UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, *Secretary*
GEOLOGICAL SURVEY
W. E. Wrather, *Director*

Bulletin 948–C

CHROMITE DEPOSITS OF BOULDER RIVER AREA, SWEETGRASS COUNTY, MONTANA

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Strategic Minerals Investigations, 1945
(Pages 63–82)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1949

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price $1.25

CONTENTS

ILLUSTRATIONS

TABLES

CHROMITE DEPOSITS OF THE BOULDER RIVER AREA SWEETGRASS COUNTY, MONTANA

By A. L. Howland, R. M. Garrels, and W. R. Jones

ABSTRACT

The chromite deposits of the Boulder River area are near the western end of the belt of noritic and related intrusive rocks known as the Stillwater complex, which extends for 30 miles along the northeastern margin of the Beartooth-Absaroka mountain range in Stillwater and Sweetgrass Counties, Mont. The deposits are readily accessible by a gravel road from the town of Big Timber up the Boulder River Valley. The chromite occurs in layers near the middle of the ultramafic zone which forms the lower part of the complex. The other rocks in the ultramafic zone are also layered and consist of various proportions of olivine and pyroxene; they range from dunite to bronzitite which contains minor amounts of feldspar and monoclinic pyroxene. Most of the olivine has been partially serpentinized, although it appears fresh to the naked eye. The layers, originally horizontal, have been tilted so that they now dip northeastward at angles of 50° to 80°.

The geologic mapping by the Geological Survey, and exploration by the Bureau of Mines and Anaconda Copper Mining Co. showed that a continuous layer of chromite averaging 5 feet in thickness and 15 percent Cr_2O_3 extends 3,000 feet along the strike. A number of cross faults with displacements of as much as 80 feet cut the chromite. They are more numerous underground than at the surface and appear to be related to a reverse strike fault which cuts off the chromite at depth.

It is estimated that there are 390,000 short tons of measured ore and 160,000 short tons of indicated ore in the block above the strike fault. The continuation of the chromite in the footwall block of the fault lies approximately 300 feet down the dip of the fault and could be reached only by sinking a shaft. To the west the chromite is covered by alluvium in the Boulder River Valley and the whole ultramafic zone pinches off half a mile west of the last chromite exposure. The chromite is poorly exposed to the east but is believed to be much thinner; the prospects for finding more ore in this area appear to be unfavorable.

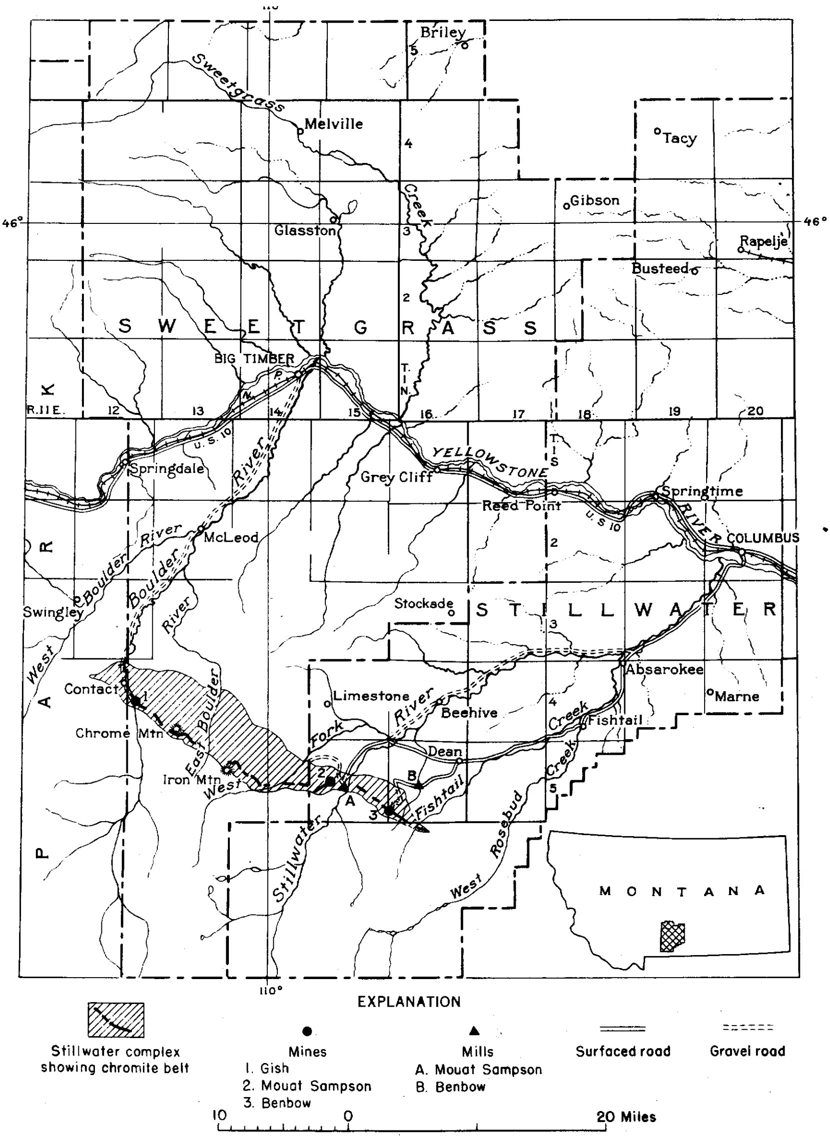

Figure 7.--Index map of the chromite deposits of the Stillwater complex, Montana

INTRODUCTION

Among the many chromite deposits that are associated with the Stillwater complex of noritic and related intrusive rocks are those on the east side of the Boulder River in Sweetgrass County, south-central Montana (see fig. 7). These deposits occur in a nearly continuous belt near the north front of the Beartooth-Absaroka Mountains, from the Boulder River on the west to Little Rocky Creek on the east.

The deposits may be reached by a 33-mile gravel road from Big Timber, a town on the Northern Pacific Railroad and U. S. Highway No. 10, at the junction of the Boulder and Yellowstone Rivers. The road leads south from Big Timber to the mountains, the first 26 miles in a broad flat which the Boulder River has cut in the plains, the last 7 miles in the bottom of a 4,000-foot glaciated canyon in which the river flows through the mountains.

