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CHROMITE DEPOSITS NEAR RED LODGE CARBON COUNTY, MONTANA

BY
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CHROMITE DESPOSITS NEAR RED LODGE,

CARBON COUNTY, MONTANA

By H. L. James

ABSTRACT

The chromite deposits described in this report are in the southeastern part of the Beartooth Range, near Red Lodge, Mont. In 1941, 1942, and 1943, the U. S. Vanadium Corp., the only producer in the district, shipped 21,958 tons of crude lump ore, averaging about 32 percent chromic oxide (Cr_2O_3), and 11,689 tons of concentrates averaging about 40 percent Cr_2O_3. The ore was mined almost entirely by open-cut methods and carried by truck to the mill and railhead at Red Lodge.

In contrast with the stratiform deposits of the Stillwater area, 30 miles to the northwest, the chromite deposits of the Red Lodge district consist of lenses and pods scattered at random in sill-like masses of serpentine, which are intrusive into a metamorphosed series of ancient sedimentary and volcanic rocks. The pods range in size from those containing a few pounds of ore to those containing as much as 35,000 tons of rock that will average 20 percent or more Cr_2O_3. The metamorphic rocks, together with the serpentine, are now found as roof pendants in the gneissoid pre-Cambrian granite which underlies most of the Beartooth Range. Dikes of diabase, porphyry, and andesite cut the granite and older rocks.

The Cr_2O_3 content of the cleaned chromite, separated mechanically from the silicate gangue, ranges from 35 to 53 percent, with the Cr:Fe ratio varying from 0.66 to 2.1. The ore as mined rarely contains more than 40 percent Cr_2O_3. Reserves of indicated ore with an average chromic oxide content of 20 percent or more are estimated at about 19,000 long tons, and it is considered unlikely that this figure can be materially increased by surface prospecting. There are, however, several square miles of upland surface deeply mantled with disintegrated rock and morainal rubble, beneath which at least a few deposits must lie concealed. Geophysical prospecting by means of a magnetometer gives promise of being useful in finding this concealed ore, since the serpentine contains enough magnetite to yield higher magnetic values than most of the country rock, and exceptionally high values are obtained over known ore bodies.

A paved highway passes through the district within 5 miles of all the known deposits, and most of the deposits are now

connected with the highway by secondary roads. The altitude of the deposits ranges from 8,000 to 11,000 feet; winter operations are seriously hampered by the heavy snowfall.

INTRODUCTION

Location.—The chromite deposits described in this report are in Carbon County, Mont., near the southeastern end of the Beartooth Range and just north of the Montana-Wyoming boundary. The Red Lodge-Cooke City highway passes through the district within 5 miles of all the known deposits, none of which are more than 20 miles by road from Red Lodge, the terminus of a branch line of the Northern Pacific Railway. The deposits on Line Creek and Hellroaring Plateaus are accessible by way of secondary roads from the main highway, but those on Silver Run Plateau are reached only by steep trails.

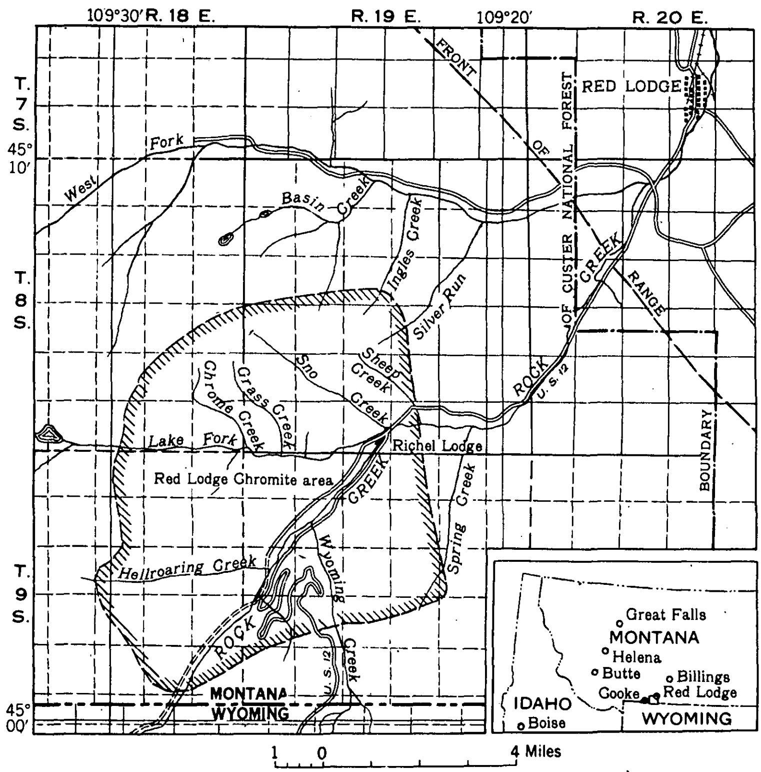


Figure 14.—Index maps of the Red Lodge chromite area. Mapped area outlined.

Field work.—The present report is based on field work done between June 12 and October 18, 1942, and between May 24 and July 26, 1943. The writer was capably assisted by D. H. Dow and Irvin Gladstone in 1942, and by G. M. Sowers in 1943. An area of about 35 square miles, which included the chromite deposits was mapped on the scale of 1,000 feet to the inch; most of the known deposits were mapped on the scale of 100 feet to the inch. The topographic base map used for the areal mapping was constructed from aerial photographs by the Topographic Branch of the Geological Survey.

Magnetometer surveys of portions of the area were made in August and September of 1942 by G. R. MacCarthy, of the Geophysical Section of the Survey, and deposits on Silver Run Plateau were trenched and sampled in 1942 by the Bureau of Mines in cooperation with the Geological Survey.

Acknowledgments.—The cordial cooperation of the officials and engineers of the U. S. Vanadium Corp., who gave freely of their surveying and statistical data, is here gratefully acknowledged. Thanks are also due Mr. J. F. Brophy of Red Lodge, who made available his maps of the Silver Run Plateau claims and who supplied much of the historical information concerning the deposits. Mr. W. R. Calloway, engineer for Montana Chrome, Inc., kindly permitted the party to use the claim maps of Hellroaring and Line Creek Plateaus which he had compiled.

Mr. K. P. Wilson, of the Soil Conservation Service, stationed at Princeton, N. J., permitted use of unpublished geological data accumulated by him while a graduate student at Princeton University.

Helpful advice was received throughout the course of the work from Mr. J. W. Peoples of the Geological Survey, who, as commodity geologist in charge of chromite, supervised the project. Professors E. Sampson and A. F. Buddington of Princeton University and the Geological Survey, made many useful suggestions during the preparation of the report. Finally, the text owes much of whatever charity it map possess to careful criticism by C. F. Calkins and T. P. Thayer.

Previous work.—The Four Chromes area of Silver Run Plateau was visited by Westgate 1/ in 1917, and was briefly described by him in Geological Survey Bulletin 725. A relatively brief but comprehensive description of the deposits of the district was published in 1937 by Schafer 2/ of the Montana State Bureau of Mines and Geology. K. P. Wilson studied the geology of the area and chromite deposits during the field seasons of 1932 and 1933 as a member of the Princeton Research Project in the Beartooth Mountains, but the results of his work have not been published. Numerous detailed and regional studies, many as yet unpublished, have been made of the Beartooth Range in the general region of Red Lodge by members of the Bighorn-Beartooth Research Association.

HISTORY AND PRODUCTION

Chromite was first discovered in the Red Lodge district in 1916, when two prospectors employed by J. F. Brophy, a coal mine operator at Red Lodge, located the Four Chromes deposits on Silver Run Plateau. The discovery aroused the interest of M. E. Martin, a local prospector, who searched for chromite until his death in 1937. Except for the initial location on the Four Chromes, all the discoveries in the area were made by Martin.

In 1933, Montana Chrome, Inc., made up mainly of Montana residents and including Martin, was organized for the purpose of developing the deposits. At the present time, this corporation still owns or controls all the known deposits in the district except the Little Nell group, which is held by the Martin estate.

1/ Westgate, L. G., Deposits of chromite in Stillwater and Sweetgrass Counties, Mont: U. S. Geol. Survey Bull. 725, pp. 83-84, 1921.

2/ Schafer, P. A., chromite deposits of Montana: Montana Bur. Mines and Geology Mem. 18, pp. 21-34, 1937.

Deposits on Highline and Hellroaring Plateaus were trenched and sampled in 1940 by the Mineral Resources Survey under the auspices of the State of Montana and the Works Project Administration.

In 1941 the U. S. Vanadium Corp. obtained a lease on the Montana Chrome, Inc., properties. The company mined chromite from the deposits from October 1941 to November 1942, and from June to September 1943, and operated a gravity concentration mill in Red Lodge from March to November 1942. The following table shows the tonnage of ore mined, the tonnage of crude lump ore shipped, and the tonnage of concentrates produced, during these periods:

Chromite production, in long tons, from the Red Lodge district in 1941, 1942, and 1943

Period	Ore mined	Concentrates produced	Crude lump ore
October 1941-November 1942.	56,460	11,689	15,748
June 1943-September 1943...	11,483*	**	6,210
	67,943	11,689	21,958

*Includes a stockpile of milling ore at the North Star claim, estimated to contain about 5,500 tons.

**Mill was not operated in 1943.

The average chromic oxide content of the concentrate was about 40 percent, and that of the crude lump ore, about 32 percent.

PHYSIOGRAPHY

The southeastern part of the Beartooth Range is characterized by a partly preserved upland surface of low relief, which has been deeply incised by the glaciated valleys of Rock Creek, Line Creek, and tributary streams. The gently rolling, grass-covered upland areas between the major streams, known individually as plateaus, are in remarkable contrast to the steep walls of the incising canyons. The plateaus, ranging in elevation from 10,000 to 11,000 feet, are snow-covered from October to June. A few peaks rise above the plateau level to more than 12,000 feet.

The valleys are typically U-shaped; the lower parts of their walls form moderate slopes, covered with timber or talus, which merge upward with the precipitous cliffs that bound the plateaus. Marshes and rock-bound lakes are numerous in the upper reaches of the valleys. Roads that ascend from the valleys to the plateaus do so in a tortuous series of switchbacks (pl. 52).

GEOLOGY

General outline.—Geologically the Beartooth Range is an uplifted block from which erosion has stripped the younger rocks to expose a pre-Cambrian core. The northern front of the range from the Stillwater River to Red Lodge is bounded by southward-dipping thrust faults 3/ and is characterized by "palisades" of nearly vertical beds of Paleozoic limestones. The canyon of the Clark Fork of the Yellowstone is generally accepted as marking the southern margin of the range, although geologically the limits are somewhat indefinite because of overlapping Tertiary volcanic rocks.4/ Presumably, at earlier stages of the Beartooth uplift, the metamorphic and igneous terrain now exposed in the core was unconformably overlain by a more or less continuous cover of Paleozoic sedimentary rocks.

In the southeastern part of the range, the oldest rocks are partly of sedimentary and partly of volcanic and igneous origin and all are highly metamorphosed. They comprise quartzite, amphibolite, and basic gneisses, with minor lenses of schist and of magnetite-rich rocks. These ancient rocks were intruded first by sill-like masses of serpentine, and then by small bodies of gabbro. The serpentine is the host rock of the chromite ores. The metamorphic rocks, together with the serpentine and gabbro, have been engulfed in the gneissoid granite which underlies the greater part of the Beartooth Range and in which the older rocks now form isolated roof pendants (pl. 53). Probably at least one-fourth of the area mapped is underlain by migmatite (literally, "mixed rock") which represents a more or less complete mixture of granitic material with highly altered remnants of earlier metamorphic rocks. The granite and older rocks are cut by pre-Cambrian diabase dikes, which in turn are cut by much younger prophyry and andesite.

Chromite deposits are found on Line Creek, Hellroaring, and Silver Run Plateaus, which are separated by the deep valleys of Rock Creek and the Lake Fork of Rock Creek. None are known to occur at an altitude of less than 8,000 feet.

Metamorphic rocks

General character and distribution.—The metamorphic rocks of the Red Lodge district are now found to occur as roof pendants and xenoliths in extensive areas of granite (pl. 54). They originally consisted of shallow-water sedimentary rocks, basic volcanics, and basic igneous rocks, and are now represented by quartzite, schist, amphibolite, and gneiss. So far as is known, all of these rocks, including the granite, are of early pre-Cambrian age.

3/ Guidebook, Bighorn-Yellowstone Valley tectonics field conference, Aug. 3-5, 1937, Billings, Mont., W. W. Gail, 1937.

Bevan, Arthur, Summary of the geology of the Beartooth Mountains, Mont.: Jour. Geology, vol. 31, pp. 441-465, 1923.

Perry, E. L., Flaws and tear faults: Am. Jour. Sci., 5th ser., vol. 29, pp. 112-124, 1935.

Vhay, J. S., Geology of a part of the Beartooth Mountain Front near Nye, Mont.: Unpublished dissertation at Princeton University, 1934.

Wilson, K. P., Unpublished studies on the Red Lodge, Mont., region: Data in files of Princeton University Dept. Geology.

Bucher, W. H., Chamberlain, R. T., and Thom, W. T., Jr., Results of structural research work in Beartooth-Bighorn region, Montana and Wyoming: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 680-693, 1933.

Chamberlain, R. T., Diastrophic behavior around the Bighorn Basin: Jour. Geology, vol. 48, pp. 673-716, 1940.

