Geology of the Greenough barite mine Missoula County Montana

Paul Norman Clawson

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ABSTRACT

The Greenough barite deposit was studied in an attempt to determine the origin and nature of the mineralization. The barite occurs in a steeply dipping vein in quartzite which is probably pre-Cambrian in age.

The area surrounding the barite deposit is underlain by slightly metamorphosed sedimentary rocks, marble and quartzite, and by a number of igneous bodies, including quartz monzonite, trachyte, and diorite. The southern part of the area is on the margin of a quartz monzonite stock. The Garnet mining district is on the south margin of this stock.

Study of the vein disclosed that it has the characteristics of both cavity fill and replacement origin. Cavity filling is believed to have been the dominant process in the formation of the vein.

A thin dike of quartz monzonite and a fault of major but unknown displacement occur within and near the barite vein. The dike is younger and the fault is older than the mineralization.

Reconnaissance study of similar nearby barite deposits shows that they form a nearly straight line, trending northeast.
The barite is believed to have been deposited by hydrothermal solutions emitted during or shortly after emplacement of the quartz monzonite stock, probably during early Tertiary time.
INTRODUCTION

Purpose of the Investigation

The purpose of this investigation was to determine the geologic setting of this important deposit of barite, and, if possible, to determine the controls of mineralization. It is hoped that this report will be of value to others who have occasion to study similar barite deposits.

Field Work

Field studies, which included an area of three and one-half square miles surrounding the National Lead Company barite mine, were conducted during the fall of 1956 and the spring of 1957. The areal geology was mapped, and a detailed map of the 900 level of the mine was prepared. Approximately 40 days were devoted to field work. Areal geologic mapping was done on aerial photographs, taken in 1952, of the Lubrecht Experimental Forest, Montana State University Forestry School. These photographs, code numbers Lub. 7-50, 7-51, 7-52, 7-53, were purchased from the U. S. Forest service in Missoula. Plate 1, the areal geologic map, was prepared from photographs 7-51 and 7-53, which were enlarged to give an approximate scale of one inch to 1000 feet; no attempt was made to correct for radial distortion. In mapping underground, horizontal
angles were plotted with a telescopic alidade and a plane table. Station to station distances were measured to the nearest tenth of a foot with a steel tape. Measurements of vein width, walls, and other features were made to the nearest quarter foot with a calibrated wood pole.

Location and Physical Features of the Area

The Greenough barite mine is located in Section 16, Township 13 North, Range 14 West, near the eastern border of Missoula County. It is readily accessible by motor vehicle the year round, by a good gravel road which joins Montana Highway 200 two miles north of the Greenough post office (See Figure 1).

The area studied is drained by Elk Creek and two of its tributaries, Cap Wallace Creek, and the North Fork of Elk Creek. (Henceforth, this stream will be referred to simply as the North Fork.) Elk Creek flows into the Big Blackfoot River, which empties into the Clark Fork, a branch of the Columbia River.

Topography within the area is rugged, with a maximum relief of approximately 1200 feet. Elevations range from 3800 feet, in the valley of Elk Creek, up to 5000 feet, on the ridge between Cap Wallace Gulch and the valley of the North Fork. Slopes are generally steep. As a general rule, the north and east facing slopes are thickly forested with second growth pine, fir and tamarack, while the south and west facing slopes are grass covered. This situation is presumed to
be due to rapid evaporation of moisture from the sunny areas. Precipitation is slightly higher than the annual average of 21 inches measured at Ovando, the nearest U. S. Weather Bureau station. Temperatures are generally moderate, but often drop to far below freezing in winter. Winter snows are heavy, and the area is snow covered from mid-November until mid-April.

Previous Work

Previous work in the area was done by J. T. Pardee, who studied the Garnet mining district several miles to the south. His areal geologic map, on a scale of 1:125,000, included the area of this report; it shows the quartz monzonite stock, the marble, and the quartzite, but does not show the trachyte or diorite porphyry dikes, or the barite vein.

The Engineering Department of the Anaconda Copper Mining Company mapped the upper level of the mine and the open pits. These maps show a limited amount of geology; due to extensive timbering, and the dangerous condition of parts of the upper level, the author did not attempt to appraise the accuracy of the geology which they show. An elevation of 1000 feet was assumed at the portal of the upper level. Hereafter in this report, the upper level will be referred to as the 1000 level, and the lower level will be referred to as the 900 level.

Acknowledgements

The author wishes to express his indebtedness to R. M. Weidman of the Department of Geology at Montana State University,
Figure 1. Index map, showing location of the Greenough barite deposit.