The deposits are on the east side of the canyon and are almost entirely covered by the Gish claims. These claims lie between Graham Creek on the north and Blakely Creek on the south, and extend southeastward from the vicinity of the river along a glaciated spur which projects into Boulder River Valley, and over into the valley of Blakely Creek, a total distance of about 2½ miles (see pl. 33). The western end of the claims, near the river, is at about 5,000 feet, and the eastern end is at an altitude of 7,500 feet. The Gish claims are near the west end of the complex, for across the Boulder River the complex thins rapidly, and two miles farther west it pinches out on the divide between the Boulder and West Boulder Rivers.

The chromite deposits were discovered in the early days of settlement of south-central Montana, but it was not until the increased demand for chromite attendant upon the first World War that any serious attempts at exploration began. The United States Chrome Company (R. P. Gish, Pres.) patented the claims, started two adits, and built a mill on the lowest outcrop, near Boulder River, but no ore was milled or shipped.

This activity started a series of investigations of the deposits by geologists and mining engineers which has continued up to the present. Two reports describing the chromite in this area have been published, one by Westgate 1/ in 1921, the other by Schafer 2/ in 1937. Many private reports also are on file with mining companies.

Field work and acknowledgements

A program of development was instituted by the Geological Survey, U. S. Department of the Interior, in 1941. In July and August of that year a detailed geologic and topographic map of

1/ Westgate, L. G., Deposits of chromite in Stillwater and Sweetgrass Counties, Montana: U. S. Geol. Survey Bull. 725, pp. 67-83, 1921.

2/ Schafer, P. A., Chromite deposits of Montana: Mont. Bur. Mines Memoir 18, pp. 11-16, 1937.

the western part of the Gish claims was made by A. L. Howland assisted by R. M. Garrels and W. R. Jones, all of the Geological Survey. The Bureau of Mines trenched and sampled the ore in September and October 1941, and diamond-drilled the deposits in 1942. The Geological Survey party, under the general supervision of J. W. Peoples, cooperated with the Bureau of Mines in their exploration, described all samples, surveyed the profiles for the diamond-drill holes, and logged the core from the holes. During the summer of 1942 the Anaconda Copper Mining Co., Defense Chrome Account, began underground development. R. M. Garrels and W. R. Jones revised the detailed map to include all new information and constructed the geologic sections and structure-contour map. Two adits were driven on the claims near the Boulder River, before development work ceased early in 1943. The chromite-bearing material from the adits and from a few trial stopes was left on the dump. Excellent cooperation was received both from the Bureau of Mines and the Anaconda Copper Mining Co. E. W. Newman and Ernest Sharp of the Bureau of Mines, and S. K. Droubay and Loyal Lohse of Anaconda deserve special mention. Thanks are due to the United States Chrome Company for permission to publish the underground data. The authors wish to express their indebtedness to F. C. Calkins for careful and helpful criticism of the manuscript.

Outline of geology

The regional geologic setting of the Stillwater complex has been described in considerable detail in published reports 3/ and, therefore, only the essential features and certain others peculiar to the immediate Gish area will be included in this report.

The Beartooth-Absaroka Mountains are the erosional remnants of a great mass uplifted in late Cretaceous or early Tertiary time. At the north-facing mountain front Paleozoic and Mesozoic rocks are turned up steeply against a pre-Cambrian core which rises abruptly to a rolling upland surface 9,000 to 10,000 feet in altitude which is cut by deep north-draining glaciated valleys.

The pre-Cambrian core at the Boulder River, within 10 miles of the mountain front, is made up of metamorphosed sedimentary rocks and the intrusive rocks of the Stillwater complex. The complex is a great sheet of layered basic rocks which presumably was intruded into the sedimentary rocks as a sill. Pre-Cambrian erosion stripped off the overlying sediments and beveled the top of the sill. During Paleozoic and Mesozoic time the eroded surface was covered with several thousand feet of sediments, predominantly limestones during the Paleozoic and sandstones and shales during the Mesozoic.

3/ Westgate, L. G., Deposits of chromite in Stillwater and Sweetgrass Counties, Montana: U. S. Geol. Survey Bull. 725, pp. 67-82, 1921.

Howland, A. L., Peoples, J. W., and Sampson, Edward, The Stillwater igneous complex and associated occurrences of nickel and platinum group metals: Montana Bur. Mines and Geol., Misc. Contr. 7, pp. 1-10, 1936.

Schafer, P. A., Chromite deposits of Montana: Mont. Bur. Mines Memoir 18, pp. 7-11, 1937.

Peoples, J. W., and Howland, A. L., Chromite deposits of the eastern part of the Stillwater complex, Stillwater County, Montana; U. S. Geol. Survey Bull. 922 N, pp. 372-398, 1940.

Crustal disturbance involving folding at the end of the Cretaceous and during the early part of the Cenozoic tilted the complex steeply to the north in the Boulder River area, and developed many faults as the crystalline rocks adjusted to the folding (see pl. 34). Erosion during the Cenozoic has removed all except in-faulted remnants of the Paleozoic and Mesozoic sedimentary rocks from the top of the uplifted mass and has truncated the complex so that it now crops out parallel to the mountain front in a strip 30 miles long and 2 to 5 miles wide.

The Stillwater complex has been divided into four zones, named in order from the bottom up: (1) the basal zone, at the south edge of the complex; (2) the ultramafic zone; (3) the banded zone; and (4) the upper zone.4/

The basal zone consists of 100 to 200 feet of diabasic norite which probably represents a chilled border of the intrusive mass. The ultramafic zone is peridotitic and made up of layers that consist of olivine, olivine-pyroxene, and pyroxene rocks. The banded and upper zones are gabbroic, being made up of layered plagioclase and plagioclase-pyroxene rocks.

The chromite deposits occur as massive layers and as disseminations near the middle of the ultramafic zone, which is about 2,400 feet thick in the area mapped in detail east of the Boulder River (see pls. 34 and 35). The chromite is a primary mineral of the ultramafic zone and is interlayered with the various rocks occurring in that zone. No chromite occurs in the banded or upper zones, even as an accessory mineral.

PRE-CAMBRIAN ROCKS

Sedimentary rocks

Sedimentary rocks, including dense grey hornfels, an iron-formation, and quartzites much altered by contact metamorphism, are found south of the complex. The hornfels is very fine grained and dense and in hand specimen resembles a fine-grained basic dike rock. The iron-formation, easily recognized by its conspicuous banding, deep brown-red surface stain, and strong magnetic properties, crops out near the base of the complex for several miles along the strike, showing the sill-like character of the intrusion.

Stillwater complex

The general relations in the Boulder River area are strikingly similar to those described in detail at the eastern end of the complex by Peoples and Howland.5/

4/ Peoples, J. W., and Howland, A. L., op. cit., p. 377.
5/ Peoples, J. W., and Howland, A. L., op. cit.

