Geology and Description of the Thorium-Bearing Veins, Lemhi Pass Quadrangle, Idaho and Montana

GEOLOGICAL SURVEY BULLETIN 1351

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By MORTIMER H. STAATZ

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A detailed description of the size, attitude, mineralogy, chemical composition, and geologic setting of the thorium veins in the northeastern part of the Lemhi Pass district

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By MORTIMER H. STAATZ

ABSTRACT

The Lemhi Pass quadrangle, an area of approximately 53 square miles, lies astride the Continental Divide in the east-central part of the Beaverhead Mountains. This quadrangle, though only a part of the much larger Lemhi Pass thorium district, is the area of the most abundant thorium veins. Through 1970, the only thorium shipped from this district was used for testing. Future development of these thorium veins depends on an increase in the value of this metal.

Rocks of the Belt Supergroup underlie the entire quadrangle and are at the surface over about 60 percent of the area. Fine-grained micaceous quartzite is the dominant rock type. Siltite, in layers from a few inches to 1,200 feet thick, is in places interbedded with the quartzite. The larger siltite units are mapped separately. The Challis Volcanics, which at one time overlaid the Belt rocks across the entire quadrangle, are now preserved in downfaulted blocks and as a few small erosional remnants. In these, the Challis can be divided into at least two major divisions: (1) a thick basalt-rhyodacite sequence and associated tuffs and conglomerates, and (2) a younger basalt. Some light-colored flows or intrusions of quartz latite or rhyodacite may belong to a third major division. Rocks of the first two divisions are separated by an angular unconformity; rocks of the third possible major division are compositionally different from those of the first two divisions, but as these light-colored rocks occur in scattered outcrops, little is known about their stratigraphic position relative to the rocks of the other two divisions. Most of the volcanic rocks in this quadrangle are in the first division, which is further subdivided from oldest to youngest into the following units: (1) Basal conglomerate, (2) quartzite-bearing rhyolite tuff, (3) conglomerate of Flume Creek, (4) vitric tuff of Lemhi Pass, (5) basalt-rhyodacite sequence, and (6) tuff of Curtis Ranch.

Diorite dikes are scattered through the rocks of the Belt Supergroup; these dikes were emplaced in Tertiary time after the Challis Volcanics.

Unconsolidated deposits of Quaternary age cover about one-fourth of the quadrangle. They are the most abundant in, and blanket most of, the northeast quarter of the quadrangle; there, they are mainly older glacial deposits, formed by the ice sheets as they spread southward. Younger glacial deposits, formed by local valley glaciers, cover the valley bottoms of some of the eastward-flowing streams.

The rocks of the area are deformed by several sets of faults and a few folds. Three sets of faults with different trends (N. 25°–40° E., N. 15°–20° W., and N. 67° E.) were formed before the Challis Volcanics were deposited.

After the emplacement of the Challis, the rocks were again faulted, folded, and tilted. The three largest faults — the Lemhi Pass, Bull Moose, and Dan Patch, which bound one or more sides of all major outcrop areas of the volcanics — were formed at that time.

Three principal types of veins occur at the 107 mapped localities in the Lemhi Pass quadrangle, as follows: (1) Veins that contain thorium, (2) veins that contain copper but do not contain thorium, and (3) barren quartz veins. The thorium-bearing veins are, by far, the most common. They range in thickness from paper thin to 30 feet, and range in length from a few feet to at least 3,900 feet. Ten veins are more than 1,000 feet each in length. Most of the thorium-bearing veins strike either N. 40°–50° W. or N. 70°–80° W. and dip steeply to the southwest. These veins occur along small faults and shears, and most of them are near the Lemhi Pass, Bull Moose, or Dan Patch faults. These veins are sheared and brecciated, and earlier gangue minerals are veined by later minerals. The thorium-bearing veins, which consist principally of quartz or of quartz and microcline gangue, are cut by veinlets of goethite and hematite that contain thorite and, less commonly, monazite. Thirty-nine minerals were identified from various veins, but many of these occur in only a few veins where they generally are sparsely distributed. Seven minerals — quartz, magnetite, specularite, goethite, thorite, microcline, and rutile — occur in at least two-thirds of the veins. Other moderately common minerals are barite, pyrite, black manganese oxide minerals, red earthy hematite, monazite, muscovite, and apatite. In addition to thorite and monazite, the thorium-bearing minerals brockite and allanite were identified in several veins. Not all the thorium occurs in discrete thorium minerals, however; some of it is in limonite. The average thoria content of some of the better explored thorium veins commonly exceeds 0.25 percent. The overall rare-earth content is about equal to the thoria content and varies from vein to vein and from place to place in the same vein. The ratio of total rare-earth oxides to thoria in various samples ranges from 0.05 to 5.2. Many of the samples are depleted in cerium and enriched in europium as compared with the normal distribution of the other lanthanides. Small amounts of silver, 0.2 to 2.0 ounces per ton, are found in samples from the Wonder, Black Rock, Buffalo, and Last Chance veins. More than 1-percent zinc occurs in some samples from the Wonder and Black Rock veins.

Copper-bearing veins are not as common as the thorium-bearing veins. Most of the copper-bearing veins, unlike the thorium-bearing veins, have a northeasterly strike. The copper-bearing veins consist principally of primary and secondary copper minerals in a quartz gangue. A small amount of copper has been produced from the Copper Queen and Bluebird properties. The veins on these two properties also contain some gold and silver.

Barren quartz veins are shorter than veins of the other two types, and, like the thorium-bearing veins, generally have a northwesterly strike.

The veins in the Lemhi Pass quadrangle are probably Tertiary in age and were formed after both the Challis Volcanics and the diorite. The copper-bearing veins are older than the thorium-bearing veins, but the relative age of the barren quartz veins to that of the other vein types is not known.

INTRODUCTION

The Lemhi Pass quadrangle is but a part of the Lemhi Pass thorium district (fig. 1). This district constitutes an oval area

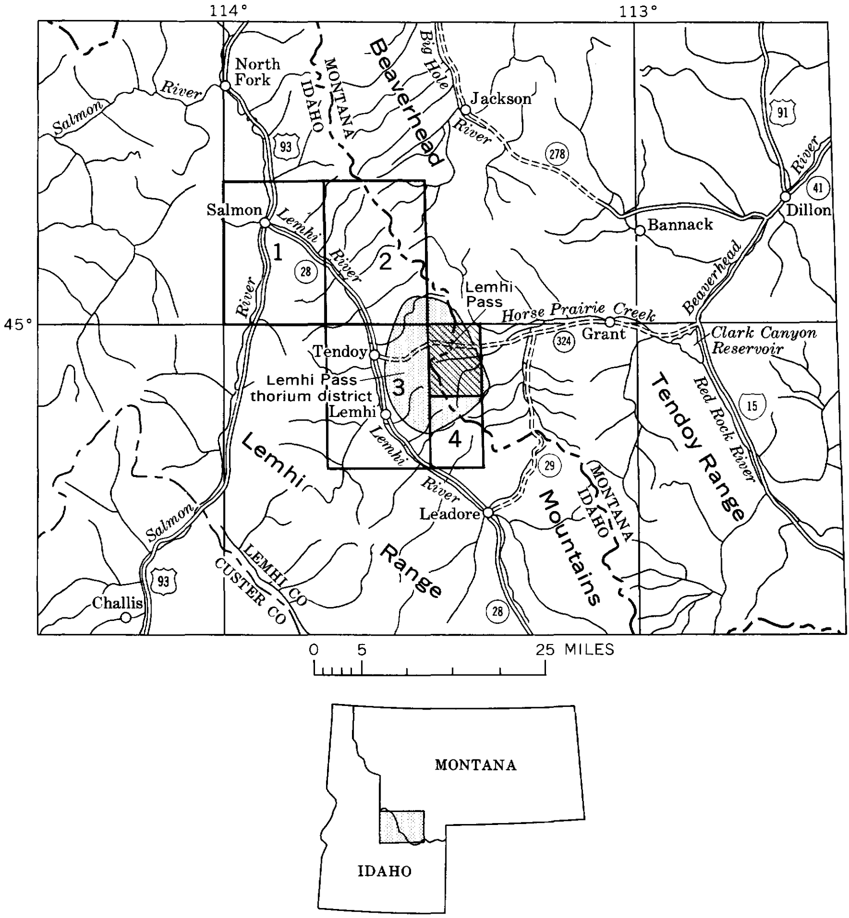

FIGURE 1. — Index map of eastern Idaho and southwestern Montana, showing location of the Lemhi Pass quadrangle (diagonal-line pattern) and the following neighboring quadrangles: (1) Salmon, (2) Baker (Goldstone Mountain), (3) Lemhi, and (4) Goat Mountain. Area of the Lemhi Pass thorium district is shown by shaded pattern.

containing more than several hundred thorium-rich veins, with Lemhi Pass near the center of its east side. This area is approximately 14 miles north-south by 10 miles east-west. The Lemhi Pass thorium district is, in turn, only part of a north-northwest-trending thorium-rich belt, at least 85 miles long, that extends northward from Bull Canyon (10 miles southeast of Leadore, Idaho) to southern Ravalli County, Mont. Thorium deposits in this belt formed at several different times and occur not only in veins, but also in carbonatite dikes and disseminated in granite. Most of the thorium veins are in the Lemhi Pass thorium district, although several occur near Diamond Creek, 8 miles north-northwest of Salmon, Idaho, and a few occur along the Salmon River about 8 miles farther northwest.

The part of the Lemhi Pass thorium district in which the veins are the largest and most concentrated is the Lemhi Pass quadrangle; therefore, the Lemhi Pass quadrangle was selected as the area in which to study details of the geologic setting and mineralogy of these deposits.

LOCATION AND ACCESSIBILITY

The Lemhi Pass quadrangle lies astride the Continental Divide in the east-central part of the Beaverhead Mountains, along the Idaho-Montana State line (fig. 1; pl. 1). Horse Prairie is a few miles east of the quadrangle, and the Lemhi River valley is approximately 7 miles to the west.

An unimproved dirt road over Lemhi Pass crosses the northern part of the Lemhi Pass quadrangle. This road connects with State Highway 28 at Tendoy, Idaho, 9 miles west of the west border of the area, and with Interstate Highway 15 at the Clark Canyon Reservoir dam, 28 miles east of the east border of the area. Salmon, Idaho, the principal town to the west, is 19 miles northwest of Tendoy; and Dillon, Mont., the principal town to the east, is 18 miles northeast of the Clark Canyon Reservoir. There are less developed dirt roads along the Continental Divide, and along parts of Frying Pan Creek, South Frying Pan Creek, Flume Creek, Sheser Creek, and Bear Creek, as well as to various prospects. Travel over some parts of these roads requires the use of four-wheel-drive vehicles.

A line of the Union Pacific Railroad runs along the east side of the Clark Canyon Reservoir.

For the most part, the area is uninhabited, with the only permanent residence being that of John Curtis, whose ranch buildings are along Trail Creek near the east edge of the quadrangle.

PHYSICAL FEATURES

The Beaverhead Mountains are the southern part of the Bitterroot Range, which forms a great part of the border between Montana and Idaho. The Beaverheads are a rugged range with peaks along the Continental Divide reaching an elevation of almost 11,000 feet. Lemhi Pass, in the north-central part of the quadrangle, at an elevation of 7,373 feet, is one of the lower points along the Continental Divide. The Lemhi Pass quadrangle includes only a small part of the Beaverheads. At the quadrangle's north border, 1½ miles north of Lemhi Pass, the Continental Divide reaches an elevation of 8,370 feet. South of the pass the divide gradually becomes higher and rises to an elevation of 9,482 feet near the south border of the quadrangle. The slopes west of the Continental Divide are, for the most part, much steeper than those to the east, and due east of Lemhi Pass, the country is characterized by rolling barren hills. South of the pass, steep-walled cirques lie along the east side of the divide, and the streams rising from them pass eastward down U-shaped valleys. Near the east edge of the quadrangle, a broad basin is formed where Sheser Creek, from the north, and Frying Pan and Trapper Creeks, from the southwest, join Trail Creek. This basin is characterized by broad gently sloping terraces of glacial till (fig. 6).

Slopes west of the Continental Divide drain either into Agency Creek in the northern part of the quadrangle or into Yearian Creek in the southern part; both of these creeks flow westward to the Lemhi River. Water east of the Continental Divide flows southward or northeastward to Trail Creek.

VEGETATION

The Lemhi Pass quadrangle is a patchwork of contrasting vegetation. The lower parts and most of the south-facing slopes are covered with low-growing gray sage *(Artemisia tridentata)*, grasses, and numerous wildflowers, whereas the higher parts and most of the north-facing slopes are covered with thick forests (fig. 11A). Lodgepole pine *(Pinus contorta* var. *latifolia)* makes up the greater part of the forests. Where there is more precipitation, or where the moisture is held longer, as on the north-facing slopes, Douglas-fir *(Pseudotsuga menzei)* is abundant. Along the tops of the high ridges, above an elevation of 8,400 feet, limber pine *(Pinus flexilis)* is the common tree. In places, alpine fir *(Abies lasiocarpa)* grows with the limber pine. Engelmann spruce *(Picea engelmanni)*, mountain alder *(Alnus tenuifolia)*, and two species of willow occur along many of the creeks. Aspen *(Populus tremuloides)* grows in the damp hollows on many hillsides. In addition, in Idaho below about 6,600 feet elevation, dwarf maple *(Acer glabrum)*, western chokecherry *(Prunus virginiana)*, and balsam poplar *(Populus balsamifera)* grow along the creeks.

The general pattern of open and forested areas in this quadrangle is controlled by the amount of moisture obtained and held, as well as by the rock type. In general, the area underlain by volcanic rocks is less forested than that underlain by other rock types. An excellent example occurs in a roughly triangular patch

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of volcanic rocks near the center of the quadrangle, between South Frying Pan and Bear Creeks; this patch is, for the most part, unforested, but it is surrounded by forest-covered areas that are underlain by Belt rocks and covered with glacial till (fig. 2).

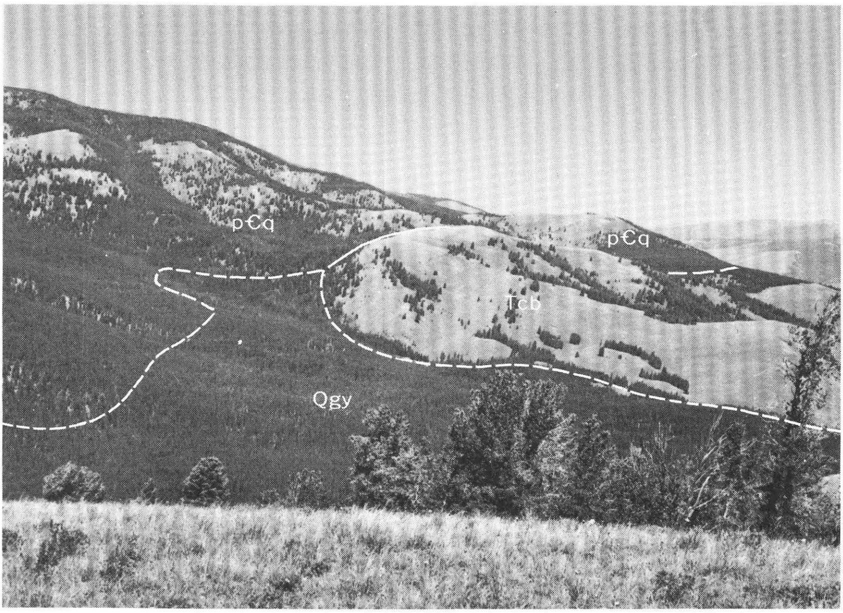

FIGURE 2. — Rocks of the basalt-rhyodacite sequence (Tcb) of the Challis Volcanics overlie those of the Belt Supergroup (p€q), as viewed northwest across the upper part of the Bear Creek drainage. Low, heavily forested land in foreground is covered with younger glacial deposits (Qgy).

HISTORY OF PROSPECTING

The Lemhi Pass area has had two periods of prospecting—the first of which was principally for copper, and the second for thorium. The first period started about 1883, when the main vein on the Copper Queen (pl. 1, loc. 43) was discovered (Umpleby, 1913, p. 120). Copper was the principal metal mined, but some gold and silver were also recovered. By 1910 the total production from this property was valued at approximately $100,000 (Umpleby, 1913, p. 120). Since that time the mine has been operated sporadically by several different owners (Schipper, 1955, p. 7–10), but production appears to have been small.

Further prospecting, mainly in the early part of the 1900's, located several other quartz and copper-bearing quartz veins.

These included veins, shown on plate 1, at the following localities: Loc. 30 (Bluebird), loc. 32 (Blue Boar), loc. 48 (Blue Ridge), loc. 25, loc. 26, loc. 28 (Idaho Pride Group), and loc. 8 (No Pay). The only recorded production from these was from the Bluebird mine working the Bluebird vein, which produced 8 tons of ore containing 1,432 pounds of copper, 3.6 ounces of gold, and 68 ounces of silver (Weed, 1926, p. 788). In about 1923 the Wonder lode (loc. 45)— a vein made up of a complex mineral association of copper, zinc, and thorium—was mined for its copper content (Sharp and Cavender, 1962, p. 44).

Thorium was discovered in this area in the spring of 1949 by Wayne Hinman (Jarrard, 1957, p. 46). Additional discoveries were made that year in both Idaho and Montana by W. G. Armenson, H. B. McKenny, G. E. Shoup, James Selway, and R. G. Denny. During the first 2 years of prospecting for thorium, several important veins were located, including the Last Chance (loc. 82), Buffalo (loc. 18), Wonder No. 18 (loc. 70), part of the Shear Zone vein (loc. 73), Trapper No. 1 (loc. 67), and Frying Pan (loc. 85). Exploration continued, and many veins were discovered in subsequent years.

Some individuals, as their number of claims increased, banded together to form companies in order to better handle the necessary assessment work. By 1960 most of the claims were under the control of a few individuals and companies. Individuals holding large blocks of claims included Jacob Schenk, Carroll Wells, Charles McConnell, Miley Evans, and George Hammond (Sharp and Hetland, 1968, p. 3). By 1969 the principal companies to have acquired property in the Lemhi Pass quadrangle were the Union Pacific Railroad, Sawyer Petroleum Co., Nuclear Fuels & Rare Metals Corp., Nuclear Fuels & Golden Pleasures Mining Co., ThO_2 and Rare Metals Exploration, Inc., and Lemhi Minerals, Inc.

Most veins in the report area have been developed only by shallow bulldozer trenches. Short adits have been driven on the Buffalo (loc. 18), Shear Zone (loc. 73), Cago No. 12 (loc. 49), and Wonder (loc. 45) veins. Underground workings are most extensive on the Last Chance property (loc. 82) near South Frying Pan Creek. The southeast end of this vein is developed by an adit 450 feet long. Near the northwest end of the vein, a second adit was driven and consists of a 900-foot crosscut and a 250-foot drift (Geach, 1966, p. 16–17). Two veins, the Last Chance and the Wonder, were explored in the early 1950's with the aid of Defense Minerals Exploration Administration loans. This money was used on both these veins for bulldozing trenches and drilling, and also on the Wonder vein for drifting.

FUTURE OF THORIUM MINING

Future development of the thorium veins is dependent on an increase in use of this metal. The chief uses up to 1969 have been in incandescent gas mantles and as a 3 percent additive in a high-temperature magnesium alloy; the amounts needed for these uses, however, are small. Thorium recovered as a byproduct from some rare-earth and uranium ores easily fulfills these needs. Thorium can also be used as fuel in certain types of atomic reactors. To date (1972) at least three prototype reactors are currently in operation, the Public Service Co. of Colorado has a 330-megawatt commercial reactor scheduled to start production this year, and four larger reactors are also on order, all of which use thorium for fuel. If this growing trend in the use of thorium-fueled reactors continues, then the demand for thorium will greatly increase.

PREVIOUS WORK

Most of the previous geologic work in the Lemhi Pass quadrangle has been on various individual mining properties. The first report was a brief description of the Copper Queen mine in 1910 by Umpleby (1913, p. 120–121). Vhay (1951, p. 11–14), in a short paper on the reconnaissance for uranium in Idaho and Montana, first reported on the new thorium discoveries in the Lemhi Pass area. During the 1950's the veins in this area were studied by many people. Schipper (1955) mapped the underground levels of the Copper Queen mine. Armstrong (1956) gave the results of drilling on the Last Chance property under a Defense Minerals Exploration Administration contract; and Shively (1960) described beneficiation tests on ore from the Cago No. 12. Sharp and Cavender (1962) first described the general geology of the area. They compiled a planimetric map from aerial photographs, at the scale of 1:24,000, of approximately an 80-square-mile area that covers approximately three-quarters of the Lemhi Pass quadrangle and extends as far west as the Lemhi River. Brief descriptions of the mining properties are also given in reports by: Trites and Tooker (1953, p. 195–208); Jarrard (1957, p. 46–47); Moen (1957, p. 7–23); Weis, Armstrong, and Rosenblum (1958, p. 36–39); and Anderson (1958, p. 45–74; 1960).

During the 1960's the State of Montana sponsored a study of the mineral deposits of Beaverhead County, and the U.S. Atomic Energy Commission studied all the major veins in the Lemhi Pass thorium district. Geach (1966) wrote a special report for the State of Montana on the thorium deposits that also includes mine maps of the two adits on the Last Chance property. For the Atomic Energy Commission, Austin (1968) gave data on analyses of samples from various properties, and Sharp and Hetland (1968) gave a brief summary of the geology of the area and described the thorium veins. The latter report includes two reconnaissance geologic maps, at a scale of 1:62,500, that cover an area of approximately 600 square miles, extending from the Mineral Hill district, 22 miles northwest of Salmon, Idaho, to Dry Canyon, 11.5 miles southeast of Leadore, Idaho. Later, Austin, Hetland, and Sharp (1970) gave a brief description of the mineralogy of some of these deposits.

PRESENT INVESTIGATIONS AND ACKNOWLEDGMENTS

Previous work in the thorium district has been concentrated on thorium veins, especially on their size, shape, and grade. Little detailed work has been done on the relation of the veins to the regional geology because of the lack of distinctive units in the Belt rocks and their generally poor exposure. Many samples of the veins were collected, but the mineralogy of the veins is poorly known, owing primarily to the small grain size of most of the minerals and the masking of minerals and their relations to one another by considerable pulverulent red and yellow iron oxides and black manganese oxides.

The present work in the Lemhi Pass quadrangle was oriented toward a detailed study of both the mineralogy of thorium veins and the regional geology. In this study the detailed mineralogy of most of the veins was investigated by the separation of the individual minerals by means of heavy liquids, a magnetic separator, and hand picking. Most of the separated minerals were then identified by X-ray diffraction.

The geology of the area was mapped in detail, and all known workings were investigated for radioactivity with a scintillation counter. Veins were mapped where possible; but where only one small radioactive spot was found, the contributing vein is not shown.

The Lemhi Pass quadrangle, an area of approximately 53 square miles, was mapped during September of 1967, and the summers of 1968 and 1969. I was assisted by Eric E. Loeb in 1967, by Duane R. Packer in 1968, and by Robert A. Langford in 1969. Mapping was done directly on topographic maps, at publication scale of 1:24,000. Aerial photographs were used to help locate position, especially in areas of scattered timber. Overburden is thick in many areas, and outcrops are few; hence, position of contacts of the units had to be inferred in many places.

E. T. Ruppel of the U.S. Geological Survey has been mapping south of the Lemhi Pass quadrangle in the Beaverhead Mountains

and to the southwest in the Lemhi Range. Discussions and a joint fieldtrip were of great aid in mapping the Belt rocks. I am also indebted to prospectors Jacob Schenk and Charles McConnell, who gave information on various properties in the area, to the Union Pacific Railroad, and to John Curtis for the many courtesies extended.

ROCKS OF THE QUADRANGLE

Three major groups of rocks are exposed in the Lemhi Pass quadrangle: fine-grained clastic sedimentary rocks, volcanic rocks, and unconsolidated deposits (pl. 1). The clastic rocks belong to the Precambrian Belt Supergroup and consist principally of fine-grained micaceous quartzite that is interbedded in places with siltite. These rocks underlie the entire quadrangle and are poorly exposed at the surface over about 60 percent of the area (pl. 1). The Belt rocks were probably at one time entirely overlain by flows and tuffs of the Tertiary Challis Volcanics. Subsequent erosion has stripped away most of the Challis, which is now exposed in only about 15 percent of the area in downfaulted blocks and small erosional remnants. Unconsolidated Quaternary deposits conceal the underlying rocks in about 25 percent of the area. The Quaternary rocks consist of older glacial deposits, river gravels, younger glacial deposits, terrace deposits, landslide deposits, and alluvium. All except the glacial deposits are only of local importance. The younger glacial deposits are mostly in some of the larger valleys of streams that head in the cirques on the east side of the Continental Divide. The older glacial deposits mask broad areas, including most of the northeast quarter of the quadrangle.