Figure 2. Talus slope composed of fragments of weathered trachyte.
for his many helpful criticisms and suggestions, and for assistance in field work; to James P. Murphy and Robert Olson of the National Lead Company for their cheerful cooperation and assistance, and for permission to use the maps referred to above; to H. R. Eisenbeis, T. Tidyman, B. L. White, C. Bebber and J. Montgomery, fellow students who provided timely assistance; and to J. P. Wehrenberg of the Department of Geology at Montana State University for his helpful suggestions and criticisms. Also, the author would like to express his appreciation to his wife, Marlene, for her help, patience, and encouragement during the preparation of this report.
HISTORY OF MINING

In 1864, placer gold was discovered in many of the streams draining the area around the present location of the town of Garnet. Shortly afterward, the gold, silver, and copper bearing veins at Garnet and Coloma were discovered. Most of these proved to be relatively shallow deposits, and by the earlier part of the twentieth century, they were nearly exhausted. An estimated $6,000,000 to $10,000,000, primarily in gold, was removed from this region. Of this total, approximately $1,000,000 to $2,000,000 is attributed to placer gold from Elk Creek (Pardee, 1917). Placer mining was done from the very head of Elk Creek and its upper tributaries down almost to the present Greenough barite mine. Apparently the placer gold was entirely derived from erosion of the gold bearing veins near Garnet and Coloma, since those tributaries which do not drain that area contain no gold. Cap Wallace Creek and the North Fork of Elk Creek, both of which drain the area east of the barite mine, contain no gold.

From the time placer mining along Elk Creek was discontinued until 1951, when barite mining began, there was very little mining activity in the area. One small deposit of silver bearing galena was exploited along the marble-quartz monzonite contact in the North Fork valley, but it proved very
small and was abandoned. No record of production was seen, but it is said that only two carloads of ore were shipped
(Personal communication, J. P. Murphy).

In 1951, the Finlen and Sheridan Mining Company of Butte, Montana, acquired a lease from the Sunset School district, and began exploiting the Greenough barite deposit, under the supervision of James P. Murphy, the present general manager. Prior to this, the barite deposit was widely known among people familiar with the area from the discontinuous surface outcrops (See Plate 4). It was not mined previously because of the lack of an outlet for crude barite, and the cost of erecting a mill to process the barite for sale.

In late 1955, when the 1000 level was almost worked out, another level, the 900 level, was begun, 110 feet lower down the hillside. At the present time, (May, 1957), the horizontal limit of the vein has been reached, and a third level is being planned.

In early 1956, the mining property and mill were purchased by the National Lead Company and since that time, have been operated by its Baroid Division. Most of the operating personnel have continued on the job under the new ownership, including James P. Murphy, general manager, and Robert Olson, mine foreman.

During 1955 and 1956, several near-surface deposits of barite, one just northeast of the mine, and two about a mile northeast, were worked by open pit methods. No separate
production figures were available to the author, but Mr. Murphy estimates that total production from the mine and the open pits has been approximately 90,000 tons, with a gross value of $900,000.
STRATIGRAPHY

Surface geology of the area surrounding the mine is shown on Plate 1. Unfortunately, the area is almost completely covered with a veneer of soil up to 12 feet thick. Because of this, most contacts between the various rock units are approximately located from observations of float.

No fossils were found in the area; consequently, age assignments are based mainly on the work of others and on structural relationships.

METASEDIMENTS

All of the sedimentary rocks in the area, with the exception of Quaternary alluvium, have been mildly affected by regional metamorphism. Almost pure sandstone has been converted to quartzite, argillaceous sandstone has been converted into micaceous quartzite, and limestone has been recrystallized to form marble. Contact metamorphism has been an important factor locally, and has probably been a dominant factor in the origin of the marble.

The quartzite has been identified by Pardee (1917) as late Algonkian in age, part of the Belt Series. C. P. Ross (Ross et al, 1955) has mapped both the quartzite and the marble as part of the Missoula Group, of upper Beltian age.
Quartzite

Most of the northern part of the area studied is underlain by quartzite, at least 4000 feet thick. The lower boundary of the quartzite is an unknown distance north of the area. Fresh surfaces of this quartzite are dominantly black in color, gradually becoming brown, then gray, as one travels to the north. Excellent exposures of quartzite may be seen along the east bank of Elk Creek, just north of the beginning of the road leading up to the mine. The rock is extensively fractured and jointed, making accurate determinations of strike and dip difficult, and often impossible. One prominent set of joints is almost vertical, and trends east-west, roughly parallel to the strike of the strata. Another set of joints is also almost vertical, and trends north-south, almost at right angles to the other prominent set. Rarely, asymmetrical ripple marks are present. Occasionally, faint traces of former bedding planes are visible, but these usually do not form planes of separation.

