite gneiss (some pyroxenite and aplite dikes)
- Quartz-feldspar-mica schists (some diorite and gabbro dikes, gneissic and schistose in places; with quartz lenses and bands of quartz and magnetite)

Scale: 0 - 3 miles
Approximate Contour Interval 200 ft.
In his report, Clapp describes the pyroxenite dike in the Boulder River region, at the western end of the deposits as follows:

"The chromite deposits occur in a pyroxenite dike over 10 miles long and from 2,000 feet to nearly a mile wide. The dike has been intruded along the contact between the prevailing quartz-feldspar-mica schists of the region, occurring to the south of the dike, and a large mass of gabbro-anorthosite gneiss, which occurs to the north of the dike. The schists have a prevailing northeasterly strike, whereas the foliations of the gabbro-anorthosite gneiss trend about N. 60° W., and dip steeply, about 70° to the northeast. The dike follows the foliations of the gneiss, also dipping to the northeast at angles from 40° to 80°, being flatter at the southeast end of the deposits. The gabbro-anorthosite gneiss is clearly intrusive into the older schists, but the pyroxenite is, on the other hand, intrusive into both the gabbro-anorthosite gneiss and the older quartz-feldspar-mica schists. Smaller pyroxenite dikes similar to the main pyroxenite dike and parallel to it, and also parallel to the foliations are found in the gneiss, and a few dikes also parallel to the main dike, are found also in the schists. To the northwest of the dike, the gabbro-anorthosite gneiss is clearly unconformably overlain by Cambrian sediments which dip to the north. Both the dike and the chromite deposits are broken by small cross faults, but otherwise do not seem to have been greatly disturbed from their original attitude."

The gabbro associated with the pyroxenite referred to by Westgate is probably the gabbro-anorthosite gneiss described by Clapp. Both men agree that the two (gabbro and pyroxenite) are
associated (probably two phases of the same magma) but there seems
to be a difference of opinion as to the age. From Clapp's descrip-
tion of the attitude of the Cambrian rocks with respect to the gabbro, one would infer that the is earlier than the Cambrian sediments
which overlie it. If this igneous unconformity is actually present
there would be no doubt as to the age, but perhaps more detailed
work, may reveal an igneous conformity between the two. Clapp's
work did not take him to the southern end of the deposits where
Westgate describes and igneous conformity with a "somewhat meta-
morphosed, but still clearly fossiliferous limestone", which he
sites as evidence that the age of the gabbro, and consequently, the
pyroxenite, is at least post-Carboniferous and probably post-Meso-
zoic. The latter interpretation is probably the case, as one would
want to expect signs of more intense deformation in rocks of pre-
Cambrian age than these rocks show, especially in an area which
has undergone as much structural deformation as this area has.

It is also probable that these basic rocks have been intruded at
the same time as similar rocks, gabbros and associated chromite
bearing peridotites, in other parts of the western United States.*

The description of the Montana rocks and ores compare very favor-
ably with those of California and Oregon except that the former are
not so badly altered. This may be satisfactorily explained by the
fact that they have recently been glaciated and the surficial alter-
ation products thus removed, and also, by the difference in climatic

725-A, pp 137-600 (1921) (page 41)

*Diller, J. S., Chromite in the Klamath Mountains, California and
conditions. The Montana deposits have been "high and dry" since probably early or middle Tertiary times and under such conditions, the alteration would progress more slowly than would the alteration of the California and Oregon deposits, which are in a region of relatively greater humidity. The California and Oregon deposits are said to be of probable Jurassic age.

The Chromite deposits

The chromite occurs as a vein or dike which runs along the middle of the pyroxenite dike. Its width is variable, from a few inches to a maximum of 8 feet, but it is persistent in length, being exposed practically the entire length of the pyroxenite dike. Where the chromite veins is not exposed at the surface, float of chromite bearing rock and ore indicates its continuity. It is also exposed through a vertical range of over 5,000 feet. Throughout this great vertical range, the ore shows very little change in character and it is said that the lower limit to which the ore can be mined will not be determined by change in the character of the ore but rather by the method or expense of mining. There are also many smaller and less persistent veins parallel to the main vein and cross veins which connect these veins to the main vein, but these are usually too far from the main vein (300 to 2,500 feet) to be mined through the same stopes as the main vein and are not in themselves large enough to be mined separately. Chromite also occurs as disseminated grains and veinlets in the country rock forming a second class or milling ore. This is more pronounced on the northeast or hanging wall side of the vein. This vein dips to the northeast at angles varying from 60° to 80°.
In reports written by other authors, the deposits have been described as districts, but the division into districts has been based more or less on the accessibility or the amount of development work which has been done in the different areas. The deposits are, however, more or less uniform in composition and character throughout the entire belt and the description of any one district is very similar to that of any other one. In this report, no distinction as to districts will be made, but names of the different areas will be given and occasionally referred to.

