5-20-1941

Some Chromite Deposits in Madison County, Montana

Russell H. W. Chadwick

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SOME CHROMITE DEPOSITS IN
MADISON COUNTY, MONTANA

By
Russell H. W. Chadwick

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Geological Engineering

MONTANA SCHOOL OF MINES
Butte, Montana
May 20, 1941
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CONTENTS

Abstract. ........................................... 1 
Introduction. ...................................... 1 
Chromite in general ................................ 3 
   The element chromium ............................ 3 
   The mineralogy of chromium .................... 4 
   The mineralogy of chromite .................... 5 
Occurrence and associations. ..................... 7 
Criteria for an origin ............................ 10 
Sources of chromite. .............................. 11 
Reserves .......................................... 13 
Strategic chromite ................................ 13 
Uses for chromium ................................ 15 
Value and grade of chromite ..................... 17 
Mining and benefaction ........................... 18 
Chromite in Montana ................................ 19 
   Origin of the Montana chromite ............... 22 
   Recent mining activity ......................... 22 
Chromite in Madison county ..................... 23 
   Location and accessibility .................... 23 
   Topography and Drainage ....................... 23 
   Historical geology ............................. 25 
   The Cherry creek series ....................... 26 
   The Horse creek area ......................... 27
CONTENTS (Cont'd)

Page

Metamorphic rocks ........................................... 28
Structure ...................................................... 29
The ore bodies ................................................ 30
Mineralogy ..................................................... 34
Genesis ........................................................ 34

General relations of the Horse creek ore ............ 34
Character of the ore .......................................... 36
Conclusions regarding the origin of the Horse
creek chromite .............................................. 37

Other Horse creek occurrences .......................... 39
The Silver Star occurrences ............................... 41
Geologic structure at the Aurora outcrop ............. 41
Mineralogy of the Aurora occurrence .................. 42
The Moonlight occurrence .................................. 42
The Ramahorn occurrence of magnetite ................. 43

Development .................................................. 44

Bibliography ................................................ 45

ILLUSTRATIONS

Plate I. Geologic map of the Stillwater-Red Lodge area,
Montana ....................................................... 21

II. Geologic map of the Silver Star-Sheridan area,
Montana ....................................................... 24

11
ILLUSTRATIONS (Cont'd)

Plates III, IV. Photomicrographs of thin-sections of
Horse creek specimens ........................................ 38

V, VI. Photomicrographs of polished sections of
Horse creek ore .................................................. 38
SOME CHROMITE DEPOSITS IN
MADISON COUNTY, MONTANA

By
Russell H. W. Chadwick

ABSTRACT
Chromite occurs in Madison County, Montana, in two areas, one
three miles southwest of Silver Star, the other five miles southeast
of Sheridan. The ore bodies are small, lenticular masses surrounded
by metamorphosed sedimentary rocks of the pre-Cambrian Cherry Creek
series. The ore was deposited from the hydrothermal solutions which
serpentinized the surrounding metamorphic host rocks. The intrusives
are Cherry Creek in age, and often show as high a degree of metamor-
phism as the enclosing gneisses. Chromite is the only ore mineral.
Its grade is low, even after concentration. The small size and low
grade of the deposits discourages further investigation.

INTRODUCTION
This paper is a thesis submitted in partial fulfillment of the
requirements for the degree of Bachelor of Science in Geological En-
gineering at the Montana School of Mines. The purpose of the work
involved in preparing the paper was, of course, to give the author
practice in the solution of one complete original problem in geology.
The writer's choice of a problem was based on a personal preference
for petrology and economic geology as branches of the science. Also,
the solution required both field and laboratory work, thus using all the professional tools developed thus far by the student-author.

The investigation of chromite at the present time, when it is classified as a strategic mineral, made the economic features of the problem more pertinent. An attempt was made to reach some conclusions as to the volume and grade of the ore present.

One occurrence in the area has been described in the literature, in an extremely short article by Jones*. Thus, there appeared a need for a more detailed study of all of the occurrences. In addition the conclusions of Jones as to origin appeared in error and in need of correction.

A precursory examination of the properties disallowed any detailed methods of examination. The small size of the deposits, and the low grade of the ore did not warrant more than sketch mapping. Sampling was done qualitatively; the whole examination pointed toward the study of the geologic features, and toward establishing a theory of genesis.

In the field the author spent the majority of his time in studying the relations of the chromite to the other basic rocks and to the surrounding metamorphic rocks. Due to the lack of development of the prospects, and to the invariable coverings by detrital material, a clear picture of these relations was not easily obtained. A large number of samples which appeared significant were cut wherever found.

Some mapping was done with plane table and alidade, although sketching with Brunton compass was found to be better suited to the work. The included geologic map is a compendium of the portions of

*Jones, Verner, Chromite Deposits near Sheridan, Montana, Econ. Geol., Vol. 26, No. 6, p. 625, 1931.
maps by Sahinen* and Tansley**.

Messrs. Ferey and Beynon of the school, and Mr. Ernest Miller of Sheridan gave the author assistance and companionship in the field.

A number of thin sections of the specimens obtained were prepared by the writer in the laboratories of the Geology Department of the school. All the microscopic examination and photography was carried out with the facilities of the department. The photomicrographs were prepared with the help of Dr. L. L. Sloss. The polished sections were briquetted and polished with the equipment of the Mineral Dressing Department and the assistance of Carlos Plenge, graduate student.

Dr. S. R. B. Cooke of the Mineral Dressing Department assisted the author in concentrating the ore. Mr. Hartzell directed the author in his analysis of the ore.

Miss Guinevere Crouch was extremely helpful in obtaining library references.

Particular thanks are due to Dr. E. S. Perry and Dr. G. F. Seager of the Geology Department for their criticism of the manuscript of this paper.

CHROMITE IN GENERAL

The Element Chromium

The metal is never found in the free state, and it was first isolated in 1857. It falls in the oxygen group on the periodic table


along with Mo, W, and U. The atomic weight of chromium is 52.01; the valence is variable, with a maximum of six.

The value of the metal is due to both its distinctive chemical and physical properties. Crystallizing in the cubic system, chromium is brittle, hard, and has a specific gravity of 7.1. Its hardness is 9, its scratch hardness 2,000 (case-hardened steel = 1,950). The metal melts at 1,615° and boils at 2,200°. It resembles iron, but takes a brighter, whiter polish.

Chromium dissolves rapidly in hot concentrated hydrochloric and sulphuric acids. It is unaffected by air, oxygen, and chlorine up to temperatures of 300°. It also resists the corrosive action of salt water, hydrogen sulphide, sulphur (in rubber and oil), organic acids, ammonia, molten zinc and cadmium in the electromotive series. Its compounds are colored; the soluble ones are very poisonous.