In hand specimen, the quartzite appears to be made up almost wholly of quartz, in grains less than 2 mm. across. In some specimens, biotite and muscovite are visible in small amounts. In the quartzite which shows traces of former bedding planes, the mica flakes are usually parallel to the former bedding.

Microscopic examination of a thin section cut from sample 11 (see Plate 1 for location) shows the quartzite to be
made up of 90% of rounded anhedral quartz grains, ranging in size from 0.1 mm. to 2.0 mm. Approximately one third of the quartz grains show strain shadows. Subhedral grains of biotite, slightly larger in size than the quartz, are evenly distributed throughout the specimen. Muscovite is present in lesser amount; the grains are equal in size to the biotite, and are intermixed with it. The flakes of biotite and muscovite appear to be oriented sub-parallel to former bedding planes. Tiny grains of zircon, apatite and magnetite are present in very small amounts.

Certain beds of the quartzite contain black spots, ranging in size from one quarter inch to one half inch across. The spotted appearance is due to aggregates of biotite, roughly spherical in shape. These porphyroblasts evidently formed by segregation of the biotite flakes, since the rock between spots is deficient in biotite. Segregations of biotite such as these are normally associated with contact metamorphism (Williams, Turner, and Gilbert, 1954); however, since the quartzite nearest the igneous bodies in the area has no porphyroblasts, it is more likely due to regional metamorphism. The presence of biotite indicates that temperatures during metamorphism were relatively low, since biotite is unstable at high temperature. Pardee (1917) reported the presence of similar spotted quartzite near Garnet, and identified the porphyroblasts as segregations of both biotite and cordierite. Cordierite was not present in any of the samples examined by
the author. No relationship of the spotted quartzite to any of the igneous rocks in the area is apparent.

Toward the north in the area studied, the quartzite becomes argillaceous; at the northernmost boundary, silt and clay make up almost half of the rock. Relative abundance of quartz, biotite, and muscovite remains the same. As the quartzite becomes more argillaceous, it is more easily weathered, as shown by the paucity of outcrops. In the northernmost part of the area, where the quartzite is most argillaceous, there are only two outcrops, both on a steep hillside.

The quartzite strikes roughly east-west and dips to the south. Dips range from 24° to 65°.

Marble

Several hundred yards south of the mine, a band of marble, about 500 feet thick, is located between the quartzite and a quartz monzonite stock. The marble is light gray in color, and is coarsely crystalline. The quartzite-marble contact is not exposed, but is thought to be conformable. The contact occurs just below the top of the ridge which extends almost due east from Elk Creek to the east boundary of the area. The marble is composed of approximately 95% of calcite, intimately intergrown in a mosaic texture. The grains range from 0.4 mm. up to 4.0 mm. in diameter with completely random distribution. The gray color is due to the presence of an estimated 3% of opaque minerals, which occur in anhedral grains.
of small size (0.05 mm. to 0.3 mm.) evenly distributed throughout the rock. Small amounts of very small flakes of biotite and muscovite are present, and subhedral grains of scapolite are also present in minor amounts (Sample 10).

The marble is believed to be the result of recrystallization of a limestone caused by the intrusion of a quartz monzonite stock, which will be discussed later. There are two good reasons to support this hypothesis: first, there are several limestones within the Belt rocks which have been subjected to equal regional metamorphism and have remained almost unchanged; second, the presence of scapolite, a typical contact metamorphic mineral indicates that chlorine has been added to the original limestone. In addition, grossularite garnet, diopside, and quartz are present in large amounts at an old prospect pit on the marble-quartz monzonite contact. Small amounts of pyrite and chalcopyrite are recognizable, along with secondary limonite, malachite and azurite. To the east along the contact, a now abandoned mine was located on a small vein of silver bearing galena. Mining removed all traces of the vein, but a search of the dump revealed traces of oxidized copper minerals and galena in vein quartz.

To the south, the marble is in sharp contact with a quartz monzonite stock. Locally the contact is irregular, but viewed as a whole it is surprizingly straight. The contact trends east-west, parallel to the strike of the marble.
Approximately one third of the area covered by this report is underlain by igneous rocks of various types. With the exception of the porphyritic diorite dike, which is pre-Cambrian, all of the igneous rocks are of late Cretaceous or early Tertiary age.

Porphyritic Diorite

A dike of porphyritic diorite intrudes the argillaceous quartzite on the west side of Elk Creek. This dike is lenticular in shape, and trends N60°W. The dike does not outcrop, and its shape was deduced from tracing float. This dike reaches a maximum thickness of 150 feet, and extends out of the mapped area. The rock is easily recognized megascopically by the plagioclase phenocrysts which make up 35% of its volume. These are whitish in color and range in size from one quarter inch to three quarters of an inch across. On weathered surfaces, the plagioclase phenocrysts stand out slightly above the bluish colored matrix. No petrographic study was made of this rock, but examination under a binocular microscope showed the matrix to be made up of approximately 30% hornblende and a large amount of plagioclase. The matrix is very fine grained, and has a granitoid texture (sample 18).