The claims in the western end, from the main Boulder River to the East Fork of the Boulder River, are known as the Boulder River group. The next group, the Fry-Dillon claims, extend from Iron creek to the west fork of the Stillwater River, a distance of 5 miles. The Benbow group of claims are near the east end of the dike. They extend from the Stillwater-Little Rocky divide, a distance of 2 miles, to the west slope of Fishtail Creek.

The area between the Fry-Dillon claims and the Benbow group have not been described, for, as yet, very little development work has been done in that area.

The pyroxenite dike has not been followed west of Fishtail Creek.
Cocurance of Chromium in General

Chromium, in general, is widely diffused in the basic rocks such as peridotites and pyroxenites. The average proportion found in 256 analyses of igneous rocks in the laboratory of the United States Geological Survey is 0.05% of chromium oxide. The native metal has never been found, neither has the sulphide with the exception of Daubréelite, an iron-chromium sulphide (FeCr$_2$S$_4$ or FeS.Cr$_2$S$_3$) occurring with troilite in some meteoric irons. The known minerals of chromium are listed below:

Chromium bearing minerals:

Oxides -

Chromite, FeO.Cr$_2$O$_3$, 68.0% chromic oxide, 32.0% iron oxide.

Gicotite, (Mg,Fe)$_6$(Al,Cr)$_2$O$_3$, chrome spinel

Chromates -

Crocoite, lead chromate, PbCrO$_4$, chromic oxide 31.1%, lead protoxide 68.9%.

Phoenicroehroite, basic lead chromate, 3PbO.2CrO$_3$

Vauquelinite, lead phospho-chromate, 2(Pb,Cu)CrO$_4$.3Pb$_2$O$_3$

Sulphides -

Daubréelite, iron-chromium sulphide, FeS.Cr$_2$S$_3$ (meteoric)

Sulphates -

Reddingtonite, hydrous chromium sulphate.

Knoxxvillite, hydrous basic sulphate of chromium, ferric iron, and aluminium.

Silicates -

Chrome diopside, containing from 1 to 218% chromic oxide.

Chrome garnet, 3BeO.Al$_2$O$_3$.6SiO$_2$.nCrO$_3$. (uvarovite)

Chrome mica, Fusionite, 2H$_2$O.K$_2$.3(Al,Fe,Cr)$_2$O$_3$.6SiO$_2$. 
Chrome tourmaline.

Chrome beryl, emerald, $3\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot n\text{CrO}_3$.

Chrome chlorite, Kämmmererite, kotschubeite, $4\text{Al}_2\text{O}_3 \cdot \text{Si}_2\text{O}_5 \cdot (\text{Al}, \text{Cr})$.

Avalite

Milosin

Alexandrolite

Wolchonekoite, a chromium bearing clay.

Of all the minerals listed above, the oxide, chromite, is the most important economically as it is practically the only source of chromium. It is found in considerable quantities only in peridotites and pyroxenites. It is the only chromium bearing mineral which has thus far been described as occurring in the Montana deposits.

According to Dana, it is an iron chromate and may be represented by the chemical formula $\text{FeCr}_2\text{O}_4$ or $\text{FeO} \cdot \text{Cr}_2\text{O}_3$, composed of $68.0\%$ chromium sesquioxide and $32.0\%$ iron protoxide. The iron may be replaced by magnesium and the chromium by aluminium and Ferric iron. The variety with less than $10\%$ chromium are usually classed as chrome spinels. It is possible to have all gradations from pure spinel, a magnesium aluminate ($\text{MgAl}_2\text{O}_4$ or $\text{MgO} \cdot \text{Al}_2\text{O}_3$) containing no chromium, through chrome spinel or picotite ($\text{Mg}_x\text{Fe}_{1-x} \cdot (\text{Al}, \text{Cr})_2\text{O}_3$), in which part of the magnesium has been isomorphously replaced by ferrous iron and part of the aluminium by chromium, containing up to $10\%$ chromium, to chromite, which contains $68.0\%$ chromic oxide. Due to this gradational series, some chromite ores cannot be
concentrated mechanically to an economic product, as the ores are chemically low grade. This is an important factor and must be kept in mind when considering the concentration of chrome ores.