Chromium may be prepared by one of four methods. These are:

1. Reduction of Cr₂O₃ in the electric furnace.
   \[ \text{FeO} \cdot \text{Cr₂O₃} + 4\text{C} \rightarrow 2\text{Cr} + \text{Fe} + 4\text{CO} \]

2. Reduction of Cr₂O₃ with Mg or Al by thermic process.
   \[ \text{Cr₂O₃} + 2\text{Al} \rightarrow 2\text{Cr} + \text{Al₂O₃} + 112,000 \text{ Cal.} \]

3. Reduction of CrCl₃ with K, Na, or Zn.

4. Electrolysis of solutions of Cr compounds, usually chromic acid.

The Mineralogy of Chromium

Chroma (Cr₂O₃) constitutes about 0.05% of the lithosphere, generally as chromite in the basic igneous rocks. However, Dana lists the following naturally occurring chromium minerals:
Molecular Composition

<table>
<thead>
<tr>
<th>Name</th>
<th>Molecular Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromite</td>
<td>FeO·Cr₂O₃</td>
</tr>
<tr>
<td>Daubreelite</td>
<td>FeS·Cr₂S₃</td>
</tr>
<tr>
<td>Uvarovite</td>
<td>Ca₃Cr₂(SiO₄)₃</td>
</tr>
<tr>
<td>Crocoite</td>
<td>PbCrO₄</td>
</tr>
<tr>
<td>Stichite</td>
<td>MgCO₃·2Mg(OH)₂·2Cr(OH)₃·4H₂O</td>
</tr>
<tr>
<td>Phoenicochroite</td>
<td>Pb·Arsenic-Chromate</td>
</tr>
<tr>
<td>Bellite</td>
<td>Ca-Idio-Chromate</td>
</tr>
<tr>
<td>Dietzelte</td>
<td>2(Pb,Cu)CrO₄·(Pb,Cu)₃P₂O₈</td>
</tr>
<tr>
<td>Uauquetinite</td>
<td>Hydrous Cr sulphate</td>
</tr>
<tr>
<td>Redingtonite</td>
<td>Cr-Fe-sulphate</td>
</tr>
<tr>
<td>Knoxville</td>
<td></td>
</tr>
</tbody>
</table>

Of the above minerals, all are rare with the exception of chromite.

Daubreelite the sulphide, is sometimes found in meteorites; crocoite generally occurs as an alteration product of galena.

The Mineralogy of Chromite

The spinel group of minerals has the general formula R'°R''₂O₃. All of the group crystallize in the isometric system, generally as octahedrons. The minerals are hard; those with non-metallic lustre have a hardness of 7.5-8; those of sub-metallic lustre have a hardness of 5.5-6.5. A list of the more common spinels and their theoretical formulas follows:

1) Spinel
   Pleonaste  MgO·Al₂O₃
   Picotite   (Mg,Fe)O·(Al,Fe)₂O₃

2) Hercynite
   Chromohercynite FeO·Al₂O₃

3) Gahnite   ZnO·Al₂O₃

4) Magnetite FeO·Fe₂O₃

5) Franklinite (Fe₉Mn)O·(Fe₉Mn)₂O₃

6) Chromite  FeO·Cr₂O₃

Rarely, if ever, are these compositions encountered in nature.
In the grouping R"O may be found varying amounts of Mg, Fe, Zn, Mn,
and in the grouping R"2O₃ different percentages of Al, Fe, Cr, Mn.
Then between the various spinels of the above list are numerous others
of gradational compositions. The names given to those containing chro-
mium are here listed with some average analyses:

<table>
<thead>
<tr>
<th>Name</th>
<th>FeO·Cr₂O₃</th>
<th>FeO</th>
<th>MgO</th>
<th>Al₂O₃</th>
<th>Cr₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chrompicotite</td>
<td>(Fe,MgO·(Cr,Al)₂O₃</td>
<td>18.01</td>
<td>14.08</td>
<td>12.13</td>
<td>56.54</td>
</tr>
<tr>
<td>Magnesiochromite</td>
<td>(Mg,Fe)O·(Cr,Al)₂O₃</td>
<td>15.30</td>
<td>14.00</td>
<td>29.92</td>
<td>40.78</td>
</tr>
<tr>
<td>Mitchellite</td>
<td>(Mg,Fe)O·(Al,Cr)₂O₃</td>
<td>15.19</td>
<td>17.31</td>
<td>29.28</td>
<td>39.95</td>
</tr>
<tr>
<td>Chromchercynite</td>
<td>FeO·(Al,Cr)₂O₃</td>
<td>27.00</td>
<td>5.33</td>
<td>27.12</td>
<td>38.64</td>
</tr>
<tr>
<td>Picotite</td>
<td>(Fe,Mg)O·(Al,Cr)₂O₃</td>
<td>24.90</td>
<td>10.30</td>
<td>56.00</td>
<td>8.00</td>
</tr>
</tbody>
</table>

Pure chromite is known only in meteorites. In this paper the word
 chromite will refer to a chrome spinel containing a fair percentage
(perhaps 25%) of Cr₂O₃.

The general properties of chromite follow:

1. Isometric, generally octahedrons.
2. Fine granular to compact.
3. Brittle, uneven fracture, hardness 5.5.
5. Lustre sub-metallic, color iron black-brownish black; brown streak, opaque.
6. Sometimes feebly magnetic.
7. Infusible, chrome-green color with borax bead.
8. Not attacked by acids, fusible with Na₂SO₄.

In the field chromite is easily confused with magnetite. The
brown streak and weak magnetism are used to distinguish chromite.
Singewald* warns against a rapid judgment of chromite ore in the field on the basis of magnetism alone. He found that a non-magnetic black spinel could be so high in iron and alumina as to contain only 7% of Cr$_2$O$_3$. By the same token a spinel containing 51% Cr$_2$O$_3$ proved to be magnetic in spite of the low iron content due to a lack of alumina. Only a chemical analysis is trustworthy where any doubt exists.

In laboratory analyses, the author ran the ore solely for chromium. The method used was that of Scott** requiring a fusion with Na$_2$CO$_3$ and Na$_2$S$_2$ in an iron crucible. After fusion, the material is dissolved in water; the caustic is removed with ammonium carbonate, and the material filtered. The filtrate is made acid with H$_2$SO$_4$, titrated with 1/5 N Mohr's salt. Back titration with permanganate gives the end point.

Apparently the only test in microscopic examination to distinguish chromite from magnetite is a brown color of the thin translucent edges of fractured grains of chromite. Etch tests are negative without exception.

Occurrence and Associations

Chromite does occur in meteorites, and in sands closely associated with the source rock. The usual statement is, however, that chromite is found in ultrabasic rocks or in the alteration products derived from them. These ultrabasics are peridotites, pyroxenites, and norites whose normal composition includes up to one percent of Cr$_2$O$_3$. (Peri-

---

*Singewald, J. T., Maryland Sand Chrome Ore, Econ. Geol., Vol. 14, p. 189, 1919.
dotite = .33 aver; pyroxenite = .27 aver.*  Where chromite is concentrated, the most commonly found gangue material is serpentine, derived from the alteration of one of the above.