This dike has been dated as pre-Cambrian by C. P. Ross (1955).
Trachyte

A small sill, or isolated remnant of a flow, of trachyte forms a steep hill at the mouth of Cap Wallace Gulch. Near the top of the hill, several narrow ribs or ridges extend roughly east-west. Strike and dip of these ridges is similar to that of the metasediments nearby. This trachyte body is roughly oval in shape. Because of its shape, and because the rock is not found elsewhere in the area, it is believed to be an irregular sill, or a short, thick flow. Closely spaced joints or fractures, parallel with the previously mentioned ridges, cause the rock to break up into tabular fragments from a few inches to several feet in the long dimension. The smaller fragments are much more common. Most of the hillside is covered with talus composed of these tabular fragments (See Figure 2). Fresh surfaces of the trachyte are light gray in color, while weathered surfaces are reddish brown. The combination of small tabular talus and the distinctive colors make this rock easy to identify from a distance. The contact between the trachyte and the argillaceous quartzite which completely surrounds it is not exposed. Outlining of the approximate limits of the trachyte was done by tracing float. Petrographic examination of the rock (sample 14) shows it to be made up of 60% sanidine, in tiny anhedral laths, forming a felty texture. These laths range in size from 0.02 mm. up to 1.5 mm. The larger sizes are extremely scarce. Carlsbad twinning is visible in many crystals. The crystals are very clear, with
no visible inclusions. Some of them are slightly zoned. A small amount of diopside, less than 1%, is present in small subhedral grains, reaching 0.5 mm. in size. About twice that amount of oligoclase is present as phenocrysts of up to 1.5 mm. in size. The oligoclase is partly resorbed. Small subhedral grains of hornblende occur in the matrix. A few phenocrysts of biotite, partly resorbed, are as much as 4.0 mm. across. Approximately one third of the rock is composed of glass.

The trachyte is believed to be either very late Cretaceous or early Tertiary in age, probably contemporaneous with the quartz monzonite body near the mine. It is older than the barite mineralization, since at the Coloma barite mine, the barite vein cuts a similar body of trachyte.

Quartz Monzonite Stock

A quartz monzonite stock underlies the southern part of the area studied, and extends southward to the town of Garnet. A small, irregularly shaped body of quartz monzonite is present in the gully immediately adjacent to the mine. This body is not laterally connected to the stock, but is believed to be a part of the stock, because of the mineralogical and textural similarity of the two.

The quartz monzonite forms bold outcrops, with a characteristic subangular, blocky appearance (See Figure 3). Outcroppings of this rock may be easily recognized from a distance by its weathering characteristics.
Petrographic examination showed this rock (sample 12) to contain 30% quartz in anhedral grains ranging in size from 0.2 mm. up to 2.5 mm. Many of the quartz grains show undulatory extinction. Orthoclase feldspar makes up 30% of the rock, and occurs in subhedral grains from 0.3 mm. to 3.0 mm. in diameter, and whitish in color. Oligoclase is present in an amount equal to the orthoclase and quartz. It occurs in anhedral to subhedral grains which range in size from 0.4 mm. to 3.0 mm. across. Albite twinning is well developed, and pericline twinning is common. Biotite occurs in subhedral flakes, which are approximately equal in size to the oligoclase. Some of the flakes show pleochroic halos around tiny zircon crystals. The biotite makes up about 5% of the rock. Hornblende is equal to biotite in amount. It occurs in subhedral grains that show strong pleochroism. Apatite and sphene occur in tiny anhedral grains. Small, anhedral grains of magnetite are disseminated throughout the rock. Very small crystals of zircon are visible in the biotite, producing pleochroic halos. Apatite, sphene, magnetite, and zircon together make up less than 2% of the total volume. The rock has a hypidiomorphic-granular texture.

The quartz monzonite stock is believed to be closely related to the Boulder batholith, and was so mapped by Ross (1955). The Boulder batholith has been assigned to the very late Cretaceous or very early Tertiary by Chapman, Gottfried and Waring (1955) on the basis of radioactive age determinations.
Figure 3. Typical appearance of weathered quartz monzonite stock.