Chromite crystallizes in the isometric system, usually as octahedrons. In the Montana ores, the octahedrons are exceptionally well developed as to form. In thin sections, square, diamond shaped, and triangular cross-sections are very common. The size of the grains or crystals is usually small, from 0.06 mm to 1 mm, the average being from 0.1 to 0.2 mm. A good recovery could be obtained by mechanical concentration by grinding to 100 mesh. Mill tests with 53% recovery have been run on 50 mesh material.

The color is black, but on very thin edges, it is translucent and of a coffee brown hue, which distinguishes it from magnetite. The fracture is uneven and sometimes conchoidal, exposing bright, fresh surfaces showing a sub-metallic to metallic luster. It is very brittle. The hardness is 5.5 and the specific gravity, 4.32 to 4.57.

The other chromium minerals may occur with chromite, but none have as yet been recognized in the Montana ores. With more study, many of them will probably be found to occur. Most of them have been described as alteration products in other chromium deposits. They are not, however, important as a source of chromium.

Practically all the commercial deposits of chromium occur in basic igneous rocks such as peridotites and pyroxenites or in rocks produced from them by alteration such as serpentine and magnesite. In the western United States, California, Oregon, Washington, an chromite occurs in serpentine derived from the alteration of
pyroxenite. In India, the chromite occurs both in serpentine and in magnesite, also derived from the alteration of basic igneous rocks.*

In Montana, the chromite occurs in peridotite which has not been very badly altered.

Peridotite is a basic igneous rock which, in its broad sense, includes the extremes pyroxenite and dunite and all the intermediate forms. Pyroxenite is composed essentially of pyroxenes with some olivine and other minor constituents. Dunite is a rock composed almost entirely of olivine. Saxonite is an intermediate form rich in olivine and also contains considerable enstatite and hypersthene. All of these rocks may contain chromite as an important accessory mineral.

Olivine and pyroxene both alter to serpentine and magnesite, but the olivine more readily than the pyroxenes. In the alteration from olivine, the volume change is 23.3%. There is also some brucite or magnesite formed in the reaction which will make the volume change still greater. The reactions are as follows:

\[
\begin{align*}
2(2\text{MgO.SiO}_2) - 2\text{H}_2\text{O} - \text{CO}_2 &= 3\text{MgO.3SiO}_2.3\text{H}_2\text{O} - \text{MgCO}_3 \\
\text{serpentine} &\quad \text{magnesite} \\
2(2\text{MgO.SiO}_2) - 3\text{H}_2\text{O} &= 3\text{MgO.2SiO}_2.3\text{H}_2\text{O} - \text{MgO.H}_2\text{O} \\
\text{serpentine} &\quad \text{brucite}
\end{align*}
\]

Due to this great increase in volume, the olivine is badly fractured and slickenside is often developed. Any iron which may be present in the olivine, is changed over to magnetite or limonite.

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*Mahadevan, C., The chromite bearing deposits of Singhbhum, India. Econ. Geol., Vol. xxiv, No. 2 (1929).
Petrography

Gabbro-Anorthosite Gneiss -

Gabbro is found to the north and in contact with the Pyroxenite dike next to the Paleozoic sediments. It is a light colored rock spotted with dark brown grains of hypersthene giving the rock a mottled or speckled appearance. The microscope shows it to be composed mainly of feldspars which make up about 70% of the rock. The feldspar is of a basic variety, andesine. No quartz was found in the specimens examined. The ferro-magnesian minerals which make up about 25% of the rock, consist of hypersthene, augite, and biotite, their relative abundance being in the order named. The hypersthene is the most important of these, making up about 30% of the rock. It occurs in rounded grains which are more or less altered. The augite occurs in small amounts in small euhedral crystals. Biotite is scattered throughout the rock in small pleochroic grains. It is less abundant than the augite. The alteration products of the different minerals make up about 5% of the rock. Among them, kaolin is present as minute translucent scales. The texture is even, medium grained. Clapp has named this rock a gabbro-anorthosite gneiss. In calling it a gneiss, he has probably done so from its field relationships as the rock shows no gneissic structure under the microscope or in the hand specimen. In his report, he states that "the foliations of the gabbro-anorthosite gneiss trends about N. 60° W., and dips steeply, about 70° to the northeast." In this report, the rock will be referred to simply as gabbro.
Dike rocks.