Diorite dikes, some as much as 6,500 feet long, are scattered throughout the area. These dikes, though they intrude only the rocks of the Belt Supergroup, are of post-Challis age.

BELT SUPERGROUP

The greater part of the Lemhi Pass quadrangle is underlain by quartzites and siltites that have been correlated with the Belt Supergroup (Sharp and Cavender, 1962, p. 5–6). These rocks are the host rock of all the veins in the quadrangle. Similar rocks extend to the north, south, and west of the quadrangle into the Beaverhead Mountains and occur even farther west in the neighboring Lemhi Range and Salmon River Mountains (Ruppel, 1968; Sharp and Hetland, 1968; Anderson, 1957, p. 14–15; 1956, p. 16–18; 1961a, p. 19–25).

Rocks of the Belt Supergroup underlie all the higher mountains and steeper slopes. Despite the relief and steep slopes, outcrops of

Belt rocks are poor. Further, more than 95 percent of the boulders and pebbles in the glacial till is made up of fine-grained quartzite pieces from the Belt rocks. Quartzite float in many areas may have been derived either from underlying bedrock or from glacial till; hence, it is not always a reliable marker of the underlying bedrock. In the past, this difficulty has caused misidentification of rock units in the Lemhi Pass quadrangle (Sharp and Hetland, 1968; Sharp and Cavender, 1962, pl. 1); consequently, in the present study I used only bedrock outcrops for determining the position of the Belt rocks.

In the Lemhi Pass quadrangle the principal rock types are light-gray fine-grained micaceous quartzite and black to greenish-gray siltite. Variously colored thick siltite units were noted in the following places: (1) The southwest quarter of the area, where a dull green to greenish-gray siltite unit is approximately 1,200 feet thick; (2) a ridge in the northeast corner of the quadrangle, where greenish-gray siltite protrudes through glacial till; and (3) the northwest corner of the quadrangle, where a light-gray to black siltite unit occurs on the north side of the Lemhi Pass fault. These siltite units may all be part of the same unit, but the following variations in the color of the overlying and underlying quartzite and their contact relations indicate that they probably belong to at least two different siltite units. Two distinctive dull-green to greenish-gray units occur in the gray quartzite of this quadrangle. One is immediately above the siltite in the northwest corner of the quadrangle, and the other is immediately below the siltite in the southwestern part of the quadrangle. The contacts of the two green quartzite units differ. The lower contact of the green quartzite near Flume Creek in the northwest corner of the quadrangle is interbedded with the siltite unit, and its upper contact is gradational. There, the color of the quartzite gradually changes from gray to light green. The basal beds of the green quartzite in the southwestern part of the quadrangle are interbedded with thick beds of gray quartzite. In contrast, the upper contact with the siltite is abrupt.

Anderson studied the Belt Supergroup along the west side of the Beaverhead Mountains when he mapped the Salmon, Baker,[1] and Lemhi quadrangles (Anderson, 1956, p. 16–18; 1957, p. 14–15; 1961a, p. 19–25, respectively). In the Salmon and Baker quadrangles, he did not attempt to divide the Belt, but in the Lemhi 15-minute quadrangle, adjacent to the west side of the Lemhi Pass quadrangle, he divided the Belt into three formations. He named

[1]On the published topographic sheet, the Baker quadrangle is designated as the Goldstone Mountain quadrangle.

the oldest formation the Apple Creek Phyllite, and he applied the names Lemhi Quartzite and Swauger Quartzite, successively, to the overlying units. The Apple Creek Phyllite, which crops out in the southwestern part of the Lemhi quadrangle, appears to be similar to the large siltite unit in the southern part of the Lemhi Pass quadrangle, although the Apple Creek is generally more metamorphosed. The Lemhi and Swauger Quartzites, on the other hand, although mapped along the east border of the Lemhi quadrangle, could not be distinguished during mapping of the Lemhi Pass quadrangle.

E. T. Ruppel (oral commun., 1968), in mapping a large area in the Lemhi Range, was able to divide the Belt rocks into seven units. Most of these units consist of quartzites that are separated by siltites. Ruppel's unit C, a siltite unit which he also found north of Leadore, Idaho, in the Beaverhead Mountains (Ruppel, 1968), is similar to a large siltite unit in the southwestern part of the Lemhi Pass quadrangle. Other similar-appearing siltites, however, occur lower in the section.

The thicker siltite units, where present, in the Lemhi Pass quadrangle were used as marker beds in an otherwise thick section of rather similar quartzite. Unfortunately, the siltite units were found in only small sections of the quadrangle. Hence, no attempt was made during mapping of the study area to separate the Belt Supergroup into formations, although the two lithologic types are shown where present (pl. 1).

LITHOLOGY

Fine-grained quartzite is the predominant rock type in the Lemhi Pass quadrangle (fig. 3). The Belt rocks are generally thin bedded—most beds range in thickness from about 1 inch to a few feet—although, in a few places, the quartzite beds are massive. In general, bedding is rather indistinct and can only be distinguished with difficulty, especially in the southern part of the quadrangle. Crossbedding occurs at some localities, but it is most common to the northwest, on the Idaho side of the Continental Divide. In places the quartzite is banded with thin layers of a slightly different shade of gray or of a slightly different grain size. In some places, layers of quartzite, 6 inches to 3 feet thick, are interlayered with siltite units that are only a few inches thick.

QUARTZITE

Although most of the quartzite in the area is predominantly light gray, some of it is medium gray and, in places, contains layers of greenish-gray and white rock. In addition, there are two

FIGURE 3. — Typical outcrop of massive micaceous quartzite in the Belt Supergroup on the ridge northeast of the Last Chance vein.

units of greenish-gray to dull-green quartzite, one of which overlies the siltite unit in the Flume Creek area, where it is overlain by gray quartzite, and the other underlies the siltite in the southwestern part of the quadrangle, where it is underlain by gray quartzite.

The quartz grains in all the quartzites are fairly well sorted and are subrounded to angular. The grain size of this mineral in individual specimens ranges from about 0.02 to 0.50 mm (millimeter) and has an average grain size of approximately 0.10 mm. This grain size would be classified as that of very fine sand (Wentworth, 1922, p. 381).

The gray quartzites, for the most part, consist of 60–80 percent quartz, 5–30 percent sericite, 1–10 percent biotite, and <1–8 percent plagioclase. In addition, some contain as much as 5 percent,

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but generally about 1 percent, chlorite. Small rounded grains of magnetite or hematite occur in most specimens. Trace amounts of zircon and apatite were found in many specimens, and a grain or two of tourmaline was found in almost every thin section. The micas, which commonly have a preferred orientation parallel to their cleavage, give the rock its foliation. The sericite and biotite generally form a mesh around the quartz grains, and they all appear to be of metamorphic origin.

In the northeastern and southeastern parts of the quadrangle, feldspathic quartzites occur. These rocks contain 30–40 percent combined plagioclase and orthoclase. The sericite content, however, drops from an average of about 15 percent to 5 percent. Most of the sericite in the feldspathic quartzite occurs as tiny laths on the feldspar, which it partially replaces. Thus, the micaceous quartzite was probably feldspathic when originally deposited, but the potassium feldspar was converted to sericite during later metamorphism. The green quartzites each contain about the same amount of quartz and of the minor accessory minerals apatite, zircon, magnetite, and tourmaline as the gray quartzite, but the two differ in the other minerals. The green quartzite in the Flume Creek area contains no biotite or feldspar and has only a minor amount of chlorite ($<$1–2 percent). The green color is due to 10–20 percent epidote, which was probably derived by metamorphism from the original plagioclase in the rock.

The green quartzite in the southwestern part of the quadrangle does not contain any epidote, but has small amounts of biotite and about 10 percent plagioclase. The green color in this rock is due to its high chlorite content (10–25 percent).

SILTITE

Siltite varies from light gray to black, and from dull green to greenish gray. Thin beds of siltite are interbedded with the gray quartzite and are generally light to dark gray. The siltite unit in the Flume Creek area is light gray to black. The siltite in the southwestern part and in the northeast corner of the quadrangle, however, is dull green to greenish gray.

The siltite is a dense rock composed of tiny subrounded to subangular grains that are fairly well sorted. Average grain size is about 0.015 mm; this size is classified as silt by Wentworth (1922, p. 381). Some scattered grains are as much as 0.2 mm across (very fine sand).

The mineralogic composition of the siltites is, in general, similar to that of the quartzites, but accurate comparisons cannot be made because the amounts of various minerals present are more difficult to estimate, owing to the smallness of the grain size. The siltites contain approximately 55–80 percent quartz, $<$1–7 percent plagioclase, 8–30 percent sericite, 0–5 percent biotite, and $\lesssim$1 percent magnetite. Trace amounts of apatite and zircon were noted in some specimens, and, as in the quartzites, a grain or two of tourmaline was found in almost every thin section. No orthoclase was noted, but, owing to the fine grain size, this mineral could be easily confused with quartz. The green color noted in some siltites is due to the presence of chlorite. The dull-green to greenish-gray siltites contained 8–18 percent chlorite, and the gray siltites contained from 0 to 2 percent chlorite.

CHALLIS VOLCANICS

The name Challis Volcanics was first applied by Ross (1927, p. 7–9) to the Tertiary volcanic rocks of central Idaho. He later (Ross, 1961) restricted the Challis to the dominantly volcanic rocks of early Tertiary age in central Idaho, north of the Snake River Plain and south of the west-flowing segment of the Salmon River. Anderson (1956, p. 18–28; 1957, p. 15–18; 1961a, p. 43–53) mapped the Challis on the west side of the Beaverhead Mountains in the Salmon, Baker, and Lemhi quadrangles. The Challis Volcanics can be traced eastward from the Lemhi quadrangle into the Lemhi Pass quadrangle.

In various areas, the Challis Volcanics have been split into several subdivisions. Ross (1962, p. 75) in central Idaho described the following subdivisions, in ascending order: A latite-andesite member, basalt and related flows, the Germer Tuffaceous Member and its equivalents, and the Yankee Fork Rhyolite Member. Ruppel (1968) divided the Challis in the Lemhi Range, south-southwest of Leadore, Idaho, into lower basaltic rocks and upper latitic and andesitic rocks. Both units contain interbedded tuffs. Anderson (1961a, p. 43–53) raised the rank of the Challis to the Challis Volcanic Group in the Lemhi quadrangle and divided it into the Cheney, Yearian, and Kadletz Volcanics. He (1961a, p. 44) noted that the Cheney Volcanics constitute an easily recognizable unit of light-colored flows and pyroclastics, in which the flows are composed largely of andesite and quartz latite and, more subordinately, of rhyolite, and the pyroclastics are composed of tuffs and tuff-breccias that range in composition from quartz latite to rhyolite. Anderson (written commun., 1963) believed that the Cheney Volcanics extended eastward into the northwestern part of the Lemhi Pass quadrangle, at least as far as the Continental Divide. The volcanic rocks in this particular area, however, are largely rhyolitic tuffs that underlie a thick sequence of basaltic rocks. Exposures of the basaltic rocks in the quadrangle on the Idaho side of the Continental Divide are poor, but the greater part of this sequence is well exposed farther east on the Montana side. The overall description of the volcanic rocks in the Lemhi Pass quadrangle most closely fits that of the lower part of the Challis, as described by Ruppel (1968), south of Leadore. Because most of the volcanic rocks in the Lemhi Pass quadrangle are so unlike those rocks described as Cheney Volcanics in the Lemhi quadrangle, this name is not used. Instead, the volcanic rocks are assigned to the Challis Volcanics and are divided informally on the basis of their local lithology.

DISTRIBUTION

Rocks of the Challis Volcanics are widely scattered over the Lemhi Pass quadrangle, but most of them occur in northwest-trending zones across the center of the quadrangle. The larger areas of volcanics are in downfaulted blocks (pl. 1), with the largest area being bounded on the northeast by the Lemhi Pass fault, and on the southwest by the Bull Moose fault (fig. 8*A*). Three faults, including the Lemhi Pass and the Dan Patch, bound most of another area of volcanics at the west edge of the quadrangle. The Dan Patch fault also forms the northeast boundary of two other northeastward-dipping bodies of volcanics in the central and southeastern parts of the quadrangle.

Several of the smaller areas of volcanics are not in downfaulted blocks, but are preserved in hollows in the prevolcanic topography. Such areas are in the southeast corner of the quadrangle, near the Orpha (loc. 106) and Reactor (loc. 107) claims; on the Continental Divide, northeast of Yearian Creek; and on the small ridge just northwest of the Last Chance vein (loc. 82). Most of the volcanics in the northeast corner of the quadrangle are difficult to categorize, as they are surrounded by glacial till; however, some of them are exposed in the upper plate of a thrust fault.

ROCK TYPES

The Challis Volcanics are separated on the basis of time into two and possibly three major divisions in the Lemhi Pass quadrangle. The oldest rocks are in the first division, which is a basalt-rhyodacite sequence with associated tuffs and conglomerates. A second division consists of younger basalts that overlie the rocks of the first division with an angular unconformity. These rocks, found in only three small areas, mark a separate period of volcanism. A possible third major division is represented by light-purple, pink, and brown flows of quartz latite that occur as scattered outcrops in the northern part of the quadrangle. These rocks are superficially different from the other volcanic rocks in the quadrangle. Owing to poor exposure, however, little is known of their position relative to the other volcanic rocks. They may be part of one of the other two divisions, or they may be a separate division. Most of the volcanics in the quadrangle belong to the first division, and these rocks were further divided on the basis of lithology into the following six units: (1) Basal conglomerate, (2) quartzite-bearing rhyolite tuff, (3) conglomerate of Flume Creek, (4) vitric tuff of Lemhi Pass, (5) basalt-rhyodacite sequence, and (6) tuff of Curtis Ranch. These units, which are fairly thick, apparently correspond to the basaltic rocks mapped by Ruppel (1968) in the lower part of the Challis Volcanics.

The volcanic units vary considerably in thickness (fig. 4). The conglomerate of Flume Creek thins from more than 800 feet at the mouth of Flume Creek to about 20 feet on Lemhi Pass, 2.8 miles to the east. The quartzite-bearing tuff is at least 1,700 feet thick along the Continental Divide south of Lemhi Pass, where it underlies the basalt-rhyodacite sequence. The tuff is absent beneath the basalt-rhyodacite sequence in the central and southeastern parts of the quadrangle.

The variations of the pyroclastic and sedimentary units in the Challis Volcanics indicate that many individual units are of little

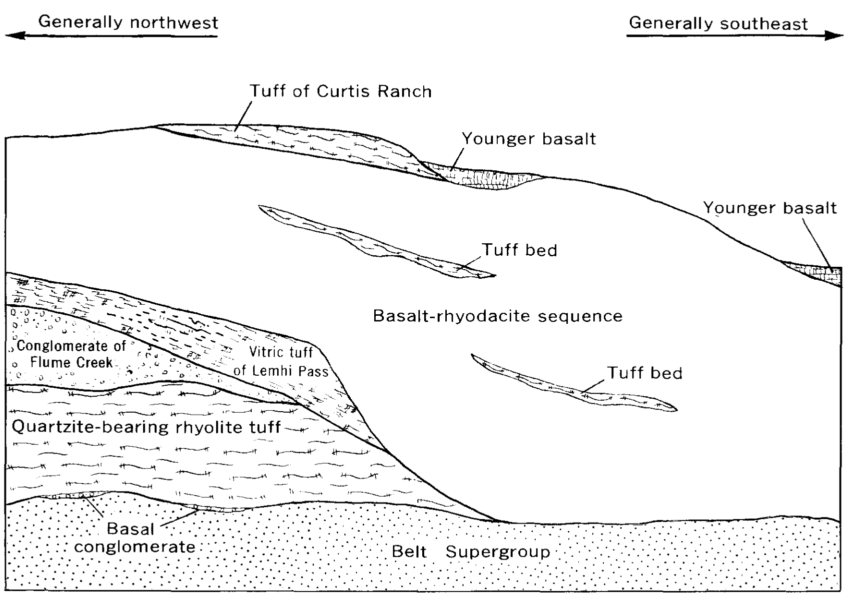

FIGURE 4. — Relationship of the various units in the Challis Volcanics to one another and to the Belt Supergroup. (No scale.)

value in regional correlation. Nevertheless, I found that within a smaller area, such as the Lemhi Pass quadrangle, they are of considerable help in unraveling the structure.

BASAL CONGLOMERATE

The basal conglomerate is the oldest known unit in the volcanics in Lemhi Pass quadrangle and underlies the quartzite-bearing rhyolite tuff into which it grades. This unit is only sporadically exposed for about three-quarters of a mile along the west edge of the volcanics just west of the Continental Divide (pl. 1). The basal conglomerate, where present, is not more than 15 feet thick. Although the unit is thin and intermittent there, thicker conglomerate units were noted at the base of the Challis in other localities (Ross, 1962, p. 74).

The conglomerate is made up of numerous well-rounded pebbles and cobbles, from 1/8 to 3 inches in diameter, set in a white tuffaceous matrix. Most of the pebbles and cobbles are micaceous quartzite from the Belt Supergroup; a few are of gray glassy quartzite, probably from the Ordovician Kinnikinic Quartzite; and some of the smaller pebbles are of white tuff. The matrix makes up less than 5 percent of the rock in the lower part of this unit, but makes up as much as 80 percent of the rock near its top.

QUARTZITE-BEARING RHYOLITE TUFF

The quartzite-bearing rhyolite tuff overlies the basal conglomerate south of Lemhi Pass, but, where the conglomerate is absent, the tuff directly overlies the quartzite of the Belt Supergroup. The quartzite-bearing tuff, although widespread in the northern part of the quadrangle, pinches out to the south. The tuff is overlain by the conglomerate of Flume Creek near Agency Creek and at Lemhi Pass. Southward, successively younger units—the tuff of Lemhi Pass and the thick basalt-rhyodacite sequence—overlie the quartzite-bearing rhyolite tuff (fig. 4).

The thickness of the quartzite-bearing tuff is difficult to measure, owing to glacial cover and to the faults that bound it in many places. Along the Continental Divide, about half a mile south of Lemhi Pass, this unit is at least 1,700 feet thick.

Most of the quartzite-bearing rhyolite tuff is pink, but ranges in color from white to reddish brown. This rock is named after its most conspicuous feature—the dark-gray quartzite fragments, which stand out against the lighter background. Actually, quartzite fragments make up only about 2–15 percent of this rock. Vitric fragments and crystals make up a larger percentage of the rock, and most of the rocks are either a vitric-crystal tuff or a crystal-vitric tuff. Because the quartzite fragments are easily seen, they distinguish this unit from the other crystal and vitric tuffs in this area. The quartzite fragments are generally subangular to subrounded, from 1/16 to ¼ inch across, although fragments as much as 1½ inches across were noted in some places. The quartzite is typical of that in the Belt Supergroup; it is fine grained and made up principally of quartz grains and interstitial sericite.

The vitric fragments are small angular pieces that are generally white on weathered surfaces. They make up about 8–50 percent of the rock. The crystal fragments are small and inconspicuous, although they commonly make up one-fourth to one-half of the rock. Quartz is, by far, the most common crystal fragment, making up 10–40 percent of the rock. A small percentage of plagioclase is generally present, and as much as 15 percent of this mineral was noted in one specimen. Sanidine made up 10 percent of one specimen, but is not generally present. Also, trace amounts of biotite occur in some of this tuff.

The matrix consists of white to pink ash. In thin section it is seen to be light-brown isotropic glass that contains a few shards.

The quartzite-bearing rhyolite tuff ranges in texture from a soft, rather porous rock to a hard, well-compacted rock. Generally, it is not welded; however, welded tuff was noted in a few places. One of these is near the switchback on the road 1,000 feet southwest of the shaft on the Copper Queen property (loc. 43). There, in an area 800 by 1,800 feet, I found a welded purplish-brown tuff that is made up of fragments of a glassy volcanic rock containing many plagioclase microlites cemented by glass. This rock type is surrounded by, and hence I mapped it with, the quartzite-bearing rhyolite tuff.

A chemical analysis was made of a specimen of the quartzite-bearing rhyolite tuff collected on the Continental Divide (table 1). Its normative composition indicates a very high quartz content. Part of this high quartz content is due to the fragments of quartzite in the tuffaceous matrix. The presence of numerous quartz crystals in this rock, however, indicates that the quartz content would be high even in the absence of quartzite. The high normative orthoclase content is somewhat surprising, as a thin section of this rock showed it to contain no potassium feldspar phenocrysts; thus, the potassium feldspar content is wholly within the ash. A high potassium content is also indicated on several samples of this tuff stained with sodium cobaltinitrite solution. According to the nomenclature of Rittmann (1952), the rock type, classified on the basis of its chemical composition (table 1), is a rhyolite.

CONGLOMERATE OF FLUME CREEK

The conglomerate of Flume Creek overlies the quartzite-bearing rhyolite tuff and underlies the vitric tuff of Lemhi Pass (fig. 4). The conglomerate is best exposed along the sides of lower Flume Creek; exposures in most other areas are poor. The greater part of this unit is in the Lemhi Pass quadrangle in the Flume Creek–Agency Creek area, where it is at least 800 feet thick, and in the adjacent Lemhi quadrangle, where it can be traced westward for about half a mile. This rock mass forms a wedge-shaped body; at its only other outcrop, on Lemhi Pass, it has thinned to about 20 feet. Southward and eastward from there it was not seen, and it probably pinches out.

The conglomerate of Flume Creek is made up of numerous well-rounded pebbles, cobbles, and boulders as much as 3 feet in diameter, set in a matrix of ash. The pebbles, cobbles, and boulders are most commonly micaceous quartzite of the Belt Supergroup, although in a few places volcanic rock—brown and purplish-gray plagioclase porphyries—are more abundant than the quartzites. Other pebbles, which occur in minor amounts, are red quartzite, siltite of the Belt Supergroup, and white massive quartz. The matrix is generally a white ash, which is altered in some places to a greenish-white clay. Also, a few crystal fragments are generally scattered in the ash. Quartz is the most abundant of these fragments; others are plagioclase, sanidine, and biotite. This conglomerate is similar in appearance to the basal conglomerate.

In places, the conglomerate of Flume Creek contains lenses of medium-grained sandstone that is made up of subrounded grains of aphanitic volcanic rock and quartz and of lesser amounts of plagioclase, sanidine, siltite, biotite, and augite. The matrix may consist of a small amount of chalcedony cement, or it may be mostly ash.

VITRIC TUFF OF LEMHI PASS

The vitric tuff of Lemhi Pass, like the underlying conglomerate of Flume Creek, occurs in a limited area and is also restricted to the Flume Creek–Agency Creek and Lemhi Pass areas. The best exposures of this unit are on the east side of Lemhi Pass, where the road zig-zagging up the pass bares the tuff in many places. The vitric tuff is overlain by the basalt-rhyodacite sequence (fig. 4). South of Lemhi Pass the tuff, as well as the conglomerate, pinches out, and 1 mile southeast of Lemhi Pass, the basalt-rhyodacite sequence rests directly on the quartzite-bearing rhyolite tuff (pl. 1). The vitric tuff is thicker on the east side of Lemhi

Pass, where it is at least 650 feet thick, than it is 2 miles to the west, where it is about 380 feet thick on the north side of Agency Creek.

The vitric tuff of Lemhi Pass is a white to greenish-white dense rock made up of ash and a minor amount of crystal fragments. The ash is made up of numerous curved glass shards set in a matrix of similar-appearing undevitrified glass. The crystal fragments constitute a small percentage of the rock and are the size of sand. They consist mostly of quartz and plagioclase, although biotite is also generally present in trace amounts. Some of the tuff in the Lemhi Pass area contains a small percentage of granule-size pieces of dark-gray micaceous quartzite. The vitric tuff, when stained with sodium cobaltinitrite, turns bright yellow, indicating that the rock contains at least a moderate amount of potassium.

BASALT-RHYODACITE SEQUENCE

The basalt-rhyodacite sequence is the thickest and most widespread unit of the Challis Volcanics in the Lemhi Pass quadrangle (pl. 1). This unit makes up about 70 percent of the area underlain by the Challis, and, in some parts of the area, it is the only volcanic unit present (fig. 2). The rocks of this unit are most common in the central and eastern parts of the quadrangle and are also abundant in the adjacent quadrangle to the east. In the central and southeastern parts of the Lemhi Pass quadrangle, the basalt-rhyodacite sequence unconformably overlies the quartzites of the Belt Supergroup. To the north—northeast of the Bull Moose fault between Frying Pan and Bear Creeks—this sequence conformably overlies the quartzite-bearing rhyolite tuff. To the northwest of Lemhi Pass and farther west in the Agency Creek area, the basalt-rhyodacite sequence may be separated from the Precambrian quartzite by four units of the Challis Volcanics—basal conglomerate, quartzite-bearing rhyolite tuff, conglomerate of Flume Creek, and vitric tuff of Lemhi Pass (fig. 4). The basalt-rhyodacite sequence is overlain by the tuff of Curtis Ranch. The entire basalt-rhyodacite sequence is exposed along the southeast side of Trapper Creek, where it is approximately 3,300 feet thick.

