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GEOLOGY AND ORE DEPOSITS OF THE LIBBY QUADRANGLE, MONTANA

BY
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WITH SECTIONS ON GLACIATION BY W. C. ALDEN
AND PHYSIOGRAPHY BY J. T. PARDEE

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GEOLOGY AND ORE DEPOSITS OF THE LIBBY QUADRANGLE, MONTANA

By Russell Gibson

ABSTRACT

The Libby quadrangle, about 800 square miles in area, lies in northwestern Montana and includes parts of the rugged Cabinet, Purcell, and Bitterroot Mountains. Most of the area is underlain by pre-Cambrian sedimentary rocks of the Belt Series, which in this district are 40,000 feet thick. The Belt rocks here are chiefly sandstone or quartzite, shale or slate, and calcareous and magnesian argillite. They are divided into the Prichard, Ravalli, Wallace, Striped Peak, and Libby formations. The Prichard, Wallace, and Striped Peak are correlated with the formations of the same name in the Coeur d'Alene district; the Ravalli is correlated with the Burke formation, Revett quartzite, and St. Regis formation of that district. In the southwest corner of the quadrangle is a very small area of the Cambrian limestone and shale.

Intrusive igneous rocks occupy 3 or 4 percent of the quadrangle. The oldest, described as metadiorite sills, are correlated with the mafic intrusives called the Moyie sills and Purcell sills, which are regarded as probably pre-Cambrian and occur extensively in the neighboring parts of Idaho and in British Columbia. Of probable Mesozoic age are a number of dikes and stocks of quartz monzonite and other granitic rocks, including a small body of very coarse-grained syenite. The largest of these, the Dry Creek stock of quartz monzonite, has an area of 20 square miles. Certain of the metadiorite dikes are of more than ordinary interest because silver-lead veins are associated with them.

A moderate degree of regional metamorphism is shown in the Belt rocks, generally by development of sericite and recrystallization of quartz grains. Contact metamorphism, indicated by development of diopside, chlorite, and amphibole in the vicinity of intrusive bodies, is widespread but not generally conspicuous.

In Mesozoic or early Tertiary time mountain-building movements bent the Belt sediments and their enclosed sills into broad open folds and displaced them along extensive fractures, the general trend of both the folds and fractures being northward. The region was elevated and invaded in depth by granitic magmas, offshoots from which formed the dikes and stocks.

During the Tertiary the region was lowered by erosion, and a surface of moderate relief was developed across the deformed rocks. In the late Tertiary or early Quaternary the region was generally reelevated, but not everywhere to the same extent. In places the surface was deformed by faulting or other structural movements. The low areas called Libby Valley and Lake Creek Valley were formed chiefly by movements along faults, which caused them to be relatively depressed and the intervening block relatively elevated. The Kootenai River, having become entrenched across the earlier rock structures, was able to hold its course in the rising area by downcutting. The cascades west of Libby, known as Kootenai Falls, are interpreted to be the result of recent continued upward movement of the mountain block.

In the Quaternary period large tongues of the southward-moving Cordilleran ice, augmented by tributary glaciers heading in cirques in the Cabinet Mountains, extended up the valleys of Libby Creek and Lake Creek. During the latest advance of the ice much till or boulder clay was deposited in places, and glacial lakes, the largest of which was Lake Missoula, occupied the lowlands when the ice receded. Silts that accumulated in a lake to a thickness of as much as 300 feet are exposed in bluffs east of Libby.

After the Mesozoic or early Tertiary igneous activity, metal-bearing lodes were formed along or near certain persistent steeply dipping faults. In the northern part of the quadrangle the lodes are enclosed both in the Belt sedimentary rocks and in the metadiorite dikes and are valuable for silver, lead, and zinc. To date they have yielded by far the greater part of a reported production of about $4,500,000. Their more abundant metallic minerals are galena, pyrite, and sphalerite, and their gangue is quartz and calcite. Ore bodies of a somewhat unusual type occurring in the Snowstorm dike contain, in addition, much pyrrhotite and a gangue predominantly composed of amphibole, garnet, and other silicates. Such bodies, in the Snowstorm mine, have so far been the most productive mineral deposits in the quadrangle. Although most of the crude ore as mined is of comparatively low grade, the concentrate produced at differerent mines contains 47 to 60 percent of lead and noteworthy quantities of gold and silver. A concentrate from one mine contains 50 percent of zinc but is low in silver and lead.

Gold-bearing veins, which have been moderately productive, are clustered in a relatively small area about 20 miles south of Libby. Most but not all of them are in the Prichard formation and, though closely associated with faults and other factures, have been formed chiecfly along bedding planes. The ore consists mainly of quartz, which is generally accompanied by relatively small quantities of one or more of the sulfides pyrite, galena, sphalerite, and pyrrhotite. In specimens from several of the mines, particles of gold can be seen with the unaided eye or under an ordinary hand lens. Ore milled and ore selected for shipment at some of the mines has yielded a third of an ounce to nearly 4 ounces of gold and an ounce or two of silver to the ton. Assay values of selected samples and specimens from several mines show a wide range, and information as to the average tenor of any considerable part of the veins is lacking.

A large number of mines and prospects, including a few just outside the borders of the quadrangle, are described individually.

INTRODUCTION

PURPOSE OF THE INVESTIGATION

Gold placers and lode mines have been worked in the vicinity of Libby and Troy, Mont., for about 50 years, and the total production of the area in gold, silver, lead, zinc, and copper is reported to be about $4,500,000. Little was known geologically about the deposits before the present investigation was begun, and not much had been published concerning the geology of northwestern Montana, but the available information indicated that there was enough hope of still further production from the metalliferous deposits to warrant the mapping and detailed study of the geology of the area, with special emphasis on the ore deposits.

FIELD WORK AND ACKNOWLEDGMENTS

Under the direction of the Geological Survey, the writer spent parts of the summer seasons of 1929, 1930, 1931, 1932, and 1934 in the Libby quadrangle. At various times he was ably assisted in the field by Ian Campbell, P. C. Henshaw, O. W. Jarrell, W. F. Jenks, C. B. Moke, J. H. Moses, R. P. Sharp, R. H. Svendsen, and A. W. Waldo. The writer is also indebted to some of these men and to S. I. Bowditch and N. E. Chute for assistance in the office and laboratory. W. F. Jenks, in addition to mapping a part of the Libby quadrangle, mapped most of that part of Trout Creek quadrangle lying between the Libby quadrangle and the Coeur d'Alene district for the purpose of correlating the rocks and the structure of those three areas. The results of his studies, which are set forth in an unpublished doctoral thesis presented to Harvard University, are included at appropriate places in the following pages. E. A. Schmitz assisted in the preparation of many of the maps.

The cost of the project were mainly borne by the Geological Survey, by Lincoln County, Mont., which in 1930 provided cooperative funds, by Harvard University, and by the California Institute of Technology. Grants from the Milton Fund of Harvard University and from research funds of the California Institute of Technology were made toward field and laboratory expenses.

The writer is indebted to G. F. Loughlin, J. T. Pardee, and W. C. Alden of the Survey for guidance in the field during visits at different times, to them and F. C. Calkins for criticism of the manuscript, and to Percy E. Raymond of Harvard University for the identification of Cambrian fossils.

PREVIOUS WORK

In 1905 Calkins and MacDonald[1] made a reconnaissance survey in northeastern Idaho and northwestern Montana from the Canadian border south to the Coeur d'Alene district and southeastward nearly to Missoula. The Libby quadrangle was included in this very large area. Previous to the present survey, their report was the most complete work on the area, and it will often be referred to in the following pages. In 1927 Pardee and Larsen[2] examined the extensive vermiculite deposits northeast of the Libby quadrangle.

The principal papers dealing with the geology or mineral deposits of the general region that includes the Libby quadrangle are listed below.

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[1] Calkins, F. C., and MacDonald, D. F., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, 1909.

[2] Pardee, J. T., and Larsen, E. S., Deposits of vermiculite and other minerals in the Rainy Creek district, near Libby, Mont.: U. S. Geol. Survey Bull. 805, pp. 17–29, 1929.

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GEOGRAPHY

LOCATION AND ACCESSIBILITY

The Libby quadrangle, bounded by meridians 115°30′ and 116° west longitude and parrallels 48° and 48°30′ north latitude, is in the northwestern part of Montana and includes parts of Lincoln and Sanders Counties. (See fig. 1.) Its area is about 800 square miles.

The Kootenai and Clark Fork Rivers cross, respectively, the northern and southwestern parts of the area. Both are followed by main automobile highways and by transcontinental railroads, the Great Northern Railway along the Kootenai and the Northern Pacific Railway along the Clark Fork. The main automobile highways are connected by a cross road through the Lake Creek-Bull River Valley. Most of the mines and lumber camps and the few ranches in the area may be reached over good secondary roads and the more remote prospects by trails.

The two largest towns in the area, Libby, the county seat of Lincoln County, and Troy, are on Kootenai River in the northern part of the quadrangle. Heron is a small settlement on Clark Fork River near the southwest corner.

TOPOGRAPHY

The area (pl. 1) contains parts of the Cabinet Mountains, several of whose peaks rise to altitudes of 4,600 to 8,712 feet above sea level. These mountains are very rugged and their flanks are gashed by deep, narrow gorges. The Kootenai River, a tributary of the Columbia, in the most southerly part of its course flows westward across the northern part of this area. It has an altitude between 2,100 and 1,875 feet and has cut transversely through the mountain ranges in a deep canyon (pl. 2), which divides the Purcell Mountains on the north from the Cabinet Mountains on the south. The Clark Fork of the Columbia River, here about 2,100 feet above sea level, flows northwestward across the southwest corner of the quadrangle in a broad but steep-sided valley between the Cabinet Mountains on the north and the Bitterroot Mountains on the south. The steep, straight front along the Cabinet Mountains is the scarp or exhumed scarp of the Hope fault.

Lying between two ridges of the Cabinet Mountains and connecting the Kootenai and Clark Fork Valleys is a through valley, which is

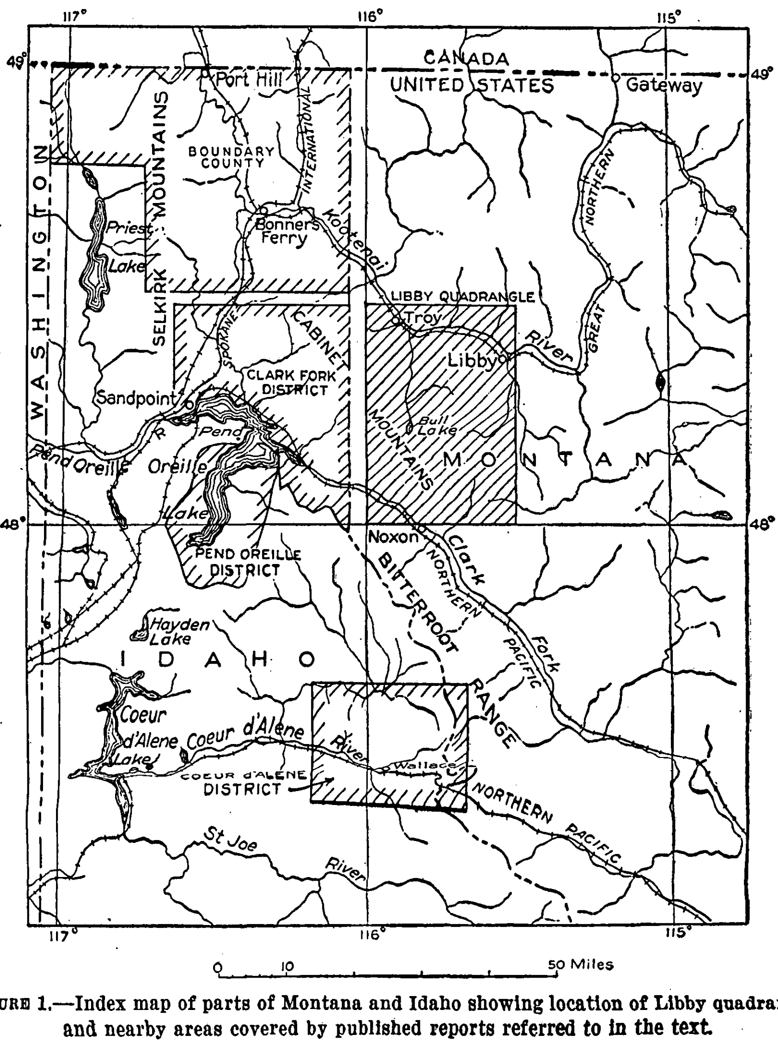


Figure 1.—Index map of parts of Montana and Idaho showing location of Libby quadrangle and nearby areas covered by published reports referred to in the text.

in a graben or downfaulted block. The valley is discussed in the sections on structure and physiography. Bull Lake lies in this valley, just north of the low Bull Lake Pass, which is on a gravelly flat 2,340 feet above the sea. The lake drains northward by way of Lake Creek to the Kootenai, and the part of the valley lying south of the pass drains by way of Bull River to Clark Fork.

Many of the valleys leading from the high mountains are gorges, about 1,500 to 3,500 feet deep in their middle and upper reaches. They were once occupied by glaciers that headed in rounded amphitheaters, or cirques, high in the mountains and extended for miles down the valleys. Many of the streams have their sources in small lakes that now occupy these cirques, and three small glaciers, two on the northeast flank of Snowshoe Peak and one on Elephant Peak, have not yet completely disappeared.

Most of the wide valleys are covered with glacial material, much of which has not been sufficiently reworked by the streams to have obliterated completely the subangularity of the pebbles and boulders or the glacial striae on them, and such material is mapped as glacial. In the flood plains of the present streams, on the other hand, belts of alluvium have been mapped. In many places, however, there is little difference in character between the two kinds of deposits, and the boundaries between them are somewhate arbitrary.

Further topographic details are given in the chapter on Physiography by J. T. Pardee (pp. 61–65).

CLIMATE AND VEGETATION

Records of the United States Weather Bureau for a period of 38 years show a mean annual precipitation at Libby of nearly 20 inches. No records are available for higher altitudes, but the precipitation is evidently much greater in the mountains than in the Libby Valley. Most of it occurs in the winter and spring, the summer and fall being as a rule comparatively dry. The lowest temperature recorded in the last 40 years was −46° F. and the highest 109°, both at Libby, but such extremes are rare. The mean annual temperature at Libby for the 36 years from 1900 to 1936 was 44.5°.

All of the quadrangle except the higher summits was formerly covered by thick stands of pines, firs, and other conifers. In Libby and Clark Fork Valleys practically all of the merchantable timber has been cut, and some of the lands have been cleared for farming. Several areas, too, have been burned, and the succeeding growth in these is mostly brush. In Lake Creek Valley, however, and on the lower mountain slopes considerable stands of saw timber yet remain, and timber suitable for mining purposes is within easy reach of most of the mines.

ROCK FORMATIONS

The Libby quadrangle is underlain chiefly by pre-Cambrian sedimentary rocks of the Belt series, mainly quartzite, argillite, shale, impure limestone, and calcareous argillite. Two very small areas of Cambrian limestone are found in the southwestern corner of the quadrangle just north of Clark Fork. Superficial deposits consisting mainly of Quaternary glacial till, outwash gravels, lacustrine silts, and stream alluvium cover most of the Lake Creek, Libby Creek, and Clark Fork Valleys.

Igneous rocks, though they occupy a relatively small proportion of the area, are widely distributed. Quartz monzonite, syenite, metadiorite, and similar rocks, in the form of stocks that are probably of Mesozoic age, underlie about 3 percent of the total surface area of the quadrangle. The most abundant of these is quartz monzonite. Metadiorite dikes, probably related to the stocks occupy a far smaller total area than the stocks, but they are of particular interest because metalliferous deposits are related to them. Metadiorite sills probably of pre-Cambrian age occur extensively in the quadrangle, but their total extent is not large.

SEDIMENTARY ROCKS

PRE-CAMBRIAN

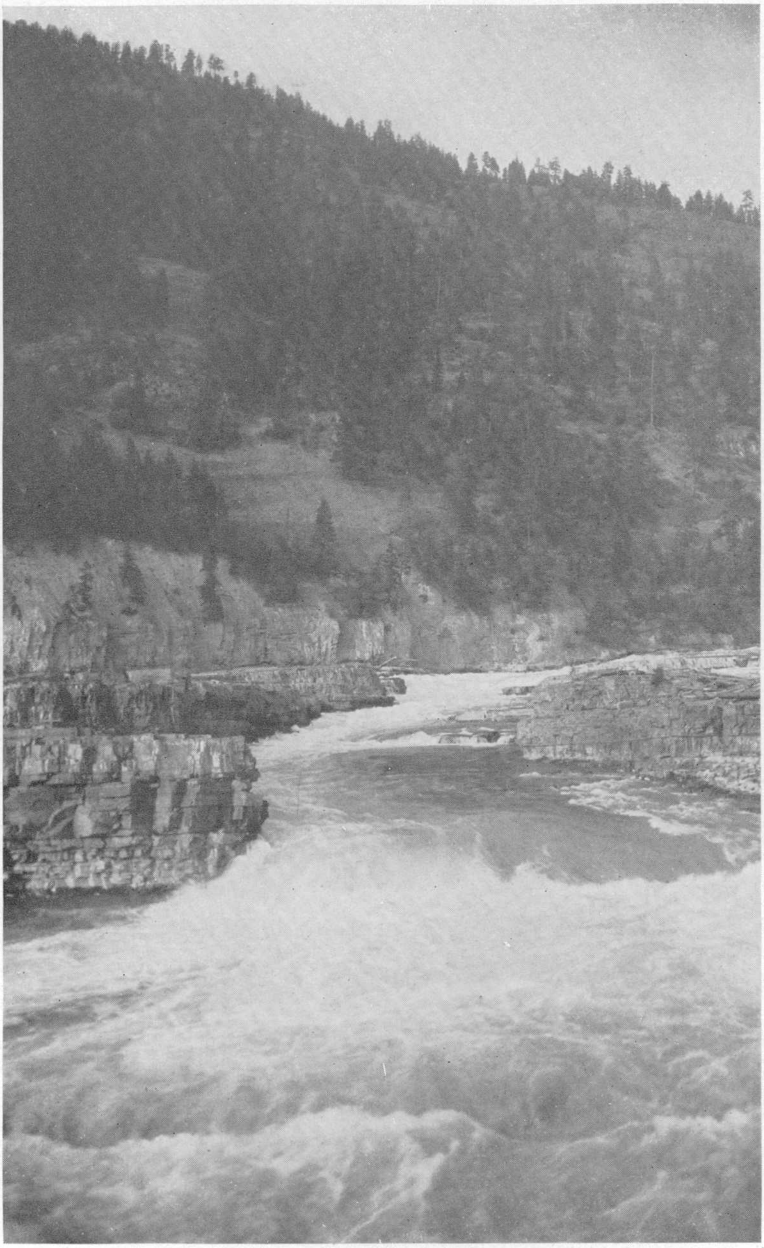
BELT SERIES

The total thickness of the Belt strata in the quadrangle is about 40,000 feet. Five formations can be distinguished. These are, in ascending order, the Prichard, the Ravalli, the Wallace, the Striped Peak, and the Libby, a newly recognized formation described on pages 17–19. For the most part these correspond with formations distinguished by Calkins[3] in northern Idaho and northwestern Montana.

The term Wallace instead of Newland is used in this report for the formation above the Ravalli because it can be correlated with the Wallace of the nearby Coeur d'Alene district. Walcott believed at first that the Wallace could be correlated with the Newland of the original Belt section and hence on the grounds of priority should be called Newland. This correlation was accepted, on Walcott's authority, by Calkins,[4] but was afterward abandoned by Walcott in favor of the view that the Wallace formation was equivalent to the Helena limestone. As there is some doubt about these long-range correlations and as the term Wallace has been used for the corresponding forma-

[3] Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, 1909.

[4] Calkins, F. C., and Emmons, W. H., U. S. Geol. Survey Geol. Atlas, Phillipsburg folio (No. 196), p. 3, 1915. Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, p. 183 (citation of Walcott), 1912.



KOOTENAI FALLS.

A cascade in Kootenai River at the head of its inner gorge. Gently inclined beds of the Wallace formation exposed. Photograph by K. D. Swan. Courtesy of U. S. Forest Service.

tion in the nearby Coeur d'Alene,[5] Clark Fork[6] and Pend Oreille[7] districts in recent years, it has seemed more expedient to use the term Wallace.

The equivalent of the Striped Peak formation of nearby regions is overlain in the Libby quadrangle by strata for which the name Libby formation has been adopted. The Striped Peak formation consists chiefly of red quartzite and sandstone 2,000 feet thick and is the most homogeneous and easily distinguished unit in the quadrangle. The Libby formation consists predominantly of light-gray and dark-gray argillite, though it also comprises a little sandstone and impure magnesian limestone.

Neither the bottom of the Prichard nor the top of the Libby formation was observed in the Libby quadrangle. A table showing correlation of the Belt series with formations in nearby regions follows:

Correlation of Belt series in the Libby quadrangle with formations in nearby regions

[Approximate thickness given in feet]

<table>
<tr><th></th><th>Coeur d'Alene district, Idaho [1]</th><th colspan="2">Clark Fork district, Idaho [2]</th><th colspan="2">Pend Oreille district, Idaho [3]</th><th colspan="2">Trout Creek quadrangle, Mont.-Idaho [4]</th><th colspan="2">Libby quadrangle, Mont.</th></tr>
<tr><td rowspan="2">Striped Peak formation</td><td rowspan="2">1,000+</td><td colspan="2" rowspan="2">4,000+</td><td colspan="2" rowspan="2">9,000+</td><td colspan="2" rowspan="2">3,000</td><td>Libby formation.</td><td>6,000+</td></tr>
<tr><td>Striped Peak formation.</td><td>2,000+</td></tr>
<tr><td>Wallace formation</td><td>4,000</td><td colspan="2">6,000</td><td colspan="2">6,000</td><td colspan="2">10,500</td><td colspan="2">12,000+</td></tr>
<tr><td>St. Regis formation</td><td>1,000</td><td colspan="2">7,500</td><td rowspan="2">Blacktail formation.</td><td rowspan="2">8,300</td><td rowspan="3">Ravalli formation.</td><td rowspan="3">5,300-9,800</td><td rowspan="3">Ravalli formation.</td><td rowspan="3">10,000</td></tr>
<tr><td>Revett quartzite</td><td>1,200</td><td rowspan="2">Burke formation.</td><td rowspan="2">3,500</td></tr>
<tr><td>Burke formation</td><td>2,000</td><td>Burke formation.</td><td>2,000+</td></tr>
<tr><td>Prichard formation</td><td>8,000+</td><td colspan="2">20,000+</td><td colspan="2">7,000+</td><td colspan="2">7,800+</td><td colspan="2">9,700+</td></tr>
</table>

[1] Ransome, F. L., and Calkins, F. C., U. S. Geol. Survey Prof. Paper 62, 1908.
[2] Anderson, A. L., Idaho Bur. Mines and Geology Bull. 12, 1930.
[3] Sampson, Edward, Idaho Bur. Mines and Geology Pamph. 31, 1928.
[4] Jenks, W. F., Doctoral thesis, Harvard University, 1936.

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[5] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey, Prof. Paper 62, 1908.

[6] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, 1930.

[7] Sampson, Edward, Geology and silver ore deposits of the Pend Oreille district, Idaho: Idaho Bur. Mines and Geology Pamph. 31, 1928.

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PRICHARD FORMATION

Distribution.—The larest area of Prichard rocks is in the northwestern part of the quadrangle, west of the Lenia fault and north and south of Callahan Creek. They underlie about three-fourths of Grouse Mountain, which is between Iron and Keeler Creeks, and most of Preacher Mountain, which is east of Gordon Creek. The second largest area, which is east of the Snowshoe fault and south of Cherry Creek, extends beyond the southeast corner of the quadrangle. Much smaller exposures are seen on Keeler Mountain and on the East Fork of Blue Creek.

Most of the gold-bearing quartz veins are in the Prichard formation, and by far the largest production of lead, zinc, and silver has come from veins associated with dikes and sills in the Prichard south of Callahan Creek.

Thickness.—As the Prichard formation is made up almost entirely of weak rocks, its structure is complicated by folding and faulting, and an accurate measurement of its thickness can hardly be made. On Grouse and Preacher Mountains, however, where the eastern or lower boundary of the formation is the Lenia fault, a minimum thickness of 9,700 feet is exposed, and the base of the formation is not exposed in the quadrangle.

Lithology.—Excepting the Striped Peak, the Prichard is the most homogenous formation in the quadrangle. It consists mostly of dark-colored argillite, which is interbedded with some light-colored sandstone and quartzite and a little thin-bedded shale.

The argillite is dark-gray to blue-gray where fresh and weathers to a dark reddish or rusty brown. It is commonly sandy and sericitic and rarely contains carbonate. Tiny grains of pyrite and pyrrhotite are disseminated in much of the Prichard, and the weathering of these sulfides may acount for the iron oxide that stains the weathered surface. Carbonate also is present, however, in some of the rusty-brown ferruginous argillite, and, as most of the carbonate in other formations contains some iron as well as calcium and magnesium, this carbonate may furnish part of the iron. Much of the argillite exhibits on fresh fracture alternate bands of light-colored and dark-colored material, the lighter-colored being commonly the more sandy.

Beds of sandstone and, more rarely, of quartzite a fraction of an inch to a few feet in thickness may appear anywhere in the formation, but they increase in number toward the top. On Grouse Mountain, about 6,500 feet below the top of the Prichard, there is a layer 300 feet thick that consists chiefly of white to gray sandstone and quartzite. The siliceous beds are invariably lighter in color than the more argillaceous beds and in some places, especially in the area of gold-bearing quartz veins in the southeastern part of the quadrangle, they are white. They are almost invariably sericitic, and a few are calcareous. The gray sandstone is likely to be shaly, and there are all gradations from argillite to sandstone.

At the top the formation becomes more sandy and lighter in color, and between the Prichard and the overlying Ravalli formation there is a transitional zone, 300 to 500 feet thick, in which gray sandstone predominates over the darker-gray sandy argillite.

Suncracks and ripple marks are sparingly present in the Prichard. In places, especially near faults, minor cleavage across the beds has been developed, and, in the area of gold-bearing quartz deposits, some veins cross from one bed to another along this cleavage.

A few thin sections of sandy beds of the Prichard examined under the microscope were found to be composed of fine grained quartz and sericite, mainly in grains 0.01 to 0.03 millimeter in diameter, with a minor proportion of chlorite. Small flakes of sericite and chlorite tend to lie parallel with the bedding. A little detrital zircon, tourmaline, apatite, and rutile are present.

RAVALLI FORMATION

Distribution.—The Ravalli is a resistant formation and forms bold outcrops and prominent talus slopes, especially where its quartzitic middle part is exposed. East of the Snowshoe fault and on the east limb of the Snowshoe anticline, which trends southward to Flattop Mountain, the Ravalli formation is exposed in a narrow band extending from Granite Creek on the north to the southern boundary of the quadrangle, a distance of 20 miles. Here it forms prominent dip slopes on the eastward-trending spurs of the high Cabinet Mountains. On some of the exposed eastward-dipping bedding planes of the quartzite there is no vegetation, and here the morning sun is brilliantly reflected from the rock. In the western third of the quadrangle, from Goat Mountain on the north to Clark Fork on the south, there are extensive exposures on both limbs of two synclines which trend roughly northward. On Sawtooth Mountain, on Billiard Table, in the area east of Flattop Mountain, and at other places where the Ravalli is relatively flat-lying, it forms extremely precipitous cliffs, and there are small waterfalls along the creeks.

At the Snowshoe and Silver Mountain mines and in a few prospects along the Snowshoe fault the east wall of the vein is Ravalli, but there are few prospects and no mines wholly within this formation. Structure rather than character of wall rock has determined the location of the mineral deposits in this region.

Thickness.—In the southeastern part of the quadrangle, between Wanless Lake and Rock Creek, the Ravalli appears to be about 10,000 feet thick. Not far south of this area, in the northeastern part of the

Trout Creek quadrangle, the thickness is 9,500 feet. Toward the northwest the formation gets thinner, and on Keeler Mountain it is only 7,000 feet thick. In the Clark Fork region,[8] however, west of the Libby quadrangle, the thickness of the Burke and St. Regis, which together are the equivalent of the Ravalli, is 11,000 feet.

Lithology.—The greater part of the Ravalli formation consists of hard, even-grained, light-gray to white quartzite or quartzitic sandstone. At any place in the quadrangle where it can be seen in sufficient thickness, this rock can be recognized and identified with confidence as middle Ravalli, the equivalent of the Revett quartzite of the Coeur d'Alene district. The individual beds are commonly 1 to 3 feet thick and rarely 10 or 15. They weather in a blocky fashion, and the edges of the blocks are sharp. Some beds of the sandstones and quartzites contain a little calcite and, in addition, a little dolomite, sericite, or iron oxide. Those beds that are ferruginous exhibit reddish or purplish tints on weathered surfaces. Interbedded with the quartzite and sandstone are thin layers of gray sandy, sericitic shale and argillite, some of which are calcareous or ferruginous. Toward the bottom the sandy shales become darker, less sandy, and more abundant. In places near the bottom both the sandy and the shaly beds contain fine-grained magnetite. As already noted, typical Ravalli rocks are separated from typical Prichard rocks by a transitional zone several hundred feet thick.

The upper part of the Ravalli grades more rapidly into the Wallace. It comprises slightly calcareous, hard, white quartzite, overlain successively by thin-bedded, gray, sandy, calcareous shale, and by thin-bedded bluish-gray sandy argillite, which is taken as the top of the Ravalli. Above this argillite the beds become more calcareous and weather buff.

Ripple marks (pl. 3 *A*), sun cracks, and cross bedding are common features of the Ravalli.

Under the microscope the sandstone is seen to be made up chiefly of quartz in grains, not well rounded, that range from 0.02 to 0.30 millimeter and average about 0.20 millimeter in diameter. Angularity of the grains is due either to granulation or to deposition of silica around some grains, which has enlarged them and changed their shape. Fine-grained sericite is scattered more or less abundantly through the arenaceous beds and is abundantly developed in the more argillaceous members. Locally, as a result of hydrothermal alteration, fine-grained, commonly untwinned albite has been introduced, forming in rare instances as much as 25 percent of the volume of the bed.