The dike, which has been intruded between the gabbro and the quartz-feldspar-mica schists, is composed essentially of pyroxenite and peridotite. The rock grades from a pyroxenite, consisting almost entirely of hypersthene, at the borders or edges of the dike, through saxonite, a rock rich in olivine, to peridotite at the center of the dike. In U. S. G. S., bulletin 725-A, pp 70-72, Westgate says, "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 becomes 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. 2) at right angles to the vein-like 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 (enstatite)

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

Figure 3.- Section of chromite vein and adjacent rock on Bonanza claim, near Boulder River, Sweetgrass County, Montana.

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 a gangue in the ore body.

4- Granular mixture of rock and chromite (1.5 inches).

5- Ore (1.5 inches).

6- Mixed rock and chromite (3 inches), making a transition between Nos. 5 and 7. The passage from the 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 planes separates the two.

7- Peridotite with scattered grains of chromite in 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 near the south margin. Particles 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. Containing many crystals of chromite measuring 0.5 mm or less. Serpentinization accompanied by the separation of magnetite and iron oxides, has gone on to a slight extent along the cracks, especially in the olivine, but the rocks 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 bands of chromite about 8 feet from footwall (24 feet).

12- Chromite (3 inches).

13- Coarse grained rock, probably peridotite (16 feet). Northward for some distance, there are belts of a coarse grained rock (peridotite? in the fine grained country rock (enstatite?).

To the west, at the tunnels, the rock within 4 feet of the ore body is peridotite (dunite) similar to rocks in bands 2 and 9 of figure 2. 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 up about three fourths of the rock. Monoclinic pyroxene is present in one of the rocks, and another shows interstitial plagioclase (labradorite). Chromite occurs in varying amounts up to a maximum of about one tenth of the rock, in subhedral to octahedral grains 1 mm or less in diameter. Serpentine, with
secondary magnetite, occurs along the cracks, especially in the olivine, but nowhere to an amount that would make the rock a serpentine."

Pyroxenite -

The most common rock in the dike is a medium grained, greenish-gray to brown pyroxenite. To the eye alone, it seems to be composed of soft brown grains of hypersthene or enstatite, but under the microscope, other minerals are seen to be present. These include olivine, feldspar, and biotite.

Hypersthene makes up about 85% of the rock. In thick sections, is unmistakably, although weakly, pleochroic, and as it has parallel extinction, this pleochroism distinguishes it from enstatite, which also has parallel extinction, but does not have the pleochroism.

The pleochroism is from pink to green. Under the microscope, the hypersthene appears as an aggregate of colorless (except for the pleochroism) grains, many of which show a fine multiple twinning.

The extinctions is parallel to the main cleavage.

 Olivine makes up less than 10% of the rock. It occurs as greenish grains in between the grains of hypersthene.

About 5% of the plagioclase feldspar, andesine, occurs in the interstices of the other mineral grains. The andesine shows alteration to sericite and kaolin. The feldspars and the few scattered grains of quartz seem to have crystallized out last as they fill in the cracks in between the other minerals.

A very little biotite, less than 1%, shows up in all sections studied. No chromite was found in the pyroxenite.

The sulphides, pyrrhotite and chalcopyrite occur rarely in the mass of the pyroxenite as irregular masses and minute veiles in
between and cutting across the other minerals. These are secondary, and have been introduced after the rock had solidified.

Both hypersthenes and olivines show alteration to serpentine along the cracks, but as a whole, the rock is fairly fresh. In no case, is the amount of the mineral serpentine great enough to call the rock a serpentine. Minute crystals of magnetite also occur along the cracks in the hypersthenes and the olivines. It is all secondary, being formed from the alteration of the two minerals which must contain small percentages of iron. In some cases, limonite is also formed by this alteration.