The basalt-rhyodacite sequence is made up principally of flows, which have a composition ranging from basalt to rhyodacite. Flows in the lower half of the sequence are more mafic, and olivine-bearing rocks are common; those in the upper half are more silicic, and olivine-bearing rocks are rare. Flow breccias and rhyolitic vitric and crystal tuffs are discontinuously interbedded throughout much of this unit.

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The flow rocks are black, dark gray, gray, purplish gray, brown, and hematitic red. Most of these rocks weather to a dark russet brown. The more mafic rocks tend to be black or dark gray, whereas the more silicic ones tend to be lighter in color. Where the silicic rocks occur near the tops of the flows, they oxidize and turn hematitic red. Tops of flows are also marked by numerous vesicles, which range in size from 0.5 to 12 mm. The vesicles in some flows are filled with chalcedony.

The flows, especially of the more mafic rocks, are commonly porphyritic, consisting of about 1–50 percent phenocrysts. The principal phenocrysts are those of olivine and dark-green pyroxene and in most rocks are the only phenocrysts. Olivine forms pale-green glassy subhedral to euhedral phenocrysts. In places, serpentine and, to a lesser extent, talc and chlorite replace the olivine along fractures and crystal boundaries. Pyroxene (which is generally augite, but in some places is pigeonite) forms phenocrysts that are considerably smaller than those of olivine. Several flows also contain a small amount of biotite. Plagioclase only rarely occurs as phenocrysts. The matrix of these flows, however, generally contains either numerous small plagioclase crystals or plagioclase microlites. Small pyroxene crystals and opaque minerals are also abundant in the matrix, and in a few flows small grains of biotite, olivine, and iddingsite are present. Locally, the matrix also contains considerable glass. Glass content of the flows ranges from 0 to 100 percent, and it is the most abundant in the upper parts of the more silicic flows. The potassium content of many of these rocks was roughly measured by staining them with sodium cobaltinitrite. Stains ranged from very faint yellow to bright orange, indicating a wide range in potassium content.

Flow breccias, made up of angular to subrounded pieces of adjacent flows surrounded by flow material, form discontinuous layers at the base of the flows. Breccia fragments range in size from $\frac{1}{16}$ inch to 3 feet across. The breccias are generally more resistant to erosion than the flows, and commonly form prominent outcrops that project above the surrounding slope. Breccias range in thickness from a few feet to about 50 feet; some can be traced for less than 100 feet, others can be traced for as much as half a mile. In some areas the resistant breccias are the only volcanic rocks exposed, and their linear form marks the trend of the volcanics.

Thin tuff layers interlayered with the flows were noted in several places. In most places these tuffs are less resistant than the flows, and their exposures are, at best, spotty. The tuffs are white, light tan, and pink, and in composition they are crystal, crystal-vitric, and vitric tuffs. Some of them are welded. The tuffs are more silicic than the flows and, apparently, are all rhyolitic. Crystal tuffs occur along the border between secs. 15 and 16 and in the SW½ sec. 22, T. 10 S., R. 15 W., on the east side of the Continental Divide (pl. 1). These rocks consist of about 35 percent crystal fragments set in a matrix of ash containing numerous shards. Crystal fragments are composed of plagioclase and lesser amounts of quartz and biotite. A crystal-vitric-tuff unit is exposed on both flanks of an anticline that crosses Bear Creek in the eastern part of the quadrangle. This tuff has about 25 percent crystal fragments and 20 percent vitric fragments set in a white to pink ash containing numerous shards. Crystal fragments are quartz, plagioclase, and potassium feldspar and a small amount of biotite. Vitric fragments are pieces of glassy volcanic rock. A few percent of dark quartzite fragments are also present. Vitric tuffs with a small percentage of crystal fragments are found in several small scattered exposures too small to show on plate 1. These tuffs are very soft and friable and consist mainly of fine ash (glass). Staining with sodium cobaltinitrite indicates that all the tuffs have a high potassium content.

Chemical analyses were made of specimens from three flows. Two of these specimens (table 1, samples 2 and 3) are similar in appearance—dark-gray rocks that contain about 20 percent olivine phenocrysts set in a matrix of augite, opaque minerals, and plagioclase microlites. The other rock (table 1, sample 4) is a hematitic-red vesicular glass. The hematitic-red glass is oversaturated in silica, having free quartz in the norm; the other two specimens do not have quartz in the norm. The red glass has the highest Al_2O_3, K_2O, and Na_2O contents, and the lowest total CaO, MgO, and total iron oxide contents of the three analyses. As suggested by the color of the hematitic-red glass, most of the iron is in ferric form. This rock would be classified from its chemical composition, according to Rittmann (1952), as a rhyodacite.

The two olivine-bearing rocks (table 1, samples 2 and 3) are not nearly so similar chemically as they appear in hand specimen. The principal differences are in the alkalis; sample 2 has twice as much K_2O, but only three-fourths as much Na_2O as sample 3. Rock nomenclature is based largely on the relative amounts of feldspar in crystalline rocks and, hence, on the alkali content in microcrystalline rocks. According to Rittmann (1952), sample 2 would be an olivine latite and sample 3 an olivine-andesine trachybasalt. Inasmuch as the hematitic-red glass was one of the most siliceous-appearing rocks and the other darker rocks appeared to be

TABLE 1. — *Chemical analyses and normative compositions, in weight percent, of rocks from the Challis Volcanics*

[Analyst, Edythe E. Engleman]

Constituent or mineral	Samples			
	1	2	3	4
Chemical analyses				
SiO_2	74.62	51.38	48.15	59.14
Al_2O_3	12.40	10.79	11.35	16.66
Fe_2O_3	.77	2.15	2.72	7.41
FeO	.34	6.39	6.21	.23
MgO	.29	14.46	14.46	.66
CaO	.84	6.20	7.38	4.20
Na_2O	2.30	1.99	2.63	3.13
K_2O	4.66	2.98	1.36	4.07
H_2O+	1.47	1.36	3.12	.87
H_2O-	1.76	.62	.73	1.90
TiO_2	.10	.74	.78	.99
P_2O_5	.03	.35	.35	.42
MnO	.04	.14	.17	.03
CO_2	.00	.11	.11	.00
Cl	.01	.01	.01	.02
F	.07	.09	.13	.09
Subtotal	99.70	99.76	99.66	99.82
Less O	.03	.04	.05	.04
Total	99.67	99.72	99.61	99.78
Normative compositions				
Quartz	42.84	....	....	17.10
Orthoclase	28.36	18.35	8.34	27.25
Albite	20.44	17.29	23.58	25.02
Anorthite	3.89	11.68	15.85	18.35
Hypersthene	.70	19.13	8.78	1.70
Olivine	....	13.98	21.71	....
Diopside	....	12.60	14.79	....
Magnetite	.93	3.25	4.18	....
Hematite	.16	....	....	7.68
Ilmenite	.15	1.52	1.52	.46
Rutile	....	....	....	.80
Corundum	2.24	....	....	.61
Fluorite	.07	.10	.16	.11
Apatite	....	1.01	1.01	1.01
Calcite	....	.20	.20	....
Total	99.78	99.11	100.12	100.09

SAMPLE LOCALITIES

1. Quartzite-bearing rhyolite tuff from peak 7,636 on the Continental Divide, 1 mile south of Lemhi Pass.
2. Olivine latite from knoll just north of Trapper Creek in the SE¼NW¼ sec. 34, T. 10 S., R. 15 W.
3. Olivine-andesine trachybasalt from low ridge between Trapper and Bear Creeks in the SW¼NW¼ sec. 26, T. 10 S., R. 15 W.
4. Rhyodacite from just east of Trapper Creek in the NE¼SE¼ sec. 23, T. 10 S., R. 15 W.

intermediate between this rock and the olivine-bearing rocks, this sequence probably contains many flows whose compositions are between rhyodacite and basalt.

TUFF OF CURTIS RANCH

This tuff forms a broad band, 1½ miles long, in the eastern part of the Lemhi Pass quadrangle on the mountainside on the Curtis Ranch, south of the ranchhouse. From the east edge of the quadrangle, the tuff is exposed northwestward almost to Frying Pan Creek, where it is covered by alluvium and glacial till. Scattered outcrops of the tuff on the west side of Frying Pan Creek and north of Trail Creek suggest its continuance to the Lemhi Pass fault (pl. 1). This tuff, which conformably overlies the basalt-rhyodacite sequence, is bounded on its upper side by a fault. Hence, its true thickness is not known, but in the central part of this outcrop band, its minimum thickness is 1,200 feet.

The tuff of Curtis Ranch is a fine-grained light-colored rock that ranges in composition from crystal to vitric tuff. The color of this tuff in various places is white, light gray, greenish white, or tan. In one of the tuff beds in the upper part of the exposed sequence some shiny white porcelanite was found. Most crystals occur as angular mineral fragments, although crystal faces are preserved in some places. Plagioclase and quartz, in that order, make up most of the crystals. In some beds potassium feldspar is also common, and minor amounts of biotite are generally present. In a few specimens a fraction of a percent of hornblende, sphene, and zircon was noted. Vitric fragments are mainly subrounded to rounded fragments of pumice. Unlike the other tuffs in this area, this tuff contains very few rock fragments. Small fragments of aphanitic volcanic rock are present in a few specimens, and fragments of micaceous quartzite are even less common. The matrix is ash (glass) and contains numerous shards and, in places, microlites. Tridymite occurs in certain beds as vesicle fillings in both the pumice fragments and the rock. Several specimens were stained with sodium cobaltinitrite; the resulting orange color indicated a high potassium content in the matrix. Compositionally, these rocks are probably rhyolites or quartz latites, or both.

YOUNGER BASALT

The younger basalt has a limited distribution. It occurs in only three areas, each of which is a little less than a quarter of a square mile (pl. 1). The younger basalt unconformably overlies rocks of the basalt-rhyodacite sequence in all three areas (fig. 4). The east edge of the northernmost outcrop, which is astride Trail Creek, apparently also overlaps the tuff of Curtis Ranch, and in the southernmost area on the west side of Bear Creek, its east edge overlaps the micaceous quartzite of the Belt Supergroup. The younger basalt differs from the other volcanic rocks in the quadrangle in that it is only gently tilted. In the northernmost area, it strikes east and dips about 15° S. A flow breccia in the adjoining basalt-rhyodacite sequence strikes north and dips 80° E. In the central area the younger basalt also strikes east, but the dip is only about 5° S., and in the southernmost area this unit is practically horizontal. The rocks of the basalt-rhyodacite sequence adjacent to these two areas have a northerly strike and have dips of 30°–55° E.

The younger basalt was formerly much more widespread, and the present exposures are but thin remnants of a much larger, thicker unit. The northern two areas are preserved because they are capped by resistant flow breccias; the southernmost area is preserved because it was deposited in a topographic hollow in the underlying basalt-rhyodacite sequence. The thickness of the younger basalt preserved in these areas ranges from about 50 to 400 feet.

The younger basalt is made up of basalt and interlayed basaltic flow breccias. The basalts are gray or brown aphanitic rocks, some of which contain olivine. The basaltic breccias consist of reddish-brown angular to subrounded fragments of basalt, ⅛–8 inches across, set in a matrix of similar material. They form discontinuous layers 20–50 feet thick, and, although composed of material similar to the basalts, they are much more resistant to weathering and form prominent outcrops that cap the underlying, poorly exposed basalt.

QUARTZ LATITE

Quartz latite occurs in a small area about a third of a mile west of Lemhi Pass and in scattered outcrops near Sheser Creek in the northeast corner of the quadrangle. The relation of the quartz latite to the other volcanic rock units is not known, owing to cover in critical places. Although the rocks of these two areas appear to be of similar composition, quartz latite in the vicinity of Sheser Creek commonly has well-developed flow structures and, for the most part, is a flow. Flow lines were not observed in the quartz latite west of Lemhi Pass, and this rock might be either a flow or an intrusive. Intrusives of quartz latite were observed along Agency Creek three-quarters of a mile west of the Lemhi Pass quadrangle. The lack of definitive data precludes the determination of either the number of quartz latite units or the age of these rocks relative to the ages of the other volcanic rock units.

The quartz latites are light-colored porphyritic rocks; most are pink to purplish brown, although some are light gray and brown. Phenocrysts, 1–2 mm in diameter, generally make up 10–20 percent of the rock. Quartz and plagioclase make up most of the phenocrysts, but biotite and potassium feldspar phenocrysts are generally present in small amounts. In some of the quartz latite west of Lemhi Pass, altered hornblende was also found. The matrix consists of tiny crystals of quartz, plagioclase, potassium feldspar, and biotite set in a devitrified glass. Several quartz latite specimens were stained with sodium cobaltinitrite by use of the method of Gabriel and Cox (1929). Orange staining not only indicated which of the small phenocrysts were potassium feldspar, but also indicated that considerable potassium was present in the devitrified glass.

In the absence of chemical analyses the classification of these rocks as quartz latite was made on the basis of their quartz and plagioclase phenocrysts coupled with a qualitative test for potassium. When complete chemical analyses become available, they might indicate, however, that some, or all, of these rocks are rhyolites or rhyodacites.

AGE OF THE CHALLIS VOLCANICS

The Challis Volcanics are of Tertiary age, although the range within the Tertiary is poorly known. Along the Lemhi River valley, the flows and tuffs are overlain by a thick sequence of clastic sedimentary rocks, which contain some pyroclastic material in their lower parts (Anderson, 1956, p. 30–31; 1957, p. 16–19; 1961a, p. 31–35). These rocks, because of their distinctive lithology, were mapped separately and were divided into several formations by Anderson. Ross (1962, p. 24), however, considered them to be members of the upper part of the Challis Volcanics. Fossils were found at several localities in the clastic sedimentary rocks. Leaves and pollen collected from them near the town of Salmon were most recently dated as Oligocene (Ross, 1962, p. 97–99). Vertebrate collections from a small area east of the Lemhi River, about 7 miles southeast of the town of Lemhi, are considered most likely to be of Miocene age (Anderson, 1961a, p. 33–34; Ross, 1962, p. 101). These clastic sedimentary rocks are younger than the Challis Volcanics mapped in the Lemhi Pass quadrangle.

Intrusive rocks that intrude the lower part of the Challis Volcanics in central Idaho were believed by Ross (1962, p. 101) to have been formed during the same period of igneous activity as the Challis Volcanics. Four samples of these intrusives were dated, by T. W. Stern, by the lead-alpha method. They ranged in age from 40 ± 10 to 50 ± 10 m.y. (million years). The related volcanics, hence, might have been emplaced in Eocene time.

Physical ties between the volcanic units in the Lemhi Pass quadrangle and those described in other areas are tenuous at best. The above data, however, indicate that the Challis Volcanics were emplaced during a major period of volcanism in central and eastern Idaho that occurred from possibly as early as Paleocene into at least Oligocene time.

DIORITE

Many diorite dikes and one small irregular body intrude rocks of the Belt Supergroup in many parts of the Lemhi Pass quadrangle. Similar intrusives were reported to have intruded the Belt rocks to the west in Idaho (Anderson, 1957, p. 27–28; 1961a, p. 54–55; Sharp and Cavender, 1962, p. 8–9). The diorite is partly altered and varies considerably in its resistance to erosion. In some places dikes or parts of dikes form well-exposed outcrops (fig. 5) ; in other places they are concealed beneath overburden. Six of the mapped dikes are exposed only in trenches or in underground workings. Scattered diorite-float rock indicates that many small poorly exposed dikes were not located. The presence of diorite dikes in some of the trenches near the thorite veins led Sharp and Hetland (1968, p. 7) to believe that most dikes were associ-

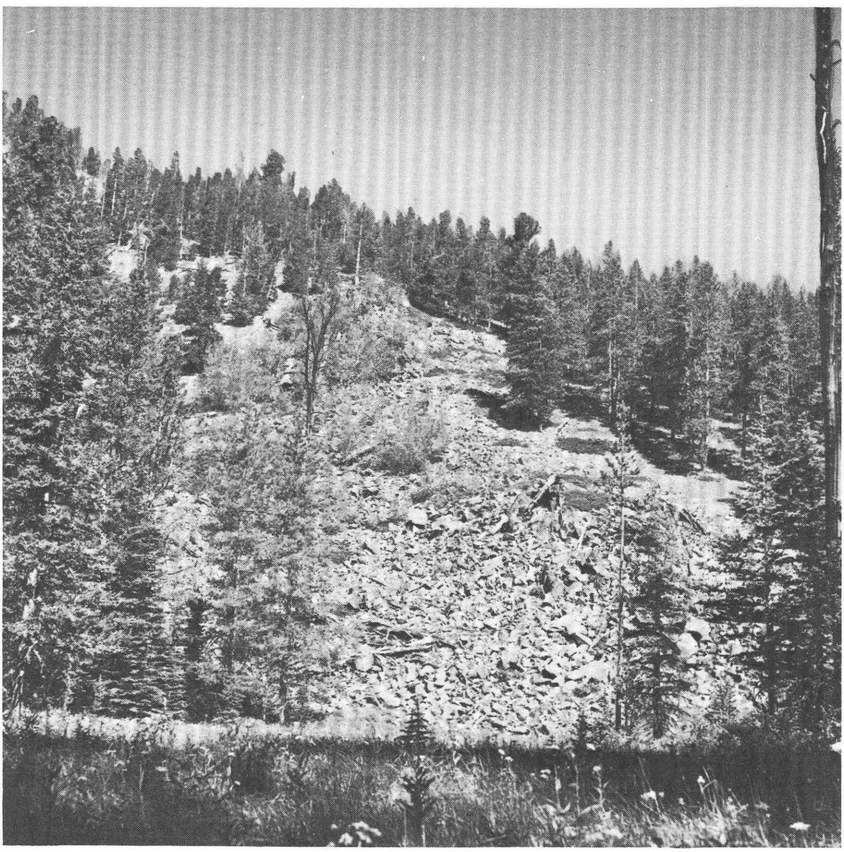

FIGURE 5. — Diorite dike, weathering to rubble, forms a small ridge on a hillside near the headwaters of Trapper Creek. Dike is about 20 feet wide.

ated with the veins. The distribution of the dikes, shown on plate 1, and the better exposures observed in the trenches near the thorite veins suggest that this association is more apparent than real.

A small irregular intrusive occurs on the southwest side of the Bull Moose fault near the east edge of the quadrangle. This intrusive is roughly 700 feet long by 500 feet in maximum width, and from it, a dike extends southeastward along the fault.

The known size of the dikes ranges from about 1 foot in thickness by 20 feet in length to as much as 200 feet in thickness by 6,500 feet in length. The largest dike is on the east side of Bear Creek near the Dan Patch property (pl. 1, loc. 98). This dike ranges in thickness from 3 to 150 feet and is 6,500 feet long. The traced lengths of six other dikes are between 1,350 and 2,800 feet. The dikes have various strikes, and some dikes bend. Most dikes, however, strike between N. 57° W. and S. 60° W. Dips are steep and may be either north or south. The dikes adjacent to veins, such as those near the Wonder (loc. 45), Brown Bear No. 2 (loc. 78), Dan Patch (loc. 98), and G & G (loc. 89) properties, have strikes parallel to the vein, indicating that both the dikes and the veins occupy the same set of fractures.

Most of the diorite is dark gray, but the color ranges from black to medium gray; some dikes are greenish gray, and some are speckled. Most of the diorite is fine to medium grained, and it is locally porphyritic. Even-grained rocks have an average grain size that ranges from approximately 0.08 to 1.0 mm in maximum diameter. Porphyritic rocks contain phenocrysts, 2–5 mm across, set in a matrix of grains that have an average diameter of 0.10–0.30 mm. The thicker dikes are generally coarser grained and more likely to be porphyritic than the thinner ones. The two largest dikes in the Lemhi Pass quadrangle—the one west of the Dan Patch property and the one near the headwaters of Trapper Creek (fig. 5)—are both porphyritic.

These intrusives, though all would be classified as diorites according to Grout (1932, p. 50), vary considerably in mineral content. This difference can be noted from the content of mafic minerals, which, in various samples, ranged widely from 20 to 70 percent of the rock. The mafic minerals also commonly vary as to both kind and amount.

The principal mafic minerals are augite, hornblende, chlorite, and biotite. Not all of them are found in all specimens of diorite. Augite (3–30 percent) and hornblende (0–30 percent) are generally the most abundant, but any one of the four may be the most abundant in any particular rock. Biotite, the least common of

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these four minerals, generally makes up only a small percentage of the diorite. In the dike on the north side of the Wonder vein (loc. 45), however, biotite makes up 35 percent of the rock. Augite forms stubby subhedral crystals; hornblende occurs as long lath-like crystals and, in thin section, ranges in color from dark brown to green; biotite forms irregular brown to green plates; and chlorite was found in pale-green irregular crystals. Chlorite is formed by alteration from the other three minerals, and in porphyritic rocks commonly forms rims around the augite crystals. Accessory mafic minerals are magnetite, hematite, and apatite. Small amounts of calcite, sericite, and epidote result from the alteration of other minerals.

Plagioclase (generally andesine) is the principal salic mineral. This mineral forms in anhedral to subhedral crystals that commonly are zoned, although twinning is generally not well developed. Small amounts of orthoclase (<1–7 percent) occur as small inconspicuous anhedral grains interstitial to the other minerals. Its presence was detected by testing the rock for potassium content by staining with a sodium cobaltinitrite solution. Quartz as small anhedral interstitial grains occurs in many of the diorite intrusives; generally, it constitutes only about 1 percent of the rock, although in one specimen about 3 percent was detected.

The diorite intrusives are, I believe, of Tertiary age, but younger than the Challis Volcanics, although authors of previous reports (Sharp and Cavender, 1962, p. 8; Geach, 1966, p. 8) generally favored the theory that the intrusives are older than the volcanics. The age of the diorite is determined relative to other rock types and structural events. The diorite intrudes the rocks of the Belt Supergroup, and is, therefore, younger than those rocks. The diorite intrusives do not intrude the Challis Volcanics and, hence, might be presumed to be older. That the volcanics are not intruded by the diorite may be due either to the intrusive being older than the volcanics or to the lack of fractures in the volcanics which the diorite could have intruded. However, the small irregular diorite body on the east edge of the quadrangle, north of North Fork Everson Creek, has a dike extending from it along the Bull Moose fault. Hence, this dike is younger than the fault, and the fault cuts the Challis Volcanics of Tertiary age. Diorite is older than the copper veins, which are, in turn, older than the thorite veins. This relationship was noted by Schipper (1955, p. 29) and by Sharp and Cavender (1962, p. 52) in the underground workings of the Copper Queen mine (loc. 43), where a copper-bearing quartz vein cuts across several diorite dikes. These dikes are also highly altered and contain sulfides. A little pyrite was found in the dike just north of the Wonder vein (loc. 45), suggesting that it also formed prior to the vein. In summary, the diorite dikes formed in Tertiary time after the major faulting that cut the Challis Volcanics, but before the veins were emplaced.

ROCKS OF QUATERNARY AGE

Six unconsolidated rock units of Quaternary age occur in the Lemhi Pass quadrangle: glacial deposits of two ages, river gravels, terrace deposits, landslide deposits, and alluvium. The river gravels cover only a very small area and, thus, are not shown on plate 1. The other five units thickly blanket about one-quarter of the quadrangle (pl. 1). The glacial deposits are more widespread than shown on plate 1; however, because the principal interest of this study is in the older, underlying consolidated rocks, the glacial deposits are only shown where the distance between outcrops of the underlying rock is more than 1,000 feet. The boundaries between the glacial deposits and the consolidated rocks, hence, are approximate. Although the younger and older glacial deposits are similar in composition, they are separated on the bases of form and occurrence.

OLDER GLACIAL DEPOSITS

Older glacial deposits blanket many of the gently sloping ridges in the northeast quarter of the quadrangle (fig. 6). These glacial deposits are particularly common in the Sheser Creek drainage, where they cover better than 90 percent of the bedrock. The till occurs from elevations of 6,600 up to 8,160 feet. South of Lemhi Pass, a large patch of till lies along the east side of the Continental Divide. The till was formerly much more widespread than now because erosion has removed much of it from the steeper slopes. West of the Continental Divide, where the topography is much steeper than to the east, the only patch of preserved till is along a flat-topped ridge.

Erosion has modified and smoothed out much of this till, and areas covered with it are typically rather featureless. The till has also helped to mask any pre-Quaternary topography, and commonly, the areas underlain by it are gently rolling. Ridges covered with till form a broad gently sloping basin centered on the Curtis Ranch on Trail Creek (fig. 6).