Figure 4. Pegmatite dike showing sharp contacts with the barite.
Quartz Monzonite Dike

A thin dike of quartz monzonite may be seen in the mine and in several exposures at the open pits. This dike is closely associated with the barite, and is younger than the barite, which it intrudes. In the mine, the dike has a nearly uniform thickness of about nine inches, although in a few places it reaches several feet in thickness. In the lower pit, this dike reaches a maximum thickness of four feet. Strike of the dike is roughly parallel to the barite vein, N60°E, and dip varies from vertical to horizontal, seldom remaining constant for more than a few tens of feet. At several places within the mine, the dike splits into two or more segments which generally pinch out after a short distance.

Petrographic examination of sample 17 shows that the dike has a granitoid texture, and is made up of 30% quartz, in anhedral grains ranging in size from 0.15 mm. to 2.0 mm; 30% oligoclase, in subhedral grains, equal in size to the quartz grains; 20% orthoclase, similar in occurrence to the oligoclase; 15% biotite, in subhedral flakes similar in size to the biotite. Minor amounts of apatite, sphene, and magnetite are present, as are a few grains of zircon. Both of the feldspars are strongly sericitized.

At some places within the mine, the quartz monzonite dike has been strongly altered. Examination of the altered parts of the dike shows much the same mineral assemblage as that present in the fresh dike, but the feldspars are so
strongly sericitized that they are almost unrecognizable. Almost all of the mineral grains within the altered portions of the dike are smaller in size than those of the fresh dike, suggesting that differences in original texture may have made these parts of the dike more susceptible to alteration. The strong sericitization of the feldspars suggests that there was probably some hydrothermal activity after emplacement of the dike.

Mineralogically, the quartz monzonite dike is similar to the quartz monzonite stock, except that the dike contains less hornblende and more biotite, and slightly less orthoclase. Texturally, the two are similar. The stock and dike are believed to be closely related; however, the dike is considered slightly younger than the stock because it intrudes the barite vein, also believed to be genetically related to the stock. The fact that the dike is enriched in biotite and impoverished in hornblende tends to support this belief, since hornblende crystallizes out of a melt earlier than biotite (Bowen, 1922).

Pegmatite

The youngest igneous rock within the mapped area is a granite pegmatite, which occurs as thin, irregular dikes which cut the barite and often form marginal intrusions along the quartz monzonite dike. At one place within the mine, between stations 3 and 5, the pegmatite appears to grade into the quartz monzonite dike. Contacts between the pegmatite and the barite are sharp, as may be seen on Figure 4.
The pegmatite is granitic in composition, and simple in mineralogy. It contains 40% quartz, in anhedral grains up to two inches in diameter; 40% orthoclase, in subhedral crystals up to three inches long, and pale yellow in color; 15% muscovite in radial aggregates up to two inches in diameter, composed of subhedral flakes; and 5% of biotite in subhedral flakes of rather small size, usually less than an inch long.

There are traces of pegmatite in many places within the mine, but most of it has been removed during mining. The pegmatite is found only within the barite and the quartz monzonite dike; it does not occur in the wallrock.

The pegmatite intrudes both the barite and the quartz monzonite dike, therefore is younger than either of them. Because of its relationship with the quartz monzonite dike, the pegmatite is thought to be only slightly younger than it. Its mineralogical similarity to the quartz monzonite suggests that it is probably genetically related to the large stock to the south, as is the quartz monzonite dike.
STRUCTURE

REGIONAL STRUCTURE

The area surrounding the barite mine is on the north limb of a large syncline, about five miles wide, with an east-west trending axis. The south limb of the syncline is complicated by minor folds. (Pardee, 1917). Folding within the area is believed to be of Laramide age, contemporaneous with that of the Phillipsburg area to the south, mapped by Calkins and Emmons (1915).

FAULTING

Faulting in the Belt rocks is complex, but is only seen to advantage within the mine workings. There is no surface expression of faulting, probably due to the thick soil cover. Within the mine, a large number of minor faults are visible, especially in the 900 level entrance adit, which is driven through the quartzite. This adit cuts more than a dozen small faults, and three fault zones, 2, 13, and 25 feet wide. (See Figure 5). These zones are characterized by closely spaced faults, brecciation of the country rock, fault gouge, and slickensides. The faults do not appear to favor any particular direction. Strikes vary from due north to due east,
and dips range from 90° down to less than 30° to the northwest and southeast. No drag is visible along any of the faults.

All of the faults in the entrance adit of the 900 level are older than the barite, although one of them enters the barite. Most of these faults have less than two inches of gouge associated with them; however, the one which enters the barite has almost a foot of gouge along it. Because of the large amount of gouge, and because of its general trend, this fault is believed to be an extension of the major fault found within the barite vein. Strike of this fault is roughly parallel to the vein, N60°E, but it does not occupy any particular position within the vein, occurring on the hanging wall, the foot wall, and within the vein at various places. It follows the dip of the vein, and is encountered in the stopes and raises. The fault may be seen to advantage between stations 3 and 5, where the drift cuts it on the hanging wall. From that point northward, the fault occurs within the vein. Just beyond station 7, it splits into two faults with unequal amounts of gouge along them. The fault with the larger amount of gouge follows the foot wall, and the other fault remains within the vein. A small high angle normal fault with slight displacement cuts the barite vein between stations 3 and 5.