Pyrrhotite and chalcopyrite

As was stated before, pyrrhotite and chalcopyrite occur in small amounts in the pyroxenite. In places, these sulphides occur in much greater quantities, as irregular masses 3 to 5 feet in diameter, composed entirely of pyrrhotite, chalcopyrite, and quartz. In between the sulphide areas, the pyroxenite is silicified and shot full of the sulphides, but no chromite is present. The quartz is entirely surrounded by the sulphides in the section studied and is therefore the first of these minerals to crystallize (see fig. 1 Pl II).

The quartz contains many inclusions of asicular or needle-like crystals of some such minerals as rutile, spinel, or tourmaline.

The silicified pyroxenite in between the sulphide areas, is a dark gray, fine grained rock. Under the microscope, it is seen to be composed of the minerals of the common pyroxenite rock of the dike and in addition, quartz, sulphides, and magnetite. No chromite has been recognized. The rock is badly fractured, the fractures being roughly parallel.
These cracks are filled with limonite and serpentine(?), alteration products of the ferro-magnesian minerals. The hypersthene is present as pleochroic grains and makes up about 10% of the rock. Quartz is abundant in small grains. Biotite is present both as the primary mineral and as an alteration product. The sulphides occur as disseminated grains and as veinlets cutting across the other minerals. The quartz and the sulphides were the latest minerals and were probably introduced by solutions after the rock had solidified.

Peridotite

The section across the dike taken from Wesgate's report (fig. 2, p. 15) shows the gradation from the pyroxenite into the peridotite. The change in mineral composition consists of an increase in the amount of olivine and a decrease in the amount of hypersthene. Chromite becomes an important accessory mineral. A petrographical analysis of a specimen taken 25 feet from the main chromite vein shows the following minerals to be present: olivine, which makes up the greater part of the rock, hypersthene, which becomes a minor constituent, plagioclase feldspar, chromite, and certain alteration products including sericite, kaolin, serpentine, and magnesite (?). No sulphides were found in this rock. This specimen, and also all the specimens of the low grade ore from the vein, shows a fine grained (microcrystalline) white alteration product in which the well shaped crystals of chromite are imbedded. In this rock, the origin is undoubtedly the feldspar as the gradation from this mineral to the feldspar can be traced (fig. 2, Pl II). In the low grade ore, where it occurs in greater amounts, and where it seems to be more intimate-
ly associated with the chromite, the origin is not so clear, as there is no feldspar present nor anything but this mineral to suggest it as having been present. In the latter case, it may at first appear to have been derived from the alteration of the olivine, as, here and there, a small fragment of olivine is completely surrounded by this mineral. (fig. 3 PI III). On the other hand, the contact or boundary between this mineral and the olivine is too sharp and distinct for a typical alteration product, and furthermore, it seems to form the gangue or matrix of the ore not being found in the areas of solid olivine.

Summarizing the facts known about this mineral:

1- It occurs only in the larger cracks, forming the matrix in the crystals of chromite are imbedded.

2- It has a microcrystalline structure, which when examined under a magnification of 1,100 diameters, shows typical wheel or circular extinction of microcrystalline substances.

3- It never occurs in the olivine alone, nor completely surrounded by olivine unless associated with feldspar or chromite.

4- Shows sharp boundaries when in contact with olivine.

5- Shows gradational boundaries when in contact with feldspar.

6- Incloses small fragments of olivine.

7- Cuts the olivine as minute veinlets.

From the above summary, it is evident that it is later than the chromite because the chromite crystals, well formed, are imbedded in it; it is later than the olivine, because it fills the major cracks which cut across the olivine; and it did not originate from the olivine, but rather from the alteration of the feldspar.

This feldspar may have been injected into the cracks after the
solidification and fracturing of the peridotite, but more likely it was the last mineral to crystallize, thus filling in the cracks left after the crystallization of the earlier minerals. That the feldspar nearerto the chromite dike has been so completely altered so that no evidence of its existence is left, and that feldspar only 25 feet away is still fresh, may be explained by the fact that the alteration of these minerals is not one of weathering, but rather one of hydrothermal solutions. One would expect the alteration to be more intense near the avenues of escape of these hydro-thermal waters, and such is the ease.

Whatever the origin or cause of the micricrystalline mineral, it is intimately tied up with the origin of the chromite, and a positive explanation of its origin would help a great deal in the explanation of the origin of the chromite.