The older glacial till consists of angular, subangular, and subrounded blocks, boulders, cobbles, and pebbles of fine-grained gray quartzite set in a matrix of sand, silt, clay, and soil. Pieces of quartzite are generally less than 1 foot across, although blocks

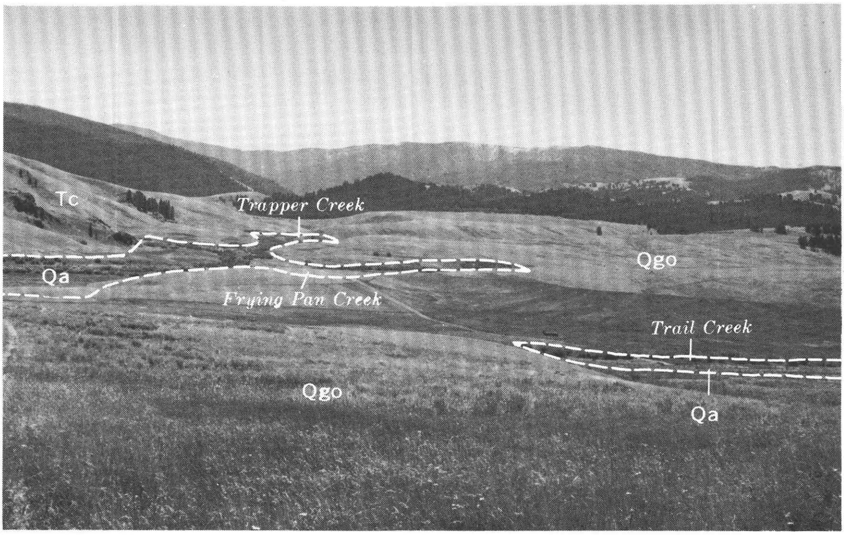

FIGURE 6. — Older glacial deposits (Qgo) in broad stream-cut terraces near the junction of Trail, Frying Pan, and Trapper Creeks. Southwestward view from north of the Curtis ranchhouse. Tc, Challis Volcanics; Qa, alluvium.

as much as 10 feet across were found in a few places. At least 95 percent of the rock fragments is quartzite. A few pieces of basalt, tuff, and rhyodacite, however, are found in the glacial till that overlies, or is adjacent to, the volcanic rocks. The fragments of these volcanic rocks are not more than several inches across, and they probably have not been transported for more than several miles. Tuff and rhyodacite found in the glacial deposit that lies southwest of the junction of Frying Pan and Trapper Creeks are unlike any volcanic rocks to the south of this area, but are similar to rocks that lie 1–1½ miles to the northeast. Thus, till in this deposit came from the north and in this area was moved up a drainage.

The older glacial deposits appear to be a product of an ice cap originating to the north of the quadrangle. The following evidence supports this statement: (1) The wide distribution of the deposits across both valleys and mountain tops; (2) the large vertical distribution over which the deposits are found; (3) the general movement of material from the north, as indicated by volcanic rock fragments; and (4) the movement of glacial material in some places up drainages, rather than consistently down them.

RIVER GRAVELS

A small patch of thin gravel (not shown on pl. 1) caps hilltop 7,381 on the north side of Frying Pan Creek in the NW¼ sec. 22,

T. 10 S., R. 15 W. This gravel is scattered over an area a few hundred feet across. The gravel forms only a thin layer, and in some places the underlying tuff is exposed. Most of the finer material has been eroded away, and what now remains are well-rounded pebbles, cobbles, and boulders, which range in diameter from 2 inches to 1 foot. The most common type of material is a micaceous quartzite that appears to have been derived from the Belt Supergroup. Other rock types include a coarse-grained quartz diorite, a coarse-grained quartz monzonite, a pink fine-grained quartzite, a white quartzite, and a biotite-quartz schist. All the rocks are well rounded and, except for the micaceous quartzite, are foreign to this quadrangle and must have been transported a long way—this type of deposit is found along old river beds. Similar deposits along the lower slopes of the Lemhi River valley were described as old river gravels by Anderson (1961a, p. 37–38). Other interpretations of these gravels are given by Sharp and Cavender (1962, pl. 1), who mapped them as glacial till, and by Sharp and Hetland (1968, pl. 1), who mapped them as Beaverhead Conglomerate.

Little evidence is available for use in estimating the age of the gravels. The elevated position of the gravels and their almost complete removal by erosion suggest that they may have been deposited about the same time as the older glacial deposits in early Pleistocene time.

YOUNGER GLACIAL DEPOSITS

Till from the younger period of glacial activity is found along the bottoms of steep-walled valleys that head in large steep-walled cirques along the east side of the Continental Divide. Some till occurs along most of them, but it was only mapped where it makes up thick deposits that completely mask the bedrock over fairly broad areas. Hence, on plate 1, younger till is shown along South Frying Pan Creek and along Bear Creek and some of its tributaries, but is not shown along North Frying Pan Creek, where it is thinner and has less definite boundaries.

The younger glacial deposits were formed by valley glaciers moving down the valleys from their source in cirques high on the Continental Divide. The basins of some of the cirques, such as those in the large cirques just east of the Continental Divide near the south boundary of the quadrangle, expose striated and polished bedrock (generally quartzite). Some cirque basins, such as the one on South Frying Pan Creek, are blanketed by till.

Till occurs both as fairly even deposits along the valley bottoms and sides and as steep-sided moraines. Lateral moraines approximately 50 feet high are found along the upper part of South

Frying Pan Creek, where a prominent topographic ridge can be seen on the north side of the creek in the SW¼ sec. 29, T. 10 S., R. 15 W. (pl. 1), and on the northwest side of Bear Creek in the NW¼ sec. 35, T. 10 S., R. 15 W., and on the north side of Trapper Creek in the east half sec. 33, T. 10 S., R. 15 W., and in several other places along South Frying Pan and Bear Creeks. A large medial moraine has formed at the junction of the valleys of an east-flowing tributary of Bear Creek with the main, north-flowing stream. This northeast-trending moraine is 3,700 feet long, has a width of 1,200 feet, and in places is as much as 120 feet high. This moraine forms a low ridge with an irregularly rolling surface. End moraines are not common, either because they were never formed or because they were eroded away after formation. A partial end moraine is found on the south side of Trapper Creek, where several hills, as much as 150 feet high, are found at the terminus of the glacial deposit (pl. 1).

The younger glacial deposits are similar in composition to the older glacial deposits, consisting of boulders of fine-grained quartzite in a matrix of sand, silt, and clay. Generally, the boulders are not more than several feet across, but in places, such as along Trapper Creek, blocks of quartzite as much as 20 feet across are found.

Inasmuch as the two ages of glacial deposits are distinguished on the bases of form and occurrence, their separation, where they join on the lower part of Bear Creek, is difficult.

TERRACE DEPOSITS

Terrace deposits are found only in the northwest corner of the Lemhi Pass quadrangle (pl. 1), where stream terraces extend upstream for almost 1 mile on Agency Creek (fig. 8*C*) and for about 2 miles upstream on its tributary, Flume Creek. The terraces lie only on one side of these two creeks—on the south side of Agency Creek and on the east side of Flume Creek. At both places the terraces are formed only where the valleys are broader, and they end where the valleys narrow abruptly. The terrace on the south side of Agency Creek can also be traced downstream for another 3 miles (Anderson, 1961a, pl. 1).

The terraces are made up of subrounded cobbles and boulders of fine-grained gray quartzite set in a matrix of sand and silt. The source of this material is within a few miles of these deposits. Similar terrace deposits are common in the Lemhi quadrangle, adjacent on the west, where, in addition to those on Agency Creek, these deposits occur extensively along the Lemhi River and Hayden Creek (Anderson, 1961a, pl. 1, p. 39–40). These deposits are similar in composition, if not in form, to the glacial deposits. They probably were formed during the same period as the glacial deposits from glacial melt water where the stream gradient flattened. The terraces have since been entrenched by stream erosion.

LANDSLIDE DEPOSITS

Five landslide deposits were mapped in the Lemhi Pass quadrangle (pl. 1). Each is small; the largest, located on the headwaters of North Fork Everson Creek, has a length of 2,700 feet and a maximum width of 1,500 feet. All are of the slump type. The upper edges of three—the one at the west edge of the quadrangle, the one on Frying Pan Creek, and the southern one on Bear Creek—are marked by arcuate scarps. All the landslides have a hummocky surface, but the hummocks are especially well developed on the two largest landslides—the one on North Fork Everson Creek and the one near the west edge of the quadrangle. Small springs are common on the hummocky surface on the landslide on North Fork Everson Creek, and a pond has formed just below the scarp on the upper edge of the southernmost landslide on Bear Creek.

The landslide deposit near the west edge of the quadrangle is made up entirely of broken quartzite of the Belt Supergroup. The other four landslide deposits are made up principally of broken basalt, although the landslide deposit on North Fork Everson Creek also contains some quartzite.

ALLUVIUM

Alluvium, as considered in this report, is the unconsolidated deposits formed in Holocene time by the streams. These deposits occupy the flat valley bottoms of Bear, Frying Pan, Trapper (fig. 6), Trail, Sheser, and Agency Creeks (pl. 1).

Alluvium in the Lemhi Pass quadrangle consists of well-sorted silts, sands, and gravels, as well as soils formed in the broader valley bottoms. Gravels, though they contain a few basalt and diorite pebbles, are made up principally of fine-grained gray quartzite.

STRUCTURE

The structure of the Lemhi Pass quadrangle is moderately complex and involves faults and folds of diverse trends. The rocks in this area have undergone at least two periods of deformation. At least one period occurred prior to the deposition of the Challis Volcanics, and one period occurred after most of the Challis was deposited.

PRE-CHALLIS DEFORMATION

Rocks of the Belt Supergroup are cut by several sets of faults that do not offset the Challis Volcanics. Two folds are believed to have been formed in pre-Challis time. The faults, as shown on plate 1, are concentrated in the northwest and southwest corners of the quadrangle, where siltite units form distinctive layers in the quartzite. Faults are probably equally common in other areas underlain by the Belt Supergroup, but were not recognized because of the lack of distinctive marker beds.

The faults can be divided according to strike into three sets. The first set consists of several faults with a N. 25°–40° E. strike; the second set consists of several faults with a N. 15°–20° W. strike; and the third consists of one large fault—the Yearian Creek fault—with a N. 67° E. strike.

The N. 25°–40° E. trending faults were mapped in both the northwest and the southwest corners of the quadrangle (pl. 1). These faults have a steep northwest, or vertical, dip. Total movement on these faults is not known, but the horizontal offsets of two faults on either side of the large cirque near the south boundary of the quadrangle is 1,600 and 3,400 feet. They are older than the Yearian Creek fault, inasmuch as it cuts off the northeast end of one of these faults three-quarters of a mile northeast of the Continental Divide.

Several northwest-trending faults of steep to vertical dip were mapped in the headwaters of Bear Creek in the southwestern part of the Lemhi Pass quadrangle, where they offset a siltite unit. One of these faults is cut by the Yearian Creek fault (pl. 1).

The Yearian Creek fault, which crosses the Continental Divide at the head of Yearian Creek, was traced for 3.6 miles from the west border of the quadrangle to the west side of Bear Creek valley. The large diorite dike of similar trend on the east side of Bear Creek might lie along the continuation of this fault. At the Continental Divide the fault dips about 68° SE.; to the west it becomes somewhat steeper. The horizontal offset on this fault is about 6,500 feet, with the north side moving east; vertical offset is not known.

The rocks of the Belt Supergroup generally have moderate dips, although in some places the dips are steep, and the beds may be overturned. The quartzite is commonly massive and its bedding indistinct. Beds are more distinct in the northwestern part of the quadrangle, where crossbedding aids in determining the top sides of beds. In the southern third of the quadrangle, crossbedding is absent, but the rocks have a well-developed cleavage (fig. 7). The cleavage is a flow cleavage developed by the parallel orientation

FIGURE 7. — Well-developed flow cleavage and bedding in outcrop of micaceous quartzite of the Belt Supergroup on ridge just south of Yearian Creek. Cleavage dips gently to the left; bedding dips steeply to the right.

of the sericite. The relation of the attitude of the cleavage to that of the bedding has proved useful in recognizing overturned beds in rocks of the Belt Supergroup in the Coeur d'Alene district (Shenon and McConnel, 1940, p. 440–444). I measured the cleavage wherever it occurred with the bedding (pl. 1), and used it for determining overturned beds. Although several periods of deformation may well destroy the usefulness of this tool, the top sides of the beds as determined by cleavage were checked with those determined by crossbedding, where they occur together in the central part of the quadrangle, and were found to be in agreement. The attitude of the rocks of the Belt Supergroup is similar to, although somewhat different than, that of the volcanic rocks. For example, north of Trapper Creek near its headwaters, the quartzite strikes east-northeast and dips moderately northwest, but the adjacent volcanics to the east have a northerly strike and a steep easterly dip. In other areas, such as southwest of Lemhi Pass, the attitude of the rocks of the Belt Supergroup and the Challis Volcanics is less divergent. Hence, some of the folding apparently

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preceded the deposition of the Challis Volcanics. Two small but well-defined folds on the east side of the Continental Divide, in the southwestern part of the quadrangle, are believed to have formed during the earlier period of deformation. These folds are about 1 mile long and are generally parallel to a nearby northwest-trending fault.

Small-scale folding has also occurred in some areas, such as north of the Lemhi Pass fault, and is indicated by diverse strike and dip symbols on plate 1.

POST-CHALLIS DEFORMATION

Deformation following the emplacement of most of the Challis Volcanics produced faulting, tilting, and folding. Three of the faults (the Lemhi Pass, Bull Moose, and Dan Patch) formed during this period are the three largest structural features in the Lemhi Pass quadrangle (pl. 1; fig. 8*A–C*). Although these three faults have a general northwest strike, they converge toward the northwest corner of the quadrangle. They bound one or more sides of the major outcrop areas of the Challis Volcanics, and the greater part of the volcanics are preserved in fault blocks.

The Lemhi Pass fault, the northernmost of these three principal faults, crosses Lemhi Pass, after which it was named by Sharp and Cavender (1962, p. 17). Exposures in most places along this fault are poor (fig. 8*B*); hence, several interpretations of the type of faulting and of the position of the fracture or fractures have been made. Sharp and Cavender (1962, pl. 1) and Sharp and Hetland (1968, pl. 1) in their reconnaissance maps of this area indicated a zone of several faults having a somewhat more westerly trend than that shown on plate 1 of the present report. Although the maps accompanying the two previous reports show several faults, they do not agree in the number, length, or position of the faults. During mapping for the present report, I noted that the offset in this area could be explained by a single major fault. Known exposures do not support the theory of several parallel faults. I do not mean to imply, however, that the Lemhi Pass fault is on a single plane; rather, the fault consists of several closely spaced shears separated by brecciated rock. This is shown by a zone of brecciation, at least 20 feet thick, that is exposed in two trenches 1,600 feet N. 15° E. and 1,600 feet N. 30° E. of the principal adit on the Buffalo property (loc. 18).

The Lemhi Pass fault has a general strike of N. 70° W. and a steep dip. It was traced across the Lemhi Pass quadrangle, a distance of 6.8 miles, and it extends for at least 3 miles to the northwest (Sharp and Cavender, 1962, p. 1). Vertical movement on this fault is probably more than 2,000 feet, with the north side up. This amount of movement is the minimum necessary to account for the vertical separation of the quartzite-bearing rhyolite tuff exposed on the south side of this fault near Lemhi Pass and of that exposed on the north side along the east edge of the quadrangle. A steep-dipping fault, with at least 1,500 feet vertical displacement, branches from the Lemhi Pass fault near the east edge of the quadrangle.

The Bull Moose fault, which was named after the Bull Moose vein (loc. 76) just south of Frying Pan Creek, forms the southwest side of the largest block of volcanics. To the northwest, at Agency Creek, the Bull Moose fault is offset to the southeast, on the Dan Patch fault. The Bull Moose was traced for 9.6 miles in the Lemhi Pass quadrangle. It has a variable strike that ranges from about N. 29° W. to N. 50° W., and it has a steep dip. Unlike the Lemhi Pass fault, the Bull Moose fault is upthrown on the south side (fig. 8*C*).

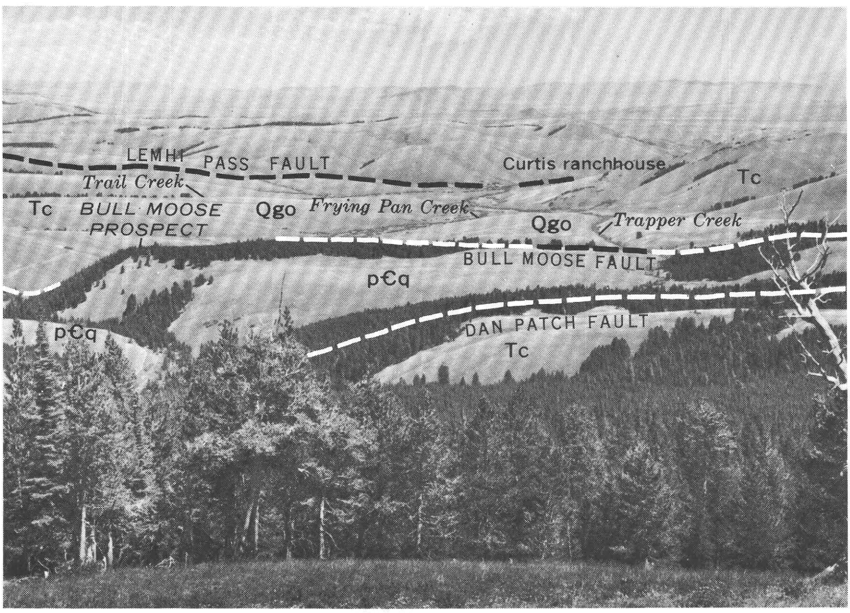
The Dan Patch fault is named after an adjacent vein (loc. 98) southeast of Bear Creek. This northwest-trending fault cuts diagonally across the quadrangle, from the headwaters of North Fork Everson Creek to Flume Creek, a distance of 9.5 miles. This fault is younger than the Bull Moose fault and offsets it by about 1 mile near the Copper Queen mine (loc. 43). The Dan Patch fault has a general N. 38° W. strike and a dip that ranges from nearly vertical to about 50° SW. Its trend is sinuous from the Wonder mine (loc. 45) to the west edge of the quadrangle. Although some of this variation is due to the change in strike of the fault, the greater part is due to the change in dip and to the effect of dip in areas of varying topography. Movement on this fault is large, with the southwest side down.

The narrow strip of land between the Bull Moose and Dan Patch faults, ½–¾ mile wide, is a horst of quartzites of the Belt Supergroup (fig. 8*A*).

A shorter northwest-striking flat-dipping fault, whose east side is up, cuts the volcanics just west of the Buffalo property (loc. 18).

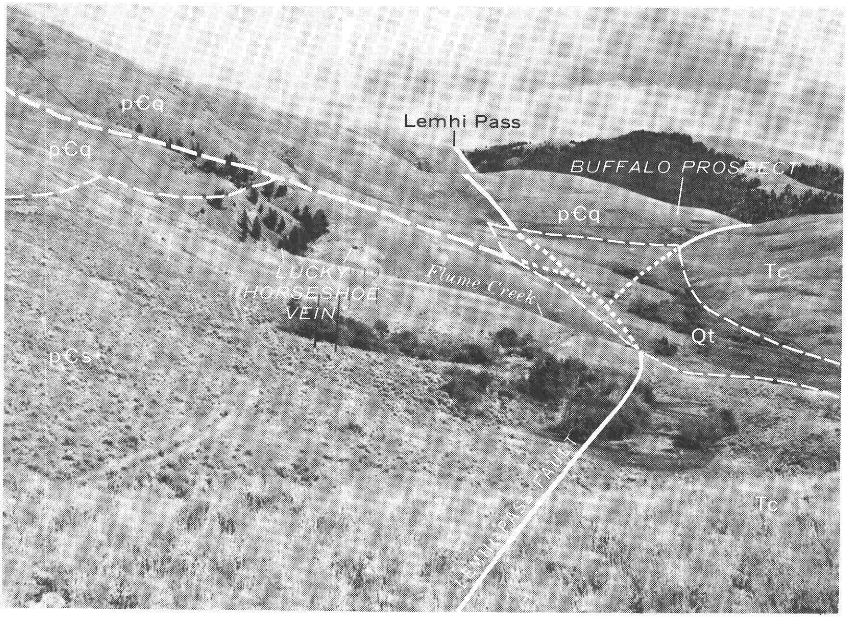
A thrust fault was mapped east of Sheser Creek in the northeast corner of the quadrangle (pl. 1). The position of the thrust is marked by a flat ledge of discontinuous quartzite breccia (fig. 9) that is made up of silica-cemented angular pieces of gray micaceous quartzite of the Belt Supergroup. Breccia forms prominent outcrops as much as 10 feet thick on the edge of the hill. In the one small exposure of quartzite beneath the breccia, the rock, although not a breccia, is highly fractured. The thrust has quartzite below it and volcanic rocks above it. The fault surface curves from practically horizontal at the east edge of the quadrangle to dipping gently to the west into Sheser Creek. Although no other thrusting was noted in the Lemhi Pass quadrangle, it is common in the Goat Mountain quadrangle, adjacent on the south. Furthermore, Ruppel's (1968) mapping showed post-Challis thrusting in the Lemhi Range southwest of Leadore, Idaho.

Following the emplacement of the first Challis Volcanics, the rocks of the study area were also tilted and folded. The greater part of the Challis Volcanics strike northwest and dip 30°–50° NE. Some of these rocks in the Agency Creek and Flume Creek areas are overturned. Three folds were formed at that time. Two north-

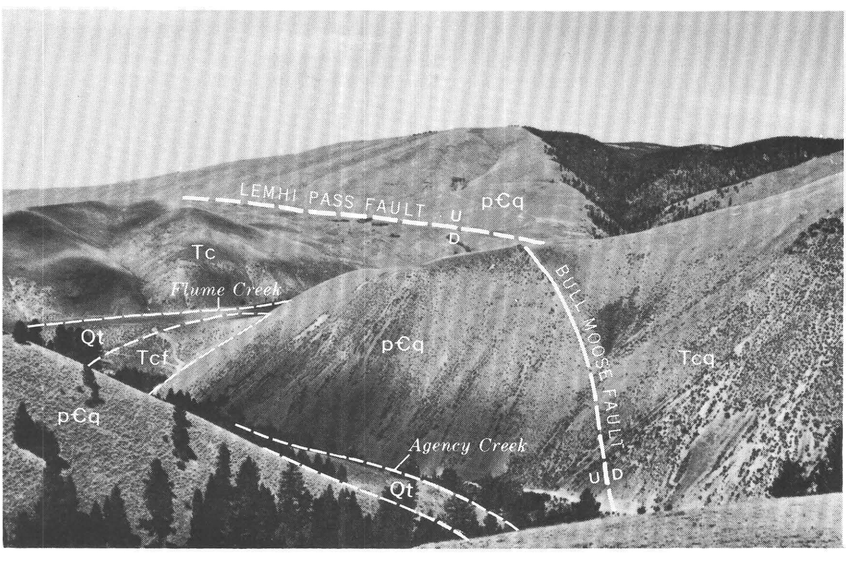


A

FIGURE 8 (above and facing page).—Major post-Challis faults. *A*, A horst of quartzite of the Belt Supergroup (p€q), bounded by the Challis Volcanics (Tc), is brought up on the Bull Moose and Dan Patch faults. The Challis is overlain by older glacial deposits (Qgo) in the basin formed by the junction of Frying Pan, Trapper, and Trail Creeks. Lemhi Pass fault is in background. View is toward the northeast. *B*, Lemhi Pass fault cutting two other faults in the Flume Creek basin. View is toward the southeast. p€q, quartzite of the Belt Supergroup; p€s, siltite of the Belt Supergroup; Tc, Challis Volcanics; Qt, terrace deposits. *C*, Bull Moose fault separates quartzite-bearing rhyolite tuff (Tcq) of the Challis Volcanics from rocks of the Belt Supergroup (p€q) on the north side of Agency Creek in the foreground; Lemhi Pass fault separates Belt rocks (p€q) from the Challis Volcanics (Tc) in the background. View is toward the northwest. Tcf, conglomerate of Flume Creek; Qt, terrace deposits.


pЄq
pЄq
Lemhi Pass
BUFFALO PROSPECT
pЄq
LUCKY HORSESHOE VEIN
Flume Creek
Tc
Qt
pЄs
LEMHI PASS FAULT
Tc

B


LEMHI PASS FAULT
U
D
pЄq
Tc
Flume Creek
BULL MOOSE FAULT
Qt
Tcf
pЄq
Tcq
pЄq
Agency Creek
Qt
U
D

C

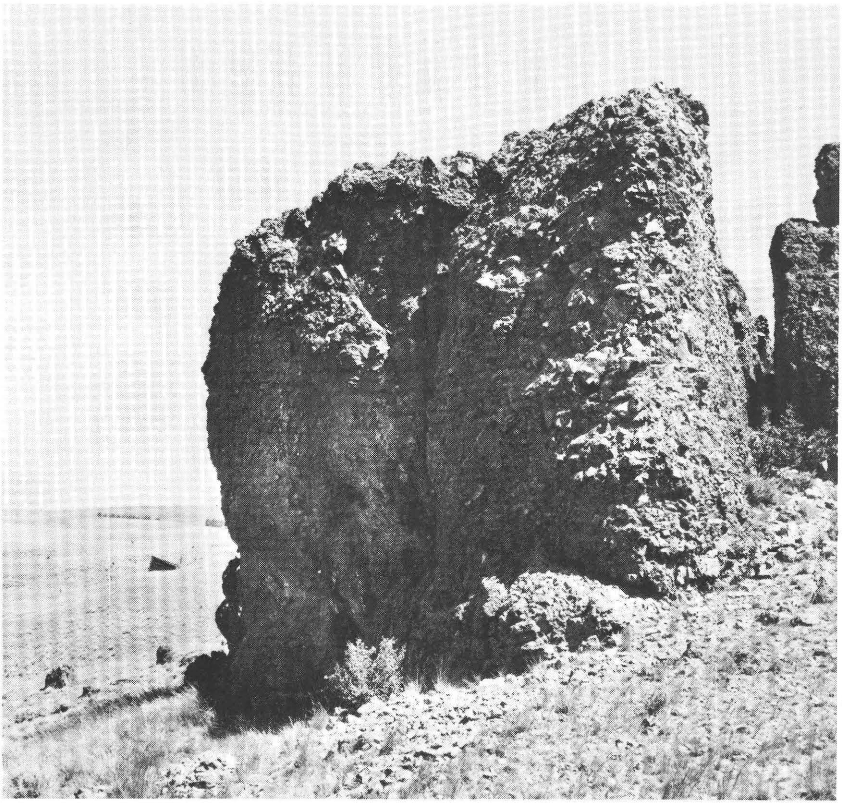


FIGURE 9.—Breccia, made up of angular fragments of quartzite from the Belt Supergroup, formed along thrust fault on the ridge east of Sheser Creek.

west-trending folds—an anticline and a syncline—are roughly outlined by a tuff bed that crosses Bear Creek in the eastern part of the quadrangle. As the tuff for most of its extent is poorly exposed, these folds are difficult to trace. A third fold, a syncline, was noted just west of these folds in the horst of Belt quartzite. This syncline, which has a general trend of N. 40° W., was traced a distance of 3.6 miles. Although this fold may have formed prior to the emplacement of the Challis, its general trend parallel to the two faults bounding the horst suggests that it was formed at the same time. For the most part, this later period of folding occurred during the emplacement of the Challis Volcanics, inasmuch as the younger basalts show only gentle tilting, although the earlier volcanics have moderate to steep dips.

