Geology of the Wasa mining area Granite County Montana

Kenneth Keith Smallwood

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GEOLOGY OF THE WASA MINING AREA
GRANITE COUNTY, MONTANA

by

Kenneth K. Smallwood
B.S. Montana State University, 1949

Presented in partial fulfillment of the requirements for the degree of
Master of Science

MONTANA STATE UNIVERSITY
1956

Approved by:

[Signatures]

Chairman, Board of Examiners

Dean, Graduate School

Date: May 29, 1956
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GEOLOGY OF THE WASA MINING AREA
GRANITE COUNTY, MONTANA
Kenneth K. Smallwood

ABSTRACT

The Wasa mining area, which is located in the Drummond Quadrangle, was studied in the summer of 1954 and a report with a geologic map and cross-sections was prepared.

Upper Paleozoic and lower Mesozoic sediments form a sharply folded, northward plunging anticline along Dunkleberg Ridge, on which the Wasa mining area is located. Two major longitudinal normal faults cut through the mining area. The western fault is the Wasa-Shamrock and the eastern fault is the Kirkendal. The hanging wall blocks are on the east side of each of these steeply dipping faults and have throws of less than 300 feet.

A north striking thrust fault is located on the east flank of the Dunkleberg anticline and is called the Homestake Thrust. This thrust has an estimated heave of 750 to 1,000 feet and the throw may be as much as 600 feet. Lower Cretaceous beds have been thrust westward over upper Cretaceous beds. Further down the east flank of the anticline, the Homestake Thrust Fault is cut by a nearly vertical fault which
dropped the upper Cretaceous sediments down against the Kootenai formation.

The Wasa-Shamrock, Kirkendal, and Homestake faults are cut by a transverse normal fault in the southern part of the Wasa mining area. Here the lower Kootenai formation has been dropped into contact with the upper Paleozoic rocks.

The Wasa mining area is of interest because of the low grade zinc deposits in it. The principal deposits occur in the hanging walls of the Wasa-Shamrock and Kirkendal faults; however, there is some disagreement about the method in which the ore was deposited. Glockzin (1953) states that most of the ore occurs in irregularly formed fissures. Popoff (1953, p. 7) believes that the ore bodies are mainly metasomatic replacements of a few favorable limestone beds and that the quartz sulphide veins are generally secondary in importance.

Correlation between sub-surface and surface geology has not been attempted.
INTRODUCTION

Purpose of the Investigation

This investigation was undertaken at the request of the Western Montana Exploration and Development Company, Missoula, Montana, for the purpose of obtaining detailed surface geological information. The results do not answer all the problems encountered in the mining operations of the past, but it is hoped that much of the knowledge gained by this surface work can be correlated with future sub-surface geological findings.

Location and Accessibility

The Wasa mining area is located in the Dunkleberg mining district. The area is in the northern portion of the Flint Creek Range of the Northern Rocky Mountain System (Fenneman, 1931, p. 214). The area is bounded on the west by the Flint Creek Valley, on the north by the Clark Fork Valley, and on the east by the Deer Lodge Valley; it is located approximately 40 miles west of the Continental Divide (Pl. II). The northern part of the Wasa mining area is located in the Drummond Quadrangle and the southern part is located in the Philipsburg Quadrangle. More specifically, the area lies mainly in Secs. 27 and 34, T. 9 N., R. 12 W.;
Plate I. Index map showing location of Dunkleberg mining district. The Wasa mining area is in the southern part of the district. Modified from Popoff 1953, Fig. 1
Plate II. Map of Western Montana showing approximate location of the Missa mining area. Enlarged from Map of the Land Forms of the United States by Baisa (1939).
but small parts of Secs. 22, 28, and 33, T. 9 N., R. 12 W. and Secs. 3 and 4, T. 8 N., R. 12 W., are included for more complete coverage.

Two dirt roads lead into the area. One road joins U.S. Highway No. 10A approximately 8 miles south of Drummond, Montana, and follows an easterly direction up the North Fork of Douglas Creek; the other road joins U.S. Highway No. 10 approximately 8 miles east of Drummond, Montana, at Jens (a U.S. Post Office) and follows Dunkleberg Creek upstream in a southerly direction. The distance from both turn-offs to the Wasa area is approximately 11 miles. Both roads have gentle grades until they reach the mining area, where the grades become relatively steep with sharp turns. The upper portions of the roads are in fairly good condition throughout the summer and early autumn because of maintenance work by the U.S. Forest Service. From November until May, they are often impassable because of heavy snows and spring rains.

Previous Work in the Area

According to Popoff (1953, pp. 2 & 3), silver-lead deposits were first discovered in the area about 1880. Frank Carnes staked the Forest Rose and several adjacent claims in 1884. From 1884-1910, other claims were recorded including the Mountain Chief, Pearl, Kirkendal, and Monarch. A small amount of oxidized silver-lead ore was mined at that time.
The Wasa deposits were discovered in 1910. The deposits were extensively explored by adits, and in 1916 Makeever Bros. of New York City diamond core drilled the Wasa ore deposits. Sixteen holes were drilled with an aggregate length of over 3,700 feet. Approximately 2,000 tons of ore were produced during World War I (Popoff, 1953, p. 3).

In 1916, J. T. Pardee (1917, pp. 241-247) made a reconnaissance geologic study of the Dunkleberg area. A field study of the general geology of the Philipsburg Quadrangle, which includes the southern part of the Wasa mining area, was made by W. H. Emmons and F. C. Calkins (1913, 271 pp.) during the years 1906 to 1910.

The depression halted all work in the area and it was not until World War II that the price of metals increased sufficiently for work to be resumed. The Forest Rose Syndicate was organized in 1941 and leased several claims which produced ore from the Wasa and adjacent Forest Rose mines. A 100-ton flotation mill was erected and from 1941-1947 treated 113,000 tons of lead-zinc ore valued at $875,000 (Popoff, 1953, p. 3).

In the summer of 1946, the United States Bureau of Mines, Albany, Oregon Branch, began an exploration program in the Wasa mining area. Thirteen core holes, with a total length of 4,506.3 feet, were drilled. In addition, 5,800 feet of roads were built and 220 acres surveyed. Approximately 16,400 linear feet of trenches were dug along the
main faults and mineralized zones. Exploration work by the Bureau of Mines was completed in the autumn of 1948. The results were published as a Report of Investigations (Popoff, 1953, p. 17).

The Western Montana Exploration and Development Company, with offices at Missoula, Montana, leased several claims from the Forest Rose Syndicate and Oscar J. Durand, Hall, Montana, in 1951, at which time some exploratory work was done.