Occurrence of the chromite -

The chromite occurs as a vein or "dike" which, according to Clapp, "follows a medial fissure in the (pyroxenite) dike". It also occurs as less persistent veins parallel to the main vein, and connected to the main vein by smaller branching veins, and also as disseminated grains and veinlets in the country rock on the hanging wall side of the main vein. The ore is "frozen" to the wall rock and on neither side is there a well defined plane separating the ore and the wall rock although the gradation is much sharper on the footwall side than it is on the hanging wall side. The following extract from Clapp's report give a good picture of the form of the deposits, "...the deposits is distinctly tabular in form, following an extensive medial fissure in the dike. In places, small branching fissures are encountered as well
as small veinlets and disseminated in the adjoining pyroxenite...

...there are a few smaller veins parallel to the main vein, but not near enough to be worked through the same stopes. In most places, they are found at distances from 300 to 2,500 feet from the main vein.

Character of the ore -

The high grade ore which occurs in the main vein seems to be fairly uniform in structure and in composition throughout the entire length of the deposits. A specimen from Stillwater County and one from Sweetgrass County look alike. The ore is an aggregate of chromite crystals, octahedral in form, held together by a thin film of some greenish mineral, may be serpentine, but is probably the same microcrystalline mineral found as a gangue in the second class ores. No thin section were made of the high grade ore but it was studied under the microscope as polished sections. The microscope does not show any other ore minerals besides Chromite. The chromite shows up as rounded grains and octahedral sections. Most of the grains are badly fractured, and in many cases, the fracturing seems to follow certain set systems, so that a regular system of microscopic cracks are developed.

The ore, besides being physically high grade, composed almost entirely of chromite, is also of a good grade chemically. Chemically pure chromite is theoretically 68% chromic oxide and 32% iron oxide or for each unit of iron oxide, there is 2.12 units of chromic oxide. The following table shows assays of ore from the Benbow group of claims. The first column shows the name of the claim, the second, percentage of chromic oxide; the third, percent-
The last column of the preceding table shows the ore to be of fairly good grade, as theoretically pure chromite should contain 2.12 units of chromic oxide per unit of iron oxide, and this ore contain an average between 1.4 to 1.8 units of chromic oxide to iron oxide. As some of the iron in the above analyses comes from the gangue minerals, the ratio of chromic oxide to iron oxide is slightly higher than the ratio given.

The high grade ore from the western or Boulder River group of claims shows slightly greater variations. Assays of these ores show from 27.8 to 41.8 percent of chromic oxide, the average of seven analyses being 36.5 %.

Second class ore -

Besides the high grade ore just described, there is also more or less second class ore to the northeast or hangingwall side of the main vein. In the second class, the chromite occurs as disseminated grains and small veinlets in the pyroxenite country rock. A hand specimen shows large crystals of altered olivine of a greenish to brownish color. In between the grains of olivine, there are long, irregular veins of a white chalky (described on page 20)
Mineral in which are imbedded the euhedral crystals of chromite. Under the microscope, the relation of the minerals is not so clear. The rock is composed entirely of olivine, and a little scattered hypersthene. The olivine makes up about 70% of the rock, the hypersthene, less than 5%. The white chalky mineral, which has been described as occurring in the peridotite near the vein, constitutes about 10% of the rocks. The olivine is highly fractured, and along the cracks, shows alteration to serpentine and magnetite. The chromite occurs as disseminated grains in the olivine, or as clusters of grains in the white, chalky matrix. The chromite grains are well shaped as a walmada and perfect octahedrons are not uncommon. Most of the grains are very small, from 0.06 mm to some which may be 1 mm in diameter. The average size is around 0.15 to 0.2 mm. The color is black, but an thin translucent edges, it has a blownish tinge. There is also a carbonate present, probably magnesite or secondary calcite, formed by the alteration of the ferro-magnesian minerals.

The second class ore runs from 4.6% to 25.3% chromic oxide, the average of ten assays being 11.8%. In a concentrating test, performed many years ago by those interested in a certain group of claims, the low grade ore assaying 13.5% chromic oxide, after having been crushed to 50 mesh, was concentrated to a 39.8% product with a 53% recovery. The test was made on a small Wilfley table.