[8] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, pp. 15–16, 1930.

WALLACE FORMATION

Distribution.—The Wallace formation occupies a larger area than any other formation in the high mountains in the central part of the quadrangle. It underlies A Peak and Snowshoe Peaks (pl. 1), the highest points, and is well exposed north and south of these peaks between the Snowshoe fault and Lake Creek Valley. In the north-central part of the quadrangle it is exposed on both limbs of an asymmetric, northward-plunging syncline, which extends beyond Kootenai River into the Purcell Mountains. It is the formation most extensively exposed on the flanks of the Mount Berray syncline, north of the Clark Fork, and it underlies the valleys of the North, Middle, South, and East Forks of Bull River. The Wallace formation encloses the Dry Creek stock except along its western border, and it is the host rock of all but one of the other stocks. It is the wall rock at the Glacier (Lukens-Hazel) mine, and it forms the west wall of the vein in the Snowshoe and Silver Mountain mines and in several prospects along the Snowshoe fault.

Thickness.—As the Wallace formation is much folded and faulted, it is difficult to find an area where its full thickness can be measured with certainty. In a section crossing Howard Lake and the southwestern slopes of Horse Mountain, beyond the eastern border of the quadrangle, the apparent thickness is at least 11,200 feet, but this measurement may be affected by the Midas fault if it extends so far north. On the western slope of Mount Berray the thickness appears to be 12,000 feet.

The formation may even attain a thickness of 16,000 feet on Snowshoe Peak and its western ridge, for most of the ridge west of this peak was traversed and no structural discontinuities were found. On Mount Sheldon in the northeastern part of the quadrangle, also east of Mount Sheldon on both sides of Kootenai River and even beyond the eastern border of the quadrangle, the Wallace has a fairly uniform western dip. In this section no faults or isoclinal folding were found to interrupt the continuity, and if none are present the formation is here at least 17,000 feet thick.

None of these figures are entirely satisfactory, but the indicated decrease in thickness from north to south continues in the Trout Creek quadrangle, the thickness of the Wallace being about 10,000 feet in the northern part of that quadrangle and 7,000 feet in the southern part.[9] A generalized section of the upper part of the Wallace formation follows:

[9] Jenks, W. F., Personal communication.

Generalized section of the upper part of the Wallace formation on Mount Berray

	Feet
Top, gray-green thin-bedded shale	1, 600
Gray-green, buff-weathering shale	1, 200
Gray-green shale	900
Dark-gray shaly quartzite	750
Dark-gray to light-gray thin-bedded shale, micaceous in some places	2, 200
Buff-weathering, light-gray and dark-gray calcareous shale	250
Total	6, 900

Lithology.—The Wallace is the most heterogeneous formation in the Libby quadrangle and the most difficult to identify with certainty because it contains beds resembling some of those in every other formation. From top to bottom argillite and shale are the dominant rocks, sandstone is much less abundant, and dolomite and magnesian limestone are present in small amounts. A little dolomite and calcite may be found in most of the arenaceous and argillaceous beds.

The most abundant rock is a gray to greenish-gray sandy argillite, which is quite commonly calcareous or dolomitic and slightly ferruginous. Good exposures may be seen on the south bank of Kootenai River opposite Koot and China Creeks. In places, where the formation is sandy, greenish-gray beds alternate with buff-colored beds. Some of the dark-gray argillite is in beds 6 to 24 inches thick made up of alternate dark-colored and light-colored laminae, but the rock does not split along these laminae.

The argillite is interbedded with thin-bedded to thick-bedded gray, greenish-gray, and brownish sandstone. In places the beds are 2 to 12 inches thick, elsewhere 1 to 4 feet, and rarely as much as 10 feet. Most of the sandstone contains a little sericite and carbonates of calcium, magnesium, and iron. Sericite can be distinguished with the unaided eye in many specimens, and hundreds of specimens were tested in the field with dilute hydrochloric acid and found to contain carbonate. Laboratory tests showed that every specimen that contained acid-soluble calcium or magnesium contained acid-soluble iron also.

A distinctive but not abundant rock found at various horizons in the Wallace formation is a very thin-bedded, soft, sericitic, light-gray to buff shale, which in places is slightly calcareous. The individual laminae are paper thin, and the rock is unlike any in the other formations. This shale is exposed at the D. and W. prospect on Prospect Creek, at the Midas mine, on Cherry Creek a quarter of a mile southwest of the Howard Placer, at the Crater prospect 1 mile east of Savage Lake, and elsewhere.

A group of beds dominantly red in color, resembling in some respects those of the Striped Peak formation and ranging from a few hundred to a thousand feet in thickness, is present in the upper third of the Wallace formation in some parts of the area. Deep-red, sandy, sericitic, ferruginous shale is the most abundant rock in this group. Interbedded with it are beds of sericitic ferruginous sandstone, some of which are slightly calcareous. Commonly the sandstone is red but of not so deep a color as the shale, but some beds are gray or greenish, and some are mottled. The best-developed ripple marks and the most diverse in size and shape observed anywhere in the Belt rocks were seen in these red sandstones and shales. The red beds of the Wallace formation are especially well shown (1) on the west limb of the Troy anticline, at Brush and Callahan Creeks and on the western slope of McConnell Mountain; (2) on the western slope of Mount Sheldon; and (3) on Little Hoodoo Mountain.

The most charactertistic rock of the Wallace formation is an algal dolomite or dolomitic limestone (pl. 4), which is found at several horizons and is almost invariably present in the group of red shale and sandstone beds just described. Algal dolomite is found also in the Striped Peak formation, where it is associated with red beds, but it is more abundant in the Wallace, and the red beds with which the algal dolomite is associated in the Wallace are more shaly than those in the Striped Peak.

On fresh fracture the typical algal dolomite is very light gray, pale greenish gray, or nearly white, fine-grained, crystalline, and seemingly homogeneous; no lamination can be discerned in the unweathered rock, and there is no hint that the material is of organic origin. As the weathered surface is approached, the rock assumes a darker-gray or buff color, which grades into brown of various shades at the surface. Within a fraction of an inch of the weathered surface the rock is seen to be laminated, the laminae being slightly different in color, in hardness, and in mineral composition. These differences, especially the differences in hardness and resistance to weathering, increase at the surface, where the exposed face becomes cellular and parallel ridges and grooves are developed. (See pl. 4 *A*.) In some places the ridges are hard and knifelike and contain much quartz and sericite, whereas the grooves between are broader and composed of soft pulverulent carbonate; elsewhere in the same block the grooves may be V-shaped and the ridges broad and flat. The laminae are nowhere straight for any great distance; they curve concentrically in domes, ellipsoids, and groups of these forms, which interfere with one another. Some of the domes are broad and others are steep-sided. Their diameter and height range from a few inches to 2 feet. Similar forms found in other areas of Belt rocks have been described by the Fentons.[10]

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[10] Fenton, C. L., and Fenton, M. A., Algal reefs and bioherms in the Belt series of Montana: Geol. Soc. America Bull., vol. 44, pp. 1135–1142, 1933.

Another characteristic feature of the Wallace, seen in no other formation in the quadrangle, is "molar-tooth" structure, which occurs in the dolomite and dolomitic limestone. As developed on the weathered surface, this structure somewhat resembles the grinding surface of an elephant's molar. It exhibits irregular cavities, curved gashes, and cells, separated by equally irregular ridges. Some of the cavities are roughly parallel for short distances; others are branching. The pitted layers are gray and composed chiefly of calcite, albite, and quartz; those that form the ridges are darker gray and consist of dolomite, quartz, sericite, and fine-grained argillaceous material (pl. 3 *B*).

Shallow-water features, such as ripple marks, sun cracks, and cross bedding, are abundant in the Wallace, and casts of salt crystals were observed at one place in the upper part of the formation. Clay-gall conglomerate is sparingly present.

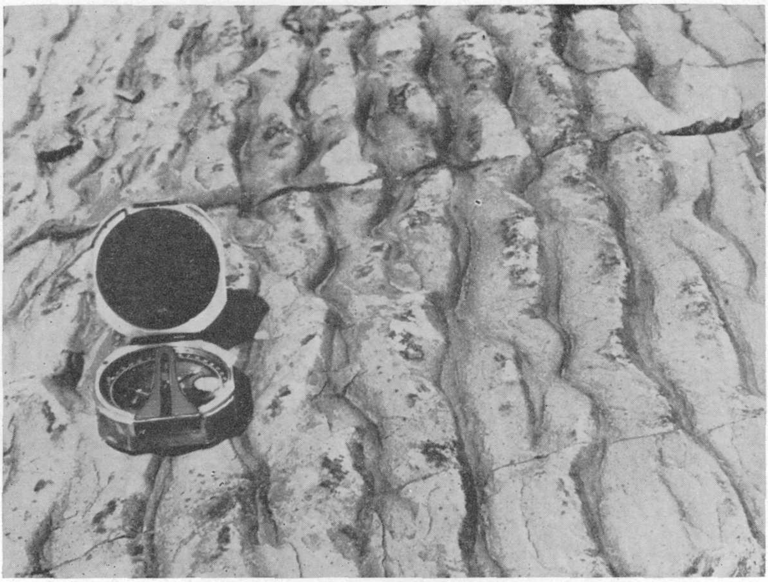
STRIPED PEAK FORMATION

Distribution.—The Striped Peak formation is exposed in deep-red cliffs at three places on each side of Kootenai River between Bobtail Creek and China Creek. It appears on both limbs of a northward-plunging anticline that forms a structural and topographic ridge at Samater Mountain. In the syncline to the west it is well exposed north and south of the Kootenai at Burrell Creek, and in the syncline to the east it underlies part of Bobtail Ridge north of the Kootenai. It appears again as part of this same series of folds in a narrow band crossing Twin, Porcupine, Camp, and Madge Creeks and is cut off by the Bull Lake fault. The only other exposure of the Striped Peak formation in the quadrangle is in the trough of a syncline whose axial plane is a little east of the crest of Mount Berray. Part of the crest of this mountain is underlain by the Striped Peak formation.

There are no prospects in the Striped Peak formation.

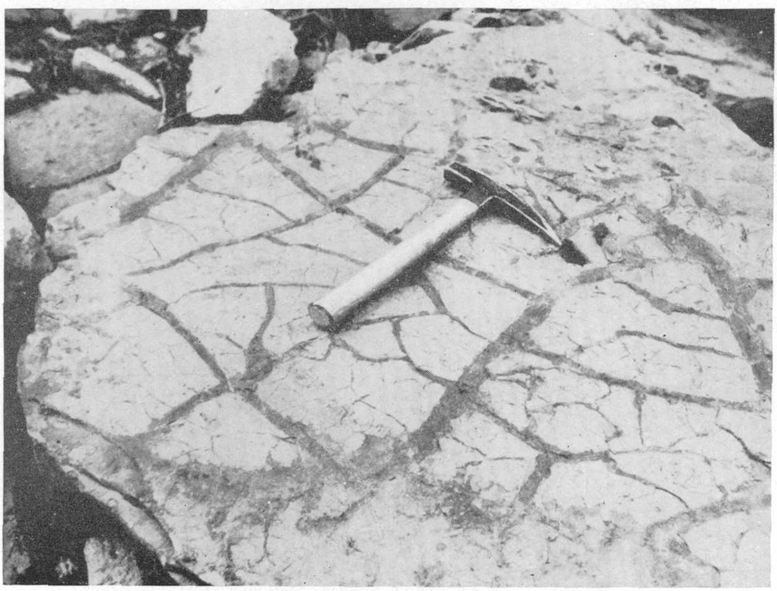
Thickness.—In several places south of Kootenai River the Striped Peak formation is about 2,000 feet thick. On Mount Berray, in the southwestern part of the quadrangle, its thickness has increased to 2,500 feet. A generalized section of the Striped Peak formation is given on page 17.

Lithology.—No formation in the Libby quadrangle is as homogeneous as the Striped Peak. The dominant rocks of the formation are dark-red to purplish sandstone and quartzite. Some of the siliceous beds are shaly and sericitic, and all of them are ferruginous. Most of the beds are only a foot or two thick, and many are less than 1 foot thick. Red sandy micaceous shales are interbedded with the sandstone and quartzite, and in places they make up a considerable part of a section. The shale is deeper red in color than the sandstone. Near



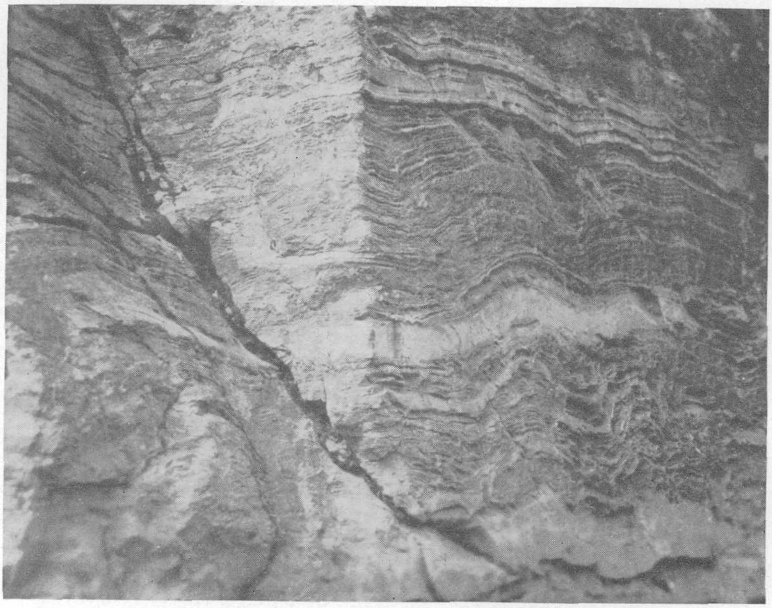
A. RIPPLE MARKS IN SANDSTONE OF THE RAVALLI FORMATION.

Photograph by C. B. Moke.



B. FOSSIL MUD CRACKS IN ARGILLITE OF THE WALLACE FORMATION.

Photograph by C. B. Moke.



A. JOINT FACE SHOWS CROSS SECTION OF BEDDING.

B. EXPOSURE ALONG BEDDING PLANE.
Photograph by W. F. Jenks.

ALGAL BEDS IN WALLACE FORMATION.

the top especially but also at other horizons are a few light-green to olive-green argillite beds, some of which grade into red argillite along the strike. Because of its obvious siliceous and argillaceous character at almost every place where it was seen, except in the exposures on Berray Mountain described below, the Striped Peak formation was rarely tested for carbonate, but in a very few places the sandy beds were found to contain a little.

Algal dolomite is found about 200 feet above the base of the formation on Berray Mountain, where it is associated with oolitic dolomite and gray sandy dolomitic limestone. This dolomite was observed nowhere else in the formation in the Libby quadrangle, but Jenks [11] reports algal dolomite and dolomitic limestone in this formation at two horizons, 1,000 and 1,500 feet, respectively, above the base, in the Trout Creek quadrangle to the south. This algal material is very similar to that found in the Wallace formation described above.

Ripple marks, sun cracks, and cross bedding are common in the Striped Peak formation.

Generalized section of the Striped Peak formation as exposed on Mount Berray

	Feet
Top, covered	500
Green sandy micaceous shale	150
Interbedded green and red sandy shale	300
Thin-bedded red and green shale; some beds show casts of salt crystals	250
Interbedded red shale, red sandstone, and algal limestone	300
Green medium-bedded shaly quartzite	50
Red shale and shaly sandstone	550
Red and gray-green micaceous shale and shaly sandstone	300
Bottom, red shale	100
Total	2, 500

LIBBY FORMATION

Distribution.—The Libby formation immediately overlies the Striped Peak formation. It consists predominantly of light-gray to dark-gray argillite, though it also comprises a little sandstone and impure magnesian limestone. It is named for the town of Libby, Mont., because it crops out extensively in ridges that overlook the town. A typical section is southeast of Flagstaff Mountain, on the south side of Kootenai River.

Flagstaff Mountain, in the northeastern part of the quadrangle, and the mountain opposite to it on the south side of Kootenai River are synclinal mountains partly underlain by the Libby formation. The syncline plunges to the northwest, and the area of exposure of these beds, the youngest rocks of the Belt series in the Libby quadrangle, consequently flares toward the northwest.

[11] Jenks, W. F., Personal communication.

The only other exposure of the formation is in Lake Creek Valley, on the flanks of the Dry Creek stock of quartz monzonite and northwest of it. This exposure is bounded on the west by the Savage Lake fault. Here this member underlies low spurs between Crowell and Porcupine Creeks, the conditions of exposure being in marked contrast with those in the Flagstaff Mountain area.

There are no valuable prospects in the Libby formation.

Thickness.—The thickness exposed in the syncline mentioned above is at least 6,000 feet. A generalized section of the Libby formation follows.

Generalized section of the Libby formation on the south side of the Kootenai River southeast of Flagstaff Mountain

	Feet
Gray sandstone	
Thin-laminated gray argillite with alternating dark-colored and light-colored laminae	400
Thin-bedded gray sericitic argillite, which weathers brown	
Thick-bedded dark-gray argillite	
Partly covered. Partly sandy argillite and dark-gray shale	900
Thick-bedded dark-gray argillite and thin-bedded light-gray shales, which weather brown	150
Thin-laminated dark-gray shale, gray sericitic argillite, and dark-gray ferruginous, magnesian limestone, in part oolitic and in part carbonaceous	300
Thick-bedded argillite with alternating dark-colored and light-colored laminae. Weathers brown	
Olive-gree sericitic argillite, which weathers brown and greenish-gray	500
Calcareous sandstone	
Dark-gray and greenish sericitic, calcareous argillite in well-jointed beds as much as 2 feet thick. Weathers brown	
Base of the formation.	
Total	2,250

As the top of the formation has been removed by erosion, its complete thickness is unknown.

Lithology.—The commonest rocks in the Libby formation are light-gray, dark-gray, and greenish-gray argillite, commonly somewhat sandy and less commonly sericitic and calcareous, in beds between 1 and 3 feet in thickness. Some beds exhibit alternate very thin light-colored and dark-colored laminae similar to those seen in the Prichard formation, and, as in the Prichard, many of these beds are ferruginous and weather rusty brown. But nowhere in the quadrangle were the Prichardlike beds observed in great volume in the Libby formation, and they therefore need never be confused with the Prichard if seen in a sufficiently large exposure.

Less abundant are thin-bedded gray sandstone and thin-bedded, dark-gray, oolitic, ferruginous magnesian limestone. The dark color of the limestone is due to finely divided carbonaceous matter. Near the bottom of the member, in Lake Creek Valley, a few beds of white ferruginous dolomite and algal dolomite were found.

Along Kootenai River, about 3,500 feet above the base of the member, there is a little greenish-gray argillite unlike any rock seen elsewhere in the Belt series. On the weathered surface of some of the calcareous layers in these beds spherical and podlike nodules of shaly material softer and darked in color than the surrounding rock are conspicuous. The greatest diameter of the nodules ranges from 6 to 18 inches. They contain a little manganese oxide, which gives them a brown color. They hold absorbed moisture longer than the harder surrounding matrix of argillite and weather more rapidly; consequently only part of each nodule remains, in a somewhat ovoid cavity.

PALEOZOIC

CAMBRIAN

Two small areas of Cambrian strata are exposed near the north bank of the Clark Fork, opposite the mouth of Elk Creek, in the southwestern part of the quadrangle. The relation of these isolated outcrops of Paleozoic rocks to the Belt series is obscured by a covering of unconsolidated glacial-lake gravels, which completely surrounds them. A fault of considerable magnitude must separate the Cambrian beds from the Ravalli formation, which forms the steep south slope of Squaw Peak to the north, and the Hope fault is believed to pass south of the Cambrian beds, separating them from several isolated outcrops of the Wallace formation in the valley of the Clark Fork. The Cambrian beds thus represent a down-faulted wedge.

The Cambrian rocks consist of interbedded black shale and light-gray thin-bedded limestone, both of which have a distinctly bituminous odor when freshly broken. Several of the shale beds contain abundant disk-shaped concretions as much as 18 inches in diameter. The total thickness of the exposed Cambrian beds is probably at least 200 feet, but it is difficult to estimate because the beds have been complexly deformed.

Preserved in the concretions and to some extent in the thin-bedded limestone and the black shale are abundant fragments of trilobites. These have been identified by Prof. P. E. Raymond and Dr. H. R. Gale,[12] who report the following forms:

Tonkinella stephensis Kobayashi.
Oryctocephalus reynoldsi Reed.
Agnostus sp. indet. (Numerous).
Micromitra (*Iphidella*) *pannula* (White).

[12] Campbell, Ian, Sharp, R. P., and Gale, H. R., A new locality for Middle Cambrian fossils near Noxon, Mont.: Am. Jour. Sci., 5th ser., vol. 34, No. 204, pp. 411–421, 1937.

The limestone beds also contain lenses in which small inarticulate brachiopods are abundant. According to Gale, "All the identifiable species in this fauna are represented in the Stephen formation, Middle Cambrian, of British Columbia, and the two most characteristic trilobites, *Oryctocephalus reynoldsi* and *Tonkinella stephensis*, are not known elsewhere." The beds are therefore probably Middle Cambrian.

Gale [13] has described Middle Cambrian fossiliferous rocks from an area on Swamp Creek, only a few miles east of the eastern edge of the Libby quadrangle and about 28 miles from the locality on the Clark Fork, but the fauna found there is entirely different from that described above.

A fauna collected by Sampson [14] from the Lakeview limestone in the Pend Oreille district of Idaho contains, according to Resser,[15] abundant Middle Cambrian forms.

IGNEOUS ROCKS

PRE-CAMBRIAN METADIORITE SILLS

SIZE AND DISTRIBUTION

The Prichard, Ravalli, and Wallace formations are invaded by a succession of sills whose original composition was probably similar to that of a diorite. Because of their altered condition they are called metadiorite in this report. None were seen in formations younger than Wallace. About 40 sills were observed, and nearly that many have been mapped. It is possible that in some places the same sill has been mapped on both limbs of a fold and has been regarded as two sills. As most of the sills are thin and discontinuous they cannot be traced far; and, as the degree of alteration of a sill may vary greatly from place to place, correlation between separate exposures is difficult.

In the northwestern part of the quadrangle the longest and most conspicuous sills are between Keeler Creek and Preacher Mountain; in the northeastern part they are on Mount Sheldon; and in the southeastern part they are east and west of the Snowshoe fault. Small sills were observed at many different places in the quadrangle, but they decrease in number and thickness toward the south.

The sills range in thickness from 10 inches to 800 feet and in length from a few feet to 10 miles. Most of them are about 100 feet thick, and only five have been traced for a distance greater than 2 miles. As they weather easily they do not commonly form conspicuous features of the topography, and hence the dimensions of many of them are probably greater than those recorded.

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[13] Gale, H. R., Cambrian fossils near Libby, northwestern Montana: Jour. Geology, vol. 42, pp. 174–179, 1934.

[14] Sampson, Edward, Geology and silver ore deposits of the Pend Oreille district, Idaho: Idaho Bur. Mines and Geology, Pamph. 31, pp. 9–10, 1928.

[15] Resser, C. E., Smithsonian Misc. Coll., vol. 92, No. 10, pp. 5–6, 1934.

About 14 percent of the total number of sills are in the Prichard, 16 percent in the Ravalli, and 70 percent in the Wallace, but the greatest aggregate thickness of sill material, roughly 1,200 feet, is in the Prichard.

COMPOSITION

The most abundant rock in the sills is a completely crystalline, medium-grained, dark-green metadiorite, composed chiefly of hornblende and tabular plagioclase, with smaller amounts of biotite and accessory minerals. Quartz rarely forms more than 15 percent of the rock, and in a very few sills it is lacking. The average grain size of hornblende, the dominant mineral, is 1.40 millimeters, and that of the plagioclase 0.60 millimeter. These interlock in random orientation.

A second type, which is relatively scarce, is a porphyritic rock, in which phenocrysts of plagioclase, quartz, or dark-colored minerals are conspicuous in an abundant groundmass similar in texture and composition to the finer-grained facies of the metadiorite. The granular and porphyritic types grade into each other.

Different sills, and even different parts of the same sill, differ both in original composition and in degree of alteration. In more than half the sills the hornblende is completely or almost completely replaced, and in some of these little or no plagioclase remains, the rock being composed almost wholly of minerals formed by hydrothermal alteration.

Under the microscope several textures and great differences in grain size are seen. The most common texture is characterized by long interlocking euhedrons of hornblende. Granular texture is seen only in the thoroughly altered specimens. Where foliation is present it is largely due to reorientation of biotite and development of chlorite.

Next to hornblende and plagioclase the most abundant minerals are chlorite, carbonate, sericite, quartz, and biotite, all of which are chiefly alteration products. Epidote and clinozoisite are erratic in distribution. The accessory minerals are orthoclase, sphene, rutile, leucoxene, apatite, magnetite, ilmenite, tourmaline, and zircon.

Hornblende.—The individual hornblende grains range in length from 0.02 to 18 millimeters and average about 1.40 millimeters. They are commonly of some shade of green and strongly pleochroic. Microscopic examination shows that they form euhedrons and subhedrons that crystallized later than the smaller plagioclase grains and enclose or partly envelop them. Some crystals penetrate crystals of feldspar, which they have partly replaced. (See fig. 2.) According to Harker [16] this texture is markedly developed in rocks in which the hornblende is

[16] Harker, Alfred, Petrology for students, pp. 67–68, Cambridge, England, University Press, 1923.

in great part derived from augite. Calkins[17] surmised that the hornblende in these sills was secondary and suggested that these rocks are uralitized diabase and gabbro. In the present study augite was seen in only one sill, where it was partly replaced by hornblende, but in the Clark Fork district, west of the Libby quadrangle, Anderson[18] found that hornblende in several pre-Cambrian sills contains cores of hypersthene and augite, and he suggests that the hornblende in all these sills has replaced pyroxene. Kirkham and Ellis[19] are of the same opinion concerning the hornblende in the pre-Cambrian sills in

FIGURE 2.—Texture of a pre-Cambrian sill. Hornblende grains cut and replace feldspar (andesine). 1, Twinned hornblende; 2, andesite; 3, quartz or plagioclase; 4, biotite. Sketch by W. F. Jenks.

Boundary County, Idaho, northwest of the Libby quadrangle. Augite is common, also, in the sills in the Wallace and other formations south of the Coeur d'Alene district. As the sills in all these areas are very similar in composition, are observed in the same formations of the Belt series, and are almost certainly identical in age, it is believed that they have had very similar histories, except that they have been affected by regional metamorphism to a greater degree in some places than in others.[20] Amphibolization of the sills has been more fully discussed elsewhere.[21]

[17] Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey, Bull. 384, p. 49, 1909.

[18] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, p. 27, 1930.

[19] Kirkham, V. R. D. and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bur. Mines and Geology Bull. 10, p. 37, 1926.

[20] Pardee, J. T., Geology and Mineralization of the upper St. Joe River Basin, Idaho: U. S. Geol. Survey Bull. 470, pp. 39–61, 1911. Calkins, F. C., and Jones, E. L., Jr., Geology of the St. Joe-Clearwater region, Idaho: U. S. Geol. Survey Bull. 530, pp. 75–86, 1913.

[21] Gibson, Russell, and Jenks, W. F., Amphibolization of sills and dikes in the Libby quadrangle, Mont.: Am. Mineralogist, vol. 23, pp. 302–313, 1938.

Optical properties of hornblende from two sills are given below.

	α	β	γ	$\gamma-\alpha$	Z∧c	2 V	Sign
Large sill between Snowstorm mine and Lenia fault	1.658	1.672	1.681	0.023	19°	77°	(−)
Sill at Martin's prospect northwest of Hayes Ridge	1.669	1.681	1.691	.022	16°	85°	(−)

Pleochroism	X	Y	Z
Large sill between Snowstorm mine and Lenia fault.	Pale yellowish blue	Dark yellowish green	Dark greenish blue.
Sill at Martin's prospect northwest of Hayes Ridge.	Pale yellowish brown	Pale olive green	Deep bluish green.

In some specimens the hornblende is fresh and makes up as much as 65 to 70 percent of the rock; in others it shows different degrees of alteration. It was the first mineral to be attacked by hydrothermal solutions and was replaced chiefly by chlorite and to a less extent by carbonate, epidote, biotite, magnetite, and albite.

Plagioclase.—Most of the feldspar of the sills is plagioclase, ranging in composition from albite to andesine. In some specimens there are two kinds of plagioclase, but zoning is in general of minor importance. As a rule, to which there are few exceptions, the feldspar of the least altered sills is oligoclase or andesine. These have commonly been replaced in the more altered sills by albite or albite-oligoclase, accompanied by common epidote and by clinozoisite. The average grain size is 0.60 millimeter, but the common range is from about 0.10 to 2 millimeters. Exceptionally the grains reach a length of 30 millimeters. The alteration of the plagioclase to minerals other than secondary sodic plagioclase is not so widespread or so conspicuous and did not begin so early as the alteration of the hornblende; a rock in which the hornblende has been completely or almost completely replaced may contain 15 to 65 percent of albite or even, less commonly, some residual andesine. In places, however, especially in the neighborhood of prospects, the plagioclase is completely replaced by sericite, clinozoisite, epidote, and carbonate.

Quartz.—Quartz is erratic in distribution and grain size but is commonly fine-grained. Much of it has clearly been introduced during the hydrothermal alteration of the sills, but even the sills that still consist mainly of hornblende and plagioclase commonly contain as much as 12 percent of quartz.

AGE

Calkins [22] in describing these sills expressed no opinion regarding their age, and no evidence as to their age was found within the quad-

[22] Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, 1909.

rangle during the present survey, and Daly did not state the age of the sills studied by him to the north. Similar sills in the Clark Fork region [23] and in Boundary County, Idaho,[24] are regarded as pre-Cambrian, because there are boulders derived from them in Anderson's Sandpoint conglomerate, thought to be of late Paleozoic age, and because they have not been found at stratigraphic levels above the Wallace. They have been correlated with the Purcell sills in Canada described by Daly [25] and Schofield.[26] The sills are more numerous in these areas in northern Idaho than they are in the Libby quadrangle and farther south. Only one sill is reported from the Trout Creek [27] quadrangle and none from the Coeur d'Alene district. The sills thus appear to decrease in number and thickness from northwest to southeast in the parts of northern Idaho and northwestern Montana discussed here. South of the Coeur d'Alene district, however, in parts of Shoshone County, Idaho, there are similar sills in the Belt rocks, one of which has been traced for 15 miles.