A. R. Glocksin, a former geology instructor at Montana State University, made a reconnaissance study of the geology of the area in the summer of 1952 which he summarized in letters dated July 10, 1952 and April 18, 1953, now on file with the Western Montana Exploration and Development Company.

Since that time, very little exploration work has been done except to reopen a few of the trenches in an attempt to better expose some of the mineralized areas. The author mapped the Wasa mining area in the summer of 1954. The area was mapped on aerial photos. Approximately 50 days were spent in the field.

Acknowledgements

The author wishes to express indebtedness to R. W. Key, M.D., President of Western Montana Exploration and Development Company, and K. P. McLaughlin, former chairman of the Geology Department, Montana State University, whose interest
made this work possible. Gratitude is also expressed to
F. S. Henkala, R. M. Weidman, and J. P. Wehrenberg for
assistance and criticism.
PHYSIOGRAPHY

Topography

From the Wasa mining area northward, the slope of the Flint Creek Range is fairly gradual, descending from a maximum of about 7,200 feet at the southern extremity of the mining area to approximately 4,000 feet in the Clark Fork River Valley.

Dunkleberg Ridge, on which the Wasa mining area is located, is a fairly prominent feature extending northward toward the Clark Fork River. It has rugged topography, with deep valleys which are not readily apparent from a distance extending from the ridge. Bald knobs are conspicuous features along the ridge.

Dunkleberg Creek, which is at the eastern boundary of Dunkleberg Ridge, drains to the north and occupies a valley about 1,000 feet deep with steep sides.

The relief in the mining area is controlled mainly by the structural influence of the folded Lower Cretaceous Kootenai formation. An anticline which plunges north toward the Clark Fork River accounts for the downward slope of Dunkleberg Ridge. Many of the lithologic units of the Kootenai formation, which normally are not very resistant, have been hardened by hydrothermal alteration and now form
the tops of the higher knobs.

The topography is controlled by folds and faults, both to the east and west of Dunkleberg Ridge. The less resistant unaltered Colorado shales partially account for the deep swales.

Drainage

The Wasa mining area is entirely in the Pacific Coast drainage system. The small perennial streams on the east flank of the anticline, namely Dunkleberg Creek and Gold Creek, drain into the Clark Fork River. Those on the west flank, Douglas Creek, Gird Creek, and Barnes Creek, all drain into Flint Creek which, in turn, flows into the Clark Fork River at Drummond, Montana.

Vegetation

The slopes of the area are well covered by conifers, but there are bald knobs which support good growths of grass that provide livestock with ample feed during the summer and early fall months.

The precipitation in the area is between 15-20 inches per year (Popoff, 1953, p. 3). Much of this is snow which may begin falling in the middle of autumn and continue into May. The valleys and wooded slopes retain the snow until June due to lower temperatures at the higher altitudes. Many thunderstorms occur during the summer.
STRATIGRAPHY

The formations exposed in the area mapped are Upper Paleozoic and Mesozoic in age. The Paleozoic rocks include the Pennsylvanian Quadrant formation and the Permian Phosphoria formation. The Mesozoic is represented by the Jurassic Ellis formation, the Lower Cretaceous Kootenai formation, and the Upper Cretaceous Colorado group. Triassic strata, as elsewhere in the Philipsburg Quadrangle, are missing and the suggestion is that during this period, the region was high and not receiving sediments or the sediments were laid down, uplifted, and then removed.

Exposures in the area are very poor. The Colorado group is probably the best exposed, but this group, in general, lies outside the mining area and, therefore, is not treated in detail by this report. Hereafter, the lower portion of the Colorado group will be referred to as the Colorado shale. The Quadrant formation, Phosphoria formation, and Ellis formation, also are not treated in detail because the exposures are so very poor and because they, like the Colorado shale, are not mineralized. But these formations are of value in interpreting the structure of the area.

Quadrant Formation

There is only one good outcrop of the Pennsylvanian
Quadrant formation in the Wasa mining area, and this is a white, fine-grained quartzite. The outcrop is from 75 to 100 feet wide and is located in the northwest corner of Sec. 3 and the southwest corner of Sec. 34; it cannot be traced for any great distance to the north except by topographic expression and float. The quartzite strikes N. 20° E. and dips 60° W.

Another quartzite unit is located approximately 400 feet west of the outcrop described above. This quartzite parallels the first unit and is indicated by a slight ridge and a heavy concentration of float along this ridge. It is believed to be part of the same formation because both units are similar in color, texture, and composition.

Quartzite float is traceable as far north as Trench 1 (Pl. III), where it is cut off by the Transverse Fault about 3,000 feet south of the mining area. Near this trench, much of the float shows the effects of shattering and some pieces have been slickensided.

The Quadrant formation in the Wasa mining area is probably between 400 and 500 feet thick.

Phosphoria Formation

No exposures of the Permian Phosphoria formation are present in the area and it is probably less than 50 feet thick. Its presence is indicated only by a few small chips of bluish phosphatic shale, and the chips are very difficult
to find. This formation is also cut off by the Transverse Fault.

Ellis Formation

As stated earlier, the Ellis formation is very poorly exposed. Only one small exposure is present and it is near the line separating Sec. 34 from Sec. 3 on the west limb of the anticline.

Samples from this outcrop indicate that the rocks have been somewhat silicified. They probably were originally argillaceous limestones or calcareous shales. One sample contains light gray chert nodules which exhibit none of the characteristics of the black chert conglomerate of other areas within the Ellis formation. Another sample from this outcrop contains nodules that are calcareous and some that are argillaceous. None of the nodules are over 5 mm in diameter. The calcareous nature of the rocks is not at all consistent as rocks, a distance of a few feet either across or parallel to the bedding, may not be calcareous. Presumably, this is dependent upon the extent of siliceous replacement of the calcite. The secondary quartz averages about 50 per cent in the samples.

The formation is probably from 300 to 400 feet thick and was traced into the mining area by following float, topographic expression, and soil color. The Ellis formation, because of its shale content, is not too resistant and
weathers quite readily. This results in topographic depression in contrast to the older, more resistant Quadrant quartzite and the younger Kootenai quartzitic conglomerates and quartzites. The weathered soils from the Ellis formation usually are a light buff color.

The formation, like the Quadrant and Phosphoria formations, is cut off on the north by the Transverse Fault.

Kootenai Formation

From the viewpoint of economic importance, the Kootenai formation is by far the most interesting. It is from this formation that all the mines on the Dunkleberg anticline obtained their ore.