Basal zone

The basal disbasic norite found in the eastern part of the Stillwater complex crops out on the west side of the Boulder River, but most of the lower contact of the complex east of the Boulder River is covered. In a single exposure of this contact on the south side of the "Gish ridge" (see pl. 34) the basal zone is missing, and fine-grained bronzitite is in intrusive contact with the underlying metamorphosed sediments. There is not enough evidence to justify even a guess as to whether this is a local anomaly or not.

Ultramafic zone

Above the basal zone where it is present, and lying on the metamorphics elsewhere, is the ultramafic zone, 2,400 feet of layered rocks rich in magnesium and iron. The dominant primary minerals are orthorhombic pyroxene and olivine; plagioclase feldspar locally forms as much as 15 percent of the rocks, and green diopside is fairly abundant in places.

For the purposes of this report, the rocks formed from the two dominant minerals may be classified as follows:

1. Bronzitite—85 percent or more pyroxene.
2. Dunite—85 percent or more of olivine.
3. Harzburgite—intermediate between dunite and bronzitite.

Some of the layers of these rocks intergrade over distances of one to several feet, but in many places the percentage of the minerals changes abruptly, giving clearly defined boundaries.

Bronzitite.—The bronzitite is recognized by a greenish-brown color on fresh surfaces, grading into brownish-red on weathered surfaces, and especially by a dense mat of interlocking, prismatic bronzite crystals. Two distinct types of bronzitite occur: (1) medium-grained bronzitite, made up of euhedral interlocking ¼-inch crystals, with a very small percentage of accessories; (2) medium-grained feldspathic bronzitite, consisting of somewhat rounded grains of pyroxene and 10 to 15 percent of interstitial plagioclase feldspar. The first-named variety is interlayered with dunite and harzburgite in the lower part of the ultramafic zone, and the second forms a massive layer approximately 1,000 feet thick which constitutes the upper third of the ultramafic zone (see pl. 34). The upper bronzitite is easily recognized and is a valuable horizon marker for exploratory work.

Boundaries between bronzitite and other rocks are in most places sharp and regular; in one section of drill core the contact between bronzitite and granular harzburgite can be determined within a quarter of an inch. In a few places, however, alternating 2- to 12-inch layers of bronzitite and granular harzburgite form a transition zone 4 to 10 feet thick. In other places dunite crosscuts the bronzitite layers.

The bronzitite is usually unaltered except near dikes and in shear zones. No detailed study has been made of alteration products, but a superficial microscopic examination indicated several different kinds of bastite-like material. The presence of dikes is often indicated by an alteration of pyroxene to a steel-gray fibrous mineral, probably an amphibole, in which the outlines of the original pyroxenes are preserved.

Harzburgite.—The olivine-pyroxene rocks have been divided into two types on a purely textural basis for convenience in mapping and structural interpretation.6/ They are poikilitic and granular harzburgite.

The granular harzburgite is a granular aggregate of olivine and pyroxene grains, in which the pyroxenes seldom exceed one half inch in length. In the Gish area the granular harzburgites are interlayered with bronzitite in the lower third of the ultramafic zone. Most specimens are brown-green on fresh surfaces and contain more olivine than pyroxene. The rock is most readily identified on the weathered surfaces where brown-stained, relatively fresh, euhedral pyroxenes stand in relief above round or irregular dark-brown pits left by weathering of olivine grains. Between the grains of bronzite there usually is a little white plagioclase feldspar. Chromite is locally present as an accessory but in very small amounts.

The poikilitic harzburgite occurs, in association with bronzitite layers, in the middle of the ultramafic zone and is the rock in which the chromite of economic interest occurs.

It contains the same minerals as the granular harzburgite, but the bronzite occurs in large poikilitic crystals enclosing rounded grains of olivine. Most of these poikilitic crystals are between 1 and 6 inches in diameter, but crystals as much as 15 inches in diameter have been seen. The rock is easy to recognize, particularly on glaciated surfaces, because the cleavage faces of the bronzite crystals reflect a high percentage of light, while the enclosed olivine grains are dull. On a sunny day the flashes from the bronzite cleavage faces can be seen from a considerable distance.

The accessory minerals of the poikilitic harzburgite are plagioclase and chromite. Details regarding the occurrence of the chromite will be discussed under the section on ore deposits. Plagioclase, which is always interstitial to the other minerals except chromite, constitutes from 1 to 15 percent of the rock, being most abundant in the olivine-rich facies, A little pyrrhotite and chalcopyrite have been found locally in the poikilitic harzburgite near the base of the chromite layer.

Visible alteration has taken place only along faults and shear zones; it consists of the development of serpentine and accessory magnetite. About 90 percent of the poikilitic harzburgite appears quite fresh to the naked eye, although the microscope shows partial alteration to serpentine, minute veinlets of which cut the olivine.

Dunite.—Dunite is a rock that contains 85 percent or more of olivine. It occurs in three ways: (1) as a facies of the poikilitic harzburgite in which the bronzite crystals are mere skeletons making up a very small proportion of the rock; (2) as layers between bronzitite and granular harzburgite in the lower third of the ultramafic zone; and (3) as irregular bodies that

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6/ Peoples, J. W., and Howland, A. L., op. cit., p. 379.

cut across both bronzitite and poikilitic harzburgite. The cross-cutting relationship is best seen in an outcrop at the western end of the map area (see pl. 35). This outcrop was mapped by Sampson on a scale of 10 feet to the inch in 1932, and the origin of the dunite has been discussed by Hess 7/ who has also given a detailed petrographic description of the rock and two chemical analyses. Elsewhere dunite has not been mapped either because of the small size and irregular shape of the bodies, or because of poor exposures. On fresh surfaces the rock is seen to be an aggregate of small brown-green grains; on weathered surfaces it has a characteristic chocolate-brown color. The surfaces of small blocks are usually smooth, owing to uniform weathering of the even-grained, nearly homogeneous olivine, in contrast to the uneven surfaces of pyroxenes in bronzitite and harzburgite. The cross-cutting masses of dunite are in general highly sheared.