As the area is invaded by dikes of late Mesozoic age, some of which are very similar in composition and appearance to the sills, it could be suggested that some of the sills are the same age as the dikes. The long sills, however, which appear to have been folded and faulted with the Belt strata and to have taken part in all the orogenic movements that affected those strata are certainly to be correlated with similar pre-Cambrian sills in northern Idaho. Only one of the sills in the Libby quadrangle regarded as pre-Cambrian exhibited a crosscutting apophysis. This was a small dike and was traced for only a few feet. The greater part of the intrusive in question is clearly a sill.

MESOZOIC(?) INTRUSIVE ROCKS

STOCKS

DRY CREEK STOCK OF QUARTZ MONZONITE OR GRANODIORITE

The largest intrusive body in the quadrangle, the Dry Creek stock, underlies the valley of Dry Creek and parts of the valleys of several other creeks on the west side of the high range between Lake Creek and Libby Creek. Some of its eastern part is drained by the West Fork of Granite Creek. The area of the Dry Creek stock is 20.5 square miles.

Except at its western border, the contact of the stock with the Belt rocks is intrusive. On the whole it is crosscutting and dips steeply outward, but in a few places it alternately follows bedding planes for

[23] Anderson, A. L., op. cit., pp. 25–26, 1930.

[24] Kirkham, V. R. D., and Ellis, E. W., op. cit., pp. 36–38, 1926.

[25] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 207–255, 1912.

[26] Schofield, S. J., Geology of Cranbrook map-area, British Columbia, Canada Geol. Survey Mem. 76, pp. 56–70, 1915.

[27] Jenks, W. F., Personal communication.

short distances and then cuts directly across them. The west side of the stock is cut off by the Bull Lake fault, described on pages 42–43.

The stock consists mainly of a very light-gray, massive, medium-grained quartz monzonite, in which feldspar, quartz, and biotite are the dominant constituents. Near the Bull Lake fault, however, the rock is foliated, the foliation becoming more and more pronounced as the fault is approached.

In two-thirds of the thin sections examined andesine is more abundant than potash feldspar. Orthoclase, some of which is perthitic, is the dominant potash feldspar; in many sections, however, a little microline is present, and in a few sections this feldspar is abundant. Hornblende is scarce, being commonly present only near the border of the stock. Accessory apatite, zircon, and magnetite are uniformly distributed; allanite is present in two-thirds of the sections studied but is nowhere abundant; sphene is even scarcer; and tourmaline and pyrite were seen in a few sections.

Certain of the accessory minerals are especially abundant at some places near the contact, but there is no development of a dark-colored border facies nor any evidence of marginal chilling. The cross-cutting contact with the sedimentary rocks is in most places sharp.

In the following table are listed the modes of three specimens taken from different parts of the stock. The fourth line shows an average of the modes of 39 rocks and probably represents closely the average mineral composition of the intrusive. For comparison the average mineral composition of the other three similar stocks in the quadrangle is given also.

Modes of specimens from Dry Creek stock and three similar stocks in the Libby quadrangle

Specimen	Quartz	Potash feld-spar	Plagi-oclase	Biotite	Horn-blende	Acces-sory min-erals	Total
East side of Dry Creek stock	22.9	19.2	41.9	15.5	--------	0.5	100
South side of Dry Creek stock	24.7	20.2	32.7	21.8	Trace	.6	100
Western central part of Dry Creek stock	22.0	10.3	51.8	15.9	--------	Trace	100
Average of 39 thin sections from Dry Creek stock	27.8	20.2	32.8	14.2	2.4	2.6	100
Average of 7 thin sections from stock at forks of Granite Creek	30.4	11.3	39.3	15.8	2.9	.3	100
Average of 11 thin sections from stock on Parmenter Creek	29.0	20.7	38.5	11.1	Trace	.7	100
Average of 2 thin sections from stock on Hayes Ridge	29.6	19.6	38.4	5.8	--------	6.6	100

The quartz exhibits no unusual features. It averages about 0.5 millimeter in diameter but has a great range in grain size, and in some sections it is segregated into coarse-grained aggregates 5 to 10 millimeters in diameter. In a few sections, especially from places near the Bull Lake fault, the quartz grains appear to be shattered or granulated.

The andesine is euhedral to subhedral and was evidently crystallized early. The grains average 0.9 millimeter in length and rarely they attain a maximum of 5 millimeters. So much of the andesine is zoned that its average composition is difficult to estimate. The zones commonly range in composition from An_{40} to An_{30}. Almost all specimens show evidence of some hydrothermal alteration, but this is not conspicuous except near the Bull Lake fault.

Orthoclase varies widely in grain size, abundance, and place in the crystallization sequence. The grains average 1 millimeter in length and reach a maximum of 3 millimeters. Orthoclase is usually less abundant than andesine, but in one-third of the sections it is more abundant. A few grains show Carlsbad twinning. In most specimens little or no microperthite can be seen except in some of the large grains, where it is conspicuous. Most of the orthoclase appears to have crystallized late, together with the quartz, so that the two minerals form a mosaic. Most of the orthoclase is nearly fresh, but in two-thirds of the sections it has been replaced in some degree by one or more of the minerals sericite, zoisite, and epidote, and in a few specimens this replacement is conspicuous.

Biotite is the most abundant primary ferromagnesian constituent, and in most sections it is the only one. Its average grain size is 0.7 millimeter. It occurs in euhedral plates, which rarely show any indication of parallelism except in specimens taken near the contacts, and is distributed in fairly uniform proportion (12 to 18 percent) through most of the specimens. The biotite is strongly pleochroic in dark greenish-brown and yellow. In general it is little altered, but small parts of a few foils in nearly every section are partly or wholly replaced by chlorite, epidote, magnetite, or sericite, or by all of them, together with a smaller quantity of leucoxene. Rutile needles are enclosed in a little of the biotite.

Part of the magnetite is in irregular grains and appears to have crystallized late. Where it replaces biotite its shape is influenced by the cleavage of the biotite. Magnetite is commonly associated with epidote and in some sections nearly surrounded by it.

Allanite is as widely distributed as magnetite but is not so abundant. Its relations to the other minerals are similar to those of magnetite, and it seems to be even more clearly a product of late crystallization.

Sphene is neither so widespread nor so abundant as magnetite and allanite. Its place in the mineral sequence is also late. All these late minerals are discussed under deuteric effects on pages 35–36.

Throughout most of the exposures of the Dry Creek stock the rock appears to be uniform in composition. Microscopic study shows, however, that there is some variation in the relative abundance of the feldspars. The average composition of the rock, as shown by 39 thin sections from the Dry Creek stock (see table above), is that of a quartz monzonite according to Lindgren's definitions,[28] which are followed here, but some parts of the stock, including the specimen analyzed (p. 27) are more accurately classed as granodiorite, and local facies of it are granitic. If, however, Johannsen's definition [29] of granodiorite be adopted, it would include most variations of this rock.

Ovoid masses a few inches to a foot or more in diameter that resemble ferromagnesian segregations are conspicuous in the Dry Creek stock. These masses contain 50 percent or more of biotite. One specimen exceptionally rich in biotite was found, when studied in thin section, to consist chiefly of a mosaic of quartz grains in which small flakes of biotite were abundantly distributed. A few large irregularly bounded crystals of potash feldspar enclosing large numbers of small biotite flakes and a few small grains of quartz were also present. The texture is thus locally micropoikilitic, although the feldspars are probably of secondary development and are to be regarded as metacrysts. This mass is probably due to reaction between the magma and inclusions of Belt or other sedimentary rock. To what extent all such segregation-like masses should be attributed to alteration of inclusions is conjectural. It seems probable that, in many of these masses at least, the nucleus is of this type and that its presence has caused the abundant crystallization of biotite in its vicinity.

A specimen of quartz monzonite from the Dry Creek stock was analyzed with the result shown in the following table. The norm, cal-

Analysis, norm, and mode of quartz monzonite from the Dry Creek stock

[George Steiger, analyst]

Analysis		Norm		Mode	
SiO_2	69. 10	Quartz	30. 48	Quartz	28. 0
Al_2O_3	15. 83	Orthoclase	20. 57	Potash feldspar	10. 3
Fe_2O_3	. 72	Albite	20. 96	Plagioclase	43. 7
FeO	2. 20	Anorthite	18. 07	Biotite	11. 3
MgO	1. 16	Corundum	1. 33	Hornblende	Trace
CaO	3. 80	Hypersthene	5. 94	Accessory minerals [1]	6. 7
Na_2O	2. 52	Magnetite	. 93		100. 00
K_2O	3. 50	Ilmenite	. 76		
H_2O [100°]	. 19	Apatite	. 34		
H_2O [300°]	. 58				
H_2O [blast]	-----		99. 38		
TiO_2	. 39	I ".4." 3.3 *Amiatose.*			
P_2O_5	. 17				
MnO	. 06				
	100. 22				

[1] Includes some sericite and epidote.

[28] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, p. 275, 1900.

[29] Johannsen, A., A descriptive petrography of the igneous rocks, vol. 2, p. 320, Univ. Chicago Press, 1932.

culated according to the quantitative classification, and the mode are also given. The feldspar ratio in the mode is that of granodiorite rather than quartz monzonite.

GRANODIORITE STOCK ON GRANITE CREEK

The small stock at the forks of Granite Creek is mineralogically and texturally similar to the main mass of the Dry Creek stock, from which it is probably an apophysis. It is a little lower in potash feldspar, however, and is unquestionably a granodiorite.

PAYNE CREEK STOCK OF METADIORITE

The Payne Creek stock, which is south of the southwest corner of the Dry Creek stock, is composed of two distinct kinds of rock. The oldest was originally a quartz diorite, but it has since undergone amphibolization and is here called a metadiorite. Cutting the metadiorite is a small body of quartz monzonite.

The metadiorite is a dark-green, massive, medium-grained rock, very similar in texture and composition to the rock of the pre-Cambrian Purcell sills. Its megascopic minerals are feldspar, hornblende, quartz, and a little biotite. Its texture, as seen under the microscope, is characterized by interlocking hornblende crystals that cut through those of quartz and zoned andesine-oligoclase grains. The average mode of four samples of the metadiorite is given below.

	Percent
Hornblende	55.4
Biotite	2.9
Zoned andesine-oligoclase	32.3
Quartz	5.4
Epidote+clinozoisite Ilmenite+leucoxene Apatite Tourmaline Chlorite	4.0
	100.0

The hornblende of the metadiorite occurs in irregular elongate crystals and is very strongly pleochroic. The optical properties of a typical sample are as follows: $\alpha=1.638$, $\beta=1.652$, $\gamma=1.665$, $\gamma-\alpha=0.027$; pleochroism, X=pale yellow brown, Y=olive green, Z=dark bluish green; $2V\ (-)=88°$ (calculated); $Z \wedge c=22°$; dispersion $r>v$ weak. These optical properties check rather closely with those given by Rice[30] for an analyzed hornblende from one of the Purcell sills in British Columbia.

[30] Rice, H. M. A., Amphibole from the Purcell sills, British Columbia. Am. Mineralogist, vol., 20, pp. 307–309, 1935.

In some thin sections the zoned andesine-oligoclase grains form an interlocking texture common in diorites, and in these sections the feldspar probably shows the original rock texture, elsewhere largely obliterated by the formation of hornblende. The quartz is finely granular and appears to have been but little recrystallized. The other minerals tabulated in the mode above are either deuteric or hydrothermally introduced.

The quartz monzonite body that cuts the metadiorite shows evidence throughout of having been appreciably altered after crystallizing. The least altered rock, which probably most nearly represents the original composition of the mass, is near the eastern contact. This rock is very similar to that of the Dry Creek stock, except for certain effects of the shearing and granulation caused by movement along the Bull Lake fault.

HAYES RIDGE STOCK OF QUARTZ MONZONITE

On Hayes Ridge is a small stock, with an exposed area of only about half a square mile, composed of quartz monzonite similar to that of the Dry Creek stock. One difference is the presence in the Hayes Ridge stock of 3 to 5 percent of muscovite, a mineral not common in quartz monzonites. Two types of rock, differing only in grain, have been noted in the stock, but they are so intermingled that they cannot be mapped separately.

PARMENTER CREEK STOCK OF QUARTZ MONZONITE

The small exposed area of intrusive rock near Parmenter Creek is believed to be the top of a stock. It is similar in composition to the other stocks, and it crosscuts folded Belt strata, which exhibit contact metamorphism similar to that observed adjacent to the other stocks. The Parmenter Creek stock, however, differs from the other quartz monzonite stocks in being somewhat porphyritic in a few places. The groundmass in the porphyritic part consists of grains that are mostly 0.1 to 0.5 millimeter in diameter, which commonly make up 20 to 50 percent of the thin sections studied, the remainder consisting largely of subhedral phenocrysts of quartz, plagioclase, and potash feldspar 3 to 10 millimeters in diameter. The essential minerals are the same in both the fine-grained and the coarse-grained parts, but plagioclase is more abundant in the coarse-grained rock.

SYENITE STOCK ON BOBTAIL CREEK

The syenite stock on the east side of Bobtail Creek forms bold, rugged outcrops, in marked contrast with the Belt rocks at this locality, which weather to gentler slopes. The texture of the rock is notable for the marked parallelism commonly shown by the large orthoclase grains, which have an average length of 1 centimeter and attain a maximum length of 9 centimeters. This pronounced parallelism is found in most parts of the rock where orthoclase is the chief constituent but is not so noticeable in the ferromagnesian facies of the rock. In some parts of every outcrop the orthoclase grains are seemingly parallel, but they fail to show any systematic arrangement for the stock as a whole. Parts of the stock are equigranular and have an average grain-size of 0.2 millimeter. The rock is prevailingly gray. It contains dark-colored segregations, a few of them as much as 50 feet long, in which the chief minerals are pyroxene and amphibole, with subordinate amounts of magnetite, sphene, and other minerals. Rarely these dark segregations are alined in streaks parallel with the large felspar crystals of the syenite; more commonly they are not. Coarse-grained, porphyritic, light-colored facies of the stock appear to be later than these segregations of dark minerals and to cut across them, but the relations are not certain.

The minerals most abundant in the stock are orthoclase, pyroxene, and andesine, which together make up more than 90 percent of the rock. Orthoclase in large euhedral grains is commonly the predominant mineral, but in the ferromagnesian facies it may amount to only 10 percent or even less. Andesine is almost invariably present, and in some places it is abundant enough to justify calling the rock a monzonite. The accessory minerals apatite, magnetite, and sphene occur in all specimens; zircon and pyrite are present in a few. Hornblende varies greatly in amount and in a few places is almost as abundant as pyroxene. A little sericite, chlorite, epidote, allanite, zoisite, leucoxene, rutile, and iron oxide have grown at the expense of other minerals. The mode of a typical specimen of this rock is given below.

	Percent
Quartz	1.3
Orthoclase	69.2
Andesine	18.0
Pyroxene and hornblende	4.5
Accessory minerals	7.0
Total	100.0

A little microperthite is present in about half of the specimens examined. Inclusions of many of the associated minerals especially apatite, pyroxene, and andesine, are common in the large grains. The orthoclase is remarkably fresh, though in some sections it is replaced to a small extent by one or more of the minerals sericite, epidote, and clinozoisite.

Andesine with a composition of An_{40} is in general a minor constituent, though it makes up as much as 35 percent of a few specimens and rarely may exceed orthoclase in abundance. It is most abundant in a fine-grained, equigranular facies of the rock, where it forms grains less than 0.2 millimeter in average length, and in the matrix of the giant-grained facies. It is twinned according to the Carlsbad, pericline, and albite laws. A few grains are zoned. Small quantities of the same alteration products that are present in the orthoclase were seen in the plagioclase. Both types of feldspar are more altered in the ferromagnesian and border facies than elsewhere.

The pyroxene is deep green and anhedral to euhedral, and it has the following optical properties: $\alpha=1.707$, $\beta=1.713$, $\gamma=1.734$, $\gamma-\alpha=0.027$; faint pleochroism; $2V(+)=65°$; $Z \wedge c=42°$; dispersion $r>v$. The grains vary greatly in size and shape. Their maximum length is about 0.6 millimeter, but their average length is much less. Some grains are twinned, and some exceedingly small subhedrons are poikilitically included in the feldspars. Most grains are unaltered, but hornblende locally replaces pyroxene along cleavage, parting, and grain boundaries. Epidote and chlorite also replace pyroxene to a very slight extent.

The hornblende may be primary in part, but most of it appears to be a hydrothermal alteration product of pyroxene. It is commonly anhedral and ranges in grain size from 0.15 millimeter to 6.5 millimeters, but the average is close to the smaller figure. The large grains have inclusions of the accessory and other minerals. The hornblende has the following optical properties: $\alpha=1.682$, $\beta=1.693$, $\gamma=1.705$, $\gamma-\alpha=0.023$; pleochroism, X=yellowish, Y=yellow-green, Z=dark green; $2V(-)=$large; $Z \wedge c=22°$; dispersion $r>v$; a few grains are twinned. It is slightly altered to chlorite, biotite, or rutile.

Quartz in irregular interstitial grains is a minor constituent of about half the sections of syenite examined, but it is invariably present in the dikes that cut the stock.

The apatite, magnetite, and sphene may in part have crystallized early, but, as explained below, the magnetite and sphene were mainly late in the sequence and were probably deuteric.

Its dominant presence as phenocrysts might be regarded as evidence that orthoclase crystallized early for the most part, but in the finer-grained and in the darker facies of the stock it appears also as a late-forming mineral; furthermore, the borders of some of the large orthoclass grains are ragged and look as though they had grown by accretion of material after the surrounding minerals had crystallized.

In the specimens consisting chiefly of pyroxene and hornblende some of the orthoclase grains are rather thoroughly altered to sericite, whereas others are fresh. In the ferromagnesian facies the pyroxene is clearly early, as orthoclase, magnetite, and sphene are interstitial to it. G. F. Loughlin has suggested that the ferromagnesian facies of the stock may represent the part of the rock that had escaped pronounced replacement by orthoclase. Features in thin sections lend some support to this idea, but unfortunately the field exposures of the two facies are not good enough to permit a satisfactory conclusion to be reached.

Microscopic study shows certain striking textural features that afford evidence of deuteric action. Sphene, an unusually abundant accessory mineral, forms some euhedral crystals, but it is more abundant in shapeless grains interstitial to or molded on pyroxene, magnetite, or other minerals or replacing feldspar. Magnetite is likewise a deuteric mineral and is interstitial to all of the essential minerals and apatite. Another deuteric effect seen in about a third of the sections is the replacement of both orthoclase and andesine along their borders by graphic intergrowths of quartz and feldspar.

The parallelism of the feldspars is evidently due to flowage just previous to crystallization of the magma rather than to any subsequent deforming influences. There is neither protoclastic texture nor evidence of strain or of recrystallization in the rock.

The feldspar crystals are elongate parallel to the *a* axis. Although the *a* axes of most of the crystals are roughly parallel, there is no apparent parallelism of the *b* and *c* crystallographic axes.

The stock is cut by light-colored dikes 2 inches to 20 feet in width, whose grain is commonly finer and more even than the average grain of the syenite. The dikes contain the same minerals as the stock, but in different proportions. Quartz is invariably present, but in some places there are only a few grains to a thin section while elsewhere there is as much as 11 percent. Although orthoclase is usually dominant, andesine makes up 59 percent of some dikes, so that the dikes range in composition from quartz syenite to quartz monzonite. No pegmatites were seen to be associated with the stock.

DIKES

DISTRIBUTION AND RELATIONS

Most of the large or persistent dikes in the Libby quadrangle are in the northwestern part of the area; some of them are exposed north and south of Callahan Creek west of the Lenia fault, and others occur north of Keeler Creek. A few dikes cut the stocks and the sedimentary rocks near the borders of the stocks, and two small dikes were observed on Ross Creek. Some of the dikes in the neighborhood of Callahan Creek are within 4 miles of a granodiorite stock and within 10 miles of a batholith, both of which are in Idaho and have been described by Anderson.[31]

The Snowstorm mine, which is the largest in the Libby quadrangle, and many of the prospects on Grouse Mountain and in the area immediately north and south of Callahan Creek are in metadiorite dikes.

[31] Anderson, A. L., op. cit.

This area contains a larger known concentration of metalliferous deposits than any other in the quadrangle. In view of this fact and of the nearness of the granodiorite plutonic intrusives in Idaho, the area is probably underlain by a stock that has not yet been revealed by erosion or penetrated by mine workings.

A few of the dikes were injected along faults in the Belt rocks or have been faulted along the contacts. The thickest dike in the quadrangle, 300 feet thick, exposed on the ridge between the Bull River and its North Fork, occupies a fault fissure. One good exposure and two areas of float indicate that a mafic intrusive body, probably a dike, extends along the Savage Lake fault and along the Bull Lake fault south of the inferred junction of these two faults. Only south of the junction, however, can the intrustive be mapped with certainty along the fault. Here it is cut by quartz veins that are nearly barren of sulfides.

The dikes closely associated with the stocks in the quadrangle are only a few inches to a few feet in thickness and are not persistent. They are too small to show on plate 1. Those more remote from the stocks are thicker, though commonly less than 100 feet thick, and have been traced for distances of as much as 3½ miles. They commonly trend northwest with the general structural pattern of the country.

CHARACTER

Dikes closely associated with stocks.—The dikes in the sedimentary rocks and in the marginal parts of stocks range in composition from granite to quartz diorite but are mostly granitic. A few of the coarse-grained dikes are somewhat porphyritic, and a few porphyritic dikes having the composition of quartz latite or of lamprophyre have been observed. Pegmatite facies are rare. Dikes are more numerous and more diverse in composition and texture within the stocks than in the adjacent Belt rocks.

The commonest dike rock is white to light greenish-gray and even-grained to slightly porphyritic; it is composed chiefly of quartz and feldspar, though it may contain as much as 15 percent of biotite. The grains in the specimens with fine texture average about 0.03 millimeter in diameter, those in the coarser-textured specimens about 0.5 millimeter. Exceptionally the grains of feldspar and biotite may attain a length of 3 millimeters. The plagioclase, which is commonly albite or albite-oligoclase, is usually subordinate in amount to potash feldspar. The latter is commonly perthitic, and a small part of it is in graphic intergrowth with quartz. The accessory minerals are the same as those in the granodiorite stocks. The dike rocks are relatively fresh. Epidote, the chief product of hydrothermal alteration, may make up as much as 22 percent of a section. Other alteration minerals present

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in much smaller quantities are chlorite, sericite, clinozoisite, and leucoxene. Tourmaline was found in all the thin sections from dikes that cut the Belt rocks, but not in the dikes that cut the stocks.

Dikes not closely associated with stocks.—Most of the dikes away from the margins of the stocks are concentrated in the northwest corner of the quadrangle, on Grouse Mountain and near the Snowstorm mine on Callahan Creek. In this area the dikes cut the Prichard formation and to a less extent the Ravalli formation. They are commonly dark-colored, richer in ferromagnesian minerals than in plagioclase, and of coarse, even texture. They exhibit many degrees of alteration. The rocks in these dark-colored dikes have been called metadiorite, because it is believed that their original composition was somewhat similar to that of a diorite. On Grouse Mountain there is a thin dike of light-colored porphyritic quartz latite called by the miners "spotted porphyry." This dike ranges in thickness from 3½ to 14 feet. In some places it follows the bedding, but elsewhere it distinctly crosscuts the Prichard formation, and in the Iron Mask mine it cuts a metadiorite dike. Similar small dikes were seen in the Ravalli formation on Ross Creek. The metadiorite dikes contain many of the veins discussed in the section on metalliferous deposits, whereas all the porphyry dikes that were seen are barren.

The metadiorite dikes, where not greatly altered, are made up chiefly of hornblende and andesine or, less commonly, sodic labradorite or oligoclase. One to 10 percent of quartz is present, and the accessory minerals are apatite, zircon, tourmaline, sphene, magnetite, and ilmenite. Where the hornblende is fresh there is little or no biotite. One of the dikes contains 25 to 40 percent of augite, all of it partly altered to hornblende. Probably all of the hornblende in the dikes was formed by replacement of pyroxene, but if this be true replacement has been so thorough and recrystallization so complete that all traces of the pyroxene have disappeared from most of the dikes. A full discussion of the amphibolization of the dikes has been published elsewhere.[32]

Many of the metadiorite dikes contain metalliferous deposits, and these dikes are in general more thoroughly altered than the petrographically similar pre-Cambrian sills. Some are now wholly or partly composed of chlorite, sericite, carbonate, quartz, and biotite, with lesser amounts of clinozoisite, epidote, and other minerals. No important metalliferous deposits were seen in dikes or parts of dikes that contained much hornblende or plagioclase, for these minerals were destroyed by the solutions that deposited the ore minerals.

The hornblende in these dikes is similar to that in the metadiorite of the Payne Creek stock except for slight differences in their optical

[32] Gibson, Russell, and Jenks, W. F., Amphibolization of sills and dikes in the Libby quadrangle, Mont.: Am. Mineralogist, vol. 23, pp. 302–313, 1938.

properties, which are described below. It also resembles that in the pre-Cambrian metadiorite sills of the Libby quadrangle except that the hornblende grains in the dikes are more uniform in size and smaller on the average than those in the sills. The hornblende is less abundant also, in the dikes, because so much of it is hydrothermally altered. It rarely makes up as much as 25 percent of a thin section, and in 80 percent of the thin sections examined it is completely altered. To a less extent than in the sills, hornblende penetrates and replaces plagioclase. The optical properties of specimens of hornblende from two dikes are given below.

Dike	α	β	γ	$\gamma-\alpha$	$Z \wedge c$	2 V	Sign
Dike at Togo prospect on Callahan Creek.	1.637	1.652	1.661	0.024	18°	80°	Negative.
Dike at Big Four prospect on Gordon Creek.	1.662	1.673	1.682	.020	17°	80°	Do.

Pleochroism for both: X, Pale olive-green; Y, olive-green; Z, blue-green.

Andesine, the dominant plagioclase in the metadiorite dikes, is present in about half the thin sections in grains that range from 0.10 to 3 millimeters in length. Unlike the plagioclase in the sills it is not altered to albite. It may be seen in all stages of hydrothermal replacement by other minerals, but it is more resistant than hornblende and may constitute as much as 50 percent of a section where hornblende has entirely disappeared. Minor quantities of graphically intergrown plagioclase and quartz were seen in a few sections.

The accessory minerals require no detailed discussion.

METAMORPHISM

AUTOMETAMORPHIC ALTERATION IN THE STOCKS

From their distribution, the shapes of their grains, and their sequence of deposition, it is inferred that the magnetite, sphene, epidote, allanite, myrmekite, and micropegmatite are largely autometamorphic in origin; that is, they were formed shortly after the consolidation of the rock but before any hydrothermal changes took place. These minerals are not especially abundant in places that are favorable for hydrothermal attack, such as the western border of the stock on Dry Creek near the Bull Lake fault, or in the marginal parts of the stock on Parmenter Creek; in fact, they are less abundant in such places than elsewhere and appear to be distributed haphazard throughout the stocks. The shapes assumed by the magnetite, sphene, epidote, and allanite also indicate that they were formed after the rock had become solid. They are molded on, or lie between, grains of all of the more abundant early minerals; in many places their shapes are exceedingly irregular, and long fingerlike protuberances or wedges of these minerals extend across or between other minerals. Magnetite appears to be molded on pyroxene and biotite in irregular shapes and to be interstitial to pyroxene and other minerals.

Micrographic intergrowths of quartz and potash feldspar or of quartz and plagioclase are found in the interior of and at the border of both kinds of feldspar, either as interstitial filling or, more probably, as products of replacement. In places the feldspar-quartz intergrowths form coronas or irregular areas cutting across cleavages and twin lamellae of the host mineral. Where evidence of replacement is clear, it is found that intergrowths of vermicular quartz and plagioclase have replaced both potash feldspar and plagioclase, whereas similar intergrowths of quartz and potash feldspar most commonly replaced potash feldspar.

The relations of these minerals markedly resemble those recorded by Gillson [33] in his study of the nearby granodiorite at Pend Oreille, Idaho. The textural relations so well illustrated by Gillson's sketches could be duplicated in most of the thin sections from the Libby stocks, and it is clear that the processes of crystallization in the magmas concerned have been closely parallel in the two localities. Anderson [34] also mentions the relations of late-stage myrmekite, sphene, and magnetite in granodiorite of the Cassia batholith in southern Idaho as "suggesting a deuteric origin." Anderson and Rasor [35] report that sphene and allanite occur in or cut all minerals except quartz in the older (darker) facies of the granodiorite of the Idaho batholith in Boise County, Idaho. Currier [36] observed the effects of "marked deuteric reactions" in the Idaho batholith in the Yellow Pine district of Valley County in central Idaho. He states that rims of plagioclase are replaced by such intergrowths in the quartz monzonite facies of the batholith, and that allanite and zoisite were formed late in the magmatic history. These intergrowths are present also in the granodiorite facies. Sphene appears to be a late mineral "possibly of an early hydrothermal stage." Anderson [37] found late growths of sphene and allanite in granodiorite of a part of the Nelson batholith and outlying stocks in the Clark Fork district of northern Idaho. Some of the stocks that he describes are within 3 miles of the Libby quadrangle.

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[33] Gillson, J. L., Granodiorites of the Pend Oreille district of northern Idaho: Jour. Geology, vol. 35, pp. 1–31, 1927.

[34] Anderson, A. L., Contact phenomena associated with the Cassia batholith, Idaho: Jour. Geology, vol. 42, p. 382, 1934.

[35] Anderson, A. L., and Rasor, A. C. Composition of the Idaho batholith in Boise County, Idaho: Am. Jour. Sci., 5th ser., vol. 27, No. 160, pp. 287–294, 1934.

[36] Currier, L. W., A preliminary report on the geology and ore deposits of the eastern part of the Yellow Pine district, Idaho: Idaho Bur. Mines and Geology Pamph. 43, pp. 8–11, 1935.

