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COLUMBIUM-RARE-EARTH DEPOSITS SOUTHERN RAVALLI COUNTY MONTANA

by

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ABSTRACT

Carbonate-rich rocks in southern Ravalli County, Montana, contain columbium and rare-earth minerals. Columbite and aeschynite are the principal columbium-bearing minerals, whereas ancylite, allanite, and monazite contain rare earths. The metallic minerals are sporadically distributed through the carbonate host rock.

The deposits occur in a northwest-trending band of pre-Beltian gneisses and schists and are localized predominantly within amphibolite layers. However, a few occurrences have been observed where rare earth-bearing carbonates are in augen gneiss, quartz-plagioclase-biotite gneiss, and quartz-hornblende schist.

Several different groups of claims have been developed by underground workings and by surface pits. One small test lot of ore was shipped to the Government Purchasing Depot.

A discussion of economic aspects pertaining to the development of these carbonate bodies is included.

INTRODUCTION

In the summer of 1954, Mr. Louis Erickson discovered and identified as columbite a submetallic iron-black mineral which he had found on Sheep Creek in southern Ravalli County, Montana. The mineral's identity was later confirmed by the Montana Bureau of Mines and Geology and by the U. S. Geological Survey at Denver, Colorado. During 1955 and 1956 the deposits were explored by William Van Matre of Butte, who shipped a small test lot of the ore to the Government Purchasing Depot in Custer, South Dakota. At the time of the writer's examination (summer of 1957) underground and surface exploration was being done by Continental Rare Metals Corporation.

The element columbium, also known as niobium, is a steel-grey metal. Alloys containing columbium are mechanically strong at high temperatures. This property led to the use of columbium alloys for certain parts of jet engines and gas turbines. One of the primary uses of this metal has been as ferrocolumbium, a stabilizer utilized in the manufacture of stainless steel. It is also used as a "getter" in vacuum tubes. Columbium carbide added to tungsten carbide improves machine cutting tools. Columbium also is used as structural and shielding material in certain nuclear reactors. Since World War II uses of this metal have increased greatly. Consequently the United States, which is deficient in columbium resources, has had to import almost all columbium used in this country. Although other occurrences of columbium-bearing minerals in Montana have been described by Cooke and Perry (1945), Heinrich (1949), and Pecora (1956), none of the deposits, including the southern Ravalli deposits, have been mined successfully.

Principal among the rare-earth elements in the carbonate deposits of southern Ravalli County are cerium and lanthanum. Cerium, the most abundant of the two, is used as a reducing agent, an optical abrasive, an ingredient in alloys, and cigarette-lighter flints. Lanthanum is used primarily in high-quality optical glass.

There is no recorded production of rare-earth metals from Montana, but the rare earths are found in minerals elsewhere in the State and have been described by Rowe (1928), Cooke and Perry (1945), Heinrich (1949), Pecora and Kerr (1953), Pecora (1956), and Sahinen (1957). Rare earths are not scarce in the United States. Most of the Nation's supply comes from a large deposit of bastnaesite (fluocarbonate of rare earths) in California.

LOCATION

Ravalli County, Montana, is one of the westernmost counties in the State (fig. 1). The southern tip of Ravalli County, which noses into Lemhi County, Idaho, is embraced on the east, west, and south by the crest-line of the southern Bitterroot Mountains. The crest-line of the "Bitterroots," as the mountain range is locally called, is the boundary between Montana and Idaho. The West Fork of the Bitterroot River, a major tributary of the Bitterroot River, bisects the tip of Ravalli County from south to north.

The area investigated is in the Mineral Point mining district near the headwaters of the West Fork of the Bitterroot River. It embraces most of Ts. 3 and 4 S., Rs. 22 and 23 W.

The Coast and Geodetic Survey triangulation point on Blue Nose Mountain, which is about $3\frac{1}{2}$ miles south of the area, is at latitude 45° 28' 21.865", longitude 114° 21' 27.336", and at an

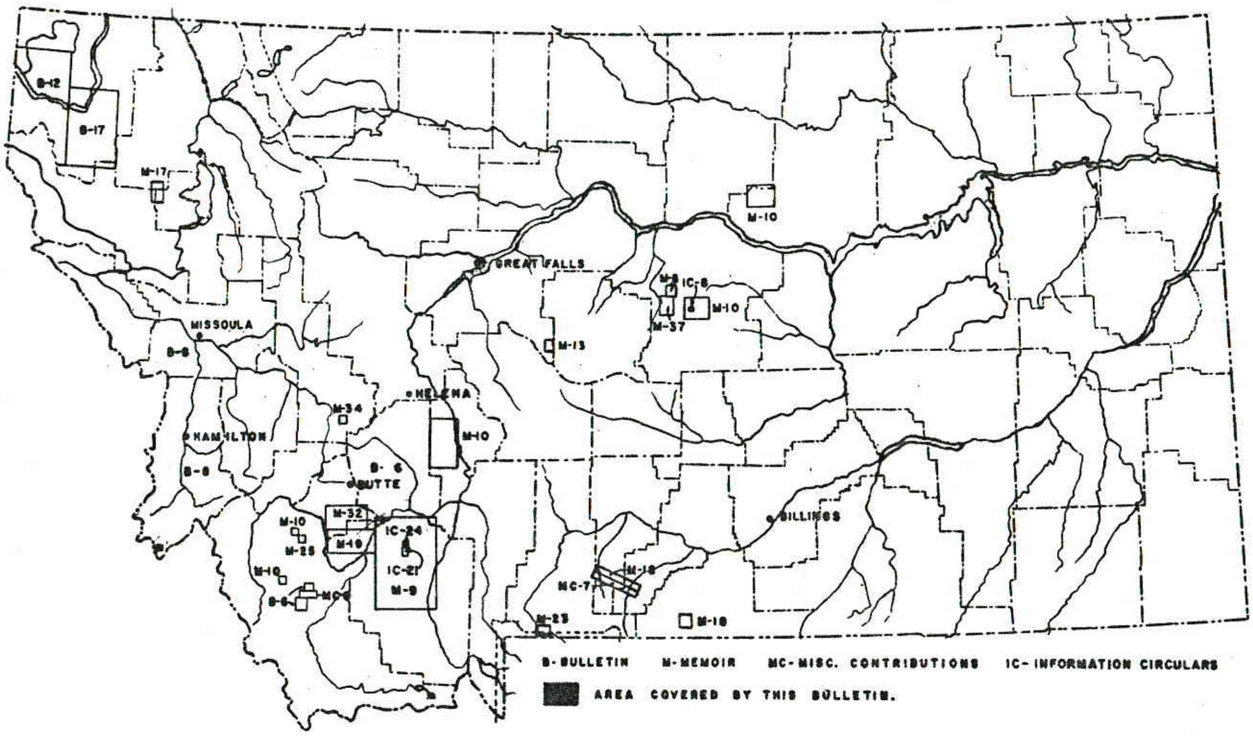

Fig. I-INDEX MAP SHOWING PUBLICATIONS OF THE MONTANA BUREAU OF MINES AND GEOLOGY ON METAL MINING AREAS.

B 6, Bannack and Argenta; B 8, Missoula and Ravalli Counties; B 12, Kootenai-Flathead; B 16, Jefferson County. M 8, North Moccasin Mountains; M 9, Tobacco Root Mountains; M 10, Gold in Broadwater, Beaverhead, Phillips, and Fergus Counties; M 13, Niehart; M 17, Hog Heaven; M 18, Chromite; M 19, Rochester; M 23, Jardine-Crevasse Mountain; M 25, Hecla; M 32, Highland Mountains; M 34, Zosell (Emery); M 37, South Moccasin Mountains. MC 7, Stillwater. IC 8, Silver Dyke; IC 21, Potosi; IC 24, Strawberry-Keystone.

elevation of 8,683 feet above sea level. Elevation of the road intersection near the confluence of the West Fork and Sheep Creek is 5,598 feet above sea level.

One fair to poor dirt and gravel road enters the area from the north. The gravel road leaves U. S. Highway 93 at the bridge spanning the Bitterroot River south of Darby and follows the West Fork of the Bitterroot River upstream to the West Fork bridge at Nez Perce turnoff. From the turnoff, a dirt road continues up the West Fork to the junction of Sheep Creek and Beaver Creek and thence up Beaver Creek to its headwaters on the Bitterroot divide, and on down into Shoupe, Idaho. This road is almost impassable except to trucks and four-wheel-drive vehicles during the winter and spring months, but automobiles can travel the road during most of the remaining months of the year. The nearest railhead is at Darby, Montana, about 45 miles to the north.

PURPOSE OF REPORT

The primary objectives of the investigation were to determine the extent of the carbonate deposits; the relationship between the carbonate deposits and the surrounding metamorphic rocks; the mineral assemblages present, their paragenesis and origin; and the economic significance of the deposits. To accomplish these objectives exposed deposits and adjacent areas were studied and a general geologic reconnaissance was made of the encompassing area.

FIELD WORK

The writer, assisted by Otis Huggins, spent two months examining the deposits during the summer of 1957. A second visit of a weeks duration was made in the spring of 1958. General geologic mapping on aerial photographs, at a scale of 4 inches to 1 mile, encompassed an area of approximately 15 square miles in Ts. 3 and 4 S., Rs. 22 and 23 W. Because most of the surface and underground exploration was being done on the slope immediately north of Sheep Creek, this area was mapped in detail with plane table and telescopic alidade for a distance of two miles eastward from the confluence of Sheep Creek and the West Fork of the Bitterroot River.

ACKNOWLEDGMENTS

Dr. F. N. Earll, Head of the Department of Geology, Montana School of Mines, supervised work for this report. Mr. Walter S. March, Jr., Associate Director, and Mr. Uuno M. Sahinen, Chief Geologist of the Bureau, suggested the problem and gave freely of their time and advice in all phases of this investigation. Dr. Bahngrell W. Brown offered many valuable suggestions, and Mr. Walter C. Ackerman gave advice on petrographic problems. Mr. William Van Matre was very helpful in planning and arranging this investigation, and Mr. Ralph I. Smith aided in X-ray determinations. Mr. C. L. Bartzen, Bureau analyst, made the chemical analyses. Mr. and Mrs. Joe E. Hart and the employees of the Continental Columbium Corporation were most cooperative, and made the writer's stay in the field a pleasant one.