Basic pegmatite.—Irregular bodies of a rock of coarse and irregular texture occur at several places in the ultramafic zone. Most of them consist mainly of 2- to 8-inch crystals of bronzite and diopside, accompanied by 10 to 20 percent of interstitial plagioclase. Some, however, consist entirely of bronzite, or entirely of diopside, or of both pyroxenes with as much as 30 percent of feldspar. In the feldspar-rich varieties the dominant pyroxene is diopside, and from 2 to 10 percent of interstitial chromite is present. This is the same type of rock that, in the eastern part of the Stillwater complex, 8/ commonly occurs on the footwall of the massive chromite layers. That relation is not general on the Gish property, but one interesting example of its occurrence may be seen on the small west-facing cliff 110 feet N. 10° E. of Bureau of Mines trench 55 (see pl. 35). There one of the pegmatite bodies is parallel to the general layering. At the bottom of the cliff the pegmatite is 6 inches across; coarse green diopside and plagioclase make up the middle part, while the upper and lower borders are fringed with a half-inch layer of chromite grains. Along the strike to the southeast, the material in the middle thins and pinches out, leaving an inch-thick layer of chromite.

Banded zone and upper zone

The upper 10,000 to 15,000 feet of the complex, between the ultramafic zone on the south and the limestones which lie on its beveled surface to the north, includes the banded and the upper zones, consisting of interlayered anorthositic, noritic, and gabbroic rocks. Although the upper feldspathic bronzitites of the ultramafic zone and the gabbroic rocks (norites) immediately above them at the base of the banded zone consist of the same minerals, the proportion of plagioclase feldspar changes abruptly at the contact of the two rocks; the feldspathic bronzitites seldom contain as much as 15 percent, whereas the norites contain 50 percent or more. The contact is easily recognized in the field, the feldspathic bronzitite being dark brown and the norite light gray.

7/ Hess, H. H., A primary peridotite magma: Am. Jour. Sci., 5th ser., vol. 35, pp. 336-340, 1938.

8/ Peoples, J. W., and Howland, A. L., Chromite deposits of the eastern part of the Stillwater complex, Stillwater County, Montana: U. S. Geol. Survey Bull. 922, p. 380, 1940.

Granite

Granite, intruded after the complex,9/ underlies the central part of the Beartooth Range and is in contact with the complex at its eastern end. In the Gish area, however, the granite is several miles south of the complex.

Basic dikes and sills

Gabbroic dikes and sills of pre-Cambrian age cut the other pre-Cambrian rocks of this area. Although dikes predominate in the ultramafic zone, sills and multiple intrusions are more common in the banded zone. The dikes are quite fresh and closely jointed. Their metamorphic effect on the complex is restricted to narrow zones in which bronzitite has been changed to an amphibole rock, and harzburgite to serpentine. Some of these dikes do not reach the surface, and they commonly split, pinch and swell within short distances.

SURFICIAL DEPOSITS

In the valleys of this area the bedrock is masked by glacial drift, alluvial fans, and talus, and on north slopes it is largely concealed by timber, brush and soil, but on the divides and on south slopes exposures are fairly continuous, particularly in the steeper valleys.

STRUCTURE

Primary structural features

The rocks of the Stillwater complex are arranged in layers—or, more precisely, greatly elongated lenses—parallel to the basal contact of the complex. These layers or lenses range in thickness from a fraction of an inch to many hundreds of feet. It is believed that the complex was intruded into nearly horizontal sedimentary rocks and that the layers of intrusive rock were originally horizontal.

In the Gish area, the ultramafic zone may be divided into three subzones. The lowest of these, approximately 800 feet thick, consists of alternate layers of bronzitite and granular harzburgite. The middle subzone, about 350 feet thick, is made up of alternate layers of poikilitic harzburgite and bronzitite, and within the poikilitic harzburgite are layers of chromite. The upper subzone, 1,000 feet thick, consists of uniform feldspathic bronzitite.

Secondary structural features

Tilt of banding

The present attitude of the layers, including those of chromite, resulted from deformation that took place after the

9/ Peoples, J. W., and Howland, A. L., op. cit., p. 382.

rocks consolidated. Some of this deformation was undoubtedly pre-Cambrian, as evidenced by the beveling of the complex by Paleozoic deposits; most of it, however, is due to the post-Cretaceous uplift. The general strike in the Gish area is N. 55°-60° W., the dip 50°-70° N. Faulting modifies the attitude of the layers in places, so that some blocks have dips as low as 30° and others are nearly vertical. Strikes also differ locally from the average by as much as 20° to 30°.

Faults

The rocks of the ultramafic zone have adjusted to the stresses to which they have been subjected chiefly by shearing and block faulting, but in a minor degree by warping. The detailed surface map of the ultramafic zone near the west end of the Gish claims (see pl. 35) shows a deceptively simple fault pattern. The rocks apparently are broken into 100- to 200-foot blocks by a set of normal faults that strike N. 30° E. and dip 75°-85° E., and by a single fault striking N. 10° E. and dipping 45°-60° NW. The horizontal displacement at the surface is 80 feet on the N. 10° E. fault, and ranges from 0 to 60 feet on the N. 30° E. set.

The three-dimensional picture given by diamond drill holes and underground work is considerably more complex, as is shown on the structure-contour map and the map of the underground workings (see pls. 36 and 37). Most of the N. 30° E. faults prove to have a somewhat smaller displacement underground than at the surface, and there are many underground faults which are cut off or die out before they reach the surface. Whereas the N. 30° E. faults are normal at the surface, most of them are reverse faults underground, suggesting a rotational effect.

Normal strike faults dipping 30° S. were found underground. Several of these were encountered in the No. 4 level directly down dip from surface trench 18. They have displacements of only 3 to 4 feet, and occur in a zone extending less than 100 feet along the strike of the layering.

This complex pattern of transverse faults made up of a relatively few normal faults at the surface with a great many small reverse faults superimposed upon them at depth, became comprehensible when underground work revealed a major fault beneath Graham Creek (see pls. 34 and 35). The Graham Creek fault is a curving reverse fault which is nearly parallel to the strike of the layering and dips 60° to 70° S. where cut by the No. 4 level. A drill hole (No. 513) in the footwall block (see pl. 35, and cross section pl. 34) intersected a sequence of layers which could be correlated with the layers in the hanging-wall block, and on this basis the fault is believed to have a dip-slip movement of about 300 feet. At the surface it is covered with glacial and alluvial debris in the valley of Graham Creek. There is little doubt that the cross faults and the minor strike faults, which cut the chromite, bound adjustment blocks in the hanging wall of this major reverse fault. The upward fading out of many of these minor faults is unfortunate from an economic point of view, for it obscures the broken character of the ore underground.

