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Geology and Occurrence of Graphite at the Crystal Graphite Mine Near Dillon, Montana

Charles K.W. Hum Hum

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GEOLOGY AND OCCURRENCE OF GRAPHITE
AT THE CRYSTAL GRAPHITE MINE
NEAR DILLON, MONTANA

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

by
Charles K. W. Hum

Montana School of Mines
Butte, Montana
May, 1943
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GEOLOGY AND OCCURRENCE OF GRAPHITE
AT THE CRYSTAL GRAPHITE MINE
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By
Charles K. W. Hum
INTRODUCTION

As a partial fulfillment of the requirements for a degree of Bachelor of Science in Geological Engineering from the Montana School of Mines a geological problem is undertaken and submitted to the Department of Geology as a thesis.

Although listed as a "critical" rather than a "strategic" mineral, graphite has assumed considerable importance in the war production plans in the past year. This is pointed out in some data obtained from the 1940 issue of "The Mineral Industry" in which the total import of graphite into the United States was 31,328 short tons, chiefly from Madagascar, Ceylon, Chosen, and Mexico, as compared to exports of 1,632 short tons.

With this in mind and with the approval of Dr. E. S. Perry, Chairman of the Department of Geology, a study of the geology and occurrence of graphite in the Crystal Graphite Mine near Dillon, Montana, was undertaken. This thesis contains the results of the survey of the deposit and the laboratory investigation conducted at the Montana School of Mines.

The field work was done in October 1942 and involved two trips to the mine and the collection of samples in
the underground workings and surface outcrops of the surrounding country-rocks. Geological reconnaissance in the area of the deposit was made under adverse conditions of snow and fog.

Mapping was done by means of a Brunton compass, sight alidade, and plane table. Distances were measured by pacing. Through the generosity of the operators, copies of claim and mine-workings maps were obtained. Pictures and notes of the area surveyed were also taken.

The laboratory work consisted of the preparation and study of thin sections from samples collected for the purpose of ascertaining the paragenetic relationship of the original minerals in the rock and the result of the alteration of these rock-forming minerals.

The problem to be considered embraces the mineralogy and the mode of formation of a very pure and vein-like deposit of crystalline graphite. This deposit is of more than ordinary interest because in its geological relations and in the character of its graphite it shows many similarities to the famous deposits of Ceylon.

Previous work on this property was done by Mr. A. N. Winchell* and Mr. E. S. Bastin* during 1911.

* See Bibliography.
GRAPHITE

Kinds of Graphite

Graphite is one of the forms under which carbon occurs in nature. It is chemically identical with diamond, being both crystallized allotropic forms of carbon.

Strictly speaking, all graphite is crystalline, but grades in which the individual grains can not be distinguished with the naked eye are commercially classed as amorphous. Classification as to "amorphous" or "crystalline" is based largely upon trade practice.

Crystalline graphite is sub-divided in (1) flake, (2) lump or vein (plumbago), and (3) dust. In commercial practice, however, dust is considered about the same as amorphous and has the same uses.

Mineralogy and Characteristics

Graphite is a soft mineral (H=1 to 2) with a metallic or sometimes dull earthy luster. Its specific gravity is 2.2. The color ranges from black to steel gray. The structure is commonly foliated masses. It is chemically inert and therefore not attacked by acids or alkalies and is also infusible but may burn to CO₂ at high temperatures.

The diagnostic features of graphite are its color, foliated nature, softness (1 to 2 on Moh's scale), its
slick feel when rubbed between the fingers and the ease with which it readily marks paper and soils the hand.

The only other mineral easily mistaken for graphite is molybdenite which has nearly the same features. However, it is distinguished by having a blue tone to its color, a higher specific gravity (4.75), and its solubility in hot nitric acid.

Uses

In 1938 reports from the United States Bureau of Mines* indicated that approximately 30 percent of the total graphite consumption was devoted to foundry facings, core washes, and similar uses. About 30 percent was consumed in dry batteries. Crucibles, lubricants, and pencils consumed about 10 percent each. Three percent was consumed in paints and stove polishes, one percent in commutator brushes, and the remainder in a large number of miscellaneous products and processes.

In foundry work graphite is used to prevent the sticking of sand particles from the sand mold to the metal, when cast. The surface of the sand is generally given a facing of graphite. The grade which may be used ranges from impure to high-quality flake.

The fair thermal conductance and high melting point of graphite qualify it for a number of refractory uses, the most important of which is the manufacture of crucibles for melting steel and nonferrous metals. For this purpose 40-50 percent Madagascar flake or crystalline graphite is mixed with refractory clay and grog (burnt clay, silicon carbide, etc.).

X-ray data indicate that graphite crystals are built up of innumerable tiny hexagonal plates that slide easily over one another if a small shearing force is applied. This property makes graphite seem greasy when rubbed between the fingers and explains its lubricating qualities. All varieties of graphite have been used in lubricating compounds. Obviously requirements are high purity and freedom from grit.