4/ Lovering, T. S., The New World or Cooke City mining district, Park County, Mont.: U. S. Geol. Survey Bull. 811-A, pp. 9-12, 1929.

Bevan, Arthur, Summary of the geology of the Beartooth Mountains, Mont.: Jour. Geology, vol. 31, pp. 448-457, 1923.

The most completely studied roof pendant is that which forms a belt across the southern part of Hellroaring Plateau. It is approximately 5 miles long, with a maximum width of about 1,500 feet. This pendant is made up, in large part, of interbedded amphibolite and micaceous quartzite, with a border of massive white quartite and magnetite or garnet-rich rocks along the north and northwest margin. Chromite has been mined at six localities along the belt from serpentine lenses that characteristically occur between amphibolite and micaceous quartzite layers. Several smaller roof pendants, consisting mainly of amphibolite, massive quartzite, and iron-rich rocks, are found on the northeastern part of the plateau between Hellroaring Creek and the Lake Fork of Rock Creek.

On Line Creek Plateau, metamorphic rocks underlie an extensive, highly irregular area on both sides of the Wyoming Creek valley. The section comprises amphibolite, schist, iron-rich rocks, and massive white quartzite. Interbedded micaceous quartzite and amphibolite, such as are found on Hellroaring Plateau, are absent. The chromite-bearing serpentine on the Highline claims occurs in a small, apparently isolated pendant which is made up largely of amphibolite.

A roof pendant about 2½ miles long and nearly half a mile in maximum width crops out along the south-facing front of Silver Run Plateau, north of Richel Lodge. The section consists mainly of amphibolite, quartz-rich gneiss (probably equivalent to micaceous quartzite in areas of less intense metamorphism), basic gneiss, and relics of massive white quartzite and iron-rich rocks. Only two small lenses of serpentine were noted, one of which contains the ore deposits of the Edsel claim. The metamorphic rocks and serpentine have been deeply embayed and profoundly altered by granite.

A narrow belt of xenoliths and small roof pendants that consist mainly of serpentine extends across Silver Run Plateau from Silver Run Creek almost to Lake Fork. A few relict bodies of amphibolite and quartzite are preserved along this belt, but, for the most part, the original wall rocks of the serpentine are represented only by gneissic or migmatitic granite.

Micaceous quartzite.—Lenses of micaceous quartzite as much as 140 feet thick are abundant in the lower part of the Hellroaring Plateau section. An individual lens cannot, in general, be traced very far. North of the adit on the Shovel claim, for example, there are six beds of micaceous quartzite below the massive white quartzite, while in the North Star-Drill area, less than half a mile to the west, an equivalent stratigraphic section contains but two.

The micaceous quartzite is fine-grained and well-banded, and contains from 10 to 30 percent biotite. The color varies from white to buff. Because of the abundant mica, the rock disintegrates rapidly when weathered and cannot be traced by float between areas of outcrop. In the more highly metamorphosed facies, green hornblende and plagioclase (andesine) are present, so that, at many places, the rock becomes a gneiss that might readily be taken for an igneous rock. Much of the rock mapped as "undifferentiated metamorphic" in the large Silver Run Plateau roof pendant is a gneiss of this type.

Amphibolite.—At least half of the total section of metamorphic rocks consists of amphibolite. The rock is dark-colored, moderately foliated, and medium- to fine-grained. Megascopically it appears very uniform in character, with hornblende the only recognizable constituent. Under the microscope the rock is seen to consist of about 50 percent hornblende, 40 percent plagioclase (near An_{33}) and 10 percent quartz.

From their mineral composition and their uniform, nonbedded character, the amphibolite layers are believed to be metamorphosed basic volcanic rocks.

The amphibolite forms layers that are as lenticular in habit as those of the micaceous quartzite, and the two rocks frequently have a complementary relation—where the amphibolite is thick the adjacent quartzite is thin, and vica versa. In view of this relation, it would seem likely that the sandstones were deposited on undulating surfaces of the volcanic rocks, the greatest thicknesses being in depressions on the volcanic surface.

Massive quartzite.—Beds of massive white quartzite occur at many places throughout the area. The rock is white, coarse-grained, and very massive. It usually contains a little green chrome mica, and in places this mineral is abundant enough to impart a greenish hue to the entire rock.

In thin section, the rock is seen to be composed of large, interlocking quartz grains, with occasional grains of microcline and of colorless to faintly green mica. The microcline and mica are always most abundant where the rock is granulated. For the whole length of the main Hellroaring Plateau pendant, a bed of massive white quartzite separates the interbedded micaceous quartzites and amphibolites from iron-rich rocks. The ease with which this rock is recognized, together with the nearly constant thickness of the bed (contrasting with the pronounced lenticularity of the micaceous quartzites and amphibolites), make it extremely useful as a horizon marker in the Hellroaring Plateau area. A similar bed of white quartzite separates amphibolite from iron-rich rocks at the Highline claims on Line Creek Plateau and also along the southern margin of the main Silver Run Plateau roof pendant. At both localities, however, the relations are somewhat obscured by embayments of granite.

Numerous layers of massive white quartzite are interbedded with the beds of garnetiferous and magnetite-rich rocks at many places in the area, notably in the roof pendants on the northeast tip of Hellroaring Plateau and on the east side of the Wyoming Creek valley.

Metamorphic rocks characterized by lenses of iron-rich rock.—The unit shown on the maps as "Metamorphic rocks characterized by lenses of iron-rich rock" is about 80 percent amphibolite, but also includes lenses of quartzite and micaceous schist, and thin lenses of iron-rich rock. These lenses of iron-rich rock, though rarely more than a few feet thick, are highly distinctive. The rock is widely variable in composition but generally contains at least 40 percent quartz and 10 to 50 percent magnetite. In places, it may contain as much as 50 percent of reddish-brown garnet. Other minerals locally abundant are hypersthene, augite, and hornblende. The rock is mostly dark, heavy, and strongly magnetic, though in some places, where garnet and pyroxenes are abundant, it is reddish in color and but weekly magnetic.

Sections of rock characterized by iron-rich beds are found on the east side of Wyoming Creek, on the northeastern tip of Hellroaring Plateau, and in the Hellroaring Lakes basin.

The iron-rich rocks at Red Lodge are similar in bulk composition to fayalite-rich metamorphic rocks that occur in the section underlying the Stillwater complex 30 miles to the northwest;5/ the differences in mineralogic composition can, in large part, be ascribed to the different conditions under which the rocks were altered.

Basic gneiss.—Layers of strongly foliated, dark-colored, medium- to coarse-grained gneiss occur at several places in the area, notably along the southern front of Silver Run Plateau and on the western part of Line Creek Plateau. In general, the layers appear to be concordant with the bedding of the nearby metamorphosed sedimentary rocks. Under the microscope, the rock is seen to consist mainly of hornblende and calcic plagioclase, both of which have been extensively altered to epidote. The composition, grain size, and mode of occurrence of these layers of dark gneiss indicate that they probably represent metamorphosed sills of coarse diabase or gabbro.

Undifferentiated metamorphic rocks.—At a number of places in the area, insufficient time was available to map the various kinds of metamorphic rocks accurately; at others, the detail was too great to be shown on the base map used. At still other places, the processes of assimilation and igneous metamorphism have gone so far that specific classification of the metamorphic rocks—that is, as quartzite, amphibolite, etc.—is difficult or impossible. At all of these localities, the rock is shown on the map as undifferentiated metamorphic. At no place, however, has massive quartzite or iron-rich rock been included in this grouping.

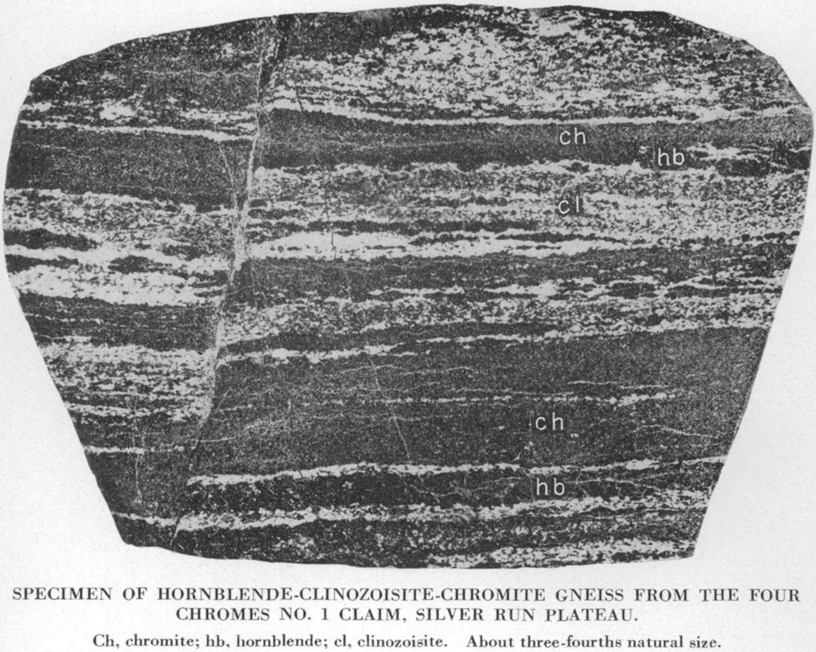
Serpentine

General characteristics and mineralogy.—The term serpentine, as used in this report and on the accompanying maps, is employed loosely to include serpentine rock and rocks produced by metamorphism of serpentine.

True serpentine, which makes up perhaps 80 percent of the total, is a dense rock, dark green to black on fresh fracture but bleaching to yellowish gray, light green, or greenish brown on exposed surfaces. This bleaching is particularly evident in serpentine exposed on the plateaus; it is presumably due to some change in state of the fine-grained, "dusty" magnetite which gives fresh serpentine its dark color. The hardness ranges from 4 to 5.5 (Mohs scale), the hard variety being found only on or near the plateau surface. In places the rock is cut by thin veinlets of silky chrysotile asbestos. Uvarovite, the green chrome garnet, is locally an accessory mineral; it is found as coatings on joint surfaces in chromite from the Drill claim and as fine disseminated grains in massive chromite from the Edsel claim.

Under the microscope, the serpentine is seen to consist mainly of a homogeneous mat of bladed antigorite, cut by stringers of fine-grained magnetite and enclosing occasional grains

5/ Howland, A. L., Sulfides and metamorphic rocks at the base of the Stillwater complex: Unpublished doctorate dissertation at Princeton University, 1933.



SPECIMEN OF HORNBLENDE-CLINOZOISITE-CHROMITE GNEISS FROM THE FOUR CHROMES NO. 1 CLAIM, SILVER RUN PLATEAU.

Ch, chromite; hb, hornblende; cl, clinozoisite. About three-fourths natural size.

of chromite. No mineralogic differences can be detected between "hard" serpentine and serpentine of normal hardness. Relict olivine was observed in several specimens, but is relatively rare.

The metamorphic effects of the later granite and pegmatite intrusives upon the serpentine have been both varied and extensive. Chlorite (probably penninite) occurs in all the slightly metamorphosed serpentine, although it rarely forms more than 5 percent of the rock. Phlogopite, a brown mica, is present in serpentine on the Gallon Jug No. 4 claim, but in general is not common. It is clearly not a primary mineral. Alteration to fine-grained, flaky talc is common, and talcose rock is particularly abundant on the Little Nell, Gallon Jug No. 3, and Gallon Jug No. 4 claims.

In many places near the chromite ore bodies, the serpentine is altered to a granular mass consisting of light-green chrome diopside or bright-green, bladed chrome tremolite, or both. Both these minerals are colorless in thin section. This rock occurs most abundantly on the Shovel and Drill claims on Hellroaring Plateau, and on the Edsel and Little Nell claims on Silver Run Plateau.

More intense metamorphism results in the development of black hornblende, which in many places makes up the entire rock. Locally, layers of hornblende are interleaved with thin layers of pinkish clinozoisite to form a gneissic rock. Layers of chromite are preserved in some of this gneiss.

Some specimens from the Four Chromes group of claims contain countless small grains of enstatite, which appear to have developed at the expense of the olivine and serpentine. The small grain size (around 0.1 mm) of the enstatite as compared with that of the primary olivine (around 2 mm), together with the details of occurrence as seen in thin section, indicate that this enstatite is secondary.

Masses of coarse biotite and green chrome tremolite as much as several feet thick are commonly found surrounding granitic pegmatites that cut serpentine. In a few places, similar alteration of the serpentine, but on a lesser scale, is found at the contacts of serpentine bodies with country rock. The biotite has locally been altered to vermiculite.

In general, the serpentine is much more resistant to assimilation than the metamorphic rocks. Its superior resistance can probably be ascribed in part to the physical properties of plasticity and imperviousness (by virture of its fine grain and interlocking texture), and in part to its peculiar chemical composition. Lenses and xenoliths of serpentine, often of considerable size, are very commonly found in granite where scarcely a trace of the original wall rock remains. Such serpentine is generally, but not always, highly metamorphosed. In addition to an increase of calcium, alumina, and silica, metamorphism of the serpentine appears to involve a progressive loss of chemically combined water until an essentially anhydrous assemblage is produced. This is followed by re-introduction of water and the formation of new hydrous minerals, thus:

Slight metamorphism				Intense metamorphism
Serpentine →	Chlorite →	Talc →	Diopside →	Hornblende
	Talc	Tremolite	Garnet	Clinozoisite
		Diopside		

← Dehydration → ← Rehydration →

In the field it was noted that the chrome-bearing silicates (tremolite, diopside, and garnet) occurred in abundance only where chromite was present in appreciable quantity.