[37] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, 1930.

RELATION OF DRY CREEK STOCK AND PAYNE CREEK STOCK TO BULL LAKE FAULT

Pronounced changes in the western part of the Dry Creek stock and in the Payne Creek stock have been caused by movement along the Bull Lake fault and by solutions rising along the fault.

The Bull Lake fault is a long normal fault with a general north-south trend. The fault plane, which in places can actually be observed, dips westward at angles between 45° and 60°. Evidence is given on p. 42 that the fault was originally a thrust, the western block riding up over the eastern. Shearing effects in both the Dry Creek and Payne Creek stocks increase westward toward the fault. Foliation is made conspicuous by the parallel orientation of biotite, which is here and there drawn out into long narrow streaks, and parallel to these streaks of biotite there are in places elongate pods of granular quartz. These linear structures in the plane of foliation plunge 20° to 70° southwest. The feldspar is granulated but unlike the quartz is not segregated into pods.

In his study of the Idaho batholith, to which these stocks may be related, Ross [38] found that the granitic rocks were intruded later than the major part of the folding but possibly before thrust faulting had ceased, and the evidence just given points to the same conclusion.

Effects of hydrothermal alteration as well as of shearing become more pronounced as the Bull Lake fault is approached. These hydrothermal changes include the alteration of biotite and feldspar to chlorite, sericite, epidote, and quartz. Near the fault, calcite and pyrite have formed in small quantity. The solutions that produced these changes are believed to have been derived from a much deeper part of the stocks than is now exposed and to have risen along the Bull Lake fault.

CONTACT METAMORPHISM

The Belt rocks near the contacts of the stocks, especially near the contacts of the Dry Creek and Hayes Ridge stocks, have been affected by contact metamorphism, but the resulting changes are not nearly so prominent as those produced by mechanical and hydrothermal processes in both igneous and sedimentary rocks along the faults, and there is only one metalliferous deposit in the contact zones around the stocks.

As some recrystallization is evident everywhere in the Belt rocks, it is difficult to determine how much is attributable to the stocks and how much to regional metamorphism that preceded intrusion. Sericite is abundant in the contact-metamorphosed argillaceous rocks, quartz grains are recrystallized in arenaceous beds, and biotite is pres-

[38] Ross, C. P., Some features of the Idaho batholith: 16th Internat. Geol. Cong. Rept., 1933, vol. 1, p. 377, 1936.

ent in many rocks. The resulting rocks other than quartzite are slightly schistose, but their original bedding is not obscured. Xenoliths as much as 10 feet long in the marginal part of the Dry Creek stock show the same mineralogic and textural changes as the adjoining beds.

Near the stocks a few beds contain grains of garnet and diopside, small masses of radial chlorite, thin laminae of actinolite, or sheaf-like bundles of brucite or tremolite. Most of the beds that contain tremolite, actinolite, or diopside also contain at least a little recrystallized carbonate, which is evidence of their originally calcareous or dolomitic character.

The most conspicuous and one of the most widespread contact-metamorphic minerals in the sedimentary rocks is biotite, which is universally present near intrusive bodies, including stocks, sills, and dikes, and increases in abundance as the igneous rock is approached. Small quantities of orthoclase, plagioclase, apatite, tourmaline, sphene, magnetite, and hematite have been introduced near these intrusives.

On Granite Creek, 2 miles east of the two largest stocks, a few thin beds that formerly consisted of magnesian limestone have been largely replaced by tremolite with less diopside. The effects of contact metamorphism are greater here than close to the stocks. This area is especially favorable for hydrothermal attack because of its proximity to the Snowshoe fault, along which there are many lead-zinc-silver prospects. The presence of these silicates along the Snowshoe fault seems attributable to hot solutions circulating along the fault rather than to contact metamorphism as commonly understood.

Around the Hayes Ridge stock the metamorphic aureole, though very irregular in width, is on the whole surprisingly wide, possibly because of the presence of other intrusive bodies not exposed. It may be, however, that the aureole overlies the inclined top of a single intrusive body. On Hayes Ridge, about 1 mile west of the stock, there is a thin bed made up of radiating needles of actinolite with interstitial epidote, calcite, and quartz, and still farther west small garnets and abundant sericite have been formed in an argillaceous bed.

AGE OF THE STOCKS

The age of the stocks and closely related intrusives of the Libby quadrangle cannot be determined from evidence gathered solely within the quadrangle. The rocks are very similar, however, to the granodiorite of the Nelson and Idaho batholiths in Idaho, outliers of which are exposed within 3 miles of the Libby quadrangle, and it is reasonable to infer that the age of the stocks is close to that of the batholiths.

Considering the large areal extent of the Idaho and Nelson batholiths, surprisingly little definite evidence of their age is given in the literature. Schofield[39] in 1915 argued that the Nelson batholith is Jurassic or post-Jurassic. Anderson[40] wrote in 1931 that "the age generally assigned to the Idaho batholith and its differentiates is late Cretaceous or early Eocene." The latest opinion of C. P. Ross,[41] who has spent much time in studying the problem, is that the Idaho batholith is Jurassic or Cretaceous and that possibly the emplacement of the batholith occupied a period of time longer than the entire Jurassic period.

A late Mesozoic age seems more probable than early Eocene, for, as Ross points out, a very large amount of erosion had taken place between the intrusion of the batholiths and the eruption of the Miocene Columbia River lavas.

STRUCTURE

GENERAL FEATURES

The Belt rocks of the Libby quadrangle are affected by folds and faults, which, for the most part, trend northwest. Faulting succeeded folding and has continued at least intermittently up to very recent time. Igneous rocks are relatively minor features in this region, but a few dikes and stocks crosscut the folded Belt rocks. The sills behave structurally as a part of the Belt series. Some structural features related to the intrusives are discussed in the sections of the report on intrusives (pp. 20–39) and on the metalliferous deposits (pp. 67–128).

Lake Creek Valley in the vicinity of Bull Lake and for a few miles northward is a graben. McConnel and Copper Mountains, Freeman Ridge, and the low mountains north of these are in the same downfaulted block.

Similar valleys in northern Idaho and southern British Columbia are discussed by Daly,[42] Schofield,[43] Kirkham and Ellis,[44] Anderson,[45] and others, and are called trenches. Their origin is in dispute. The Lake Creek-Bull Lake Valley for part of its length is certainly bounded by faults and appears to be structural in origin, but it has been greatly modified by glacial and stream erosion.

The structural feature of most economic importance is faulting. Most of the metalliferous veins, more particularly the lead-zinc-silver

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[39] Schofield, S. J., Geology of Cranbrook map-area, British Columbia, Canada Geol. Survey Mem. 76, p. 95, 1915.

[40] Anderson, A. L., op. cit., p. 28.

[41] Ross, C. P., op cit., pp. 369–385.

[42] Daly, R. A., Geology of the North American Cordillera at the 49th parallel: Canada Geol. Survey Mem. 38, pp. 599–600, 1912.

[43] Schofield, S. J., op cit., pp. 167–168.

[44] Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bur. Mines and Geology Bull. 10, pp. 31–33, 1926.

[45] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, pp. 5–9, 1930.

veins, are related to steeply dipping, crosscutting faults, some of which are persistent and have great vertical displacement. Not all of the large faults, however, have valuable mineral deposits related to them.

FOLDS

Most of the folds are large, open, asymmetric anticlines and synclines whose axial planes commonly dip northeastward. The folds trend northwestward, and most of those in the northern and eastern parts of the quadrangle plunge to the northwest. On the flanks of the major folds there are minor open folds, especially where the Wallace is exposed. Near the southern ends of the Snowshoe and Rock Lake faults and in the vicinity of Troy, and to a less extent elsewhere, the folds are closed or nearly isoclinal. Crumpling and shearing are developed locally near the Bull Lake fault, as noted more fully below.

Many of the folds are small compared with the area as a whole, but a few persist for many miles. The Snowshoe anticline can be traced from Samater Mountain, 3 miles northwest of Libby, to the southern border of the district, where it is cut off by the Rock Lake fault. It trends nearly due north and plunges to the north. For most of its length it is broken at the crest by the Snowshoe fault. Along most of the western border of the quadrangle part of a large persistent syncline trending northwestward can be traced, the west limb of which was mapped in Idaho by Anderson.[46] South of the Clark Fork Anderson has mapped the same syncline, offset by the Hope fault.

Other well-developed synclines are shown at Mount Berray and at Flagstaff Mountain, where there is the largest exposure in the quadrangle of the Libby formation.

FAULTS

Long, steeply-dipping, persistent faults, which commonly trend north to northwest and have large displacement, are important structural features in this region, especially with reference to physiography and to metalliferous deposits. The wide Lake Creek-Bull Lake Valley is bounded by such faults, and the largest metalliferous deposits are related to some of them. The Hope fault and a few others strike between west and northwest. Some of these are clearly later than the north-south faults. A fault through Spar Lake strikes northeast, but, as its existence is inferred entirely from the geologic mapping and its fault plane was not observed, its age and its relation to the general structure are not known.

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[46] Anderson, A. L., op cit., p. 40.

The faults are later than the folds, and there have been at least three periods of movement along some of the faults, but owing to the degree of previous folding, no clear evidence was observed that the fault blocks have been appreciably tilted except possibly those related to the Bull Lake fault along the foot of the mountains east of Lake Creek, as described by Pardee under the heading "Physiography." Along some of the mineralized faults there has clearly been renewed movement and renewed deposition of ore; along a few faults there is evidence of relatively recent movement since the retreat of the ice; and along the Bull Lake fault there probably has been a reversal of movement. The major faults will be discussed individually below.

LENIA FAULT

The Lenia fault was recognized and named by Calkins,[47] who mapped a part of it near Troy and along the Kootenai River in Boundary County, Idaho. The fault has been traced continuously for 10 miles within the Libby quadrangle, and it is probably much longer. It almost certainly continues southward either under Bull Lake or, less probably, through the Trio prospect, west of the middle of Bull Lake. Kirkham [48] followed it northward in Idaho to the Canadian line and believes it to be a continuation of the Moyie fault, described by Daly [49] and Schofield.[50]

The Lenia fault was seen underground at only one place, in the Liberty mine. Here the gouge and breccia zone is 20 feet wide, and the fault is vertical. It probably remains nearly vertical to the northern border of the quadrangle, its sinuous course being due to variations in strike. There is no evidence to indicate that movement along the fault was other than vertical. Its downthrow is on the east, and in the northwestern part of the quadrangle it brings the upper part of the Wallace formation in contact with the lower part of the Prichard all of the Ravalli formation being cut out. The displacement there is at least 26,000 feet.

From Lime Butte southward the fault is concealed under glacial deposits and alluvium, but what is believed to be its most probable continuation extends southward along the west side of the Lake Creek-Bull Lake Valley and under the bottom of the lake. At the south end of the lake this fault separates the Wallace (?) on the east from the Ravalli on the west. It probably dies out south of Ross Creek.

The fault in the Trio prospect on Emma Creek is roughly parallel with the Lenia fault for much of its length, but the displacement near

[47] Calkins, F. C., Geological reconnaissance in northern Idaho and northwestern Montana; U. S. Geol. Survey Bull. 384, p. 53, 1909.

[48] Kirkham, V. R. D., and Ellis, E. W., op. cit., pp. 34–35. Kirkham, V. R. D., The Movie-Lenia overthrust fault: Jour. Geology, vol. 38, pp. 364–374, 1930.

[49] Daly, R. A., op cit., p. 138.

[50] Schofield, S. J., op. cit., pp. 94–95.

the prospect is much less than that along the Lenia fault to the north, the Ravalli being exposed in both walls. The fault appears to dip 55° westward, and its downthrow is on the east, but as crushing has been intense and the fault zone has been complicated by a landslide the structural relations were not deciphered with certainty. Fault-breccia float was found about a mile and a half north of the Trio prospect, but the fault was not traced farther in that direction.

It is possible that the fault in the Trio prospect is a split from the Lenia fault and that the two are connected about a mile north of Bull Lake. South of the Trio prospect the fault was mapped entirely on physiographic evidence. It is thought to continue southward along a north-south ravine, just south of Weasel Gulch, to cross Ross Creek, and perhaps to die out in the ravine south of Ross Creek. The two knobs at the mouth of Dry Creek suggest, however, that it may continue still further.

Kirkham connects the Lenia fault with the Bull Lake fault, but this interpretation is believed to be incorrect, for reasons discussed further on.

There are no mines or prospects along the Lenia fault, but on Grouse Mountain and along Callahan Creek, west of the fault, there are veins in sheared metadiorite dikes and in Belt rocks.

BULL LAKE FAULT

The Bull Lake fault was so named by Calkins,[51] who saw it in two places and supposed it to be an overthrust. It is, however, a normal fault with younger beds exposed in the relatively downthrown block on the west. It dips 45° to 60° west and has been traced for 13 miles along a curving course, concave toward the east.

There is good evidence that at an earlier period in its history the fault was a thrust, but Calkins' inference that it is so at present seems to have been chiefly based on a mistaken identification of the rocks to the east as belonging to a formation younger than the Striped Peak; the present relations of the Belt rocks on the two sides of the fault indicate that it is now normal. The quartz monzonite of the Dry Creek and Payne Creek stocks is foliated near the fault, and the foliation, which is essentially parallel to an observed fault plane, gradually increases in intensity toward the fault; both the quartz monzonite in the footwall and the Belt rocks in the hanging wall are brecciated. The fault zone in one place is at least 200 feet wide. The sedimentary rocks along the east side of the fault are crumpled (pl. 5) and schistose throughout a zone that, south of Payne Creek, attains a width of three quarters of a mile. Calkins observed some of this evidence, from which he rightly inferred that so much foliation and shearing was not likely

[51] Calkins, F. C., op. cit., pp. 55, 66–67.

to have been produced by normal faulting along a fissure with a dip of 45°.

South of Crowell Creek (pl. 6) the footwall of the fault forms a scarp about 60 feet high, and for a short distance the fault separates quartz monzonite on the east from glacial material on the west. It is possible that there has been recent renewed movement along the fault here, but on the other hand the relations observed may be due to differential erosion. Along the Savage Lake fault, also, as discussed below, there is inconclusive evidence of recent movement. The Bull Lake fault was not observed north of Madge Creek.

The Bull Lake fault is joined by the Savage Lake fault, described farther on, south of Crowell Creek. From this junction the fault trends southward and then curves to the southeast. The fault was not observed where it crosses the spur north of the forks of Bull River, but was assumed to be in a zone that separates little-folded Wallace strata on the west from strongly folded and sheared Wallace strata on the east. Farther southeast, on the lower end of the west ridge of Ibex Peak, the fault appears as a zone 150 feet wide containing much barren quartz. The adjacent strata, which have in part been metamorphosed to quartz-mica schist, are closely folded. Continuing southeastward, the fault probably passes close to a small area, just north of the mouth of Chippewa Creek, where there is abundant float of vein quartz and iron oxide. Nearby is a small outcrop of the Wallace formation, with the bedding vertical and parallel to the projected line of the fault. Farther south, on the ridge east of the summit of Mount Berray, the fault is presumed to be marked again by abundant vein quartz and by contorted bedding in the adjacent Wallace formation. Here several narrow parallel, vertical shear zones were observed, probably subsidiary to the main fault. About a mile farther south a small metadiorite sill on the south face of Mount Berray appears to be cut off by the fault. Beyond here the Bull Lake fault is lost in Wallace strata that are neither strongly folded nor sheared.

Kirkham [52] interpreted his great Moyie-Lenia overthrust as extending across Lake Creek Valley, north of the Dry Creek stock and connected it with the Bull Lake fault, which he assumes may continue to the Clark Fork. No evidence was found in the present survey that either of these faults continues to the Clark Fork. Kirkham shows the Lenia fault with downthrow on the east, whereas the Bull Lake fault, with which he connects the Lenia, has its downthrow on the west. Moreover, stratigraphic evidence indicates that there are faults extending for several miles on both sides of the Bull Lake-Lake Creek Valley, west of the Dry Creek stock and north of Bull Lake, yet in this area Kirkham shows only one fault.

[52] Kirkham, V. R. D., op. cit.

SAVAGE LAKE FAULT

The Savage Lake fault is largely inferred. It was mapped partly on physiographic and partly on structural evidence.

This fault was seen at only one place—the Crater prospect, a mile east of Savage Lake, where it is vertical and strikes north. The fault zone is here at least 40 feet wide, and the downthrow is on the west. From here southwestward the fault is believed to follow the steep mountain front, which is regarded as a fault scarp similar to that along the northeast side of the Clark Fork. The fault then swings southward along the east side of a few isolated low hills of the Libby formation, most of which are surrounded by glacial material. A persistent metadiorite dike, which in most places is buried in the till, probably follows the Savage Lake fault. One outcrop of metadiorite was found along the Bull Lake fault 2½ miles south of its inferred junction with the Savage Lake fault, and two areas of angular float of the same rock were found along the Savage Lake fault, one near Crowell Creek and the other near Porcupine Creek.

Along the mountain front east and southeast of Savage Lake there are slight depressions and small swamps, which possibly indicate recent downward movement of the depressed block near the mountain.

It may be argued that part or all of the Savage Lake fault may be a northward continuation of the Bull Lake fault. For some distance both north and south of the inferred junction of the two faults, however, field evidence was found indicating that what is here called the Bull Lake fault is the same fault that was so named by Calkins. It seems proper, therefore, to regard the Savage Lake fault, about which much less is known, as a different fault.

O'BRIEN CREEK FAULT

The existence of the O'Brien Creek fault was first suggested by the abrupt rise in the mountain front facing O'Brien Creek, north of Kootenai River. There is incomplete evidence that the fault continues from Savage Lake north-northwestward to the northern boundary of the quadrangle. Stratigraphic evidence indicates that the downthrow is on the west. The fault, as will be shown, dips steeply to the west and is therefore normal.

In the "island" of Wallace formation just north of Savage Lake the beds are intensely folded. The beds at the northeast end of this outcrop dip northeast, whereas those at the southwest end dip northwest. In a small prospect in metadiorite at the southwest end of the outcrop is a quartz vein, containing a little sulfide, which strikes northwest. The fault is thought to pass through this outcrop in a north-northwesterly direction and to cross the Great Northern tracks about a mile further on. The finding of metadiorite and a quartz vein along this supposed fault line, as along the Savage Lake and Bull Lake faults farther south, would not be regarded as sufficient evidence of faulting were it not for the supporting evidence nearby, given below.

About a mile north of Savage Lake, along the Great Northern right-of-way, the fault probably passes through a narrow zone of sheared and strongly folded Wallace strata. The shear zone dips steeply westward. Half a mile north-northwest of this locality, along Kootenai River, the strata are closely folded, crumpled, and sheared. Along the east side of some narrow ravines trending northwestward, slickensided fault faces of the Wallace cut across the general structure; these faces dip about 60° southwest.

From Kootenai River northward the fault is concealed under alluvium. It passes very close to the mountain front on the east side of O'Brien Creek where the stream crosses the parallel 48°30′ N., for here, also, are small benches and ravines that trend north-northwest, similar to thoses along Kootenai River described in the preceding paragraph. No slickensided surfaces were found, however, along O'Brien Creek.

SNOWSHOE FAULT

The Snowshoe fault, named by Calkins for the Snowshoe mine, was traced during the present survey for 16 miles. It strikes north or a little east or west of north for most of its length and is nearly vertical. It cuts the crest of the northward-plunging Snowshoe anticline. The western side, which is topographically the higher, is downthrown. At the north the fault is cut off by a small fault along Horse Creek. Its southern end swings a little to the southeast, and it dies out in the Snowshoe anticline east of Elephant Peak. This anticline is truncated farther south by the Rock Lake fault, which strikes more toward the northwest than the Snowshoe fault and has its downthrow mainly on the northeast. The Rock Lake fault continues southeastward beyond the quadrangle. On Calkins' reconnaissance map [53] he shows tentatively one long fault in this area; however, there are two overlapping faults, though the Rock Lake fault was probably caused by the same stresses that produced the Snowshoe fault.

Veins along the Snowshoe fault are opened up in the Snowshoe and Silver Mountain mines and in several small prospects.

ROCK LAKE FAULT

The Rock Lake fault is at least 12 miles long; it extends from Dad Peak southeastward past Wanless Lake and beyond the southern boundary of the quadrangle. The fault is vertical in the three exposures that were observed—east of St. Paul Lake, at the Price pros-

[53] Calkins, F. C., op. cit., pl. 1.

pect, and near the south shore of Wanless Lake. Its strike is N. 33° W. for most of its length. The displacement along the fault has been irregular in amount and direction, but the movement has been essentially vertical. At its north end none of the complicated adjustments have taken place that would probably have occurred if the movement had a large horizontal component. For most of its length the downthrow is on the northeast, but for a short distance near Flattop Mountain, where the sharp Snowshoe anticline is truncated, the upthrow is on the northeast. Near St. Paul Lake the vertical displacement is about 2,500 feet.

Except at the Price, the Martin, and two other prospects, all of which are small, no evidences of metalliferous mineralization were seen along the Rock Lake fault.

HOPE FAULT

A normal fault with the downthrow on the southwest, named by Calkins [54] the Hope fault, was traced by him and later by Anderson [55] from Hope, Idaho, to Heron, Mont., a station on the Northern Pacific Railway 2 miles east of the western border of the Libby quadrangle. During the present survey the fault was found in Montana to be more sinuous in its course and more complicated than was formerly supposed. It was traced along the Clark Fork and across the southwestern corner of the Libby quadrangle, and its course was followed by Jenks [56] across the northeastern part of the Trout Creek quadrangle to a place east of Vermillion Creek. No actual exposure of the fault was seen in either quadrangle or in the Clark Fork district, Idaho, because it is everywhere concealed by till and alluvium, but its course is marked by the discordance in stratigraphy on opposite sides of the river and by parallel faults both in Idaho and in Montana. Moreover, the Cabinet Mountains on the northeast side of the Clark Fork present in many places a steep, straight escarpment, and there is a marked discordance in the altitudes and in the character of the summit levels on opposite sides of the Clark Fork. In the Libby quadrangle and in the Trout Creek quadrangle [57] the Bitterroot Mountains, southwest of the river, are broad and gently undulating, and their altitude nowhere exceeds 6,000 feet, whereas the Cabinet Mountains, northeast of the river, are rugged and sharply serrate, and attain summit altitudes of 8,700 feet.

As Anderson [58] points out, the fault is probably complex, comprising

[54] Calkins, F. C., op. cit., p. 55.
[55] Anderson, A. L., op. cit., pp. 44–47.
[56] Jenks, W. F., Geology of portions of the Libby and Trout Creek quadrangles: Doctoral thesis, Harvard University, 1936.
[57] Jenks, W. F., op. cit.
[58] Anderson, A. L., op. cit.

many fractures distributed through a wide zone. That the fault is close to the Cabinet Mountain front near Heron is shown by parallel faulting in prospects, by the fact that the Wallace formation on Fatman Mountain is on the same line of strike as the Ravalli formation along the East Fork of Blue Creek, and by the discordance between the Cambrian limestone and the Ravalli formation about a mile northeast of Heron. Here two small areas of Middle Cambrian, now surrounded by till, are assumed to represent a wedge-shaped block that has been brought down on the southwest side of the Hope fault. In the Libby quadrangle and in the Trout Creek quadrangle to the south, the beds on the southwest side of the fault are younger than those on the northeast side, and Jenks[59] has shown that the folds match sufficiently well to indicate that most of the movement has been vertical. Anderson,[60] on the other hand, as a result of his work in Idaho, concluded that the structures there do not match and that if the movement were mainly vertical displacement it must have been extremely great. He therefore believed that most of the movement had been horizontal. Evidence in the Libby quadrangle is insufficient to determine which of these apparently conflicting views is the more applicable.

In the south-central part of the Libby quadrangle the Wallace formation is exposed on both sides of the Clark Fork, and there the displacement along the Hope fault is not so great as it is farther northwest and southeast. At Fatman mountain the Wallace formation is brought opposite the lower part of the Ravalli formation, and northeast of Heron the Cambrian rocks have been dropped at least 18,000 feet. Jenks,[61] in tracing the fault along the Clark Fork southeastward from the south-central part of the Libby quadrangle, has found that the displacement increases southeastward also.

There are no valuable prospects close to the Hope fault, but the Blue Creek and the Broken Hill mines, which are within a mile and a half of the Hope fault, have produced ore from veins in a fault that trends northwestward across Blue Creek and Sawtooth Mountain. This fault swings to the southeast and probably joins the Hope fault northeast of Heron. Neither mine was active in 1934.

SUMMARY OF STRUCTURE

The major structural features of the Libby quadrangle are folds and faults. The folds are, for the most part, large open anticlines and synclines that trend about north-northwest. Most of the faults, including those of greatest throw, strike in the same direction, but some of them strike nearly north and others northwestward.

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[59] Jenks, W. F., op. cit.
[60] Anderson, A. L., op. cit.
[61] Jenks, W. F., op. cit.

The folding preceded the major faulting. The Snowshoe anticline is cut off at its southern end by the Rock Lake fault, the Mount Berray syncline is truncated at its northern end by the Bull Lake fault, and several folds are cut by the Hope fault.

Faulting of at least three periods may be distinguished. The earliest is represented by the reverse movement along the Bull Lake fault, the second by several vertical faults of great displacement, and the third by the Hope fault and by renewed movement along other faults.

The compressional stresses that produced the folding cannot have produced the numerous long, vertical or nearly vertical faults along which the movement has seemingly been vertical. The quartz monzonite and similar intrusives invaded the region late in the period of folding, and it is believed possible that these faults may be a direct result of the upward movement of the magma that crystallized to form the quartz monzonite and related intrusive rocks and that caused a differential uplift of blocks of folded Belt rocks. The Hope fault also may have originated at this time, though the greatest movement along it occurred much later than the movement along other faults.

Sampson[62] has shown that in the Pend Oreille district many of the faults were caused by the upward pressure of magma, and he therefore calls them "intrusion faults." Anderson[63] has also found evidence in the Clark Fork district, though it does not seem quite so clear as that adduced by Sampson, that faulting is directly related to intrusion. In the Libby quadrangle the total exposed area of intrusives is not so great as in either of the other two areas, and consequently the evidence of the relation between intrusion and faulting is less clear. Only two intrusive bodies, the Dry Creek and Payne Creek stocks, are bordered on one side by faults that may be regarded as somewhat similar to "intrusion faults," whereas Sampson found several faults of this type. The presence of several small exposed stocks, the evidence of contact metamorphism 2 miles from any outcropping intrusive body, and the numerous metalliferous veins all testify, however, to the presence not far below the surface of a body of igneous rock having a much greater area than that of any exposure of such rock within the quadrangle.

In their larger relationships the stocks are distinctly crosscutting bodies, but around the Hayes ridge stock and locally at the periphery of the Dry Creek stock a certain amount of doming is evident. It is within the range of possibility that in the Libby quadrangle as well as in Idaho some of the faulting is due to an upward push of a magma, though part of the movement may be due to subsequent collapse or settling back of the upper, first-cooled portions of the stocks.

[62] Sampson, Edward, Geology and silver ore deposits of the Pend Oreille district, Idaho: Idaho Bur. Mines and Geology, Pamph. 31, pp. 12–16, 1928.

[63] Anderson, A. L., op. cit. pp. 40–42.

A. CRUMPLED BEDS IN WALLACE FORMATION.

Exposure east of Bull Lake fault. Scale shown by pencil near center. Photograph by C. B. Moke.

B. VIEW IN FISHER CREEK MINE.

Underground exposure of thick, gently dipping bed vein of quartz.

FAULT SCARP ON EAST SIDE OF LAKE CREEK VALLEY.

Faceted ends of mountain spurs along a scarp produced by movement along Bull Lake fault. Part of Bull Lake and timbered floor of valley in foreground. Photograph by courtesy of Washington National Guard, 116th Photo Section.

Renewed movement along metalliferous veins in faults has offset and brecciated these veins to some extent. There is some evidence for renewed movement since glaciation along a few faults, but it is not conclusive.

AGE OF FOLDS AND FAULTS

The time at which the major structural disturbances took place cannot be closely determined from evidence within the quadrangle. As in other regions in western Montana,[64] some tilting of the Belt rocks may have taken place before Cambrian time. In the Philipsburg quadrangle [65] the angular discordance of the Belt rocks beneath the Cambrian is as great as 30°, but that is unusual. The small down-faulted block of Cambrian rocks on the Clark Fork and another small area of folded Cambrian rocks seen a few miles east of the quadrangle make it obvious that much of the folding and faulting are post-Cambrian. Workers [66] in nearby regions have referred the principal folding and faulting in those regions to the Rocky Mountain revolution in late Mesozoic time, and the similar disturbances in the Libby quadrangle probably occurred during that same revolution. There may have been slight renewed movement along a few of the faults since the Pleistocene glaciation.

PLEISTOCENE GLACIATION [67]

By WILLIAM C. ALDEN

From studies of a broad region that includes the Libby quadrangle, it seems clear that this part of northwestern Montana was considerably glaciated during both early and late Pleistocene time. Nearly every mountain gorge in the Cabinet and adjacent ranges was occupied by glaciers heading in amphitheaters, or cirques, high up on the flanks of the mountains and extending down to the lower levels. (See pl. 7.) The southward-moving Cordilleran ice, moreover, which covered vast areas in British Columbia, nearly submerged the mountains of the Purcell Range between the two arms of the Kootenai Valley and extended large minor tongues southward up the valleys of Libby Creek and Fisher Creek. It also probably moved up the valley of Lake Creek, through the pass at the head of Bull Lake, and thence down the Bull River Valley, to or beyond the big bend of the river between its junc-

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[64] Clapp, C. H., Geology of a portion of the Rocky Mountains of northwestern Montana: Montana Bur. Mines and Geology Mem. 4, p. 29, 1932.

[65] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, p. 30, 1913.

[66] Kirkham, V. R. D., and Ellis, E. W., Geology and ore deposits of Boundary County, Idaho: Idaho Bur. Mines and Geology Bull. 10, p. 29, 1926. Anderson, A. L., op. cit., p. 48. Clapp, C. H., op. cit., p. 29. Ross, C. P., Some features of the Idaho batholith: Internat. Geol. Cong. 16th Rept., 1933, vol. I, 1936.