The softness and lustrous black color of graphite make it an ideal constituent in pencil leads, and, in fact, its name is derived from a Greek word meaning "to write". The usual formula calls for 50 or less percent graphite, mixed with clay, and perhaps small percentages of stibnite and tallow or lampblack.

Graphite is mixed with manganese dioxide in dry batteries to lower internal cell resistance. Crystalline flake, natural amorphous, and artificial amorphous grades have been used.

Because of its inertness and opacity graphite may
be employed in paints for the protection of bridges, smoke stacks, tanks, and other exposed surfaces.

The above uses account for the largest portion of graphite consumption.

Occurrence and Production

Foreign:

The world's largest sources of graphite are in central Europe, but the material is mostly too low grade for export overseas. This takes in the area of U. S. S. R., Bavaria, Moravia, and Austria. Graphite occurs in almost every country in the world from Greenland to South Africa. The imports from Chosen, Ceylon, Madagascar, and Mexico constitute our principal supply.

United States:

Graphite is distributed widely in the United States. Virtually every State in the Union that contains metamorphic rocks has reported the occurrence of graphite, and attempts have been made at one time or another to mine the most promising deposits. However, in recent years, the production of crystalline graphite in the United States has been insignificant, and the output of natural amorphous graphite has been confined to a few hundred tons annually.

The principal producing states are New York,
Alabama, Nevada, and efforts are being made to revive the production in California, Georgia, Montana, Texas, Virginia, and perhaps other states.

HISTORY AND ORGANIZATION OF THE PROPERTY

About the year 1899 a deposit of graphite was discovered by Mr. Robbins, a prospector, in Van Camp's canyon, 18 miles southeast of Dillon. When it proved not to be a lead mineral the deposit was forgotten. It was not until January, 1901, that a company was formed by Mr. Pearl I. Smith to systematically develop the property. This company, known as the Crystal Graphite Company, put a number of men to work on the group of claims, known as Last Chance, Homestake, Bird's Nest, Mayflower, Eureka, Faithful, Lucky Boy, and the Ground Hog. On this last claim was erected the camp site with a few cabins and a cook-shack. In 1903 Mr. Smith leased the property to the Copper Cliff Mining Company of Chicago which operated for a year. From 1904 to 1917 not much work was done to improve the mine. From 1917 to 1920 the price of graphite soared, and under Mr. Smith's management the mine produced graphite which was sent to eastern markets. Between 1920 and 1930 only yearly assessment work was performed to protect the mine and claims. In 1930 explorative work was again started.
However, the program was dealt a heavy blow when Mr. Smith passed away in 1937. In the summer of 1938 the property was surveyed for patent and patent was issued on the Ground Hog Claim in the name of Mr. Ralph Smith, son of Mr. Pearl I. Smith. During 1941 Mr. R. Smith leased the property to Mr. Abbot Pond who later assigned the lease to the present operators. At the time of the writing of this report the property was being operated in the name of the Crystal Graphite Mining Company under the management of Mr. Reibhoff.

At the present, development work is being conducted at the mine where nine men are employed. The work consists of driving an adit 250 feet below the old workings and putting the mine in condition for operation.

Building of a new road to the mine has been authorized by the Government at the expense of $12,000. All indications point toward the start of construction as soon as the weather permits.

GEOGRAPHY

Location and Accessibility

The principal workings on the graphite property are about 9 miles southeast of Dillon at the south-
west end of the Ruby Range. They occupy what is
known as Crown Point at an approximate elevation of
8,300 feet (Dillon quadrangle topographic sheet of the
U. S. G. S.) on the ridge between Van Camp canyon and
Timber Gulch.

These deposits are reached from Dillon, which is
on the Oregon Short Line railroad, by a drive of about
13.5 miles to the southeast over a gravel and dirt
road; the last three-mile stretch rises approximately
1,000 feet across steep terrain.

Drainage and Relief

The maximum relief of the area is about 3200 feet.
Crown Point, not far from the mine, has an elevation
of 8,000 feet, and Dillon lying in the valley of the
Beaverhead River has an elevation of about 5,100 feet.
The graphite deposits are 8,050 feet above sea level.
The mountains rise abruptly from the stream valley to
the plateau level of the Ruby Range. The range has
but a few inaccessible spots, although it is well
dissected by streams.

Drainage in the graphite-bearing area is down
the western slope of the mountains, into Blacktail
Deer Creek. Near Dillon Blacktail Deer Creek joins
Beaverhead River, which in turn empties into the
Jefferson River. Consequent drainage is finally in-
to the Gulf of Mexico through Missouri and Mississippi
TOPOGRAPHIC MAP
of area near
CRYSTALLINE GRAPHITE DEPOSIT
SCALE: 1" = 1 MILE  CONTOUR INTERVAL 200'
REDRAWN FROM U.S.G.S. DILLON QUADANGLE TOPOGRAPHIC MAP

LOCATION OF DEPOSIT
Rivers. Jefferson River joins the Gallatin and Madison Rivers northeast at Three Forks, Montana, to form the Missouri River. Most of the streams in the graphite-bearing area are intermittent except Axis and Timber Creeks.