Some of the serpentine exhibits a pronounced banding that is due to shearing. This banding parallels the contacts with the country rock, and is emphasized in places by selective development of amphibole and pyroxene in some of the layers.

Distribution

Lenses of serpentine have been found in almost every part of the area mapped. Where the original wall rocks remain, these lenses, with but one or two minor exceptions, appear to be concordant with the bedding of the enclosing rocks. They vary widely in size. The greatest width observed is about 200 feet (at both the North Star and Highline claims) and the greatest length about 2,000 feet (at the Four Chromes group of claims). In a general way the larger bodies of serpentine are limited to the amphibolite and micaceous-quartzite parts of the metamorphic section. The serpentine lenses in the iron-rich rocks and massive quartzite, though numerous, are much smaller. The distribution of the major areas of serpentine is shown on plates 53 and 54.

Hellroaring Plateau.—The great majority of the serpentine bodies on Hellroaring Plateau are found in the main roof pendant on the southern part of the plateau, where about 25 individual lenses were located (pl. 56). These range in size from lenses a few feet long to one that is 1,500 feet long and as much as 200 feet wide. They are found at many stratigraphic horizons in the metamorphic rocks but are most abundant in the micaceous quartzite-amphibolite part of the section. The ore-bearing serpentine lenses of the Pick, Shovel, Gallon Jug, Gallon Jug No. 1, and Gallon Jug No. 2 claims occupy approximately the same stratigraphic position in this section, as indicated by their relation to the massive quartzite; the serpentine on the North Star claim and on the western part of the Drill claim occupies a more southerly and stratigraphically lower horizon. In the Gallon Jug No. 2 area, in addition to the serpentine in the micaceous quartzite-amphibolite section, there are two large lenses which are higher in the metamorphic series and closer to the massive quartzite, and north of the Shovel adit about 10 small lenses are clustered in or close to the massive quartzite, near the axis of a minor fold. None of these contain chromite except as a minor accessory mineral.

Three rather large bodies of serpentine occur in the roof pendants on the northeastern part of the plateau, and a number of small xenolithic pods are found, enclosed in granite, in the Hellroaring Lakes basin.

Line Creek Plateau.—The Highline ore deposits, on Line Creek Plateau (pl. 57), occur in a single serpentine body, which is at least 1,000 feet long and as much as 250 feet wide. The presence of serpentine float southeast of the working indicates that the rock may continue farther in that direction.

Many very small lenses, most of them too small to be shown on the areal map, occur in the thick metamorphic section exposed along the east side of the Wyoming Creek valley.

Silver Run Plateau.—A belt of small roof pendants and xenoliths consisting largely of serpentine can be traced for several miles across Silver Run Plateau. The Little Nell (pl. 58) and Four Chromes (pl. 59) groups of claims are on this belt. The original country rock has been almost completely obliterated by the later granite, but the serpentine, which is much more resistant to assimilation, is preserved as lenses as much as 2,000 feet long and 150 feet wide. The serpentine was obviously not limited to a single horizon in the pre-granite metamorphic series, for the granite between paralled lenses of serpentine frequently contains remnants of the older metamorphic rocks into which the serpentine was intruded. This is well shown on both the Four Chromes and Little Nell maps.

A few small lenses of serpentine are found along the southeastern front of Silver Run Plateau, above Richel Lodge. The Edsel group of claims has been located on one of these lenses. The serpentine in the lens has been metamorphosed to amphibole-pyroxene rock.

Gabbro and norite

Several small bodies of gabbro were observed in the district, but most are too small to be shown on the general map. The small body of gabbro west of the Shovel adit (see pl. 56) is a dark, foliated rock containing as much as 40 percent of pink potash feldspar, which, judging from its frequent vein-like habit, is not primary but has been introduced. As the gabbro contains an inclusion of chromite-bearing serpentine, it must be younger than the serpentine; its extensive alteration, particularly by introduction of feldspar, indicates that it is pre-granite.

A large mass of norite crops out on the headwaters of Quad Creek, a short distance south of the Line Creek ore deposits. It is definitely pre-granite in age, but its age relation to the serpentine is not known. Most of the rock is dark-colored and coarse-grained, and is made up of about equal parts hypersthene and plagioclase (An_{60-70}), with accessory hornblende, biotite, and quartz, although lighter and darker facies are present.

Granite, migmatite, and pegmatite

Two main types of granite are present in this area, though no attempt was made to differentiate them in mapping. The major type is a foliated, gray, biotite granite of medium to coarse grain. The other, which occurs as small bodies cutting the first, is a pink microcline granite in which mafic minerals are scarce or even totally absent. In many places the pink granite is coarse-grained, almost pegmatitic in appearance; much of it shows no foliation, and none of it is as distinctly foliated as the gray type. These two granites appear to be correlative with those found in the Cooke City mining district, 25 miles to the west,6/ where Lovering named the gray variety the Goose Creek granite and the pink variety the Cooke granite. The age relations and general characteristics of the granites in the two areas are similar. In some parts of the Red Lodge area, notably on Line Creek Plateau and on the eastern part of Hellroaring Plateau, distinction between pink and gray granites is lacking, possibly because of extensive contamination by older rocks.

6/ Lovering, T. S., op. cit.

In general the foliation in both granites appears to be a primary (flow) structure. The rocks only rarely show granulation and, at a number of places in the area, angular blocks of foliated metamorphic rocks are found enclosed in granite, with the foliation of the granite being subparallel to the outlines of the blocks and entirely without relation to the foliation of the metamphoric rocks.

Migmatite forms a considerable part of the rock shown on the areal map as "granite and migmatite." This rock appears to be an admixture of granitic material with partly assimilated remnants of the older metamorphic rocks into which the granite was intruded. These remnants may be in the form of small inclusions of recognizable metamorphic rock, or, where the older rock was amphibolite or a similiarly basic rock, they may be dispersed as "strings" or "clots" of dark minerals. Where the older rock was quartzite, the dispersed material becomes indistinguishable from the igneous matrix. Excellent exposures of migmatite are found along the switchback highway (U. S. 12) between Rock Creek and Line Creek Plateau.

Pegmatite is abundant throughout the district, and, as with the granite, two distinct varieties are present. The white pegmatite, which is usually very coarse-grained, consists of white microcline, quartz, some albite, and biotite. The biotite, all of it partially chloritized, forms curved foils interstitial to large, rounded crystals of microcline, which may be as much as 4 inches in diameter. The pink pegmatite, which consists almost entirely of pink microcline and quartz, is generally less coarse-grained; its minerals locally are graphically intergrown.

In many places on Hellroaring Plateau, nearly horizontal sheets of both the white and the pink pegmatite truncate the bedding of the metamorphic rocks. Pink pegmatite is particularly abundant in the area north of the Shovel ore deposit, and also in the exposures on the Gallon Jug No. 1 claim.

Dike rocks

Diabase

Steeply dipping or vertical dikes of diabase cut the granites and older rocks throughout the district. They are believed to be pre-Cambrian in age, since they nowhere cut the Paleozoic strata which occur on the borders of the Beartooth Range. The dikes characteristically trend northwest, and individual dikes as much as 100 feet wide may be traced for several miles.

Megascopically, the diabases are dark-colored, with a rusty appearance where weathered. They are of fine to medium grain; the medium-grained varieties usually have a diabasic texture, being made up of interlocking feldspar laths and interstitial dark minerals. In thin section, a few specimens were seen to be composed of plagioclase, augite, and hypersthene, with minor amounts of secondary biotite and sericite; the majority, however, are highly altered to a fine-grained mass of uralitic hornblende, chlorite, sericite, quartz, and epidote.

In the Gallon Jug No. 1-No. 2 area, diabase forms a complex mass of intersecting dikes which separates the ore-bearing serpentine into several segments.

Porphyry

Porphyry intrusions are numerous in the area, as they are throughout the Beartooth Range,7/ and have the form of dikes, sills, and laccoliths. Steeply dipping dikes as much as 300 feet wide are found throughout the area and, most commonly, have a northeasterly trend. A number of complex, sheetlike masses of porphyry occur on the northwestern edge of Line Creek Plateau, and less abundantly, in other parts of the area. Dips are gentle to moderate. Several of these sheets can be seen in the cliffs on the east side of the Wyoming Creek valley.

The porphyries range from buff to gray. They have euhedral phenocrysts of feldspar, as much as 2 inches in length, set in a fine-grained or aphanitic matrix. Some of the phenocrysts are of plagioclase (An_{10-30}) and some are of orthoclase; those of orthoclase are commonly larger, but less numerous. The buff-colored porphyry is generally coarser-grained than the gray porphyry and a larger proportion of its phenocrysts are of orthoclase. The porphyries are Cretaceous (pre-Livingston) in age,8/ and cut all other rocks in the area.

Andesite

Three dikes of andesite were observed in the district, one on the Little Nell area, and one on the Edsel area of Silver Run Plateau. Specimens from the Edsel and Four Chromes dikes are practically identical in appearance; both are gray and fine-grained, with small phenocrysts of plagioclase (zoned from a core of An_{45} to a rim of nearly pure albite) and of hornblende. The Little Nell dike is similar in appearance to the others except for its greenish color, which is due to an intense alteration that has formed much epidote.

The age relations of the andesite to the porphyry could not be determined within the district. The andesite is probably related to the widespread volcanics of the Livingston formation, of Upper Cretaceous and Paleocene age, which are found along the Beartooth front some distance to the northwest.9/

STRUCTURE 10/

General features.—The Beartooth Range, considered regionally, is a broad, northwest-trending, anticlinal uplift, bordered on the northeast by southward-dipping thrust faults and on the southwest by overlapping Tertiary volcanic rocks. The present erosional surface in the southeastern part of the range exposes a structurally deep level in which isolated roof pendants of old

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7/ Rouse, J. T., Hess, H. H., et al., Petrology, structure, and relation to tectonics of porphyry intrusions in the Beartooth Mountains, Mont.: Jour. Geology, vol. 45, pp. 717-740, 1937.

8/ Rouse, J. T., Hess, H. H., et al., op. cit., pp. 736-738.

9/ Vhay, J. S., Some features of the Livingston formation near Nye, Mont.: Am. Geophys. Union Trans., 20th Ann. Mtg., pt. 3, pp. 433-437, Nat. Research Council, 1939.

10/ Time limitations during both the field work and the preparation of this report have prohibited exhaustive treatment of the regional aspects of the structure.

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metamorphic rocks are found completely surrounded by later granite. The most general trend of the belts of metamorphic rock and serpentine, and of the foliation in the granite, is northeast, or nearly at right angles to the long axis of the range and to the nearest (north) margin of the range. A general parallelism of pre-Cambrian structures with the present outlines of the range has been reported by Ernst and Hans Cloos,11/ and by Lammers.12/ Presumably, the northeast structural trend in the Red Lodge chromite area would be interpreted as being structurally coincident with parts of the eastern nose of the range (approximately 10 miles to the southeast) rather than to the areally closer north margin.

The main period of deformation was apparently early pre-Cambrian, as the late pre-Cambrian diabase dikes cut indiscriminately across structures in the metamorphic rocks and foliation in the granite. The diabase dikes, however, as well as the much younger prophyries, are cut by numerous faults of small displacement, which are probably related to the uplift of the present range during the Laramide orogenic period.

The granite that underlies the greater part of the area shown on the areal map (pl. 53) is a relatively small part of the extensive batholith that extends almost the whole length of the Beartooth Range.13/

In the mapped area, the granite shows a strong foliation marked by planar alinement of dark minerals or of inclusions. Linear structure, if present, is obscure. The foliation has a general northeast trend, although locally it may deviate widely or be contorted. Dips are steep.

The major trend shown by the strike of both bedding and foliation in the metamorphic rocks and by the general outlines of the roof pendants is also northeast, roughly parallel to the major trend of foliation in the granite. Dips of both bedding and foliation are everywhere steep and locally inconsistent as to direction. On Hellroaring and Highline Plateaus the northeasterly trend is modified by several steeply plunging folds or flexures (see pls. 56 and 57). The contacts with the granite are prevailingly concordant but locally crosscutting.

Faults are numerous, but all those found in the mapped areas were of relatively minor importance and showed no particularly systematic trend or direction of offset. Many of the fault fissures observed were filled with quartz and all were steep; the movement, where determined, appears to have been nearly horizontal.

Relation of serpentine to structure

The relation between the distribution of serpentine and the structure of the older rocks is shown by the structural map of the area (pl. 54). The serpentine masses, particularly on Hell-

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11/ Cloos, Ernst, and Cloos, Hans, Pre-Cambrian structure of the Beartooth, the Bighorn, and the Black Hills uplifts, and its coincidence with Tertiary uplifting (abstract): Geol. Soc. America, Proc. 1933, p. 56, 1934.

12/ Lammers, E. C. H., Pre-Cambrian control of Laramide structures in the Beartooth Range, Montana and Wyoming (abstract): Geol. Soc. America Bull., vol. 50, p. 1918, 1939.

13/ Bevan, Arthur, Op. cit., p. 448.

roaring Plateau, are especially thick and more numerous near the axes of synclinal rolls in the metamorphic rocks. The chromite-bearing serpentine lenses at the Highline claims, the North Star and Drill claims, and the Gallon Jug Nos. 1 and 2 claims, are all on or near synclinal axes. The serpentine at the Pick and at the Gallon Jug No. 4 claims appears to be related to similar but less clearly defined structures.