[67] Based on observations of W. C. Alden and of Russell Gibson, J. T. Pardee, and other geologists.

tion with the East Fork Valley and Copper Gulch. To each of these valley glaciers several of the local mountain glaciers were tributary.

It has not thus far been possible clearly to differentiate the deposits formed at the earlier stages of glaciation in this area from those of the last or Wisconsin stage of glaciation. The following brief description applies principally to the features developed during the last advance and recession or melting away of the ice. The distribution and directions of advance of the several lobes of the Cordilleran ice

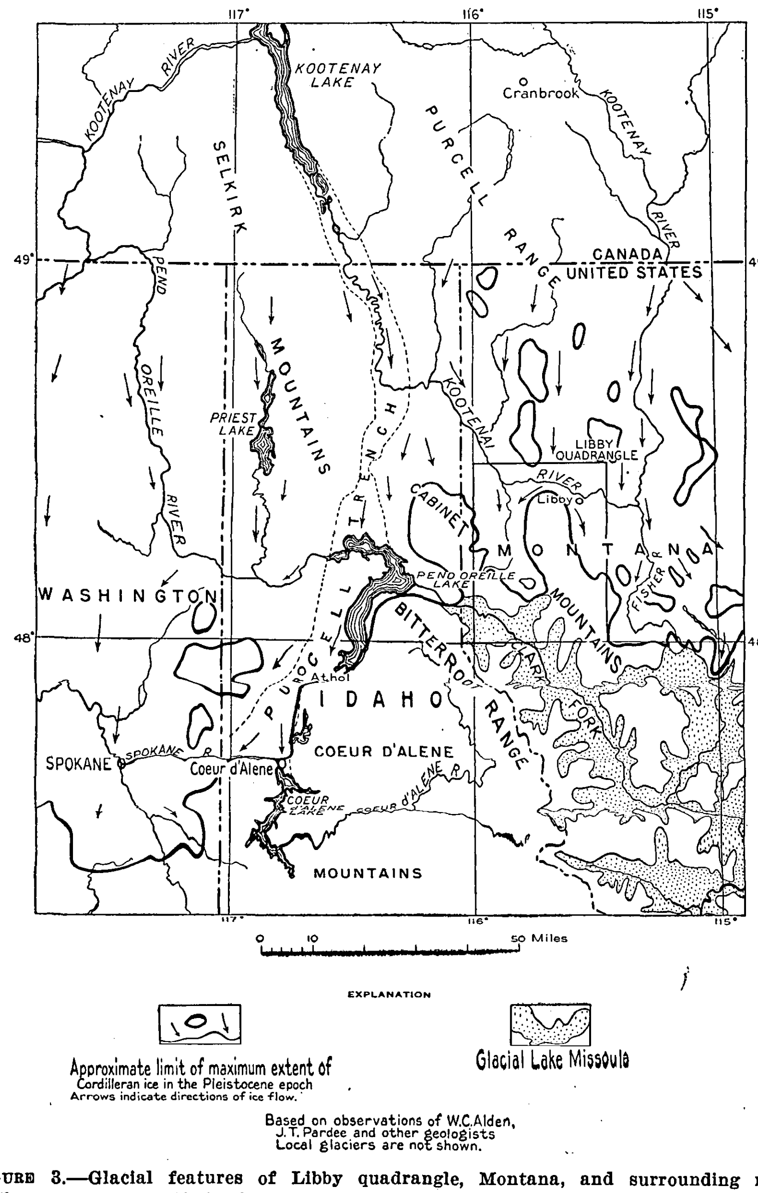


FIGURE 3.—Glacial features of Libby quadrangle, Montana, and surrounding region. Shows approximate limit of maximum extent of Cordilleran ice in the Pleistocene epoch.

in and adjacent to this quadrangle are indicated on figure 3. At a few places glacial striae showing the direction of movement of the ice have been noted. Five miles north of Libby, in the NE¼ sec. 10, T. 31 N., R. 31 W., on one of the rock ledges beside the logging railroad, the striations trend southwestward parallel to Pipe Creek.

The deposits formed during the advance of the ice consist very largely of heterogeneous and unstratified mixtures of rock flour, clay more or less sandy, and subangular to angular large and small fragments or boulders of the various kinds of rock overrun by the moving ice. This drift material, which composes the ground moraine, is referred to as boulder clay or glacial till. Compact, rusty, oxidized till is exposed 3 miles northwest of Libby at the mouth of the gulch that has been cut into the upper terrace. This till is overlain 100 feet above the creek by 50 feet of laminated silt, above which is coarse terrace gravel. Till is also well exposed in the bluffs at the sides of the inner valleys of Cherry and Granite Creeks, south of Libby. One of these exposures in the SE¼ sec. 34, T. 30 N., R. 30 W., shows the following:

Deposits 6 miles south of Libby

	Feet
3. Loamy silt	10–20
2. Till, rusty, buff to brownish, very stony and compact, standing in a vertical face with erosion buttresses and pinnacles	About 70
1. Gravel, coarse, with abundant disintegrating granite pebbles	5

There are several similar exposures of till in these bluffs farther south and north. At one of these, about 5 miles south of Libby and west of U. S. Highway No. 2, in the NW¼ sec. 35, T. 30 N., R. 31 W., the bluff exposes a vertical section of a small drumlin, whose crest rises 20 to 50 feet above the flat surface of the surrounding terrace gravels. This drumlin is composed of dense compact till 5 to 135 feet thick, which was deposited on top of earlier well-stratified stream gravel without disturbing it. The hill was given the smooth elliptical or semiovoid form characteristic of a drumlin by the overriding glacier. After the ice melted, stream gravel was swept northward down the valley and spread out on the bottom land, surrounding the drumlin and burying all but its crest. Still later Granite Creek eroded its inner valley to a depth of 100 to 150 feet and cut away part of the deposits, exposing a section of the drumlin and of the overlying and underlying gravels. The face of the compact till deposit has since been carved by erosion into striking buttresses. (See pl. 8.) The axial trend (somewhat east of south) of this and other neighboring small drumlins, together with the lithologic composition of the till, seems to indicate that this ground moraine was deposited by a lobe of the Cordilleran ice.

The limit of this southward-moving ice in Libby Creek Valley appears to have been about 14 miles from Libby, in secs. 3 and 4, T. 28 N., R. 30 W., and almost as far south in the Cherry Creek Valley, where there appears to be a terminal moraine deposit. It is possible that this southward-moving ice was met by local glaciers heading in the Cabinet Mountains, moving down the several mountain gorges and issuing onto the piedmont slopes. The Granite Creek Glacier, in particular, transported many large and small granite boulders. There are now two small bodies of glacier ice composing Blackwell Glacier, high up on Snowshoe Peak, and there is also a little glacier in the north flank of Elephant Peak, 10 miles farther south. All of these are about 7,000 feet above sea level.

As stated above, the extent to which the mountains within (north of) the great bend in the course of the Kootenai River in the United States were overridden by the Cordilleran ice is not yet definitely known. Apparently, as indicated by Daly's studies[68] the Purcell Mountains along the international boundary were nearly, if not wholly, submerged beneath the ice at one or more stages of glaciation. Judging by local features and by conditions to the east and west, a lobe of this ice appears to have extended southward to the Kootenai Valley, past Troy, and up the Lake Creek Valley. This tongue continued through the gap at the head of Bull Lake and 10 miles down the Bull River Valley to the big bend between East Fork and Copper Gulches, where there is a pitted terminal moraine deposit partly blocking the valley. This bend is 30 miles from Troy. It is not certainly known that the ice extended so far south of Libby and of Troy during the Wisconsin stage of glaciation, as is shown on figure 1, but it may have done so and is so shown on figure 3. The character of the till exposed in some places south of Libby and the degree of its induration and oxidation suggest that some of it, at least, may be of pre-Wisconsin age.

Judging from the topographic map of the Libby quadrangle, much of the ice in the Lake Creek-Bull River through valley came from tributary glaciers that occupied the gorges heading in cirques on the mountains of the Cabinet Range to the east and west, and there may likewise have been some tributary glaciers heading in the Purcell Mountains north of the Kootenai Valley. It seems probable, however, that a trunk glacier, a lobe of the northern ice, advanced southward down the Yaak River Valley to and up the Kootenai Valley and thence south past Troy. It seems probable, also, that the narrow parts of the Kootenai gorge both east and west of Libby were occupied by glacier ice, at least at the times of its maximum extent. The river is flowing over rock ledges at Jennings, east of Libby, and that is the case

[68] Daly, R. A., Geology of the North American Cordillera at the forty-ninth parallel. Canada Dept. Interior, Rept. Chief Astronomer, 1910, pt. 2, pp. 577–598, 1913.

also at Kootenai Falls, 11 miles west of Libby, and for some distance below them. Below the falls the river is actively cutting a narrow winding inner gorge below a rock terrace. It is also cutting in rock near the mouth of Lake Creek, 1 to 2 miles above Troy. Apparently the gorge in these parts has never been deeper than it is now.

About 1938, U. S. Highway No. 2 was shifted from the broad gravelly terrace top north of Savage Lake and graded down along the bluff below the northern edge of the terrace. Some of the cuts along this new grade beside the railroad exposed glacial till containing striated stones below the terrace gravel. Other cuts in the gorge near and east of Kootenai Falls also exposed till.

At no place farther south between the Kootenai River and Bull Lake did the writer see any exposures of glacial till, nor were any glaciated rock ledges observed. All the exposures seen were of laminated silt, sand, or gravel. More thorough examination may reveal more definite evidence that a glacier from north of the Kootenai River actually traversed the Lake Creek-Bull River trough. The moraine at the big bend 30 miles south of Troy, in and near the NW.¼ sec. 18, T. 27 N., R. 32 W., is about 150 feet high, and its top is pitted with kettle holes formed by the melting of buried masses of glacier ice. Unsorted, coarse, gravelly drift is exposed in a bluff about 100 feet high where the stream swings against the north foot of the moraine west of the bridge. This moraine may originally have extended far enough eastward to form a dam clear across the valley bottom, but there is not a broad gap where the stream flows through east of the road. Through much of the distance between this outer moraine and the divide south of the head of Bull Lake the stream flows through a flat, marshy bottom where water is said to stand 20 to 40 feet deep in places, owing to the obstructed drainage. The writer has found no definite evidence that a glacier advanced farther down the Bull River Valley than this moraine. Such erratic boulders as have been observed on the sides or bottom of the lower part of the valley up to 4,200 feet above sea level may have been dropped from ice floating on glacial Lake Missoula. Pardee,[69] however, reports that he found well-preserved glacial flutings and striae on the spur opposite Copper Gulch at levels 100 to 200 feet above the road. This locality is about 1¼ miles below the bridge mentioned above.

There is evidence from various general relations that the terminus of this trunk glacier at the last, or Wisconsin, stage was near the pass just south of the head of Bull Lake, but there is no well-marked terminal moraine at this place. There is what appears to be a considerable morainal deposit near the road at the west side of the pass, south of Ross Creek, and an extensive gravel terrace at the east side of the pass

[69] Personal communication.

extends southward about a mile and a half from the lake to a steep bluff, where it is cut off by a stream coming from the east. The terrace, 2,400 to 2,500 feet above sea level, bears a loamy soil and is underlain by coarse gravel. It probably represents deposition of glacial outwash in the 2,500-foot level of glacial Lake Missoula at the Wisconsin stage of glaciation. It may originally have extended clear across the pass and subsequently have been partly cut away by the outflow of water ponded in Lake Creek and Kootenai Valleys by the receding ice front. As at the earlier stage of glaciation, this trunk glacier was probably joined by several tributary glaciers heading in the Cabinet Mountains on the east and west.

As shown on the topographic map, there are several passes across the interstream mountain ridges west of Lake Creek Valley, and these may at times have served as spillways for glacial waters flowing southward to glacial Lake Missoula when the trunk glacier occupied Lake Creek Valley. Their altitudes range from 4,400 down to 2,500 feet above sea level. The lower of the passes, south of Troy, were doubtless traversed by the ice itself. There are also notable remnants of a gravel terrace built around some of the lower hills and in the mouths of the tributary valleys at 2,400 to 2,500 feet above sea level. These appear to be the correlatives of the highest terrace tops of the filling along the east side of the valley at about the same altitudes. Most of the unconsolidated deposits observed in the valley north of Bull Lake appear to have been laid down during the final recession of the ice front.

So far as the writer has observed, there is no clear evidence that any of the Cordilleran ice invaded the valley of the Clark Fork anywhere in Montana above the vicinity of the Idaho-Montana State line. It is evident, however, that at one or more stages of the Pleistocene epoch the north-south through valley known to geologists as the Purcell Trench, which separates the Selkirk Mountains on the west from the Purcell Range, the Cabinet Mountains, and the Bitterroot Mountains on the east (fig. 3) was invaded by a great tongue of the Cordilleran ice. This great trunk glacier, which has been designated by Anderson,[70] the Rathdrum Lobe extended southward at one or more pre-Wisconsin stages of glaciation to the vicinity of the Idaho-Washington State line west of Coeur d'Alene, Idaho. At the last, or Wisconsin, stage this glacier reached the south end of the Pend Oreille Lake Basin and the vicinity of Athol, Idaho, and there laid down considerable terminal moraine and outwash deposits. According to Daly,[71] this glacier had a thickness of about 5,500 feet in the Kootenai Valley at the international boundary.

[70] Anderson, A. L., Some Miocene and Pleistocene drainage changes in northern Idaho: Idaho Bur. Mines and Geology Pamph. No. 18, p. 14, pl. 1, 1927.

[71] Daly, R. A., op. cit., pp. 586–687.

At each glacial stage it is probable that the valley of the Clark Fork was blocked by the great glacier, and that a minor lobe of ice advanced a few miles up this valley east of the Pend Oreille Basin, completely obstructing the stream and impounding its waters behind a dam of ice 2,000 feet or more in maximum height. The east front of this ice dam was near the Idaho-Montanta State line, about 4 miles northwest of Heron, Mont. The former presence of the glacier ice is shown by striated rock ledges at several places and by glacial boulders and other drift material on the mountain slopes up to heights of 1,000 to 2,300 feet above the present channel of the Clark Fork. The writer found striated stones on the mountain slope west of the village of Clark Fork, Idaho, at an altitude of 3,800 feet, and E. Stebinger[72] found glacial boulders on Antelope Mountain, just east of the village, 4,350 feet above sea level. The impounded waters rose to the level of the lowest available outlet, which, judging from the topographic maps, was at one or two notches in the mountain crest 2 to 3 miles southwest of the village of Clark Fork, or about 9 miles west of Heron. The present altitudes of the bottoms of two of these notches are about 3,800 and 4,100 feet, respectively. These cols, however, may have been lowered somewhat. The name Glacial Lake Missoula was given by Pardee[73] to the extensive lake thus formed in the Clark Fork Valley. This lake at its maximum was more than 200 miles long, and its waters extended far up into many tributary valleys.

There is evidently no reason to doubt that the mouth of the Clark Fork Valley was tightly closed by an ice dam near the Idaho-Montana State line during the Wisconsin and pre-Wisconsin stages. There is, however, so far as noted by the writer, no well-marked terminal moraine in the valley of the Clark Fork. This is perhaps because the glacial ice dam was bordered by the water of Lake Missoula, which was at times 1,000 to 2,000 feet in depth. The contours on the topographic map of the Libby quadrangle show a broad bench extending from the west to the south of Heron, the top of which is 2,400 to 2,500 feet above sea level, or 300 to 400 feet above the river on the north. Elk Creek, in order to reach the river after leaving its mountain gorge, first flows east, then turns north around the end of this ridge or bench and enters the valley southeast of Heron, and it has spread its alluvial gravel as a broad fan or intermediate terrace between Smeads Station and Heron. Where it transects the terraces east of Heron, Elk Creek has cut through the capping of coarse, bouldery gravel and into the underlying bedrock. It seems probable that bedrock also underlies the 2,400-foot to 2,500-foot bench at no great depth, although the writer saw no bedrock where he crossed the bench. Near

[72] Unpublished field notes.

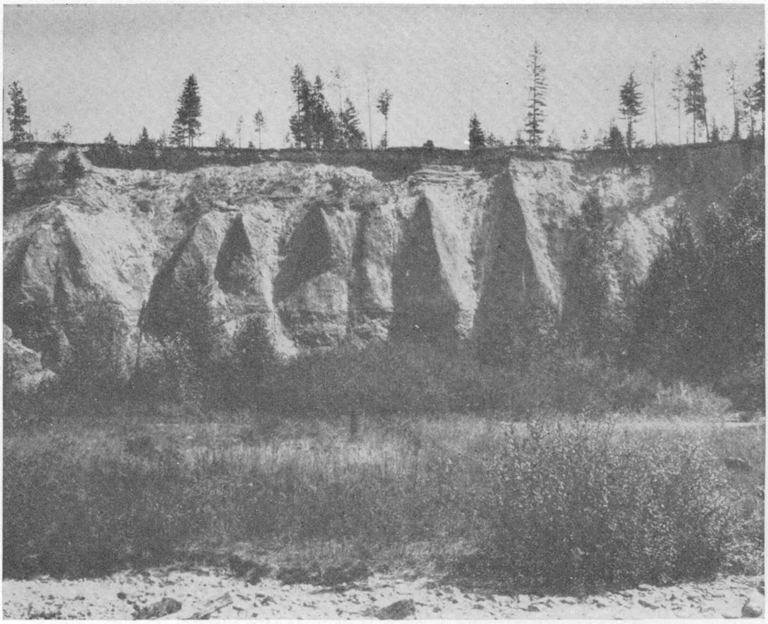
[73] Pardee, J. T., The Glacial Lake Missoula: Jour. Geology, vol. 18, pp. 376–386, 1910.

the roads traversed, the surface of the bench is smooth and gently undulating, where not eroded. It is mantled with fine loamy clay, probably silt of Glacial Lake Missoula, and contains but few boulders. The railroad and the highway south of the river for a mile or more east and 2 to 3 miles west of Heron are on the 2,250-foot terrace. Farther to the west for some distance east and west of the State line, they are graded along the south bluff of the inner gorge. Here the river terrace gives place to the upper bench, which extends north to the railroad and the bluff along the river bank. This part of the bench, at least, probably represents the terminal moraine. Here there are many 3-foot to 5-foot boulders and subangular blocks embedded in the coarse, bouldery gravel which overlies the bedrock. Some of the boulders are as much as 10 to 15 feet in diameter. They consist mostly of green and red argillite, but some are of granitic rock. Near the State line and for a mile or two farther east the coarse gravel, though mostly unstratified, is in part poorly bedded, with cross beds dipping westward downstream as though the material had slumped or been redeposited, either while the ice dam was melting back from contact with the accumulating deposit or shortly thereafter. Near Cabinet, Idaho, the bedrock rises in the section, and the river has cut an inner gorge through it which in places is barely 100 feet wide. The relations near and north of this gorge suggest that when the pitted terrace there was formed the front of the glacial lobe had melted back several miles from its most easterly position, and that the marginal parts of its surface had become so much lowered as to permit Lake Missoula to be drawn down to a level not more than, or below, an altitude of 2,500 feet above sea level. As the lake dwindled, the reestablished Clark Fork was gradually extended northwestward and began to develop the lower terraces and to cut its inner gorge. This gorge is mainly in the valley filling, but it extends down into the bedrock at many places. Probably, however, Lake Missoula did not drop below the 2,500-foot level until the fronts of the Cordilleran ice lobes that occupied the Columbia River Valley and the Pend Oreille River Valley in northeastern Washington had receded somewhat north of the 49th parallel, so that the water could escape along the Pend Oreille to the Columbia River. (See fig. 3.) Each of the several lower terraces along the Clark Fork in western Montana may mark the reaching of a new outlet, or some of them may mark stages in cutting through the several rock barriers encountered by the reestablished stream between the Montana-Idaho State line and the Columbia River.

Judging from the topographic map, there were glaciers in the Bitterroot Mountains and also in some of the gulches heading on the southwest flank of the Cabinet Mountains, but none of these are known to

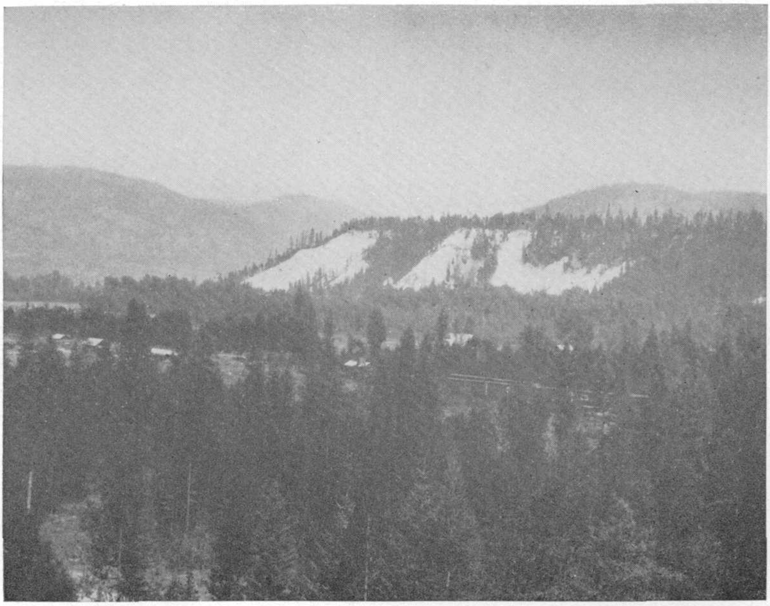
BACK WALL OF CIRQUE AT HEAD OF GRANITE CREEK.

Exposure of Wallace strata, dipping northwestward. Photograph by K. D. Swan. Courtesy of U. S. Forest Service.



A. SECTION OF DRUMLIN 5 MILES SOUTH OF LIBBY.

Shows undisturbed stream gravel, which underlies and partly overlies compact glacial till. Photograph by W. C. Alden.



B. TERRACES EAST OF LIBBY.

View across top of lower terrace to bluff 300 feet high below upper terrace. Light-colored areas are exposures of horizontally bedded lacustrine silt. Photograph by W. C. Alden.

have extended down to the Clark Fork Valley. Rock Creek Glacier, in the southeastern part of the quadrangle, may have reached an arm of Lake Missoula and deposited in it the drift filling at Rock Creek Meadows, 3,700 feet above sea level. So also Swamp Creek Glacier, heading in the cirque that now contains Wanless Lake, may have discharged to an arm of Lake Missoula and have contributed considerable material to the great delta deposit that is spread out at the mouth of the great gorge 10 to 18 miles southeast of the mouth of Bull River.

How far northward Lake Missoula extended up the Thompson River Valley is not certainly known to the writer. When the front of the East Kootenai glacial lobe began to retreat northward at the Wisconsin stage of glaciation, either the Thompson Valley branch of Lake Missoula extended northward so as to cross the divide (about 3,345 feet above sea level) or local preglacial lakes ponded in the headwater branches of Fisher River Valley (fig. 3) expanded until they formed a single branching lake. The former presence of such a lake is shown by considerable deposits of laminated, lacustrine silt, in places overlying glacial till, as far north in the Kootenai Valley as Jennings. The waters of this glacial lake may have extended northward through the Swamp Creek pass to the Libby Creek Valley. Near the junction of Swamp and Libby Creeks, near U. S. Highway No. 2 and a short distance east of Hoodoo Mountains, there is a small flat-topped butte locally known as "Paul Bunyan's grave" (sec. 31, T. 29 N., R. 30 W.). This is an erosion remnant of the upper terrace, at that place 2,900 feet above sea level. A bare scarp at the sound end of the butte exposes the following section:

Deposits at "Paul Bunyan's grave" on Libby Creek

	Feet
3. Gravel, coarse	10
2. Silt, stratified and sandy	50
1. Till, very stony clay, many pebbles striated	30–40

These beds are illustrative of the three different types of deposits in this basin: (1) Glacial, (2) glacio-lacustrine, and (3) fluvial or glacio-fluvial. The laminated silt (No. 2) was evidently deposited in a temporary lake dammed by the front of the Cordilleran ice when it was retreating northward. If this lake rose high enough to discharge southeastward across the pass, which is about 3,345 feet above sea level, to the Thompson River there must have been 400 to 500 feet or more of water at "Paul Bunyan's grave."

Although the relations of the glacial lake in the Libby Creek Valley are not entirely clear, it is evident that such a lake occupied the basin for a considerable length of time after the melting of the ice that deposited the till. This is indicated by the considerable thickness of undisturbed, laminated silt that underlies the smooth high terrace, 2,400 to 2,500 feet above sea level, east of lower Libby Creek. (See pl. 8 *B*.) Where examined by the writer, nearly the full height of the bare bluff east of the Libby sawmill, in the NW¼ sec. 11, T. 30 N., R. 31 W., consists of light-colored silt 300 feet thick, so fine and dense as to be almost massive, and without distinct laminae yet splitting along smooth horizontal bedding planes when dry. No pebbles, boulders, or fossils were seen embedded in the silt, but at one place there was exposed, below the silt, 15 feet of cobblestone stream gravel. The stream gravel capping "Paul Bunyan's grave" and the corresponding terrace remnants (2,900 feet above sea level), and also lower ones on the east and west and farther north, must have been deposited after the ponded waters were drawn down to lower levels by the opening of a lower outlet westward down the Kootenai Valley. Such is the gravel overlapping the drumlin described above (p. 51). The coarse gravel capping the terrace traversed by the road east of Libby Creek was spread out as alluvial fans by creeks heading in the hills to the east. The gravels are, in general, above the upper level of the lacustrine silt in this basin, being at least 2,400 to 2,450 feet above sea level.

A road cut below the terrace, directly above the north end of the Libby bridge, showed laminated silt whose eroded top was overlain by 15 feet or more of coarse bouldery gravel. Silt overlain by coarse gravel is also exposed about 3 miles northwest of the bridge, where the road between Bobtail Creek and Pipe Creek climbs the bluff of the upper terrace. At the same locality (sec. 20, T. 31 N., R. 31 W.) 50 feet of stratified sandy silt is exposed in a gulch just east of Pipe Creek. The silt overlies till and is overlain by a thick deposit of coarse cobblestone gravel, which caps the upper terrace and surrounds a small rock hill. From an altitude of 2,600 feet at the head, this terrace slopes down to 2,400 feet above sea level at the crest of a bluff about a mile north of the river and 350 feet above it. Evidently this upper terrace gravel came down from the north. East of Pipe Creek, at the place where the road and the logging railroad run down to the river, the high terrace has been so eroded as to develop several lower terraces bordering the river. As shown by exposures along the road and railroad, the upper terrace (a) is capped with coarse gravel from the north. Under the next lower terrace (b) is fine, stratified sand and silt like that east of the sawmill south of the river, apparently with no included pebbles. Below the next, (c) which is a minor step, there is fine partly stratified sand. Cuts at the lower edge of the next terrace (d) show pebbles coming in over stratified sand, below which is unstratified sandy material containing subangular cobblestones and 1-foot to 2-foot boulders. This material looks somewhat like till, but no striated stones were found in it. Beneath the next step (e) is coarse cobblestone gravel, about 2,200 feet above sea level. Such gravel is also seen beneath the two lower steps (f) and (g), which are just above the north end of the Libby bridge. The roads running up and down the river from the bridge are on these terraces.

As stated above, the road cut at the north end of the bridge showed 15 feet or more of coarse, bouldery gravel overlying fine, laminated lacustrine silt. Some of the boulders measure 2 by 3 by 4 feet. The relations of the several deposits indicate that when the level of the glacial lake was lowered by the opening of a new outlet down the Kootenai Valley, the river was reestablished and began cutting away the lacustrine beds, developing terraces and depositing, in place of the silt, coarse material such as could be transported only by a vigorous flow, with some assistance perhaps of floating ice in carrying the larger boulders. The lowest gravel terrace (h) is the one on which the town of Libby is built south of the river and on which north of the river is the tourist camp below the highway. There are remnants of these gravel terraces, but not of the silt, at intervals along the highway all the way up the Kootenai Valley to the international boundary above Rexford. As indicated above (p. 54), the altitude of the upper terrace, about 2,400 to 2,500 feet above sea level, appears to have been controlled by an outlet southward to the Clark Fork Valley by way of the pass near Bull Lake south of Troy.

The writer has not made a detailed examination of the deposits in the valley north of Bull Lake except at a few places. Four or 5 miles south of Kootenai River, in sec. 8, T. 30 N., R. 33 W., where a road climbs the bluff to the broad terrace 2,300 to 2,400 feet above sea level, only lacustrine silt is exposed. Near the top of the bluff at this place there is a kettle hole containing a small pond, which presumably occupies a basin formed by settling after the melting of a considerable buried mass of glacier ice. About 3 miles farther north, sliding in the face of the bluff above the road affords a large exposure above the talus. Up to the 2,240-foot level, about 115 feet above the road, the material is fine, stratified, lacustrine silt. Overlying this is about 15 feet of coarse gravel partly cemented to conglomerate, which is overlain in turn by 30 feet or more of sand and fine silt. The edge of the terrace, above the bluff, is about 2,300 feet above sea level. So far as noted the beds are undisturbed and show no evidence of having been overridden by a glacier. Some of the silt layers are a foot or more thick, and, as in the silt at Libby, there is little or no such indication of seasonal deposition as is recorded by varved clays. No included pebbles or fossils were noted. Inasmuch as the lower silt is overlain by a thick bed of stream gravel, which is in turn overlain by silt, it is possible that the lower silt was deposited in water ponded earlier than the last stage of glaciation. The laminated silt is, however, undisturbed. The terrace (2,300 to 2,400 feet above sea level) surrounding the ice-block depressions, in which lie Savage Lake and adjacent ponds, is capped with coarse gravel. This high terrace was probably completed when the glacier front had receded so far north and the filling of silt in the ponded water had reached such a level as to permit gravel to be washed out upon it by the Kootenai River from the gorge to the east. One of the most notable remnants of this terrace 2,400 to 2,500 feet above sea level lies on the northeast side of the river opposite Troy. On the smooth flat at the top of the bluff is a farmhouse overlooking the river from a height of 600 feet. Bedrock and talus are exposed in places in the bluff below this terrace. In cuts on the road leading up to the house only till-like gravelly material was observed.