There is only one mappable unit within the formation. This unit occurs at the top of the Kootenai formation and is called the Gastropod limestone. The lithologic continuity of the bed, in contrast with the stratigraphically lower units, is so pronounced that it is an exceedingly valuable marker bed. Along the flanks of the Dunkleberg anticline, where the bed is exposed, very little silicification has taken place.

The strata below the Gastropod limestone have been subjected to intense alteration. Only in isolated places do the originally variegated lower beds exhibit the prominent maroon and green colors so characteristic of the formation elsewhere. The predominant colors are now moderate shades
of blues, greens, and grays except where oxidization of pyrite mineralization has produced brown stains.

Approximately one-half to three-fourths of a mile south and slightly west of the Wasa mines, on the west limb of the anticline, a rather poorly exposed section of the Kootenai formation was examined. Alteration decreases southward, so this section has not been greatly affected.

A section was measured in this area and found to compare in thickness with measured sections from nearby areas. The Kootenai formation is approximately 1,650 feet thick but some error may have been introduced by the use of a Jacob Staff, the absence of dips within unexposed units, and the absence of exposed contacts both at the bottom and top of the formation (Pl. III).

The following is a description, with thicknesses, of some of the units of the Kootenai formation as measured with a Jacob Staff south of the Wasa mines in Sec. 33 and Sec. 34.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
<th>Thickness in feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.</td>
<td>Gastropod limestone, numerous fresh water gastropods, crystalline. Blue, and weathers light blue. Consists of three members and interbedded gray and green shales. Contacts indefinite</td>
<td>220</td>
</tr>
<tr>
<td>28.</td>
<td>Unexposed</td>
<td>65</td>
</tr>
<tr>
<td>27.</td>
<td>Limestone, shaley, light blue-green. Weathers very light gray</td>
<td>18</td>
</tr>
<tr>
<td>26.</td>
<td>Shale, calcareous, thin bedded, faintly mottled dark green. Some shale float on a 17 foot unexposed interval</td>
<td>22</td>
</tr>
<tr>
<td>25.</td>
<td>Unexposed</td>
<td>10</td>
</tr>
<tr>
<td>24.</td>
<td>Shale, blocky, calcareous, green. Some maroon and reddish green fissile shale</td>
<td>8</td>
</tr>
<tr>
<td>No.</td>
<td>Description</td>
<td>Layer Number</td>
</tr>
<tr>
<td>-----</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>8</td>
<td>Shale, non-calcareous, red, green, gray</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>Limestone, dense, dark. Contains calcareous nodules</td>
<td>42</td>
</tr>
<tr>
<td>10</td>
<td>Sandstone, shaley (medium sized angular quartz grains), greenish. Weathers light gray. Possibly a thin dark dense limestone 10 feet from bottom</td>
<td>25</td>
</tr>
<tr>
<td>11</td>
<td>Mostly unexposed; possibly shale, sandy, medium green to dark</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>Sandstone, medium gray, grading vertically into a shaley siltstone and becoming coarser near the top of the siltstone</td>
<td>73</td>
</tr>
<tr>
<td>13</td>
<td>Shale, fissile and often slabby, both calcareous and non-calcareous. Light gray, maroon, and green</td>
<td>140</td>
</tr>
<tr>
<td>14</td>
<td>Unexposed</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>Limestone, dense, siliceous, dark greenish-gray with a few interbedded shales. Weathered surface is lighter with dark conspicuous blebs in the limestone. Weathers brown just beneath the surface</td>
<td>35</td>
</tr>
<tr>
<td>16</td>
<td>Unexposed, but float is shale, non-calcareous, green and maroon. Weathers very dark</td>
<td>35</td>
</tr>
<tr>
<td>17</td>
<td>Shale and limestone, interbedded. Some limestones have light colored calcareous nodules within them. Limestones are mostly dark gray in color. Weathers dark</td>
<td>25</td>
</tr>
<tr>
<td>18</td>
<td>Shale, blocky and fissile interbedded, green and black. Some shaley limestone</td>
<td>25</td>
</tr>
<tr>
<td>19</td>
<td>Shale, calcareous and dense, green to gray. Weathers green</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>Upper portion unexposed, but probably green and maroon shales. Lower portion shales, calcareous, blocky, maroon with slight green tinge to almost black</td>
<td>30</td>
</tr>
<tr>
<td>21</td>
<td>Shale, slightly calcareous to non-calcareous, fissile, mottled red, green, black. Last 10 feet rather blocky</td>
<td>30</td>
</tr>
<tr>
<td>22</td>
<td>Mostly unexposed; but some shale, siliceous, dense, black, green, and dark gray</td>
<td>20</td>
</tr>
<tr>
<td>23</td>
<td>Shale, non-calcareous, maroon and green</td>
<td>12</td>
</tr>
</tbody>
</table>
7. Sandstone, shaley, medium gray with red non-calcareous patches, becoming more shaley near top .................................................. 20
6. Shale, fissile, non-calcareous, black, dark gray, green. Some-what mottled appearance .................................................. 15
5. Shale, mostly unexposed, dark maroon .................................. 65
4. Shale, sandy, green, gray, reddish gray ........................................... 15
3. Unexposed, but float indicates shale, dense, non-calcareous, black .......................................................... 75
2. Unexposed. Probably dark limestone and shale ........................................... 500
1. Quartzite, conglomeratic, basal unit dark. Red quartzite with red interbedded shale ........................................... 130

Total .................................................................................. 1650

All attempts to trace the units into the mining area were fruitless, with the exception of the Gastropod limestone. On the west limb of the Dunkleberg anticline, occasional outcrops of this fossiliferous unit can be found. The United States Bureau of Mines exposed, by trenching, the Gastropod limestone around much of the anticline (Popoff, 1953, figs. 4a and 4b), except in the southeast quarter of Sec. 34 near the North Fork of Gold Creek (Pl. III).

East and slightly north of drill hole 11 (Pl. III), on a high bald knob, Kootenai rocks are exposed along the south slope and they seem to be typical of lithologies found in most of the float and exposures throughout the mining area. For this reason, these rocks will be described in detail.

Sample 1 (a):

This rock is a silicified sandy limestone, in which most of the calcium carbonate has been replaced by
microcrystalline silica. The color is a medium gray and is
tan on weathered surfaces. Alternate light and dark bands
are present. The dark bands appear to be calcareous with
some pyrite mineralization. The light bands are siliceous
and this effect is probably produced by replacement of the
calcite.

The outer surfaces of the rock show the effect of
differential weathering. The hardness of the rock varies
from about 4½ to 7.