Climate and Vegetation

The area is high and semi-arid, with an average annual precipitation of from ten to fifteen inches. The maximum and minimum temperatures are about ninety degrees and minus thirty degrees respectively; however, the below-zero temperature is dry and generally calm and the summer evenings are cool. Annual mean temperature is 43.6 degrees. As stated, altitude of the region is about a mile above sea level.

The area in general is covered with hardy grasses, sagebrush, red fir, spruce, and pine. The sagebrush is usually dense on the northern slopes of the canyons, whereas the southern slopes are generally covered with fir, spruce, and pine. Along the bottom of the canyons where water is more plentiful poplars and willows are found. At the camp-site only grass and sagebrush are seen. Timber for the mine is cut from the fir and pine in Van Camp Canyon and then dragged 2,500 feet over a trail to the mine where it is cut to size.
GENERAL GEOLOGY

In general the rocks in the vicinity of the graphite deposit are schist and gneiss of pre-Cambrian age, however, cutting the metamorphic complex are dikes and irregular igneous masses. Of particular interest are pegmatite dikes with which are associated the graphite deposit. About one-quarter mile west of the deposit massive beds of pre-Cambrian dolomitic limestone lie interbedded with schist and gneiss. Paleozoic sediments are present about eight to twelve miles from the graphite deposit. Lake deposits and alluvium lie in the major valleys.

SEDIMENTARY ROCKS

Within the area of the graphite deposit there is a complete lack of unmetamorphosed sedimentary rocks. At least none have been found to date, and the topography and areal geology indicate that the chance of there being any near the surface, is indeed remote. There may have been sedimentary rocks here in the geologic past but they are now altered by intense metamorphism or absent due to erosion.

However, sedimentary rocks of Paleozoic age are found across Blacktail Valley roughly 8 miles to the south and further north along the Ruby Range, 14 miles away, the same series is again exposed.
GEOLOGIC MAP
of area near
CRYSTALLINE GRAPHITE DEPOSIT
SCALE: $\frac{1}{4}" = 1$ MILE
REDRAWN FROM PRELIMINARY GEOLOGIC MAP OF WESTERN MONTANA
METAMORPHIC ROCKS

Metamorphic rocks comprise the only rocks in the immediate vicinity of the graphite deposit with the exception of igneous intrusions, and it is believed by the writer that they constitute the Cherry Creek series of Montana. This group of rocks is to be correlated with the same series which is widely distributed throughout southwestern Montana. The geologic age of the Cherry Creek is not definitely known; it is much older than the Belt series of late Proterozoic age, and it may be either Huronian (early Proterozoic) or Archean in age.

The type Cherry Creek section, which is exposed on Cherry Creek in the Gravelly Range, about sixteen miles southeast of Ennis, Montana, is an intensely folded series consisting of interbedded feldspar gneiss, quartz mica schist, garnetiferous gneisses and schists, crystalline limestone, quartzite, and hornblende biotite schist.

Due to deep burial that resulted in high pressures and intense compressive forces the primary characters of the rocks have been so altered that it is difficult to ascertain whether they were originally sedimentary or igneous. However, the presence of thick bodies of marble interbedded with the metamorphic
rocks, their high degree of banding with the bands of widely different characteristics, and the presence of highly siliceous gneisses point toward a sedimentary origin.

The average strike of the beds at the graphite deposit lies between N. 45° E. and N. 60° E. with north-westerly dips of from 30° to 60°, and they show numerous minor faults.

The outstanding lithologic units of this series exposed in the area of the deposit are the crystalline limestones which form the western slopes of Van Camp and Axes Canyon, and the prominent outcrop just south of the camp site. A repetition of this limestone member is believed to be due to faulting and folding. It is conspicuous because of its light reddish-brown color due to weathering and its peculiar velvety sheen. On a fresh surface it varies from a pure white or cream to a greenish-blue color. The absence of bedding is readily noticed in this member of the series. The thickness of the limestone is from 500 to 750 feet.

At the junction of the road leading up to the mine and the one to the entrance of the adit, is seen a lens of hornblende biotite schist about 75 feet thick. This greenish-black rock is characterized by the shiny surfaces of the large hornblende crystals. The weathered surface shows only a very slight difference from a
A. A pit fifty feet northeast of the shaft showing an exposure of graphite veins in the Cherry Creek formation.

B. Looking southwest across Blacktail valley from the Crystal Graphite Mine. In the background are exposures of Paleozoic rocks and in the foreground is the dump of the second level workings, and the road from the camp-site to the mine workings.

C. A view of the limestone member of the Cherry Creek series looking northwest from the camp.

D. A view of the Ruby Range taken from Dillon, Montana. The arrow indicates the location of Crown Point.
Views of outcrops and terrain in the vicinity of the Graphite Deposit.
fresh break of this rock.

Other striking members of this series when examined closely are the garnetiferous schists and gneisses. These are dark brown in color on a fresh surface and assume a reddish-brown tint on weathering. The color depends upon the relative proportions of garnet, feldspar, mica, and hornblende present. The garnet crystals range from microscopic sizes up to diameters of one-half inch in various beds of this member. The outcrops of this rock occur in scattered ridges north of the camp.