The significance of this observed relation of serpentine and structure is not entirely clear. Detailed examination shows that the serpentine in most of the lenses has been intensely sheared, and that the chromite ore bodies in these lenses have been sheared, broken, and probably rotated. On the other hand, specimens of serpentine from other lenses show, under the microscope, typical "mesh structure" with small islands of olivine of parallel optic orientation separated by serpentine. It seems highly doubtful that the lenses from which these specimens were obtained could have undergone much movement without destruction or at least distortion of such a delicate texture.

The serpentine bodies that occur near the axes of the folds are distinctly lenticular, whereas those that bear no obvious spacial relation to folds—as at the Four Chromes, the Little Nell, the Edsel, and the Gallon Jug No. 3 claims—occur as layers that are narrower but have greater strike length and less variation in width. On the Gallon Jug No. 1 claim (see pl. 56) half a dozen pods of serpentine are found within a strike length of about 500 feet occupying the same stratigraphic horizon; this appears to be a clear case of segmentation of an originally continuous sill or lens as a result of flowage.

These observed facts lead the present writer to conclude that the major structural features of the serpentine bodies can be best explained by the two-stage sequence of events outlined below:

1. Intrusion of serpentine, during the earlier phases of the major orogeny, as lenses and sills which in places may have been localized by folds in the sedimentary and volcanic rocks.

2. Continued deformation, culminating in the emplacement of great granite batholiths which metamorphosed, stoped, and assimilated much of the earlier rock. Under the influence of high temperatures, high confining pressures, and strong shearing forces—the latter now indicated by the pronounced flowage structure in the granite and the foliation in the metamorphic rocks—some of the serpentine was squeezed toward the axes of the folds, which were loci of least pressure. Although the primary shape of many of the serpentine bodies may have been changed only in moderate degree, some of them may have undergone extensive mass movement. Those serpentine bodies that are pod-shaped, with a relatively large maximum width compared with the length, quite possibly owe much of their present form and position to plastic flowage. Serpentine lenses that were located at considerable distance from the axes of the flexures might be somewhat attenuated but, at least locally, might be relatively little affected.

The plastic nature of serpentine, which would permit flowage, is shown in the Red Lodge area by its frequent inability to sustain through-going fractures. Many faults that are well-defined in the country rocks are dissipated in the serpentine, and in several places, such as the Line Creek and Pick workings, large dikes end abruptly in the serpentine or are forced to change direction.

Mass movement of serpentine under pressure is probably not an uncommon phenomenon. One of the most completely described areas in which this apparently has occurred is the Mount Diablo area of California, where a complex jumble of serpentine and Franciscan sediments forms a pluglike "intrusion" which has domed the surrounding sediments.14/

ORE DEPOSITS

General features.—The chromite deposits of the Red Lodge region are definitely podlike in form, belonging to the general class of chromite deposits typically found in the serpentine belts of the Pacific Coast,15/ Cuba,16/ and elsewhere, and for which Sampson 17/ has proposed the term "sackform." They contrast sharply with the layered or "stratiform" type of chromite deposit exemplified in the Stillwater complex,18/ 30 miles to the northwest.

A number of deposits similar to those described in this report are found throughout the central Cordilleran region. The chromite deposits of the Red Lodge, Silver Star,19/ Sheridan, and Pony localities in Montana, and at Casper, Wyo.,20/ are all very similar in occurrence and general habit. All are of pre-Cambrian age and antedate the emplacement of the regional pre-Cambrian granites.

A noteworthy feature of the Red Lodge deposits is the relatively large amount of ore present in so small an amount of serpentine, as compared, for example, with the Pacific Coast

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14/ Taff, J. A., Geology of Mount Diablo and vicinity: Geol. Soc. America Bull., vol. 46, pp. 1079-1100, 1935.

15/ Thayer, T. P., Chromite deposits of Grant County, Oreg.: U. S. Geol. Survey Bull. 922-D, 1940.

Rynearson, G. A., and Smith, C. T., Chromite deposits in the Seiad quadrangle, Siskiyou County, Calif.: U. S. Geol. Survey Bull. 922-J, 1941.

Wells, F. G., Page, L. R., and James, H. L., Chromite deposits of the Pilliken area, Eldorado County, Calif.: U. S. Geol. Survey Bull. 922-O, 1941.

Wells, F. G., Page, L. R., and James, H. L., Chromite deposits in the Sourdough area, Curry County, and the Briggs Creek area, Josephine County, Oreg.: U. S. Geol. Survey Bull. 922-P, 1941.

16/ Thayer, T. P., Chrome resources of Cuba: U. S. Geol. Survey Bull. 935-A, 1942.

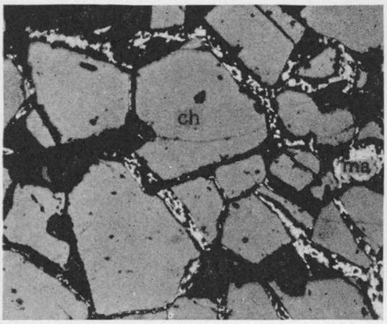
17/ Sampson, Edward, "Chromite deposits," Chapt. IIIa, pt. 1, in Ore deposits as related to structural features, edited by W. H. Newhouse, pp. 110-126. Princeton Univ. Press, Princeton, N. J., 1942.

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

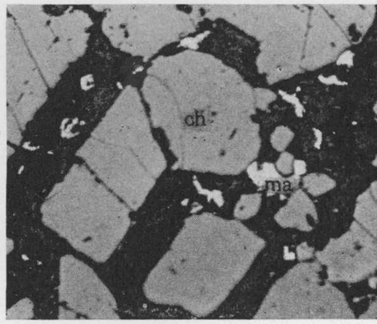
19/ The Silver Star chromite deposit, Madison County, Mont.: U. S. Dept. Interior, Geol. Survey, press notice 27618, Oct. 1, 1943.

20/ Chromite deposits of Casper Mountain, Natrona County, Wyo.: U. S. Dept. Interior, Geol. Survey, press notice 4482, Sept. 14, 1942.

Stephenson, H. K., Contributions to the mineralogy of chromite based on the chromite deposits of Casper Mountain, Wyo.: Unpublished dissertation at Princeton University, 1940.

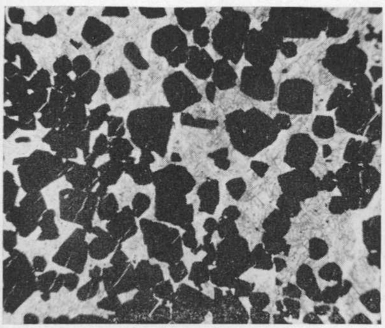


A

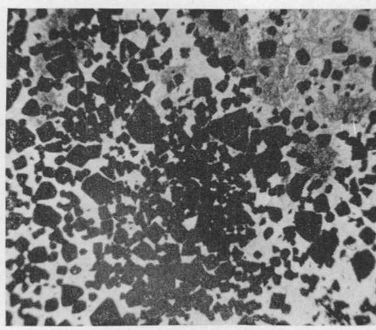


B

A, *B*. Typical occurrences of magnetite (ma, white) with chromite (ch, gray). Polished sections, × 55.

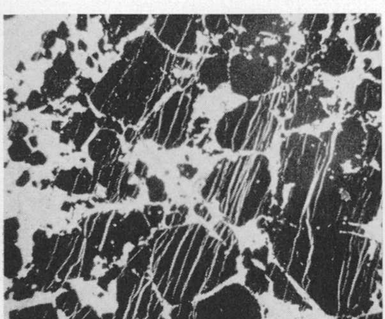


C

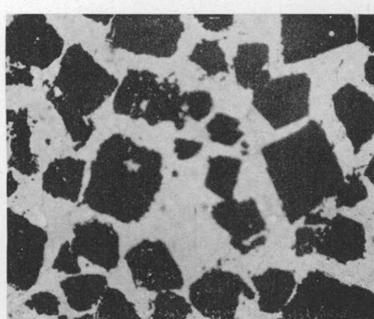


D

C. Subhedral chromite in talcose matrix. Thin section, × 14.
D. Poorly developed nodular ore from the Four Chromes claim. Thin section, × 10.



E



F

E. Fractured chromite from the North Star ore body. Thin section, × 14.
F. Euhedral chromite grains showing slightly granulated borders. Thin section, × 14.

PHOTOMICROGRAPHS OF CHROMITE ORE FROM THE RED LODGE DISTRICT.

occurrences, where the ore bodies are of approximately the same size as those in the Red Lodge district but the enclosing serpentine masses are many times as large.

The term "ore," as used in the Red Lodge area and in this report, applies to rock that will average 20 percent or more Cr_2O_3. A substantial percentage of the ore mined to date has been chromite "sand" from deeply disintegrated outcrops on the plateau surfaces.

Mineralogy

The composition of chromite, the only ore mineral of chromium, is highly variable. The formula is written as $(Mg,Fe)O \cdot (Fe,Cr,Al)_2O_3$, which permits a wide range in the chromium content of the pure mineral. The partial analyses (table 11, page 169) of the Red Lodge ores and cleaned chromite show a wide variation of chromic-oxide content and of the chromium-iron ratio.

A complete analysis of a chromite concentrate, obtained from an ore specimen from the Gallon Jug No. 4 claim, is given below. The chromite falls in the "aluminian chromite" field in the classification proposed by Stevens.21/

Complete analysis of chromite concentrate from the Gallon Jug No. 4 claim. [R. E. Stevens and M. K. Carron, analysts]

	Percent		Percent
Cr_2O_3	50.64	NiO	0.08
Al_2O_3	11.57	V_2O_3	Trace
*Fe_2O_3	8.30	SiO_2	.20
*FeO	20.50	H_2O+	None
MgO	8.16	H_2O-	.08
MnO	.46	P_2O_5	.01
TiO_2	.14	S	None
CaO	.04		
		Total	100.18

*Calculated from total iron to give a 1:1 ratio of RO/R_2O_3.

Most of the cleaned chromite concentrates and ores listed in table 11 contain a small quantity of magnetite. Microscopic examination of polished sections of the ores shows that magnetite forms considerably less than 1 percent of all the specimens except one from the Four Chromes claim (HJ-34-42), which contained perhaps 2 or 3 percent. The mode of occurrence of the magnetite is shown in photomicrographs a and b on plate 60. The specimen with the highest iron content and lowest Cr:Fe ratio (HJ-81-42) is strongly magnetic, but microscopic examination reveals scarcely a trace of magnetite, and after 3 hours in concentrated HCl, which attacks magnetite, the mineral was completely untouched. So far as could be determined by microscopic methods, this chromite is quite as homogeneous as those with higher chrome content; the magnetism and high iron content are properties of the chromite itself and not due to admixture with magnetite or any other mineral. The mineral does not appear to be zoned. Stephenson,22/ as a result of his studies of somewhat similar but higher iron chromite from Casper, Wyo., found that the outer parts of grains of the most highly magnetic and iron-rich chromite were etched by concentrated HCl. He concluded that these outer zones were

21/ Stevens, R. E., Composition of some chromites of the Western Hemisphere: Am. Mineralogist, vol. 29, pp. 1-34, 1944.

22/ Stephenson, H. K., Op. cit.

composed of chromite containing more iron than the core and that the difference in composition was due to a peripheral, isomorphous replacement of an earlier chromite by a more iron-rich variety.

The analyses indicate that, in general, chromium and iron bear a complementary relation to each other. Increase in chromium content usually means a more or less proportionate decrease in iron content and vice versa, so that the total iron-chromium content remains approximately constant. This relation is shown graphically in figure 15.

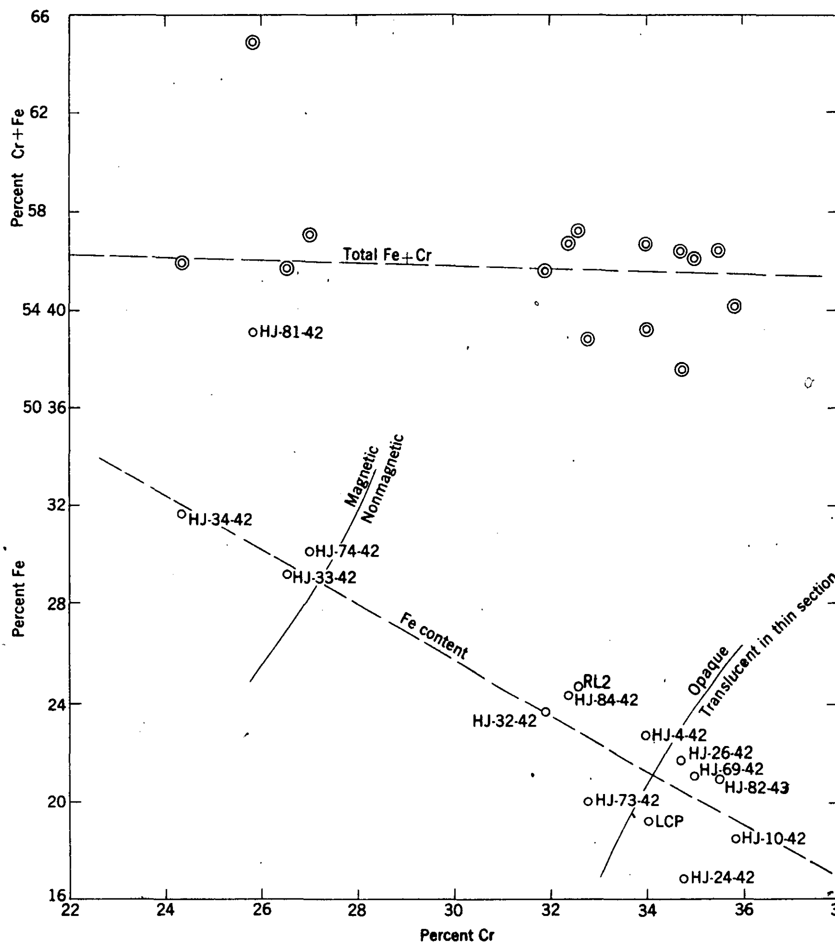


Figure 15. Graph showing chromium-iron relation in chromite from Red Lodge district. Data from analyses listed in table 11.