As in the Lake Creek Valley, so also in the Kootenai Valley near and below Troy, most of the unconsolidated deposits observed by the writer appear to have been deposited during and after the recession of the ice front northward.

The several terraces below the 2,400-foot level were developed by streams cutting into the valley fill and spreading coarse gravel over the lacustrine silts. In places the streams cut their inner gorges into the bedrock as lower outlets were opened down the Kootenai Valley. From Troy northward to Yaak River, U. S. Highway No. 2 is on a broad low terrace, nearly 600 feet below the upper gravel terrace.

There is an interesting exposure in the bluff below the terrace, 2,000 feet above sea level, at the north end of the Troy railroad yards. At this place there has been considerable excavation, giving a clean exposure, near the south end of which coarse gravel is exposed for 25 feet above the railroad, that is, to a level 40 or 50 feet above the river. This gravel is overlain by a thick deposit of fine, laminated, lacustrine silt. Above the silt and lapping down over the cut-off ends of the silt beds there is coarse bouldery gravel with some cross bedding, which dips northward downstream like a torrential deposit. The pebbles and boulders, some of which are 2 to 4 feet in diameter, are in part smoothly rounded and in part subangular. None, so far as noted, show glacial striations. The gravel extends to the top of the bluff at the eastern edge of the flat terrace, 2,000 feet above sea level and about 200 feet above the river. A notable feature here is the disturbed condition of the uppermost silt beds. These are very much contorted, with small folds overturned from north to south as though the disturbance were due to the push of glacier ice advancing up the valley from the northwest. No glacial till was observed in the section, but the disturbed condition of the silt beds suggests that they were deposited immediately in front of the last glacial lobe that traversed this part of the Kootenai River Valley, either during its advance or a little earlier. The bouldery gravel that overlies the silt and forms the top of the terrace 2,000 feet above sea level was probably deposited by the Kootenai River, after the water ponded by the last retreating ice front had been drawn down about 500 feet or more from its maximum height, 2,500 feet above sea level, by the opening of the present outlet of the valley to the Columbia River. In cutting down to its present level, the Kootenai River has had to erode the narrow inner gorge that is cut to a depth of 300 to 400 feet in the bedrock floor at the Montana-Idaho State line near Leonia, Idaho, 14 miles below Troy. As indicated above (p. 53), the Kootenai River is now cutting a narrow sinuous inner gorge in the somewhat broader rock floor of the canyon below the Kootenai Falls, which are about 8 miles above Troy, in sec. 13, T. 31 N., R. 33 W. (see pl. 2).

PHYSIOGRAPHY

By J. T. Pardee

The Libby quadrangle is within the extensive mountainous region that occupies large parts of northwestern Montana and central and northern Idaho. More specifically, it lies chiefly in the central part of the Cabinet Mountains but includes parts of the Purcell Mountains to the north and the Bitterroot Mountains to the south. The mountains are maturely dissected by narrow stream-cut valleys, the local relief is commonly 2,000 to 4,000 feet, and the extreme ranges of altitude are from about 1,900 and 2,100 feet, respectively, along Kootenai and Clark Fork Rivers to 8,712 feet on Snowshoe Peak. Among the larger topographic features are two low areas, the general form of which suggests the term basin, and intervening between these basins a broad highland, which includes the highest and most rugged part of the Cabinet Mountains. (See pls. 1 and 9.)

The basins may conveniently be named Libby Valley and Lake Creek Valley. Both trend about north-northwest, are crossed by Kootenai River, and contain wide areas of lowland at levels within a few hundred feet of that of the streams. Libby Valley is about 30 miles long and is 5 miles wide near the middle. It includes the lowlands along Pipe Creek and Libby Creek and, near the head of Fisher River, a group of comparatively low rounded foothills at the south. At both ends the mountains close around it. The western border is a relatively straight and well-defined line, but near the middle its northern part is offset about 2 miles to the east. The eastern border is somewhat less regular.

Lake Creek Valley is about 20 miles long and 2 to 4 miles wide. It includes the lowlands along O'Brien Creek and Lake Creek and those at the forks of Bull River, and in the northern part, a hill called Freeman's Ridge. Its eastern border is a very definite and regular line with a westward offset of a mile or more in the northern part; the western border is irregular. The ends of the basin are enclosed by mountains, except at the south where the relatively narrow valley of Bull River leads out to the Clark Fork Valley.

At the southwest the quadrangle includes part of an extensive lowland along the Clark Fork River, a feature that will be described farther on.

The rugged highland that separates the Libby and Lake Creek Valleys extends unbroken from the gorge of Kootenai River 40 miles south-southeastward to Vermilion River. It is known in local usage as the Cabinet Range, a term which serves to distinguish it from other parts of the Cabinet Mountains.[74] Among its more noteworthy smaller topographic features are the gorgelike valleys along stretches of Kootenai River adjacent to the basins, a trenchlike valley just east of the Libby quadrangle partly occupied by Swamp Creek that affords a low pass between Libby Valley and the valley of Fisher River (pl. 9), and the narrows along the lower course of Bull River.

The valleys (pl. 9) are underlain by glacial drift and other surficial deposits of Quaternary age. These deposits rest on the eroded surface of older rocks, chiefly of the pre-Cambrian Belt series, which also compose the mountains, (See pl. 1.) These rocks are folded and are broken by faults; the general trend of the structure is northwestward.

The gorges mentioned, as well as the multitude of narrow valleys that dissect the uplands, were evidently cut by streams. In places, relatively small notches or trenches have been developed along faults or along certain less-resistant beds by selective erosion. The larger valleys, however, appear to require more than erosion to account for them. The bedrock under their floors, though largely concealed by unconsolidated materials, is exposed at so many places that an observer can satisfy himself beyond any doubt that it is generally the same as the rock of the mountains without any noteworthy differences in composition or structure that might modify its resistance to erosion.

Although there are no noteworthy differences in composition or structure between the rocks in which the gorges and the basins are formed, the differences in their cross profiles (pl. 9) are so great as to suggest entirely different histories. For example, the feeble streams that drain the basins could hardly have excavated such wide hollows while the vigorous Kootenai was able to cut only narrow gorges. Glaciation, described elsewhere (pp. 49–61), has modified the basins somewhat, and the fact that their longer dimensions are generally parallel with the structural features may mean that selective erosion has played a part; but these aids to stream erosion appear far from sufficient to account for the differences between the basins and the gorges. It is concluded therefore, that the basins are mainly of structural origin.

The occurrence of a scarplike slope at the east side of Lake Creek

[74] The Cabinet Range as defined by Calkins in U. S. Geol. Survey Bull. 384, pp. 14–15, extends from Bonners Ferry, Idaho, southeastward to the junction of Jocko Creek with Flathead River in Montana and includes several partly separate mountain groups that are now known collectively as the Cabinet Mountains and are so labeled on recent maps.

Valley (pl. 6) suggests a fault along which a relative depression of the valley or elevation of the adjoining mountain block may have occurred. In fact, evidence of faulting along this side of the valley with downthrow toward the valley, is given by Calkins,[75] and further evidence has been added elsewhere in the present paper (p. 42). A cross profile a few miles south of Troy (pl. 9, profile *B–B'*) likewise suggests depression of the valley gradually fading out to the west and elevation and tilting of the Cabinet Range on the east. The position of the fault line is indicated by direct evidence at points just south of Kootenai River and opposite the north end of Bull Lake. Elsewhere, as indicated by physiographic evidence only, it follows the eastern margin of the valley from Kootenai River south to the forks of Bull River, its trace being generally concealed by alluvium. North of Kootenai River the abrupt rise of the Purcell Mountains on the east suggests a fault extending northward up O'Brien Creek Valley, and this fault is established by stratigraphic evidence (p. 44). There are indications that this fault is offset north of the river about 1½ miles to the west of the one previously described.

For Libby Valley the evidence of faulting is based on physiographic evidence alone. South of Libby the range on the west presents a straight and well-defined front (pl. 1); west of this line, as described by Calkins,[76] the spurs rise, at first rather steeply and then more gently toward the peaks (pl. 9, profile *D–D'*); east of it is a zone of comparatively low rounded foothills. As shown by the geologic map (pl. 1), the mountain front is essentially a dip slope along the quartzite of the Ravalli formation and might, ordinarily, be regarded as entirely explained by selective erosion. Owing to the difficulty previously mentioned, however, of accounting for the great amount of excavation necessary, relative depression is suggested along a strike fault that is parallel or nearly so with the bedding. For such a fault, of course, the evidence afforded by stratigraphic displacement is lacking.

For most of the east side of Libby Valley detailed information is lacking. A fault that may have controlled the location of the Swamp Creek trench is mentioned by Calkins.[77] Projected northwestward this fault would extend along the east side of Libby Valley. A downthrow on either of these hypothetical faults would help explain the valley.

The gorgelike narrows along the lower course of Bull River apparently marks the position of a former divide. The drainage pattern of the surrounding area (pl. 9) indicates that the east Fork of Bull River was among the headwaters of a northward-flowing stream that probably was captured by a short stream of steep gradient tributary

[75] Calkins, F. C., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, p. 67, 1909.
[76] Calkins, F. C., op. cit., p. 77.
[77] Calkins, F. C., op. cit., pp. 82, 83.

to Clark Fork. This channel may later have been enlarged by large streams of southward flowing glacial meltwater.

The lowland at Heron, in the southwest corner of the quadrangle, is part of a stretch of the valley of Clark Fork River 2 to 5 miles wide that extends, without noteworthy deviation from a course of about N. 45° W., from Thompson Falls to Lake Pend Oreille, a distance of about 70 miles. Along the northeast side of this valley the mountains rise steeply from a regular base line that suggests a fault, trace of which is concealed by terraced Pleistocene lake and stream sediments. The mountains on the opposite side show a less regular base line. The Hope fault (pp. 46–47) is known to extend southeastward along Clark Fork Valley at least as far as Vermilion River, and physiographic features indicate that it continues to Thompson Falls and beyond for an undetermined distance up the valley of Cherry Creek, a tributary of the Clark Fork from the southeast. As suggested by Anderson,[78] this fault has apparently controlled the location of Clark Fork Valley below Thompson River.

Many of the geologists who are familiar with the mountainous region of western Montana and central and northern Idaho interpret the physiographic history in the light of two main events: (1) The development by erosion in late Cretaceous or Tertiary time of a surface of generally moderate to small relief across the previously deformed and elevated rocks and (2) regional re-elevation in late Tertiary and Pleistocene time, followed by development of the present rugged topography by the erosion of streams and glaciers. The re-elevation was not uniform throughout, partly because of faulting, which in places produced depressions characteristically bordered on one or both sides by scarps.[79]

In the vicinity of the Libby quadrangle the forms that are regarded as remnants of the Tertiary erosion surface or that may be inherited from it include flat or gently sloping areas on the summits of divides in the Bitterroot Mountains, southwest of Clark Fork Valley. The surface that these areas presumably represent now lies at altitudes ranging from 5,000 to 6,000 feet (pls. 1 and 9, profiles *D–D′ and E–E′*). West of Lake Creek Valley similar forms appear to represent a surface that rises from about 5,000 feet near the valley to 6,500 feet or more in the adjoining part of Idaho. The Cabinet Range east of

78 Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, p. 8, 1924.

79 Reed, J. C., Gold-bearing gravel of the Nez Perce National Forest, Idaho: Idaho Bur. Mines and Geology Pamph. 40, pp. 12–13, June 1934. Anderson, A. L., op. cit., pp. 49–59; Cretaceous and Tertiary planation northern Idaho: Jour. Geology, vol. 37, pp. 747–764, 1929. Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: U. S. Geol. Survey Prof. Paper 27, pp. 26–27, 1904. Umpleby, J. B., An old erosion surface in Idaho: Jour. Geology, vol. 20, No. 2, pp. 139–147, 1912; Geology and ore deposits of the Mackay region, Idaho: U. S. Geol. Survey Prof. Paper 97, pp. 19–21, 1917.

Lake Creek Valley and northeast of Clark Fork Valley rises to a general summit level of 7,000 feet or more. It shows no definite remnants of the old erosion surface, but their absence may be reasonably explained as the result of the especially severe erosion of that area resulting from its relatively great height.

From the foregoing considerations it is concluded that Lake Creek Valley is chiefly the result of faulting that deformed the Tertiary erosion surface, causing the block beneath the valley to be relatively depressed and the adjoining mountain block on the east to be relatively elevated. The cross profiles suggest that the valley block and the northern part of the mountain block were tilted slightly eastward. Evidences of comparatively recent movement between these blocks are mentioned elsewhere (pp. 43–44). Kootenai Falls, also, may be interpreted as evidence of a very recent upward movement of the block. The falls (pl. 2), a scenic feature of the gorge that Kootenai River has cut between the Libby and Lake Creek Valleys, form a cascade at the head of an inner gorge about 3 miles long. They appear entirely unrelated to any of the glacial features and are therefore assumed to have been initiated by uplift along the fault east of Lake Creek Valley (p. 44). Considering the vigor of the river and the fact that the rock is not particularly resistant, the upstream migration of the falls may easily have been accomplished since Pleistocene time.

The character of the deformation that produced Libby Valley is less definitely indicated. The valley area may have been depressed along either or both of the hypothetical faults along its sides.

As already mentioned, the Clark Fork River has eroded its valley along the Hope fault from Thompson Falls to the Idaho line. Anderson,[80] referring to the extension of the fault in Idaho, concluded that renewed movements along the fault so displaced the Tertiary erosion surface that it is now about 1,500 feet higher on the north side of the fault than on the south side, and elsewhere in the present paper (p. 46) Gibson and Jenks have called attention to the fact that in the vicinity of the Libby quadrangle the surface is higher northeast of the fault than southwest of it. Cross profiles (pl. 9, profiles *D–D′* and *E–E′*) indicate that the Clark Fork Valley is excavated 3,000 feet below the Tertiary erosion surface as shown on the south.

Northeast of the river remnants of the Tertiary erosion surface, if there ever was one, are lacking, and there appears to be no very strong proof of post-Tertiary movement along the fault. However, the gently descending slope of the Tertiary surface from the south toward the river suggests a downward movement with a slight tilting toward the fault which may have determined the original position of the stream.

[80] Anderson, A. L., op. cit., p. 46.

GEOLOGIC HISTORY

As most of the Libby quadrangle is underlain by rocks of the Belt series and contains no other indurated sediments except two extremely small outcrops of Middle Cambrian, knowledge of its geologic history is necessarily incomplete. The folding, faulting, and igneous intrusion can be dated only in the light of work done by others in nearby regions where the geologic record is fuller and more legible.

In the Libby quadrangle this record begins with the deposition of fine-grained clastic sediments in a vast shallow sea. In the entire column of 40,000 feet of Belt rocks no unconformity was observed, yet the whole series is characterized by evidences of deposition in shallow water, such as cross bedding, mud cracks, clay-gall conglomerate, ripple marks, and casts of salt crystals. This evidence implies a prolonged gradual subsidence, which kept pace with sedimentation.

Near the close of pre-Cambrian time or possibly during Paleozoic time the Belt rocks were invaded by diorite sills which resemble the Purcell sills of southern British Columbia and similar sills in northern Idaho but are not so abundant nor in general so thick. They are not found in formations younger than the Wallace, where they might be expected to occur if they were Paleozoic or later in age.

At the close of the pre-Cambrian, the region was uplifted and the Belt series was somewhat deformed and eroded before a new period of subsidence led to the incursion of the Cambrian sea. How extensive the Cambrian embayment was is unknown. The fauna in the small exposure of Cambrian rocks east of the quadrangle is different from that in the very small Cambrian outcrops on the Clark Fork, and in neither of these was the Cambrian seen in contact with older rocks. The history of any sedimentation that may have occurred in the area between the Cambrian and the Pleistocene is unrecorded; whatever sediments may have been laid down in this interval have been removed by erosion.

In the Rocky Mountain revolution of late Mesozoic or early Tertiary time the Belt and any younger sediments that had been deposited were bent into great folds and to some extent were thrust faulted, and the area was elevated to a mountain system. At or near the close of the folding the region was invaded by a body of magma of batholithic proportions, and many steeply dipping persistent faults were formed. The uppermost parts of the batholithic magma are now exposed as quartz monzonite stocks. The magma also sent forth dikes, which cut both the stocks and the sedimentary rocks into which some of them extended for great distances. In cooling and becoming differentiated, the magma gave off the solutions that produced the ore deposits.

During all of the time since the area has been above the sea it has been subjected to erosion and weathering, but these processes have been especially active since the area became high and mountainous. During Pleistocene time especially, when glaciers covered most of the quadrangle, erosion was greatly accelerated. These later episodes in the geologic history have been more fully considered in the sections on Quaternary glaciation (pp. 49–61) and Physiography (pp. 61–65).

ORE DEPOSITS

HISTORY OF MINING AND OUTPUT

Placer gold is said to have been discovered in this region as early as 1867,[81] but owing to the hostility of the Indians, by whom several prospectors were killed, little work was done on the deposits for some time. The first prospecting in the Coeur d'Alene district of Idaho was done in 1878, and it is thought that prospectors from that region drifted into the Libby country in the early eighties to renew the search for placer gold. Among the first to locate placer ground near Libby were Tom Shearer and B. F. ("Doc") Howard. They were followed by John Leigh, George Reider, "Lawyer" Burton, Mart Conners, James Powers, and others, and by 1887 a small town had grown up on Libby Creek near Ramsey Creek, where the first placer mining was carried on.

One of the earliest enterprises was the Howard placer, operated by the Howards and William Williams on Libby Creek, where some of the coarsest gold ever found along this creek is said to have been mined. A group of mining men, chiefly from Butte, later bought out Williams and the Howards, acquired more ground, and formed the Libby Placer Mining Co. This company installed a hydraulic outfit, and the project is said to have paid small dividends. Other placer deposits were soon found, notably on Cherry, Little Cherry, and Howard Creeks, and on West Fisher River.

One of the oldest deep mines of the district is the Silver Mountain (formerly the Silver Crown), a small property on Granite Creek, located by George Blackwell and associates in 1887. At about the same time the Silver Butte, on a branch of the Fisher River, was opened by William Criderman. A concentrating plant at the Silver Butte, reported to have cost $150,000, was burned in 1905. Mines on Shaughnessy Hill, north of Shaughnessy Creek, were located about 1889 by Tom Shaughnessy and W. A. Hillis; some of these mines are included in the Glacier Silver-Lead group, which was productive in the summer of 1930.

About 1890 several placer claims were staked on Little Cherry Creek. They were later bought by the Comet Mining Co.

Gold-quartz veins were discovered on West Fisher River and its tributaries in the nineties. The Fisher Creek mine, called the "Bran-

[81] Schrader, F. C., Gold-bearing ground moraine in northwestern Montana: U. S. Geol. Survey Bull. 470, pp. 70–74, 1911.

agan," one of the earliest, ran a 10-stamp mill for several years. The American Kootenai and Blacktail mines also erected small stamp mills, both of which are said to have been destroyed by snowslides. These mines in the Fisher River drainage basin obtained their early output from the oxidized parts of quartz veins parallel to the bedding.

The vein at the Snowshoe mine was first opened in 1892, but extensive development work was not begun until 1900. The total output to date is reported to have been about 130,000 tons, which yielded $1,086,000 in net smelter returns for lead, silver, and gold. It is common talk among the old miners that this property was not well managed, and the present owners believe that at times in the past as much as 40 percent of the concentrates were lost as a result of inefficient milling. The mine has been idle for many years, and most of the workings are inaccessible, but the present owners have expressed a belief that the mine still contains proved or partly blocked out ore.

From 1902 to 1909, according to Schrader,[82] most of the placer gold came from the Libby Placer Mining Co.'s deposit and from the Vaughan-Greenwell placer of the Eldorado claim group, which is on Howard Creek a short distance upstream from the Libby placer. Schrader reports the total value of placer gold for this period as $52,178.

The Montana placer, on Cherry Creek, which was opened about 1905, was taken over from the Howards in 1915 by J. E. Leary, M. Neary, Sam Miller, and associates, who spent $60,000 in developing the property.

The Midas mine, formerly the Rose Consolidated, was first located in 1905 and is credited with some output of gold and tungsten concentrates between 1916 and 1918.

The largest mine in the area, the Snowstorm (formerly the B. & B.) on Callahan Creek 5 miles southwest of Troy, is said to have supplied some substantial shipments before 1905. Shipments were reported each year from 1917 to 1928. According to officials of the Troy Mines Co., which now controls the Snowstorm, the total output to date in lead, zinc, silver, and gold has been at least $4,000,000, and the present ore reserves amount to 150,000 tons. The 500-ton Snowstorm mill at Troy, which treated the ores and also custom ore from other properties in the Troy district, was destroyed by fire in May 1927, and the mine has been shut down most of the time since.

The Comet Mining Co. is reported to have bought placer claims on Little Cherry Creek in 1908 and to have worked them between that date and 1915, when mining ceased because operation became unprofitable.

Other lode mines that are credited with shipments are the Big Eight,

[82] Schrader, F. C., op. cit., p. 71.

Cabin Queen, Tip Top, Liberty, Pathfinder, Silver King, and Silver Strike.

The table on page 70 summarizes by decades the production of gold, silver, copper, lead, and zinc in the area from 1901 to 1937, inclusive. The Sylvanite district, north of the Libby guadrangle, and the Silver Butte district, just south of the quadrangle, are included in this summary, even though mines in those districts have not been described in the present report. Calkins, in a written communication, remarks that at the time of his reconnaissance in 1905 Sylvanite was a typical ghost town, entirely deserted, the houses in fair condition except for sagging roofs. The mines were idle and apparently had been abandoned when the oxidized ore played out. It evidently was revived about 1930. Even less is known of the Silver Butte district, from which no ore was shipped between 1901 and 1930, and only 15 tons were shipped during the period 1931–37.

The figures do not include all of the gold the area has yielded. Data for the years before 1901 are not available, yet it is reasonably certain that there was some production of placer gold before that date. Schrader[83] states that the district had yielded gold for 20 years before he examined it in 1910.

OUTLOOK FOR MINING

Except possibly at the Snowstorm, Snowshoe, Glacier (formerly called the Lukens-Hazel), and some of the other larger lode deposits, mining operations in the Libby quadrangle have been rather spasmodic and not very profitable. Among the reasons given by the miners for this result are lack of capital, remoteness of location, especially of the gold-quartz veins, and certain inherent features of some of the deposits. Several of the smaller lodes have given promise of profitable exploitation, but their operators have not had capital enough to explore them and block out reserves. Some of these mines depend upon mountain streams for power to run mills or other equipment, and the owners could not afford to build power plants with enough storage capacity to carry over periods of low water. Fairly elaborate equipment has been available to operate other small lodes, but these attempts proved unprofitable, partly, it would seem, because of unskillful management and lack of technical advice. As in other mining districts, there has been some waste of funds in the premature building of mills and other ill-considered operations.

The burning of the Snowstorm mill at Troy in 1927 has seriously retarded mining operations and diminished production in that district, for the mill concentrated custom ore from mines near Troy as well as the Snowstorm ore; other causes, however, may have contrib-

[83] Schrader, F. C., op. cit., pp. 71–72.

Gold, silver, copper, lead, and zinc produced in the Libby, Troy, Sylvanite, and Silver Butte districts, Montana, 1901—37

[Compiled by C. N. Gerry, Bureau of Mines, U. S. Department of the Interior]

District and county	Period	Ore (short tons)	Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Total value
Lincoln County:								
Libby (Snowshoe, Cabinet)	1901–10	71, 158	3, 427. 41	117, 170	279	5, 833, 551		$358, 278
	1911–20	14, 825	2, 805. 61	40, 618		1, 987, 944		171, 137
	1921–30	37, 531	2, 118. 05	69, 047	466	1, 200, 558	26, 186	172, 648
	1931–37	12, 876	4, 030. 73	25, 549	1, 454	233, 804		133, 949
		136, 390	12, 381. 80	252, 384	2, 199	9, 255, 857	26, 186	836, 012
Troy (Callahan Creek, Grouse Mountain)	1901–10							
	1911–20	219, 942	2, 054. 72	514, 178	108, 770	20, 805, 067	4, 934, 886	2, 478, 634
	1921–30	148, 482	753. 63	198, 063	15, 571	8, 494, 965	1, 819, 887	864, 227
	1931–37	1, 856	33. 20	2, 127	15, 699	173, 328	216, 182	22, 405
		370, 280	2, 841. 55	714, 368	140, 040	29, 473, 360	6, 970, 955	3, 365, 266
Sylvanite (Yaak)	1901–10	175	54. 93	556		6, 423		1, 718
	1911–20							
	1921–30	12	19. 20	42		2, 040		551
	1931–37	22, 235	6, 370. 09	24, 119	11, 077	228, 034		246, 254
		22, 422	6, 444. 22	24, 717	11, 077	236, 497		248, 523
Sanders County:								
Silver Butte (Vermillion)	1901–10							
	1911–20							
	1921–30							
	1931–37	15	268. 37	48				8, 519
		15	268. 37	48				8, 519

uted to the decline of mining activity since 1927. The completion of the Glacier Silver-Lead Co.'s modern 300-ton mill on Granite Creek in 1930 might have stimulated production in the mines south of Libby had it not been for the decreasing prices of metals during that year and those that followed.

The area of gold-quartz veins is about 35 miles south of Libby, the nearest railway point, from which supplies must be brought. Over part of this distance there are no good roads, and some miners incurred the expense of transporting ore on pack horses to the end of the automobile road, from which it was then carried by truck to Libby. In 1932 the Midas was the only property in the gold-quartz district that had electric power and modern milling equipment.

As many of the gold-quartz veins are thin and not continuous much waste rock must be mined, and no large ore bodies have thus far been developed. Owing to the improvement in transportation and appreciation in the value of gold that has occurred in recent years, however, some of the veins might yield a profit if mined in a sufficiently economical manner. Records of assays, which do not seem extravagant, quoted by owners of the Tip Top mine suggest that there may be places in this area where several quartz veins and the intervening country rock impregnated with sulfides could be mined together as low-grade gold ore. Thorough sampling would be necessary, however, to determine whether any such bodies are extensive and continuous enough to be profitably mined on a large scale and at low cost.

CLASSIFICATION

The ore deposits of the Libby quadrangle include gold placers and several kinds of lodes. The placers are small and are now not very productive, though they were much more so in the past. The lodes may be classified as gold-quartz veins, silver-lead veins, and copper veins. The copper veins are few, scattered, and not commercially important. Almost all of the silver-lead deposits contain some gold, and most of the copper deposits contain some silver. A few of the silver-lead veins contain a good deal of sphalerite and might perhaps appropriately be called silver-lead-zinc veins, but only two of them contain zinc in commercial quantity.

DISTRIBUTION

The gold-quartz veins are for the most part in the Fisher River drainage basin and on Libby Creek, in the southeastern part of the quadrangle. A few small prospects in which gold is the only metal sought are in the northern part of the quadrangle, the largest of them being the Herbert prospect on Prospect Creek.

The silver-lead veins are most abundant in four localities, namely, (1) on Grouse Mountain and on Callahan Creek northwest of Grouse Mountain, (2) at and near the Glacier mine on Shaughnessy Creek, a small tributary of Granite Creek, (3) along the Snowshoe fault, especially at the Snowshoe mine, and (4) along the Blue Creek fault, near Fatman Mountain, north of the Clark Fork. Small isolated silver-lead prospects are found elsewhere in the quadrangle.

The copper veins are small and are developed in isolated small prospects of Squaw Peak, Copper Mountain, Cedar Creek, and Copper Gulch, and along the Rock Lake fault. One of these, the Premier, contains barite and was opened up primarily for that mineral.

GEOLOGIC RELATIONS OF THE LODES

The lode deposits are veins extending along faults and shear zones in the Belt rocks and in the accompanying metadiorite dikes and sills. They have been formed partly by fissure filling and partly by replacement.

All of the gold-quartz veins and the copper veins are in sedimentary rocks of the Belt series. Of the three most important silver-lead veins, the Snowstorm, which has been the most productive to date, is in a metadiorite dike injected into Belt rocks; the other two, the Snowshoe and the Glacier are along faults in the Belt rocks. The smaller silver-lead veins are about equally divided between the Belt rocks and the metadiorite sills and dikes. The sills, though they are larger, more numerous, and more widespread than the dikes, contain fewer veins than the dikes, and only one prospect in a sill has been productive.

Excepting two small prospects on Parmenter Creek, no veins in or near the quartz monzonite or similar rocks now exposed at the surface have been prospected.

PLACER DEPOSITS

The first gold placer workings in this district were in the stream gravel along the present stream beds, and all the deposits that have been worked with profit are in the valleys and low places. A large area of gravel on higher ground, examined in 1910 by Schrader[84] of the Geological Survey, was found to be of too low grade to be workable.

The miners commonly report that there is a surface concentration of gold in the till but that it is insufficient to make pay ground, and attempts to handle large quantities of till appear to have been unprofitable. It is only where the gold has been reconcentrated from

[84] Schrader, F. C., op. cit., pp. 62–74.

the till or from the gravel in former stream channels, or where the preglacial placers are undisturbed, that the ground is rich enough to yield a profit. Miners who have been able to pan gold at many places from the surface of the till have sometimes hastily concluded that large bodies of such ground were rich throughout, and rumors thus set on foot have caused men unskilled in placer mining to waste their money in attempting to mine moraines without adequate preliminary prospecting. The necessity for technical advice and skilled management in these enterprises cannot be overemphasized. Placer gold has not been recovered in appreciable quantity, so far as the writer knows, except from stream-washed gravels close to bedrock in the present channels of Libby, Howard, and Cherry Creeks, or from ancient channels very close to those of the present streams. Some of these gold-bearing gravels lie underneath the till and are therefore older than the till.

The early miners used rockers and ground sluices and worked out only the shallow ground. Later a steam shovel was used at one property and hydraulic outfits at several. In 1934 hydraulicking was carried on at the Libby Creek Gold Mining Co.'s pit on Libby Creek above Howard Creek and at the Red Gulch placer, on Libby Creek just below the mouth of Little Cherry.