Close to the mine workings are found outcrops of quartz-mica schist. They appear light gray on the weathered surface. This rock is composed chiefly of quartz and biotite with small amounts of hornblende and feldspar. Banding is well defined.

The lithologic units are exposed and believed to be in the middle and lower divisions of the Cherry Creek series.

Studies of the Pony and Cherry Creek series are being made by John C. Rabbitt of Harvard University which will add much to the present knowledge regarding these rocks.

IGNEOUS ROCKS

In general the only igneous rocks found in the immediate area are pegmatites and diabase dikes. However about three and one-half miles to the east is an
intrusion of an ultramafic complex about four and one-half miles long and a mile wide. It trends N. $45^\circ$ E. and apparently dips $20^\circ$ to $30^\circ$ northwest.

Dikes

Cutting across the Cherry Creek rocks near the deposit is a diabase dike of basic nature. It is thirty feet wide and strikes N. $50^\circ$ W. An excellent exposure is seen near the mouth of Van Camp Canyon where it has cut the limestone slope, and has weathered to form a reddish brown talus. Although the dike does not actually crop out along its strike with the exception of the above exposure it can be readily traced by the characteristic reddish brown soil of its weathering. This dike was traced for a mile and could be seen to extend further on. This was the only dike, other than pegmatite, found by the writer in the immediate area.

Megascopically the diabase is a dark green to grayish-black holocrystalline rock with a medium grain texture. Microscopic examination shows interlocking crystals of plagioclase, augite, and magnetite. The composition is as follows:

<table>
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<tr>
<th>Mineral</th>
<th>Percentage</th>
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<tr>
<td>Plagioclase</td>
<td>40%</td>
</tr>
<tr>
<td>Augite</td>
<td>35%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>25%</td>
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Pegmatites

An intrusive of graphite-bearing pegmatite is seen to cut the Cherry Creek rocks in the underground workings of the mine. On the surface the pegmatite is not a very prominent feature. Only a few outcrops of it are seen. The road going up to the mine cuts one of these outcrops, and the others show up along the strike of the pegmatite eastward from the mine. The general trend is N. 50° E. to N. 65° E. Its dip is 60° to 65° to the northwest. From the way it is striking the pegmatite appears to be parallel to the structure of the surrounding country rock, but its dip shows rather the indiscriminate cutting through the Cherry Creek series. The surface outcrops do not shown enough to determine its width. However, a rough estimate would be eight to twelve feet.

Megascopically the pegmatite is leucocratic. In some places it is composed of very coarse crystals and in others it shows a definite graphic texture. The composition ranges from nearly all white, massive to glassy quartz, to quartz and feldspar with some mica. Under microscopic examination with crossed nicols the feldspar is seen to be microcline with its characteristic "gridiron" or "plaid" pattern. What little mica is present is biotite. The quartz shows an undulating extinction between crossed nicols signifying straining.
Structural Geology

General Features

The graphite occurrence under discussion lies in an uplifted block of gneiss and schist separated from the Ruby Range by the broad Sweetwater Basin which is at least fifteen miles wide. The top of this block, which is from 7,000 to 8,000 feet above sea level, forms a high sage brush covered plateau with little relief.

The structural geology of the graphite-bearing area involves two rather widely different types: (1) the structure of the schists and gneisses, and (2) the relatively recent faulting.

Faulting and Folding

Folding in this general region of gneiss and schist must have been very intense in pre-Cambrian time to change the character of the original material laid down into the present rock types found. The structural pattern was further complicated after pre-Cambrian time by successive mountain-building movements in the late Mesozoic and the Cenozoic eras which imprinted their own structural pattern on these pre-existing rocks.

The constancy of the northwest dips of the beds
between the mine and the mouth of Axes Canyon gives a deceptive conception of the thickness of the Cherry Creek series, for instead of one great northwestward dipping series, the formations probably are repeated again and again by folding and faulting. The following sketch will illustrate what is meant.

![Diagram illustrating probable structure in the metamorphic series.](image)

On the surface, fault features are inconspicuous in the rocks of the Cherry Creek, but in the underground workings numerous faults may be seen. Most of these were formed after the graphite deposition for they cut the graphite veinlets. They carry much gouge but not graphite except a little that has been dragged out from the veins.

**Geologic History**

As previously stated, the metamorphic rocks are believed to be of sedimentary origin, which tells of

*Information gathered from a discussion with Dr. E. S. Perry.*
ancient pre-Cambrian seas. The intensity of metamorphism indicates deep burial. The occurrence of an early period of pre-Cambrian mountain making is problematical, but following the intense metamorphism came prolonged erosion which exposed the schists and gneisses in pre-Cambrian time. Twenty to thirty miles north and west of the graphite deposit several thousand feet of upper Proterozoic sediments (the Belt series) were then laid down on the metamorphics, but it is not believed that the Belt rocks were deposited southeast of Dillon.