At the surface the faults have no consistent topographic expression. Where the faults have been accompanied by shearing and serpentinization, glacial scour has in most places gouged saddles. A saddle generally indicates the presence of a fault, but the absence of a saddle does not mean that displacement has not occurred, for there is no direct relation between the size of the fault and the amount of shearing, and consequently of erosion, along it. The large N. 10° E. fault is marked by a 5- to 20-foot zone of sheared, serpentinized material along which a very marked trough has been eroded, but the N. 30° E. fault nearby to the east, which has nearly as much displacement, is almost impossible to trace by alteration, even though it crosses a glacially polished surface. It is inferred, however, that the prominent northeast-trending saddle 400 feet southeast of Bureau of Mines trench 64 is a fault of fairly large displacement, and that the northwest-trending saddle between trenches 55 and 57 is also a fault valley.

The dikes were intruded in pre-Cambrian time, before the major faulting, but many of them were places of weakness when the stresses came; along most of them, therefore, there has been at least a small amount of displacement.

Joints

Most of the major joints are parallel to faults, but an exception is presented by one very prominent set that strikes N. 20° W. and dips 45° S. Glacial quarrying along this set has formed the conspicuous cliff extending north-northwest from trench 35.

ORE BODIES

General statement

All gradations from barren rock to almost pure chromite exist in the complex. The term "ore bodies" is limited, however, in this report to deposits that contain more than 15 percent of chromite and are more than 1 foot in width. These figures were chosen arbitrarily as minima for material of economic interest.

Lean disseminations of chromite occur in all the ultramafic rocks of the Stillwater complex, but all the major concentrations are in the poikilitic harzburgites. On the Gish claims there is but one ore body—a remarkably continuous layer of massive and disseminated chromite which, on the average, is 5 feet in width and has a chromite content of 35 percent for the entire length of its outcrop, which extends almost continuously from the westernmost exposure of the ultramafic zone, on the east side of Boulder Canyon, for 3,000 feet southeast. It is labeled "main chromite" on the detailed surface map (see pl. 35).

The eastern two-thirds of this 3,000-foot strip is cut by several faults, beyond which it disappears under talus and alluvium. Outcrops are few on the eastern part of the claims, and although a few thin streaks of chromite have been seen, no "ore body" in the sense defined above has been found. This "main chromite" may possibly have an eastern continuation that has not been discovered, but it is believed to thin eastward.

Several other layers of massive chromite in the poikilitic harzburgites are exposed in the part of the Gish area that was mapped in detail. Although they nowhere exceed 6 inches in thickness and are not of economic interest, they are valuable horizon markers, helpful in underground work, in correlation between drill holes, and in mapping the surface geology.

The first of these is 40 to 50 feet "stratigraphically" above the main chromite, in the same poikilitic harzburgite layer, and can be traced with minor breaks throughout the 3,000 feet in which the main chromite has been found. Its thickness ranges from 0 to 6 inches and averages 2 inches.

In another higher poikilitic harzburgite layer which crops out on the north side of the "Gish ridge" (see pl. 35), there are three other regularly spaced, 2- to 6-inch layers of massive chromite. They are not so continuous as the layers in the lower poikilitic harzburgite, for they pinch out and reappear both down dip and along the strike. In diamond-drill hole No. 19 (see pl. 35) all three layers were represented in the core, but in hole No. 17, drilled at a stepper angle from the same collar, only two were encountered.

Other thinner streaks of massive chromite and rich disseminated chromite occur irregularly in the poikilitic harzburgite, both parallel to the general layering and cross cutting it, but are seldom traceable more than a few feet.

On Blakely Cliff, which extends along the east side of Blakely Creek beyond the Gish claims, the entire chromite-bearing portion of the ultramafic zone is exposed but includes no layer comparable to the main chromite on the Gish claims. The map and accompanying cross section (pl. 38) show that there are many layers of chromite essentially parallel to the boundaries between rock types. However, none of the massive layers averages more than 2 or 3 inches in thickness over an outcrop length of 50 or more feet; any given layer, traced along the outcrop, may swell from 2 inches to 12 inches within a few feet, then pinch and disappear entirely within the same interval. Outcrops in which disseminated chromite constitutes as much as 25 percent of the rock mass (shown by stippled pattern on map) are common, but the boundaries of such concentrations are extremely irregular, and there is also a great variation in the degree of concentration of chromite within such masses, so that there are no minable blocks which would average more than 5-10 percent Cr_2O_3. The grade of the chromite concentrations is comparable to that on the Gish claims, and typical analyses are shown in table 1. The irregularity of the chromite concentrations and of the rock types in general may have a close genetic relation to the high olivine content of the poikilitic harzburgite in this area.

The chromite-bearing zone is covered on the long gently sloping ridge extending from Blakely Cliff up to the East Boulder Plateau (see pl. 34). A few exploratory pits have been dug to bedrock by claim holders, but where chromite is exposed, it is similar to that on Blakely Cliff and of no economic interest.

A fairly continuous chromite layer less than 500 feet "stratigraphically" above the base of the complex has been found in many other parts of the complex. It has not been found on the east side of Boulder River Canyon, although it may be present locally and obscured by heavy cover. However, on the west side of the canyon, a unique occurrence may represent this layer. A few hundred feet north of the base of the complex and approximately 60 feet above the river (see pl. 34), chromite is exposed in a small trench. The chromite grains are concentrated into 2- to 6-inch nodules scattered through a dunitic matrix. The nodules are approximately 50 percent chromite; the matrix contains a few percent of disseminated chromite, and a little chalcopyrite and pyrrhotite in grains and blebs. The maximum width of the nodular zone is about 10 feet, but even in the very limited exposure it is markedly irregular. The nodular character of the chromite and the presence of the closely associated sulfides are very unusual in the Stillwater complex, where the chromite is, in general, uniformly distributed along the strike and not associated with the sulfides.

It is clear that the chromite has been concentrated in exactly the same way that other rock minerals have been concentrated to form nearly monomineralic layers. The western part of the Gish claims is one of three or four places in the Stillwater complex in which a great deal of the chromite has been concentrated into nearly massive layers, and it is, like those other places, a part of the ultramafic zone in which the other rock layers are regular and well defined. Elsewhere the boundaries are irregular and gradational, and the chromite is also disseminated irregularly and over a much greater vertical range.

Mineralogy

The mineralogy of the chromite concentrations is simple and resembles that of the rest of the complex. In the layers on the Gish claims, the only ore mineral is chromite, $(Fe,Mg)O\cdot(Cr,Al,Fe)_2O_3$, and it is accompanied by olivine, pyroxene, and plagioclase. Olivine is the most abundant gangue mineral, pyroxene and plagioclase seldom making up more than a few percent of a chromite-rich layer.