The estimated composition of the rock is as follows:

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td></td>
</tr>
<tr>
<td>Calcite</td>
<td></td>
</tr>
<tr>
<td>Dark minerals (Pyrite, limonite, etc.)</td>
<td>5</td>
</tr>
</tbody>
</table>

Sample 1 (b):

This sample was taken very close to Sample 1 (a) but
is coarser grained. The color is about the same and it is a
silicified calcareous sandstone. Silica has replaced the
calcite and has firmly cemented the quartz grains. Some of
the quartz grains are 1 mm. in diameter.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica</td>
<td></td>
</tr>
<tr>
<td>Crystalline</td>
<td></td>
</tr>
<tr>
<td>Microcrystalline</td>
<td></td>
</tr>
<tr>
<td>Pyrite, limonite, magnetite</td>
<td></td>
</tr>
</tbody>
</table>

The pyrite is disseminated throughout the sample.

Sample 2:

This was a dense silicified limestone and minute
Pyrite blebs are disseminated throughout. Fresh colored surfaces are bluish gray to blue and weather to a lighter gray color. The hardness varies from approximately 6 to 7.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica (mostly microcrystalline)</td>
<td>75</td>
</tr>
<tr>
<td>Calcite</td>
<td>23</td>
</tr>
<tr>
<td>Pyrite, limonite, magnetite</td>
<td>2</td>
</tr>
</tbody>
</table>

Sample 3:

The appearance of this sample is much the same as those above but somewhat bluer in color on fresh surfaces. This rock is a silicified sandy limestone which became silicified because of the hydrothermal introduction of silica which replaced much of the calcium carbonate.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica Crystalline</td>
<td>15</td>
</tr>
<tr>
<td>Silica Microcrystalline</td>
<td>75</td>
</tr>
<tr>
<td>Calcite</td>
<td>8</td>
</tr>
<tr>
<td>Pyrite, limonite, magnetite</td>
<td>2</td>
</tr>
</tbody>
</table>

Samples taken up the slope of this bald knob are not appreciably different. A study of these rocks reveals the nature of some of the more poorly exposed Kootenai strate within the mining area.

Most of the beds on the Dunkleberg anticline seem to dip quite steeply with the exception of the area between the Koski adit and the Wasa-Shamrock Fault. Oriented samples from this area were collected in an effort to determine, by thin section, the attitude of these beds. This work was
Colorado Shale

As stated previously, no attempt was made to map all of these shales and the overlying shales and sandstones because it was considered beyond the scope of this paper, and therefore, only the shales a few feet above the Kootenai-Colorado contact were mapped.

Generally, the lower portion of the Colorado group consists of thin bedded calcareous shales and sands overlain by approximately 500 feet of black fissile shales (Emmons and Calkins, 1913, p. 80). Above these shales, calcareous sandstones predominate becoming less calcareous near the top. The Colorado shale is probably better exposed than the older Mesozoic formations.

Tertiary (?) Igneous Activity

During late Cretaceous or early Tertiary time, igneous rocks were intruded into the area, cutting older sediments and, in some instances, spreading along the bedding planes. The youngest sediments that have been affected are in the Colorado shale.

Two separate granitic intrusions are known in the northeast portion of the Philipsburg Quadrangle. The earlier intrusion, located along the east front of the Flint Creek Range, has been strongly sheared, but the later intrusion, a
porphyritic granite which cuts the first intrusion, shows no effects of shearing. These intrusions are apparently early Tertiary in age because they are not affected by the faults which cut the Cretaceous sediments and are older than the ash beds in the valleys. The ash beds are thought to be Miocene in age.

Early Tertiary sills mapped as diorites and gabbros (Pardee, 1917, Pl. X) are located as close as half a mile both to the north and to the east of the Forest Rose mine.

It is clear that the Dunkleberg anticline is partially surrounded by igneous intrusions, probably lower Tertiary in age, and ranging in composition from acid to basic. It is also probable that igneous rocks underlie the mining area and the depths to these rocks may not be great. These igneous rocks were probably the source of the mineralising solutions of the Wasa mining area.
RESUME OF HISTORICAL GEOLOGY

The brief description of the general geology of the surrounding area is abstracted from Calkins and Emmons (1915, pp. 22-24).

Proterozoic Era

Sands, later consolidated into the Neihart quartzite, are the oldest beds in the area. They show the effect of much washing probably by wave action along a beach. The area, including the Philipsburg and Drummond quadrangles, was submerged during the Neihart time by a sea whose shore remained within, or near, these quadrangles until 1,000 feet of sediments had accumulated. There probably was considerable subsidence during the deposition of the sands. Subsidence continued and deposition of regularly banded and fine-grained bluish muds throughout an extensive area in Montana and Idaho indicates a somewhat deeper and more widespread sea was present. Some quartzite is found interbedded with the argillites. The sediments are known as the Prichard formation and are approximately 5,000 feet thick.

The Ravalli formation, approximately 2,000 feet of quartzite, was deposited under shallow water conditions. The quartzites are less pure than the Neihart quartzites.
Cross-bedding is present in some of the quartzite beds.

The Newland formation, approximately 4,000 feet thick, is composed of limestones and interbedded ferruginous sandstones and shales indicating shallow water and subaerial deposition. The deposition of clastic and non-clastic sediments may be the result of rivers entering and leaving the basin. The basin waters became saturated with magnesium, iron, and calcium carbonate which were precipitated. No gypsum or salt was precipitated. An alternate explanation for these precipitates is that they might be attributed to aquatic organisms which were capable of precipitating carbonates from dissolved bicarbonates.

The Spokane formation which Clapp and Deiss (1931, p. 694) correlated with the lower part of the Missoula group, is approximately 5,000 feet thick and is made up of sandstones and shales. It is similar to the Newland formation except that the limestones are generally absent in the Spokane formation and both suggest deposition in shallow water or on dry land. The land surface was elevated and the sediments gradually became coarser. In general, the Spokane formation was probably formed as a deposit laid down by the shifting currents of a muddy river on a large, subsiding delta plain. Small lagoons separated by wholly dry land areas were probably a prominent feature. Red muds from recently dried up lakes were intermingled with wind-blown sands.
Paleozoic Era

In late pre-Cambrian and early Cambrian time, the land surface was exposed to erosion by crustal unrest. Several thousand feet of the late pre-Cambrian Missoula group were eroded and finally the area was reduced to rather low relief. The unconformity thus produced is general throughout the Rocky Mountain region.