Cambrian time began with most of Montana a land surface, because lower Cambrian sediments are not found. The middle part of the Cambrian period marks the beginning of the long period of Paleozoic and Mesozoic sedimentation which lasted at least to the end of the Cretaceous period.

The folding of this series of sediments including rocks of late Cretaceous age tells of the Rocky Mountain period of orogeny. It was followed by large scale block faulting in Tertiary time.

Igneous activity in the form of lava flows preceded the mountain making, because andesitic lavas in this portion of Montana are involved in the folding; but most of the intrusive masses are believed to have been introduced after folding, because they cut the
A. A close-up of Crown Point with the arrow indicating the location of the Crystal Graphite Mine. In the foreground is the road leading from the camp to the mine workings.

B. A closer view of the workings of the mine with the dump of the first level seen in the foreground.

C. A view of the camp site as seen from Crown Point.

D. The arrangement of the camp buildings.
Views of the Crystal Graphite Mine and Camp-site.
folds. In the middle or latter part of the Tertiary period lava again spread over many areas.

The large intermontane valleys were sites of extensive lakes in middle Tertiary time, and in these lakes accumulated the thick masses of lake sediments now exposed in the valleys.

THE CRYSTAL GRAPHITE MINE

The main workings of this mine are all on the patented Ground Hog claim with the exception of an adit started on the Antelope Claim immediately south of the Ground Hog claim and extended northward beneath the Ground Hog at a level of 280 feet below the present workings. The operators hope to intersect the mineralized zone of graphite in this adit, and then connect the adit by a raise to the third level of the Ground Hog workings.

Timber in the workings opened since the mine was in production during World War I have rotted, and caving of ground has resulted, thus making many portions of the mine inaccessible. The only portions visited were the Brown, Thompson, Magee, and King stopes in which development work was proceeding. However, of considerable importance, is the fact that little timbering is necessary in the stopes, due to the firmness of the wall-
rock. This is especially true when hand-sorting in the stope is practised, as this procedure furnishes ample waste for filling.

The present operators are hand-sorting the graphite and shipping it to industrial points in the East in the form it is mined. With the method of mining used, hand-sorting is not difficult. The stope is cut in the waste of the hanging wall, and the graphite is left on the foot-wall. It is then scraped and dug out of the vein, as far as can be reached by hand scappers on sheets of canvas. It is then dumped into sacks and carried out of the mine.

To the best knowledge of the writer graphite is the only economic product produced from this mine.

General Character of the Graphite Deposit

In the main workings of the mine the graphite occurs in or associated with a pegmatite dike which has intruded the Cherry Creek rocks, and also in a mineralized portion of the country-rock adjacent to the intrusive. The mineralized zone including the pegmatite is from 100 to 125 feet wide. The graphite is found chiefly in veins and along faults fissures not parallel with the bedding of the Cherry Creek rocks. The bedding here strikes about N. 50° E. and dips 55° NW., while the graphite occurs in a fault vein which strikes N. 60° W. and dips
about 65° NW. The graphite also occurs in veins and faults in several other positions. Some of these veins have been cut by faults which carry only a small amount of graphite that apparently has been dragged from the vein.

In the various stopes opened up it is seem that the graphite is in irregular bunches, pockets, stringers, and vein-like masses. These occurrences are similar to the mode of deposition of vein-material in zones where the rocks have yielded to stresses, not by clean fracturing but by irregular shearing. In such places irregular lenticular masses called "kidneys" by the miners, which may reach from eight to 18 inches in thickness and from three to eight feet in diameter, are in evidence.

Structure of the Graphite

The structure of the graphite is rather difficult to describe and may be best understood by examination of Plate IX. When broken between the fingers the graphite separates into splinters which are roughly spear-head shaped and from 1/4 to 1 inch in length. From reports on Mr. E. S. Bastin's investigations of the graphite deposits in Ceylon and near Dillon, Montana, there is much similarity between both deposits. The differences are noted particularly near the surface, where thin
films of iron oxide may occur along parting planes between the graphite plates. The graphite is a little more softer than that from Ceylon and grinds up more easily, and its luster is not quite so brilliant. However, in comparison it must be remembered that the Crystal Graphite workings are much more shallow than the Ceylon mines, and that surface alteration has produced certain changes which should be less noticeable when greater depths have been reached.

The Main Workings

The location of these workings has been already given. They consist of a number of drifts, cross cuts, stopes, and a winze which are shown in Plate VII. The outcrops of country rock in the immediate vicinity of these workings, as mentioned before, are of intensely metamorphosed sedimentary rocks (garnetiferous schists and gneisses and quartz schists) which are intruded by granitic igneous rocks (pegmatite). Underground there are numerous evidences of minor faulting.

Underground Workings.

The first 50 feet of the first level adit may be regarded as a crosscut but the workings beyond largely follow graphite "veins". The wall rocks here exposed are pegmatite and quartz schists. Seventy feet from the entrance is the Thompson stope. Here a group of
A. This illustrates clearly the method of mining graphite at the Crystal Graphite Mine.
   (1) The graphite is removed from the vein by hand scrappers and collected on sheets of canvas.
   (2) The wall is then drilled and blasted, thus exposing the vein again. The cycle is repeated.