The chromite occurs chiefly in small, well-developed octahedral crystals which average about 0.03 inch (30 mesh). Ninety percent of the chromite crystals are between 0.05 and 0.02 inch (25 to 30 mesh) in size; the maximum variation is from about 0.005 to 0.3 inch (200 to 3 mesh). Many of the grains contain minute inclusions of a serpentine-like mineral (bastite?), probably derived from orthorhombic pyroxene. These inclusions make up about 3 percent of the area of the chromite grains as seen in thin section.

The gangue minerals are olivine, pyroxene (bronzite and diopside), and plagioclase. Olivine is by far the most abundant, followed by pyroxene, with plagioclase a poor third. The chromite may occur within or surrounding olivine. Few conclusions have been drawn concerning the sequence of crystallization, except that plagioclase is later than olivine or pyroxene, and that the chromite crystallized during the entire period of formation of the other minerals. The chromite is unquestionably an original mineral; it crystallized from a magma, originated simultaneously with the enclosing rock, and does not represent a later replacement or fissure filling.

A series of analyses of cleaned chromite (see table 1) shows the variations in the composition of the chromite. It should be noted that the cleaned mineral shows a range in Cr_2O_3 content from 40.5 to 50.98 percent and in Cr:Fe ratio from 1.23 to 1.99. Figure 8 shows the relative positions of the specimens from the Gish property in the columnar section.

Table 1.—Analyses of chromite from the Boulder River area
Analysts: M. K. Carron and R. E. Stevens

	Gish property											Blakely Creek Cliff area			
Concentrate:	P315	P317	G26	G27	G28	G35 1/	G36 2/	G37 2/	G39	G40	G17-330	G6	G2 1/	G4 1/	G7 1/
Cr_2O_3	46.02	40.51	46.92	44.61	46.35	47.10	43.89	40.5	47.82	49.62	46.35	50.98	48.73	47.61	48.60
Al_2O_3	19.38	--	--	--	--	--	--	--	--	--	--	13.10	--	--	--
Fe_2O_3	3.87	--	--	--	--	--	--	--	--	--	--	3.79	--	--	--
FeO	18.38	--	--	--	--	--	--	--	--	--	--	22.11	--	--	--
MgO	11.19	--	--	--	--	--	--	--	--	--	--	8.21	--	--	--
MnO	0.18	--	--	--	--	--	--	--	--	--	--	0.24	--	--	--
TiO_2	0.50	--	--	--	--	--	--	--	--	--	--	0.80	--	--	--
CaO	0.04	--	--	--	--	--	--	--	--	--	--	0.04	--	--	--
SiO_2	0.28	--	--	--	--	--	--	--	--	--	--	0.70	--	--	--
V_2O_3	tr.	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H_2O +	0.16	--	--	--	--	--	--	--	--	--	--	0.14	--	--	--
P_2O_5	--	--	--	--	--	--	--	--	--	--	--	0.01	--	--	--
S	--	--	--	--	--	--	--	--	--	--	--	0.01	--	--	--
Total	100.00											100.13			
Cr	31.48	27.72	32.10	30.53	31.72	32.22	30.02	27.7	32.72	33.97	31.72	34.89	33.36	32.59	33.27
Fe	16.96	19.47	19.03	21.42	21.03	18.20	19.14	22.6	21.33	19.18	18.82	19.88	16.74	17.55	18.60
Cr:Fe	1.86	1.42	1.69	1.43	1.51	1.77	1.57	1.23	1.53	1.77	1.69	1.75	1.99	1.86	1.79
Ratio RO:R_2O_3	1.01											1 3/			
Crude ore:															
Cr	--	--	25.41	4.52	7.30	27.19	14.01	6.44	6.69	15.98	9.30	29.07	31.29	25.10	30.00
Fe	--	--	16.96	12.19	13.10	17.44	14.16	--	12.96	14.53	12.55	18.48	17.38	17.06	18.50
Cr:Fe	--	--	1.50	0.37	0.56	1.56	0.99	--	0.52	1.10	0.74	1.57	1.80	1.47	1.62
Cr_2O_3	34.58	13.38	37.13	6.61	10.66	39.71	20.48	9.42	9.78	23.37	13.60	42.48	45.71	36.69	43.84
Chromite	76.0	33.0	79.2	14.8	23.0	84.4	46.7	23.3	20.4	47.1	29.3	83.3	93.8	77.0	90.2

1/ Non-magnetic 2/ Slightly magnetic 3/ Calculated

P315 Massive ore, trench 39, Gish property; collected by J. W. Peoples.

P317 Disseminated ore, trench 29, Gish property; collected by J. W. Peoples.

G26 Massive ore 2 inches above base of main chromite, trench 24, Gish property; collectedtby R. M. Garrels.

G27 Disseminated chromite in dunite, 44 inches above base of main chromite, trench 24, Gish property; collected by R. M. Garrels.

G28 Rich disseminated chromite in dunite, 65 inches above base of main chromite, trench 24, Gish property; collected by R. M. Garrels.

G35 Massive chromite, base of main chromite, trench 47, Gish property; collected by R. M. Garrels.

G36 Rich Disseminated chromite, 30 inches above base of main chromite, trench 47, Gish property; collected by R. M. Garrels.

G37 Dunite and chromite, 50 inches above base of main chromite, trench 47, Gish property; collected by R. M. Garrels.

G39 Disseminated chromite in dunite 18 inches above base of main chromite, trench 60; Gish property; collected by R. M. Garrels.

G17-330 Chromite stringer, 0.1 inch thick, in serpentinized dunite, U. S. Bureau of Mines diamond-drill hole 17, 330 feet below collar, Gish property; collected by R. M. Garrels.

G6 Chromite layer "D", elevation 7,580 ft., Blakely Creek cliff; collected by R. M. Garrels.

G2 Chromite layer "F", elevation 7,730 ft., Blakely Creek cliff; collected by R. M. Garrels.

G4 First chromite layer east of "F" layer, elevation 7,758 ft., Blakely Creek cliff; collected by R. M. Garrels.

G7 Chromite layer "D", elevation 7,880 ft., Blakely Creek cliff; collected by R. M. Garrels.

All trenches were dug by the U. S. Bureau of mines.