The ore bodies are generally of one of the following forms:

1) Pipe-like, as in the Wood Mine of Pennsylvania.
2) Sill-like, as in the Stillwater or Bushveld complexes.
3) Schlieren, or ill defined streaks in the country rock.
4) Pockets or lenses, as in North Carolina, Oregon and Northern California.

In the past it was thought that all chromite deposits were formed by an early crystallization of the mineral probably followed by gravity differentiation. Vogt**, in 1893 classed chromite as a magmatic product, grouping it with the titaniferous magnetites, in the Gabbro of Norway. However, the abundance of field evidence shows the smaller bodies to be intrusive into the surrounding rocks. Microscopically, many chromite ores contain few if any euhedral crystals, the material being found interstitial to the silicates.

---

*Clarke, F. W., The Data of Geochemistry, U. S. G. S. Bull. 770.
To explain the late position of chromite in the sequence of formation some investigators turn to a remelting at depth of sunken crystals, and later injection of the chrome-rich liquid. Bowen regards remelting temperatures as too high, and proposes instead a gradual enrichment of the chrome content of early-formed spinel in continual reaction with a magma of basaltic composition. In this process, olivine and anorthite may react with the liquid to form pyroxene and the ever-more-chrome-rich spinelled.

Fisher* recognizes three periods of crystallization of chromite:
(1) The early magmatic period, in which chromite may be the first mineral crystallized or contemporaneous with olivine. (2) Chromite of the late magmatic period, interstitial and in cracks in the groundmass silicates, or replacing these pyrogenic minerals. (3) Chromite of the

hydrothermal stage, due to the action of heated solutions on the chromite already crystalline as well as on that remaining in the parent magma. These same solutions cause the serpentinization of the silicates. Fisher says that most of the chromite found belongs to the late magmatic stage. Other recent writers have likewise noted the evidence for an origin other than an early pyrogenic one.

Criteria For An Origin

In the field the size, form, and relations to the surrounding rocks of an ore body may be indicative of its mode of formation. Thus large, pseudostratified bodies such as the Bushveld complex suggest differentiation "in situ". Contrariwise, small plug-like or vein-like deposits with sharp boundaries suggest some sort of injection.

However, in the microscopic examination of chromite, certain criteria have been distinguished* as useful in establishing the sequence of mineralization.

1) Obicular texture—rounded chromite included in silicate grains in turn coated with chromite layers indicates two generations of minerals.

2) Chain structure—An accumulative pattern, the synneusis structure of Vogt, is composed of generally euhedral or subhedral crystals of chromite connected at their apices. The structure implies an early crystallization and later freedom to "swim together".

3) Silicate inclusions in chromite—indicating, of course, a late crystallization for the spinel.

4) Fracturing of the grains—settled euhedral crystals in fresh

*Sampson, E., May Chromite Crystallize Late? Econ. Geol., Vol. 24, p. 632, 1929.
rock would not likely be fractured as would those which were acted upon by the hydrothermal solutions causing serpentinization.

5) **Alteration of walls**—injected chromite should cause a greater alteration of the immediately adjacent walls of a band than of the material a short distance from the contact.

6) **Chromite veinlets**—stringers of chromite cutting the primary silicates is obvious evidence of a later injection.

7) **Corrosion of grains**—rounded and embayed chromite grains may indicate crystal settling or the action of hydrothermal solutions, but certainly not a late magmatic origin.

8) **Variation in grains**—Sampson described some microscopic textures which required a complicated interpretation. Large irregular patches of chromite were surrounded by clouds of smaller chromite crystals. These, with small olivine crystals, were contained in large bronzite grains. Then, early olivine contained chromite poikilitically. The olivines were surrounded with late magmatic chromite. Reaction with the remaining liquid formed bronzite at the expense of the olivine.

Sources of Chromite

Chromite was first described in France. It was mined at Roros, Norway in 1820, but in 1827 the Reed mine, near Baltimore, Maryland, became the first important producer. Maryland and Pennsylvania supplied the few thousand tons of ore required by the world per year until about 1860 when the Turkish ores began to dominate the market. The Appalachian supply had become about exhausted by 1880 and mineral from Asia Minor was imported to supplement the small California production in supplying U. S. demands.
<table>
<thead>
<tr>
<th>YEAR</th>
<th>WORLD PRODUCTION (long tons)</th>
<th>U.S. PRODUCTION (long tons)</th>
<th>LEADING PRODUCERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>1830</td>
<td>Maryland</td>
<td>Penna.</td>
<td></td>
</tr>
<tr>
<td>1860</td>
<td>Turkey</td>
<td>Maryland</td>
<td></td>
</tr>
<tr>
<td>1880</td>
<td>Turkey</td>
<td>Calif.</td>
<td></td>
</tr>
<tr>
<td>1890</td>
<td>36,000</td>
<td>3,000</td>
<td>Turkey New Caled. U.S.</td>
</tr>
<tr>
<td>1900</td>
<td>50,000</td>
<td>100</td>
<td>Russia New Caled. Turkey</td>
</tr>
<tr>
<td>1910</td>
<td>119,000</td>
<td>9,000</td>
<td>Rhodesia New Caled. Russia</td>
</tr>
<tr>
<td>1915</td>
<td>158,000</td>
<td>4,000</td>
<td>New Cal. Rhodesia Russia</td>
</tr>
<tr>
<td>1918</td>
<td>325,000</td>
<td>85,000</td>
<td>U.S. India New Caled.</td>
</tr>
<tr>
<td>1920</td>
<td>235,000</td>
<td>3,000</td>
<td>New Cal. Rhodesia India</td>
</tr>
<tr>
<td>1925</td>
<td>303,000</td>
<td>500</td>
<td>Rhodesia India New Cal.</td>
</tr>
<tr>
<td>1930</td>
<td>552,000</td>
<td>81</td>
<td>Rhodesia Russia New Cal.</td>
</tr>
<tr>
<td>1935</td>
<td>793,000</td>
<td>523</td>
<td>Russia Turkey Rhodesia</td>
</tr>
<tr>
<td>1938</td>
<td>1,125,000</td>
<td>825</td>
<td>Turkey* Rhodesia So. Africa</td>
</tr>
<tr>
<td>1939</td>
<td></td>
<td>3,614</td>
<td></td>
</tr>
</tbody>
</table>

*Rhodesia = Southern Rhodesia

As may be seen on the accompanying table the great deposits of Southern Rhodesia, Turkey, Russia, South Africa, New Caledonia and India have all been leaders in world production since 1900. Russia has doubtless the greatest production today—from the deposits in the Ural Mountains. The Southern Rhodesian chromite occurs in pre-Archean schists in or near the Great Dyke of norite. The South African deposits lie in the great Bushveld complex. Greece, Yugoslavia, Japan, Cuba, and recently the Philippines, are also capable of considerable production.
In North America, deposits have been worked in the Kenai Peninsula of Alaska, Quebec in Canada, Washington, Oregon, California, Montana, Wyoming, Pennsylvania, Maryland, Georgia. Two thousand small and widely scattered deposits are known in the United States.