VEIN STRUCTURE

Structure of the barite vein is rather simple. It forms a roughly tabular shaped body which strikes approximately
N60°E, and dips 70°SE. At station 5 on the 900 level, the vein intersects the fault described above, on the hanging wall, and the strike of the vein becomes N45°E. The dip remains unchanged. The fault is believed to be pre-ore in age, because the gouge associated with it does not contain any crushed barite, and the amount and texture of the gouge remain unchanged from that present where the fault is in the quartzite wallrock. The barite vein alternately pinches and swells, both laterally and vertically, as shown on Plate 2 and Fig. 7. Robert Olson, foreman at the mine, states that the vein is widest in the places where the major fault forms the hanging wall. This may have been caused by the damming effect of impermeable fault gouge, which restricted movement of the mineralizing solutions in these places. It may be that the pinches and swells are due simply to irregular openings and variations in permeability of the wallrock along the fault.

On both the 1000 and the 900 level, the vein splits, at its east end, into two veins of unequal size. On the 1000 level, the smaller vein, less than two feet wide, continues along the course of the main vein for about 70 feet, then splits into small stringers that are uneconomic to mine. The larger vein, about four feet thick, swings to the north about 15°, continues for less than 90 feet, and then splits into small stringers. No reason for the splitting of the vein was discovered. At its southwestern extremity, the vein ends
Figure 5. Fault breccia just north of station 8 in the 900 level adit. Area shown in photo is ten feet wide and seven feet high.

Figure 6. Fault gouge along the major fault between stations 3 and 5 in the 900 level drift.
rather abruptly, changing from a massive vein over three feet wide to a few small stringers which pinch out within a few feet. No reason for this was found.

The vein varies in width from a few inches or less, at either end, to a maximum of over twenty feet. The average width is estimated to be approximately seven feet.

The barite vein is cut by a sub-parallel quartz monzonite dike which extends almost the full length of the vein. This dike does not maintain a fixed position in relation to the vein. Like the fault, the dike is found on the foot wall, on the hanging wall, and within the vein at various places within the mine. A pegmatite dike, probably contemporaneous with the quartz monzonite dike, is present in some places within the barite vein. Both of the dikes are younger in age than the barite.

The barite mineralization is not vertically continuous between the 900 and 1000 levels of the mine. Figure 8, a longitudinal section between the levels, shows the approximate outlines of the barren rock in the plane of the vein; this plate is based on a sketch by Robert Olson. No attempt was made to draw a detailed longitudinal section in the plane of the vein because the stopes are partly filled with broken ore, and are extremely dangerous to enter.

A large number of laminations are present with the barite vein. Some of the laminations are marked by limonite stains; others appear to be due to small amounts of dark inclusions
Figure 7. Idealized vertical section through raise 901 looking southwest.
within the barite. The laminations do not have any preferred orientation; they vary from normal to the vein to parallel to it. Spacing of the laminations is extremely irregular, ranging from less than an inch to several feet. In some places, no laminations are visible. Two possible modes of origin are suggested; the laminations may be due in part to both. One possibility is post-ore fracturing, and later filling of the fractures. There has been some post-ore movement within the vein, as shown by the minor offsetting of thin stringers of the quartz monzonite dike and by the fault which cuts the vein between stations 3 and 5. Another possible cause of the laminations is that the vein may have been deposited in several cycles, with very slight compositional differences among the barite-bearing solutions.

Study of a sample of barite showing laminations, sample 20, under a binocular microscope did not disclose any textural differences within or adjacent to the laminations. Two oriented thin sections were prepared, one in the plane of the lamination and the other normal to it. Petrographic study of these thin sections revealed that no textural differences exist within or near the laminae, and that the laminae do not reflect a preferred optical orientation of individual grains of barite, nor a preferred shape orientation.

The barite varies in texture from sugary to very coarse grained, with individual crystals occasionally reaching several inches in length. Polysynthetic twinning is very
Figure 8. Idealized longitudinal section from raise 901 to raise 903, showing extent of waste in the plane of the barite vein.

(Based on a sketch by Robert Olson)
prominent in the coarse grained barite. Traces of the cleavage on these coarse crystals are often curved. No relationship between grain size and any other features within the vein was observed.