The variation in the percentage of chromium and iron in the chromite bears little or no relation to the degree of alteration shown by the minerals that form the matrix. The minerals that occur with chromite in the analyzed specimens are given in table 12. The translucency and the magnetic character of the chromite are also listed. From the lack of correlation between composition of the chromite and alteration of the groundmass, two tentative conclusions are drawn, as follows:

Table 11.—Partial analyses of cleaned chromite and chromite ore from the Red Lodge district, Montana. [R. E. Stevens and M. K. Carron, analysts]

Specimen	Cleaned chromite				Ore				
	Cr_2O_3	Cr	Fe	Ratio Cr/Fe	Cr_2O_3	Cr	Fe	Ratio Cr/Fe	Percent chromite in ore
HJ-10-42	52.33	35.81	18.47	1.94	35.46	...	...	...	67.8
HJ-82-43	51.84	35.49	21.00	1.69	35.30	24.17	15.06	1.60	68.1
HJ-69-42	51.15	34.98	21.17	1.65	36.78	25.16	16.47	1.53	71.9
HJ-24-42	50.77	34.75	16.86	2.06	39.98	...	...	...	78.8
HJ-26-42	50.64	34.68	21.74	1.60	36.50	25.0	16.40	1.52	72.0
LCP.....	49.71	34.02	19.26	1.77	34.25	...	...	...	69.0
HJ- 4-42	49.62	33.97	22.72	1.49	33.32	...	...	...	67.2
HJ-73-42	47.92	32.79	20.07	1.63	37.97	25.98	16.82	1.54	79.2
R. L.-2.	47.61	32.58	24.70	1.32	30.39	20.80	17.31	1.20	....
HJ-84-42	47.31	32.39	24.35	1.33	31.08	21.27	16.70	1.21	65.7
HJ-32-42	46.59	31.89	23.69	1.35	31.50	...	...	...	67.6
HJ-74-42	39.46	27.00	30.09	.90	27.62	18.90	20.61	.92	70.0
HJ-33-42	38.72	26.52	29.19	.91	25.22	...	...	...	65.2
HJ-81-42	37.73	25.82	39.05	.66	24.26	16.60	27.97	.59	64.2
HJ-34-42	35.68	24.36	31.61	.77	23.92	...	...	...	67.1
									Av. 69.6

HJ-10-42. Massive ore from center pit of Edsel claim, Silver Run Plateau.
HJ-82-43. Massive ore from most northerly pit on main ore body on Drill claim, Hellroaring Plateau.
HJ-69-42. Massive ore from main open pit on Highline workings, Line Creek Plateau.
HJ-24-42. Massive ore from North Star open pit, Hellroaring Plateau.
HJ-26-42. Massive ore from the discovery exposure of Gallon Jug No. 4 claim, Hellroaring Plateau.
LCP. Massive ore from main open pit on Highline workings, Line Creek Plateau.
HJ-4-42. Massive ore from west pit of Edsel claim, Silver Run Plateau.
HJ-73-42. Massive ore from discovery exposure of Gallon Jug No. 1 claim, Hellroaring Plateau.
R. L.-2. Massive ore from dump at upper west adit on Little Nell claims, Silver Run Plateau.
HJ-84-42. Massive ore from dump at upper west adit on Little Nell claims, Silver Run Plateau.
HJ-32-42. Massive ore from adit on Shovel claim, Hellroaring Plateau.
HJ-74-42. Massive ore from large pod exposed in pit near northeast end of Four Chromes No. 1 claim, Silver Run Plateau.
HJ-33-42. Massive ore from pit 150 feet west of creek on Four Chromes No. 1 claim, Silver Run Plateau.
HJ-81-42. Lower pit on east side of Chrome Creek, Little Nell claims, Silver Run Plateau. Magnetic.
HJ-34-42. Strongly magnetic nodular-appearing ore from discovery cut on Four Chromes claim, Silver Run Plateau.

1. The major variation in composition of the chromite is primary. The range in composition, though large, is no greater than that found in a number of other districts where metamorphism has not been a complicating factor. (See, for example, analyses of Cuban ores listed by Thayer.23/

2. Chromite, as a mineral, is more or less inert in the presence of granitic solutions. Some transfer of chromium is locally indicated by the presence of green chrome diopside and tremolite, but probably nowhere has this transfer of chromium been extensive enough to seriously modify the primary composition. The two highest-grade ores analyzed are in a matrix of chrome diopside and chrome tremolite. Determination of the chromic oxide content of chrome diopside from the Edsel claim indicates a Cr_2O_3 content of 0.66 percent (R. E. Stevens and M. K. Carron, analysts).

In thin section, the "massive" ore is seen to consist of closely spaced but not tightly packed grains, which probably average between 0.2 and 0.5 millimeters (65 to 30 mesh) in diameter. Shearing has reduced a considerable portion of the chromite to small fragments 0.1 millimeter in diameter (150 mesh) or less, although in a few specimens, grain diameters are as much as 1 millimeter (about 15 mesh). The chromite grains in some of the unsheared specimens frequently exhibit octahedral outlines, but more often the grains are rounded or irregular in shape. All the analyzed chromite concentrates that contained more than 34 percent chromium (about 49.7 percent Cr_2O_3) were dark-brown and translucent in thin section; those that contained less were opaque. Photomicrographs of thin sections of typical ores are shown on plate 60.

The common gangue minerals include serpentine (antigorite), chlorite, diopside, tremolite, muscovite, and talc. In general, they are the same minerals that make up the enclosing serpentine rock, though chlorite and muscovite are much more abundant between the grains of chromite than in the serpentine. Most of the ore that has been mined has had a gangue consisting mainly of serpentine with a little chlorite and talc. As all of these minerals are soft and of low specific gravity, grinding of the ore and gravity concentration of the chromite is relatively simple. Some of the chromite, however, is in a matrix consisting of diopside and tremolite, both of which are hard and of moderate specific gravity. Such ore requires more grinding in order to free the chromite and, consequently sliming losses are increased. Furthermore, once freed, this chromite is more difficult to separate by gravity concentration from the diopside and tremolite than it would be from a gangue of lower specific gravity. The minerals found in the ores, together with their composition, hardness, and specific gravity, are listed in table 13.

Practically all the ore contains a small quantity of magnetite which, in gravity milling, is concentrated with the chromite. Laboratory tests, made in the Geological Survey laboratories on two samples obtained from the U. S. Vanadium Corp. mill at Red Lodge, indicate that at least some of the magnetite could be removed by magnetic methods, although the increase in value of the concentrate would probably not justify the cost of installation and operation of the additional equipment. The results obtained from the test are tabulated on page 172.

23/ Thayer, T. P., op. cit., pp. 18, 19. (Bull. 935-A).

Table 12.—Table showing gangue minerals of analyzed ores, with chromic-oxide content, color in thin section, and relative magnetic permeability of corresponding chromite.

Specimen	Claim	Cr_2O_3 of chromite	Matrix*	Color of chromite in thin section	Magnetism**
HJ-10-42	Edsel.............	52.33	Diopside-tremolite...........	Dark brown...........	Nonmagnetic
HJ-82-43	Drill.............	51.84	Tremolite-diopside-garnet....	Dark brown to opaque.	Nonmagnetic
HJ-69-42	Highline..........	51.15	Serpentine-talc-chlorite.....	Dark brown...........	Nonmagnetic
HJ-24-42	North Star........	50.77	Serpentine-chlorite..........	Dark brown...........	Nonmagnetic
HJ-26-42	Gallon Jug No. 4..	50.64	Talc.........................	Dark brown to opaque.	Nonmagnetic
LCP.....	Highline..........	49.71	....	....	....
HJ-4-42.	Edsel.............	49.62	Tremolite-chlorite...........	Opaque...............	Nonmagnetic
HJ-73-42	Gallon Jug No. 1..	47.92	Tremolite-talc...............	Opaque...............	Nonmagnetic
RL-2....	Little Nell.......	47.61	Diopside-tremolite-talc-..... chlorite.	Opaque...............	Nonmagnetic
HJ-84-42	Little Nell.......	47.31	Chlorite-tremolite-diopside..	Opaque...............	Nonmagnetic
HJ-32-42	Shovel............	46.59	Tremolite-chlorite-diopside..	Opaque...............	Nonmagnetic
HJ-74-42	Four Chromes No. 1	39.46	Tremolite-olivine-serpentine-talc-enstatite.	Opaque...............	Magnetic
HJ-33-42	Four Chromes No. 1	38.72	Olivine-serpentine-enstatite-chlorite.	Opaque...............	Magnetic
HJ-81-42	Little Nell.......	37.73	Tremolite....................	Opaque...............	Magnetic
HJ-34-42	Four Chromes......	35.68	Serpentine-talc..............	Opaque...............	Magnetic

* Minerals listed in order of abundance.
** As determined with a cobalt-steel horseshoe magnet.

Table 13.—Minerals found in the ores, with chemical formula, hardness, and specific gravity of each. (Data from standard textbooks on mineralogy)

Mineral	Composition	Hardness	Sp. gr.
Common:			
Chromite.......	$(Fe,Mg)O,(Fe,Cr,Al)_2O_3$	5.5	4.1 -4.9
Serpentine (Antigorite).	$3MgO \cdot 2SiO_2 \cdot 2H_2O$	4 -5.5	2.5 -2.65
Diopside.......	$CaMg(SiO_3)_2$*	5 -6	3.2 -3.38
Tremolite......	$Ca_2Mg_5(OH)_2(Si_4O_{11})_2$*	5 -6	2.9 -3.2
Talc...........	$3MgO \cdot 4SiO_2 \cdot H_2O$	1 -1.5	2.7 -2.8
Chlorite (Penninite)..	$5MgO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 4H_2O$	2 -2.5	2.6 -2.85
Mica (Muscovite)..	$H_2KAl_3(SiO_4)_3$	2 -2.5	2.76-3
Magnetite......	$FeO \cdot Fe_2O_3$	5.5-6.5	5.17-5.18
Scarce:			
Olivine........	$(Mg,Fe)_2SiO_4$	6.5-7	3.3 -3.6
Garnet (Uvarovite)..	$3CaO \cdot Cr_2O_3 \cdot 3SiO_2$	7.5	3.41-3.52
Enstatite......	$MgSiO_3$	5.5	3.1 -3.3
Pyrite.........	FeS_2	6 -6.5	4.95-5.10
Garnierite.....	$H_2(Ni,Mg)SiO_4$ + water	Soft	2.3 -2.8

* Contains a small quantity of chromium.

Uvarovite, the green chrome garnet, is present in moderate quantity in the ore from the Drill and the Edsel claims but in general is scarce. Coatings of garnierite, a green, nickel-bearing silicate, were found on joint surfaces in the Line Creek, Pick, and North Star workings. Pyrite, the only sulfide recognized, is present in most specimens but only in minute quantities.

Results of laboratory test on chromite concentrates* from the Red Lodge mill of the U. S. Vanadium Corp. [M. K. Carron and R. E. Stevens, analysts]

	Cr_2O_3	Cr	Fe	Cr:Fe
Table concentrate:				
As received......................	38.97	26.68	18.81	1.42
Magnetic fraction (1.16 percent).	23.27	15.23	48.88	.31
Nonmagnetic fraction............	39.22	26.83	18.74	1.43
Jig concentrate:				
As received......................	45.65	31.23	22.83	1.37
Magnetic fraction (0.99 percent).	22.07	15.09	53.78	.28
Nonmagnetic fraction............	46.72	31.98	22.66	1.41

* At the time the samples were taken, most of the ore in the mill had been mined from the Highline claims on Line Creek Plateau.

Structure and form

The chromite is found in lenses ranging in size from those containing a few pounds of ore to those containing 35,000 tons or more. Most of the ore bodies consist of closely spaced, massive blocks of ore separated by highly sheared serpentine, though a few are massive throughout. The contacts of some of the ore bodies with the serpentine host rock are gradational, but most are sharply defined. Where the contacts are gradational, the chromite in the border zone is generally coarser-grained than that near the center of the ore body. Primary banding is not common, having been observed at only three places—in the North Star open pit, in the Gallon Jug discovery pit, and in the center pit on the Edsel claim. Ore from the Four Chromes claim shows a poorly developed nodular structure.

The pods generally show a divergence in both strike and dip with that of the enclosing serpentine masses. This divergence rarely exceeds 35° for the larger pods. Except at the Gallon Jug No. 4 claim, where relations have been confused by cross-cutting granite and by landslipping, the strike of the larger ore bodies on Hellroaring Plateau makes a clockwise angle of 15° to 35° with the strike of the serpentine. This consistency of angular divergence over a considerable area may be due to rotation of the brittle masses of ore during regional deformation, while the more plastic serpentine was being sheared parallel to its contacts.