PREVIOUS WORK

Lindgren (1904) describes the rocks of the area as quartzitic schists which become more micaceous to the south and west, and which grade into typical gneiss on upper Beaver Creek. He also points out the significant presence of a "little coarsely crystalline limestone" on Beaver Creek. [As to the age of the rocks, Lindgren (1904, p. 57) says, ".....there is nothing to prove the age of the sediments (quartzitic schists), except that they once rested on a gneiss which has the characteristics of an Archean series. The similar conditions might justify a guess that the quartzites are of the same age as the Lolo series, possibly Precambrian."]

Kaiser (1956) mentioned briefly that columbite had been found on Sheep Creek. His paper deals almost entirely with a similar deposit in Lemhi County, Idaho. There columbium, thorium, and rare earths occur in carbonate bodies, the trend of which is approximately in line with the northwest trend of the deposits in southern Ravalli County. The general features of the Idaho carbonates are remarkably similar to those of the Sheep Creek area, however, in Idaho, columbium occurs in the minerals rutile and ilmenite rather than in columbite and aeschynite. Both deposits have the following minerals in common: calcite, actinolite, magnetite, monazite, ilmenite, and possibly the ancylite group of rare-earth carbonates.

Sahinen (1957, p. 53) examined the first discovery pit on Sheep Creek, and noted the presence of columbite and monazite in the pinkish to brown-colored carbonate rock.

The Geologic Map of Montana (1955) depicts the rock types of the southern tip of Ravalli County as Precambrian Ravalli formation. Elsewhere in Montana, the Ravalli formation is composed primarily of meta-quartzites and argillites. Although meta-quartzites do occur to a limited extent, argillites were not found within the area.

P H Y S I O G R A P H Y

A person viewing the surrounding country from the vicinity of Blue Nose Mountain would probably be impressed by the relatively uniform elevation of ridge lines to the south and west in Idaho, and to the north in Montana. Many authors, including Lindgren (1904), Umpleby (1912), Thompson and Ballard (1924), and Davidson (1933), consider the uniformity of crest lines to be the expression of a late Tertiary peneplain. Daly (1912, p. 643) and Alden (1953, p. 44) are not in agreement with the Tertiary peneplain concept and consider the region to be the expression of one period of uplift, that of the Laramide Orogeny, followed by erosion.

The Bitterroot Range, which rises above the level of the ancient "peneplain", has long been considered the result of block faulting. The eastern front of the 'Bitterroots' has been pointed out as a prime example of a fault scarp. However, Ross (1952, p. 136, 137) has shown that the facets on spurs and ridges, which extend into the Bitterroot Valley, are actually dip slopes. Although Ross does not overlook the possibilities of faulting and uplift during the intrusion of the Idaho batholith, he considers Lindgren's evidence of faulting, such as minute shears and parallel lineation of foliated minerals, to be the result of chemical and physical changes effected by metamorphic processes during the placement of the Idaho batholith.

Despite a few minor disagreements as to the existence of an elevated plateau area and the methods of uplift and intrusion of the Idaho batholith, most investigators do strike a certain tone of agreement on the general history of the region and on the age of intrusion. Chapman and others (1955, p. 609), reporting on an age-dating method based on the lead-alpha activity ratios in zircon and monazite, have pinpointed an area of agreement with the statement, ".....it seems reasonably clear that the bulk of this enormous body (Idaho batholith) is probably mid-Cretaceous."

The relief in the Mineral Point mining district is fairly great, about 3,000 feet. Within the mapped area, elevation ranges from 5,500 feet to 7,500 feet above sea level. Hill slopes average about 20 degrees.

Streams in the area, as well as throughout most of the surrounding mountain country, are generally swift and are still effectively eroding narrow V-shaped valleys, a factor that characterizes the region as one of well-developed youthful topography.

The climate of this region is like that of most of the northern Rocky Mountains. Snowfall is usually heavy during the winter months, and snowdrifts frequently remain on the north slopes of the higher ridges throughout the year. The latter part of June and the months of July and August are usually hot and dry with rather high daily variations of temperature.

The most prevalent timber in the area is lodgepole pine, which blankets the northern slopes and ridges. Yellow pine and Douglas fir grow predominantly on the south slopes.

GENERAL GEOLOGY

The columbium- and rare earth-bearing carbonate rocks occur in a northwest-trending belt of crystalline metamorphic rocks, which have been intruded by dikes and sills. The belt is exemplified by mineralogically similar bands of metamorphic rock that generally strike northwest and dip northeast, but are locally complicated by folding and faulting (fig. 2).

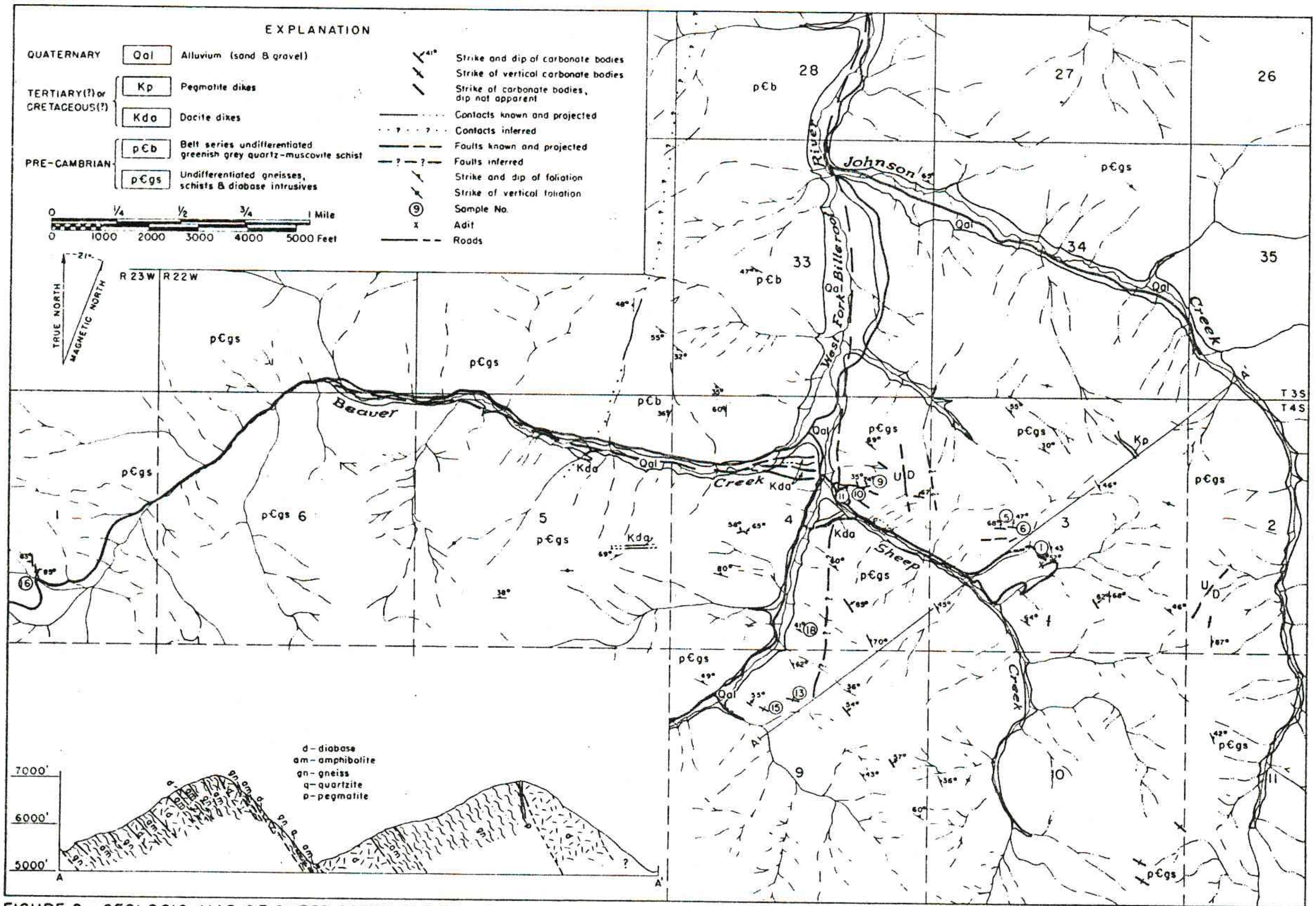

FIGURE 2—GEOLOGIC MAP OF SHEEP CREEK AND BEAVER CREEK AREA, SOUTHERN RAVALLI COUNTY, MONTANA.

Metamorphic rocks include augen gneiss, quartz-plagioclase-biotite gneiss, quartz-plagioclase-hornblende gneiss, quartz-hornblende schist, quartz-muscovite schist, amphibolite schist, amphibolite and quartzite.

Dikes are mainly of porphyritic dacite. However, abundant rhyolite float on the ridge above the Sheep Creek No. 3 adit indicates that a rhyolite body may occur in that area. Pegmatite dikes are numerous throughout the area, and although there is a possibility that they may occur as metamorphic and as intrusive pegmatites, no attempt was made to differentiate between them in the field. Diabase occurs as dikes and sills with indefinite boundaries within metamorphic rocks. Consolidated unmetamorphosed sedimentary rocks are not present within the area.

PRE-BELTIAN ROCKS

Pre-Beltian rocks, characterized by a distinctly crystalline appearance, underlie the greater part of the area. The remarkable similarity to pre-Beltian gneisses and schists elsewhere in Montana and in Idaho and the intensive metamorphism that they have undergone is the basis for classification as pre-Beltian.

Gneissic rocks are typified by a parallel arrangement of platy minerals and an arrangement of granular minerals in layers, which gives the rock a banded appearance. In general most of the gneissic rocks are spotted with metacrysts which, along with elongate and lenticular minerals, are usually oriented with their longest axes approximately parallel to the plane of foilation. Some minerals in which the grains are predominantly equidimensional, such as quartz, display a moderate to good degree of parallel C-axis orientation.

Gneissic rocks commonly grade one into the other. Some gneisses, such as the quartz-plagioclase-biotite gneiss, contain biotite as the only mafic mineral, but in others, such as the quartz-plagioclase-hornblende gneiss, hornblende and biotite occur in almost equal amounts. Augen gneisses are conspicuous because of a large percentage of orthoclase metacrysts which may be either dominant or subordinate to the plagioclase content.