VEINS

Veins were noted at 107 localities (pl. 1) in the Lemhi Pass quadrangle. Although most of these veins were located, as indicated by old claim posts and workings, the names of the claims could not always be ascertained, owing to destruction of the location notices over the years. Hence, in order to discuss various veins, I have given each locality a number, starting with 1 in the northwest corner of plate 1 and numbering consecutively to 107 near the southeast corner of this map. The better known veins are also named on the map, and both the vein numbers and the known name of the property are given in table 2. At some localities several veins occur, commonly in the same trench. Where several veins occur at one locality they were all given the same locality number. Where close together, these veins may not be shown separately on plate 1; however, they are listed separately under the one locality number in tables 2, 3, and 5.

In general, the veins do not crop out, although commonly the more quartzose parts of the thicker veins may be exposed. A small part of the Last Chance vein (loc. 82) on the northwest side of South Frying Pan Creek forms a prominent outcrop. Parts of the Beaverhead (loc. 64), Contact (loc. 52), and veins at localities 57 and 59 on the north side of North Frying Pan Creek are well exposed. Thinly covered thorium-bearing veins were commonly discovered with a geiger or scintillation counter. A few hidden veins and extensions of many known veins were found and explored by trenching (fig. 10*A*). The greater part of even the thickest veins may be concealed under a thick cover of overburden. Three examples of increase in known vein length by further trenching were found at localities 82, 73, and 75 by comparing the lengths of veins as exposed in 1952 with those exposed in 1969. Sharp and Cavender (1962, p. 29) reported that in 1952 the Last Chance vein (loc. 82) was exposed for about 1,200 feet; further work has since increased its known length to about 3,900 feet. In 1952 the northwest-trending vein on the Black Rock property (loc. 75) was exposed for 100–150 feet (Sharp and Cavender, 1962, p. 40); I traced it in 1969 for about 1,630 feet. A vein on the old Trapper No. 4 claim was inferred to be about 500 feet long by Sharp and Cavender (1962, p. 34). This vein has since been found to be on the northwest end of the Shear Zone vein (loc. 73), which actually contains several adjacent veins in one long zone that stretches for at least 6,000 feet. The extension of these three veins or vein systems were all hidden by cover, from a few feet to more than 20 feet thick, and extensive trenching was necessary to expose the greater part of them.

With one exception, all veins in the Lemhi Pass quadrangle occur in rocks of the Belt Supergroup. Most of these veins occur in the quartzite, but veins at localities 1 (Lucky Horseshoe) and 14 cut

TABLE 2. — *Dimensions and attitude of the veins in the Lemhi Pass quadrangle*

[ND, no data]

Loc. No.	Name of claim or vein, where known	Number of veins	Vein, if more than one	Type of vein[1]	Exposed length (ft)	Thickness (ft)	Strike	Dip
1	Lucky Horseshoe	1		Th	1,400	0.8– 1.5	N. 67° W.	70° NE.
2	In Trust	1		Th	ND	ND	ND	ND.
3		(2)		Th	ND	ND	ND	ND.
4		1		Th	80	.1– 1.3	N. 70° W.	75° SW.
5		1		Th	100	1.2– 1.5	N. 50° W.	53° SW.
6		1		Th	6	.5	N. 16° E.	29° NW.
7	Buffalo (Stenson)[3]	1		Th	100	1.5– 2.2	N. 75° W.	75° SW.
8	No Pay[3]	1		Cu	150	.3– .6	N. 30° W.	30° SW.
9	Betty Jo Nos. 1 and 2	1		Th	425	1.0	N. 35° E.	20° NW.
10		1		Th	200	ND	N. 55° E.	ND.
11		1		Th	ND	ND	ND	ND.
12		1		Th	ND	ND	ND	ND.
13		1		Th	ND	.3	ND	ND.
14		1		Th	ND	.5+	ND	ND.
15	Big Dean No. 1	1		Th	100	.5+	ND	ND.
16		2	North vein	Th	150	.1– .2	N. 40° W.	60° SW.
			South vein	Q	200	8	East-west	Steeply north.
17	Summerwell adit[3]	2	North vein	Cu	100	.05	N. 60° W.	ND.
			South vein	Cu	150	.1	N. 55° W.	80° S.
18	Buffalo	4	Vein in northwest trench A.	Th	40	2	N. 50° W.	52° SW.
			Vein in northwest trench B.	Th	4	.4	ND	ND.
			Vein in west trench	Th	75	2.0– 2.5	N. 75° W.	Steep.
			Vein in easternmost trenches.	Th	250	2.0–11	N. 5°–27° W.	60° SW.
19	Black Bull Fraction No. 4.	1		Th	40	10+	ND	ND.
20	Black Bull No. 3	2	Northwest-trending vein.	Th	20	.3– 1.0	N. 77° W.	45° SW.
			Northeast-trending vein.	Th	15	.5– .7	N. 62° E.	53° NW.

21	Deer Fraction 1A	2	West vein	Th	60	2.0– 3.0	N. 72° W.	70° SW.
			East vein	Th	20	.3	N. 67° W.	45° SW.
22	Deer No. ?	(4)		Th	6	1	N. 76° W.	65° SW.
23	Deer No. ?	1		Th	50	ND	N. 67° W.	ND.
24	Deer No. ?	1		Th	250	2	N. 68° W.	Steep.
25	Rufus	1		Cu	850	.3– 3	N. 78° E.	90°.
26		1		Q	10	.8	N. 85° W.	81° NE.
27	Woodstock	1		Q	6	3	N. 80° W.	ND.
28	Idaho Pride Group[3]	1		Cu	350	[3].5– .9	N. 83° E.	ND.
29		1		Th	15	.1– .4	ND	ND.
30	Bluebird[3]	2	Northwest vein	Cu	ND	ND	ND	ND.
			Southeast vein	Cu	450	[3].5– 3	N. 40° E.	[3]90°.
31		(5)	Veinlets in conglomerate.	Th	ND	ND	ND	ND.
32	Blue Boar[3]	1		Q	100	.2– 1	N. 72° W.	Near vertical.
33		3	North vein	Th	6	.5– 1.2	N. 25° W.	84° NE.
			Central vein	Th	6	ND	ND	ND.
			South vein	Q	25	1.0	N. 80° W.	ND.
34		1		Q	30	25	N. 40° W.	75° SW.
35		1		Th	80	.7	N. 58° W.	63° SW.
36		1		Cu	8	.01– .2	N. 3° W.	40° NE.
37	Black Bear	1		Th	75	1 –19	N. 45° W.	ND.
38		1		Th	18	1	N. 47° W.	ND.
39	Big Lost Nos. 1 and 2	1		Th	500	ND	N. 29° W.	ND.
40	Thorite No. 3	1		Th	350	.3– .5	N. 86° W.	82° SW.
41	Uranium Queen or Surprise Nos. 5 and 6.	1		Th	50	[3]2 – 3	N. 60° W.	65° SW.
42	Three and one[3]	1		Th	20	[3].5– 1	[3]N. 30° E.	[3]89° SE.
43	Copper Queen	2	North vein	Cu	1,300	[6].2– 9	[3]N. 40°–70° E.	40° NW.–70° NE.
			South vein	Cu	500	1.0	N. 67° E.	80° NW.
44		1		Cu	75	7	N. 85° W.	54° SW.
45	Wonder	1		Th	[3]1,200	<1 –10	East-west	[3]40°–89° S.
46	Wonder No. 3	1		Q	10	1.4– 2.3	N. 55° W.	70° SW.
47	Badger No. 10	1		Th	20	1.5– 7	N. 42° W.	Steep.
48	Blue Ridge or Iron Dike.[3]	1		Q	[3]40	ND	[3]N. 45° W.	Steeply north.[3]

See footnotes at end of table, p. 48.

TABLE 2. — *Dimensions and attitude of the veins in the Lemhi Pass quadrangle* — Continued

Loc. No.	Name of claim or vein, where known	Number of veins	Vein, if more than one	Type of vein[1]	Exposed length (ft)	Thickness (ft)	Strike	Dip
49	Cago No. 12	1		Th	2,800	0.3–13	N. 55° W.	46°–48° SW.
50		1		Th	150	.2	N. 38° E.	ND.
51	Cago No. 10	4	Main vein	Th	100	1.3	N. 45° W.	Steep.
			Northeast veinlet	Th	6	ND	ND	90°.
			Central veinlet	Th	6	ND	ND	35° N.
			Southwest veinlet	Th	6	ND	ND	75° S.
52	Contact	1		Th	1,950	.7–10	N. 70° E. N. 55° W.	26°–56° S.
53		1		Th	90	2	N. 45° W.	ND.
54		1		Th	20	ND	N. 75° W.	ND.
55		2	East vein	Th	60	3+	N. 39° W.	Steeply southwest.
			West vein	Th	50	4.5	N. 30° E.	40° NW.
56		1		Th	150	1+	N. 85° W.	ND.
57		1		Th	108	2 – 5	N. 75° E.	ND.
58		1		Th	45	1 – 1.5	N. 45° W.	ND.
59		1		Th	400	2 –10	N. 70° W.	ND.
60	Benny	1		Th	100	.7	N. 80° W.	ND.
61		1		Th	55	ND	ND	ND.
62		1		Th	ND	ND	N. 38° W.	ND.
63		1		Th	72	.9	N. 75° W.	ND.
64	Beaverhead	1		Th	525	2 – 4	N. 85° E. N. 70° W.	40° S.
65		1		Th	15	ND	ND	ND.
66		1		Th	140	3 – 8	N. 77° E.	ND.
67	Trapper No. 1	1		Th	235	5 –11	N. 75°–85° W.	45°–60° SW.
68	Lucky R or Little Dandy No. 5.	1		Th	ND	ND	ND	ND.
69		1		Th	ND	ND	ND	ND.
70	Wonder No. 18	4	North vein	Th	ND	ND	N. 75° W.	ND.
			West vein	Th	100	.7– 1	N. 44° W.	65° SW.
			East vein	Th	100	1.5– 2.0	N. 38° W.	30° SW.
			South vein	Q	310	7 –10	N. 70° E.	80° SE.
71		1		Q	270	4	East-west	ND.

72	Little Dandy No. 1	1		Th	90	2.5	N. 75° W.	80° NE.
73	Shear Zone	[7]	Zone treated as a unit	Th	6,000	.5– 2.5	N. 55° W.	65°–81° SW.
74	Dictator No. 6	1		Th	ND	.1	ND	ND.
75	Black Rock or Radio[3]	2	Northwest-trending vein.	Th	1,630	2 – 6	N. 47° W.	70° SW.
			Northeast-trending vein.	Th	140	.7– 1	N. 75° E.	75° NW.
76	Bull Moose[3]	1		Th	[3]60	[3].1– .3	N. 45° W.	85° SW.
77	Brown Bear No. 3	1		Th	ND	ND	ND	ND.
78	Brown Bear No. 2	2	North vein	Th	65	1	N. 79° W.	ND.
			South vein	Th	400	.5	N. 80° W.	ND.
79	Skyline No. 1	1		Th	100	.4	N. 70° W.	ND.
80	Brown Bear No. 5	1		Th	ND	ND	ND	ND.
81		1		Q	30	.6	N. 55° E.	50° NW.
82	Last Chance	1		Th	3,900	[8]7 –30	[8]N. 65°–80° W.	[8]43°–70° SW.
83	Big Horn	1		Th	ND	.5	ND	ND.
84		1		Cu	ND	.6	ND	ND.
85	Frying Pan and Frying Pan No. 2.[3]	3	West vein	Th	100	3	N. 30° W.	54° SW.
			Central vein	Th	10	.7	N. 55° W.	ND.
			Southeast vein	Th	1,100	.5– .7	N. 36°–73° W.	72°–78° SW.
86	M.S.D. No. 7	1		Th	30	.5+	N. 48° W.	ND.
87	M.S.D. No. 1	1		Th	20	2 – 2.5	N. 30° W.	60° SW.
88	Black Widow Nos. 15 and 16.	1		Th	10	ND	N. 55° W.	ND.
89	G&G Nos. 6 and 8	1		Th	1,300	1 – 2	N. 48° W.	Steep.
90	G&G Nos. 1, 2, and 5	2	North vein	Th	1,600	.8– 2	N. 48° W.	58° SW.
			South vein	Th	55	ND	N. 35° W.	Steep.
91	B&B Nos. 1 and 4	1		Th	20	.5	N. 74° W.	90°.
92	Atomic Blast Nos. 7 and 8.	1		Th	ND	ND	ND	ND.
93	Thorite No. 1	1		Th	300	.9	N. 45° W.	85° NE.
94	Saddlehorn No. 3	1		Th	300	.2– .5	N. 41° W.	ND.
95	H.R.S. No. 1	1		Th	20	.9	N. 70° E.	65° SE.
96	Lucky Day Nos. 1 and 2.	2	West vein	Th	25	.5	N. 45° W.	ND.
			East vein	Th	85	1	N. 38° W.	90°.
97	Dan Patch No. 3	1		Th	ND	ND	ND	ND.

See footnotes at end of table, p. 48.

TABLE 2. — *Dimensions and attitude of the veins in the Lemhi Pass quadrangle* — Continued

Loc. No.	Name of claim or vein, where known	Number of veins	Vein, if more than one	Type of vein[1]	Exposed length (ft)	Thickness (ft)	Strike	Dip
98	Dan Patch	2	North vein	Th	1,050	0.3– 2.5	N. 77° W.	60°–80° SW.
	Nos. 1 and 2.		South vein	Th	95	.2– 1	N. 40° W.	70°–80° SW.
99		1		Th	225	.5– .8	N. 81° W.	ND.
100		1		Th	150	5.7	N. 82° W.	82° SW.
101		1		Th	100	ND	N. 80° E.	ND.
102	Big Thor Nos. 1 and 2	1		Th	125	.3	N. 65° W.	Steep.
103		1		Th	50	ND	N. 36° W.	ND.
104	Silvertip Nos.	2	North vein	Th	25	1.0	N. 50° W.	ND.
	1, 2, and 3.		South vein	Th	50	ND	N. 35° W.	ND.
105	Atomic Blast	2	North vein	Th	15	.1– 1.3	N. 31° W.	20° SE.
			South vein	Th	225	.4	N. 65° E.	ND.
							N. 82° W.	
106	Orpha	1		Th	115	6	N. 55° W.	ND.
107	Reactor Nos.	2	Northeast vein	Th	1,650	.3– 3	N. 42° W.	72° SW.–78° NE.
	1, 3, and 5.		Southwest vein	Th	325	3	N. 64° W.	60° SW.

[1]Th, thorium-bearing veins; Cu, copper-bearing veins that do not contain thorium; Q, barren quartz veins.
[2]Irregular veinlets.
[3]Data from Sharp and Cavender (1962).
[4]Several lenses.
[5]Veinlets.
[6]Data from Schipper (1955).
[7]Several.
[8]Data from Geach (1966).

siltite. At locality 31, the basal conglomerate of the Challis Volcanics is abnormally radioactive, and in places quartz-feldspar veinlets have replaced part of the conglomerate matrix.

The veins in the Lemhi Pass quadrangle can be divided into three principal types, dependent on the presence or absence of thorium and copper. These are (1) veins that contain thorium, with or without other metals, (2) veins that contain copper but do not have any thorium, and (3) quartz veins that do not contain either thorium or copper. Sharp and Cavender (1962, p. 25) presented a somewhat similar classification based on mineral association, but I found that in the different veins thorium occurs in different minerals or in various amounts of several minerals. Hence, I have used the somewhat broader classification based on elemental composition. In addition, Sharp and Cavender (1962, p. 25) listed a fourth type of vein consisting of a copper- and thorium-bearing quartz vein. The copper content in this type of vein is generally very small, and some typical thorium-bearing veins, such as the Last Chance and Shear Zone, may locally contain a small amount of copper. Because the copper-bearing veins that contain thorium are difficult to distinguish from those that do not contain copper, I have classified all the thorium-bearing veins together.

The thorium-bearing veins are more numerous than the other veins. Veins at 87 of the 107 localities are thorium bearing; veins at three localities consist of both thorium-bearing minerals and barren quartz; veins at nine localities are copper-bearing; and veins at eight localities consist of barren quartz. The thorium-bearing veins are also more widely distributed; they were found nearly everywhere in the quadrangle except the northeastern part, which, for the most part, is covered with glacial deposits. Most of the copper-bearing veins and barren quartz veins are confined to the northwest corner of the quadrangle. The only exceptions to this are the thin seams containing copper minerals that occur along the shears beneath the thrust fault at locality 36.

Veinlets (loc. 31) of quartz and feldspar, which occur in a small area southeast of the Bluebird claim in the basal conglomerate of the Challis Volcanics, contain a small amount of thorium, but differ somewhat from the other thorium veins. Although these veinlets contain some thorium, the radioactivity is due principally to uranium (table 5, loc. 31). The greater parts of these veinlets consist of quartz and feldspar, like many of the thorium-bearing veins. A sparse suite of heavy minerals contained goethite, hematite, muscovite, rutile, pyromorphite, biotite, garnet, tourmaline, and staurolite. The first six were found in some of the thorium-

A

FIGURE 10 (above and facing page).—Extent of veins outlined by workings. *A*, Long trench exposes the Last Chance vein (loc. 82) on the south side of North Frying Pan Creek. Adit cuts vein approximately 250 feet below the surface. *B*, Three adits driven on the main vein of the Copper Queen mine (loc. 43) indicate trend of vein.

bearing veins; the last three, however, were not. The differences in mineralogy can possibly be explained as caused by the chemical reaction of the vein fluids with the tuffaceous matrix of the conglomerate.

THORIUM-BEARING VEINS

DIMENSIONS AND ATTITUDES

The thorium-bearing veins are irregular tabular bodies ranging in thickness from paper-thin seams to 30 feet. About half of the veins average more than 1 foot thick, and about one-eighth of the veins are more than 5 feet thick. The thickest vein is the Last Chance (loc. 82), which is from 7 to 30 feet thick (Geach, 1966, p. 12, 15). Locally, several other veins, such as the Wonder (loc. 45), Black Bear (loc. 37), Cago No. 12 (loc. 49), Contact (loc.

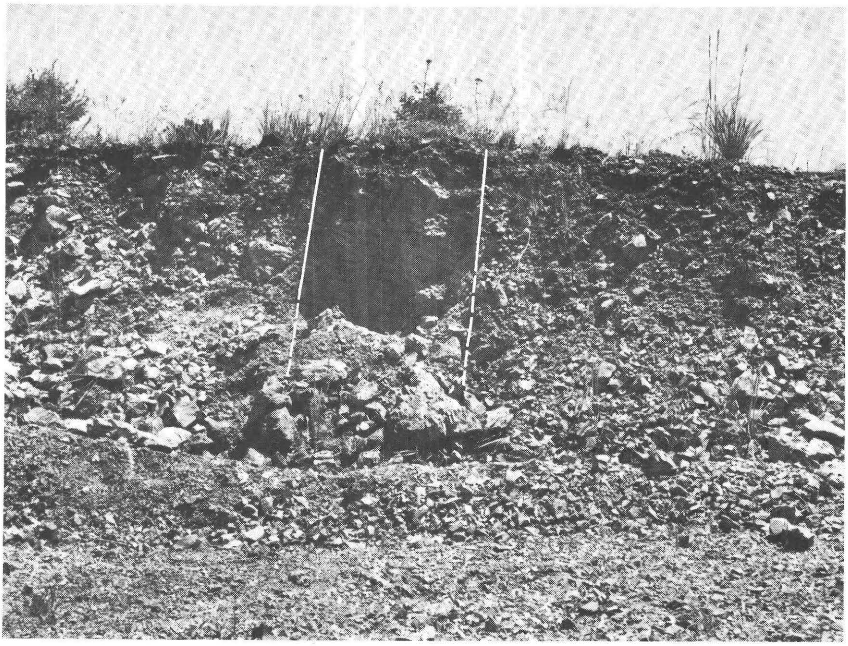
B

52; fig. 11), and Trapper No. 1 (loc. 67), are as much as 10 feet thick. Most veins are extremely variable in thickness. The long N. 77° W. striking vein on the Dan Patch property (loc. 98) is only 4 inches thick in the southeasternmost trench, but in the trench 150 feet to the northwest, it is 2½ feet thick. One of the veins exposed at the Atomic Blast (loc. 105) ranges in thickness from 1 inch to 1.3 feet along the side of one trench. The Contact vein (loc. 52), in a 140-foot-long trench, ranges in thickness from 0.7 to 10 feet. The big Cago No. 12 vein (loc. 49), along 25 feet of underground drift, decreases in thickness from 12 to 6 feet. The large Last Chance vein (loc. 82), although it has no abrupt pinches and swells, ranges in thickness from 7 to 30 feet. A few veins are fairly uniform in thickness. The long N. 42° W.-striking vein on the Reactor property (loc. 107) ranges in thickness from 1.5 to 2.0 feet for at least 975 feet of strike length.

A

FIGURE 11 (facing page and above).—Closeup views of thorium veins. *A*, Gently dipping Contact vein (loc. 52) cuts micaceous quartzite in wall of trench. Vein here is 2.5 feet thick. Sample MHS–16–69 was collected at this locality. *B*, Steeply dipping Little Dandy No. 1 vein (loc. 72) is 2.5 feet thick. Sample MHS–8–69 was collected at this locality.

The veins range in length from a few feet to at least 3,900 feet. (See Last Chance, loc. 82, table 2; fig. 10*A*.) Because of poor exposures, only the minimum lengths of many veins are known. Most of the thinner, less radioactive veins are not as well explored, and many are exposed in only one place. Although the Last Chance is the longest single vein known, the complex Shear Zone vein (loc. 73; Geach, 1966, p. 15, 18) is even longer—it was traced for about 6,000 feet. The Shear Zone vein is not a single vein, but is actually a shear zone along which several closely spaced and branching veins occur. Owing to poor exposures, the exact lengths of the individual veins are only sketchily known, and the entire zone, therefore, is labeled as a single unit in table 2. In addition to the Last Chance (fig. 10*A*) and the Shear Zone, thorium-bearing veins



B

at 10 other localities are known to be more than 1,000 feet long (table 2). These veins are Lucky Horseshoe (loc. 1); Wonder (loc. 45); Cago No. 12 (loc. 49); Contact (loc. 52; fig. 10*A*); Black Rock (loc. 75); Frying Pan (loc. 85); G&G Nos. 6 and 8 (loc. 89); G&G Nos. 1, 2, and 5 (loc. 90); Dan Patch (loc. 98); and Reactor (loc. 107). Eight of the veins greater than 1,000 feet long in the Lemhi Pass quadrangle are in Montana.