Size of the deposits -

The main deposit varies in width from 3 1/2 to 8 feet. At the western end, there is from 6 inches to 2 feet of first class ore along the footwall side, the average width being 14 inches.
The remaining 2 to 8 feet, averaging 4 feet, is second class ore. This is particularly true not of the northwest end on the Bonanza claims, where the deposits are well exposed and has been most developed and most carefully examined. At other places, however, where the exposures are as good, similar deposits of virtually the same size are shown. The veinlets in the second class ore are seldom more than a few inches thick and many are only a fraction of an inch in width, but the parallel veins at a distance from the main vein vary in width from 1 to 14 inches, averaging between 6 and 8 inches. Although some second class is associated with the parallel veins, it is conspicuous only in a few places.

Although the depth of the deposits cannot be determined, it is probable, considering their nature, and the fact that they are exposed through a vertical range of 4,300 feet, that they extend to mineable depths.

Widths of vein on various claims:

1- Boulder River group,
   First class ore, 5 inches to 3 1/2 feet, average, 13 to 2 feet.
   Second
   Second class ore, average width about 4 feet.

2- Fry-Dillon claims,
   West end, 18 inches first class, farther east, 9 to 11 inches.
   Climax claim, width of ore drops to 8 inches.
   Dixie Queen, between 3 and 4 feet exposed fara distance of 20 feet
   Average thickness greater at east end than in the middle.

3- Benbow claims,
   Majestic, 5 feet 6 inches of first class and 3 feet second class.
   Eclipse, 3 feet 8 inches; Lucky Strike, 4 feet 4 inches to 6 feet
   War Eagle, 4 feet of banded ore.
   East of Majestic, 3 feet 4 inches of first class, 2 feet second
The origin of the ore -

Several theories have been advanced as to the origin of the ore, one by Clapp and three by Westgate. For sake of completeness, all four theories will be given.

Clappe Theory -

The character and occurrence of the deposits prove conclusively that it was formed at high temperatures and that its origin is closely associated with that of the pyroxenite with which it occurs. It is furthermore, clear, as described above, that the chromite was crystallized later than the dark minerals of the pyroxenite, and largely after the pyroxenite had solidified to a sufficient extent to make effusion parallel to its foliations and trend could be formed. It also appears as if the pyroxenite as clearly related to the associated gabbro-anorthosite gneiss, being a differentiate of the gabbro-anorthosite magma. The pyroxenite is, however, distinctly intrusive into the gabbro-anorthosite gneiss since it has been chilled along its contact with the gneiss. The only adequate explanation of the differentiation of the original gabbro-anorthosite magma into an acidic portion, which crystallized into the gneiss, and a basic portion, which crystallized into the pyroxenite, is that of fractional crystallization aided by gravitative separation. In this manner a more acidic and lighter magma may be formed above a more basic and heavier magma. It is conceivable that the upper portion being cooler, crystallized, forming the gabbro-anorthosite gneiss, while the lower basic portion was still fluid enough to be injected into the upper crystallized portion to form the pyroxenite dikes.

The last constituents of the pyroxenite magma to crystallize were obviously chromite, quartz, and feldspar. These minerals
evidently remained in solution in the more volatile portions of the pyroxenite magma until a late stage in its crystallization, but when the pyroxenite had solidified sufficiently to fracture under the strains to which it was subjected during foliation, then the more volatile residual portions of the magma carrying the chromite quartz, and feldspar, was forced into the fractures and porespaces of the pyroxenite to form the chromite veins or dikes and disseminated deposits.

Clapp's theory explains the relationship of the gabbro and the pyroxenite, but he does not mention the peridotite phase of the dike. By volatile residual portions of the magma, he probably means aqum-igneous solutions similar to those in granitic magmas which form the sulphide ore deposits. This is comparable to the formation of sulphide veins in that the chromite and the sulphides both are insoluble minerals and should crystallize out first.

Westgate offers the following explanations:

"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 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 anstatite), and 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 dike are parts of the same problem.

"The following possible explanations of the chromite..."
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 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 anstatite 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 the 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 2. Differentiation in place has probably occurred but was a minor factor in the production of the present ore body.

3- The chromite and the adjoining peridotite may be more basic differentiation products intruded into the earlier formed pyroxenite towards 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 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 a more
basic part of the later magma dragged out into band during intrusion. Some differentiation in place by gravity may have occurs 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 transtension 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 these hypothesis of origin is correct, it implies that the chromite body has a very considerable extent downward, certainly in hundreds and perhaps thousands of feet. All the field evidence corroborates this conclusion!"