Many gradations exist as mineral and textural varieties between the gneissic rocks. Locally, light and dark bands persist for many feet, both laterally and vertically, whereas other outcrops display bands that pinch and swell within short distances.

Schistose rocks show subparallel orientation of the platy and micaceous minerals--biotite, hornblende, and muscovite, interlayered with minute bands of quartz and plagioclase. Dominant schistose rocks in the pre-Belt are amphibolite schist and quartz-hornblende schist.

A series of rocks intermediate in composition between amphibole schist, amphibolite, and diabase is present. Massive amphibolite and amphibole schist grade imperceptibly one into the other within short distances. In some places equigranular fine- to medium-grained hornblende and plagioclase are aligned giving the rock a linear texture, and locally, plagioclase metacrysts up to one centimeter in length are aligned with their long axes subparallel to the plane of foliation. In the equigranular amphibole schist lineation becomes very noticeable near carbonate bodies. Contacts between diabase and amphibolite are indistinct because of varying amounts of pyroxene and amphibole in both rocks near the contact.

Quartz-Plagioclase-Biotite Gneiss

The quartz-plagioclase-biotite gneiss is a light- to dark-gray banded rock composed mainly of quartz, oligoclase, and biotite, with lesser amounts of orthoclase, microcline, olivine, hornblende, and cordierite. Apatite, magnetite, ilmenite, garnet, kyanite, rutile, spinel, muscovite, and epidote occur as accessory minerals.

The gneiss occurs throughout the metamorphic series in this area as fairly distinct bands interlayered with amphibolite, quartzite, diabase sills, and intermediate gneissic rocks. Because of its high-quartz content it is more resistant to erosion than the mafic rocks and forms sharp ridges.

Quartz, the most abundant mineral in the gneiss, occurs as small, equidimensional grains ranging in size from .05 mm. to 0.5 mm. in the groundmass, and as larger metacrysts 2 mm. to 1 cm. on a side. Very minute fragmented grains of quartz are strung out in pod-shaped masses throughout the rock and usually surround larger grains. In general the quartz grains are free of inclusions, however, some of the larger grains contain sparse inclusions of apatite and rutile. Irregular quartz blebs in orthoclase are fairly common. Plagioclase is predominantly oligoclase ($Ab_{80}An_{20}$) and is most conspicuously displayed as well-formed metacrysts which range in size from 0.5 cm. to 1 cm., with an occasional grain as long as 1 inch. Scattered anhedral grains up to 0.2 mm. in size occur in the groundmass. Albite twinning is present in all oligoclase, and carlsbad and pericline twins occur in some of the larger crystals.

Microscopically, feldspar crystals are seen to contain abundant inclusions of apatite, epidote, and kyanite. Kyanite occurs as crystals. Oligoclase, orthoclase, and microcline also enclose grains of quartz and biotite. Ilmenite grains are usually mantled by a fine-grained, highly birefringement mineral (rutile ?) intermixed with an opaque substance which is believed to be leucoxene. Cordierite, though not abundant, is distributed throughout the fine-grained quartz matrix along with magnetite, muscovite, olivine, and apatite.

Quartz-Plagioclase-Hornblende Gneiss

The quartz-plagioclase-hornblende gneiss is not distinguishable from quartz-plagioclase-biotite gneiss in the field, but it is described here to exemplify the gradational rock types which can and do occur in the Sheep Creek area.

The megascopic description of this rock corresponds closely with that of the quartz feldspar gneiss just described, and it will not be repeated.

Microscopically this gneiss is seen to contain hornblende as an additional mafic mineral. The hornblende is not the dominant mafic mineral, but is present in varying amounts associated with biotite. In general, however, the total mafic mineral content is higher than in other quartz-plagioclase gneisses. Ilmenite seems to be predominant over magnetite. Dravite, a magnesium tourmaline, is present in minor amounts as small grains.

Two other features of interest are: (1) the greater degree of fracturing and bending in minerals such as plagioclase and biotite; and (2) orthoclase resorption or replacement rims around oligoclase grains. Bending and fracturing in the plagioclase grains is exemplified by offset and bent twin lamellae. Biotite flakes present a wavy pattern in that they are commonly bent around other minerals. A possible explanation might be based on the abundance of platy minerals, which would permit greater freedom of movement along foliation planes. Plagioclase grains, which range in composition from oligoclase to the more calcic variety andesine, are commonly rimmed with orthoclase.

Augen Gneiss

Augen gneiss is a black and pink mottled rock which displays a prominent alignment of biotite, quartz, orthoclase, and oligoclase.

Hand specimens of the rock are very deceptive in appearance, for the black shiny biotite flakes appear to constitute the bulk of the rock except for the metacrysts. However, under the microscope the groundmass is seen to be dominantly quartz. The cataclastic (crushed) texture of the rock is extremely prominent in thin section and very fine quartz particles seem to flow through the more coarsely granular groundmass and around the larger crystals. The augen gneiss contains abundant quartz, biotite, oligoclase, microcline, and orthoclase with minor amounts of cummingtonite (?), magnetite, rutile, calcite, apatite, and epidote. As in the quartz-plagioclase-biotite gneiss, the metacrysts of orthoclase, microcline, and sodic plagioclase contain many inclusions.

Over all, the augen gneiss presents a picture of dynamic movement and chemical addition. It has probably been derived, like the other gneissic rocks in the area, from a parentage of impure arkosic rocks.

Amphibolite

The amphibolite is dark gray to greenish black in color and is composed mainly of amphibole and plagioclase with variable amounts of quartz, biotite, and augite along with minor amounts of microcline, apatite, epidote, magnetite, and sphene. In most specimens the amphibolite is equigranular with grain sizes averaging about 0.5 mm. However, grain-size differs from outcrop to outcrop, as does lineation. In the vicinity of pegmatite dikes and carbonate bodies the plagioclase content seems to increase, and linear texture is more apparent.

Amphibole is the most abundant mineral in the rock and occurs as aggregates of actinolite and hornblende surrounding plagioclase grains.

Plagioclase is more calcic than in the gneissic rocks and is predominantly labradorite ($Ab_{45}An_{35}$). In almost all places, even where the amphibole minerals seem to be badly altered, the plagioclase appears fresh.

Augite occurs as intergranular blebs in the amphibolite and diabase rocks. The result is a complex series of rocks between amphibolite and diabase, with pyroxene content increasing toward the contact on the amphibolite side and amphibole content increasing in the same manner on the diabase side.

It should be mentioned here that most of the carbonate bodies which contain columbite and rare-earth minerals, as well as unmineralized bluish-gray marbles, occur within amphibolite. These carbonate bodies will be discussed in the section on economic geology.

Quartz-Hornblende Schist

Quartz-hornblende schist is a minor rock type in the Sheep Creek area. It usually occurs in bands less than 10 feet wide and has been found within the more massive bands of amphibolite adjacent to quartzite layers and in one place adjacent to a carbonate body.

Microscopically, the rock is seen to consist of blue-green hornblende layers separated by aggregates of quartz grains. Varying amounts of brown biotite occur within the amphibole layers.

Quartzite

Narrow bands of white fine- to medium-grained quartzite are interlayered with amphibolite and with gneissic rocks throughout the area. Most specimens display lineation of scattered biotite flakes and rarely, fractured and elongate blebs of altered pyrite streak the rock. The "quartzites" actually grade from pure quartzite to leptite, which is a feldspar-rich quartzite with minor amounts of dark minerals. In most places the leptite is associated with gneissic rocks, and the quartzite occurs as narrow bands within amphibolite.

Diabase

Diabasic rocks are very prevalent east of the West Fork. They form indistinct sills and intrusive bodies with unrecognizable boundaries. The diabase is a fine- to medium-grained equigranular rock which is usually dirty brown in color. Its most distinguishing feature in the field is the presence of narrow black raised welts on the surface of the rock which are raised about 1/8 of an inch from the surface. The welts or ribs usually occur along intersecting straight lines that form rhombohedral patterns. It is believed that the ribs represent fractures that were later healed by actinolite.

In thin section, the general appearance of the diabase is very similar to amphibolite; plagioclase and pyroxene in about equal amounts make up the bulk of the rock. Dominant pyroxenes are enstatite and hypersthene.

Quartz, brown biotite, magnetite, and sphene occur in minor amounts. Actinolite not only fills fractures but also forms thin alteration rims around most pyroxene grains. The alteration rims are more noticeable close to fractured zones. Plagioclase, as in some amphibolites, is remarkably fresh in appearance. Its composition is variable, from bytownite ($Ab_{20}An_{80}$) to labradorite ($Ab_{35}An_{65}$).

It is interesting to note the similarity between the plagioclase in diabase and amphibolite. Both rocks contain calcic plagioclase as opposed to the more sodic plagioclase in the gneissic rocks. This may be due to the proximity of the two basic rock types and the effects of magmatic emanations from the diabase on the parent rock of the amphibolite. Alternative suggestions might be that the amphibolite is a marginal differentiation of the diabase, or that the diabase is the end product of metamorphic action on amphibolite.

BELT ROCKS

A distinctly different metamorphic rock occurs in a narrow belt along the western slope of the West Fork. It is a quartz-muscovite schist, and differs not only in outcrop expression but also in mineralogy and in degree of metamorphism. The quartz-muscovite schist, which is slightly crenulated, ranges from light gray to greenish gray to light brown. It is distinctly foliated and characterized by the silky sheen of muscovite flakes on the surface of fracture planes. The schist commonly weathers into small flakes and thin brownish fragments which cover the hill slopes. Quartz and muscovite grains, along with a few scattered grains of magnetite and rutile, make up the rock. Stress conditions, if present, must have been rather slight because the cataclastic (crushed) texture so prevalent in the gneissic rocks is almost non-existent. The only evidence of deformation is in the slightly wavy extinction of some quartz grains, as seen beneath the microscope and in the preferred orientation of muscovite cleavage planes parallel to the plane of schistosity.

The quartz-muscovite schist has been tentatively assigned to the Belt series on the basis of differences in lithology, mineralogy, and metamorphic expression from the pre-Beltian rocks described in the previous section and on the similarity to other Belt rocks in Montana and Idaho.