Among consumers the United States is by far the most important, utilizing about 50% of the world's production. Germany is the only other major consumer; Russia probably is becoming increasingly important.

Reserves

Fairly well outlined reserves of 20,000,000 tons of ore are available in Rhodesia, South Africa, and Turkey. In the U. S., low grade (84,000 tons of 42% average Cr$_2$O$_3$ produced in 1918) reserves amount to perhaps 1,000,000 tons.

In August, 1939, Congress appropriated $10,000,000 for the purchase of stock-piles of strategic minerals. Chromite was one of the four items which were to be given first priority. In addition, each year the U. S. Geological Survey is to receive $150,000, and the U. S. Bureau of Mines $350,000 for the purpose of surveying, drilling, and developing properties containing strategic minerals. Under this program, large underground chromite deposits near Casper, Wyoming, and Stillwater and Sweetgrass counties, Montana, have recently been outlined. These occurrences contain millions of tons of low-grade ore, requiring concentration or new metallurgical processes to be useful in the steel industry.

Strategic Chromite

Aside from its increased importance in the greater general steel production during wartime, chromium acquires some special duties.
Chromium-rich stainless steels are needed for hospital use, and for chemical-resisting containers. Armor plate and armor-piercing projectiles are made from the tough stainless steel. This non-corrosive material naturally performs a number of functions in navy material.

Dyes for olive drab cloth and certain leathers of army use contain chromates.

During 1917-1918 the demand for chromium increased fourfold; chromite having been previously used mainly for refractory purposes rather than in steel-making. Although there will be no such proportional rise in the world demand for the metal in this war, there will be a greatly increased demand. Now, to make the problem of chromite acute, the sources of enormous supply now necessary are distant, and transportation hazardous.

Unlike most metals most chromium is irrecoverable, once used. Chromium plate represents a complete loss of the metal as do chromium chemicals and chrome refractories. The alloys, ferrochrome, and the stainless steels are the only products from which the element may be recovered.

In 1939, U. S. imports of chromite were from the following sources:

<table>
<thead>
<tr>
<th>Source</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>37%</td>
</tr>
<tr>
<td>Cuba</td>
<td>21%</td>
</tr>
<tr>
<td>Turkey</td>
<td>5%</td>
</tr>
<tr>
<td>New Caledonia</td>
<td>5%</td>
</tr>
<tr>
<td>Greece</td>
<td>3%</td>
</tr>
<tr>
<td>Other countries</td>
<td>29%</td>
</tr>
</tbody>
</table>

Of this trade, U. S. capital controlled the low grade Cuban production and some of that in New Caledonia, Rhodesia, and the Phili-
ppines. The Philippines are becoming an extremely important producer of both high and low grade ores, ranking fourth or fifth in 1939. Of the world’s production, about two-thirds is controlled by British capital, and about half of the deposits are in British Territory.

Uses for Chromium

The functions of the metal may be divided into three groups: chemical, refractory and metallurgical. In 1927, U. S. consumption was distributed among the three above groups as follows: 13%, 41%, 46%.

1) Metallurgical Functions.

a) Pure chromium is ductile, has a high melting point, is resistant to corrosion. Uses for the metal may be developed.

b) Chromium as a non-ferrous alloy gives strength while not affecting electrical conductivity.

c) Ferro-chromium is used to introduce chromium during alloy steel making. High-Carbon Ferrochrome (66-71% Cr, 4% C) is cheaply made in the blast furnace, is used to make hard alloy steels. Low-Carbon Ferrochrome is expensively made in the electric furnace, is used in making stainless steels.

d) Chromium in cast iron refines the grain, increases wear resistance, increases strength and hardness by the formation of carbides.

e) Chromium steels. These important materials are separated into various grades as follows:

(1) 3% & less of Cr is used in making bearings, steel rolls, magnets, grinding balls, machine parts, metal-working tools, rails and in strong, lightweight structural
steels (with Ni, Mo, V).

(2) 3-12% Cr is used in making anti-corrosive tubing (with Ti, Ch) in engine valves (with Si), in high speed steel (with W, V).

(3) 12-20% Cr is the range of the stainless steels which are strong, ductile and non-corrosive. With the addition of Ni, Mo, Cu all manner of properties are available. The 18 (Cr)-8(Ni) stainless steel is widely used. Other than the familiar household uses, stainless steels are becoming increasingly popular in architectural decoration. The greatest use of these products is, however, in the food industries, in oil cracking in paper milling, in laundry work, as well as in autos, ships, trains and planes.

(4) 20% Cr alloys are used in furnaces, pressure machines, mine pumps, calcine bins. They are highly resistant to sulphur gasses.

Many other chromium alloys will doubtless be developed, utilizing the corrosion-resisting and strengthened properties of the metal.

2) Refractory functions.

a) Chromite bricks are very resistant to corrosion by metals, slags, and vapors. For this reason they are used at the slag line of basic open hearth furnaces. Their neutral character makes the bricks essential in separating acid from basic refractories in a furnace using both.

b) Crushed chromite and chromite cements have special refractory uses.
3) Chemical functions.

a) Dyes and pigments of red, green, yellow, khaki, and brown are produced as a number of chromium compounds.

b) CrO$_3$ or chromic acid anhydride is the chief constituent of chromium electroplating baths. Chromium plate is widely used for three reasons: (1) its ability to take a high, decorative polish, (2) its resistance to corrosion, (3) its hardness and resistance to wear. Chromium plating is used on automobiles, household articles, in oil cracking plants, paper mills, on tools and smooth rolls.

Value and Grade of Chromite

In general, chromite buyers are satisfied with statements of chrome and iron content, although sometimes silica and alumina percentages are demanded.

The steel ferro-alloy trades demand 45% Cr$_2$O$_3$ content with an Fe content not exceeding $1/3$ of the Cr$_2$O$_3$. Bonuses and deductions are made for favorable or unfavorable percentages of the two constituents.

The refractory makers require ores of a chrome content above about 35%, and containing less than 5-8% of silica. If the source of ore is near and the price low, these buyers may accept a slightly lower, but no bonus is given for ores of higher chrome content.

The chemical industries demand ore with a chromic acid content of 50% or better. Penalties and payments are made against materials slightly below or above the required content. Iron content is generally not considered.
In discussing the marketing of chromite, the dominant factor must be the high grade and cheap mining of the foreign deposits. Prices for chromite are quoted (cost, insurance, freight) at North Atlantic ports. The average price for the last 10 years has ranged from $16.12 per long ton in 1929 to $23.25 in 1939. In 1939, the low grade (33%) Cuban ores sold for $16.50 per long ton, while the high-grade ores (53%) of New Caledonia brought $37 per long ton.

The government, in purchasing chromite for its stock-piles lists the following specifications:

1) The ore must pass a 6-inch screen. No more than 10% may pass a ½-inch screen.
2) \( \text{Cr}_2\text{O}_3 \geq 48\% \text{ min}, \text{ Fe max } 1/3\% \text{ Cr content, S max } 0.50\%, P \text{ max } 0.20\% \).