Most of the thorium-bearing veins strike N. 40°–50° W. or N. 70°–80° W., although almost every direction except due north is represented (table 2). The predominant strikes were determined by plotting the 87 veins whose strike is known (fig. 12); 37 of them are in one or the other of these principal directions, and 34 more are within 10° of these two directions. The average strike of the 12 veins that are more than 1,000 feet long ranges from N. 42° W. to east-west. Strike on individual veins commonly varies, but these variations are more apparent on the larger veins. The Last Chance vein for most of its length has a strike of N. 65° W., but at its northwestern end it strikes N. 80° W. Five measurements made along the 1,950-foot Contact vein, from east to west, showed the following variations in the strike: (1) N. 70° W., (2) N. 55° W., (3) N. 72° W., (4) east-west, and (5) N. 70° E.

Most of the veins dip steeply to the southwest, although they may dip moderately to steeply either to the north or south (figs. 11, 12). Out of a total of 46 veins in which at least one dip measurement was made, 32 veins dip steeply to the southwest. Individual veins commonly vary in dip. The hanging wall of the Last

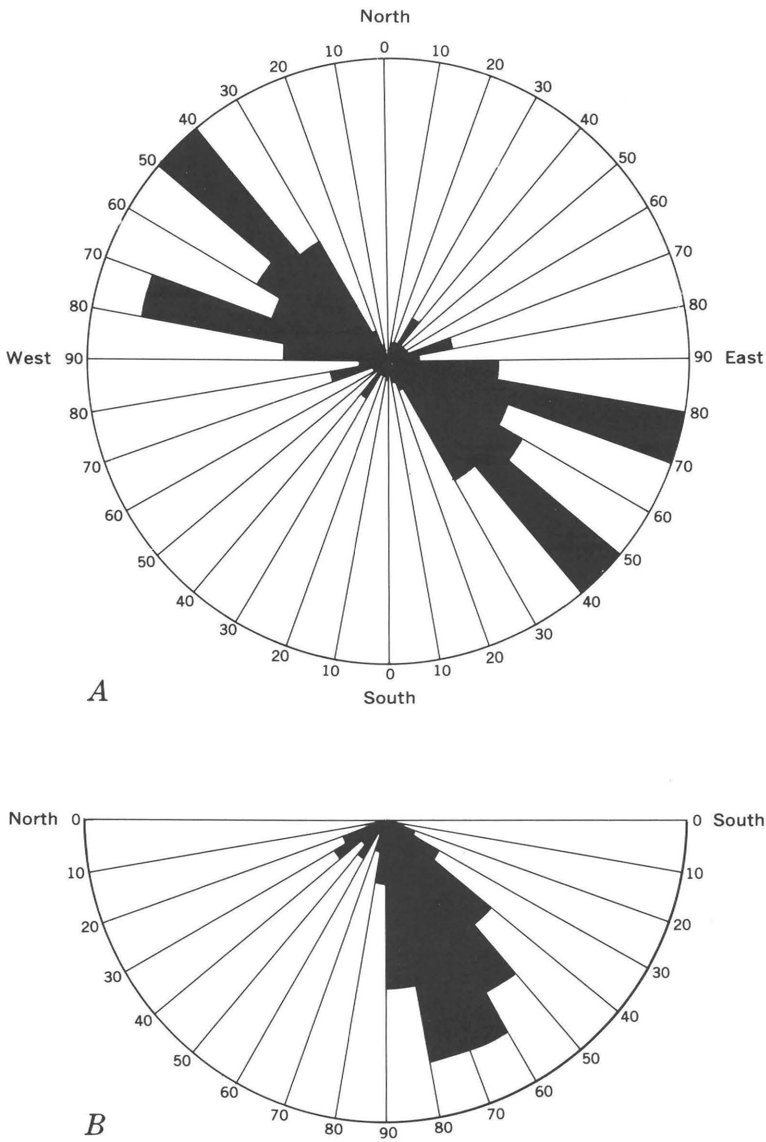


FIGURE 12. — Attitudes of thorium-bearing veins in the Lemhi Pass quadrangle. *A*, Strike diagram on 87 veins. *B*, Dip diagram on 46 veins.

Chance vein (loc. 82), where it is exposed in the adit just northwest of South Frying Pan Creek, varies from 43° to 70° SW. (Geach, 1966, fig. 5). Sharp and Cavender (1962, pl. 5) plotted 11 dips on the main Wonder vein (loc. 45). These vary from 40° to 89° S. and average about 73° S. Several dips taken on the long northeast vein on the Reactor claims (loc. 107) varied from 72° to 85° SW.

RELATION OF VEINS TO STRUCTURAL FEATURES

The thorium-bearing veins occupy small faults, fractures, and shears, as indicated by shear planes with slickensides, which were best exposed in underground workings. Some of the better exposures of fracturing in veins are (1) several shears along and within the Last Chance vein (loc. 82) in the adit just above South Frying Pan Creek; (2) the highly fractured zone that contains many closely spaced shears on the long Shear Zone vein (loc. 73); and (3) slickensided shears along veins on the Cago No. 12 (loc. 49), Wonder (loc. 45), Buffalo (loc. 18), Deer (loc. 21), Black Bull No. 3 (loc. 20), Trapper No. 1 (loc. 67), Black Rock (loc. 75), and Beaverhead (loc. 64) properties.

Fracturing and shearing not only occurred prior to the emplacement of the veins, but also continued after they were deposited. Almost all the veins are sheared and brecciated (fig. 13). Quartz and feldspar are commonly granulated, and most of the fractures are filled with quartz and iron oxides, but in some veins the fracture fillings also contain sericite, manganese oxides, thorite, and calcite.

The fractures occupied by the thorium-bearing veins were evidently formed by the same deformation that produced Tertiary faulting. The thorium-bearing veins are most abundant in the northwest quarter of the Lemhi Pass quadrangle, where the three faults either intersect or approach each other (pl. 1). Seventy percent of the vein localities are in this area. Most of the veins are within 1 mile of the Dan Patch, Bull Moose, or Lemhi Pass faults (pl. 1); veins in only 15 out of 90 localities are at a greater distance. Furthermore, most of the veins at greater distances are small. Of these veins, only the northeast vein on the Reactor property (loc. 107) was traced for more than 325 feet.

The strike of most of the veins is either parallel or at a fairly acute angle to the strike of the long Tertiary faults (pl. 1). The Lucky Horseshoe (loc. 1) is parallel to the Lemhi Pass fault. The principal veins on the Black Rock (loc. 75), Wonder No. 18 (loc. 70), Frying Pan (loc. 85), Bull Moose (loc. 76), G&G Nos. 6 and 8 (loc. 89), G&G Nos. 1, 2, and 5 (loc. 90), Last Chance (loc. 82), and Reactor (loc. 107) are virtually parallel to either

FIGURE 13. — Brecciated Last Chance vein (loc. 82). Part shown is made up of quartz and untwinned microcline. Crossed nicols. Photograph by L. S. Hedricks.

the Dan Patch fault or the Bull Moose fault. They are probably formed on small subsidiary breaks. The veins that were formed in the vicinity of, and at small angles to, the faults apparently are of two types—those formed in tension fractures, and those in tight shears. Tension fractures are formed by shear movement along the big faults and are fairly open fractures; they are most common adjacent to the big faults. Several veins of this type occur adjacent to the Dan Patch fault: the Wonder (loc. 45), the H.R.S. No. 1 (loc. 95), and the Dan Patch Nos. 1 and 2 (loc. 98). Veins formed in tension fractures, though not too common among thorium-bearing veins, are fairly common among copper-bearing veins. Veins occupying tight shears are typified by the Shear Zone vein (loc. 73)—a group of en echelon, branching, and closely spaced veins that occupy a narrow shear zone between South Frying Pan Creek and the Continental Divide (Geach, 1966, p. 15, 18). The rocks along this zone are highly sheared and are stained with iron oxides. The veins in this zone are irregular and commonly lens-like. Actually, the Shear Zone vein (loc. 73) is only the southeast end of a much larger shear zone that can be traced by the veins along it for at least 2.7 miles from South Frying Pan Creek to a ridgetop at the northwest end of the Cago No. 12 (loc. 49). Along

FIGURE 14. — Some of the veins exposed on the north side of North Frying Pan Creek. Two large oval veins cropping out near the center of the mountain represent parts of a single vein that is parallel to the slope of the hill. Other veins on this mountain are out of sight just over its crest, on the crest, and downhill, to the right, below the Beaverhead prospect. All these veins are a part of those occurring in a major shear zone.

this shear are 22 vein localities, representing such well-known veins as the Cago No. 12 (loc. 49), Contact (loc. 52), Trapper No. 1 (loc. 67), and the Beaverhead (loc. 64; fig. 14). This highly sheared, somewhat irregular zone has been a locus of mineralizing solutions, and further exploration may well extend it to the northwest.

MINERALOGY

Many minerals were found in the thorium-bearing veins. Most of them occur in only minor quantities and in only a few veins. In general, the thorium-bearing veins consist mainly of a quartz or quartz and microcline gangue cut by abundant iron oxide veinlets that contain thorite and, less commonly, monazite.

All the veins are similar in that they are generally sheared and brecciated. Older quartz and microcline gangue are generally granulated (fig. 13). Much of the quartz shows wavy strain shadows and is sutured. The earlier gangue minerals are commonly cut by later veinlets (fig. 15*A*).

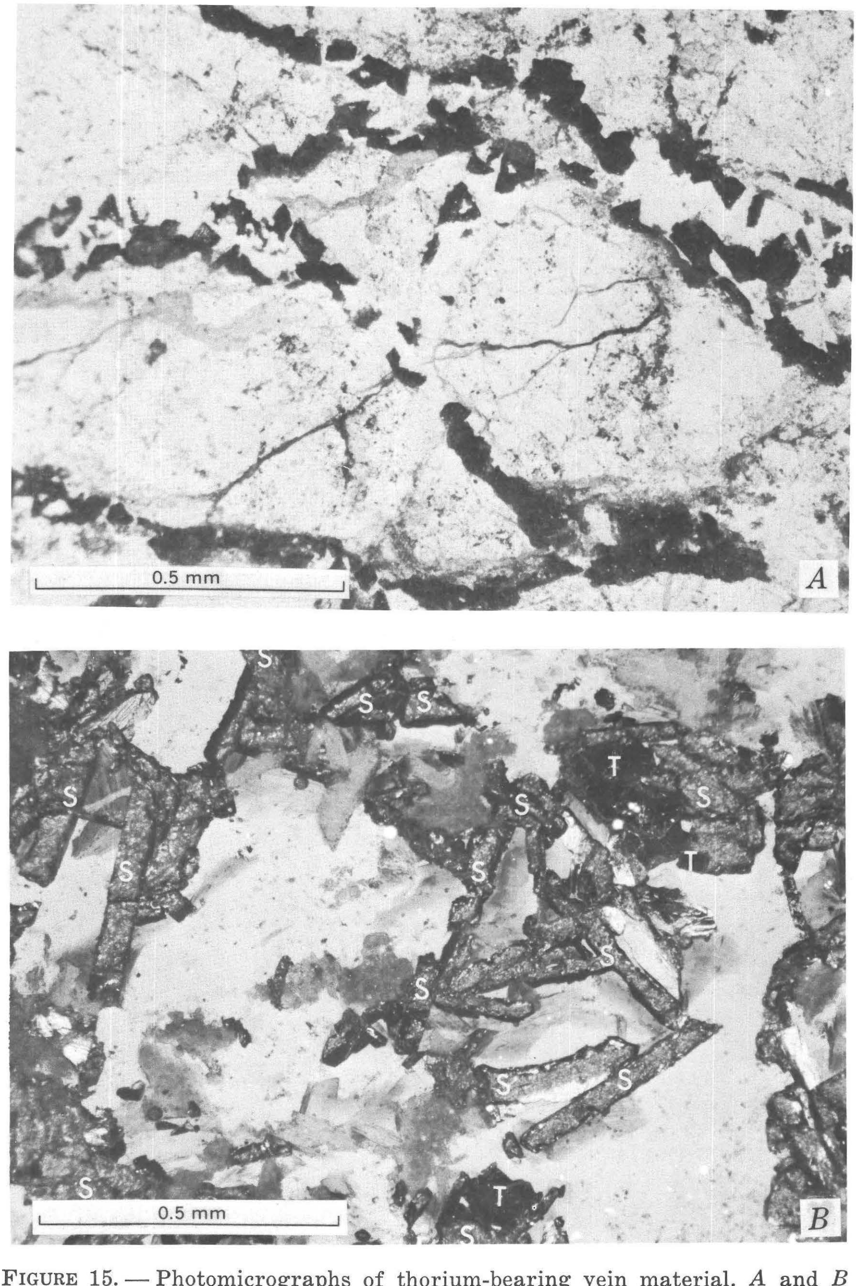
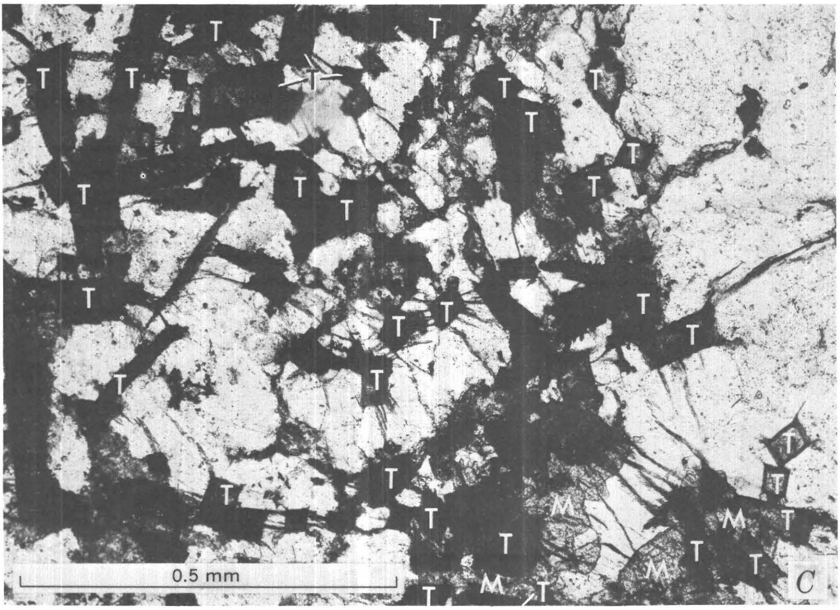
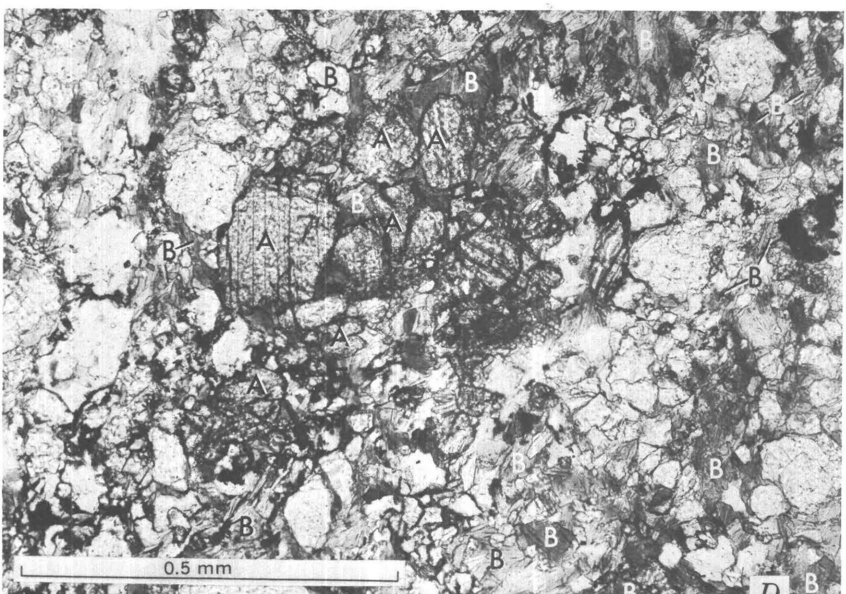


FIGURE 15. — Photomicrographs of thorium-bearing vein material. *A* and *B*
A, Triangular and diamond-shaped thorite crystals (black) fill fractures
transmitted light with the polars set at 85°. *B*, Tabular gray plates of
Thor Nos. 1 and 2 vein (loc. 102). Microcline makes up white and gray
with the polars set at 85°. *C*, Diamond-shaped and lenticular thorite
Late monazite (M) envelopes some of the thorite. Note radiation cracks
allanite crystals (A) nest in a mesh of darker gray stringy biotite
are quartz and microcline.





photographed by R. B. Taylor; *C* and *D* photographed by L. S. Hedricks.
in quartz vein (loc. 41). Picture taken in both dark-field reflected light and
specularite (S) completely or partly surround thorite crystals (T) in the Big
matrix. Picture taken in both dark-field reflected light and transmitted light
crystals (T) set in a matrix of quartz at the Last Chance vein (loc. 82).
in quartz adjacent to both the thorite and the monazite. *D*, Large light gray
crystals (B) in the Lucky Horseshoe vein (loc. 1). Light-colored minerals

The mineral content of most veins is difficult to determine. Iron oxides, especially hematite and goethite, are abundant in most veins. These minerals, plus manganese oxides in some veins, effectively mask other minerals. For example, although microcline is one of the more common vein minerals, it is generally so stained from iron oxides as to be unrecognizable in hand specimen. Many minerals have been so heavily stained by iron oxides that, even viewed through a microscope, they appear yellowish brown or red. Furthermore, some minerals, such as thorite, rutile, apatite, and muscovite, typically occur in grains so small that they are readily discerned only by use of a microscope. Hence, only quartz, the iron oxides, manganese oxide, and (where present) the green secondary copper minerals are readily identifiable in hand specimen.

The following method was used to study and identify minerals from various veins: A 2- to 10-pound chip sample was taken from across a vein and then ground to about —20 mesh. A split was taken and sieved, and the +100-mesh —20-mesh fraction saved. Any oversize material was ground to —20 mesh. A half pint of this sized fraction was washed to remove dust particles that cling to the grains and make identification difficult. The cleaned and sized material was divided into heavy and light fractions by use of methylene iodide in a separatory funnel. The light fraction generally made up more than 90 percent of the sample. The heavy fraction was spread out, and a magnetic fraction was separated from it with a hand magnet. The magnetic fraction was generally very small and consisted of scrap iron from the grinders and a small amount of magnetite. The rest of the heavy fraction was then divided, by use of a Frantz Isodynamic Separator, into four parts on the basis of its magnetic properties. Each of the six fractions of the original sample was examined under a binocular microscope, and the minerals in each fraction were recorded. Any mineral not readily identifiable was picked out of the sample and identified by its X-ray-diffraction pattern and, in a few instances, by spectrographic analysis.

A total of 86 samples from 50 vein localities were examined, and the results are given in table 3. Undoubtedly, this list of minerals is not complete, inasmuch as the minerals in any one vein are generally erratically distributed, and not all veins were sampled. The greatest number of different minerals was found in the Last Chance vein (loc. 82, table 3), which, also, was sampled the most (15 samples). Undoubtedly, additional samples from other veins would add to the list of minerals found in individual veins.

In table 3, 42 different minerals or varieties of minerals are listed. Seven of these minerals are common and were found to

TABLE 3. — *Mineralogy of the thorium-bearing veins in the Lemhi Pass quadrangle*

[Minerals listed in italic type were identified by X-ray diffraction]

Loc. No.	Vein, if more than one	Number of samples examined	Principal gangue minerals	Other gangue minerals	Iron oxide minerals	Thorium-bearing minerals	Other minerals
1		3	*Quartz*, microcline	*Biotite*, muscovite, *barite*, *calcite*, plagioclase, fluorite, apatite.	*Specularite*, goethite, magnetite.	*Allanite*, *monazite*, thorite.	*Rutile*, chalcopyrite.
4		1	Quartz		*Specularite*, *red hematite*, *goethite*, magnetite.	*Thorite*, *monazite*	Galena.
5		1	*Quartz*	Calcite, *apatite*, barite.	*Goethite*, specularite, magnetite.	Thorite	*Rutile*, pyrite.
18	Vein in west trench	1	Quartz, microcline	Calcite	Specularite, magnetite.	do	Pyrite, rutile.
18	Vein in east trench	2	*Quartz*		*Specularite*, goethite, magnetite.	Thorite, *monazite*	*Rutile*, pyrite.
19		1	Microcline	Quartz, barite, muscovite.	Specularite, goethite, magnetite.	Thorite	*Rutile*.
20	Northeast-trending vein	1	Quartz, calcite	Barite, chalcedony	Specularite, magnetite.	do	Pyrite.
21	West vein	1	Quartz	Calcite	do	do	Rutile.
21	East vein	1	*Quartz*	Calcite	Specularite, red hematite, goethite.		*Rutile*, pyrite.
31		1	*Quartz*, microcline	Biotite, *garnet*, *staurolite*, *tourmaline*, *muscovite*, barite.	*Goethite*, red hematite		*Pyromorphite*, rutile, manganese oxide mineral.
35		1	*Quartz*		*Gray hematite*, specularite, *lepidocrocite*, magnetite.		*Rutile*.
37		2	*Microcline*	Quartz, *barite*, chlorite.	*Gray hematite*, specularite, magnetite.	Thorite	*Pyrolusite*, *rutile*, *pyromorphite*, *wulfenite*.
40		1	Quartz, microcline	Barite, plagioclase, *chlorite*, epidote.	Specularite, goethite, magnetite.	do	Rutile, pyrite.

TABLE 3. — *Mineralogy of the thorium-bearing veins in the Lemhi Pass quadrangle* — Continued

Loc. No.	Vein, if more than one	Number of samples examined	Principal gangue minerals	Other gangue minerals	Iron oxide minerals	Thorium-bearing minerals	Other minerals
45		5	*Calcite, quartz, siderite.*	*Microcline, apatite, muscovite, barite.*	Red hematite, specularite, goethite, magnetite.	Thorite	*Sphalerite*, chalcopyrite, *rutile*, manganese oxide mineral, pyrite, malachite, chrysocolla.
47		1	*Quartz, microcline*		Specularite, *goethite*, magnetite.	do	*Rutile*, pyrite.
49		4	*Quartz*, microcline		Specularite, *goethite, red hematite*, magnetite.	Thorite, *allanite* (?) *monazite.*	*Rutile*, pyrite, galena, chalcopyrite.
52		3	*Quartz*, microcline		Specularite, goethite, red hematite, magnetite.	*Monazite*, thorite	Rutile.
54		1	Quartz	Chalcedony	Specularite, goethite	Thorite	Pyrite, chrysocolla, rutile.
55	West vein	1	Quartz, microcline		Specularite, goethite, magnetite.		Rutile, pyrite.
56		1	*Quartz*	Microcline, chalcedony.	do		*Rutile*, pyrite.
57		1	Microcline, quartz		do	Thorite	Rutile.
59		1	*Quartz*	Muscovite	Specularite, goethite	*Brockite*, thorite, *allanite.*	
61		2	*Quartz*, microcline		Goethite, specularite, magnetite.	Thorite, *monazite*	*Jarosite, bastnaesite*, rutile.
63		1	*Quartz*	Microcline	*Goethite*, magnetite	*Monazite*	*Rutile*, manganese oxide mineral, pyrite.
64		1	*Quartz*, microcline	*Barite*	Specularite, red hematite, goethite, magnetite.	Thorite, *monazite*	Pyrite, rutile.
66		1	Microcline, quartz		Goethite, specularite, red hematite, magnetite.		
67		2	*Quartz*	Microcline, muscovite, *barite.*	*Goethite*, specularite, magnetite.	Thorite	*Rutile.*

70	West vein	1	do	Muscovite, *apatite*, barite.	*Specularite*, magnetite.	*Monazite*	Manganese oxide mineral, *rutile*.
70	East vein	1	do		*Specularite*, goethite, magnetite.	Thorite	Manganese oxide mineral, pyrite.
72		1	Microcline	Quartz, muscovite, fluorite.	*Goethite*, *red hematite*, specularite, magnetite.	do	Pyrite.
73		5	*Quartz*, microcline	*Barite*	*Goethite*, *specularite*, magnetite.	*Thorite*, *monazite*, *brockite*.	Manganese oxide mineral, rutile.
75	Northwest-trending vein	1	do	*Apatite*, *barite*	Specularite, goethite, magnetite.	*Thorite*, *brockite*	*Manganese oxide mineral*, *rutile*.
75	Northeast-trending vein	1	Microcline quartz	Calcite, *apatite*	Goethite, specularite, magnetite.	do	Manganese oxide mineral.
82		15	*Quartz*, microcline	*Barite*, *apatite*, calcite, biotite, muscovite.	Specularite, *goethite*, *red hematite*, magnetite.	Thorite, *monazite*, *brockite*.	*Pyrolusite*, *psilomelane*, *jarosite* (?), pyrite, malachite, *rutile*, chrysocolla.
85	Central vein	1	*Quartz*	Microcline, barite	*Goethite*, *specularite*, magnetite.	Thorite, *brockite*.	
85	Southeast vein	1	*Quartz*, chalcedony	Siderite (?) barite, apatite.	*Goethite*, specularite, magnetite.	*Monazite*, thorite	*Rutile*.
86		1	*Quartz*		*Goethite*, *red hematite*, magnetite.	*Brockite*, *monazite*.	
89		2	*Quartz*, microcline	Dolomite (?)	Specularite, *goethite*, magnetite.	Thorite, *brockite*	*Manganese oxide mineral*.
90	North vein	2	Quartz, microcline	Barite, *apatite*	*Goethite*, magnetite	*Brockite*, thorite	Manganese oxide mineral, *rutile*.
93		1	Quartz	Muscovite, *apatite*	*Goethite*, specularite, magnetite.	Thorite	Manganese oxide mineral, pyrite.
94		1	do	*Muscovite*	Goethite, magnetite	*Monazite*, thorite	Manganese oxide mineral, *rutile*.
95		1	*Quartz*	*Muscovite*, barite	*Red hematite*, specularite, magnetite.	Thorite.	
98	North vein	1	*Quartz*, microcline	Barite	*Goethite*, specularite, red hematite, magnetite.	do	Rutile.