The assignment of the quartz-muscovite schist to a group or to a formation within the Belt would necessarily be questionable because of insufficient evidence on the vertical and lateral extent of the formation. It has, therefore, been designated on the geologic map as Belt undifferentiated (p€bu) with the understanding that it is probably basal Belt (Prichard ?) rather than middle or upper Belt. In view of the fact that pre-Beltian rocks are exposed in this area, it may be possible that the contact of Prichard (?) with old rocks is exposed in this area. The contact between Prichard and pre-Beltian rocks has not been found in either northwestern Montana or in Idaho.

CRETACEOUS-TERTIARY ROCKS

During the Cretaceous and possibly the Tertiary period porphyritic dacite and pegmatite dikes were intruded into the metamorphic series. Pegmatites cut all other rocks in the area, but the span of time between dacite pegmatite intrusion is not apparent. Davidson (1933, p. 11) reports rhyolite dikes intruded along faults that cut dacite dikes in the Mineral Hill mining district in Idaho, which is south of the Mineral Point district in Montana. Therefore the sequence of intrusion may have been porphyritic dacite, rhyolite, and then pegmatite.

Porphyritic Dacite

The porphyritic dacite dikes are light gray to dirty-yellowish brown in color and are tabular bodies seldom exceeding 30 feet in width. They usually occur in or are adjacent to greenish-colored breccia zones. The dikes are numerous near the intersection of the West Fork fault and the Beaver Creek fault. Most specimens contain plagioclase, quartz, and biotite phenocrysts. The phenocrysts range in size from 5 mm. to 10 mm. Near breccia zones altered rock is a dirty-brown color and much of the textural detail is obscured.

Petrographically, plagioclase ($Ab_{90}An_{10}$) is seen to be the predominant mineral. The groundmass is microcrystalline but appears to be composed of plagioclase and quartz.

Greenish breccia zones contain fragments of badly altered dacite in a groundmass, which resembles the dacite groundmass. This suggests recurrent movement along the breccia zones. Significant amounts of calcite (enough to effervesce in cold hydrochloric acid) were noticed in breccia fragments taken from the road cut west of Sheep Creek No. 2 adit.

Pegmatite Dikes

Pegmatite dikes in the area are tabular to lenticular bodies composed primarily of massive quartz, with lesser amounts of pink orthoclase, hydrobiotite, and scattered grains of ilmenite and magnetite. The dikes are randomly distributed throughout the area. A large pegmatite which outcrops on the ridge north of the Sheep Creek No. 3 adit contains lightly colored rose quartz. Locally, a few of the pegmatites contain large books of hydro-biotite up to 4 inches wide.

STRUCTURE

The southern tip of Ravalli County is in a structural province characterized by the effects of regional uplift, intrusion of the Idaho batholith, block faulting, and intrusion of dikes. Within the investigated area, metamorphic bands generally strike northwest and dip northeast. There are minor variations in the northwest trend, but the variations occur as small swirls and folds within mineralogically similar bands.

On a local scale, the most significant structure is the pronounced schistosity and foliation in the metamorphic rocks. In an area such as this, where outcrops are scarce, foliation and schistosity are virtually the only mappable structures. The accuracy of such a mapping method is questionable, for as Gross (1955, p. 323) pointed out, schistosity is not always parallel to bedding planes and that it is usually impossible, in the field, to distinguish between schistosity and other types of planar structure, such as fault shears and intrusive contact shears. For this investigation it is assumed that foliation and schistosity are parallel or approximately parallel to the contacts between rock types.

Also on a local scale but less noticeable are small folds, a few of which are isoclinal, whose axes trend north and plunge to the north. In many cases the axial plane is vertical.

Boudinage structure, on a small scale, is apparent in the area. Small quartz boudins have been observed in amphibolite and gneissic rocks. Boudinage structure is generally believed to have been formed by the stretching and shearing of layered metamorphic rocks.

Faulting on a large scale has probably occurred in the area. However, only slight evidence for movement was found in the form of dacite dikes and adjoining breccia zones which occur along portions of the West Fork of the Bitterroot River and Beaver Creek. Most outcrops of dacite and dacite breccia were noted near the junction of Beaver Creek and the West Fork.

Minor faults that affect the carbonate bodies will be described in the section on economic geology.

E C O N O M I C   G E O L O G Y

Unlike the well-known association of columbium and rare-earth minerals with pegmatite dikes, the Ravalli County deposits occur in calcium carbonate-rich rocks. The carbonates, as these calcium carbonate rocks will be called for the sake of brevity, are restricted to a narrow zone of pre-Beltian metamorphic rocks. Within the metamorphic rocks the carbonates are, for the most part, restricted to amphibolite layers, although occurrences have been noted in augen gneiss, quartz-plagioclase-biotite gneiss, and quartz-hornblende schist.

In general, the carbonates are concordant with the surrounding structures and parallel the over-all trend of the metamorphic bands to the northwest.

MINERALOGY

The following minerals have been found in mineralized carbonates:

actinolite	chalcopyrite	monazite
aeschynite	columbite	pyrite
allanite	fersmite	pyrrhotite
ancylite (group)	hydro-biotite	quartz
barite	ilmenite	rutile
calcite	magnetite	siderite
	molybdenite	

The entire suite of minerals listed on the preceding page was not observed in each occurrence of the mineralized carbonates. In general, mineral and metal content differs from outcrop to outcrop and even differs considerably within distances of a few feet along the outcrop. Grain size of individual minerals is also quite variable. One of the most significant generalities, concerning mineral distribution, is the preferential occurrence of rare-earth and columbium minerals along one of both sides of the carbonate body. Exceptions to this general zoning are found in carbonates where the total rare-earth content is exceptionally high.

Actinolite

Dark-green felted actinolite occurs in and adjacent to most of the carbonate bodies. It fills narrow fractures in carbonate and host rock and forms masses of radiating fibers surrounding other crystals. This form of amphibole is most prominent in the carbonates near pegmatite dikes.

Aeschynite

Heinrich* has tentatively identified as aeschynite a complex columbate of rare earths, uranium, thorium, and columbium which was found in massive prismatic crystals up to 6 inches long and 4 to 5 inches wide. Aeschynite is a shiny black mineral displaying very good prismatic cleavage parallel to the length of the crystal. It is highly radioactive. The only known occurrence of these crystals is in the carbonates in the SE$\frac{1}{4}$ sec. 10, T. 4 S., R. 22 W. Here, aeschynite is a component of smaller lenticular masses in pink carbonate rock, and is associated with scattered monazite, allanite and columbite grains.

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*Personal communication.

Allanite

A cerium-bearing epidote, allanite, occurs as coarse black euhedral crystals up to one inch long. In several mineralized carbonates within the Columbine No. 1 claim (fig. 4) allanite occurs abundantly along the hanging wall and is associated with large felted aggregates of actinolite and small quartz veins 1 to 2 inches wide. The carbonate, here, has a high rare-earth content and is a very deep pink in color, and as in several other places where either allanite or monazite is concentrated, the carbonate bodies are slightly radioactive. Although the thorium content of the allanite is not known, two analyses involving all minerals, one by Dow Chemical Company and the other by Fluo Rescent X-Ray Spectrographic Laboratory, fail to record so much as a trace of thorium. The thorium content of monazite from the Sheep Creek area, which usually contains appreciable amounts of thorium at other localities, was negligible or less than 1 percent. X-ray analyses by the writer did reveal trace amounts of thorium in bulk samples.

Ancylite

The presence of ancylite in the Sheep Creek deposits was first noticed by personnel of the U. S. Geological Survey. During the course of this investigation the writer observed numerous small grains, under the microscope, which correspond favorably with published data on ancylite (Winchell and Winchell, 1951, p. 122). It was further observed that an abundance of ancylite imparted a pinkish to reddish color to the rock, and that as the ancylite content increased the color became more intense. Grains of ancylite range in size from less than .009 mm. to 0.25 mm. and occur as intergranular blebs in a matrix of calcite. This rare carbonate mineral is associated with almost all minerals in the suite, but appears to be more abundant near columbite, aeschynite, allanite, and monazite.

Barite

In the Sheep Creek and Beaver Creek deposits, barite occurs abundantly as individual grains in a calcite matrix, but is almost indistinguishable in some hand specimens. However, on the Rocky Point No. 5 claim north of Woods Creek a large vein-like body about 8 feet wide occurs along the east side of a carbonate body. A grab sample from this barite outcrop assayed 94.1 percent barium sulfate and 5.6 percent silica.

Calcite and Siderite

The predominate gangue minerals are calcite and siderite with calcite usually the more abundant. Both occur as subhedral to anhedral grains of many different sizes. They generally surround all other minerals.

Viewed microscopically the carbonate grains are very cloudy and appear to contain abundant inclusions, but the inclusions were not identified. Some of the calcite probably contains strontium.

Chalcopyrite, Molybdenite, Pyrite, and Pyrrhotite

Sulfides occur similarly throughout the area. All occur as small individual grains sporadically distributed within the carbonates.

Molybdenite and nickeliferous pyrrhotite have been found only in the two adits on lower Sheep Creek, but chalcopyrite and pyrite have been noted in widely scattered localities.

Columbite

The mineral, around which the economic interest of the carbonate bodies has centered, is columbite. It occurs as irregular patches and euhedral crystals .04 mm. to 2 inches wide in a matrix of siderite and calcite. In hand specimen it is black with a submetallic luster and has a hematite-red streak. Thin sections show a distinct blood-red color on thin edges of grains, but the bulk of the mineral is black and opaque. One of the most distinctive features of columbite in thin section is its sieve texture produced by numerous small blebs of calcite within the mineral. Small veinlets of secondary calcite cut across many columbite grains, and fersmite commonly forms wedge-shaped inclusions within the larger grains.

Columbite may be, at first glance, difficult to distinguish from magnetite in hand specimen, but the absence of magnetism and reddish-brown columbite streak serve to distinguish it in the field.

X-ray diffraction patterns of the mineral show close correlation with patterns for columbite, very low in tantalum content, from other deposits. X-ray spectrographic analyses indicate that the columbite was either lacking in tantalum or that tantalum was present only in traces.

The distribution of columbite throughout the deposits is very erratic. Semiquantitative X-ray spectrographic analysis almost always reveals the presence of columbium, but analyses above 0.10 percent are the exception rather than the rule. It should be pointed out, however, that only a small number of samples were taken by the writer and that an accurate determination of over-all ore tenor would have to be based on far more widespread sampling.