Mining and Benefaction

Production of chromite in the United States has been in the past usually from small rich lenses or bands which were exposed at the surface. These high grade "spots" were easily gouged out by open pit methods. Mining costs are low in this sort of an operation, probably ranging around $1.00 per ton. When underground methods become necessary, the cost increases to around $5.00 per ton.

In both lensy and banded deposits the walls are distinct, and values easily determinable.

Subsequent to breaking of the ore, hand sorting is generally used to maintain grade. In most cases, this is as far as benefaction is carried. Where the grade is low (below 45%) and concentration must be effected, the following steps are generally taken:
1) The ore is crushed in a jaw crusher to permit easier handling (to $\frac{3}{8}$ inch perhaps).

2) The chromite grains are freed from the gangue (generally at about 35 mesh). Stage crushing in rolls will prevent the formation of too many slimes.

3) The material is sized by wet screening or by hydraulic classification.

4) The various sized products above 200 mesh are tabled separately; rougher and cleaner operations may be required in each case.

5) The 200 mesh product or slimes are concentrated on slime tables or vanners.

It is possible to substitute magnetic separation for 4) and 5), but hydraulic methods are cheaper and more easily used. Where magnetite grains occur as impurities in the concentrate, they may be removed by magnetic means.

CHROMITE IN MONTANA

Aside from the deposits in Madison County to be described, chromite occurs in two great areas in Montana. The Boulder-Stillwater area and the Red Lodge area have been studied at length by the Princeton Research Project*, by the Montana Bureau of Mines and Geology**, and by government*** and private surveys. The accompany-

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**Schafer, P. A., Chromite deposits in Montana, Montana Bureau of Mines and Geology, Memoir No. 18, 1937.

ing geologic map (Plate 2) shows the approximate location and relations of these deposits.

The writer here presents verbatim Schafer's summation of his description of the Stillwater complex deposits.

"The region is a high plateau cut deeply by transverse streams. It is readily accessible by car in but two localities, Boulder Valley and Stillwater Valley. Elsewhere pack trails lead up onto the plateau areas. A great differentiated igneous sheet of pre-Cambrian age has intruded metamorphic rocks, and later was tilted so that at present the general dip is northward, but the attitude of the sheet ranges from horizontal to vertical, and locally is even overturned, dipping as much as 30° southward. The basal differentiate is very basic igneous rock (bronzitite, harzburgite, dunite, and basic norite). Within the sheet is an apparently continuous band of chromite and chromite-bearing peridotite extending 27 miles, the full length of the sheet.

"The chromite-bearing material is composed of massive ore and disseminated (low-grade) ore occurring in juxtaposition. Combining the two classes of ore, the average exposed width is about four feet. Sufficient evidence is present to indicate that such a width may persist the entire 27 miles. However, lack of exposures in numerous areas preclude the possibility of considering the unexposed stretches as possible ore, however, they might be considered as "speculative ore". Present rough estimates indicate the probability of the presence of about 10,000,000 tons of possible ore and about 20,000,000 tons of speculative ore.

"The quality of the ore will vary according to the manner of mining, and milling. For ore containing between 35 and 40 percent Cr₂O₃, it would be necessary to sort carefully, and the above tonnage would be cut in less than half. If no sorting is done, the average quality would be about 20 percent Cr₂O₃ in the western half of the region and about 29 percent Cr₂O₃ in the eastern half.

"The estimated maximum grade that could be achieved by milling is about 45 percent Cr₂O₃. This figure was determined by calculating out the impurities in the ore. Kemp gives a similar figure obtained by concentrating the chromite. Roessler, in a mill test, obtained concentrates with 44.75 percent Cr₂O₃."
"From the standpoint of operation, the properties adjacent to the Boulder and Stillwater Rivers have a distinct advantage in that they can be worked all year around. However, at considerable cost the Benbow property might become an all-year producer. The altitude of the Eclipse tunnel, about 8,100 feet above sea level, is not so great as to preclude winter mining if the proper precautions are taken."

In general, the Red Lodge deposits may be correlated with those of the Stillwater complex as shown in Plate 1. However, the area is markedly different in detail of both geology and topography. The region is a plateau, reaching 9,000-10,000 feet above sea level. Steep-sided, glaciated valleys dissect the plateau to give a relief of 4,000 feet in places. The chromite exposures are scattered, and with one exception are located on the plateau, making them most inaccessible.

It is thought that the chromite-serpentine band represents a more highly metamorphosed narrower portion of the great sill that is the Stillwater complex. However, the Red Lodge deposits have undergone pre-Cambrian folding, faulting, and intrusion by granite which altered the sill and the surrounding metamorphics. Following Paleozoic and Mesozoic sedimentation, the region was again faulted and intruded by a number of dikes.

"The chromite always occurs in serpentine, or hornblendite derived from the further metamorphism of serpentine. The ore bodies appeared to be very lenticular, reaching widths of 20-30 feet in places. In length, a single body could seldom be traced for more than 200 feet. The ore is low grade with low \( \text{Cr}_2\text{O}_3 \) and high Fe content."

Origin of the Montana Chromite

The chromite bodies of the Stillwater complex gives evidence of having been formed at least in major part by gravity differentiation. The foot-wall of the main band is perfectly defined, and the ore is disseminated in the hanging wall. The continuity of the bands and their concordant relations with the sill as a whole is almost irrefutable evidence of differentiation "in situ".

The chromite is found enclosed in grains of olivine, bronzite, and plagioclase in some places, and in others is interstitial to the silicates, or even filling veinlets. Then, apparently both early and late magmatic and hydrothermal chromite are present. Local serpentinization around, and local lensing of the chromite bodies indicates some late metamorphic action affected parts of the bands.

The Red Lodge chromite lenses commonly contain the mineral as veinlets indicating, possibly, a recrystallization and injection of the chromite during late metamorphism.

Recent Mining Activity

During the past two years the Benbow and Moat properties in the vicinity of the Stillwater river have been surveyed by the U. S. Geological Survey and diamond-drilled by the U. S. Bureau of Mines. As the quantity of developed ore was sufficient, a large gravity concentration mill is to be built in the area in the near future. The Red Lodge deposits are by some observers considered to be too inaccessible, too small, and too iron-rich to be utilized just at present.
CHROMITE IN MADISON COUNTY

Location and Accessibility

Two general areas in Madison County in southwestern Montana were studied by the author. As shown in Plate II, the Horse Creek area lies four miles south and four miles east of Sheridan, Montana. The second area lies two miles south and two miles west of the town of Silver Star.

Silver Star is 39 miles southeast of Butte, Montana, along State Highway 41. Sheridan is 18 miles south of Silver Star. A branch of the Northern Pacific Railroad passes within a few miles of either town, and the Northern Pacific Transport Company maintains a bus and truck route through both places. From the highway, both areas may be closely approached by automobile on dirt roads.