Other than the previously mentioned fault, no control of mineralization is evident. It is likely that the mineralizing solutions followed along a fault or an irregular fracture, depositing barite in cavities, and that as the fissure was re-opened, more barite was deposited until the vein reached its present thickness. The pinches and swells that occur in the vein could easily be due to irregularities along such a fault or fissure. Successive movement along the fault would cause new openings for deposition of barite (Bateman, 1950, p. 114).
The barite vein itself is simple, both structurally and mineralogically. Barite makes up about 95% of the vein; inclusions of wallrock in small fragments are present in an amount equal to less than 5%, generally near the margins of the vein; and at one place in the 1000 level, at the southwest extremity of the vein, pyrite is present in rather large amounts. The barite is often limonite stained, suggesting that minor amounts of pyrite may have been present within the barite. It is more likely that the iron stains found in the 900 level were derived from leaching of the concentration of pyrite above by meteoric water.

The vein has the characteristics of both replacement and cavity filling. All megascopic characteristics point toward a cavity fill origin. Boundaries of the vein are sharp; composition of the vein almost constant; outlines of the vein are regular; and inclusions of wallrock within the vein have many sharp edges. No vugs are present, but this does not preclude a cavity fill origin. Petrographic study of a thin section, number 19, across an inclusion of wallrock, shows some evidence of replacement. Numerous isolated grains and small aggregates of quartz grains are present, completely surrounded by barite; many microscopic veinlets of barite with indefinite, feathery
boundaries invade the quartzite; and the contact of quartzite and barite shows embayments and ragged boundaries. No one of these criteria above conclusively proves replacement; but the occurrence of a number of them together very strongly suggests it. Study of a single thin section does not provide sufficient evidence to attribute the vein to replacement, but it leads one to believe that replacement has played a part in forming the deposit.

In the opinion of the author, cavity filling was the dominant factor in the origin of the vein, and replacement was minor.

The hydrothermal solutions which deposited the barite are thought to have been emitted during the emplacement of the small body of quartz monzonite which forms the bedrock in the immediate area of the mine. This body is badly decomposed in all exposures, possibly indicating hydrothermal activity during deposition of the barite. The quartz monzonite dike, and the pegmatite, both of which are definitely younger than the barite, are believed to be offshoots of the quartz monzonite stock farther to the south.

As stated previously, the vein is made up almost entirely of barite, with a small amount of pyrite near the uppermost margin. Three possible reasons for the simple mineralogy will be advanced. First, it is conceivable that the hydrothermal solutions which deposited the vein carried only barite, with a small amount of iron. It is extremely unlikely
that an element as rare as barium would form the major constituent of hydrothermal solutions given off during emplacement of a quartz monzonite stock. Second, it may be that the present barite vein is the remnant of a vein that contained other minerals in its upper portions, now eroded away. Several things tend to support the second hypothesis: the extreme insolubility of barite, which would cause it to be deposited earlier than more soluble minerals; and the presence of pyrite in the uppermost part of the vein. Solubility of barite under hydrothermal conditions is unknown; it may be markedly different from that at normal temperature and pressure. Another possible reason for the purity of the barite might be that solutions which originally carried many other elements may have deposited them while traversing more reactive strata.

The mineralized zones at Garnet, adjacent to the same quartz monzonite stock, are known to contain barite as a gangue mineral (Pardee, 1917). It is possible that these zones are the upper portions of veins similar to those postulated in the second hypothesis above, since all of the veins at Garnet are topographically, and probably structurally, higher than the Greenough barite vein. This hypothesis does not agree with the generally recognized paragenetic sequence, unless those minerals which precede barite in the sequence are present at greater depth in the vein. It is possible that minerals which are usually deposited before barite were present in only minor quantities.
OTHER MINERAL DEPOSITS IN THE AREA

Barite is the only valuable mineral found in sufficient quantities in the immediate area to make mining feasible. Several small deposits of copper and silver-bearing galena occur along the marble-quartz monzonite contact in the southern part of the area, but these proved to be of insignificant size. Many people feel that a good deal of placer gold still remains in Elk Creek, but this is a matter of conjecture. In the fall of 1955, a deposit of barite was discovered near the town of Coloma, several miles south of the area of the present Greenough mine. This deposit was leased from the owners of the claims and is worked by open pit methods by the National Lead Company. To the author's knowledge, these deposits, together with the worked out veins at Garnet and Coloma, are the only present or past occurrences of valuable minerals in significant quantities in the immediate area.

A prospect adit approximately 75 feet long was found at the marble-quartz monzonite contact about half mile from Elk Creek in the valley of the North Fork. This adit was driven along a thin copper bearing quartz vein which was too narrow to pay for mining, in the hope that it would widen (Personal communication, Leonard Hall). Just above the portal of this
adit is the small zone of contact metamorphic minerals mentioned in the description of the marble. Little could be ascertained from a study of the adit, because the walls and back are almost completely covered with a coating of calcite deposited by water percolating through the overlying marble.