B. A close-up of the graphite "veins" in the Brown stope. Note the nearly vertical dip of the vein-masses and the worked out "kidneys".

C. A underground picture of the graphite-bearing pegmatite. Shown is a graphite vein in the pegmatite and the contact of the intrusive and the country rock.

D. The entrance to the adit on the Antelope Claim. Above it are prominent outcrops of the Cherry Creek formation.
Surface and Underground pictures of the workings of the Crystal Graphite Mine.
graphite veinlets were encountered the widest of which is from two to three inches with several "kidneys" present which were eight inches wide and roughly from two to three feet long. The strikes of the veins are N. 45° E. and dip 60° NW.

In the Brown stope which is accessible by a cross-cut from the first level adit the graphite occurrence is very similar to that of the Thompson stope. Here, too, the graphite is in vein-like masses four inches wide with several large "kidneys". These "kidneys" may sometimes yield several hundred pounds of graphite a-piece. The veins strike N. 65° E. and dip 87° NW. In the graphite found here thin films of iron oxide often occur along parting planes between the graphite plates.

In the Magee stope, where a graphite vein is shown in cross-section, one of the best exposures now to be seen in the mine is present. The stope is accessible by a winze from the first level. The wall rock here is altered quartz schists and is traversed by a nearly vertical fracture along which graphite has been deposited. The ore body is about a foot wide and consists of an irregular net-work of graphite veinlets enclosing many schist fragments. The graphite forms about half of the vein material, and veinlets locally unite to form irregular bunches. The strike of the veins is N. 50° E.
and dips are 70 NW. The King stope is just an extension of the Magee stope.

As said before these stopes were the only portions of the mine that were accessible without chancing a fall of ground.

Mineralogy

The graphite is characteristically a sub-metallic steel gray, crystalline to massive, material with a very high carbon content in the neighborhood of 95%. The specific gravity is 2.2, hardness about 1, and it has a slick feel such as is characteristic of all graphite. Often a seemingly pure piece of graphite will give a low assay due to entrapped fragments of country-rock.

Associated minerals are few as the pegmatite and quartz schist in which the graphite is found are made up essentially of quartz and feldspar. The quartz constituting the greater portion of the pegmatite, can be seen to form excellent anhedral crystals, whereas the quartz schist contains equal portions of feldspar and quartz. The quartz is generally clean and glassy.

The feldspar is made up mostly of microcline both in the schist and in the pegmatite. The microcline forms anhedral crystals which are seen only under the microscope. Under crossed-nicols the characteristic "gridiron" or "plaid" structure is seen. As stated
PLATE IX

A. A specimen of high grade graphite showing clearly its crystalline structure. (Taken from the bottom of the winze near the King stope)

B. A specimen of graphite-bearing pegmatite showing graphite with radiating crystals found at the west end of the Magee stope.

C. Specimen of crystalline graphite in a garnetiferous mica schist.

D. A picture showing veinlets of graphite cutting quartz-feldspar schist and also some high grade graphite.
Photographs of graphite-bearing rocks.
before, the feldspar of the pegmatite is scarcely altered whereas kaolinization has replaced entire crystals in the quartz schists. Of interest are the disseminations of graphite in the schist as well as the occurrence of crystalline graphite in vein-like structures. These disseminations appear in the schist as thin flakes inter-layered with the other minerals of the schist.

Paragenesis.

From underground observations it is readily seem that the graphite veins and veinlets cut the quartz schist indiscriminately. From this it is safe to assume that the deposition of graphite took place after the formation of the schist. Further evidence was gathered from thin-section study, where fragments of quartz and feldspar were seen to be enclosed by graphite crystals.

In the typical, unaltered pegmatite the quartz and microcline appears to have crystallized out nearly simultaneously, both possessing anhedral crystal-forms. Graphite, where found, cuts both the quartz and microcline, and forms irregular patches between the crystals of the rock-forming minerals. From this evidence it appears that the graphite is late, and was injected or deposited in the pegmatite after (or shortly after) its solidification. This places the order of crystal-
A. A thin-section of the graphite-bearing pegmatite showing coarse crystals of (a) quartz, (b) microcline slightly altered, and (c) graphite crystals. Crossed nicols, x23.

B. Photomicrograph of graphite in quartz-feldspar schist (Magee stope) showing crystals of (a) quartz, (b) graphite, and (c) microcline altered to kaolin. Crossed nicols, x23.

C. Another section of the quartz-feldspar schist with graphite present. (Magee stope) Crossed nicols, x23.

D. A thin-section of graphitic-feldspar gneiss showing alteration of feldspar to kaolin. Crossed nicols, x23.

E. Another portion of the graphite-bearing pegmatite showing crystals of (a) graphite, (b) quartz, and (c) microcline. Crossed nicols, x23.