Much of the placer gold is 0.926 to 0.945 fine.[85] Some of the gold is in the form of nuggets, as Schrader observed, but much of it occurs in very small flaky particles with well-rounded edges. Other grains are gnarled or cinderlike but roughly spherical, or long and slightly bent. A few grains have a little quartz adhering to them. The color of the gold ranges from various shades of yellow to rusty red.

SOURCE OF THE GOLD

More or less gold is present in veins that have been prospected or mined on Libby, Cherry, and Howard Creeks, on nearly every tributary to these creeks, and on other creeks that head high in the Cabinet Mountains and flow in a general easterly or northeasterly direction. These veins have been exposed to weathering and to the erosive action of streams and glaciers for a very long time. As a result, the small particles of gold that weathered out have been transported and concentrated in the present and former stream channels.

GOLD-QUARTZ VEINS

ASSOCIATED COUNTRY ROCK

There are more gold-quartz mines and prospects in the Prichard than in any other formation in the Libby quadrangle. Fairly pure gray argillite that weathers to a rust color, laminated siliceous shale,

[85] Mineral Resources U. S., 1908, pt. 1, p. 450, 1909.

argillaceous sandstone, and white sericitic sandstone are the wall rocks seen in various properties. Only one mine, the Midas, and a few prospects are in the Wallace formation. At the Midas mine a vein occurs in impure sandstone, calcareous and sandy shales, and impure limestone, so that here, evidently, the kind of wall rock did not influence the character of the vein. Perhaps this is true of the district in general. In the Coeur d'Alene district, also, most of the gold quartz veins are in the Prichard formation, but Ransome [86] says, in commenting on the fact, that "it would be difficult to disprove the suggestion that the occurrence of the gold ores in the Prichard is merely a coincidence, the slate happening to be exposed by erosion over areas where the deposition of gold had been determined by deep-seated causes entirely independent of the rocks now visible at the surface."

No veins in the sills or dikes have been rich enough in gold to be worked solely or chiefly for that metal.

STRUCTURE AND GENERAL CHARACTER

The veins are commonly parallel to the bedding and have therefore been called bed veins. Some of them, however, cut across the beds at a low angle, and a few are vertical, and some distinctly crosscutting veins change their course and become bed veins. The veins pinch and swell within short distances, and one vein may split into two or more branches that fray out into the country rock. Others come in above or below a pinched vein, or where one vein splits into several the intervening country rock may be mineralized. Where the veins are not parallel to the bedding they commonly cut across at low angles and invariably have a steeper dip than the beds, whether or not the beds are nearly horizontal.

The thickness of the veins ranges from a few inches to 6 feet and averages between 1 and 2 feet. Inclusions of country rock in all stages of replacement by quartz are common, and where a vein is several feet thick a considerable part of it may consist of such inclusions. The inclusions have had no apparent effect on the introduction of metals.

It is common to find gold-quartz bed veins related to faults and shear zones of comparatively steep dip. Good ore has been mined from bed veins in the Little Annie, Tip Top, and Fisher Creek mines, and elsewhere near steep crosscutting faults, and in a few places ore has been found in the faults. In the Little Annie a small amount of rich ore was mined from one vein in a vertical fault. At the Sunrise prospect a nearly vertical fault vein, which has been traced by open cuts for 1,000 feet along the strike, contains visible native gold, though no ore had been produced from it up to 1934, when it was examined.

[86] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, p. 143, 1908.

At the Herbert prospect, on Prospect Creek, open cuts have shown a vertical shear zone containing veins of quartz that encloses a little partly oxidized sulfide. The quartz pans well, and the veins are reported to yield about 0.3 ounce of gold to the ton.

Although bed veins have clearly been displaced by some of the cross faults, it is not everywhere certain whether the displacement occurred before or after the deposition of the sulfides and gold. In some places, as at the Fisher Creek mine, the quartz and sulfides have been shattered by movement along faults. Some of these faults probably originated before any deposition of vein minerals and were subjected at least twice to renewed movement, once after the quartz was formed and again after the sulfides were deposited. Good ore is locally associated with faults that may have originated since the deposition of sulfides and gold. Movement has taken place along these cross faults therefore, during at least three different stages—during or before the introduction of quartz, after the introduction of quartz, and after the introduction of sulfides and gold.

Movement has taken place also within the bed veins parallel to their walls and has developed sheeting or ribbon structure in the veins. Under the microscope it can be seen in thin and polished sections of the ores that solutions found brecciated parts of these sheeted zones to be favorable places for the deposition of sulfides and gold. The features above set forth are similar to those in gold quartz veins of certain other districts. In the Alleghany district, California, according to Ferguson and Gannett,[87] high-grade shoots in gold-quartz veins are associated with minor transverse faults that were formed after the deposition of the quartz, and other shoots are localized where the shattering of quartz in the vein permitted ingress of the gold-bearing solutions. Hewett,[88] also, in describing the gold lodes of the Sumpter quadrangle, Oregon, has pointed out certain relations between quartz, sulfides, and gold in the veins of that and many similar districts. He interprets these relations as showing "that the veins were first filled with quartz that was barren of gold and sulfides and that these minerals were deposited late in the history of the vein, with or without associated quartz, after one or more intervening epochs of crushing."

There has been a distinct prejudice heretofore on the part of prospectors for gold in this district in favor of bed veins, especially those that are nearly horizontal, but, so far as the writer has observed, the attitude of the country rock has had little to do with the deposi-

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[87] Ferguson, H. G., and Gannett, R. W., Gold quartz veins of the Alleghany district, Calif.: Am. Inst. Min. Met. Eng. Tech. Pub. 211, pp. 35–36, 1929; U. S. Geol. Survey Prof. Paper 172, pp. 56–58, 1932.

[88] Hewett, D F., Zonal relations of the lodes of the Sumpter quadrangle [Oregon]: Am. Inst. Min. Met Eng. Trans., 1931, pp. 305–346.

tion of ore. The productive bed veins in the Little Annie mine are at the crest of an anticline and are nearly horizontal, the veins in the Tip Top and Fisher Creek mines are east of the crest and dip eastward at successively steeper angles, and the Midas vein, 3½ miles northeast of the Little Annie, is far down on the limb of the same anticline and dips 55° NE.

Persistent steeply dipping cross faults are not so conspicuous in the area of gold-quartz veins as they are elsewhere in the quadrangle. Where mineralized they are leaner in sulfides than in the northeastern part of the quadrangle, and where prospected for gold they are commonly reported to be less rich than the bed veins. As mentioned above, however, some good ore shoots have been found in bed veins closely associated with cross faults, and in two recently opened prospects, the Herbert and Sunshine, paying quantities of gold have been found in quartz veins that cut across the beds.

MINERALOGY

Quartz makes up 95 to 98 percent of most of the veins. It is milky white where it is not stained as a result of oxidation of sulfides, and it rarely contains vugs. Under the microscope the quartz grains are seen to range from 0.005 to 17 millimeters in greatest diameter, the average being about 1.0 millimeter. The grains very commonly interlock somewhat like the parts of a jigsaw puzzle, and they rarely show crystal faces. As a result of shearing, the quartz in many places shows ribbon or platy texture parallel with the bedding, and the beds adjacent to the veins are sheeted in the same direction. This texture is commonly developed in good ore but may be present also in poor ore. Under the microscope the ribbon quartz shows strain shadows, brecciation, and small faulted veins. Sericite, and to a more striking degree sulfides and gold, are related to the brecciated areas. Very commonly both gold and sulfides are seen under the microscope to have replaced small brecciated grains of quartz, but both have also penetrated and replaced large solid grains of quartz.

Sericite, the only conspicuous gangue mineral other than quartz is present in all the veins, but it apparently is residual from incompletely replaced country rock and is therefore not strictly a vein mineral. The veins contain small quantities of siderite, dolomite, and calcite, as well as a very little chlorite and epidote which have probably been derived from the country rock.

Pyrite, galena, sphalerite, and pyrrhotite are the most abundant of the metallic minerals, though commonly not more than one of them is abundant in any one vein. Chalcopyrite is present in about two-thirds of the veins seen but is everywhere scarce. Arsenopyrite, tetrahedrite, magnetite, and scheelite likewise are scarce and occur only here and there.

Pyrrhotite, pyrite, and sphalerite are early minerals, deposited in the order named. In the veins they are commonly coarse-grained, but pyrrhotite and pyrite where they are disseminated in the wall rock near the vein are fine-grained. Sphalerite is ordinarily confined to the veins, and pyrite is the most widespread of the three. In a few places these sulfides had been shattered before they were replaced by others, but the sulfides are much less commonly brecciated than the quartz. Galena and chalcopyrite follow sphalerite in the depositional sequence. Galena is as widespread as pyrite and a little more abundant. Specimens high in galena have yielded the best assays for silver.

Native gold coarse enough to be readily seen is found in ores from the four largest mines described in this report—the Fisher Creek, Golden West, Midas, and Tip Top. Ore from the Tip Top mine is shown on plate 10. The following account of its relations to other minerals is based on study of specimens from those four properties.

Gold appears to be concentrated in those veins or parts of veins that contain or have contained sulfides. Thus far, the richest ore has come from quartz veins at least a foot thick. Where the miners say that gold is disseminated through several feet of sedimentary rock, close examination will show that the rock is partly replaced by tiny veins of quartz, containing sulfides and gold in such quantity that the veined rock is minable as a low-grade ore. Gold also occurs in quartz without sulfides, most commonly where the vein has been sheared and brecciated. Next to quartz, the commonest associate of gold is sphalerite. Under the microscope gold is seen in many specimens to have replaced sphalerite or to have been deposited along boundaries between sphalerite and some other mineral, commonly quartz, galena, pyrite, or pyrrhotite. (See pl. 11.) Gold was found less commonly along contacts between quartz and galena, pyrite, or pyrrhotite. A little sericite, which may be residual, occurs in the brecciated quartz with the gold and sulfides. A little tetrahedrite and scheelite are present in the Midas ore, but neither mineral was seen in close association with gold.

Where gold replaces sulfides it is smooth and dark yellow and occurs in irregular grains or in elongate wirelike or lenticular particles. Where it replaces sphalerite it may have straight edges controlled by the sphalerite cleavage. In oxidized ore the gold is gnarled, rough, or spongelike.

During or after the deposition of gold a little fine-grained pyrite and a second generation of quartz were added. In vuggy ore pyrite of this stage can be seen in very small crystals perched on quartz; in massive ore pyrite in strings of small cubes replaces the early minerals.

Recent glaciation has removed the upper parts of the veins, and postglacial erosion has been rapid. Oxidation is therefore not conspicuous.

but its extent varies greatly from place to place; for example, very little sulfide is left unoxidized in the ore mined at the Tip Top, about 75 feet below the surface, whereas the ore at the Little Annie, which is not much deeper than the Tip Top, is very little oxidized. Visible native gold is common in both mines. Between these extremes there are all degrees of oxidation. Limonite is the commonest oxidation product, cerussite and anglesite are present in some ores, and very small quantities of malachite, azurite, pyromorphite, and manganese oxides occur in a few places. A little native copper was seen at the Betty Mae.

TENOR

Mill recoveries of 0.29 to 2.42 ounces to the ton are reported by the operators of some of the mines. A shipment of 39 tons of high-grade ore from one mine is said to have yielded nearly 4 ounces of gold and about 1 ounce of silver to the ton. Assays of selected samples of ore from still other properties ranged from a trace to 24.86 ounces of gold to the ton. No other one metal is sufficiently abundant in the gold-quartz veins to pay for mining it, but silver, lead, copper, and a little tungsten make up part of the total production from these veins.

Early records are not complete enough and well-authenticated assays are too few to establish any ratio between gold and silver that would be significant. According to smelter returns and to assays of samples selected by the writer, silver is more abundant, by weight, than gold, except in the very richest ores. Three selected samples of rich ores, which assayed 1.66, 4.91, and 24.86 ounces of gold to the ton, contained more gold than silver.

SILVER-LEAD VEINS

The silver-lead and silver-lead-zinc veins from which most of the production of the Libby quadrangle has come are found in the Belt rocks, in the dikes, and to a less extent in the sills; all of them are in faults and shear zones.

VEINS IN SEDIMENTARY ROCKS

The veins in the Belt rocks commonly strike north to north-northwest and are vertical or dip steeply to the east. A very few dip westward. The Snowshoe vein at the Snowshoe mine and for most of its length is nearly vertical, but near its southern end it dips 80° E. The vein at the Blue Creek mine is vertical. The veins at the Glacier mine dip northeast. The veins commonly range in thickness from a fraction of an inch to 3 feet, and the fault zones or shear zones that contain them are 3 to 6 or rarely 10 to 12 feet wide. In places the deposit consists of a single vein, but more commonly it is a lode, made up of several veins together with intervening sheared sections of partly replaced country rock and a little gouge and breccia. The greatest observed thickness for a lode is 12 feet, seen in the Snowshoe mine.

The ore minerals form stringers, veins, and irregular bunches at the borders or in the interior of the quartz veins, and intervening sheared sections of country rock are silicified but contain less sulfide. To a minor extent small veins replace the country rock near the shear zones. Most of the movement along the faults took place before any mineralization, but later movement in the plane of the veins has brecciated successively the quartz and the sulfides. In the Glacier mine, and to a less extent elsewhere, the veins are cut by minor faults, which have about the same strike as the veins but which may dip more steeply or less steeply than the veins and either in the same or in the opposite direction. The movement on most of these faults that were seen has been less than 10 feet. Rarely a vein is offset laterally for a short distance by a steeply dipping fault whose strike is about at right angles to that of the vein. Most of the veins are confined to the shear zones, but in places a vein sends off branches, diverging from it but slightly, into the country rock. Many of these branches are faulted where they leave the shear zone. Since these branch veins are barren or lean they have rarely been followed in mining.

VEINS IN DIKES

The most persistent and most productive veins in dikes or alongside them strike northwestward with the dikes. Most of them dip southwestward, but a few dip to the northeast, and a very few are vertical. The veins that dip in the same direction as the enclosing or adjoining dike are the most persistent; those that dip in the opposite direction do not persist far in the sedimentary rocks after they leave the dike. All the paying mines in metadiorite dikes are in dikes that cut the Prichard formation. The veins may be either in the interior of the dike or at the contact of the dike with the sedimentary rock, and any vein may change from one position to the other along the strike. In the country rock alongside the dikes there are small veins and sparsely disseminated grains of sulfides. In most of the prospects the veins are short nonpersistent irregular bodies a few inches to 7 feet in width, and the dike rock exposed in any mine opening commonly shows only a little disseminated sulfide or barren vein material for most of its length. The stopes in the accessible parts of the Snowstorm mine, which is the largest in the district, are 25 to 280 feet long, 15 to 75 feet high, and 8 to 10 feet wide. The veins enclosed in dikes occur less commonly than the veins in the sedimentary rocks at places where the rock has obviously been sheared before mineralization, but mineralized dike rock is invariably near if not within a zone of faulting or shearing. The dikes are closely knit, tough rocks, and except at contacts the faults in them are not continuous. Short post-ore faults, especially in the Grouse Mountain dike, split some of the veins lengthwise and displace them slightly along the strike or up or down the dip. In the Big Eight, Little Spokane, Universal, Iron Mask, and other properties post-ore faults parallel to the bedding or nearly so continue across the contact into the dikes and displace the dikes and enclosing veins a few feet.

VEINS IN SILLS

The veins in or near the sills which have invaded the Prichard, Ravalli, and Wallace formations are smaller and more erratic in their occurrence than the veins in dikes, and have been less productive. At the Silver King and Liberty mines, which are the only two properties that have shipped ore from veins in sills, the veins in the sills were less productive than those in shear zones in sedimentary rock near the sills or at the sill contacts. These veins reach a maximum thickness of 2 feet at the Silver King.

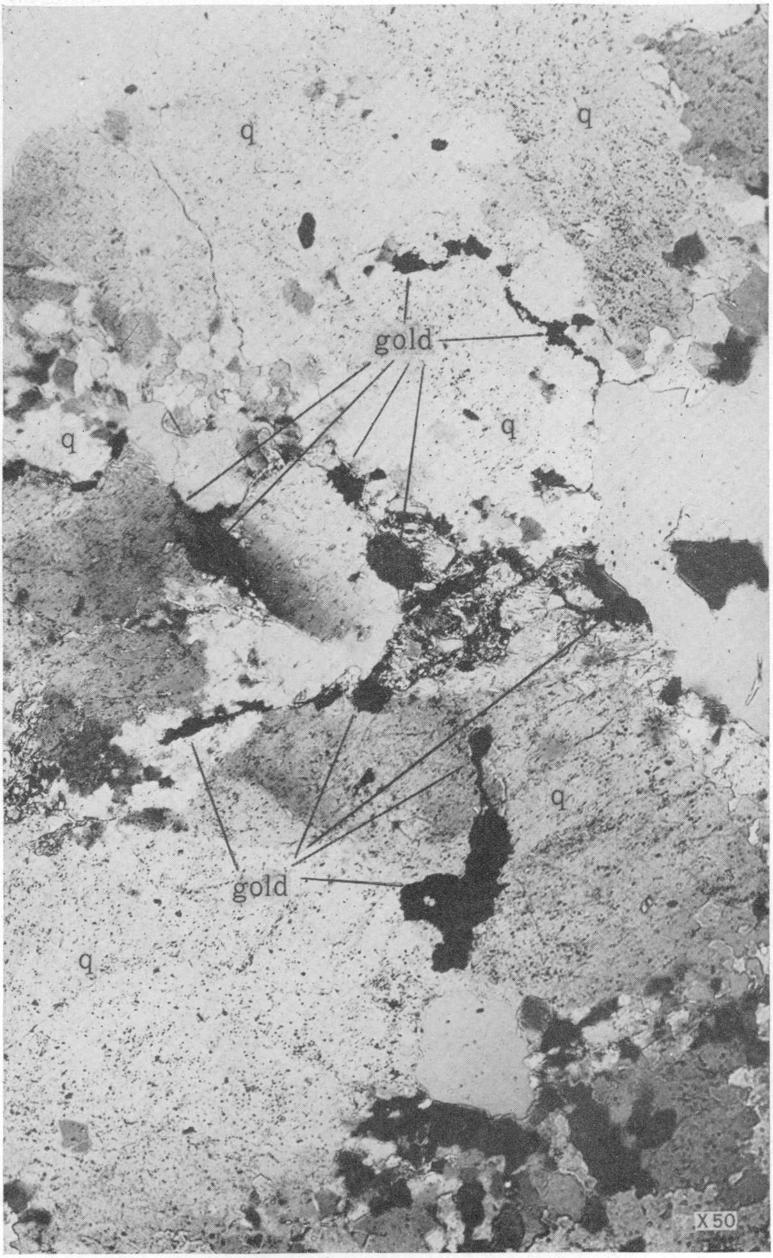
MINERALOGY

The chief metallic minerals in the silver-lead veins are galena, pyrite, and sphalerite. Sphalerite is not quite so widespread as the other two, but it occurs as abundantly as galena in a few prospects and in the Snowstorm, Snowshoe, and Glacier mines. Sphalerite is likely to be a little more abundant in the veins in dikes than in those in the sedimentary rocks. Pyrrhotite, arsenopyrite, chalcopyrite, magnetite, and scheelite, named in order of abundance, are in general subordinate, but in eight properties (about one-sixth of the total number of silver-lead prospects) pyrrhotite or arsenopyrite is the dominant metallic mineral. Only two of these properties, however, have shipped ore. The chief gangue minerals are quartz and calcite. Ankerite, sericite, biotite, chlorite, amphibole, and garnet are neither so widespread nor so abundant. In the veins in the Snowstorm dike, however, chlorite and amphibole are among the abundant gangue minerals, and garnet is present in noteworthy quantity.

COPPER VEINS

So far as the writer is aware the copper veins in the Libby quadrangle have not been commercially productive. They are rather widely scattered and relatively inaccessible, and they contain very little copper. Like the silver-lead veins most of them strike northwestward. They are found in the Prichard, Ravalli, and Wallace formations and range in thickness from 1 to 6 feet.

Quartz is the chief mineral in these veins; chalcopyrite is widespread but not abundant; and tetrahedrite and magnetite are the only other noteworthy minerals. In some veins small amounts of one or more of the minerals galena, pyrrhotite, pyrite, bornite, and calcite are present. The sulfides have been partly replaced by supergene



ORE FROM TIP TOP MINE.

Shows native gold in brecciated quartz (*q*). Thin section. Crossed nicols.

ORE FROM LITTLE ANNIE MINE.

Shows native gold at boundaries between galena and sphalerite. *g*, Gold; *sl*, sphalerite; *gn*, galena; jet black spots, holes. Polished section.

malachite, azurite, and chalcocite. Assays of selected specimens show a trace to 0.10 ounce of gold and 8 to 25 ounces of silver to the ton.

ORIGIN OF THE ORES

The most influential factor in localizing the ore deposits of the Libby quadrangle has been geologic structure. The silver-lead veins are in or near steeply dipping fault fissures or shear zones in the Belt rocks, in metadiorite dikes, and to a minor extent in sills. The gold-quartz veins are commonly parallel with the bedding of the Belt strata, though a few are crosscutting, but the most productive are near steep crosscutting faults. The faults to which both kinds of deposits are related strike north to northwest. The ores are found both in the large persistent faults of the district and in smaller parallel or subparallel faults apparently related to the large faults. The Snowshoe veins are along the Snowshoe fault, and the Glacier veins are along shear zones 1½ miles east of the Snowshoe fault. The Lenia fault is barren, but the Snowstorm veins and the veins on Grouse Mountain are closely associated with minor faults in the disturbed region that extends for 2 miles west of it.

Character of wall rock seems to have had little influence on ore deposition. The Snowstorm veins are in a dike, the Glacier veins are in the Wallace formation, and the Snowshoe veins have Wallace strata on one wall and Ravalli strata on the other. Most of the gold-quartz veins are in the Prichard formation, but the Midas mine and a few prospects are in the Wallace, and the Mustang prospect is in the Ravalli.

Ore deposits in many other mining districts are genetically related to stocks of granitoid rocks like those in the Libby quadrangle, but here there are no veins within the stocks, and the areal distribution of the veins appears to have no definite relation to the outcrops of the stocks. Nor is there any observed zoning or symmetrical arrangement of the ores about the intrusive masses. There is strong evidence, however, that if erosion had gone a little deeper apophyses or offshoots from deeper parts of the exposed bodies of quartz monzonite would have been revealed. The abundance of dikes in the Grouse Mountain area and the mineral associations, especially the garnet-ambibole-chlorite gangue, at the Snowstorm and Big Eight mines indicate nearness to an intrusive mass, but the nearest outcrop of granular intrusive rock is about 3 miles west of the Snowstorm. Near the Victor-Empire, Double Mac, and Silver Mountain properties, on Granite Creek, there is a more conspicuous development of such minerals as tremolite, actinolite, diopside, sphene, and zoisite in the sedimentary rock than there is at the very border of the Dry Creek and Granite Creek stocks of quartz monzonite, 3 miles farther west. Here also the occurrence of contact-metamorphic minerals may indicate that a stock not yet revealed by mining or by erosion is much less than 3 miles distant underground. The Snowshoe mine is 4½ miles from the nearest exposed intrusive mass, the Hayes Ridge stock of quartz monzonite, and the surface area of that mass is only about half a square mile. The aureole around this small stock is very irregular, however, and in places remarkably wide, amphibole, garnet, and epidote being found in the sedimentary rocks a mile or two from the contact.

These conditions are somewhat similar to those in the Coeur d'Alene district, Idaho, about 25 miles south of the Libby quadrangle, where the ores likewise are in the Belt rocks and may be related to the same source as the small monzonite stocks in that area. Ransome [89] says, "At first glance the monzonite masses appear inadequate to account in any way for the ore deposits, some of which, as at Wardner, are 8 miles from the nearest small exposure of the intrusive rock." Ransome believed, however, that these masses exposed at the surface grow larger with depth and are parts of a large mass of monzonite, probably a batholith. He concludes: "The source of the ores is thought to lie in the underlying batholith from which the exposed masses are probably offshoots."

In the Clark Fork district, 2 miles west of the Libby quadrangle, where ores also occur in Belt rocks, the granodiorite stocks contain no ore deposits. Anderson [90] says, however, that "mineralization is confined about the margins of the granodiorite stocks or above such stocks, as is suggested south of the Hope fault near the town of Clark Fork . . . Other scattered deposits are also not far from bodies of granodiorite, which are either exposed on the surface or indicated immediately below the surface by contact metamorphism of the sedimentary rock."

In view of the foregoing arguments and of the similarity between the ores of the Libby quadrangle to those of the Coeur d'Alene and Clark Fork districts, it is believed that, even though there is no obvious direct relationship between the ore bodies and the exposed quartz monzonite stocks, the source of the ores in the Libby quadrangle is the same as the source of the intrusive stocks and their accompanying dikes. The persistent steeply dipping fault and shear zones in or near which the largest and most valuable deposits thus far discovered lie served as deep-reaching channels, and along the more accessible and permeable channels in these zones ore-bearing solutions have moved upward and deposited ores. The source of the solutions is believed to have been an underlying cooling batholith, the highest protuberances of which form the stocks exposed on the surface.

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[89] Ransome, F. L., and Calkins, F. C., Geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, pp. 135–137, 1908.

[90] Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, p. 88, 1930.

MINES AND PROSPECTS

GOLD-QUARTZ MINES AND PROSPECTS

FISHER CREEK

The Fisher Creek Mining Co. owns six lode claims and two placer claims, all patented, on the south side of Bramlet Creek, a little less than 2 miles above the junction of the West Fisher River and Bramlet Creek roads. The mine, called locally the "Branagan," has not been worked for many years. It is reported that in 1901–3, in a run of 26 months, the Branagan owners "cleaned up" $150,000, although at that time their milling was only 60 percent efficient.

Quartz bed veins in the eastward-dipping Prichard formation have been opened up at several places along the outcrop, and all the adits are connected underground by extensive gently dipping stopes. Five of the openings have been numbered on the map (fig. 4) for the sake of convenient reference. As the map shows, the stopes are exceedingly irregular in shape and range in height from 2 or 3 feet to 12 feet. The thickest quartz vein seen (pl. 5 *B*) is 4 feet thick, but the wall rock near the larger veins contains small veins or is impregnated with quartz. In adit No. 1, two 1-foot bed veins are separated by as much as 3 feet of rock, but in places the quartz breaks across from one vein to the other and the entire 5 feet has been mined. In this same adit a 1-foot vein thickens to 2 feet in a distance of 40 feet. Commonly, if one vein pinches out, another is found above or below it along another bedding plane nearby, and the two veins may overlap.

Sulfides are present, though not common, in all the quartz veins. They are everywhere more or less oxidized. In order of abundance the primary metallic minerals seen are pyrite, galena, pyrrhotite, chalcopyrite, sphalerite, and native gold. Pyrite is present in all the ore that was examined, and galena in nearly all; the other sulfides are rare. Gold was seen only in specimens from the face of adit 4. The sulfides are irregularly distributed through the vein in disseminated grains and bunches, but they appear to be concentrated in or close to sheared areas. Not all such areas in the quartz contain sulfides, however, partly because some of the movement that fractured the quartz took place after the sulfides were formed. As a result of partial oxidation the sulfide patches in all parts of the mine are friable, and are discolored with small quantities of iron oxide and, less commonly, manganese oxides. The remnants of ore left at the faces of several adits indicate that the oxidized ore is not yet exhausted. Sericite, the only gangue mineral other than quartz, is present in greater or lesser quantity in all specimens. As sericite and quartz are the chief constituents of the wall rock, it is not everywhere possible to determine whether these minerals were introduced with the veins or constituted part of the original walls.

Steeply dipping or vertical fault fissures, some of which contain 12 to 24 inches of breccia and gouge, are conspicuous in the backs or in the walls of the stopes and drifts. They strike north or a little east or west of north, and most of those whose attitude could be accu-

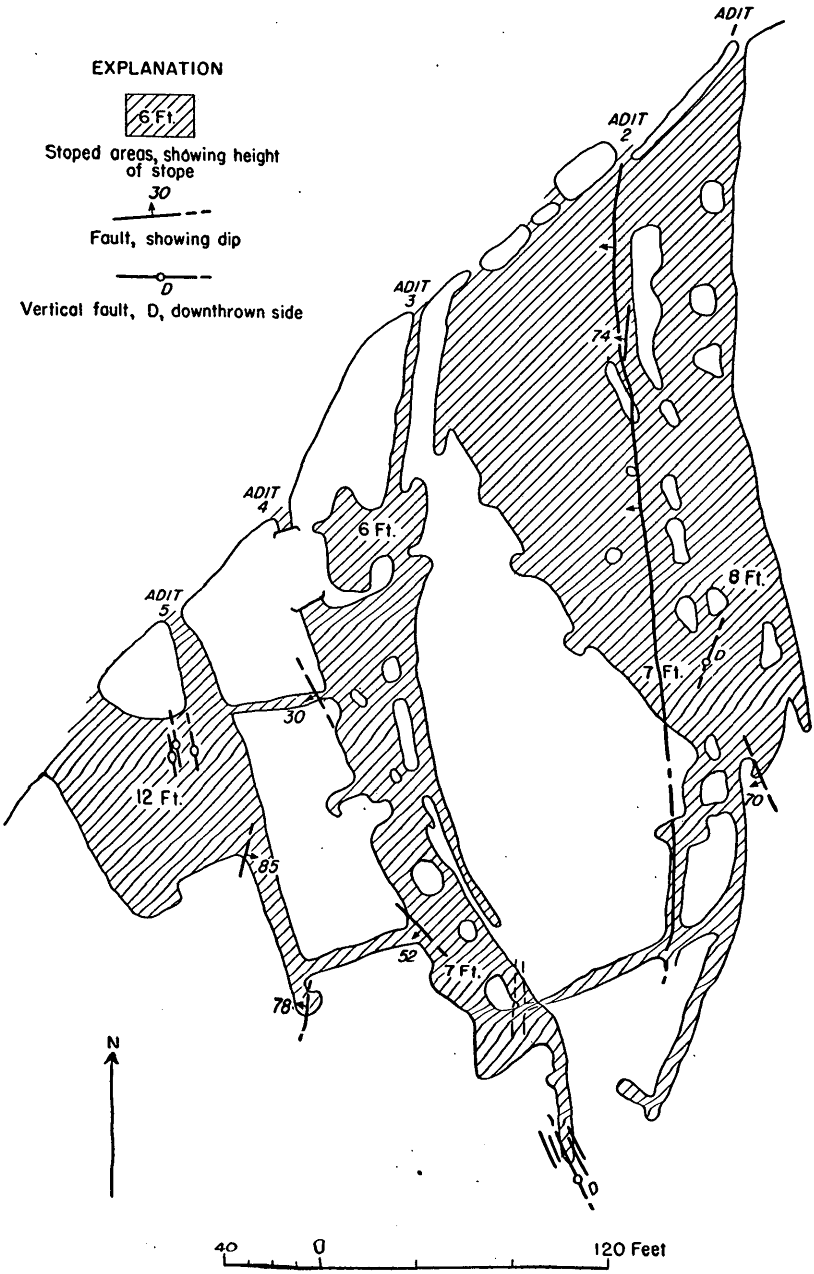

FIGURE 4.—Plan of Fisher Creek mine.

rately determined dip west. The fault at the face of adit No. 1 is marked by a layer of breccia 1 foot thick and the fault in adit No. 4 near the second crosscut to adit No. 5 by a 2-foot layer. The fault fissure in adit No. 2 contains more than 1 foot of breccia and gouge. Because of the similarity of the beds above and below the veins, the amount and direction of displacement on the faults cannot readily be measured, but apparently the vertical displacement is only a foot or two and the downthrow consistently on the east. The horizontal displacement may be greater than the vertical. There has been little or no mineralization along the faults, and they have not been explored to any extent by the miners. The last movement, along the few faults where it could be determined with certainty, occurred after the deposition of the quartz. It is significant, perhaps, that faults are exposed in every stope and that the strongest and most persistent fault is in the largest stope.