Topography and Drainage

Both Silver Star and Sheridan are situated in the broad alluvium-filled valley through which flows the Jefferson River. At Twin Bridges, about halfway between the two towns, the Big Hole, Beaverhead, and Ruby Rivers join the Jefferson flowing northward. These three streams drain almost the entire area to the south and west within the state.

The general topographic features of the district can best be seen from Twin Bridges, at an elevation of about 5,000 feet above sea level. To the northeast the Highland Mountains rise to an altitude of about 10,000 feet. To the west, the Tobacco Root Mountains reach about the same elevations. Here the mountain front apparently was formed by downdropping of the valley floor. To the south, the Ruby range forms
GEOLeOGIC MAP of the
SILVER STAR - SHERIDAN
AREA in MADISON COUNTY
MONTANA

Geology after Mont. State Bur. of
Mines and Geology-Memoirs No. 8, 19

Scale

1 mile 2 3 4
Figure 2. A general view of the Jefferson Valley looking toward Sheridan from the area just west of Silver Star. Showing the Highland foothills in the foreground, the bottomlands along the Jefferson River, the benchlands, the foothills of the Tobacco Root Mountains (left), and the Ruby Range in the background (right). (Infra red film.)
a high, narrow ridge separating the Ruby River from the broad valley of the Beaverhead and Big Hole to the northwest.

The valley floor, away from the foothills, consists of a gently sloping benchland and a bottomland along the river. The benches hold only sparse vegetation but the bottoms have proved to be excellent farmland. The precipitation in the area ranges from ten to fifteen inches per year; the extremes of temperature are 90° and -30° Fahrenheit.

Historical Geology

In the Tobacco Root and Highland Mountains, all three of the pre-Cambrian formations which are now differentiated, the oldest Pony gneiss, the Cherry Creek series, and the youngest Belt formation may be found. None of these are exposed over any distance, however, and their relations are obscure. It may safely be said that both Pony and Cherry Creek deposition were followed by periods of uplift, folding, intrusion by igneous masses, and erosion. Belt deposition was also followed by long erosion.

During the Paleozoic, an enormous thickness of mainly shales and limestones was deposited, for the most part conformably, upon the underlying pre-Cambrian rocks. In Mesozoic time, the area received little deposition until upper Jurassic. Following the laying down of the lower Cretaceous Kootenai formation, the area was again uplifted, folded and intruded during the Laramide orogeny. During the orogeny, the late Cretaceous Livingston volcanics blanketed the area. Both the great Boulder Batholith which in part underlies the Highland Mountains, and the Tobacco Root Batholith were emplaced at this time.
Tertiary time saw the passing of Cretaceous folding and thrusting into tensional block faulting. Continued volcanic activity aided the formation of intermontane basins by damming streams. Crustal movements continued all through Tertiary time, continually altering the drainage pattern. The Jefferson Valley received perhaps a thousand feet of Tertiary lake beds.

Pleistocene glaciation is very evident in the features of the high peaks, the glaciers apparently did not reach down here into the Jefferson valley.

The Cherry Creek Series

The chromite deposits in both the areas here described are enclosed in the great series of metamorphic rocks grouped together as the Cherry Creek series. This grouping is based on the more truly gneissic character of the underlying Pony series, and on the relatively unmetamorphosed appearance of the overlying Belt formation. The Cherry Creek series may be split into three lithologic units as follows:*

1) Upper Division--quartz-feldspar gneiss and quartz-mica schists.

2) Middle Division--dominantly crystalline limestone with varying amounts of quartzite and mica schists.

3) Lower Division--garnetiferous schists and gneisses.

The rocks are undoubtedly chiefly of sedimentary origin. In general, any one area may exhibit one particular rock type, but on close

inspection the "strata" change rapidly across the section. Commonly, pebbles can be seen inclosed within the "strata".

The Horse Creek Area

Horse Creek crosses State Highway 41 at a point 3.7 miles south of Sheridan. Following southwestward, it drains a seven mile long strip of low hills underlain entirely by Cherry Creek rocks.

Figure 3. The entrance to Horse Creek looking eastward. (Infra red film.)

The dirt road follows the creek up to and beyond the chromite outcrops.
Figure 4. The area around the Horse Creek chromite outcrops (looking east). (Infra red film).

Metamorphic Rocks.

The creek very nearly parallels the strike of the metamorphic rocks which are exposed prominently along it. In the area, the meta-

Figure 5. The Cherry Creek rocks in outcrop along Horse Creek. (Infra red film.)
Morphic rocks are generally a pinkish-colored, arkosic-looking, quartz-feldspar gneiss. The bedding planes of the various "strata" are clearly marked; the schistosity within the rock is conformable with the bedding. In places, the rock is a grey-tan, sandy, nondescript material which would doubtless be termed a quartzite. Cropping out at various points along the creek are some extremely dark hornblende- or hypersthene-gneisses in narrow bands. In many places, prospectors have dug into this material in searching for chromite.

A small patch of Cretaceous or Tertiary andesite capping the hill above the chromite outcrop was disregarded as unrelated to the deposits.

Structure.

The rocks along Horse Creek are relatively undisturbed. The "beds" strike N. 30° E. and dip about 20°-35° N. W. Slight folding is evidenced in a few places. In certain outcrops, one of the horizons may

Figure 6: Folded rocks along Horse Creek. (Infra red film.)
show a lenticular character, with the lenses, or "augen", surrounded by more schistose material. In hand specimen, the gneisses have augen structure. Faulting in the area is not evident, although faults could easily be obscured by the detritus and by the similarity of the rocks everywhere.

The Ore Bodies.

The chromite deposits along Horse Creek are poorly exposed. The more easterly showing has been dug into on the surface, and an adit driven into the serpentine for 75 feet. As exposed, the chromite exists as lenses or pods in a small mass of serpentine rock. These ore bunches
are not outlined by schistosity or definite walls. However, the break between the chromite and the serpentine is sharp and not gradational. Overall, the chief concentration of chromite is within an area about 30 feet long and perhaps 15 feet across on the slope.

Figure 8.

The serpentinized rock enclosing the chromite is itself lenticular in cross section. It crops out for perhaps 150 feet along the strike of the enclosing metamorphic rocks, and is separated from them by narrow zones of granular and foliated serpentine. Its thickness may reach 30 feet. The immediately adjacent rocks are somewhat ser-
Figure 9. Hand specimen showing chromite bunches in the serpentine.

Figure 10. Looking N. W. from Horse Creek road toward adit. Outcrop of acid rock (foreground), serpentine outcrop above dump in center rear.

Serpentinized, which makes the contact somewhat vague in places. The chromite is in the center of this mass.

To the east and north of the serpentine and chromite is a large lenticular zone of dirty, grey-green rock, exhibiting a prominent outcrop over an area of 200 feet by 100 feet. This material is completely serpentinized, and contains disseminated chromite. It is thought to be different from the chromite bearing serpentine rock on the basis of its appearance in outcrop. By its position in the field, it is thought to be that portion of the hypersthene-gneiss which has been completely altered by the serpentinizing solutions. It is separated from the acid metamorphics above and from the dark rocks below by a zone of schistose serpentine.