The silver-bearing galena deposit was also located in the valley of the North Fork, about a mile from Elk Creek, on land owned by the Anaconda Copper Mining Company. It, too, was on the marble-quartz monzonite contact. This deposit was mined by means of an adit, a cross cut, and a raise, probably 75 feet high, which reaches the surface. Apparently the deposit was marginal at best, and pinched out below the adit level. The adit continues on beyond the cross cut for a total distance of about 300 feet. Examination of the mine dump disclosed that a small amount of copper, in the form of azurite and malachite, was present in the ore. The adit begins in quartz monzonite, then passes alternately through marble and quartz monzonite several times. This shows that the contact is not a simple plane, but a rather complex interfingering of the quartz monzonite with the marble. This interpretation is corroborated by the several disconnected outlying bodies of the quartz monzonite shown on the areal geologic map. Within the adit, many high angle faults were seen, all of them striking approximately east-west, roughly parallel to the contact. These faults only occur in the marble, so are older
than the quartz monzonite. Near the contact, the marble is finer grained than away from it, indicating that some recrystallization has taken place.

Directly across the ridge north of the abandoned lead-silver mine, and 700 feet away, a rather large deposit of barite was mined by open pit methods. This deposit was called the upper pit. To the west of this deposit about 800 feet is another near surface deposit of barite, which was mined in the same way. This second deposit, called the middle pit, is believed to contain 30,000 tons of barite not possible to mine by open pit methods (Personal communication, R. K. Collins). The geological situation at both these deposits is similar to that at the main barite deposit. Both are fissure veins in quartzite, and both are closely associated with a dike of similar appearance to the quartz monzonite dike in the mine. No trace of the major fault was seen at either place, however. Neither of these deposits appears to be connected laterally, either with each other, or with the main barite vein, although both of them are found roughly on the trend of the main vein.

A superficial examination was made of the Coloma barite deposit in the late fall of 1956. Two veins, each several feet in width, are separated by a horse of the quartzite wallrock estimated to be six feet wide. The veins strike $S65^\circ E$ and dip $65^\circ NE$. Stringers of barite pierce a dike of trachyte megascopically similar to the trachyte found at the mouth
of Cap Wallace Gulch. From the similarity of the two rocks and the barite veins, it was concluded that the Greenough barite deposit, as well as the Coloma deposit, is younger than the trachyte.
MINING AND MILLING

The Greenough barite deposit is mined by shrinkage stopping. Ore chutes are constructed in the drift, then raises are driven upward in the ore. From the raises, the ore is drilled and blasted down, to fall into the ore chutes. After each blast, only enough ore is withdrawn to give the miners room to work above the broken ore. In this way, about three quarters of the broken ore remains in each stope until the maximum vertical extension is reached, then all the remaining ore is withdrawn and the stope is filled with waste.

In the 1000 level, the back and walls were supported with timbers, and lagging was used extensively. This proved to be an expensive and unreliable way to prevent caving. In mining the 900 level, pillars of barite are left in place between stopes to support the walls. The use of pillars of ore instead of timbers reduces costs, and there is less chance of caving. At a number of places timbers and lagging are used for support, especially in brecciated zones and around the ore chutes.

After mining, the crude barite is trucked to the mill, located on the Big Blackfoot River and on the Chicago, Milwaukee, and St. Paul railroad (See Figure 1). At the mill
the barite is crushed, concentrated by jigging, ground, to pass a 325 mesh screen, and packaged in 100 pound sacks. The barite is shipped by rail, to all of the Rocky Mountain states, Canada, Alaska, and to Texas. About 95% of the barite produced here is used in oil well drilling. Minor users include the glass and paint industries, and sugar refiners.
CONCLUSIONS

The Greenough barite is a good example of a hydrothermal vein type mineral deposit. Although some replacement has taken place, it is primarily a cavity filling. Its close association with neighboring igneous rocks, its presence in non-reactive quartzite, its downward, rather than lateral extent, the lack of most of the features characteristic of replacement deposits, and the occurrence of the barite vein along a fault, all indicate a fissure vein deposit produced by hydrothermal solutions derived from a nearby plutonic body.

The Coloma barite deposit, which appears to be very similar to the Greenough deposit, occurs in a similar geologic setting. The presence of barite in the gold-bearing quartz veins at Garnet shows that barite has been deposited from hydrothermal solutions in this region.

The barite vein is believed to be the remnant of a vein which carried a more varied assemblage of minerals in its upper portion.
BIBLIOGRAPHY


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