In general, the columbite grains are scattered throughout the groundmass, but locally they cluster along one wall of the carbonate body. No correlation between columbium content and total rare-earth content was observed.

Fersmite

Dr. Milton of the U. S. Geological Survey has found fersmite, a calcium-columbate, in specimens from the Sheep Creek deposits. The fersmite, which occurs as brittle dark-brown to black wedge-shaped crystals, intergrown with columbite, is described fully by Hess and Trumpour (1959, p. 1-8).

Hydro-biotite

Large books of hydro-biotite up to 6 inches wide occur throughout most of the carbonate bodies. In the Sheep Creek No. 1 and 2 adits it fills fault fissures and also occurs as large diseminated euhedral crystals surrounding calcite.

Ilmenite and Rutile

These two minerals are relatively rare in carbonates within the area, but do occur together in the carbonate body in the Beaver Creek adit in SE$\frac{1}{4}$ sec. 1, T. 4 S., R. 23 W.

Ilmenite, surrounded by rutile, is disseminated throughout the carbonate which is light tan to gray in color. The grains of ilmenite with rutile rims are between .04 mm. and .65 mm. across. Rutile has entirely replaced the ilmenite in certain grains, except for scattered remnants.

Although columbite has not been observed in samples from the Beaver Creek adit, X-ray spectrographic analyses reveal the presence of columbium in quantities greater than would be considered trace amounts. The only explanation that the writer has for this phenomenon is that the ilmenite, as in the Idaho deposits, contains significant quantities of columbium within its space lattice. During the breakdown of ilmenite to rutile, small quantities of perovskite, a calcium titanite, may have formed in which columbium can proxy for titanium in the lattice (Winchell and Winchell, 1951, p. 91). The presence of perovskite has not been confirmed.

Magnetite

Magnetite although not abundant is a fairly common constituent of the carbonates and occurs as very minute specks or as large subhedral grains up to one inch in diameter. No significant association or spatial relationships were observed for this mineral.

Monazite

Honey-yellow to reddish-brown crystals of monazite are usually conspicuous within the pinkish carbonates.

The monazite appears to be most abundant in specimens containing a large percentage of other rare-earth minerals. It occurs as anhedral grains and as euhedral crystals ranging in size from tiny intergranular blebs to large prismatic crystals 2 to 3 cm. across.

Quartz

Insignificant amounts of quartz are present in almost all carbonates as small grains in the matrix and as minor veinlets. Individual quartz grains are usually about the same size as the enclosing calcite but are distinctively brecciated. They appear to be single grains which have been fractured in place.

PARAGENESIS

Although precise inter-mineral paragenetic relations could not be established with any degree of certainity, a few generalizations can be made. Rare-earth constituents such as allanite, ancylite, and monazite appear to have formed later than most of the calcite. Columbium-bearing minerals such as columbite and aeschynite also appear to have formed later than the bulk of carbonate minerals, but the relationship between rare-earth and columbium-rich minerals is not apparent. Minor quartz veinlets and secondary calcite stringers cut across all other minerals and rocks and are thus the most recent addition to the deposits.

WALL ROCK ALTERATION

Specimens of wall rock were collected from the crosscut in the Sheep Creek No. 1 adit for the purpose of making a study of wall rock alteration. Thin sections were made of three specimens taken 2, 5, and 10 feet away from the carbonate body. They will be referred to as No. 2, No. 5, and No. 10.

No. 2 section displayed the following minerals: quartz, olive-green biotite, calcite, hornblende, ilmenite, and magnetite. The rock is a fine-grained quartz-biotite schist containing abundant calcite. Quartz occurs as small grains scattered throughout the groundmass surrounded by larger biotite grains and calcite. The olive-green biotite is similar in appearance to hydro-biotite and is badly crushed and bent. Calcite is so abundant that the rock will effervesce vigorously in cold dilute hydrochloric acid. The calcite surrounds all other minerals and fills small fractures. Scattered grains of calcite are laced by opaque needlelike inclusions. Hornblende and ilmenite are minor constituents with hornblende predominating over ilmenite.

No. 5 section contains labradorite ($Ab_{46}An_{54}$), altered hornblende, brown biotite, augite, ilmenite, and apatite. Labradorite and hornblende are the dominant minerals, brown biotite and augite are second in abundance, with ilmenite and apatite as minor accessories. Calcite is not present. The most striking feature about this specimen is the presence of altered hornblende. It is dark brown, pleochroic, has high birefringence, and resembles actinolite in form but not in color. It appears as brown, felted grains which are generally larger than the surrounding groundmass.

No. 10 section contains the same mineral assemblage but with one interesting variation. Altered hornblende is surrounded by actinolite which is in turn surrounded by rims of blue-green hornblende. Each mineral displays jagged edges as it grades into the other.

The conclusion to be drawn from this study is that an alteration of minerals has taken place in the wall rock adjacent to this carbonate body. It is realized, however, that additional studies would have to be made adjacent to other carbonates, both mineralized and unmineralized, before these alteration effects could be attributed to either hydrothermal or metamorphic processes.

STRUCTURE

The most noticeable structure within the carbonates is irregular pinching and swelling. This not only occurs where the ore body deviates in direction but also along relatively straight portions. It is suggestive of boudinage structure, for in many instances the carbonates pinch out, and then swell to an original width of 4 or 5 feet.

A braided fault system is invariably found in the carbonates and is usually parallel in strike and dip with the carbonate bodies. Fault gouge is thickest where individual small faults intersect and may account for the boudin-like expression of the carbonate-rich bodies. Fragments of mineralized carbonates are present within the gouge.

Numerous small cross faults are observed in underground openings, a few of which offset the carbonates slightly, usually less than 5 feet. Others end abruptly against strike faults.

One large flat-lying fault, which cuts diagonally across the portal of the Sheep Creek No. 1 adit, has offset the carbonate body about 60 feet. This fault dips north into the hill. The hanging wall has been displaced upward and to the east, relative to the footwall. Many smaller low-angle faults, seen in Sheep Creek adit No. 2, offset carbonate bodies from west to east, but displacements are only 1 to 2 feet.

LITHOLOGIC CONTROL

One of the significant features of the mineralized carbonates is their presence in metamorphic rocks of different kinds. Although most of the carbonates occur in amphibolite, two occurrences were noted in gneissic rocks. One occurs above the Sheep Creek adit No. 1. Here, a pink carbonate containing visible columbite crystals is in augen gneiss. The carbonate is about 3 feet wide and is at a slight angle to the foliation of the gneiss. The second is in the central part of S$\frac{1}{2}$ sec. 4, T. 4 S., R. 22 W. where a 1- to 2-foot wide stringer of tan carbonate occurs within quartz-plagioclase-biotite gneiss. Although columbite was not observed in the carbonate, the X-ray spectrograph did reveal minor amounts of the elements columbium and strontium, and traces of the rare earths.

SHEEP CREEK DEPOSITS

Many mineralized carbonates have been uncovered along the ridge north of Sheep Creek since the initial discovery in 1954. Most of the larger carbonate bodies are exposed by bulldozer trenches and three of the most highly mineralized zones have been explored by adits.

The Sheep Creek No. 1 and No. 2 adits (figs. 3, 4, and 5) are on the Dark Star claim. Carbonates at the portal sites are deep pink in color and contain large crystals of columbite and monazite along with fersmite, magnetite, ancylite, and barite.

Sheep Creek No. 1 adit (fig. 4) follows the north (left) wall of a 2½- to 3-foot wide carbonate body that displays minor pinch and swell structure. A contact between amphibolite and augen gneiss was encountered near the face of this adit. Foliation in augen gneiss intersects the contact at an angle which suggests a fault contact. Fault gouge, though very thin, is present between the rock types. The carbonate body, in amphibolite, is gradually wedged out as the contact is approached, but is cut off by a small cross fault before reaching the augen gneiss. Slickensides indicate movement of the carbonate parallel to the strike of the fault.

The Sheep Creek No. 2 adit (fig. 5) follows a lower and more westerly portion of the same carbonate body which has been displaced about 60 feet to the west along a low angle fault.