Below the above outcrop, above the typical acid gneiss, there is a zone of dark, black hypersthene-hornblende gneiss. This material
lenses out towards the chromite, and narrows to the east to a continuous band a few feet thick. This band is traceable over an unknown length. The rock is clearly a part of the original metamorphic series.

A few hundred feet to the west of the above showings, two other cuts have been made along the general strike of the serpentine band. One of these has shown a pod of blocky serpentineous rock about four feet in diameter, surrounded by extremely schistose material composed of chlorite, biotite and talc. From the material on the dump at the cut, apparently this or other pods here contained some chromite. The second cut has exposed over ten feet vertically of blocky serpentine rock, containing prominent veinlets of magnetite in the fractures.

A granite pegmatite containing quartz, oligoclase, and biotite transgresses the metamorphic rocks at the location of the adit previously mentioned. Narrow, it occupies shear zones in the lensy ser-
pentine, in contact with which it is highly altered. Elsewhere it is fresh, showing beautiful graphic structure and twinning of the feldspars.

Mineralogy.

The only ore mineral found in the deposits is chromite. It occurs in large amounts in the serpentine \((\text{H}_4\text{Mg}_3\text{Si}_2\text{O}_9)\). Magnetite in fine grains is found associated with the serpentine. In one section, a bleb of pyrite was noted, included in a chromite grain.

In five analyses of the ore the following results were obtained:

<table>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td>(\text{Cr}_2\text{O}_3)</td>
<td>22.46</td>
<td>22.20</td>
<td>22.61</td>
<td>31.45</td>
<td>30.60</td>
</tr>
<tr>
<td>Fe</td>
<td>14.73</td>
<td>17.60</td>
<td>15.38</td>
<td>-----</td>
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</tr>
</tbody>
</table>

1-3 are selected samples of ore.
4,5 are table concentrates free of silicates.

From the above analyses of the concentrated mineral, it can be seen that the chromite is low grade, doubtless containing much Mg, Al, or Fe in the spinel molecule. It is between a picotite (8% \(\text{Cr}_2\text{O}_3\)) and a chromohercynite (38% \(\text{Cr}_2\text{O}_3\)) in composition.

The chromite is extremely magnetic, almost as much as magnetite. It has a definite brown streak, however, and a darker, more vitreous appearance than the magnetite of the vicinity. No euhedral grains were seen in the thin sections or in the ground ore. The grains vary in size from 35 mesh to "bean" ore.

Genesis.

General Relations of the Horse Creek Ore.—In a chromite deposit formed by differentiation "in situ", the following features should be evident:
1) A thick overlying section of ultrabasic rocks.

2) A persistent lateral extent of the related rocks.

3) An increase in chromite concentration toward the base of the enclosing zone, with a sharp break between the chromite and the underlying rock.

4) A banded structure of the ore.

None of these relations was apparent in the deposits. Only a few feet of serpentinous rock overlay the chromite. The chromite and serpentine appeared to be confined to a very short lateral distance. The chromite showed nowhere any tendency toward a regular gradation into the surrounding rocks. The ore was bunchy rather than banded.

A chromite deposit formed from chrome-rich hydrothermal solutions should show the following features:

1) An indifference to the host rock.

2) An injected appearance of the ore bodies.

3) More intense alteration of the walls in the vicinity of the chromite.

4) Alteration of all the rocks containing the chromite.

All of these features are evident in the deposits. The hypersthenite-gneiss which was intruded could not have contained any chrome. The "bunchy" character of the ore would indicate injection, although it might be due solely to the later metamorphism. Wherever the chromite is found the containing rocks have been serpentinized, but the serpentinization does not continue to as great an extent very far from the serpentine.
On the basis of general relations alone, the author would dismiss the theory of differentiation "in situ".

Character of the Ore.

From petrographic and mineralographic studies of the textures and relationships to other minerals of the chromite, much was learned regarding the genesis of the ore. (The sketch map, Figure 8, shows the location of some of the samples from which thin sections were made.)

Chromite formed by differentiation "in situ" would be expected to demonstrate the following microscopic evidence:

1) Euhedral or subhedral crystals forming "synneusis" or chain structures.

2) Inclusion of chromite in the late primary silicates.

3) Some embayed grains, due to the high temperatures during settling.

4) At least residuals of some typical magmatic minerals.

The above cited evidence appeared to be lacking in these deposits. Chain structures were conspicuously absent. No inclusions of silicates in chromite were noted. The chromite was never found in euhedral crystals. Much embayment of the chromite grains was noted, but this could have been due to the action of hydrothermal solutions as well. The only mineral known to have been altered by the serpentinizing solutions was the hypersthene, which was determined as a constituent of the metamorphic rock.

The following features are thought to be conspicuous in chromite of the late magmatic stage:
1) Chromite interstitial to the silicates.
2) Residual silicate inclusions in the spinel.
3) Possible flow structures in the ore.

Of these features, the second was completely absent. The writer noticed nothing that could be considered flow structure. In addition, although chromite and serpentine were found in the gneiss, there were no primary silicates found there.

The following criteria are listed as indicative of a hydrothermal origin for chromite:

1) Chromite veinlets through and apophyses into the host rock minerals.
2) More intense alteration of the pre-existing minerals near the chromite.
3) A massive, continuous character of the ore.
4) Chromite replacing and interstitial to the earlier minerals.

All of the above features were noted by the writer, with the possible exception of the replacement of earlier minerals by chromite. The accompanying photomicrographs illustrate some of them.

Conclusions Regarding the Origin of the Horse Creek Chromite.

The author believes the present evidence to point unmistakably to a hydrothermal origin for the deposits on Horse Creek. It is thought that differentiation "in situ" would be impossible in so narrow a band as that included between the typical acid metamorphic rocks. The lack of any recognizable large bodies of ultrabasic rocks in the area would seem to preclude any late magmatic crystallization-injection theory. These findings are entirely in disagreement with the
Figure A. Disseminated chromite (c) in chrysotile (ca) and antigorite (a) serpentine. Note magnetite elongated parallel to biotite cleavage.

Figure B. Tiny angorite (a) grains apparently oriented according to the replaced silicates.

Figure C. Chromite (c) concentrated in serpentine.

Figure D. Interstitial appearance of the chromite grains (c) in antigorite.
Plate IV

Sample W-1. Ordinary Light x25

Figure A. Chromite (c) veinlet cutting serpentine.

Sample 7. Ordinary Light x25

Figure B. Chromite surrounding hypersthene (h) in hypersthene-hornblende (hb) gneiss.

Sample 8b. Ordinary Light x25

Figure C. Chromite (c) surrounding hypersthene (h). Amphibole (a) is hornblende.