Westgate discards the solution theory first, on account of its inability to account for the chromite crystals, but I do not see any conflict there as pyrite crystallizes out of aqueo-igneous solutions in the same way; and second, because it does not account for the peridotite facie on the pyroxenite dike. But why should it? The peridotite could have been formed by a continuation of the process that produced the pyroxenite, and then the chromite deposited in it from the aqueo-igneous solutions.

Westgate's second hypothesis, in my estimation is not as well fitted to the case as the first, as this deposit has very few of the characteristics of a deposit formed by magmatic segregation in place.

His third hypothesis is probably the closest approximation of true conditions of all the three preceding ones. As he states, "all the field evidence corroborates this hypothesis", and one might add, "as does the microscopically work".

The following explanation is very similar to Westgate's third hypothesis:
A deep seated magma of fairly uniform composition began a slow process of crystallization deep below the present surface of the ground. There were insoluble minerals, such as chromite, olivine, hypersthene, crystallized first, and then settled to the bottom of the magma, leaving the upper part of the magma poorer in these constituents and richer in the more acidic constituents such as the feldspars. The differentiation, however, was not complete and much of the feldspar still remained as a fluid matrix in the lower or more basic magma. The more acidic magma was then intruded into this position, and continued in the process of crystallization and solidification being practically cold before any further igneous activity took place. Deep down below this solidifying magma, the more basic part was still in the process of magmatic differentiation, which resulted in the formation of the pyroxenite and the peridotite and the chromite facies. As the more basic constituents crystallized out, they settled to the bottom, and the upper portion became leaner in these constituents. This proceeded until the pyroxenite phase practically devoid of any of the chromite, and peridotite contain it only as disseminated grains. This last division of the magma was then intruded into the overlying rocks, along the contact between the earlier gabbro and the shists. During this last intrusion, the chromite segregation was drawn out into bands, and the crystalline chromite floating in a matrix of fluid feldspar was forced in between the aggregates of olivine crystals which were already solidified, thus forming the second class ore. The feldspar was later altered by hydrothermal solutions into the white microcrystalline mineral.
Tonnage and transportation
(from Westgate's report)

Basis of Estimates.

The tonnage of the ore body depends upon 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 a thousand feet or more. This belief is borne out by the facts that 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 throughout 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 expenses of mining than by the disappearance of the ore. In making the tonnage calculations, the very moderate depth of a hundred 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 4 groups of claims. The Bonanza group, controlled by the Boulder River Chrome Co., covers about 3,600 feet of the main chromic belt. It rises from an altitude of 5,700 feet (200 feet above Boulder River) on Iron Mountain creek to 6,800 feet on Iron Mountain Ridge.
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 7,800 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 5 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 and an average width of 14 inches for the higher grade ore and a depth of 100 feet, we would have approximately 47,000 tons of ore carrying about 40% of chromic oxide. Taking an average width of 4 feet for the adjacent low grade or of the hangingwall, we would have nearly 150,000 tons of concentrating ore running about 12%. This ore can be mined at the same time as the other ore. Whether it can 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 alongside the richer chromite mass, an ore body between 4 and 13 feet in thickness is obtained. The narrower high grade band of ore alone, with an average thick-
ness of 1 foot, and a length of 10,000 feet of the total 3 miles or more of the 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 for ore approaching 35% 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 metallurgical character of the ore, not 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 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 with out great difficulty, but the ore body rises rapidly in the hills to the southeast, and it will by increasingly expensive to get the ore out the farther the workings are from the river.

Fry-Dillon claims -

The development on the Fry-Dillon property, is less extensive than that on either Boulder River of 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 ton would be indicated.

To get the ore out, it must be taken 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 autotrack road extends 40 miles to Columbus, where it meets the Northern Pacific railway.

Benbow Properties —

The ore body on the Benbow property can be followed at intervals for 8,000. Where opened, it ranges in width from 3 feet 4 inches to 5 feet 6 inches. A width of three feet and a depth of a hundred 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, and then 5 miles of roadway to Dean, not a difficult matter. From Dean to Columbus, 31 miles, there are fairly good roads. The Benbow properties are nearer to the railway than any other properties along the belt.