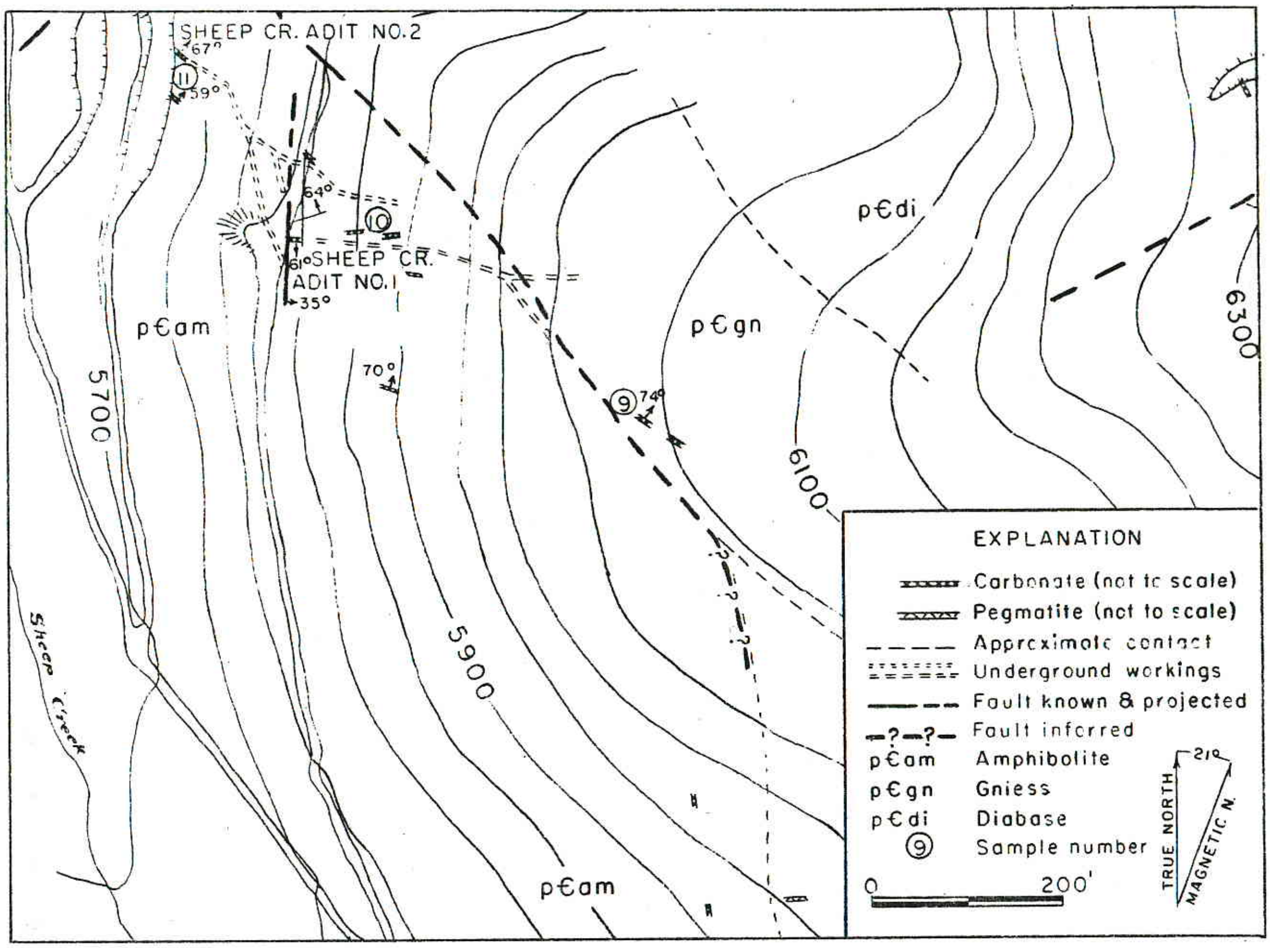

Figure 3.--Geologic map of lower Sheep Creek deposits, sec. 4, T. 4 S., R. 22 W., southern Ravalli County, Montana.

Mineralogical changes along the length of the carbonate bodies are displayed within these adits. Fine-grained calcite and pink color with accompanying rare-earth and columbium content give way to sparsely mineralized coarse white calcite which contains numerous books of hydro-biotite. Several mineralized zones are apparent in each adit.

A channel sample taken across a 3-foot carbonate body about 400 feet northeast of Sheep Creek adit No. 1 (figs. 2 and 3, sample 9) contained 5.4 percent silica (SiO_2), 3.9 percent barium oxide

(BaO), 50.0 percent calcium carbonate ($CaCO_3$), 1.2 percent sulfur (S), about 3 percent strontium oxide (SrO), and less than 0.30 percent columbium (Cb). Cerium, lanthanum, neodymium, praseodymium, gadolinium, yttrium, and manganese were also detected in the sample. Cerium and lanthanum are the most abundant rare-earth elements in all samples.

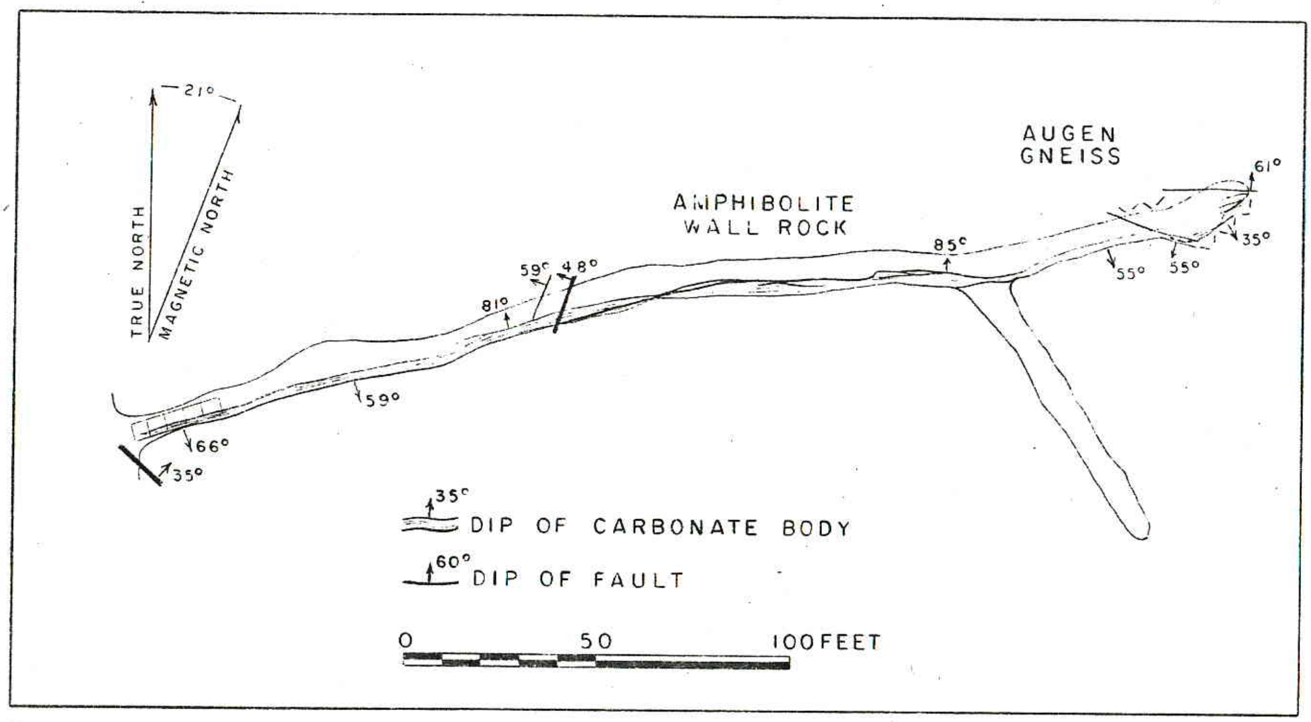

Figure 4.--Geologic map of Sheep Creek adit No. 1, southern Ravalli County, Montana.

Sample 10 (figs. 2 and 3) which represents $2\frac{1}{2}$ feet of carbonate, contained 18.3 percent silica, 12.7 percent barium oxide, 43.7 percent calcium carbonate, 0.7 percent sulfur, about 2 percent strontium oxide, and less than 0.10 percent columbium. Other elements detected were cerium, lanthanum, praseodymium, neodymium, manganese, and a trace of tantalum.

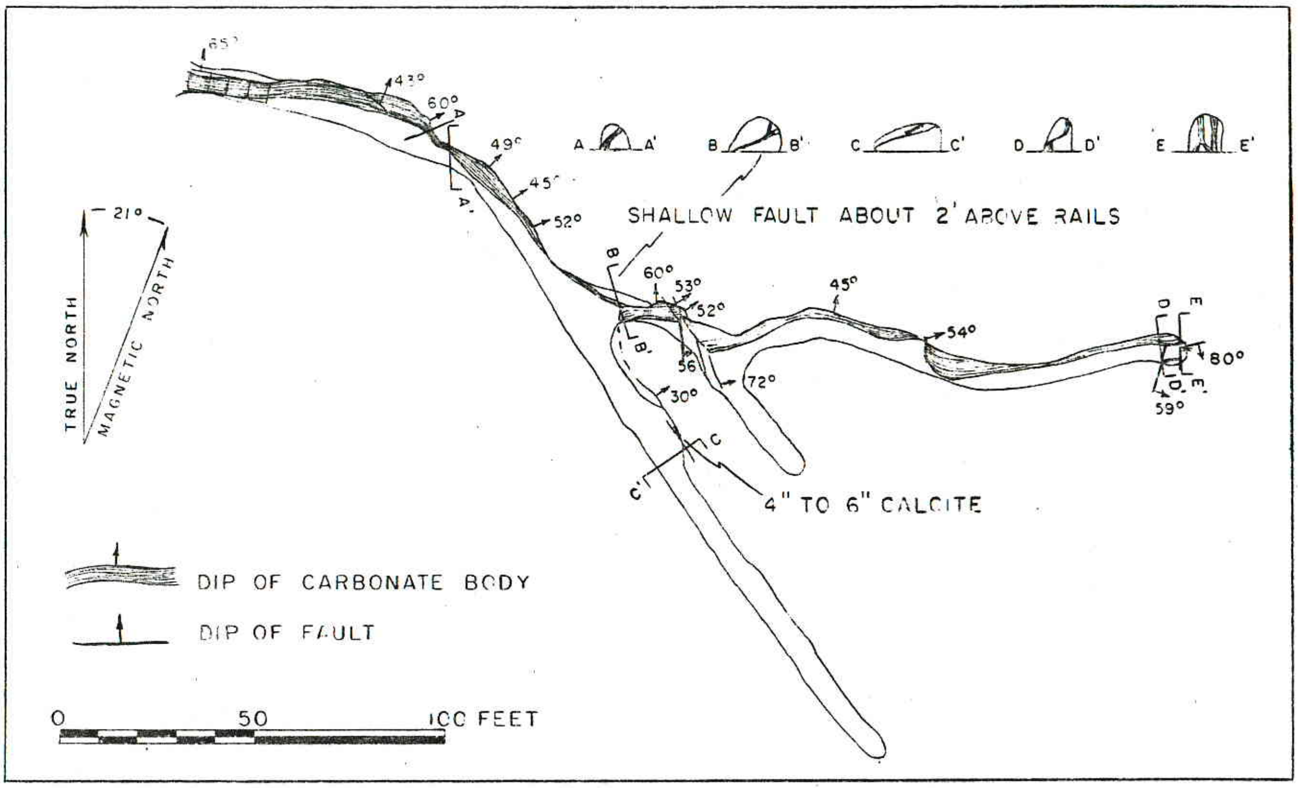

Figure 5.--Geologic map of Sheep Creek adit No. 2, southern Ravalli County, Montana.

A $3\frac{1}{2}$-foot sample from the portal of the Sheep Creek adit No. 2 (figs. 2 and 3, sample 11) contained 16.8 percent silica, 4.5 percent barium oxide, 63.4 percent calcium carbonate, 1.4 percent sulfur, about 4 percent strontium oxide, and less than 0.10 percent columbium. Other detected elements were cerium, lanthanum, neodymium, manganese, and thorium.

Sahinen (1957, p. 54) reports an analysis of carbonate ore from the Dark Star claim which shows 5.0 percent columbium, 0.65 percent neodymium, 3.2 percent cerium, 2.0 percent lanthanum, and 3.6 percent strontium. Other analyses observed by the writer have reported as much as 15.0 percent cerium, 10.0 percent lanthanum, 2.0 percent praseodymium, 2.0 percent neodymium, 0.4 percent gadolinium, and lesser amounts of yttrium.