In middle Cambrian time, subsidence permitted the seas to invade the land, presumably from the south. The Flathead quartzite, which is from 50 to 250 feet thick, was deposited while the seas were shallow. As the seas became deeper, glauconitic green sands and calcareous muds were successively deposited and these sediments are now included in the Silver Hill formation. The formation is from 100 to 300 feet thick. Continued calcareous oosre deposition, under rather deep water conditions, resulted in the Hasmark formation which contains 100 to 1,000 feet of dolomite.

The Hasmark is overlain by the Red Lion formation and both were deposited under similar geologic conditions. The Red Lion formation consists of approximately 290 feet of calcareous shale and siliceous banded limestones and the latter form prominent outcrops which make very useful horizon markers.

It is believed that shale beds alternating with the limestones were deposited as a result of uplift and resultant erosion of the source area, keeping the Cambrian seas muddy.
In late Cambrian or post-Cambrian time, the Philipsburg area was more extensively uplifted as indicated by the sandy nature of the Maywood formation. This formation is between 200 and 300 feet thick and consists of a basal calcareous sandstone, red flaggy limestones, and interbedded shales. The age of the formation is not definitely known but it was believed, by Emmons and Calkins (1913, p. 65), to have been deposited during Ordovician or Silurian time. Hanson (1952, p. 25) believes the Maywood formation is lower to middle Devonian in age.

It is uncertain whether or not the Philipsburg Quadrangle might have been an elevated land surface between the deposition of the Red Lion and the Maywood formations. No sediments are found between the Maywood formation and Jefferson dolomite, which is upper Devonian in age. This lack of sediments and the local conglomerate present at the base of the Jefferson dolomite seems to indicate that the quadrangle stood above sea level during Ordovician and part of Silurian. In upper Devonian time, the land surface was rapidly depressed, and approximately 1,000 feet of Jefferson dolomite and evaporites accumulated (Sloss and Laird, 1947, p. 1404). During late Devonian, no sediments corresponding to the Three Forks formation, present in central Montana, were deposited suggesting that the region was again emergent.

About 1,500 feet of relatively pure Madison limestone was deposited during lower Mississippian time. Much of it
is rich in mollusk and brachiopod remains. This was the last period that conditions permitted deposition of such pure limestones.

Conditions, as indicated by the lithologic differences between the Madison limestone and the overlying Amsden formation, were very different in late Mississippian and early Pennsylvanian time. This change was very sudden and the lithologic character of the 100 to 300 feet of red shales and impure limestones seems associated with inland sea conditions where much evaporation occurred. In other areas in Montana, gypsum beds and salt crystals are found in similar Mississippian and Pennsylvanian rocks.

The Quadrant formation which is from 350 to 800 feet thick consists mainly of quartzites which are probably beach deposits. The quartzites seem to have been superimposed upon the fine-grained rocks of the underlying Amsden formation after a period of erosion because deposition that was continuous might have resulted in a gradual instead of an abrupt change in lithology. Therefore, it is assumed that in early Pennsylvanian time, an inundation took place and the beach sands were deposited along the advancing margin of the sea. Later, phosphatic limes were deposited from an enclosed shallow sea. These phosphate beds of Permian age, are extensive indicating a shallow sea that extended continuously over a large part of Montana, Wyoming, Idaho, and Utah.
Mesozoic Era

Triassic rocks are absent in the area, but it is not known whether it was a positive area during that time, or whether the sediments were laid down, uplifted, and then removed. The latter might be more reasonable as the chert pebbles found in the Jurassic Ellis formation are thought, by some, to have been derived from previously existing Triassic rocks. During the deposition of the 430 feet of Ellis formation, the seas must have been shallow and the shoreline nearby, because some of the beds are conglomeratic and also because of the presence of carbonaceous and argillaceous materials in the limestones.

Pre-Laramide movements elevated the floor of the Ellis sea which then became the site for fresh water deposition. There appears to have been a large interior basin extending over a wide area in Montana and Canada. This area seems to have been partly occupied by lakes, marshes, and river flood plains. It was in such an area that the lower Cretaceous Kootenai formation was deposited. The formation is between 1,500 to 1,600 feet thick. Some coal has been found not far from the Philipsburg Quadrangle in Cretaceous sediments.

Limestone beds representing marl deposits, some containing fresh water snails and clams, occur in the Kootenai formation.

After deposition of the Kootenai formation, the area
was again uplifted and some erosion took place. Following the uplift, submergence began in lower Cretaceous time. The first deposits consisted of black mud now known as the Colorado shale. The sediments contain much carbonaceous material. The succeeding Colorado units are less calcareous indicating a shallower sea, either as a result of increase in sedimentation or of uplift. The Colorado group is about 1,500 feet thick. K. P. McLaughlin and D. M. Johnson (1955, pp. 120-123) determined the stratigraphic thickness of the Colorado shale and overlying Montana group along Hoover Creek and Warm Springs Creek. The two creeks are within 15 miles north and east, respectively, of the Wasa mining area. The Colorado shale along Hoover Creek has a thickness of over 3,000 feet. The Montana group, consisting of sandstones, siltstones, and shales, is 3,730 feet thick.

Cenozoic Era

Tertiary Period

The history recorded in pre-Tertiary time was relatively uneventful. It was marked by sedimentation, uplift, erosion, and re-submergence. In the relatively short Tertiary period, a far more complex history was recorded. The earth's crust that had been relatively stable from Algonkian through Mesozoic time was orogenically deformed during late Cretaceous and early Tertiary time, and the resulting geologic structures record these events. Igneous activity
was common in Tertiary time as attested to by intrusions, lava flows, and pyroclastics. During the Tertiary period, the region was mostly a positive area exposed to erosion.

Physiographic Development

Two major older sculptural features are recognized. They are the flat, upland surfaces, and the bedrock slopes of the broader valleys. The most acceptable hypothesis for the regional development of the two topographic features is that the region was reduced to low relief in pre-Eocene time, followed by uplift and erosion. Broad valleys were formed in the upland peneplain in late Eocene time. These valleys were filled with gravel and volcanic ash. The valleys, then, are younger than the plateau-like remnants of the old, flat surface. The gravels were then tilted and the peneplain warped by the deformation that followed in early Oligocene time.

During late Oligocene or early Miocene time, the depressions, formed by tilting and faulting, began to accumulate lava, tuff, ash, and detrital materials from renewed volcanic activity. Some lakes were probably formed in the basins, and volcanic action likely resulted in some ponding of streams.