F. Section of the diabase dike showing crystals of (a) magnetite, (b) augite, and (c) feldspar. Crossed nicols, x23.
Photomicrographs of graphite-bearing rocks.
lization as microcline and quartz, and then graphite.

Origin of the Graphite Veins

There have been many and varied theories proposed to account for the origin of graphite veins, but none have yet proven wholly satisfactory. However, enough knowledge is at hand to rule out certain of these theories. The Dillon deposit cannot be classed as metamorphosed interbedded coals as the graphite forms irregular veins systems that cut across the foliation of the enclosing rocks. The origin as to lateral secretion from the wall rock is not feasible because of the sharpness of the vein walls. Any theory of fissures being filled with asphalt or other carbonaceous material which was later metamorphosed into graphite, may be discarded as the veins themselves are younger than any igneous intrusive capable of causing any such changes. The theory as to the formation of graphite from materials in a magma is supported by some, but to the knowledge of the writer the constituents of magma would not warrant such a concentration of carbon compounds as to bring about such a large deposit of graphite as seen at the Crystal Graphite mine.

The hypothesis of deposition from some sort of a solution along fracture-planes in the rocks appears to be the most likely theory. In short, this graphite
occurs in true fissure-veins. In regard as to the origin and nature of such solutions and the temperatures and pressure under which the graphite was deposited from them, practically nothing is known, and can only be speculated on. The more widely accepted speculations are briefly: (1) subliming of carbon vapors to form graphite; (2) decomposition of metallic carbides to form graphite; (3) the yield of graphite on decomposition of hydrocarbons; (4) the reaction of oxides of carbon and hydrogen to bring about the formation of graphite. The relative merits of these various views are discussed in a paper by Mr. A. N. Winchell* to which the reader is referred for further detail.

As to the origin of the graphite at the Crystal Graphite Mine the writer believes that it was brought about by the intrusion of a pegmatite through limestone. This line of speculation is along that of number four in the paragraph above. The pegmatite decomposed the limestone into lime and various oxides of carbon which in turn reacted with constituents of the molten intrusive such as hydrogen to give forth carbon which was deposited as graphite. It must be remembered that probably these reactions took place under extremes of pressure and temperature with the element of time in the picture, too.

* See Bibliography-Second reference.
Probable Age of the Deposit

The formation of the graphite deposit appears to be associated with the introduction of the pegmatite dike with which the graphite occurs. Sufficient information is not on hand to place the age of the pegmatite or the graphite. The general appearance of the pegmatite in thin sections under the microscope suggests that it is related to the post-Cretaceous igneous intrusive. The feldspar crystals show only a very slight alteration and in most cases appear fresh, which would point toward a late geologic age. But this evidence alone is not adequate. Also the quartz of the pegmatite does not show "wavy" extinction, a characteristic of quartz which has been subjected to regional metamorphism; and the feldspar crystals do not show distortion by folding or metamorphism.

By general appearance it is also possible that these pegmatites might belong to a series of pre-Cambrian (pre-Beltain) pegmatites which occur widely scattered in southwestern Montana. These cut the pre-Belt rocks and stop at the contact of Belt sediments in other areas of Montana where pre-Cambrian rocks are exposed.
ECONOMIC CONSIDERATIONS

The crystalline structure and purity of the graphite make it exceptionally well suited for use in the crucible-making industry, the crucibles being used in the melting of special steels and alloys for the production of arms and munitions. The current sea-board (Eastern coastal points like New York City) price at the time of the writing of this report is from 12¢ to 15¢ per pound of graphite F.O.B., for graphite that will stand on a 50 mesh screen. For minus 50 mesh material which is classified as flakes, and for dust the price is from 8¢ to 12¢ per pound F.O.B. The freight cost of shipping from Dillon to sea-board points is $16.80 per ton; to Detroit it is $12.60; and to Pittsburg and Chicago the rate is $12.20.

Considerable graphite was shipped from the Crystal Graphite Mine during the period of the first World War. According to the information obtained the property had a total production at that time of about 2,200 tons of graphite about two-thirds of which was produced in 1916-17-18. The price of graphite then ranged from 5¢ to 18¢ per pound.

According to the operators the property is not in actual operation at the present and the work being done consists mostly of a development nature. However, some graphite has been marketed. About the only expense in-
involved in producing the graphite is that of mining and shipping, since the graphite is separated from the country-rock by hand during the process of mining, thus eliminating the cost of milling and concentration. The graphite which is sacked for shipping is quite free of gangue and may range from 75% to 98% carbon. Material that is too small or too low in grade for hand sorting "goes over the dump" thus creating a stock-pile which will be milled and concentrated in the future when the proposed mill is erected according to the operators.

At the time of the writer's visit to the mine the development work had not proceeded far enough to prove the continued existence of the said deposit below the old workings, but prospecting already done shows very good signs that it does.