Underground workings of the Sheep Creek No. 3 adit (figs. 6 and 7) SW$\frac{1}{4}$ sec. 3, T. 4 S., R. 22 W. which are accessible by way of the Sheep Creek road, are confined to one crosscutting adit through black fine-grained amphibolite. The crosscut is about 410 feet long from the portal to the point where the carbonate is intersected. Here the carbonate body ranges from 2 to 4 feet wide and is streaked with pink and white bands of carbonate rock separated by narrow bands of schistose wall rock. This portion of the ore body appears to be the down-dip extension of surface exposures.

A 10-foot composite sample from the surface outcrop, intersected by the Sheep Creek No. 3 adit, averaged 8.1 percent silica, 3.8 percent barium oxide, 57.9 percent calcium carbonate, 0.9 percent sulfur, about 2 percent strontium oxide, and less than 0.10 percent columbium. Cerium, lanthanum, neodymium, praseodymium, and yttrium were also detected.

A large carbonate body on the east end of the Columbine No. 1 claim (fig. 6) gave the highest columbium content of all samples taken. This 8-foot wide body is unusual in that it contains abundant large allanite crystals and also contains sizeable masses of felted green actinolite. A pegmatite dike, which strikes at about 90 degrees to the carbonate, was observed 10 feet east of the carbonate, but minerals common to the rare-earth deposits were not noted in the pegmatite.

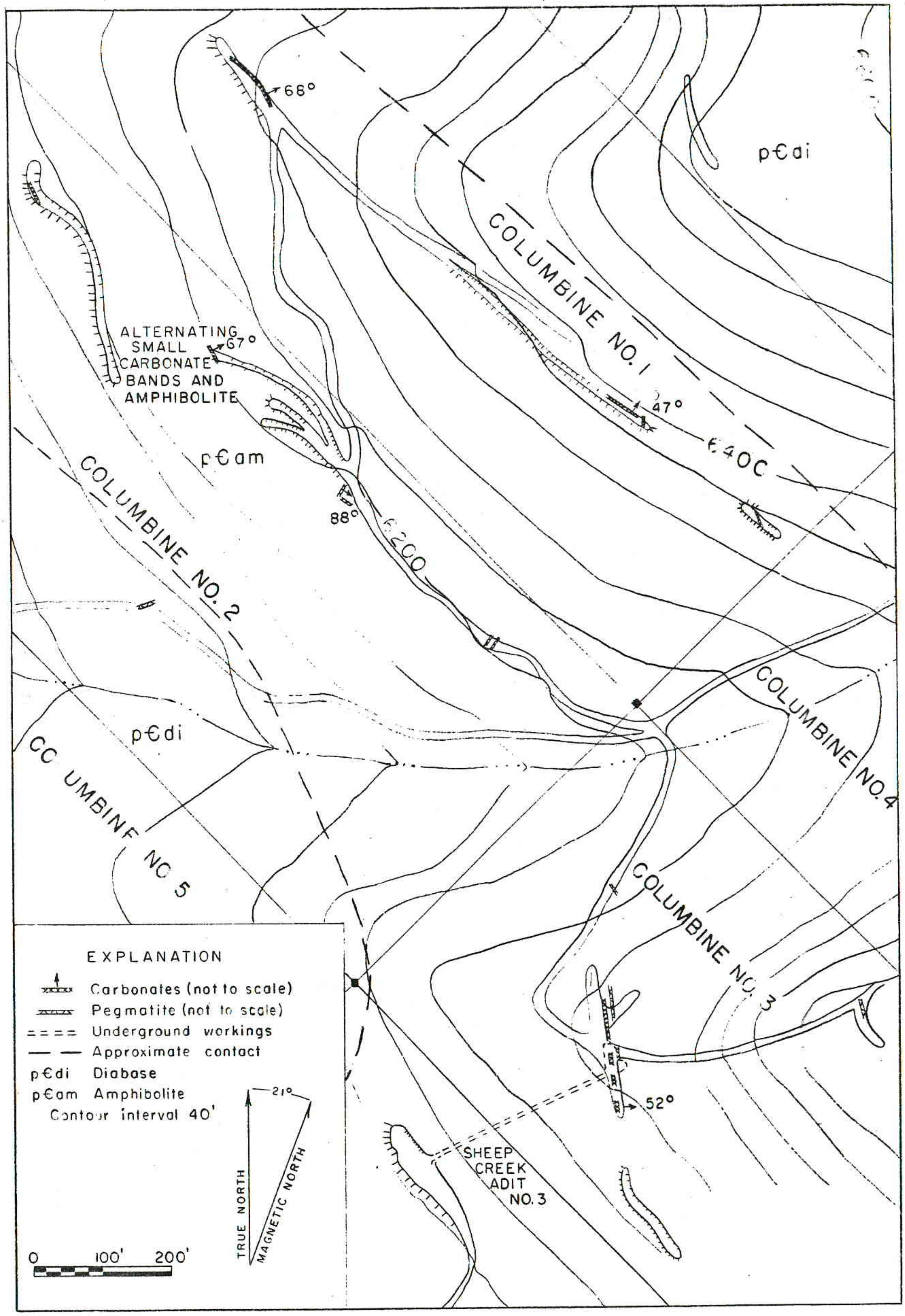

Figure 6.--Geologic map of upper Sheep Creek deposits, sec. 3, T. 4 S., T. 22 W., southern Ravalli County, Montana.

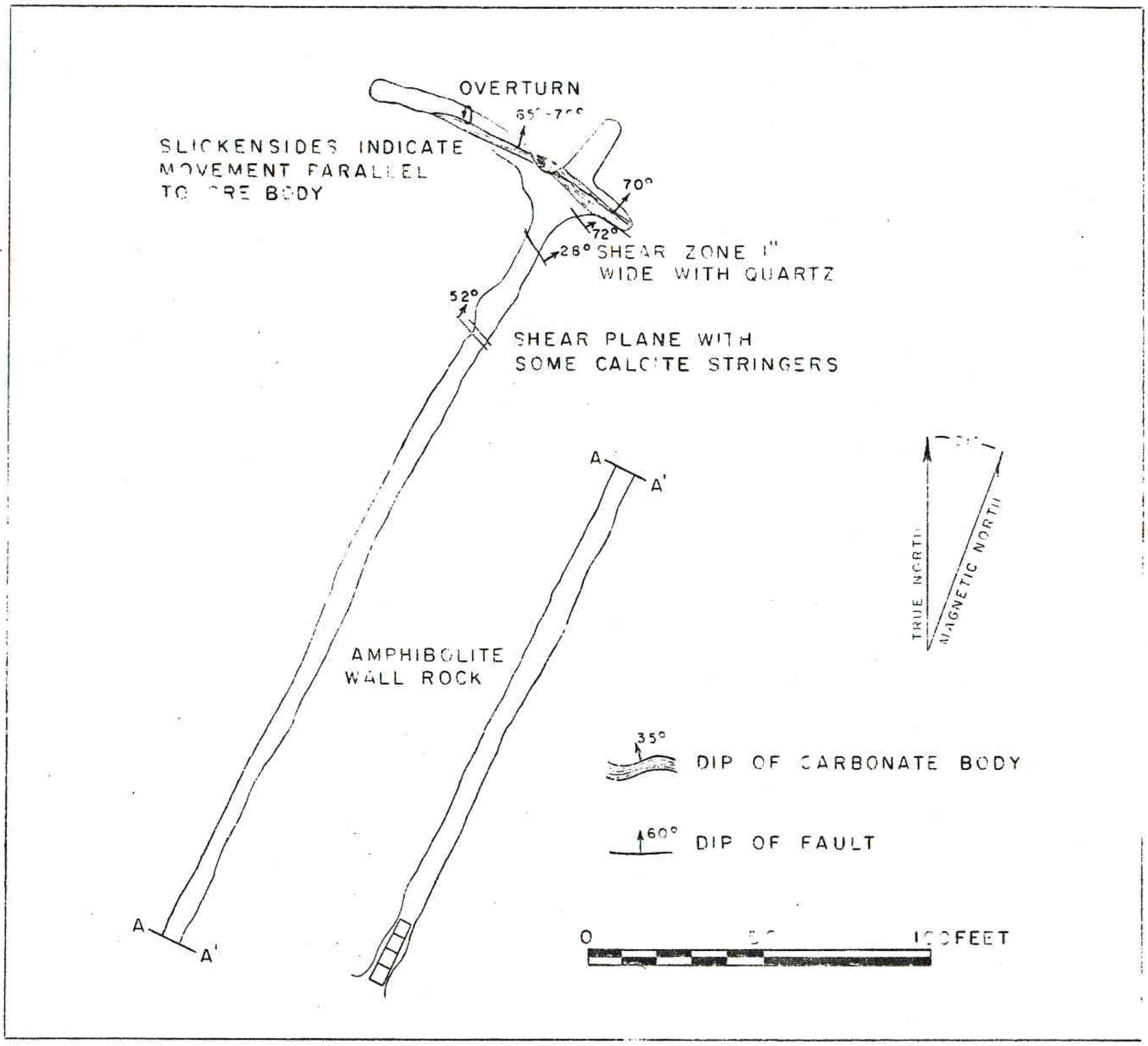

Figure 7.--Geologic map of Sheep Creek adit No. 3, southern Ravalli County, Montana.

Two samples were taken from the carbonate-no. 6 across the southern 5 feet and no. 5 across the northern or hanging wall 3 feet of the body. Sample 5 contained the following: 6.4 percent silica, 25.0 percent calcium carbonate, about 1 percent strontium oxide, and between 1 and 3 percent columbium. Sample 6 contained the following: 3.6 percent silica, 25.2 percent calcium carbonate, 0.1 percent sulfur, about 1 percent strontium oxide, and less than 0.2 percent columbium. In addition to the lanthanum, cerium, neodynium, praseodymium, yttrium, and manganese usually detected, uranium, thorium, copper, and tantalum were also found to be present.

Numerous other mineralized carbonates occur within the Sheep Creek drainage; however, they all conform to the general descriptions given above, but are usually less mineralized. One other carbonate worthy of mention is the small body in the SE$\frac{1}{4}$ sec. 10, T. 4 S., R. 22 W. nearest the section line (fig. 2). It is this outcrop which contains aeschynite crystals. The aeschynite occurs within a pink carbonate in a small lense-like mass about 1 foot wide and 3 to 4 feet long. Monazite, columbite, and allanite also occur within the carbonate rock.