Origin and localization

The chromite is clearly of magmatic origin, and its formation was essentially contemporaneous with that of the enclosing serpentine rock. This is indicated by complete limitation of chromite to serpentine bodies, by the occurrence of disseminated grains of chromite as a pyrogenic mineral throughout the serpentine, and by the fact that the minerals that form the matrix of the chromite are identical with those that make up the enclosing serpentine. The mode of concentration of the chromite into ore bodies, however, is far from being clearly understood. This is particularly true for massive pods with sharp contacts.

The lack of correlation between the size of the ore bodies and the size of the enclosing serpentine, together with the pod-like form and the sharpness of the contacts, militates against a concept of simple separation from the immediately adjacent igneous rock. Emplacement of the ore before final consolidation of the serpentine is indicated by narrow dikelets of unsheared serpentine cross-cutting banded ore at the North Star ore body.

These considerations lead the writer to the conclusion, shared by Thayer,24/ Stockwell,25/ and others, that though the ultramafic rock (in this case, serpentine) can be considered the ultimate source of the chromite, the actual separation of a chromite-rich phase took place at depth, and the present observed distribution of ore is the result of essentially

24/ Thayer, T. P., op. cit., p. 27.
25/ Stockwell, C. H., Chromite deposits of the eastern Townships, Quebec: Canadian Inst. Min. Metallurgy Bull. 382, Feb., 1944.

contemporaneous intrusion of chromite-rich and chromite-poor fractions of the original ultramafic magma. Thayer has suggested that the bodies of massive ore were carried up as solid xenoliths; Stockwell believes that the chromite-rich fraction was a mobile crystal mush. Without attempting exhaustive discussion of these theories, it may be pointed out that the smooth, lenticular form of the Red Lodge ore bodies, though possibly due to later shearing, would seem to be inconsistent with a concept of xenolithic introduction, and the general absence of banding would seem to indicate that the ore bodies were not emplaced by flowage of magma containing suspended crystals of chromite. A third hypothesis, possibly only applicable to chromite in serpentine (as opposed to chromite in dunite or other rocks of low water content), is suggested here, namely that the chromite-rich fraction may have been predominantly liquid and immiscible with the serpentine magma. The ratio of chromite to gangue in the massive ore (see table 11) shows remarkably small variation. The amount of chromite in the 14 analyzed specimens of massive ore averages 70 percent, with a total range from 64 to 79 percent. This relatively constant amount of chromite might well be interpreted as indicating that the chromite-rich fraction was a magma of more or less fixed composition, which, upon crystallization, formed a rock with nearly constant proportions of chromite and serpentine.

The distribution of the chromite pods in the serpentine appears to be completely haphazard. Apparently the original dip length of the ore bodies was approximately equal to the strike length, so that partly eroded pods can be expected to extend, on the average, to a depth approximately equal to half the strike length. A sufficient number of pods has now been mined to indicate that this generalization is essentially correct. Doubtless many ore bodies occur at greater depths in the serpentine lenses as the known ore bodies are merely those that by chance have been eroded, but the possibility of discovering any except those immediately beneath the surface is small.

GEOPHYSICAL EXPLORATION FOR ORE

Three areas on Hellroaring Plateau and one on Line Creek Plateau were tested with an Askania vertical magnetometer by G. R. MacCarthy of the Geophysical Section of the Survey. Each of these areas was mapped on a grid, generally with stations at 20- or 25-foot intervals along traverse lines that were 100 feet apart and approximately normal to the general trend of the serpentine. The completed report on this investigation is not yet available but the general results may be briefly outlined. The preliminary study indicates that magnetic properties of the Red Lodge rocks and chromite ores are very similar to those at the Casper Mountain, Wyo., deposit, where considerable detailed geophysical work has been done.26/

The relative magnetic properties of the common rocks at Red Lodge, summarized below, show a wide range. In general, very high anomalies were recorded over known chromite ore bodies. Serpentine, because of its content of disseminated magnetite, yields moderate to high magnetic values, so fairly accurate delineation of contacts with most of its wall rocks can be made.

26/ Chromite deposits of Casper Mountain, Natrona County, Wyo.: U. S. Dept. Interior, Geol. Survey, press notice 4482, Sept. 14, 1942.

Diabase yields anomalies that are as high as those obtained over serpentine and chromite and which are distinguished only by a somewhat greater degree of polarity, as indicated by strong highs immediately adjacent to strong lows. The magnetite-rich lenses in the metamorphic rocks, though yielding extremely high magnetic values, are nearly everywhere far enough away from the chromite-bearing serpentine bodies so that they do not confuse interpretations of the serpentine or chromite relations.

Relative magnetic anomalies of common rocks in the Red Lodge chromite district

Low	Moderate	High	Very high
Granite Quartzite	Serpentine	Chromite Serpentine	Chromite Iron-rich metamorphic rocks
Amphibolite Porphyry		Diabase	Diabase

Hellroaring Plateau

Three magnetometer grids were surveyed on Hellroaring Plateau—one each at the Shovel, North Star-Drill, and Gallon Jug No. 2 areas.

The North Star-Drill area, in which the geology was mapped and reasonably well understood prior to geophysical work, was outlined as a more or less large-scale test to determine whether or not useful information could be obtained by use of the magnetometer. The results were quite positive and easily interpreted.

The two lenses of serpentine that were crossed by most of the traverse lines were registered as definite highs. A typical profile is shown in figure 16 with the geology along the same line of section shown beneath. Exceptionally high readings were obtained over the known ore bodies at the Drill and North Star pits, and a few very high readings, comparable to those obtained at the ore bodies, were registered in the 800-foot distance between the two.

A narrow strip near the adit on the Shovel claim was tested along short traverse lines that were spaced at 50-foot intervals and directed across the strike of the beds. Readings were taken at 25- or 50-foot intervals along the traverse lines. Local high values were obtained along a narrow belt for a distance of several hundred feet southwest along the strike from the adit, which would appear to indicate that a number of small serpentine lenses are concealed beneath the overburden.

A magnetic map was made on a 50-foot coordinate grid in the Gallon Jug No. 2 area. The geology here is complicated by a highly irregular system of diabase dikes, so that the results are difficult to interpret and few positive statements can be made. The magnetic readings indicate that either the chromite-bearing serpentine or the diabase that is exposed in the open pit workings, or both, continue to the west. The "nose" of metamorphic rock shown on the geologic map south of the open pits gave uniformly low anomalies, so it apparently does not contain serpentine.

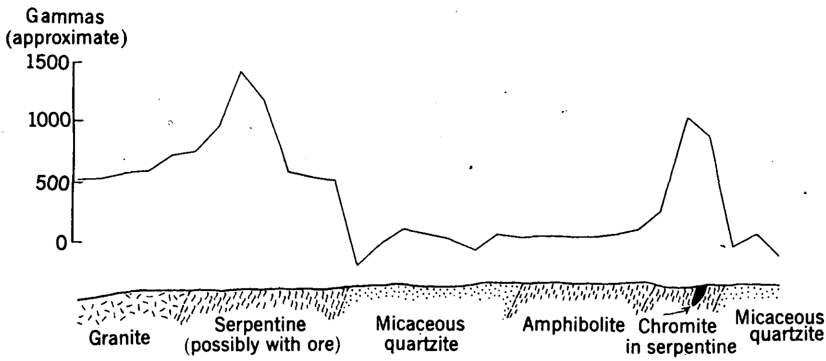


Figure 16. Magnetic profile and geologic cross section along traverse line "F." North Star magnetometer grid. Data from survey by G. R. MacCarthy, using Askania magnetometer.

Line Creek Plateau

A considerable area on the Highline claims on Line Creek Plateau, which included the known ore bodies, was tested with the magnetometer at 20-foot intervals along nearly north-south traverse lines spaced 100 feet apart (see pl. 57). Very high magnetic anomalies were recorded along each traverse line in the 400-foot interval between the eastern and western ore bodies. The zone of high anomaly continues for about 250 feet southeast of the eastern pit. Anomalies are uniformly low between the most westerly pit and the highway.

Value of the magnetometer in prospecting for chromite.—The results obtained with the magnetometer in the Red Lodge chromite district indicate that the instrument may be of real value in prospecting for this type of ore. Both the serpentine and chromite yield higher magnetic anomalies than the common igneous and metamorphic wall rocks, so that it may be possible to trace them even in covered areas. At several places, the magnetic and geologic pattern was found to be very similar to that found at the known ore bodies. As yet, however, none of these apparently favorable zones have been explored further, though it seems quite possible that drilling or trenching might reveal ore.

RESERVES

None of the Red Lodge ores meet the normal peacetime specifications for any type of chromite ore. They are much too high in iron for use in refractory brick, and too low in chromium for chemical or metallurgical purposes. A comparison of the Red Lodge ores with the 1940 Metals Reserve Company specifications for metallurgical chromite is given below:

	Cr_2O_3	Cr:Fe
Red Lodge ores (massive)...	24 to 40 percent	0.6:1 to 1.8:1
1940 Metals Reserve specifications.	28 percent minimum	3:1 minimum

The Metals Reserve specifications for 1940 also required that the ore be able to pass through a 6-inch screen and that not more than 10 percent be able to pass a ½-inch screen. Even if mill concentrates were acceptable, the experience of the U. S. Vanadium Corporation at Red Lodge indicates that the best product obtainable from the Red Lodge ores by gravity concentration would contain less than 45 percent Cr_2O_3 with a chrome-iron ratio of about 1.6:1. However, in 1941 and 1942, when the imports of high-grade chromite were largely cut off, it was found possible to utilize Red Lodge ore by mixing it with stockpiled foreign chromite so as to obtain a satisfactory furnace charge. The concentrates were made into briquets and used in similar fashion.

Accurate estimation of reserves in the Red Lodge district is difficult because of the podlike form of the ore bodies, but at best the tonnage available is small and there is little hope of large or long-continued production, even under wartime economic conditions. However, as most of the ore bodies can be worked by open-cut methods and are now accessible by road, immediate production is possible with but a small expenditure of equipment and manpower.

The following estimates of probable reserves (table 14) in partly mined deposits are based on measurements of surface dimensions and on drill-hole data obtained from the U. S. Vanadium Corporation. Tonnage estimates for deposits that have not been explored are based on surface dimensions and on the assumption that the depth will be, on the average, half of the exposed strike length. Mining operations in the district have been extensive enough to prove that this assumption is valid, although it is recognized that any single estimate may be considerably in error. Estimates are in long tons, and "ore" is here defined as rock that contains more than 20 percent Cr_2O_3. Reduction of the "cutoff" grade below 20 percent would not substantially increase the tonnage figures, as most of the ore bodies have relatively sharp contacts with the enclosing serpentine. In fact, if more care were exercised in mining and sorting, so that there was less dilution of the ore by waste from the pit walls or by barren serpentine from within the ore body, the overall grade of ore could probably be raised to 30 percent Cr_2O_3 without appreciably lowering the total output of chromite.

Since most of the ore in the larger known ore bodies has been taken out, the amount of ore that might ultimately be mined in the district is almost entirely dependent upon the discovery of deposits at present unknown. All the deposits that have been exploited, with the exception of those on the Highline claims, are on the exposed rims of the plateaus. These rims, in which outcrops are practically continuous, have been thoroughly prospected. Over large parts of the plateaus, however, exposures are scarce or absent, and at least a few ore bodies may be present beneath the mantle of disintegrated rock and morainal rubble that masks the rock surface. In general the ore seems to be more susceptible to disintegration than the serpentine and much of the country rock, and, since even the resistant rocks rarely crop out on the plateau surface, new ore bodies are not likely to be discovered by surface prospecting.

Table 14.—Tonnage mined and reserves of indicated ore, in long tons, remaining in individual deposits in the Red Lodge district. (All figures to the nearest 100 tons)

Plateau	Area or claim	Tonnage mined	Remaining reserves
Line Creek.....	Highline.................	24,100	5,000
Hellroaring....	North Star...............	34,800*	**
Do...........	Drill....................	1,700	1,000
Do...........	Gallon Jug No. 2 area....	1,300	800
Do...........	Gallon Jug No. 4.........	500	11,000
Do...........	Pick.....................	5,300	...
Do...........	Shovel...................	200	500
Silver Run.....	Four Chromes.............	...	300
Do...........	Little Nell..............	...	200
Do...........	Edsel....................	...	100
	Totals.................	67,900	18,900

* Includes an estimated 5,500 tons of milling ore containing 10 to 20 percent Cr_2O_3 on the North Star stockpile.

** No accurate data available but remaining tonnage probably negligible.

Even on the plateau surfaces, it seems probable that the general locations of most, if not all, of the main serpentine bodies are known, even though their exact outlines have not been established. Magnetic mapping in those areas where serpentine is poorly exposed or known only from float, followed by trenching or drilling in zones of high magnetic anomaly, might locate new ore bodies. The most favorable areas for prospecting have already been explored with the magnetometer, and as discussed earlier, several such zones of high anomaly have been indicated. These have not been tested further. Other more or less favorable areas which have not been mapped magnetically are as follows:

1. The area immediately west of the known ore bodies on the Gallon Jug No. 4 claim.
2. The northern part of the Gallon Jug No. 1 claim. (This would be an extension of the Gallon Jug No. 2 grid.)
3. The Pick claim.
   a. The covered area east of the known ore body.
   b. The area west of the known ore body, on the west side of the porphyry dike exposed in the open pit.