OTHER ECONOMIC MINERALS

Besides the deposit of graphite in this general area there is also a deposit of talc about two miles away in a northwesterly direction. The talc is being mined at the present by the Tri-State Minerals Company and is being shipped to Ogden, Utah, for treatment. It occurs as a large lenticular body and lies parallel with the bedding of the limestone member of the Cherry Creek series. The body has a strike of N. 70° E. and a dip of 20° to the northwest.
Also three and a half miles southeast of the graphite deposit there is found a nickel-bearing rock in an ultramafic intrusive that has intruded the Cherry Creek rocks. According to the writer's knowledge this deposit is not being worked, due to its lowness in grade.

From information gathered from prospectors in this general area deposits of tungsten may be present.

CONCENTRATION OF GRAPHITE-BEARING ROCK

For the writer's own information and possibly as a preliminary study of the milling and concentrating characteristics of the graphite ore of the Crystal Graphite Mine, experimental work in concentration of the ore was undertaken. This work was done in the Mineral Dressing Laboratories of the Montana School of Mines.

An attempt was made to obtain as representative a sample as possible under the prevailing conditions, from the Brown, Magee, Thompson, and King stopes and also from the various dumps on the workings. These were mixed together to make a product that would represent a fairly accurate sample of ore which would be treated in the proposed mill.

As the time was limited, only flotation and sink-and-float fractionation investigations were performed.

The ore was first crushed in a Traylor 2\(\frac{1}{2}\) inch Bull Dog Gyralory and then in an Engelbach Coffee Mill crusher.
to pass a 10 mesh Tyler screen in entirety. The crushed ore was coned and quartered and one quarter taken as a head sample. 1,305 grams of this were placed in a Ro-Tap machine on a 28 mesh Tyler screen, and screened for twenty-five minutes. This sizing gave 620 grams of -28 mesh material and 683 grams of +28 mesh material.

**Flotation Test**

Batch flotation tests were conducted in a 600 gram Fagergren laboratory flotation cell. From the 620 gram sample of -28 mesh material 39.8 grams of cleaner concentrates, 27.5 grams of middlings, and 548 grams of tailings were obtained. The reagents used were 0.2 lbs. of pine oil as frother and collector in the roughing operation, 0.1 pound of sodium silicate to disperse the silicate minerals in the first cleaning operation and 0.05 lbs. of pine oil in the second cleaner operation. All reagent quantities are expressed in pounds per ton of ore.

This combination of reagents effected excellent flotation of the ore.

Table 1 presents analytical data and recoveries obtained by flotation of the ore.

**Sink-and-Float Fractionation**

Since the graphite has a specific gravity of 2.2 it would therefore float on a liquid having a specific
gravity somewhat higher than this. On the other hand, silicate mineral of quartz, having specific gravities of approximately 2.6 would sink. Therefore acetylene tetrabromide (specific gravity of 2.95) diluted to a specific gravity of 2.35 was chosen to serve as the heavy liquid. To obtain this specific gravity 355 cc. of acetylene tetrabromide was diluted with 145 cc. of benzene having a specific gravity of 0.879.

Microscopic examination of the sink product thus obtained showed much interlocking between gangue and graphite, indicating that such a process would not be satisfactory for concentrating the graphite.

Table II presents data obtained from the sink-and-float test.

Both the flotation concentrates and the float on 2.35 specific gravity contained as a major impurity a brownish mineral.
TABLE I
Flotation concentration of minus 28 mesh fraction of graphite-bearing rocks.

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight grams</th>
<th>Weight %</th>
<th>Assay per cent</th>
<th>% of the Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaner Conc.</td>
<td>39.8</td>
<td>6.4</td>
<td>67.7</td>
<td>91.47</td>
</tr>
<tr>
<td>Middlings</td>
<td>27.5</td>
<td>4.5</td>
<td>5.6</td>
<td>5.32</td>
</tr>
<tr>
<td>Tailings</td>
<td>548.0</td>
<td>89.1</td>
<td>0.17</td>
<td>3.21</td>
</tr>
<tr>
<td>Composite</td>
<td>615.3</td>
<td>100.0</td>
<td>4.736</td>
<td>100.00</td>
</tr>
<tr>
<td>Head Sample</td>
<td>-</td>
<td>-</td>
<td>3.6</td>
<td>-</td>
</tr>
</tbody>
</table>

TABLE II
Sink-and-Float fractionation of minus 10 plus 28 mesh fraction of graphite-bearing rocks.

<table>
<thead>
<tr>
<th>Product</th>
<th>Weight grams</th>
<th>Weight %</th>
<th>Assay per cent</th>
<th>% of the Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float</td>
<td>20.1</td>
<td>2.99</td>
<td>41.5</td>
<td>56.12</td>
</tr>
<tr>
<td>Sink</td>
<td>652.5</td>
<td>97.01</td>
<td>1.0</td>
<td>43.88</td>
</tr>
<tr>
<td>Composite</td>
<td>672.6</td>
<td>100.00</td>
<td>2.211</td>
<td>100.00</td>
</tr>
<tr>
<td>Head</td>
<td>-</td>
<td>-</td>
<td>3.6</td>
<td>-</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

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In closing, I must say a final heartfelt "thank you" to Mr. Edmund M. Fern for having so generously helped in the synthesis of this thesis.
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