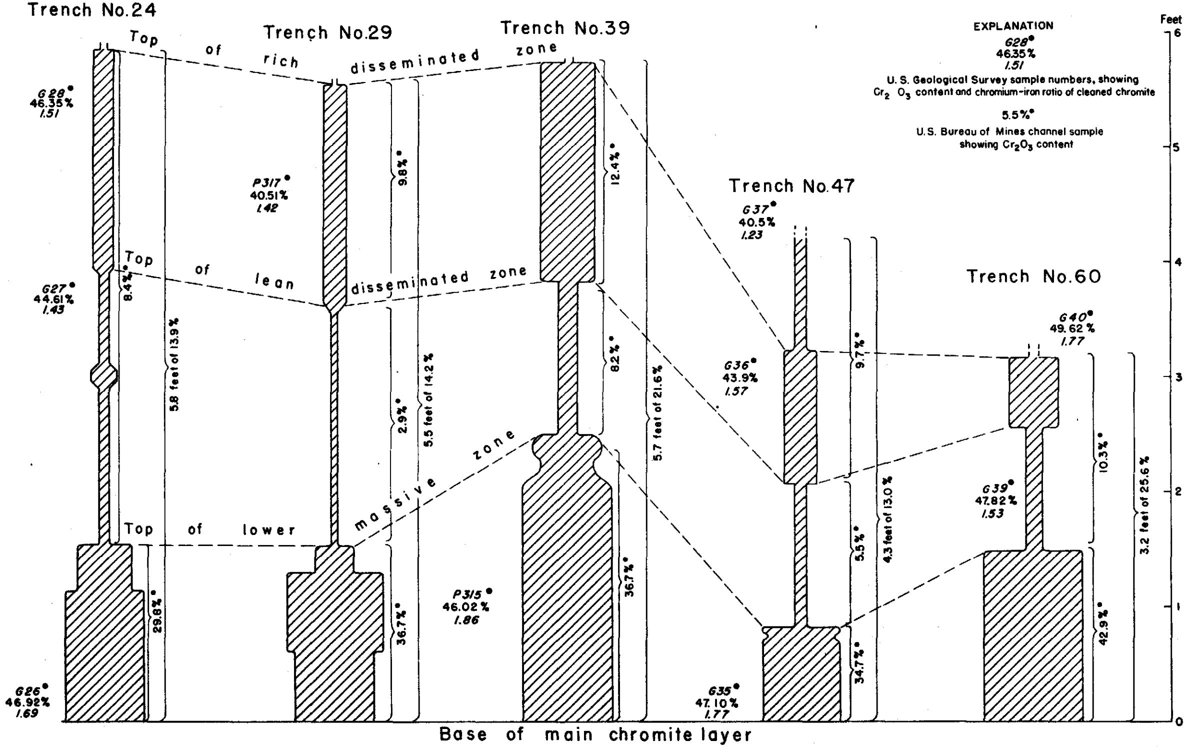

Figure 8.—Columnar sections of the main layer on the Gish claims, Sweetgrass County, Montana, showing the range in Cr_2O_3 content of the ore and corresponding variations in composition of some of the Chromite; Width of columns proportional to grade of ore, Based on Bureau of Mines assays and visible variations in distribution of chromite.

It is not known what controls the variation in composition, but it is suggested, on the basis of these analyses and of analyses from other parts of the Stillwater complex and elsewhere, that disseminated chromite in most cases is lower in chromic oxide content and Cr:Fe ratio than immediately adjacent massive chromite.

Table 2 shows the chief physical and chemical properties of the chromite and the gangue minerals.

Table 2.—Physical and chemical properties of chromite and gangue minerals

Mineral	Approximate Chem. Comp.	Hardness	Specific Gravity	Remarks
Chromite	$(Mg,Fe)O \cdot (Cr,Al,Fe)_2O_3$	5.5	4.4	Small black octahedral grains
Olivine	$(Mg,Fe)_2SiO_4$	6.5-7	3.3	Rounded green-brown grains
Bronzite	$(Mg,Fe)SiO_3$	5.5	3.3	Brown-green "bronzy" prismatic crystal or irregular and skeletal crystals
Clino-pyroxene	$Ca(Mg,Fe)(SiO_3)_2$	5.5	3.3	Green prismatic or skeletal crystals
Plagioclase	15 $NaAlSi_3O_8$+ 85 $CaAl_2Si_2O_8$	5-6	2.7	Irregular, white interstitial masses
Serpentine	$H_4Mg_3Si_2O_9$	2.5-4	2.5	Green-brown to black, greasy alteration product

Although the rocks appear fresh except near dikes and along faults and shear zones, microscopic examination shows that most of the olivine grains associated with the chromite are about half-altered to serpentine. The chromite, however, is apparently unaffected by secondary processes, except in cases where there has been very strong serpentinization; there the grains often appear corroded and partially leached away.

Main chromite layer

The main chromite layer on the Gish claims, which is the only one of economic interest, is remarkably constant in character throughout its entire length of 3,000 feet along the crest of the ridge. In its typical development it consists of a basal 12- to 20-inch regular layer containing 80 to 95 percent of massive chromite, overlain by 2 to 3 feet of lean disseminated material containing 5 to 10 percent of chromite, which in turn grades upward into 1 to 3 feet of rich, disseminated material containing 20 to 40 percent of chromite. In at least one place, between surface trenches 20 and 21, the whole layer pinches out. Everywhere else, however, the lower massive zone is present and may be traced along several hundred feet of outcrop between trenches 35 and 50 with a variation in width of no more than 2 or 3 inches. The two layers of disseminated ore are not so clearly marked and persistent. Occasionally the zone of lean disseminated ore in the middle disappears, leaving 3 or 4 feet of the richer material of the lower and upper zones; elsewhere it thickens to 4 or 5 feet, so that the total thickness of the three zones, averaging 15 to 20 percent chromite, is 7 or 8 feet. Forty-four assays by the Bureau of Mines, representing the three divisions, for a thickness of 5 to 5.5 feet give an average of about 35 percent chromite and 15 percent Cr_2O_3. Assay sections across typical trenches are shown in figure 8.

The total amount of chromite in different sections of this main layer varies but little with its change in thickness; where the layer is thin, chromite is more massive, and where it is thick, the ore is leaner. Where the gangue is rich in pyroxene, the chromite tends to be concentrated in a relatively thin and massive layer; where the gangue is almost exclusively olivine, the chromite is less concentrated. An excellent example of this was found in diamond-drill hole 24, which intersected the chromite layer down dip between trenches 3 and 5 (see pl. 35 section A-A'. The lower poikilitic harzburgite layer was notably rich in olivine, and sections several feet long consisted of a rock composed of olivine with 10 to 15 percent of interstitial plagioclase feldspar. No concentration of chromite comparable to the main band at the surface was encountered, but the whole poikilitic layer was richer than average in disseminated chromite, and seven or eight thin streaks of massive chromite and of rock rich in disseminated chromite were found, so that the aggregate amount of chromite was probably at least as great as that generally encountered.