TABLE 3. — *Mineralogy of the thorium-bearing veins in the Lemhi Pass quadrangle* — Continued

Loc. No.	Vein, if more than one	Number of samples examined	Principal gangue minerals	Other gangue minerals	Iron oxide minerals	Thorium-bearing minerals	Other minerals
98	South vein	1	Quartz	Microcline	Specularite, *goethite*, magnetite.	Thorite	Rutile.
100		1	Microcline	Quartz	Goethite, specularite, magnetite.	do	*Rutile.*
102		1	Quartz, *microcline*	Biotite	Goethite, specularite, red hematite, magnetite.	Thorite, monazite	Do.
104	North vein	1	*Quartz*, microcline	*Muscovite*, barite	*Goethite*, specularite, red hematite, magnetite.	*Monazite*, thorite	*Pyromorphite.*
105	North vein	1	Quartz, microcline	*Barite, apatite*	Specularite, red hematite, *goethite*, magnetite.		
106		1	Microcline	Quartz, *diopside*	*Goethite*, magnetite	Thorite, *monazite*	Malachite.
107	Northeast vein	2	do	*Quartz*	Specularite, red hematite, goethite, magnetite.	*Thorite.*	

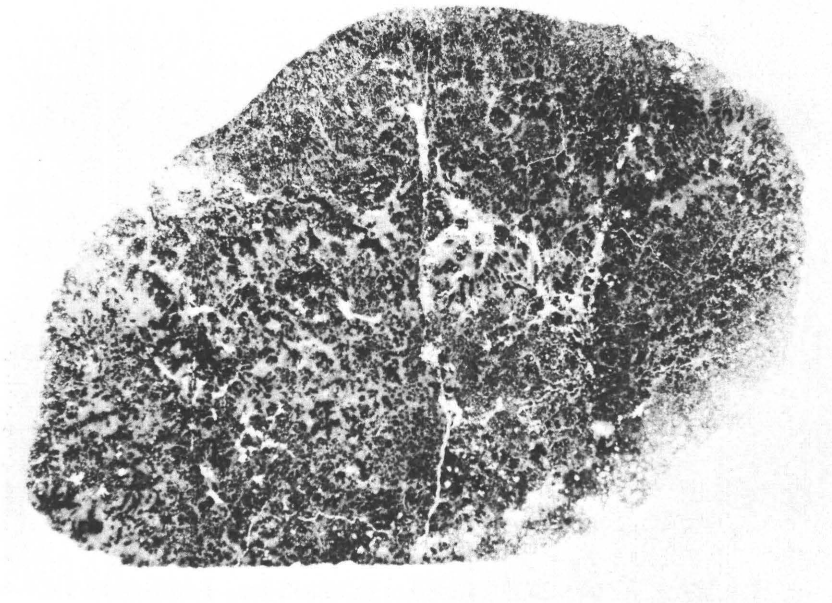
occur in two-thirds or more of the veins sampled. These are quartz, magnetite, specularite, goethite, thorite, microcline, and rutile. Other moderately common minerals are barite, pyrite, black manganese oxide minerals, red earthy hematite, monazite, muscovite, apatite, brockite, and calcite. The other 26 minerals were found in fewer than five of the veins.

The mineral content of the veins is not only large and varied, but not all the thorium occurs in discrete thorium minerals; some of it may be taken up in some manner by the iron oxides. In many samples the amounts of various thorium minerals recovered in heavy liquids are only a part of what the thorium analysis of the bulk sample seems to indicate should be present. The sample used for mineralogic work was the +100-mesh fraction. The thorium content of the fines (−100 mesh) of five splits sifted from the samples used for mineralogic work were measured and compared with the thorium content of the bulk samples (table 4). In each pair of samples the fines contained a significantly greater amount of thorium. This indicates that some of the thorium-bearing mineral breaks up more easily than most of the sample and is, hence, concentrated in the fines. The thorium could be in the iron oxides, which are known to be concentrated in the fines, or it could be in a discrete thorium-bearing mineral or minerals, or it could be in both. To study this matter further, several large uncovered thin sections of radioactive vein material containing abundant limonite were prepared, and autoradiographs were made of them by J. R. Dooley. Autoradiographs, made in 12½ hours, of some of the more radioactive slides showed a number of bright spots which could be correlated with discrete thorium minerals, such as thorite, brockite, and allanite. Autoradiographs, made in 120 hours, of some of the other slides showed two types of spots (fig. 16). One type showed small scattered bright-white spots, which could be correlated with discrete thorium minerals. The other type showed a less bright haze of tiny gray spots through all the limonitic parts. These spots, which are less radioactive than the discrete thorium minerals, are scattered at random within the limonite and indicate that some of the thorium is in the limonite, where it may occur

TABLE 4. — *Thorium content, in percent, of the bulk and —100-mesh samples by gamma-ray spectrometric analysis*

[Analysts, C. M. Bunker and C. A. Bush]

Loc. No.	Name of claim or property	Sample No.	Thorium content	
			Bulk sample	—100-mesh sample
18	Buffalo	MHS–141–68	0.087	0.14
73	Shear Zone	MHS–163–67	.37	.45
82	Last Chance	MHS–151–68	.14	.25
82	do	MHS–155–67	.26	.47
82	do	MHS–157–67	.54	1.05



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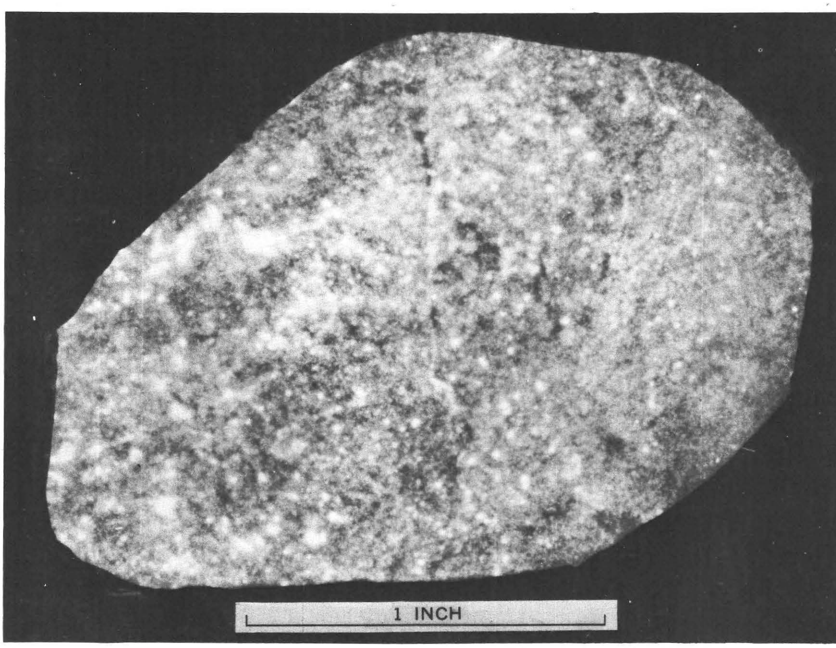

B

in the lattice of this mineral or may be absorbed in the limonite as minute crystals of some thorium mineral.

Some of the more important or more interesting minerals will be discussed further:

Quartz. — Quartz is the commonest vein mineral in the district and the only mineral that was found in all the veins. Generally, quartz is the principal gangue mineral, but in several veins microcline is the more common. Much of the quartz is coarsely crystalline. Some of it is milky white to gray, but some is also commonly stained brown to red by hematite or limonite. Although quartz was among the first minerals to crystallize, it also fills at least two generations of veinlets.

Microcline. — The second most common gangue mineral is microcline, which is light pink to tan and is commonly stained by iron oxides. Microcline is the principal mineral in nine veins, and at six of these veins—localities 19 (Black Bull Fraction No. 4), 37 (Black Bear), 72 (Little Dandy No. 1), 100, 106 (Orpha), and 107 (northeast vein at the Reactor)—it is greatly in excess of quartz. Most of the feldspar occurs in aggregates of small grains that appear in hand specimen to be large single grains. Although this mineral has well-developed cleavage, the cleavage is not readily visible in the fine-grained aggregates. Under the microscope the microcline is dusty looking, and under crossed-nicols has an irregular, patchy appearance. Generally, the mineral is not twinned, but a few grains showed crosshatch twinning typical of microcline. In some samples, identity of the microcline was verified by X-ray diffraction. Microcline commonly occurs with iron oxides, and staining effectively disguises its presence at many outcrops. Five samples (two from loc. 82, the others from locs. 4, 5, and 18) of iron oxide rich vein material were analyzed for potassium content on the multichannel analyzer at the same time that the thorium was measured. All the potassium is assumed to be in microcline, which was the only potassium-bearing mineral detected during microscopic examination of any of these specimens. The microcline content of these five specimens, which was calculated from their potassium content, ranged from 8 to 59 percent.

FIGURE 16 (facing page). — Limonite-rich vein material from the northeast-trending Black Rock vein (loc. 75). *A*, Photograph of vein. Black, dark-gray, and light-gray areas are black, brown, and yellow limonite, respectively. White veinlets are quartz. Photograph by L. S. Hedricks. *B*, Autoradiograph of same specimen. White spots are from the thorium minerals thorite and brockite. Fine gray haze over most of the rest of the specimen represents radiation from a much weaker, widely scattered, very fine grained source within the limonite. Autoradiograph by J. R. Dooley. Exposure time was 120 hours.

Carbonate gangue minerals. — Carbonate minerals are common in the thorium-bearing veins in the Powderhorn district, Colorado (Olson and Wallace, 1956, p. 702), Mountain Pass district, California (Olson and others, 1954, p. 33–34), and the Wet Mountain district, Colorado (Brock and Singewald, 1968, p. 4). Within the Lemhi Pass quadrangle, however, they are comparatively scarce. Calcite was detected in only nine veins, dolomite in one (loc. 89), and siderite in two (locs. 45 and 85). (See table 3.) Furthermore, in only two veins was carbonate at all abundant. These two veins were the northeast-trending vein at locality 20 (Black Bull No. 3) and the vein at locality 45 (Wonder). White calcite made up over half the sample collected on the vein at the Black Bull No. 3. Both siderite and calcite are abundant in some parts of the Wonder vein, where siderite is commonly intergrown with barite, and both are generally sheared. Calcite occurs in some parts of this vein as thin veinlets cutting across the other minerals.

Hematite. — Hematite occurs in three forms in the thorium-bearing veins—specularite, red earthy hematite, and massive gray hematite. These forms commonly occur together. Specularite is the most common of the three types and was found in all but six of the veins sampled (table 3). This form of hematite occurs as thin shiny black tabular crystals (fig. 15*B*). Identification of this mineral is aided by the red internal reflections, which can be seen along a few cracks when viewed through the binocular microscope. Grain size varies considerably from place to place from microscopic to as much as one-fourth of an inch in length (Anderson, 1961b, p. 188). Red earthy hematite generally has an irregular form that in some places may be vuggy. Its typical cherry-red color readily identifies this species as hematite. The gray massive hematite is less abundant than the other two varieties. Positive identification of the gray massive type was made by X-ray diffraction. All three types of hematite occur as fillings of thin veins and as irregular masses. Thorium minerals commonly occur adjacent to, or surrounded by, hematite (fig. 15*B*).

Limonite. — Limonite is another common iron oxide mineral that occurs abundantly in almost every vein (table 3). Limonite varies from a dense, black material, through a shiny-dark-brown or tan granular material to a vuggy ocherous yellow material. More than one variety can occur in the same deposit, and a sample taken at locality 67 (Trapper No. 1) contained both a shiny-dark-brown and a yellowish-tan limonite. Although the color and texture of the limonite suggest that at least several different limonite minerals are present, the identification of 29 specimens, including the two types from locality 67, by X-ray diffraction indicates that all but one was goethite. The limonite in one specimen, which was collected from the northeasternmost-known thorium-bearing vein in the quadrangle (loc. 35), is lepidocrocite. The limonite, like the hematite, occurs either in veinlets that cut across the gangue minerals or as irregular masses. Thorite commonly occurs in limonite.

Magnetite. — Magnetite was found in most vein samples, but generally only in trace amounts. It typically occurs as aggregates of tiny black grains. In a few places, such as at the east vein of the Wonder No. 18 (loc. 70), small black octahedrons were recognized. Small crystals of magnetite are commonly enclosed in specularite crystals.

Manganese oxide minerals. — Some veins, in addition to containing iron oxides, contain one or more earthy manganese oxides. The black manganese minerals generally mask the color of the iron oxide minerals. Some veins that are almost entirely black are the Wonder (loc. 45), the east and west veins on the Wonder No. 18 (loc. 70), and both veins on the Black Rock (loc. 75). The black manganese minerals are extremely fine-grained and are black to steely gray, and some grains have a conchoidal fracture. X-ray-diffraction patterns of the manganese oxide minerals were commonly diffuse, and in many of the patterns, the particular manganese oxide could not be identified. From the three best defined patterns, however, psilomelane was identified in the Last Chance vein (loc. 82), and pyrolusite was identified in both the Last Chance and the Black Bear (loc. 37) veins.

Thorite. — Thorite is the most important thorium mineral economically and was found in samples from most of the veins (table 3). Inasmuch as thorite is fine grained and commonly is thoroughly intermixed with the iron oxides, it is probably present in veins in which no thorium mineral was identified. Thorite forms small shiny-dark-red enameloid-appearing crystals that commonly occur along fractures in the veins (fig. 15*A*, *B*, *C*). Thorite is tetragonal, and its crystals have a diamond-shaped cross section (fig. 15*A*, *C*). The crystals are very small, commonly only 0.04 mm in cross section. In a few veins, fractures radiate out through the matrix from the thorite crystals (fig. 15*C*). In thin section, the thorite crystals are light yellow to deep orange; some are virtually isotropic, and others have appreciable birefringence. Although thorite may be the only mineral in some fractures (fig. 15*A*), in many it is surrounded by iron oxides—especially specularite (fig. 15*B*). Thorite is also commonly associated with monazite, which commonly mantles (fig. 15*C*) and, in places, penetrates the thorite.

The composition of thorite is commonly expressed as $ThSiO_4$, but the Th may be replaced by appreciable amounts of rare earths and the SiO_4 by PO_4. For example, although thorite was the only thorium or rare-earth mineral identified in the seven veins at localities 5, 19, 40, 93, 95, and 98 (two veins), analyses of these samples showed a high rare-earth content (table 5). The thorite is the most likely host for these rare earths. The phosphorus content of thorite grains from three veins was determined by electron-microprobe analysis by G. A. Desborough. No phosphorus was detected in several grains tested from the Lucky Horseshoe (loc. 1). Three of five grains of thorite examined from the Wonder (loc. 45) had no phosphorus, but the other two consisted of about 6-percent phosphorus. Part of the thorite grains examined from the Frying Pan (loc. 85) were luminescent under the electron beam. The luminescent parts contained roughly 10-percent phosphorus, whereas the nonluminescent parts contained about 5 percent. The above rather sketchy results indicate that the phosphate content of the thorite may vary from vein to vein, grain to grain, or even in the same grain. Sharp and Hetland (1968, p. 10) considered the principal thorium mineral to be phosphatian thorite or auerlite. Because only part of the thorite is phosphatian, and because the amounts of it as compared with the amounts of the nonphosphatian type were not determined, I prefer to use the more general term "thorite."

Most of the thorite is partly metamict—that is, the X-ray diffraction pattern of unheated thorite commonly showed broad, poorly defined peaks. The major peaks were present, however, and the mineral could be identified from the pattern. The X-ray pattern of thorite heated to at least 600° for 1 hour had sharp well-delineated peaks and showed many additional minor peaks that did not appear in the pattern of the unheated material. Weak birefringence of many grains also indicates that metamictization is not complete and that the thorite still has some of its original crystal order.

Monazite. — Monazite is the second most important thorium mineral in the veins in the Lemhi Pass quadrangle. This mineral was found in roughly one-third of the veins examined (table 3), and it was identified by Ross and George (1966, p. 26–28) in about four other veins. Where present, it is generally not as abundant as thorite, but in samples collected on veins at localities 1 (Lucky Horseshoe), 52 (Contact), 85 (southeast vein on Frying Pan), 94 (Saddlehorn No. 3), and 104 (north vein on Silvertip), it is much more abundant than thorite. And, in samples from localities 63 and 70 (west vein on Wonder No. 18), monazite was the only thorium mineral noted.

The monazite occurs in small, generally anhedral to subhedral crystals. It is commonly associated with thorite with which it may be intergrown (fig. 15*C*). Monazite occurs with thorite along fractures in earlier quartz at locality 67 (Trapper No. 1; Sharp and Cavender, 1962, p. 33), and at locality 82 (Last Chance). Monazite varies in color, and the following colors were seen in the samples examined: cream, tan, brown, orange, and yellow. Some of this difference in color is due to admixture with iron oxides, and some reflects differences in composition. Such differences in composition are also indicated in the X-ray-diffraction pattern by shifts in position of various peaks and by differences in the relative heights of the peaks. Some of the mineral identified as monazite might be the isostructural mineral cheralite (a phosphate-silicate of thorium, calcium, and rare earths).

Brockite. — Brockite, a calcium-thorium phosphate, was first described by Fisher and Meyrowitz (1962) from the Wet Mountains, Colo. Since then, I have identified it in thorium deposits in the Chico Hills, N. Mex.; in Monroe Canyon, Utah; and in the Lemhi Pass district. It probably is not a rare mineral in thorium veins, but because it is commonly fine grained and is associated with iron oxides, it is difficult to distinguish in hand specimens. It is isostructural with the rare-earth mineral rhabdophane. The X-ray patterns of the two are indistinguishable, but brockite differs from rhabdophane in having a high thorium content. A solid solution probably exists between these two minerals.

Brockite was identified in nine veins (table 3), where it occurs with thorite or monazite, or both. In most veins it is not as abundant as the other two thorium minerals, but at localities 59, 89 (G&G Nos. 6 and 8), and 90 (G&G Nos. 1, 2, and 5), brockite is the principal thorium mineral. Manganese oxide minerals occur in most veins in which brockite is found. Most of the brockite is very fine grained. In most veins this mineral ranges in color from yellowish orange to reddish orange, but in a sample from the Shear Zone (loc. 73), it is tan. Viewed through a binocular microscope, it is commonly indistinguishable from some of the monazite and apatite. All the brockite was identified by its X-ray-diffraction pattern.

Allanite. — Allanite is relatively rare in the Lemhi Pass quadrangle; it was found in samples from only three veins (table 3). Allanite is common only at the Lucky Horseshoe claim (loc. 1), where, though erratically scattered, it is the principal thorium-bearing mineral. At the Lucky Horseshoe, allanite forms subhedral greenish-brown to dark-brown crystals that are generally surrounded by a dark-mahogany-brown mesh of biotite crystals (fig. 15*D*). Some thorite and monazite were also detected in this vein. Allanite occurs as irregular shiny-black crystals in a vein at locality 59. None of the allanite was completely metamict.

Bastnaesite. — The rare-earth fluocarbonate bastnaesite is extremely scarce. It was found only in minor amounts in one of the two samples taken from the vein at locality 61, along the Continental Divide. This mineral occurs as tiny tan grains intergrown with quartz and thorite. In appearance, bastnaesite is a rather nondescript mineral that could be easily mistaken for apatite, monazite, or brockite. However, monazite also occurs in this vein and can be distinguished from the bastnaesite by its reddish-brown appearance.

Bastnaesite most commonly occurs in carbonatites, but it also is found in minor amount in a silicate-rich environment, such as in syenite near Wausau, Wis., and in a pegmatite in the Tendoy Range, just east of the Beaverhead Mountains in Montana. Hence, although bastnaesite may occur in other veins in the Lemhi Pass district, it is very unlikely that this mineral would be abundant in the predominantly siliceous veins.

Barite. — Barite occurs in many thorium veins in the United States, and in addition to those in the Lemhi Pass thorium district, it is common in thorium veins in the Wet Mountains, Colo. (Christman and others, 1959, p. 523), Powderhorn district, Colorado (Olson and Wallace, 1956, p. 702), and Mountain Pass district, California (Olson and others, 1954, p. 52). Barite is referred to in the Lemhi Pass district as "a pertinent diagnostic mineral and an essential part of thorium mineralization" by Anderson (1961b, p. 188), and, indeed, it was not found in either the copper-bearing veins or the barren quartz veins. Barite was observed in only about half the veins in the Lemhi Pass quadrangle (table 3). Within the veins its distribution is erratic—it occurs as massive aggregates in one part of the vein and is absent in another part. Two samples were cut, 18 feet apart, in the adit on the Shear Zone (loc. 73) just north of South Frying Pan Creek. One contained about 40 percent barite; the other had less than 1 percent.

Most of the barite occurs as aggregates of white platy crystals. At the Black Rock (loc. 75), pinkish-white cryptocrystalline barite that, in places, is bordered by clear-green barite was detected by Sharp and Cavender (1962, p. 40), and at the Black Bear (loc. 37) I found clear pink plates of barite. Barite commonly replaces earlier quartz, specularite, and thorite, and it, in turn, is replaced by later quartz, feldspar, and calcite (Anderson, 1961b, p. 189).

At the Last Chance property (loc. 82) an earlier generation of barite and hematite was fractured and then veined by later barite and hematite (Sharp and Cavender, 1962, p. 31).

Apatite. — Although apatite was found in about one-third of the veins examined in detail (table 3), none of the samples contained as much as 1 percent. Apatite generally occurs as microscopic crystals that are either acicular or chunky. Much of it is tan or yellowish orange, due at least in part to staining by goethite, but some crystals are dull white, shiny white, pink, or clear yellow. Apatite commonly occurs in the same vein with the phosphate minerals monazite and brockite in the Lemhi Pass area. Small amounts of apatite are common in thorium veins in other districts, and it occurs in some of the veins in the Powderhorn district, Colorado (Olson and Wallace, 1956, p. 702), the Mountain Pass district, California (Olson and others, 1954, p. 52), the Porthill district, Idaho (Adams and others, 1964, p. 1737), and in the Wet Mountains, Colo. (Staatz and Conklin, 1966, p. B131).

Rutile. — Rutile occurs as tiny grains in 34 of the 50 veins examined (table 3). Although present in many of the veins, it is a relatively rare mineral in most of them. Crystals vary in color from a shiny black, through dark brown, olive green, and orangish yellow to tan. In some veins and, in some instances, in the same sample, two color types of rutile were found. At locality 21 (Deer Fraction 1A), both orange and tan varieties of rutile were recognized, and at locality 47 (Badger No. 10) both shiny-black and tan varieties were identified. The physical properties and probably the chemical compositions of the rutile also change, inasmuch as the various types of rutile were recovered in different magnetic fractions. The rutiles all have a greasy to shiny luster, and most types occur as short stubby crystals, many of which are striated. Anatase, a polymorph of rutile, was reported by Ross and George (1966, p. 26–28) in samples collected by the U.S. Atomic Energy Commission from five of the 12 veins that they studied in the Lemhi Pass quadrangle. I found rutile in all five of these veins, but did not find any anatase in the veins in the quadrangle. Although rutile and anatase are chemically identical, their X-ray-diffraction patterns are markedly different.

Pyrite. — Small quantities of this mineral are fairly common. A few grains of pyrite were found in at least one sample from 18 of the 50 veins examined (table 3). Pyrite occurs in small, brassy, shiny, commonly striated cubes or pyritohedrons. In some veins the pyrite has been completely replaced by goethite that has formed pseudomorphs of pyrite. In one vein (loc. 54), cubes and pyritohedrons of both pyrite and goethite were found.