After the filling of the basins, a period of extensive erosion and deposition occurred energized by deformation in Pliocene time. As a result, the older streams drain out through deep mountain gorges instead of established passes.
This was probably because the basins were completely filled with sediments. Some of the passes might have been blocked by later Pleistocene gravel deposits. The streams could escape in any direction through gaps that might not be coincidental with the established passes, and new gaps were cut. Consequently, the drainage of the Philipsburg Valley is northward through a canyon instead of southward through the lowest part of the bedrock rim.

As a result of drainage changes, a broad layer of volcanic ash was removed in post-Miocene time, following which the valleys again became areas of deposition. The higher areas still supplied sediments through vigorous erosion and the gravels have been spread over the valley floors. The higher terraces are remnants of this deposition and are probably Pliocene in age.

Quaternary Period

It is thought that during early Quaternary time the climate was similar to that which now exists in the Canadian Rockies. This would mean that the climate was much colder and the precipitation much heavier than at present. As a result, many glaciers formed in the higher areas and descended down the preglacial valleys. As they entered the broader, warmer valleys, melting counterbalanced the flow from the higher areas, and water from the glaciers spread gravel and mud across the floors of the valleys.

The climate became warmer and the glaciers vanished.
Erosion cut deeply into many of the glacial features and many moraines were partially removed.

There is fairly good evidence that at least two major glaciations occurred in the area, and probably there were several others. These two major glaciations left moraines and sculptural evidences. Between these two glacial stages, there seems to have been a considerable time lapse because of the great disparity of preservation of glacial deposits.

During periods of glacial action, the streams were forced to change their courses to the south and much ponding occurred. Glacial Georgetown Lake was forced to establish a drainage northward along the west side of the Flint Creek Range. The Philipsburg valley reverted to its former northward drainage after the ice had receded.

Since the last glaciation, little erosion has occurred. The cirques have accumulations of talus below them, accumulated by frost action. The streams have become more sharply entrenched, and in the lower valleys, the hollows below the moraines have been alluviated.
STRUCTURE

Introduction

Faults and folds within the Philipsburg Quadrangle generally have a northerly trend. In the northeast part of the quadrangle, the folds are very tight and a northward plunge is common. Many of the anticlines have axial planes which dip to the east, and often the west limbs of the structures are overturned (Emmons and Calkins, 1913, p. 141).

The faults vary from low angle thrusts to high angle reverse and normal faults, and the majority of the northward trending normal faults are downthrown on the east. Thrusting has been mainly from the west and the most prominent thrust in the Philipsburg Quadrangle is named the Philipsburg Overthrust. The throw of this thrust can be measured in miles and it has been suggested that the thrust is a southerly continuation of the Lewis Overthrust (Emmons and Calkins, 1913, p. 146). Most of the thrusts have been cut by numerous high angle normal and reverse faults, which further complicate the situation (Emmons and Calkins, 1913, p. 141).

The folds and faults in the southeast part of the Drummond Quadrangle, in which the Wasa mining area is located, follow the same pattern as those of the adjacent Philipsburg Quadrangle.
The Wasa Mines are located near the axis of the Dunkleburg anticline. The anticline has been faulted extensively, and the relationships and displacements of the main faults have been greatly masked by numerous smaller faults and also by rock alteration which obliterated bedding planes. In addition, much of the area is overgrown with timber and covered by overburden.

The main faulting in the area roughly parallels the anticlinal axis with the exception of a transverse fault that cuts the structure approximately one-half mile south of the Wasa Mines. Along the east flank of the fold, an east dipping thrust has been located, and it can be observed in Trench No. 6. The fault is named the Homestake Thrust (Pl. III).

The two faults of most interest from the standpoint of mining operations are the northerly striking faults intersected by the Wasa and Kirkendal adits. The western fault has been named the Wasa-Shamrock Fault (Popoff, 1953, p. 10). The eastern fault, not previously named, will be referred to as the Kirkendal Fault after the adit which intersects it. One other major fault, located along the West Fork of Dunkleberg Creek, has not been named (Pl. III). It may be a steeply dipping normal or reverse fault.

Emmons and Calkins (1913, p. 141) believed the deformation in the Philipsburg Quadrangle occurred in late Cretaceous or early Tertiary time. The Cretaceous sediments
have all been involved in the folding, and some of the later intrusions show the effects of movements. Most of the folds and thrusts in the Philipsburg Quadrangle have been cut by later normal faults.

The sediments in the mining area were probably folded in early Tertiary time and the major faults were subsequent to the folding. After the folding, the Homestake Thrust formed, and later the longitudinal normal faults developed. The last development was the normal Transverse Fault which displaced all the others.

Folds

Dunkleberg Anticline

The Wasa Mines, as previously indicated, are located near the axis of the north plunging, tightly folded Dunkleberg anticline. The upper Paleozoic and Mesozoic formations have been folded tightly into a nearly symmetrical anticline. Approximately 2 miles south of Trench 13 along the extension of the anticline, however, the axial plane dips to the east and the west limb of the structure is vertical, or might even be overturned (Calkins and Emmons, 1915, Structure Sections).

The attitude of the folded beds was determined mainly along the gastropod limestone member of the Kootenai formation because very few reliable strikes and dips could be obtained elsewhere. The limestone dips approximately 60°
west along the west flank of the anticline and the dips vary from 60° to 80° east along the east flank. However, the steeper dips were obtained in trenches 1 through 6 along the Homestake Thrust (Pl. III).

Subsidiary Folds

Two subsidiary folds were inferred between the Homestake Thrust and the West Fork of Dunkleberg Creek. One very small outcrop of Gastropod limestone located near the Homestake Thrust probably is connected to another small outcrop of the same limestone a short distance to the east. The attitudes of the two outcrops indicate that the first might be the east limb of a small anticline and the second the east limb of a small syncline.

Faults

The Wasa-Shamrock Fault

The Wasa-Shamrock Fault zone is of great interest because it is from this zone that the Wasa No. 1, 2, and 3 mines have produced ore. Associated with the hanging wall block of the fault are two distinct, nearly parallel, gossan zones. They have been designated the east and west gossan zones and will be discussed later.

The strike and dip of the fault taken in Trench 13 along the hard siliceous limestone footwall surface varies as greater depth is attained. The dip seems to flatten slightly with depth and the strike swings slightly more to
the northwest. Near the surface in Trench 13, the strike is approximately N. 3° W. and the dip is about 55° to 60° N.E. In the bottom of the trench, about 15 feet lower, the strike is N. 13° W. and the dip is 52° N.E. This would suggest a concavity of the zone, which, however, might be simply a local irregularity of the fault surface. Glockzin (1952) established reasonably good control in the underground workings of the east gossan zone, which is approximately parallel to the fault, and found that it is concave to the northeast. He tended to divorce the gossan zones from the Wasa-Shamrock Fault and to treat them as independent fault zones. He also suggested that the west zone steepens greatly with depth and locally it may even dip west. The reason for this statement is the fact that in the underground workings, no intersection between the two gossan zones and the fault has been found. However, it should be pointed out that a shallower dip than anticipated would account for the same results and would coincide with shallower dips found underground along the east gossan zone. It seems likely that the gossan zones cannot be divorced from the main fault and that they are approximately parallel to the fault and are genetically related to it.