BEAVER CREEK AND WEST FORK DEPOSITS

Fewer mineralized carbonates occur within the Beaver Creek drainage. One deposit contains visible columbite grains in a light tan-colored matrix. This carbonate in NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 4, T. 4 S., R. 22 W. is banded with alternating 5- to 12-inch layers of carbonate and amphibolite.

The Beaver Creek adit (fig. 8) has been driven for 160 feet along a light bluish-gray marble which gradually pinches out at the face. Fault gouge is braided throughout the body and where pinch-out occurs the gouge is about 6 inches wide. Small blocks of marble can be seen in the crushed material. Although columbite was not observed in the marble, which contains abundant ilmenite, a semi-quantitative X-ray analysis revealed a small amount, less than 0.10 percent, of columbium. Chemical analyses from a sample taken at the portal of the adit (fig. 2, sample 16) report an average of 14.4 percent silica and 54.6 percent calcium carbonate. Barium oxide and sulfur content were nil and strontium and manganese oxide were not reported. The usual assemblage of rare-earth elements were present with the exception of praseodymium and neodymium.

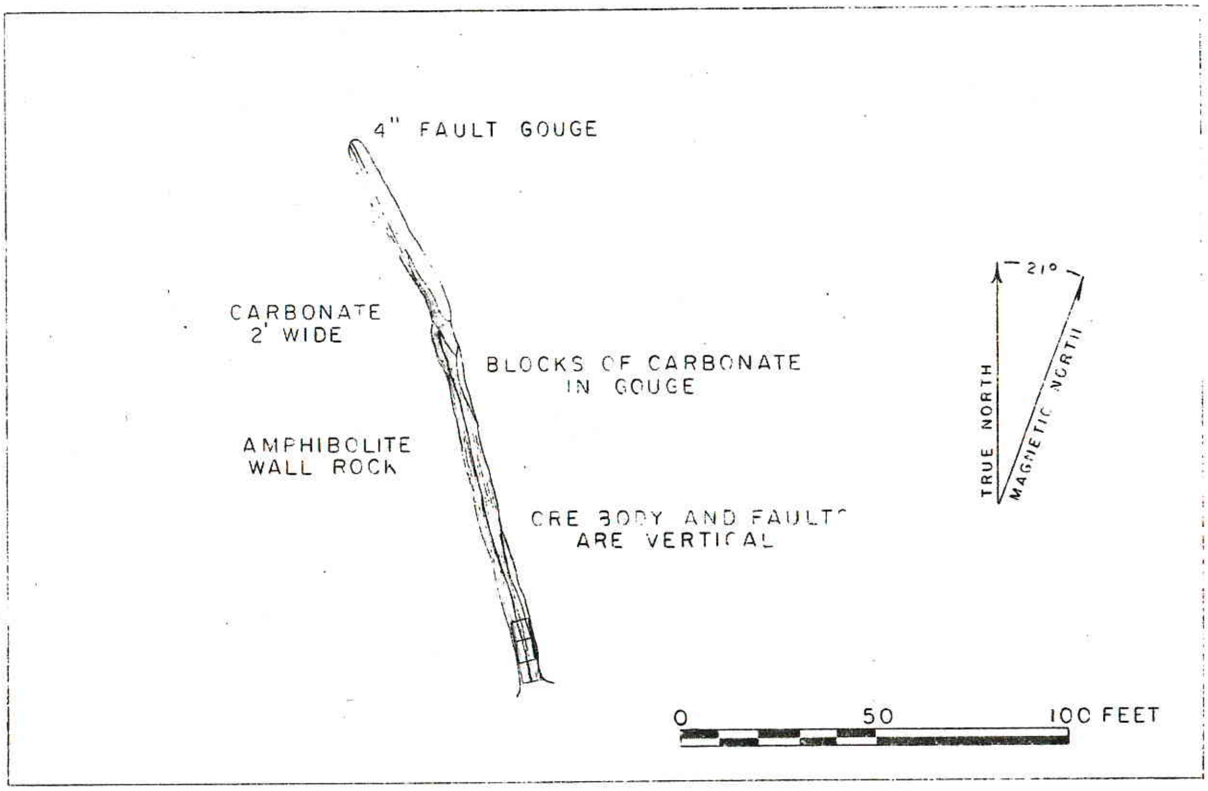

Figure 8.--Geologic map of Beaver Creek adit, southern Ravalli County, Montana.

Several smaller carbonate bands occur on the ridge east of the West Fork of the Bitterroot River and south of Sheep Creek. One columbite-bearing carbonate body occurs in coarse-grained gneissic rocks (fig. 2, sample 18). A qualitative analysis revealed a measurable amount of columbite and detected the presence of lanthanum, cerium, manganese, and strontium.

Several other samples (fig. 2, samples 13 and 15) were taken across pinkish-colored carbonates in the $E\frac{1}{2}NW\frac{1}{4}$ sec. 9, T. 4 S., R. 22 W. Sample 13 contained 17.0 percent silica, 3.1 percent barium oxide, 49.7 percent calcium carbonate, 0.9 percent sulfur, about 1 percent strontium oxide, and less than 0.3 percent columbium. Sample 15 contained 21.2 percent silica, 3.4 percent barium oxide, 52.0 percent calcium carbonate, 0.9 percent sulfur, about 3 percent strontium oxide, and less than 0.1 percent columbium. Cerium, lanthanum, yttrium, praseodymium, tantalum, and manganese were also detected in these samples.

WOODS CREEK DEPOSITS

Numerous small light-tan carbonates occur along Woods Creek, which is just north of the area shown in figure 2. Many have been uncovered along the ridge north of the creek. The carbonates or marble bands range from a few inches to $3\frac{1}{2}$ feet wide and are usually interlayered with amphibolite. Columbite, barite, monazite, and magnetite are visible in several of the larger carbonates. Barite is especailly abundant along the east wall of a large carbonate on the Rocky Point No. 5 claim. About 8 feet of white barite is exposed.

ORIGIN

Two kinds of carbonates occur within the area. The first and most important is the mineralized carbonate which contains varying amounts of valuable minerals of uncertain origin. The second is the "blue marble". It is relatively unmineralized. In the writer's opinion, the blue marbles are of sedimentary origin and differ from the mineralized carbonates only in that they have escaped mineralization. This opinion is based on appearance and association. The appearance is that of a recrystallized limestone, uniformly colored, dense, and equigranular. The association is with metamorphic rocks considered to have been derived from sedimentary rocks. The above classification is generalized and may represent the extremes of two related metamorphic limestones in which the degree of mineralization has differed.

The salient features of the mineralized and unmineralized carbonates are presented below:

Mineralized Carbonate	Unmineralized Carbonate "blue marble"
1. Contains columbium and rare-earth minerals.	1. No appreciable mineralization but does contain small amounts of monazite*
2. Widths up to 8 feet.	2. Widths generally less than 2 feet.
3. Shades of tan, buff, pink, and red colors usually in irregular bands.	3. Uniform blue-gray color.
4. Occur in different pre-Beltian metamorphic rocks.	4. Occur in amphibolite only(?)
5. Fairly continuous laterally and horizontally but with varying widths.	5. Form narrow bands and small boudins.
6. Relatively widespread throughout area.	6. Scattered small bodies.

The problem of origin of the rare-earth and columbium minerals. in the carbonates is somewhat more complex. Of the many hypotheses that have been advanced to explain similar rare-earth occurrences in carbonate-rich rocks, three will be considered here.

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*Heinrich, E. W., Personal communication.

The first is fracture filling by gaseous or liquid carbonate-rich solutions carrying columbium and rare-earth elements. This is essentially the hypothesis advanced by Pecora (1956, p. 1551) which embodies an association of "carbonates" with alkalic igneous rocks.

The second is origin by gaseous or liquid solutions carrying columbium and rare-earth elements. Although similar to the first hypothesis, the implication is that calcium carbonate is either lacking in the solutions or is present in small quantities. In other words, the deposits would actually be columbium and rare-earth hydrothermal replacement deposits in marble.

The third hypothesis suggests concentration of the "exotic" elements by metamorphic segregation whereby the rare elements are transferred from the country rock to the marbles (lateral secretion) during metamorphism.

ECONOMIC CONSIDERATIONS

The economic aspects to be considered in the transition from prospect to mine are many and varied.

Observation of the ore bodies has also revealed spotty concentration of columbium minerals, a fact which suggests that selective mining practices will have to be followed if these deposits are to be developed. It should be emphasized, however, that the writer's conclusions are based upon a relatively small number of samples, and that a widespread sampling program would be required to establish truly reliable data on ore grade and reserves.

The structure of the deposits should also be a prime consideration. Irregularities in width, possibly in both horizontal and vertical directions, will affect mining methods. The narrow portions of ore bodies will undoubtedly be difficult to mine if selective methods become necessary.

Future prospecting should be concentrated in areas where amphibolite and diabasic rocks are present, for it is within these rocks that most of the carbonates occur. Favorable sites, it has been noticed, are usually situated in small saddles, and along ridges where a change in slope occurs. The prospector would do well to carry a small bottle of dilute hydrochloric (muriatic) acid with him in the field because effervescence of the wall rocks often reflects the presence of nearby carbonate bodies.

Placer deposits should be prospected. Columbium and rare-earth minerals have high specific gravities and would be expected to concentrate along stream bottoms. The grade of such placers is not foreseeable, and the extremely narrow width of most valleys in the area makes the formation of large placer accumulations unlikely. However, wider valleys on the larger streams, such as the West Fork and Johnson Creek and selected areas on the other streams, may prove amenable to small-scale placer operations.

GLOSSARY

ARKOSE is a sandstone composed of material derived from the mechanical disintegration of granitic rocks; it may contain over 25 percent of feldspars.

CATACLASTIC. Pertaining to a texture found in metamorphic rocks in which brittle minerals have been broken and flattened in a direction at a right angle to the pressure stress.

MAFIC. Pertaining to or composed dominantly of the magnesian rock-forming silicates; said of some igneous rocks and their constituent minerals.

MEGASCOPIC. A term applied to observations made with the unaided eye.

METACRYST. Any large crystal developed in a metamorphic rock by recrystallization.

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