The footwall, or base, of the massive layer is very sharply marked, whereas the hanging wall grades into leaner rock. The chromite shows no consistent variation in chemical composition with "stratigraphic" position.

CHROMITE RESERVES

General statement

Under the present methods for utilizing chromite, the chromite deposits on the Gish claims are clearly submarginal, and contain no "ore," in the sense of material that can be extracted at a profit. In the event of emergency demands, however, or of major changes in present methods of using chromite, the highest-grade material may become of economic interest, and its amount and character are accordingly worth considering.

There are a number of difficulties in dividing a submarginal deposit into measured, indicated, and inferred ore, and before attempting to do so, it is expedient to discuss the nature of the material to which the term "ore" is applied. The main layer of chromite has a remarkably constant width and grade along its exposed strike length between trenches 3 and 64. No other layer on the property contains even a small fraction of the chromite concentrated into this one. This layer represents a natural unit, essentially homogeneous throughout its length, having sharp assay boundaries on both walls. If the Gish property is ever to be worked in the future, operations will probably be confined to the main chromite layer. Measured, indicated, and inferred ore are consequently limited to material of comparable width and grade. No attempt will be made to estimate quantitatively the mining losses through structural complications, although such losses will certainly occur and may be large; instead the total amount of chromite 5 feet wide and containing 15 percent of Cr_2O_3 is given in the tonnage figures, and the structural conditions are described, so that anyone interested can make his own estimate of mining losses.

Measured ore

The boundaries of the ore that has been blocked out by surface and underground work and drill holes so that its grade, mineral content, and structural characteristics are accurately known, are as follows (see pl. 35):

The upper boundary is the surface from trench 3 on the west to trench 42 on the east. Chromite was uncovered and assayed in almost all of the trenches between these two limits. Though not actually uncovered in trench 3, the chromite was cut almost directly below the trench in the No. 5 level, at a depth of 65 feet below the surface.

The lower boundary extends from the intersection of the No. 5 level with the chromite layer directly down dip from trench 3, eastward along the No. 5 level to its intersection with the Graham Creek fault. From there eastward to a point directly down dip from trench 42 the boundary is the Graham Creek fault. The intersections of the No. 4 and No. 5 levels with the fault give an accurate measure of strikes and dip at two points on the fault, so that the trace of the fault on the chromite layer can be interpolated between the two levels and can be extrapolated to the east with little possibility of error.

The western limit is taken as a line directly down dip from the intersection of the chromite outcrop and the fault west of trench No. 3. The easternmost limit was set as the fault that passes between trenches 42 and 43. This was chosen because diamond-drill hole 18, the easternmost point at which underground evidence is available, intersects the chromite a few feet west of this fault.

This block of measured ore is shown by solid contours on the structure-contour map (pl. 36). It has a width of 5 feet, a length of 2,000 feet, and an average depth of 370 feet. Since by analogy with similar ore elsewhere in the complex 10/ 9.5 cubic feet constitute a short ton of ore, the blocked out reserve is about 390,000 short tons.

Indicated ore

A relatively small amount of indicated ore is present at each end of the measured ore. The block at the western end has the No. 5 level as an upper, and the Graham Creek fault as a lower boundary, and extends eastward from trench 3 to the intersection of the No. 5 level with the Graham Creek fault.

The eastern block extends from trench 43 to trench 64 at the surface, and is bounded on the lower side by the Graham Creek fault. Its western boundary is the fault striking N. 30° E. between trenches 42 and 43.

The amount of ore present in these two blocks is 160,000 short tons, calculated on the same basis as the measured ore.

Inferred ore

All of the chromite east of trench 3 and above the Graham Creek fault is either measured or indicated. From the constancy of width and grade of the ore above the fault, it is assumed that a similar tonnage of chromite of comparable grade and width lies in the footwall within the same strike boundaries. This inferred ore has not been intersected in the drill holes or adits, but on the basis of the sequence of layers cut by diamond-drill hole No. 513 its upper edge lies approximately 300 feet below the No. 5 level, and could be mined only by sinking a shaft. It seems very unlikely that this ore will be worked in the near future even under conditions of severe national emergency.

It is doubtful whether there is any ore east of trench 64. As indicated previously, it is not known whether the main chromite east of trench 64 is covered or whether it becomes much thinner. The weight of evidence, from studies of float blocks and stratigraphic relations, is in favor of a rapid thinning of the main layer.

West of trench 1 the main chromite layer is covered with alluvium, and in this direction the nearest exposure of chromite is on the west side of the Boulder River. There the chromite is nodular and disseminated, and none that has been seen is comparable in grade to that on the east side. It is probable, more over, that the Graham Creek fault cuts off the main layer a few hundred feet west of trench 1, in which case the footwall continuation would be deeply buried. The whole of the ultramafic zone pinches off to the west within half a mile of trench 1.

10/ Peoples, J. W., and Howland, A. L., op. cit., p. 396.

SUMMARY

Almost all of the chromite that might be mined on the Gish property has been proved by surface and underground work and by diamond drilling. About 390,000 short tons of chromite averaging 5 feet in width and 15 percent in Cr_2O_3 content has been proved. This chromite, if all gangue were removed on milling, would yield a product containing 45 percent of Cr_2O_3, with a Cr:Fe ratio of 1.6.

Viewed in terms of availability to mining, the western part of the measured ore, from trench 3 to the large west-dipping fault at trench 30, is fairly continuous, has a steep dip, and is relatively unbroken. Beyond the fault the dip is much flatter, and the chromite layer is serpentinized and is broken by a large number of small high-angle reverse faults with a consistent displacement to the left.

The 160,000 short tons of indicated ore would be more difficult to mine than the ore completely developed. In the western part, below the No. 5 level, it is anticipitated that the ore will become more broken in the vicinity of the Graham Creek fault. In the eastern part, beneath trenches 42 to 64, the dips of chromite layers are flatter (30°-45°), the ore is cut by numerous faults at the surface, and even more faults may be expected at depth near the Graham Creek fault.

The best chromite on the Gish claims undoubtedly has been completely proved by the development work. Any future utilization of the property must be planned with a view to extracting the known deposit. There is no ground for expecting that other, richer, or more easily available material will be discovered nearby.