The Wasa-Shamrock Fault is believed to be a normal fault but the displacement has not been established. It occurs on the west limb of the anticline and is said to be a bedding plane (?) fault (Glockzin, 1952). It appears to be a bedding plane fault as exposed in Trenches 13 and 14 (Figs.
1 and 2), and for this reason Glockzin feels that it is overturned in these trenches and will eventually reverse its dip toward the west. In this area, the lower Kootenai formation should begin to wrap around and form a nose dipping gently to the north. It has been found underground that the east gossan zone has a northward strike and an eastward dip. This attitude is probably guided by the Wasa-Shamrock Fault and if so, part of the Wasa-Shamrock Fault would have to cut across the bedding plane and could not there be a bedding plane fault. It has been impossible to obtain reliable strikes and dips between the Wasa-Shamrock and Kirkendal faults, but in general, they seem to substantiate the idea that the lower stratigraphic units of the anticline are beginning to wrap around as would be expected near the nose of an anticline.

The alteration of the beds along the Wasa-Shamrock Fault in Trench No. 13 makes it virtually impossible to identify specific units of the Kootenai formation; but it seems possible that the siliceous limestone footwall, because of its appearance and distance from the anticlinal axis, might be the same limestone as found in a normal section about 450-500 feet above the base of the Kootenai formation.

Because the only rocks present in Trench No. 13 are probably lower Kootenai in age, the maximum displacement probably would not be over 300 feet, and very likely the relative displacement might be as low as 100 to 200 feet. This fault and the associated gossan zones have been traced
for a distance of 500 feet north and 2,500 feet south of Trench No. 13

The East and West Gossan Zones

Two gossan zones have been cut by Trench Nos. 13 and 14 (Figs. 1, 2, and 3). These brecciated zones are located in the hanging wall of the Wasa-Shamrock Fault, with which they are approximately parallel, and were probably formed in fractures which permitted minor adjustments during movement on this major fault. In Trench 13 the east zone is 22 feet wide and averages 2.70 per cent zinc; an average of 4.75 per cent zinc was obtained in a 10 foot zone. The west gossan zone is 16 feet wide and averages 1.88 per cent zinc in the same trench (Popoff, 1953, p. 10). The distance between the two zones in Trench 13 is approximately 5 feet and becomes greater to the south.

The two zones have been traced southward for a distance of about 2,500 feet and it was found that they became much narrower in this direction (Popoff, 1953, p. 10). The distance of both of the gossan zones from the footwall of the Wasa-Shamrock Fault is probably not greater than 200 feet at any time and the two are separated by rock which appears to be silicified.

The strike of the east gossan zone has been fairly well established by Glocksin (1952) who located the zone in nine different places, both on the surface and underground. The strike and dip of the west gossan zone has not been
Figure 1. A view to the south showing Trench No. 13 in the middle foreground, and Trench No. 14 high in the background. Dark areas in Trench No. 13 are the east and west gossan zones in the hanging wall with the Wasa-Shamrock Fault surface on the right.
Figure 2. View south in Trench No. 13 before excavation was completed, showing fault surface along the footwall on the right and the hanging wall in the middle and left side of the photograph.
Figure 3. View of the south side of Trench No. 13 showing brecciation of the rocks in the hanging wall of the Wasa-Shamrock Fault and portions of the east and west gossan zones.
established nearly as well, and the zone has not been located underground. The average width of the two zones is between 15 and 20 feet.

**Problem of Locating the Two Gossan Zones**

The mining operation of the past failed to find the intersection of the two zones and hence missed the areas where the highest grade of ore would be expected.

The possible reasons for not finding the intersection might be: (1) the projected dips of the zones (especially the west gossan zone) have not been valid; (2) that the many small faults have displaced the two zones more than anticipated. In either possibility, more control will have to be established to ascertain a correct average dip for the west gossan zone. Since Glocksin made his study of the area, more material has been excavated from Trench 13 and the dip of the Wasa-Shamrock Fault seems to flatten and the strike swings a little to the northwest. Upon the hypothesis that the west gossan zone will be parallel to the Wasa-Shamrock Fault, because of its nearness and apparent genetic relationship, it is assumed that with depth the dip of this zone will decrease and the strike will swing somewhat more to the northwest from the originally established dip of N. 30° W. The revised strike is approximately N. 130° W. and the new dip approximately 52° N.E. It must be remembered, however, that the control has not been established over a large enough area to make this new strike and dip entirely
reliable.

The apparent northeastward concavity of the west gossan zone seems to agree with the northeastward concavity of the east gossan zone established by Glockzin (1952). Glockzin stated that the dips varied downward from $30^\circ$ to $50^\circ$ N.E. and in calculating the intersection of the two zones, he used an arbitrary dip of $47^\circ$. This dip might not represent the attitude of the zones at depth.

The intersection of the two zones was calculated, by the writer, using a map of the underground workings of the Wasa No. 3 mine, drawn by F. C. Hancock, mining engineer for the Western Montana Exploration and Development Company and modified by Glockzin. The calculations were based on a N. $13^\circ$ W. strike and a $52^\circ$ N.E. dip for the west gossan zone and a N. $23^\circ$ W. strike and a $47^\circ$ N.E. dip (Glockzin, 1952) for the east gossan zone. It was found that if Core Drill Hole No. 7 (Pl. III) had been extended approximately 70 feet the zone of intersection would have been located.

It is likely that the average dips of the gossan zones are somewhat less than previously thought, and the effect would cause the strike of the intersection to swing considerably to the east explaining why the mining operations missed the intersection.

Much more detailed work is necessary before a satisfactory solution can be found to the above problem, but perhaps the supposition that the zones merge into one zone
is the most tenable.

Kirkendal Fault

The Kirkendal Fault branches from the Wasa-Shamrock Fault and very little is known about it except where the fault is cut by the Kirkendal adit. In the adit, Popoff (1953, p. 15) determined the strike to be slightly west of north and the dip 65° to 70° east. The fault probably is a normal fault because, the Wasa-Shamrock Fault from which it branches, is a normal fault and Emmons and Calkins (1913, p. 142) stated that the majority of the north striking faults have their down throw sides on the east. It is virtually impossible, from present data, to estimate the displacement.