Lead minerals. — Three lead minerals—galena, pyromorphite, and wulfenite—occur sparsely in several veins. A few tiny gray cubes of galena were found in samples from veins at localities 4 and 49 (Cago No. 12). A small pocket of galena crystals has also been reported from the Last Chance vein (loc. 82) by Austin, Hetland, and Sharp (1970, p. 6). Pyromorphite, a secondary lead mineral, was found at three vein localities — localities 31, 37 (Black Bear), and 104 (Silvertip Nos. 1, 2, and 3). The pyromorphite occurs in irregular crystals of different colors at the different deposits. It is sulfur yellow at locality 31, greenish white at locality 37, and tan at locality 104. In general the kind of minerals associated with the pyromorphite varies from locality to locality (table 3), but barite is common to all. Some of the pyromorphite at the Black Bear (loc. 37) is intergrown with the lead molybdate wulfenite. Wulfenite is very scarce and is found in thin bright-yellow plates.

Zinc minerals. — The zinc mineral sphalerite was found only in the Wonder vein (loc. 45). This mineral is not distributed throughout the entire vein, and I found it in only one of five samples. This sample was collected from a pit where the vein is exposed about 100 feet west of the creek. Sharp and Cavender (1962, p. 46) also noted that they found this mineral west of the creek. Most of the sphalerite is transparent and "grass green" in color. A little of the dark-brown iron-rich variety of marmatite was also reported by Sharp and Cavender (1962, p. 46).

The zinc mineral calamine was reported by Ross and George (1966, p. 26) in a sample from the northwest-trending vein on the Black Rock property (loc. 75). A semiquantitative spectrographic analysis of this sample indicated that it contained from 0.1 to 1 percent zinc (Ross and George, 1966, p. 21).

CHEMICAL COMPOSITION

The range in thoria content of the thorium-bearing veins in the Lemhi Pass quadrangle is fairly well known, because more than 175 analyses have been reported (Trites and Tooker, 1953, p. 194, 195, 198, 201, 205; Sharp and Cavender, 1962, p. 62–67; Austin, 1968, p. 6–12). In addition, I had 77 new thoria analyses (table 5) made on the veins in this quadrangle. The range of thoria content reported in the Lemhi Pass quadrangle is from 0.0020 to 9.4 percent. The high value was determined by a wet chemical analysis (Austin, 1968, p. 6) of an 0.8-foot sample across a vein in the Shear Zone. The thoria content of the Shear Zone is very erratic, but at least half of the samples analyzed contained more than 1 percent.

The analyses published by early workers in this area were done in the following three steps: (1) A radiometric measurement of the total radiation, (2) a chemical analysis for uranium, and (3) a calculation of the thoria content necessary to produce the amount of radiation present after subtracting the amount of radiation caused by the small amount of uranium. Later, some of the analyses were done by both chemical and spectrographic methods. All the thoria analyses done for this report (table 5) were made by a gamma-ray spectrometer by C. M. Bunker and C. A. Bush. The accuracy of this method is ±3 percent.

Some veins are represented by one sample; others by many. Tenor of individual veins commonly varies from place to place along the vein. An example of how great this difference can be was found in the small adit near the southeast end of the Shear Zone, where two channel samples that were cut across the vein 20 feet apart yielded 0.0081- and 2.49-percent thoria (table 5). Generally, the variation is less.

The grade of large parts of some veins is commonly higher than that of other parts, and, hence, the grade can be improved in some veins by selective mining. Four samples of the Last Chance vein (loc. 82) taken in the west adit near the west end of the vein had a thoria content that ranged from 0.26 to 1.45 percent (table 5). Three samples from near the east end of this vein taken in the east adit had a significantly lower thoria content; it ranged from 0.074 to 0.20 percent. Grades on veins cannot be reliably estimated from the results of only a few analyses. The veins with lesser amounts of thoria, in general, attracted the least interest and are, therefore, not as well explored as the richer veins. The average known thoria content of the better explored veins commonly exceeds 0.25 percent. The average thoria content, based on analyses from the present study plus others from published data (Austin, 1968, p. 6–12; Sharp and Cavender, 1962, p. 62–67), exceeds 0.25 percent in at least major parts of the following veins: Lucky Horseshoe (loc. 1), the vein in westernmost trench on the Buffalo property (loc. 18), both the west and east veins on the Deer Fraction 1A (loc. 21), Wonder (loc. 45), Contact (loc. 52), Beaverhead (loc. 64), Trapper No. 1 (loc. 67), the east vein at the Wonder No 18 (loc. 70), Shear Zone (loc. 73), both the northwest-trending and the northeast-trending veins on the Black Rock property (loc. 75), Last Chance (loc. 82), G&G Nos. 6 and 8 (loc. 89), both the north and the south veins at the Dan Patch Nos. 1 and 2 (loc. 98), and the northeast vein on the Reactor property (loc. 107). Some of the other veins may have an equally high thoria content, inasmuch as only those veins for which at least three thoria analyses were available were considered.

Rare-earth analyses are difficult to make, and not nearly so many samples were analyzed for rare earths as for thorium. For this study, analyses were made for the 14 lanthanides and for yttrium in 31 samples (table 5). A chemical concentrate that contained all the rare earths and thorium, plus minor amounts of calcium, barium, and titanium, was first prepared by V. E. Shaw. The various elements in this concentrate were then determined by X-ray fluorescence by J. S. Wahlberg.

The total rare-earth oxide content of these 31 samples varies from 0.073 to 2.20 percent, and the average is 0.428 percent. The rare-earth content is about equal to the thorium content in the veins of this area. The ratio of total rare-earth oxides to thoria ranges from 0.049 to 5.24 (table 5). Data are the most abundant for the Last Chance vein, from which nine samples were analyzed for rare earths. For this vein, the ratio between the rare-earth oxides and thoria varies from 0.55 to 2.04.

The rare earths can be divided into 14 lanthanides and yttrium. All rare earths have similar atomic radii; hence, they can easily substitute for one another, and they are always found together. Some rare earths are much more abundant than others, and the abundance of the various rare earths in most minerals is proportional to their crustal abundance. In general, the average crustal abundance of the lanthanides having even atomic numbers decreases with an increase in atomic number. A similar decrease in abundance also occurs in lanthanides of odd atomic number (Adams, 1969). This distribution pattern of the lanthanide content occurs in many rare-earth-bearing minerals, but may be markedly different in a few, owing to the partial separating out (fractionation) of the rare earths. Thus, in most rocks in which the rare-earth minerals are not fractionated, cerium is the most common lanthanide with an even atomic number, and lanthanum is the most common lanthanide with an odd atomic number. In many veins of the Lemhi Pass quadrangle, however, the rare-earth elements were so fractionated that the proportions among them vary in different veins. Consequently, in different samples, one of the five elements—cerium, neodymium, gadolinium, dysprosium, or samarium—was the most abundant lanthanide of even atomic number, and either lanthanum or europium was the most abundant lanthanide of odd atomic number. Neodymium was, by far, the most common lanthanide with an even atomic number in our samples from the thorium veins. The excess of neodymium over cerium in many of our samples may not be due to its enrichment in various minerals, but rather to a depletion of cerium. In some environments cerium can be oxidized from Ce^{+3} to a Ce^{+4} (Adams, 1969, p. C42), and may then be largely excluded from minerals containing the other rare earths. In two of the vein samples, dysprosium was the predominant even-numbered lanthanide. The predominance of this element may be due to the occult presence of a mineral, such as xenotime or cenosite, or to some multiple-oxide minerals of rare earths, such as titanium or niobium. The lanthanides in these rather rare minerals are commonly fractionated in such a way that the heavier ones are dominant. The three samples with high gadolinium content also contained moderate amounts of brockite, and the highs may reflect the rare-earth distribution in this mineral.

Generally lanthanum is the most abundant lanthanide of odd atomic number in the thorium veins, but europium was the commonest odd-number lanthanide in about one-third of the samples. Furthermore, another 40 percent of the samples showed europium enrichment, as compared to its neighboring odd-number elements. This enrichment of europium occurred in over 70 percent of the samples and, hence, is an extremely common feature of the thorium-bearing veins. As thorite is the most common rare-earth-bearing mineral, and was recognized in most of the mineral separates, it was also the most likely host for the europium-enriched rare-earth assemblage in these samples.

In addition to thorium and rare earths, several other potentially valuable metals are known to occur in veins in the area. Gold has been an important by-product in the Copper Queen mine. Very little gold was found, however, in the 27 samples that I collected from the thorium-bearing veins (table 5). The most gold (0.020 ounce per ton) was found in sample MHS–60–69 from the Wonder property, and 14 of the samples yielded 0.0006 ounce of gold per ton, or less.

Silver in amounts of as much as 2 ounces per ton was reported by Sharp and Hetland (1968, p. 10) in "the Wonder Lode–Black Rock vein." Although the veins on these two properties are not connected, a vein on each property is high in silver. The two samples (MHS–19–69 and MHS–60–69, table 5) that I had analyzed for silver from the Wonder property had 0.99 and 0.52 ounce per ton, and the one sample (MHS–63–68) from the Black Rock yielded 0.23 ounce per ton. Significant amounts of silver were found in a sample collected from the vein in the east trench of the Buffalo property and in one of three samples from the Last Chance property. These two silver-rich samples contained 0.38 and 0.20 ounce of silver per ton, respectively.

Copper, lead, zinc, and molybdenum minerals were detected in several of the thorium-bearing veins. Copper is the most widespread, but is of only local importance within any one vein. Copper is the most common in the Wonder vein (loc. 45), and at one time small amounts of copper-bearing ore were shipped to the Copper Queen mill (Sharp and Cavender, 1962, p. 44). The two samples from the Wonder claim (table 5, loc. 45) that were analyzed for copper yielded 0.42 and 0.44 percent; the sample (MHS–63–68) from the Black Rock had 0.15 percent copper; and none of the other seven samples analyzed for copper (table 5) exceeded 0.10 percent.

Lead minerals were noted in five veins (localities 4, 31, 37, 49, and 104). Ten samples were analyzed for lead (table 5), including two that came from veins containing visible lead minerals. The lead content in the 10 samples ranged from 0.0064 to 0.23 percent. Highest value came from locality 104, where pyromorphite was identified in the vein. Mineralization of lead does not appear to be related to that of zinc, copper, or silver, inasmuch as the higher lead values are not found in the veins with the higher values of these other three elements.

High zinc values have been reported in both the Wonder and the Black Rock veins (Ross and George, 1966, p. 21). A sample (MHS–19–69) from the Wonder vein, west of a small creek, in which sphalerite was identified, contained 3.70 percent zinc; a sample (MHS–60–69) from the vein on the east side of the creek yielded 0.40 percent zinc. A sample (MHS–63–68) from the northwest-trending vein at the Black Rock contained 1.10 percent zinc. Analyses of samples from the G&G Nos. 6 and 8 and Black Bear claims contained 0.10 and 0.08 percent zinc, respectively. Zinc minerals were identified from the heavy-mineral separates in only one sample (MHS–19–68) from the Wonder claim. In all the others it is occult, being probably effectively disguised by the abundant iron oxides. Hence, occult zinc minerals may occur in several other veins.

The only molybdenum mineral detected (table 3) is wulfenite, and it was found sparingly in a sample from the Black Bear vein (loc. 37). The molybdenum content of this sample (MHS–133–68) was 0.024 percent.

COPPER-BEARING VEINS THAT DO NOT CONTAIN THORIUM

DIMENSIONS AND ATTITUDES

Irregular copper-bearing veins or shear zones were detected at nine localities in the Lemhi Pass quadrangle. The copper minerals at two of these localities (locs. 8 and 36) are in seams that coat fractures in a shear zone; at the other localities the copper minerals occur in quartz veins that range in thickness from half an inch to 9 feet (table 2). At localities 8 and 36, the shear zones that contain copper average 4 inches and 1 foot thick, respectively. The best known vein, the north vein on the Copper Queen property (loc. 43), ranges in thickness from a few inches to 9 feet and has an average thickness of about 3½ feet (Schipper, 1955, p. 27).

The known length of the copper-bearing veins varies from less than 8 feet to 1,300 feet. A small copper-bearing vein at locality 84 is completely within a pit and is not more than 8 feet long. Workings along the north vein on the Copper Queen property (loc. 43; fig. 10*B*) help delineate the longest vein of this type. Other long copper-bearing veins are the Idaho Pride Group (loc. 28), the south vein on the Copper Queen property (loc. 43), the Bluebird (loc. 30), and the Rufus (loc. 25). These veins were traced for 350, 500, 450, and 850 feet, respectively.

The shear zones that contain the copper minerals strike N. 3° W. and N. 30° W. The strike of the copper-bearing quartz veins, on the other hand, ranges from N. 55° W., through east-west, to N. 40° E. (table 2). Unlike the thorium-bearing veins, more than half the copper-bearing veins (six of the nine measured) have a northeast strike. The northeast-striking copper-bearing veins are, by far, the most economically important, as this group includes the five largest ones. Individual copper-bearing veins also vary somewhat in strike, and the north vein on the Copper Queen (loc. 43) is reported to range from N. 40° E. to N. 70° E. (Sharp and Cavender, 1962, p. 51).

The copper-bearing quartz veins have a moderate to steep dip; a few are vertical, and the rest dip either to the north or to the south. The north vein on the Copper Queen property follows a curved fault, and above the 150-foot level this vein dips 40°–70° NW., but below this level the dip direction reverses, and on the 250-foot level the vein dips steeply to the southeast (Schipper, 1955, p. 27).

RELATION OF VEINS TO STRUCTURAL FEATURES

The copper-bearing veins, like the thorium-bearing veins, occur along shears, fractures, and small faults. Shearing can be seen along both veins on the Copper Queen property (loc. 43; table 2), and the south vein formed, at least in part, by replacing a fault breccia (Schipper, 1955, p. 29). Most veins on the Idaho Pride (loc. 28) follow shear planes (Sharp and Cavender, 1962, p. 53). Movement on these fractures continued after the emplacement of these veins, and the veins are commonly brecciated. Many of the fractures in granulated quartz are filled with younger quartz and hematite.

The fractures that contain the copper-bearing quartz veins are related to the big Tertiary faults. All 10 of these veins are within 1 mile of one of the big faults, and seven lie within one-fourth of a mile of them. Nine of these veins also occur in the northwest quarter of the Lemhi Pass quadrangle, where the three long Tertiary faults either intersect or approach each other. The strike of the copper-bearing quartz veins is at an acute angle to that of the neighboring large faults (pl. 1). The fractures that these veins fill are probably caused by tension. Some of these veins that are fairly thick and that lie immediately adjacent to one of the big faults—such as the two veins on the Copper Queen property (loc. 43) and the one on the Rufus claim (loc. 25)—resemble gash veins.

The strikes of the two shear zones with copper minerals along them (locs. 8 and 36) are different from those of the copper-bearing quartz veins and from each other (table 2). One shear zone (loc. 36) underlies a thrust and strikes N. 3° W. The other shear zone (loc. 8) strikes N. 30° W. and does not appear to be related to any other nearby fracturing.

MINERALOGY

The mineralogy of the copper-bearing veins is somewhat simpler than that of the thorium-bearing veins and consists principally of primary and secondary copper minerals set in a gangue of white quartz. Specularite and limonite are commonly found in at least some parts of these veins but is not nearly so common as in the thorium-bearing veins.

Chrysocolla and malachite are the copper minerals generally observed in surface exposures and shallow cuts. Copper sulfides are commonly exposed in the deeper workings. Bornite was detected in both veins on the Copper Queen (loc. 43) and the No Pay (loc. 8) (Sharp and Cavender, 1962, p. 52, 54). Chalcopyrite is present in both veins in the Copper Queen (loc. 43), Idaho Pride Group (loc. 28; Sharp and Cavender, 1962, p. 52, 53), and in the south vein at locality 17. The two veins on the Copper Queen have, by far, the greatest concentration of copper minerals, and their mineralogy is best known. The principal ore mineral on the Copper Queen property is bornite. Other copper minerals are chalcopyrite, chalcocite, cubanite, covellite, cuprite, chrysocolla, malachite, and azurite (Sharp and Cavender, 1962, p. 52; Schipper, 1955, p. 31). Other minerals include gold, molybdenite, pyrite, hematite, and limonite. Quartz is the principal gangue mineral, and calcite is present in some parts of these veins. Gold was an important by-product of this mine, and Sharp and Cavender (1962, p. 52) stated that it is closely associated with the bornite. Molybdenite is scarce and was found only in a thin quartz stringer on the dump of the shaft.

The other veins are not nearly so well known, and fewer minerals have been formed. Several minerals not found at the Copper Queen, however, were noted in other veins. Chalcedony was identified in the southeast vein on the Bluebird (loc. 30) and at the Idaho Pride Group (loc. 28; pl. 1), and barite was found in the southeast vein on the Bluebird.

CHEMICAL COMPOSITION

Because the emphasis of the present study was on thorium-bearing veins and because no new copper-bearing veins have been discovered for many years, I did not sample any of the latter. Several generalities on the composition of these veins can be given, however, on the basis of the visible mineral content and of past analyses. The veins may be roughly divided into (1) shear zones or veinlets with a fairly high copper content but having a very limited thickness (<1 in.); (2) moderate to thick (0.5–7 ft) quartz veins with a generally low overall copper content; and (3) moderate to thick quartz veins, which at least in places, have a high copper content. In the first category are veins at localities 8, 17, and 36. Veins at localities 25, 28, 44, and 84 are of type 2, and the present exposures are visually estimated to contain less than 0.2 percent copper. Veins at the Bluebird (loc. 30) and Copper Queen (loc. 43) belong to type 3 and are the only two known producers in the quadrangle. These veins have an erratic metal content, and mining has been carried out on the richest areas. One shipment of 8 tons of ore was reported (Sharp and Cavender, 1962, p. 52) from the Bluebird. It contained 9 percent copper, 0.45 ounce of gold per ton, and 8.5 ounces of silver per ton. Grade on three shipments of ore from the Copper Queen has also been published (Sharp and Cavender, 1962, p. 51). These are (1) two carloads of ore in 1908 yielded 45 percent copper, 1 ounce of gold per ton, and 8 ounces of silver per ton; (2) 448 tons of ore in 1911 had 29.4 percent copper, 0.81 ounce of gold per ton, and 5.2 ounces of silver per ton; and (3) 18 carloads of ore in 1912 contained 28.3 percent copper, 1.24 ounces of gold per ton, and 6 ounces of silver per ton. In addition, Schipper (1955, p. 30) reported that three channel samples of two branches of the south vein cut in 1954 yielded 19 percent copper, 0.25 ounce of gold per ton, and 7 ounces of silver per ton.

BARREN QUARTZ VEINS

Quartz veins that contain neither thorium nor copper form irregular tabular to lens-shaped bodies that range in thickness from 0.6 to 25 feet (table 2).

These veins are much shorter than the two other types, and their known lengths are from 6 to 310 feet. The average length of these 11 barren quartz veins is 76 feet.

The quartz veins strike from N. 40° W., through east-west, to N. 55° E. Most of them have a northwesterly strike, and, although they are few, the frequency distribution of their strikes appears to be similar to that of the thorium-bearing veins (fig. 12). The barren quartz veins dip steeply either to the north or to the south.

The quartz veins, like the other two types of veins, occur along small faults, shears, and fractures. Movement along at least some of the fractures continued after the veins were emplaced. The Blue Boar and Blue Ridge veins (locs. 32 and 48) are brecciated and, in places, are made up of fragments of quartzite and vein quartz cemented by dark-gray coarsely crystalline quartz (Sharp and Cavender, 1962, p. 56).

The fractures that contain the barren quartz veins were formed, like the other vein types, at the same time as the big faults of Tertiary age. All 11 of the mapped quartz veins (pl. 1) have a distribution that is similar to that of the copper-bearing quartz veins, which, except for the lack of copper minerals, they closely resemble.

The direction of strike of most of these veins forms an acute angle with the direction of strike of the nearby faults (pl. 1). Such nearly parallel veins—especially those occurring adjacent to the major faults—as at localities 26, 27, 32, 33, 70, and 71, occupy fractures formed by tension. Some of the veins, which strike in other directions, may occupy fractures formed by shear.

The mineralogy of the quartz veins is rather simple and is primarily quartz and minor amounts of limonite and hematite. In one vein (loc. 27) a small amount of chlorite was found, and in two veins (locs. 32 and 48), Sharp and Cavender (1962, p. 56) reported chalcedony, montmorillonite, rutile, and pyrite. Most of the quartz is white and opaque, and in places two generations are present. At locality 34, white quartz is banded with gray quartz.

Mineralogic and radiometric examinations of these quartz veins indicated that the veins lack any recognizable minerals that contain valuable metals. Inasmuch as gold may occur as finely dispersed grains that are not easily detected, chip samples were taken of three veins (table 4) and were assayed. These samples contained 0.0017, less than 0.0015, and 0.0017 ounce of gold per ton, respectively. These veins are (1) the rutile-bearing quartz vein at locality 32 (Blue Boar), the thickest quartz vein in the area, (2) the 25-foot banded vein exposed at locality 34, and (3) the quartz vein streaked with hematite and limonite at locality 46 (Wonder No. 3).

AGE AND ORIGIN

All the veins in the Lemhi Pass quadrangle are believed to be post-Challis Volcanics, postdiorite, and preglacial. The veins were emplaced during two periods; the copper-bearing veins were emplaced first.

The veins in the Lemhi Pass quadrangle, with one known exception, lie along shears and fractures in the rocks of the Belt Supergroup. The post-Challis date for these veins is suggested by two lines of evidence: (1) The shears and fractures are associated with the three large faults of Tertiary age that cut the Challis Volcanics. Most of the veins are in the northwest corner of the quadrangle, where the three faults converge, and most of the veins are within 1 mile of one of the faults. (2) Thorium mineralization occurs in pits at two localities that are apparently along the Lemhi Pass fault. The thorium-bearing veins of the Lemhi Pass area are also younger than the diorite dikes. Sharp and Hetland (1968, p. 7) noted that the dikes have been locally mineralized by thorium-bearing veins, and Schipper (1955, p. 21) reported that four dikes in the workings of the Copper Queen mine are mineralized by the copper veins.

Not all the veins appear to have formed at the same time. Two ages of veins can be demonstrated in the lowest adit on the north vein of the Copper Queen mine. There, about 350 feet from the portal, Schipper (1955, p. 30, pl. 13) described a copper-bearing vein that has been offset a few feet by a small fault along which a thin thorite-bearing vein has been emplaced.

The mineralized veins are overlain by glacial deposits and are therefore older.

Data are few on the source of the mineralizing fluids in the Lemhi Pass quadrangle. Thorite-hematite quartz veins, however, are not unique to the Lemhi Pass area, and a comparison with other deposits furnishes tangible clues. Veins in parts of the Wet Mountains, Colo.; in the Powderhorn district, Colorado; and in the Wausau district, Wisconsin, are indistinguishable from those at Lemhi Pass. In other areas, such as at Mountain Pass, Calif., carbonate gangues are more common than quartz gangues. One or more alkalic stocks are commonly associated with areas that contain thorium veins. Alkalic stocks are present in the Wet Mountains, Powderhorn district, Mountain Pass, and Wausau district.

Commonly, small irregular carbonatite bodies or dikes are associated with these alkalic bodies. One small carbonatite dike has been found to date in the Lemhi Pass district. This dike occurs near the thorium-bearing vein at locality 77 on the Continental Divide. The carbonatite consists principally of gray calcite with rosettes of iron-oxide-stained apatite crystals and clots of green chlorite and dark-gray magnetite. In addition minor amounts of shiny-black specularite, brown granular goethite, chalcopyrite, malachite, and monazite were identified. The carbonatite dike is adjacent to a 6-foot-diameter outcrop of breccia which may possibly offer a clue to a buried alkalic body. This breccia, which is apparently a small pipe, has large subrounded fragments of individual black hornblende crystals that are 1–5 inches across and smaller fragments of diorite set in a greenish-gray matrix of calcite that contains scattered crystals of magnetite and minor amounts of chlorite, quartz, biotite, plagioclase, and tremolite. A partial spectrographic analysis of the matrix of this rock is given in table 6. This analysis was made for 30 elements but these did not include the elements silicon, aluminum, sodium, and potassium. The high barium, strontium, and lanthanum contents of this sample suggest that at least part of this rock has alkaline affinities.

TABLE 6.—*Partial semiquantitative spectroscopic analysis of the matrix of breccia pipe*

[Looked for but not detected: Ag, As, Au, B, Be, Bi, Cd, Mo, Sb, Sn, W, Zn. >, greater than. Analyst: K. C. Watts]

Element	*Percent*
Fe	10
Ca	10
Mg	5
Ti	.5
Mn	.2
	Parts per million
Ba	>5,000
Co	50
Cr	200
Cu	30
La	150
Nb	50
Ni	100
Pb	10
Sc	15
Sr	3,000
V	100
Y	30
Zr	100

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