It is the writer's opinion, based on the approximate ratio of ore to serpentine in the well-explored parts of the district, that the total amount of ore that might be discovered in the covered areas will not exceed 100,000 tons.

DESCRIPTIONS OF DEPOSITS

All the deposits in the area except those on the Four Chromes claims on Silver Run Plateau were discovered and staked by the late M. E. Martin, and the Four Chromes group was claimed by Martin after the original owners permitted assessment work to lapse. At the present time, all claims on Line Creek and Hellroaring Plateaus, together with the Four Chromes and Edsel groups on Silver Run Plateau, are owned by Montana Chrome, Inc., and are under lease to the U. S. Vanadium Corp. None of the claims are patented. The Little Nell group is owned by the M. E. Martin estate, of Red Lodge.

Locations of claims on Hellroaring Plateau are shown in plate 61, and those on Line Creek Plateau in figure 17.

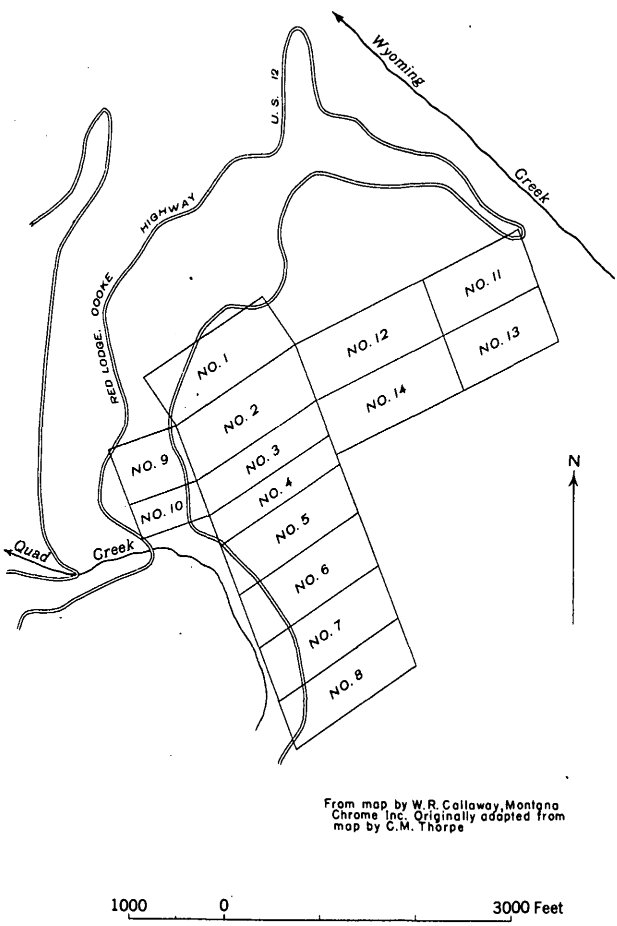


Figure 17. Map of the Highline claims, Line Creek Plateau.

Deposits on Hellroaring Plateau (see pl. 56)

Pick mine

The Pick mine (pl. 62), on the eastern slope of Hellroaring Plateau, was opened on a single lens of ore approximately 80 feet long and in places as much as 15 feet wide. The original development work, done by M. E. Martin, consisted of two short adits; these were later obliterated by a large open cut, from which much of the ore in the lens was taken. The remainder of the ore was recovered by stoping from a crosscut adit 50 feet lower in altitude. A long crosscut adit, 200 feet vertically below the bench and directly beneath the upper adit, was driven in 1933 by Montana Chrome, Inc. The adit intersected about 10 feet of serpentine 360 feet from the portal, but only a few inches of ore was encountered. A raise was driven a short distance but was soon abandoned.

The ore body, which is now regarded as completely mined out, consisted of numerous blocks of massive ore separated by highly sheared, talcose serpentine. It was cut off abruptly on the northwest by a porphyry dike about 50 feet wide. The ground beyond the dike is talus-covered, and no attempt has been made to find a segment of ore which may lie beyond the dike.

Between January and November of 1942, 5,343 tons of ore was mined from the Pick claim.

Shovel claim

The Shovel claim, on the east slope of Hellroaring Plateau, above the Pick claim, covers three known occurrences of ore. The discovery pit was sunk in a chromite-bearing serpentine inclusion in gabbro, about 100 feet northwest of the main serpentine zone. Large blocks of ore in the talus along the main serpentine zone prompted the U. S. Vanadium Corp. to drive a short adit (fig. 18) into the talus. Ore was encountered after about 25 feet of drifting, but was lost a short distance further in.

The ore, which in part is as much as 7 feet wide, is blocky, and is of relatively low grade despite its massive appearance (see table 11, p. 169). The matrix of the chromite comprises bright-green chrome tremolite, chrome diopside, and chlorite; numerous veinlets of these minerals cut the ore.

About 900 feet southeast of the adit, a small pile of ore at the mouth of a caved trench indicates another lens. The ore is practically identical in appearance with that in the adit. Between this occurrence and the adit, there are discontinuous patches of serpentine float.

North Star claim

The North Star claim covered a large lens of ore which cropped out on the eastern lip of Hellroaring Plateau, at a place where it overlooks the basin known locally as the "Pocket." This ore body, now practically mined out, was the largest known in the district. It yielded some 35,000 tons of ore, averaging approximately 25 percent Cr_2O_3, about half of which was shipped directly as crude lump. The ore from this deposit was relatively

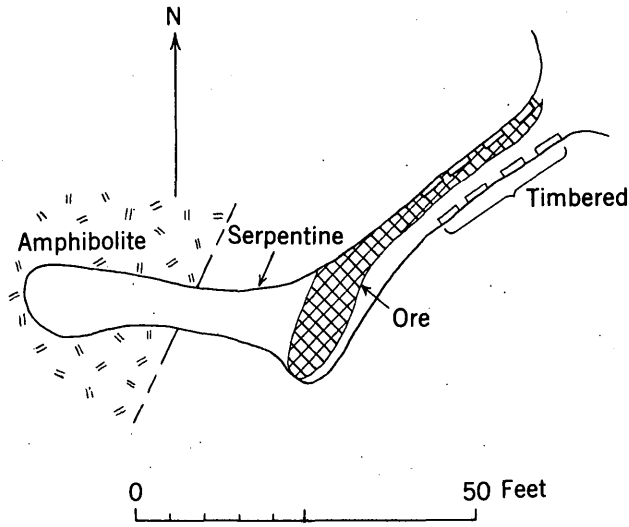


Figure 18. Plan of the Shovel adit.

high grade for the district; the massive ore contained 35 to 44 percent of Cr_2O_3 with a chrome-iron ratio of about 1.8:1, and a few carload shipments of lump ore assayed as high as 41 percent Cr_2O_3.

The ore body, like that at the Pick mine, consisted of blocks of massive ore separated by highly sheared and squeezed serpentine. In general a sheath of disseminated ore, locally several feet thick, surrounded the main lens. The chromite in this outer zone was coarser-grained than that in the more central parts of the ore body. Banded ore was observed in one place, but made up a very small percentage of the total. The lens maintained an average width of about 40 feet and a minable length of about 150 feet. It dipped steeply to the south; the east end was nearly vertical. The position of the lens at two successive levels is shown in figure 19. Approximately 11,000 tons of crude lump ore and several thousand tons of "milling-grade" ore was mined in 1943 from that part of the ore body below the lower profile shown in figure 19. The crude lump was shipped directly and the milling-grade ore, which probably contains 15 to 20 percent Cr_2O_3, was stockpiled at the mine.

In the upper levels, the western end of the ore body was cut off from the main part by a fault striking N. 5° W. and dipping 75° E. The horizontal offset of this fault, as indicated by the displaced serpentine contacts, is about 20 feet, but the upper part of the ore body, probably because of recent slumping, showed a greater apparent horizontal offset. Lower down, the fault lost its identity; the movement apparently has been taken up by general shearing of the serpentine and ore. The ore west of the fault did not prove to be minable except in selected places.

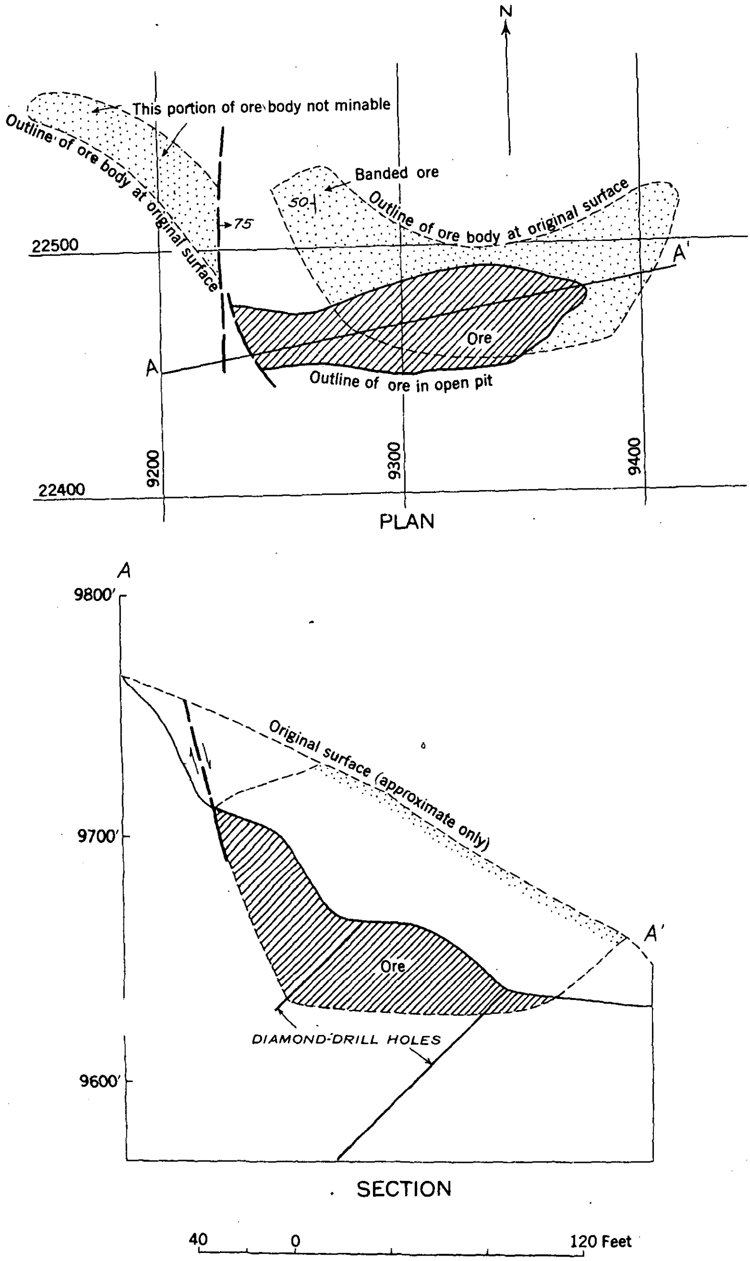


Figure 19. Successive plans and profiles of the North Star ore body.

The deposit was mined from a series of benches in a large open pit, being ideally situated topographically for this type of operation. The proportion of shipping ore increased with depth, for much of the higher-grade ore near the surface had disintegrated to chromite "sand," which did not meet the physical requirements for crude lump ore.

The chromite was in a matrix consisting mainly of antigorite serpentine, with minor quantities of olivine, chlorite, and muscovite mica. A narrow, highly irregular pegmatite dike cut the ore body; its contacts with the serpentine were generally marked by masses of chrome tremolite and biotite.

Gallon Jug claim

The Gallon Jug claim lies immediately north of the North Star claim and likewise covers ore that crops out on the plateau rim. The ore is contained in serpentine occupying a higher stratigraphic position than that at the North Star.

The deposit, which is snow-covered until mid-August, is exposed in a single small pit. A lens of banded and massive ore about 6 feet wide has been uncovered for a strike length of 10 feet, but its continuation in either direction along the strike could not be observed because of snow and talus. A bulldozer scraping 50 feet to the west did not reveal any ore.

Drill claim

Ore is exposed in two places on the Drill claim. The main deposit is in serpentine continuous with that at the North Star. Examination prior to mining showed an elongate lens of ore, extending about 160 feet horizontally and 100 feet vertically, exposed in the northern rim of the plateau. The average width of the ore was between 5 and 10 feet, as shown in the outcrops and in several small trenches. Between July and October 1942, 1,691 tons of ore was mined from the southern tip of the lens by open cut, but further mining and drilling indicated that the lens extended only to a shallow depth, and that the plunge of the ore body was nearly parallel to the topographic slope. The ore is hard, compact, and massive, and is distinctive in that it contains an appreciable quantity, possibly 3 to 4 percent, of uvarovite, the green chrome garnet.

A small amount of ore has been exposed in bulldozer scrapings in the serpentine near the northeastern tip of the plateau, about 400 feet east of the main lens. Several thin pods, none of which were more than 18 inches wide, have been trenched, but appear to have no productive possibilities.

Gallon Jug No. 1 claim

Ore is exposed at two places on the Gallon Jug No. 1 claim, in serpentine bodies that occupy different stratigraphic horizons.

A small lens of ore near the road switchback in the west center of the claim was uncovered during the road building. On the surface, the lens is about 40 feet long and averages about 2 feet wide. Short drill holes indicated that the ore pinched out at a depth of less than 10 feet. A few tons of ore were loaded from the surface "sand."