Homestake Thrust

The Homestake Thrust, which is located along the east limb of the Dunkleberg anticline, was exposed by Trenches 1, 6, and 10 and Core Drill Holes 1, 2, and 12. Farther south the thrust is located near the east edge of the map area (Pl. III) and extends almost to North Gold Creek.

This fault was not recognized as a thrust fault previously. Beds that appear to belong to the lower part of the Kootenai formation have been thrust westward over the younger Colorado rocks in this area. Near Trench No. 6, the thrust fault dips quite steeply to the east but probably becomes much less steep at depth. The heave produced by
thrusting along the east limb of the anticline seems to be roughly 750 to 1,000 feet and the throw may be as much as 600 feet.

Transverse Fault

The Wasa-Shamrock, Kirkendal, and Homestake faults are all cut by a transverse fault which is located near Trench No. 1 and Trench No. 31 (Pl. III). This fault, which has been named the Transverse Fault, is probably a normal steeply north dipping fault because its trend swings northward at lower elevations. The fault surface is not exposed.

The axial plane of the Dunkleberg anticline does not appear to be displaced appreciably by the fault, but the interpretation of the structure is complicated by local broadening of the crest of the fold just south of the Transverse Fault. The local broadening is inferred from the poor exposures of the formations. Lack of overall offset of the axis coupled with the rough symmetry of the Dunkleberg anticline indicates that the fault is a dip slip fault. The presence of lower Kootenai rocks, on the north, adjacent to the quadrant quartzite, on the south, indicates that the relative downward displacement of the north block has been from 600 to 800 feet.

The westward extension of the fault has not been found but it is unlikely that a fault of such magnitude would die out in such a short distance as shown on the map (Pl. III).
West Fork of Dunkleberg Creek Fault

A longitudinal fault near the West Fork of Dunkleberg Creek cuts the older Homestake Thrust (Pl. III). Little is known about the fault and it may be either a steeply dipping normal or reverse fault. The east side has dropped and has brought the Colorado shales into contact with the older Kootenai formation. The fault has not been traced any appreciable distance in either direction.

Relative Ages of the Faults:

Summary

The Wasa-Shamrock and Kirkendal faults are thought to be younger than the Homestake Thrust. No evidence was found to support this supposition except that Emmons and Calkins (1913, p. 142) state that the usual sequence in the Philipsburg Quadrangle is folding and thrusting followed by the development of longitudinal normal faults.

It is not possible to trace the West Fork of Dunkleberg Creek Fault southward across the Transverse Fault. It may terminate against the Transverse Fault, in which case it is younger, or it may be cut by the Transverse Fault and would then be older. By analogy with the Wasa-Shamrock, Kirkendal, and many north-trending faults in the Philipsburg Quadrangle, the West Fork of Dunkleberg Creek Fault should be a normal east-dipping fault (Emmons and Calkins, 1913, p. 142) and would probably be younger than the Transverse Fault. All the other major faults along the Dunkleberg anticline are older than the Transverse Fault.
MINERALIZATION

No study was made of the mineralization in this area since it was considered to be beyond the scope of this paper. The types of deposits and ore genesis have been discussed, to some extent, by Pardee (1917), Glockzin (1952,1953), and Popoff (1953).

Pardee believed that the Wasa deposits were formed by contact metamorphism (1917, p. 243). He stated that the siliceous hydrothermal solutions which replaced the calcareous materials at depth in the rocks were accompanied by pyrrhotite, pyrite, and chalcopyrite and were followed by sphalerite which partially replaced the other sulphides (1917, p. 245).

Glockzin (1953) was uncertain as to the type of deposit. He seemed to feel that the ore was deposited along fissures with a minor amount of metasomatism. He also made note of the possibility of ore at depth, either in the Ellis formation or the Madison limestone a depth of 300 feet and 700 feet respectively. In the opinion of the writer, the vertical distance of 700 feet to the top of the Madison limestone is insufficient; perhaps 900 to 1,000 feet would be more correct.

Popoff (1953, p. 7) believed the ore bodies were
replacements of a few favorable limestones and that quartz-sulphide veins were secondary in importance. He also stated that the sphalerite was introduced in the later stages and replaced much of the pyrite.

The depth of oxidation is very shallow even though the vein outcrops are completely oxidized. The zones of oxidation are not over 50 feet deep. These zones have been sampled by Popoff (1953). Local concentrations of unleached sphalerite have been located but generally the zones assay very poorly.

Zinc is the most important mineral in the Wasa mining area. The deposits are quite low grade. Other minerals identified in the mines are: sphalerite, galena, chalcopyrite, tetrahedrite, siderite, and very small amounts of gold and scheelite.
CONCLUSIONS

Only one unit in the Wasa Area, the Gastropod limestone, was found to be consistently mappable. Many of the other contacts were inferred from soil color, topographic expression, float, and an occasional outcrop. In most places where bed rock can be found, the alteration of the beds has been so intensive that identification is nearly impossible. In other places within the area, the rocks are covered by overburden and by a dense growth of vegetation.

It has been proven reasonably well that the folding, faulting, and mineralization occurred in post-Cretaceous time. Eardley (1951, p. 319) believes that the mineralization, in the Philipsburg Quadrangle, probably occurred in early Eocene time. However, at least one igneous intrusion occurred earlier. In the Wasa mining area, the sharply folded Dunkleberg anticline was formed and a westward thrust developed on the east flank. After the development of the thrust, the anticline was extensively faulted, mainly by east dipping longitudinal normal faults, and mineralizing solutions were intruded into the brecciated fault zones. The solutions were probably derived from an igneous intrusion which was either contemporaneous with or later than the faulting. Subsequent smaller adjustment faults developed. The longitudinal normal and thrust faults were all cut by a
transverse fault in the southern part of the Wasa mining area. This transverse fault is steeply dipping and drops the lower Cretaceous rocks into contact with the upper Paleozoic rocks.

The Homestake Thrust Fault and the Wasa-Shamrock Fault are the only ones that have been traced for any distance, and more work should be done on the others, including the west gossan zone along the hanging wall side of the Wasa-Shamrock Fault.

The surface geology presented in this paper should be further explored for accuracy by both trenching and subsurface methods. Any further investigation should include a petrographic study of the rocks, and attempts should be made to correlate the sub-surface with the surface geology. Special attention should be given the numerous small faults observed in the underground workings.
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