Sample 8b. Ordinary Light x25

Figure D. Recrystallized chromite in hypersthene (h) and hornblende (hb).
Figure A. Chromite (c) grains embayed by serpentine. x28

Figure B. Parallel fracturing of massive chromite. x28

Figure C. Contact of the chromite (c) with the barren serpentine. x 28

Figure D. Fracturing of the massive chromite (c) and rounding of grain edges by serpentine. x28
Figure A. Showing the lack of chain structures in the rounded chromite (c) grains. x28

Figure B. Showing the parallel fracturing of the large chromite (c) grains. x28

Figure C. Massive chromite (c) contrasted with the rounded grains in the serpentine. x28

Figure D. Typical acid gneiss, showing twinned oligoclase (sericitized) (o), quartz (q). Crossed nicols. x25
author's original conception of chromite deposits, so that the evidence has been thoroughly sifted and weighed.

As the Cherry Creek series was metamorphosed before Belt time, and as the metamorphic character of the chromite deposits is indisputable, the emplacement of the deposits doubtless took place during the orogenic period following the Cherry Creek. Chrome-rich solutions were injected into the sediments after their consolidation, perhaps during the time that they were deep-seated and undergoing metamorphism. The understanding of the high temperatures necessary for the solution of chrome to give the hydrothermal solutions is not hard if the temperatures and pressures necessary to metamorphose the sediments are considered. It is thought that the hypersthenegneiss was already crystalline before it was locally altered by the chrome-bearing, serpentinizing solutions.

It must be state, however, that an understanding of the processes and structures of metamorphism greater than that of the writer might allow a totally different interpretation for the evidence. It would seem possible that at great depth an ultrabasic body might be emplaced as a sill in the metamorphic rocks, differentiated, and the products of differentiation isolated from one another by some metamorphic process. This would explain the concentration of chromite where no great overlying body of ultrabasics occurs. Again, an ultrabasic body could be present in the area to furnish late magmatic chromite. However, the chrome-bearing, serpentinizing, hydrothermal solutions provide the simplest theory that appears tenable to the author. The author's microscopic evidence may be based on structures due entirely to re-
crystallization, so that it cannot be regarded as perfectly conclusive.

Other Horse Creek Occurrences.

Three-fourths of a mile southwest of the above described occurrences, on the summit of the ridge south of the Horse Creek road, chromite is again exposed in some small cuts. In the largest of these, a five-foot band of chromite-bearing gneiss has been exposed for ten feet along its strike (N. 20° E.). Its dip is 45° W., giving it an attitude which fairly well conforms with that of the previously-described deposit. Trenches dug to either side of the cut have failed to disclose any more of the chromite. However, along the general strike to the northeast, serpentinous rock was disclosed in a small cut. Additional trenching would probably disclose the extent of the lense of chromite rather than a continuous body of the ore.

Figure 13. Lower Horse Creek Chromite Prospect.
The chromite here occurs in rock of a definite metamorphic character. It is a fine-grained, bluish-black gneiss composed of chromite and containing zones of altered quartz, feldspar, and hornblende. Very little serpentine is present. The rock has a greenish appearance due to the presence of epidote. On both sides of the chromite band the metamorphic rocks are a dark hornblende-gneiss, containing zones of lighter-colored, feldspathic material.

The "chromite-gneiss" is blocky, in two parallel bands. These are separated from each other and from the wall rock by more schistose zones.

This deposit is spacially, and without doubt genetically, related to the upper Horse Creek occurrence. Either due to a lack of accompanying serpentine, or to an early separation from this "lubricating substance during metamorphism, the chromite was subjected to more intensive metamorphism than that in the other occurrence, and its original character completely destroyed.
The Silver Star Occurrences

As shown on the accompanying geologic map, the chromite near Silver Star is exposed in an area roughly one mile south and three miles east of the town, in the foothills of the Highland Mountains. The most westerly outcrop lies about 1,500 feet east of the Aurora Mine which may be reached by automobile. The second outcrop is located about a half-mile east of the first, at a lower elevation. It occurs immediately along a road, just east of the Moonlight Mine. Both prospects are within Section 10, Township 2 S., Range 6 W. For convenience, the terms Aurora and Moonlight will refer to the outcrops near these mines.

Geologic Structure at the Aurora Outcrop.

The Aurora pit is ten feet square, six feet deep. The chromite is exposed in an irregular band four feet thick. The chromite itself is blocky, but its contacts with the walls are wavy, indicating a probable lenticular structure. The walls are schistose, with much

Figure 15. Gneissic structure of the chromite and serpentine from the footwall of the Aurora pit.
development of chrysotile asbestos and talc, and tiny stringers of chromite in the shear planes. In the immediate vicinity of the chromite, the rocks are not easily traced. Apparently there has been some faulting and deformation in the area, obscuring the relations. The prominent, ridge-forming quartzite overlying the deposits strikes N. 25° E. and dips 30° S. E. Overlying the chromite are dark-colored metamorphic rocks which have been serpentinized locally. The material is deceptive, being a light tan on weathered surfaces. At present there are no indications of the continuity of the ore. The claim owners, however, expect to dig trenches along the strike in hopes of developing more ore.

Mineralogy of the Aurora Occurrence.

The chromite in the pit near the Aurora Mine is blue-black, coarse-grained, non-magnetic. It shows flat shear planes upon fracturing. An analysis of the ore gave the following:

\[
\begin{align*}
\text{Cr}_2\text{O}_3 & \quad \text{Fe} & \quad \text{SiO}_2 \\
34.18 & \quad 21.32 & \quad 16.12
\end{align*}
\]

This would seem to indicate a high grade of chromite, but a lack of alumina would keep down the magnetism in spite of a high iron content.

The serpentine is very light-colored, a pale blue-green near the chromite. Chrysotile fibres a half-inch long were developed in some of the shear zones. Sericite occurs along the shears, and between grains in the chromite.

The Moonlight Occurrence.

Here a vertical dike-like mass of chromite, 12 inches thick,
forms a prominent outcrop over a twenty-foot length. The material is in an extremely deformed zone, and little of the relationships with the surrounding rocks can be seen. The wall rock is serpentinous, but its original character has been lost during metamorphism. The chromite, however, is massive in outcrop; it is fine-grained and non-magnetic. The outcrop could not be traced over any distance, although the rocks in the area are well exposed.

The Ramshorn Occurrence of Magnetite

Chromite was reported on Current Creek, a few miles northeast of the Horse Creek occurrences. The writer traversed a 1,200 foot section of extremely dark metamorphic rocks there but was unable to identify any chromite. The rocks observed contained great thicknesses of magnetite, a great deal of garnet, augite, and some quartz. Due to a complete lack of any visible serpentine, in addition to the acidic and magnetic character of all the material in view, a more detailed examination was foregone.
Development

With the possible exception of the Aurora occurrence, the ore bodies are too small and too low-grade to allow any serious consideration from an economic standpoint. The ore at Aurora is fairly high-grade; hydraulic concentration and tabling might furnish a marketable concentrate from it. It is almost certain, however, that there is not enough ore present to warrant development at present prices.
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