A rather large pod of massive ore, 40 feet long and having a maximum width of 13 feet, is exposed near the southwestern corner of the claim. No development work has been done on it. The serpentine in which this pod occurs occupies a stratigraphic horizon near the top (west side) of the oldest micaceous quartzite bed, and was probably once a continuous lens several hundred feet long. This serpentine is now found in nearly a dozen segments, which have been separated by faulting, by pegmatite and granite intrusions, and by the intrusion of a complex mass of diabase.

Gallon Jug No. 2 claim

Chromite-bearing serpentine, separated from the serpentine of the Gallon Jug No. 1 by diabase, has been exposed in the northwestern corner of the Gallon Jug No. 2 claim. The main ore body, which is locally as much as 8 feet wide, is cut into two segments by a diabase dike 30 feet wide. A number of deep pits and trenches have been sunk on or near this lens, from which 1,283 tons of ore has been extracted. The workings were abandoned in September 1942 because of the mining difficulties caused by the diabase. It is to be noted, however, that the dike dips 70° S., and there may be a substantial tonnage of ore below its footwall. A second lens of ore is exposed in the bulldozer scraping 60 feet north of the dike and crosses the boundary into the Boulder claim. This ore body is rather hard to measure accurately because of deep weathering, but it appears to be about 30 feet long and 2 or 3 feet wide.

The large lens of barren serpentine that crops out in the southwestern corner of the Boulder claim is stratigraphically higher than that described above, and, despite the fact that the two lenses are but 100 feet apart in one place, they are probably not connected.

Gallon Jug No. 4 claim

The Gallon Jug No. 4 claim is on the southern rim of Hellroaring Plateau near the headwaters of Lost Picket Creek. The ore body is on a large, complex landslip, which faces the creek from the south and which was doubtless due to oversteepening of the valley walls during regional glaciation. The landslip apparently is now stabilized. Plate 63 is a photograph of the area, taken from the porphyry hill north of the creek. The geologic map of the deposits (pl. 64) shows the rocks forming a complicated structural pattern, which has probably been made more complex by the landslip. The main serpentine lenses appear to be clustered near a synclinal roll in the metamorphic rocks, but the original relations have been largely obscured by the effects of the granite emplacement.

Three separate lenses of ore have been uncovered. The largest of these averages about 8 feet in width and is exposed for a strike length of 165 feet. Considerable chromite float is found for a distance of about 50 feet northwest of the

PHOTOGRAPH OF THE GALLON JUG NO. 4 AREA, FROM THE SOUTHEAST.

Chromite deposits on break in slope just below end of road; limit of landslide shown by scarp crossing switchback.

exposed ore, indicating that the ore body may have a minimum strike length of over 200 feet. About 15 feet north of this ore body, and in the same lens of serpentine, is a second, much smaller deposit. It is about 15 feet long and 3 feet wide. A third ore body, which crops out on the crest of the spur about 200 feet west of the main lens of ore, is about 5 feet wide and 15 feet long. The ore in all three of the lenses is massive and has a matrix consisting mainly of fine-grained talc.

These deposits yielded 529 tons of crude lump ore in 1943, and the amount of ore that remains seems to be considerable. Assuming a depth equal to approximately half the known strike length, the main ore body would be 165 feet long, 80 feet deep, and 8 feet wide, and might be expected to contain about 10,000 tons of ore. Recovery of a large part of this ore might prove difficult, however, as it is likely that the ore body is cut at many places in depth by granite, and may have been broken up by the post-glacial landslipping. The two smaller lenses may each contain about 500 tons of ore.

Other areas on Hellroaring Plateau

Float ore has been found on the Gallon Jug No. 3 claim, but so far as is known the bedrock source has not been located. Ore showings are reported to occur on the Bluebird No. 2 and the Rainbow No. 4 claims east of the Pick mine, but the writer did not examine them. Schafer 27/ describes the chromite on the Rainbow No. 4 as follows:

> "Chromite occurs on the Rainbow No. 4 claim in thin stringers 4 to 8 inches wide lying parallel to the schistosity of the surrounding serpentine and hornblende schist. It is exposed on a small outcrop which is surrounded by talus and soil. No attempt has been made to trace it by trenches or pits."

Serpentine is exposed in the cliffs facing the basin of Hellroaring Creek, but none of it has been shown to contain chromite.

Deposits on Line Creek Plateau

The only known deposits on Line Creek Plateau occur on its northern tip, between Wyoming Creek and the main fork of Rock Creek, and are covered by the Highline group of claims (fig. 17). Between October 1941 and June 1942, 23,964 tons of ore, most of it of milling grade, was mined from open pits on the Highline No. 2 claim. A large part of the ore was chromite "sand" taken from the deeply weathered outcrops of the ore bodies. The open-pit workings were abandoned by the U. S. Vanadium Corp. in June 1942, because of the increasing amount of waste rock that had to be handled as the pits were deepened. In 1943, the claims were subleased to Mr. N. W. Staley and Mr. Tony Rom, who reopened the main ore body from an inclined shaft. This operation yielded 126 tons of ore, which was sold to the U. S. Vanadium Corp.

The three ore bodies that have been discovered and worked (pl. 57) occur in a steeply dipping mass of serpentine at least

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27/ Schafer, P. A., Chromite deposits of Montana: Montana Bur. Mines and Geology Mem. 18, p. 28, 1937.

1,000 feet long and as much as 250 feet in greatest width. The country rock includes granite, granitic gneiss, and amphibolitic gneiss. The serpentine is cut by a northwest-dipping porphyry dike about 30 feet wide, which comes to an abrupt, blunt-nosed termination exposed in the pits. The largest and most westerly ore body is about 120 feet long and 20 feet in average width, and has been worked to a depth of approximately 70 feet. It strikes nearly at right angles to the trend of the enclosing serpentine, stands almost vertical, and apparently plunges to the south. Drilling data indicate that about 5,000 tons of ore remained below the floor of the pit, prior to the 1943 operations by Staley and Rom. The most northerly ore body, on the east side of the porphyry dike, was about 140 feet long and 6 feet wide. It has been worked to a depth of about 50 feet, and is believed to be mined out except for a few hundred tons.

The third lens of ore (now mined out) was completely separate from the two described above and lay about 400 feet to the southeast. It was about 70 feet long and 5 feet wide, and extended to a depth of about 50 feet.

Chromite float is said to have been found some distance southwest of the Highline workings, but as far as is known to the writer, no bedrock discoveries have been made.

Deposits on Silver Run Plateau

The Little Nell and Four Chromes groups of claims have been located on a belt of serpentine roof pendants that crosses Silver Run Plateau in a northeasterly direction, extending from the Lake Fork of Rock Creek (in sec. 36, T. 8 S., R. 18 E.) to the West Fork of Rock Creek (in sec. 11, T. 8 S., R. 19 E.). Only a small part of the belt is chromite-bearing. The Edsel group of claims has been staked out on the highly metamorphosed remnants of one or more serpentine lenses that crop out on the southern front of the plateau above Richel Lodge, in the NE¼ sec. 33, T. 8 S., R. 19 E.

The chromite deposits on this plateau are considered by the writer to have practically no economic possibilities.

Little Nell group

The claims making up the Little Nell group (see pl. 58) are in secs. 29, 30, 31, T. 8 S., R. 19 E., and extend in a northeasterly direction across Chrome Creek, Grass Creek, and the intervening areas of Silver Run Plateau. They are owned by the M. E. Martin estate. The only chromite deposits mapped or seen by the writer on this group of claims are those in sec. 31 adjacent to Chrome Creek. These deposits are about 4½ miles by steep trail from Richel Lodge on the main highway.

The geology of the area consists essentially of a narrow, elongate roof pendant made up largely of serpentine, separated from the granite on the east by an irregular body of porphyry at least 600 feet wide, and from the granite on the west by an irregular zone of gneissic rock and pegmatite. In a few places, small inclusions of serpentine are found in the granite on the east side of the porphyry. A fault, which displaces the serpentine on the south side of the creek about 350 feet to the west, is believed to be present beneath the channel of chrome Creek.

The chromite deposits, which are of very minor importance, have been explored by means of a number of pits and three short adits (fig. 20). The upper west adit opened up a lens of ore,

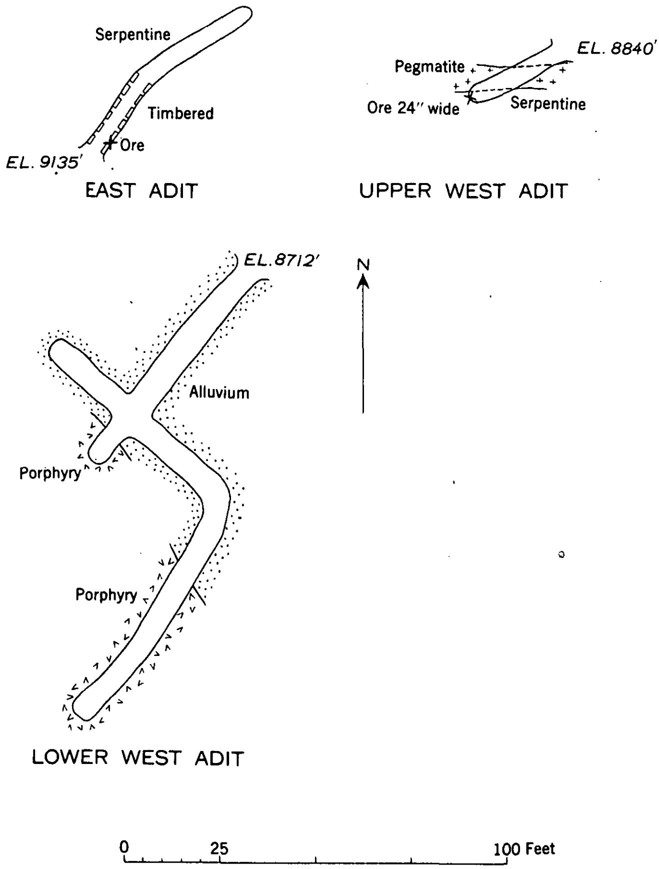

Figure 20. Underground workings on the Little Nell claims.

from which about 15 tons has been taken out and piled on the dump. The lens, about 2 feet wide, is exposed in the face of the drift, but no ore is present in the bottom, back, or sides. The lower west adit, begun in alluvial material, encountered nothing but porphyry. The upper east adit is almost entirely in serpentine, though a little ore is visible on the southeast wall about 10 feet in from the portal, and a very small amount has been piled on the dump.

Three pits have been dug in the serpentine between the east adit and the creek. The upper two pits are slumped, but, judging from the dump material, little if any ore was found. The lower pit exposes a face of low-grade, banded ore about 8 feet wide with a small proportion of massive chromite. An analysis of the massive ore (HJ-84-42 in table 11) shows it to be very high in iron. The chromite is in a matrix of tremolite with some talc.

A lens of ore is exposed in a small trench 300 feet northwest of the main serpentine zone, but it is only about 12 inches wide and its strike length is less than 10 feet.

Four Chromes group

The Four Chromes group of claims (see pl. 59) are on Silver Run Plateau, in secs. 21, 28, 29, T. 8 S., R. 19 E. The chromite deposits on the Four Chromes No. 1 claim were the first discovered in the Red Lodge district and were visited by Westgate as part of the chromite investigations by the Geological Survey during World War I.28/

The general geology and location of the ore deposits are shown in plate 59. The main serpentine body, which contains most of the ore uncovered in the area, is nearly half a mile long but hardly anywhere more than 100 feet wide. It is almost completely enclosed in granite, although in places small remnants of the original pre-granite country rock are preserved.

Pods of ore are found along a strike distance of about 2,000 feet and through a vertical distance of 300 feet. The largest ore body, which is 20 feet long and 12 feet wide, is exposed in a pit on the serpentine belt about 300 feet east of the creek. Except for this one pod, no deposit in this area is more than 8 feet long or 2½ feet wide, most being much smaller. Contrary to the general rule for the district, the chromite ore here is very resistant to weathering and forms actual croppings or a residual accumulation of massive boulders, where the adjacent country rock and serpentine have disintegrated to a sandy soil.

Twenty-three trenches and pits have been dug along the main serpentine belt. Most of this work was done by the Bureau of Mines in October 1942, though several of the larger pods of ore had been trenched at a prior date.

The chromite is of poor quality, being low in chromium and very high in iron (see table 11). Ore from the Four Chromes claim contains several percent of magnetite intergrown with the chromite grains.

Edsel group

The Edsel group of claims is on the southern front of Silver Run Plateau, between Snow Creek and Sheep Creek, at an elevation of about 8,000 feet in the NE¼ sec. 33, the NW¼ sec. 34, and the SE¼ sec. 28, T. 8 S., R. 19 E. The ore, exposed in two pits, is contained in a discontinuous belt of injection gneiss and granite in which only occasional inclusions of metamorphosed serpentine

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28/ Westgate, L. G., Deposits of chromite in Stillwater and Sweetgrass Counties, Mont.: U. S. Geol. Survey Bull. 725, pp. 83-84, 1921.

remain to indicate the original host rock of the chromite. The westernmost pit exposes a broken lens of ore, about 12 feet long and 4 feet wide, enclosed in granitic gneiss and pegmatite. The center (discovery) pit has been sunk in a lens of banded and massive ore 5 feet wide, the length of which cannot be more than 15 feet. A third pit, east of the two described, did not encounter ore.

Most if not all of the lenses very likely were originally small, but they probably were further diminished or broken up by the intrusive granite. Despite the high grade of the chromite (see table 11), the deposits on this group of claims offer little possibility of being even of minor economic importance.

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