A specimen of incompletely oxidized ore containing a very little sphalerite, galena, and pyrite assayed 1.66 ounces of gold and 1.44 ounces of silver to the ton.

GOLDEN WEST MINING CO.

The Golden West Mining Co. has two properties on the West Fisher River, the Little Annie and the New mines. The company's central camp, in the valley, may be reached by a secondary road that connects with a good highway to Libby. Its equipment includes a Diesel engine and compressor, with which air is piped to both mines. The Little Annie mine is 1,200 feet and the New mine 700 feet vertically above the camp. Several large cabins have been erected at the main camp and at the Little Annie mine.

Little Annie.—The Little Annie mine, on the north side of the stream, is worked through two nearly parallel adits, trending N. 10° E., which are connected by a crosscut, and at the time of examination a total of 300 feet of workings had been opened. The country rock is sandstone and laminated sandy argillite of the Prichard formation. The argillite is bluish gray on fresh fracture but weathers rusty brown.

The ore occurs in quartz veins as much as 2 feet thick that lie for the most part parallel with the beds, which are nearly horizontal or dip gently to the northwest. The chief primary metallic minerals are sphalerite, pyrite, galena, and native gold, gold being readily seen in many hand specimens. The close association of gold with sulfides in this and other mines and the order of deposition of these minerals indicate that the sulfides influenced the deposition of the gold. A little pyrrhotite and a very little chalcopyrite are present, and small quantities of sericite and siderite are enclosed in the quartz. The wall rock near the vein contains enough disseminated pyrrhotite to cause the rock to weather brown.

Faulting of the veins parallel with the beds is shown at the contact by grooved and slickensided surfaces of quartz and within the veins by local shattering in the quartz. Sulfides and gold characteristically follow the shattering, as can be seen in the hand specimen but more strikingly under the microscope. Obscure, nearly vertical cross faults were seen, but their net displacement is small.

The ores that are being mined at present are but little oxidized. This fact is of unusual interest in view of the history of several other gold lodes in the Fisher River drainage basin, which according to MacDonald[91] were not formerly regarded as workable below the zone of oxidation.

According to officials of the Golden West Mining Co., one shipment of 39 tons of ore from the Little Annie yielded 3.874 ounces of gold and 1.05 ounces of silver to the ton.

On Golden West ground east of the Little Annie there are bed veins as much as 4 feet thick, containing sulfides in small quantity. These veins pinch and swell abruptly. One of the largest of them decreases from 24 to 12 inches within a distance of 8 feet; at this place, however, smaller parallel veins come in above the main vein. The bed veins are crossed by veins about half as thick, which themselves appear to turn off along the bedding at no great distance. Assays of the crosscutting veins are said to show that they are not nearly so rich as the bed veins.

New.—Very little work has been done at the New mine, on the south side of the West Fisher River, A short adit at an altitude of 4,900 feet has opened up nearly horizontal quartz bed veins, which resemble those at the Little Annie mine but are neither so thick nor so rich in sulfides. Galena, zinc blende, and pyrite are the chief metallic minerals. The ore is partly oxidized and contains limonite. Pannings of this oxidized ore showed native gold. The wall rock is gray sericitic sandstone and gray, laminated, sericitic siliceous argillite. Assays of ore from the New mine are said to average $50 to the ton, chiefly in gold.

MIDAS

The Midas property, which includes the former Rose Consolidated, is on the county highway, about 1 mile southeast of Howard Lake and 21 miles by air line almost directly south of Libby. The property comprises eight unpatented lode claims and one placer claim. According to Mr. Frederic Keffer, engineer for the mine, who gave the writer information about its history, production, and milling equipment, the mine was taken over by the Midas Gold Mining and Milling Co. in 1926 and has since been absorbed by or consolidated with the Spokane-Idaho Copper Co., of Spokane, Wash.

[91] MacDonald, D. F., Economic features of northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 285, p. 50, 1906.

In addition to the stopes, more than 3,000 feet of drifts, crosscuts, and raises are open and accessible. Diesel engines furnish power for an electric hoist, pump, locomotive, and other machinery. Equipment in the 75-ton mill include jaw and cone crushers, ball mill, sampler, Dorr classifier, flotation machines, concentrating tables, and cyanide tanks.

The claims were first located in 1905, but there is no record of early production except between 1916 and 1918, when gold bullion and tungsten concentrates amounting in value to $27,000 were produced. In a test run in 1928 about 1,000 tons of ore, much of it low-grade, netted $6,034. This lot contained 317.14 ounces of gold, 503 ounces of silver, 77 pounds of copper, and 1,029 pounds of lead. In 1929 production was negligible. From August 1, 1932, to July 1, 1933, the ore produced was valued at $20,962 and included 990.79 ounces of gold, besides a little silver, lead, and tungsten. The production for July 1933 is estimated at about $5,000. The total production of the Midas thus appears to have been at least $59,000.

The ore occurs in a quartz vein that ranges in thickness from a few inches to 6 feet and averages at least 1 foot. For the most part the vein is parallel to the beds, which here strike N. 20°–30° W. and dip 40°–60° NE., the average dip being about 55°. In places the vein may dip more steeply than the bedding and cut across it, but the relations are not perfectly clear. At the Montezuma prospect, 2 miles south of the Midas, similar veins locally dip at a steeper angle than the beds. A few small veins split off and enter the hanging wall, but for the most part the vein is clean and well defined. The wall rock, which belongs to the Wallace formation, consists partly of calcareous shales, some of which are made up of paper-thin laminae, partly of sandy shales or sandstones, that are commonly more massive than the shales, and partly of limestones that are banded and in places contorted. The prevailing color of these rocks when unweathered is gray; on weathered surfaces they are buff and the limestone shows characteristic cellular forms.

Next to quartz, the most abundant minerals in the vein are scheelite and carbonate. A little sericite and chlorite are present, and a very little galena and tetrahedrite. Native gold associated with iron oxide, malachite, and scheelite can be seen with the aid of a hand lens. The gold is gnarled and wirelike and deep yellow. Everywhere the ore is partly oxidized, but as sulfides were not abundant the vein quartz and wall rock are not much stained.

Brecciated and silicified hanging-wall rock, in which the matrix of the breccia is vein quartz and the fragments limestone, indicates that faulting took place before or during the introduction of quartz and that the vein may occupy a fault. Faulting along northward-trending or northeastward-trending faults must have taken place, however, after the formation of the quartz vein, for in at least two places these faults offset the vein a little.

TIP TOP

The Tip Top group, formerly called the Blacktail, comprises 2½ patented and 11 unpatented lode claims on the slopes north of Bramlet Creek and south of the West Fisher River. It includes Blacktail Mountain, between Bramlet Creek and West Fisher River. The property has a 10-stamp mill, situated on the Bramlet Creek road less than 2 miles above its junction with the West Fisher River road, which is a good highway to Libby. The mill is run by water power from Bramlet Creek and is connected by a small aerial tram with an ore bin higher on the mountain. Ore mined on the north side of the mountain is hauled around to the bin by sled over an old narrow-gage railroad grade. Several cabins have been built near the Bramlet Creek road. The total production of the property is not known, but according to Mr. O. V. Miller, one of the present owners, about $2,300 in gold has been taken out during recent years in test runs.

Quartz veins on Blacktail Mountain have been mined by open cuts and short adits, none of them longer than 300 feet. The veins on the Tip Top property are numerous, but few of them are as much as 2 feet thick, and many are only a fraction of an inch thick. They commonly are parallel with the beds or cut across them at low angles and are flat-lying or dip very gently eastward, but there are a few cross veins about perpendicular to the beds. The veins pinch and swell to form podlike lenses, and locally they are contorted into small folds. In places tiny veinlets of quartz, some of them microscopic, ramify through the wall rock. The veins are developed along the outcrops by many openings, none of which are long enough to reveal the extent of the oxidized zone or deep enough to show the changes in mineralogy with depth. The stopes are not large. The quartz vein being mined in any particular adit may be only a foot or two thick, but the wall rock above and below the vein may carry gold. One of the richest veins seen is in a shallow prospect on the Bondholder claim, on the north side of Blacktail Mountain. This vein, which is 1 foot thick, contains abundant visible grains of gold.

The only minerals other than gold that were seen in the veins are quartz, sericite, sphalerite, pyrite, pyrrhotite, and iron oxides. Assays reveal that small amounts of gold and silver are present in ores where no gold is visible. The sulfides are very scarce and in most places are represented only by their alteration products. Iron oxides form less than 1 percent of most of the ores seen. The grains of gold are irregular in size and shape but are commonly very thin, rough, and spongy or gnarled. Under a hand lens 20 to 30 grains can be seen in some specimens within the space of a square inch. The high-grade quartz is rough and honeycombed where sulfides have weathered out, and in some places it shows ribbon texture, but elsewhere quartz of this same appearance is barren.

The rocks that contain the most productive veins are white sericitic sandstone and light-gray sericitic argillite of the Prichard formation. The sandstone is thin-bedded, and some of the individual beds are made of such thin laminae and are so weakly cemented that a specimen can be broken in the hand. Where seen near the veins both sandstone and argillite contain tiny grains of iron sulfide or iron oxide or holes where these minerals have weathered out. Some beds of the white sandstone that contain very little metallic mineral but are cut by quartz veinlets a fraction of an inch thick will yield gold upon panning. These beds, according to Mr. Miller, contain $1 to $7 in gold to the ton through a thickness of several feet. That the veins have been faulted along the walls is shown by grooved and slickensided quartz. They have also undergone small vertical displacements along obscure cross fractures that strike northwest and dip southwest. Mr. Miller says that good ore has been found near these faults, as it has at the Fisher Creek ("Branagan") mine, across Bramlet Creek from the Tip Top. Microscopic examination of Tip Top ores shows that both gold and sulfide mineralization were related to cracked and brecciated masses of quartz, easily permeated by the mineralizing solutions. An assay of a picked specimen, a thin section of which shows a striking localization of sulfides in shattered quartz, showed 4.91 ounces of gold and 1.39 ounces of silver to the ton. There was no visible gold in this specimen, and it contained little sulfide.

GOLD HILL

The Gold Hill mine is in the Thompson Falls quadrangle, about 3 miles southeast of the southeast corner of the Libby quadrangle, in sec. 4, T. 25 N., R. 30 W., on a northward-flowing tributary to Silver Butte Fisher River. Several quartz bed veins between altitudes of 4,065 and 4,425 feet have been prospected by open cuts. The wall rock is gray to white sandstone and argillite, probably belonging to the Prichard formation, which commonly strikes northwest and dips 45° NE. The veins, which are 7 to 14 inches thick, are at least 98 percent quartz, but they contain thin seams of pyrite and sphalerite with less galena and a very little chalcopyrite. Oxidation is shallow but is thorough near the surface, where small grains of gold are easily visible with a hand lens in the iron-stained quartz. A thin film of covellite coats some of the pyrite and sphalerite.

Since this property was examined in 1934, it has been reliably reported that 1,200 feet of development has been done on the veins in four adits, a blacksmith shop, assay office, and other buildings have been erected, and a gasoline engine, compressor, and other equipment have been installed.

AMERICAN KOOTENAI

The American Kootenai mine is on the south side of West Fisher River, at an altitude of 4,900 feet, three-fourths of a mile below Mill Creek. The mine is said to have been operated as a gold-mine for the 2 years prior to 1910, when the surface plant was destroyed by fire.

Three adits with a total of 600 feet of workings have opened up bed veins of quartz and crosscutting veins near bed veins in white sandstone of the Prichard formation, which appears to have been favorable for mineralization. In places there are lodes made up of numerous thin crosscutting veins in a sandstone bed 15 to 20 inches thick. Elsewhere an irregular bed vein ranging from 1 to 5 feet in thickness has been mined, but no stopes more than 6 feet high were seen in any of the adits, and the average height of the flat stopes is 2 or 3 feet. The beds dip about 25° NE. The veins are exceedingly irregular in thickness, pinching and swelling markedly within short distances. In most of the workings seen they showed very little pyrite, partly because there was little metallic mineralization and partly because the adits are shallow and oxidation has been rather thorough. Two northwestward-striking post-quartz faults have offset the veins very little if at all.

FOURTH OF JULY

The Fourth of July prospect is about half a mile north of lower Geiger Lake, on the southeast side of Fourth of July Creek, at an altitude of 5,150 feet. An old road, now little better than a trail, connects the prospect with the Bramlet Creek road. It is said that a small mill on the property was burned in 1909.

Several quartz veins parallel to the bedding of the sandstone and argillite of the Prichard formation have been mined in long open cuts on the steep valley side, and one adit 80 feet long has yielded a little ore. The veins strike N. 25° W. and dip 10°-13° NE. One vein averages 12 inches in thickness for 400 feet along the strike, but in places it swells from 12 inches to 20 inches in 50 feet. Another vein ranges from 8 inches to 12 inches in thickness and splits into two or more branches. The quartz is commonly stained with iron oxide, and it carries a little galena, but nowhere in shoots more than 2 inches thick.

HERBERT

The Herbert group includes 10 claims in sec. 29, T. 30 N., R. 31 W., on the north side of Prospect Creek, at an altitude of 3,200 to 3,500 feet. The camp, which is reached by a secondary road from the Granite Creek road, includes several cabins and a blacksmith shop containing a gasoline engine, a compressor, and a steel sharpener.

The country rock, which is gray sericitic sandy shale and sericitic sandstone of the Wallace formation, is sharply folded, and the beds dip steeply to the west and to the east. Near the top of the ridge several shallow trenches have disclosed a group of narrow vertical quartz veins in a zone about 20 feet wide, which trends northwest, parallel to a fault seen in an adit lower on the hill. The quartz veins and intervening rock contain tiny pyrite grains, or vuggy iron-stained cavities where sulfide has weathered out. A little gold can always be panned from the oxidized rock containing these quartz veins. When the property was visited in 1934, 300 feet of work had been done in an adit about 300 feet above the camp on Prospect Creek. Two steeply dipping northwestward-trending faults were seen in this adit, but the lode had not been encountered.

MONTEZUMA

The Montezuma group of six claims is about 2 miles south of the Midas mine, on the north side of the West Fisher River just below the mouth of Standard Creek, and is reached by a first-class road from Libby.

Quartz veins a few inches to 20 inches in thickness have been explored by several open cuts and by adits, the longest of which is 385 feet. The altitude at the portal of this adit is about 3,575 feet. The veins strike northwest and dip 40°-50° NE. In some places they are parallel to the sedimentary wall rocks, but elsewhere they dip more steeply than the beds. The veins pinch and swell and have been sheared, commonly parallel with the walls. The wall rocks are light-colored sandstone, buff calcareous shale, and buff-weathering dolomitic limestone of the Wallace formation.

The chief metallic minerals in the veins are tetrahedrite, galena, pyrite, and chalcopyrite. None of them are abundant. As the prospects are shallow, all the ore seen is partly oxidized and contains malachite, azurite, and limonite. Assays show that partly oxidized ore in which there is a little residual sulfide contains both gold and silver.

MUSTANG

The Mustang group of four claims is on the south side of Standard Creek about 2½ miles southwest of the Midas mine. The claims are reached by a trail from the road to the Midas. An adit 300 feet long has opened up a quartz vein 7 to 18 inches thick, which in places splits into a lode of similar thickness composed of thin, closely spaced veins. In an open cut on top of the ridge a few hundred feet above the adit there is a lode of the same type 30 inches thick, which is thought by the owners to be a continuation of the lode in the adit.

The wall rock in the adit comprises gray to buff sandstone and argillite of the Ravalli formation. Some of the sandstone beds are calcareous, and all are shaly; the argillite contains more or less sand. Tiny disseminated grains of pyrrhotite are so numerous in some of the sandstone beds that a drop of hydrochloric acid placed on a scratched area on a specimen will evolve hydrogen sulfide. One of the sandstone beds is nearly pure white and resembles the poorly cemented sandstone bed on the Tip Top property, on Blacktail Mountain, already described, which yields a little gold by panning. The beds strike N. 30° W. and dip 28°–33° NE. The vein strikes with the country rock but dips at steeper angles, in places as steep as 45°.

As the workings are shallow, all parts of the vein that were seen are well oxidized. The quartz encloses a little pyrite and galena but is honeycombed and stained with iron oxide where sulfides have weathered out. A little pyromorphite is present. The vein is sheeted and shows "ribbon quartz" structure. This may be partly the result of replacement of sheared wall rock, as suggested by the fact that the wall rock close to the vein is sheeted parallel to the walls and contains thin veins and podlike masses of quartz. Rock of this type is thoroughly iron-stained and therefore conspicuous. Sulfides and quartz were deposited together in areas made permeable by shearing. After the vein was formed, shearing again occurred and brecciated the quartz in places.

WAY UP

The Way Up prospect has three adits, with a total of about 600 feet of workings, on the north side of West Fisher River at altitudes between 5,600 and 5,780 feet. The prospect is near the head of the stream and is reached by trail from the end of the road to the Golden West camp. The adits, one above the other, are driven on an irregular shear zone as much as 4 feet wide, which strikes N. 2°–25° W. and dips 65°–85° NE. The country rock is brown-weathering laminated shale of the Pritchard formation west of the shear zone and light-colored calcareous Ravalli sandstone east of the shear zone. The beds are much folded on both sides of the shear zone, and the direction of dip varies. Cleavage is more prominent in some places than bedding.

Quartz veins, none more than 2 inches thick, are irregularly distributed in the shear zone along cleavage planes that dip southeastward, and less numerous veins extend along the bedding to distances of several feet from the shear zone. Some of the quartz veins contain a little pyrite and galena, slightly oxidized. Where the calcareous wall rock has weathered near the veins it contains a little manganese oxide.

A selected specimen of slightly oxidized ore from the dump, lean in pyrite and galena, assayed 0.49 ounce of gold and 0.50 ounce of silver to the ton.

WILLIAMS

The Williams group of seven claims is near the head of a valley that lies between Twin Peaks and Great Northern Mountain and is drained by a tributary of Libby Creek. Some of the claims are on top of the ridge extending westward from Great Northern Mountain to

Twin Peaks. The property is reached by a trail from the Betty Mae prospect.

Bed veins and crosscutting veins in nearly horizontal or gently dipping gray sandy argillite and shale have been opened by several short adits and open cuts at altitudes between 5,900 and 6,400 feet. The longest adit has about 200 feet of workings but no stopes. The open cuts are on top of the ridge at the head of Standard Creek, at an altitude of 6,400 feet. The wall rock here is Prichard with horizontal bedding.

The bed veins contain as much as 2 feet of quartz enclosing a little galena, which is partly altered to lead carbonate and sulfate, and a little iron oxide, some of which is pseudomorphous after pyrite. In some places the veins are not confined to any one bed but grade into lodes or crumpled mineralized shale. Movement has taken place along the walls and within the veins, especially between vein quartz and included fragments and slivers of sericitic shale, which have been partly replaced. The sericite appears to have acted as a lubricant.

The crosscutting veins, which strike east or northeast and dip steeply southward or southeastward, are in some places parallel with the general direction of the shearing in the argillite. They range in thickness from a few inches to 2 feet, and any one vein varies rapidly in thickness along its strike or dip. These veins, insofar as they could be observed are much richer in galena and its oxidation products than the bed veins, and they contain a little chalcopyrite partly altered to iron oxide. As the exposures of the veins are not numerous, however, these apparent differences in mineral composition may not be significant.

A selected specimen rich in galena and containing a little chalcopyrite assayed 0.04 ounce of gold and 8.71 ounces of silver to the ton.

BETTY MAE

The Betty Mae group comprises six unpatented claims near the head of Goat Creek, a tributary of Libby Creek near its source. An excellent cabin has been erected on the property. Six shallow openings have been made on nearly horizontal quartz veins in northwestward-dipping sandstone and sandy argillite of the Prichard formation. The chief primary metallic minerals are pyrrhotite, sphalerite, chalcopyrite, and galena. As a result of oxidation, small quantities of limonite, native copper, melanterite, anglesite, and cerussite have been formed. The vein quartz was sheared before the sulfides were deposited, and later movement in the same veins has brecciated the sulfides to a slight extent. According to Frank Warington, one of the owners of the property, a selected sample was found to contain 10 percent of copper, 20 ounces of silver, and half an ounce of gold to the ton.

BLUE BIRD AND MAYBE

The Blue Bird and Maybe claims are on the west side of Hoodoo Creek east of the eastern border of the quadrangle. Several shallow open cuts have been made on a shear zone 2 feet wide, which strikes N. 50° W. and dips 78° SW., in greenish and gray argillite that strikes N. 8° E. and dips 34° SE. The shear zone has been traced for about 1,500 feet on the surface. In places it shows as much as 2 feet of quartz, with patches of galena and chalcopyrite. Oxidation of this part of the vein has produced limonite, malachite, azurite, anglesite, and pyromorphite. According to Herman Bockman, who owns the claims, assays of a picked sample that contained a very high percentage of copper showed $2 in gold to the ton.

DIAMOND JOHN

The Diamond John prospect is on the north side of Libby Creek at an altitude of 4,350 feet, about 3 miles by secondary road and trail above the main road to Howard Lake. A 60-foot adit has been driven N. 25° W. along two westward-dipping bed veins of quartz 3 feet apart, each of which has a maximum thickness of 16 inches. Pyrrhotite, the dominant sulfide, and small amounts of galena, sphalerite, pyrite, and chalcopyrite are related to sheeted and shattered areas in the quartz and are especially abundant where the sheeting is parallel with the bedding. The wall rock is light brownish-gray sandstone and bluish-gray siliceous argillite of the Prichard formation. The oxidation of disseminated sulfides in these rocks stains the weathered surface brown.

According to Isak Ludvikson, one of the owners, assays of selected samples show small amounts of both gold and silver.

ILLINOIS-MONTANA

The Illinois-Montana group is said to include two lode claims and one placer claim, all patented. It is on the north side of the North Fork of Lake Creek about a quarter of a mile northeast of large Geiger Lake, at an altitude of 4,950 feet, and may be reached by trail from the Bramlet Creek road. An adit 240 feet long, driven northwestward along the bedding, has exposed several bed veins of quartz ranging from 4 to 30 inches in thickness, which carry very small quantities of galena and limonite. The wall rock is dark-gray argillite and light-colored sandstone of the Prichard formation, striking N. 15° W. and dipping about 20° NE. Some of the highest-grade ore is reported to have come from the face of the adit, where two bed veins separated by a foot or two of shale are cut by a vertical fault striking about N. 15° W.

IRISH BOY AND RAMBLER

The Irish Boy and Rambler claims are on the southeast side of Lake Creek, near its junction with the North Fork, at an altitude of 4,200 feet. They may be reached by trail from the Bramlet Creek road. Bed veins of quartz 4 to 6 inches thick and less persistent crosscutting veins half an inch to 12 inches thick are exposed in open cuts. The country rock, which strikes northwest and dips 35° NE, is rusty-weathering sandstone and argillite of the Prichard formation, with a well-developed fracture cleavage along which the cross veins extend. A little galena, some anglesite derived from it, and limonite, sericite, and carbonate were the only other minerals seen in the quartz veins, but it is reliably reported that the veins contain free gold, which is said to have been panned from Lake Creek below them. A selected specimen of ribbon quartz high in galena assayed a trace of gold and 5 ounces of silver to the ton.

LIBBY

The Libby prospect includes two unpatented claims on the south side of the West Fisher River, high on the slope west of the Tip Top group, from which it is reached by trail. Five short adits, the longest 100 feet in length, have been driven in a southerly direction to explore quartz veins. The country rock consists of gray sericitic sandstone and sericitic argillite belonging to the Prichard formation. These rocks are commonly stained brown with iron oxide, which is scattered abundantly through some beds in tiny grains. The cleavage of the shale is in many places more prominent than the bedding.

The quartz veins range in thickness from a fraction of an inch to 2 feet or more and are exceedingly irregular; one vein, for example, pinches from 12 to 5 inches in a distance of 13 feet, and the 5-inch part then branches into several small veins. The veins are so numerous that where one pinches out another may be picked up above or below. A vein may follow the bedding for a short distance and then break across it and follow the cleavage to a higher bedding plane. Two parallel bed veins may be connected by many of these cross veins, and some veins cut across both cleavage and bedding. Such irregularities characterize veins of all sizes, even those of microscopic dimensions. Specimens of sandstone or argillite from near the veins, when studied under the microscope, are seen to be cut by numerous tiny veinlets of quartz in process of gradually replacing the rock. The only metallic minerals seen in the veins are galena, its oxidation products—cerussite, anglesite, and pyromorphite—and a little iron oxide. The pyrite formerly present is completely converted to limonite.

According to John Fredericks, owner of the property, one sample assayed 0.63 ounce of gold to the ton.

OLSEN AND SWITZER

Near the head of Bramlet Creek, several quartz veins parallel with the bedding have been opened up by short adits and open cuts, at altitudes between 4,650 and 5,350 feet, on eight unpatented claims belonging to L. J. Olsen and Elmer Switzer. The claims are reached by trail from the end of the road to the Tip Top mine. The country rock, a bluish-gray to light-gray argillite of the Prichard formation, lies horizontal or dips very gently to the north, northeast, or southeast. The veins, which are 6 to 48 inches thick, have been disturbed by faults that are commonly parallel with the bedding, the movement on them being shown by gouge and by shearing and grooving of the quartz rather than by offsetting of beds. The sulfide content of the vein is about 90 percent galena; the remainder consists of pyrrhotite, zinc blende, chalcopyrite, and pyrite. The sulfides are in or near sheared and granulated quartz.

DOME

The Dome prospect, on the southeast side of the South Fork of Parmenter Creek at an altitude of 5,500 feet, is one of the few prospects very near to a granodiorite stock. It lies a few hundred feet from the Parmenter Creek stock and 2 miles northeast of the Dry Creek stock. The country rock, which is thin-bedded reddish to buff sericitic sandstone of the Wallace formation, is much folded. In a small open cut and on the surface nearby there are numerous quartz veins a few inches to 3 feet or more in thickness, which commonly follow the bedding whether its dip is gentle or steep. In the veins and disseminated in the wall rock are small quantities of pyrite, partly oxidized to limonite, and of magnetite and earthy and specular hematite.

GOLDEN BEAR

The Golden Bear is on the southeast side of the South Fork of Parmenter Creek, at an altitude of 2,900 feet, near the contact of the Parmenter Creek stock. A few shallow open cuts in Wallace rocks and in granodiorite near the contact reveal quartz veins of irregular size and shape, which contain a little magnetite and pyrite, the latter partly altered to limonite. Small quantities of pyrite are disseminated in both the sedimentary rocks and the granodiorite. According to Claude Tester, one of the owners, veins in the sediments have been shown by assay to contain small quantities of gold.

SUNRISE

The Sunrise prospect is about 4 miles southeast of the southeast corner of the Libby quadrangle, in the Thompson Falls quadrangle, in sec. 9, T. 25 N., R. 30 W. A quartz vein that strikes N. 55° W. and dips 80° SW. is exposed for 1,000 feet along the strike, in 15 shallow open cuts at altitudes of about 5,300 to 5,500 feet. The country rock, a white sandy argillite similar to the argillite of the Prichard formation on Blacktail Mountain, strikes N. 25° W. and dips 60° NE. The vein, which is 6 to 18 inches thick, contains a little magnetite and partly oxidized pyrite and chalcopyrite. In places it is brecciated or shows ribbon texture. Tiny grains of native gold may be seen with a hand lens in the oxidized parts of the vein, which are stained with limonite.

SILVER-LEAD MINES AND PROSPECTS

GROUSE MOUNTAIN-CALLAHAN CREEK AREA

SNOWSTORM

The largest mine in the quadrangle, the Snowstorm (formerly the B. and B.), is on Callahan Creek about 5 miles southwest of Troy. In 1931, when the mine was examined, it was idle and the workings were largely caved, so that only the parts of the sixth and seventh levels that are shown on the map (fig. 5) were examined. The old mine maps from which these levels were traced show more workings. Some of the following information was kindly furnished by Samuel B. Holbert, general manager of the Troy Mines Co., which controlled the Snowstorm and Montana Morning mines in 1931.

According to the volumes of Mineral Resources the Snowstorm reported production every year from 1917 to 1928, inclusive. MacDonald [92] who hastily examined the mine in 1905, stated that considerable shipments had been made prior to that year. The mine is said to have produced, in all, at least $4,000,000 in lead, zinc, gold, and silver. Developed ore reserves in 1931 (including probable ore) were said to be 207,000 tons, but much of this was in inaccessible parts of the mine, above the sixth level.

The development work includes several adits at different altitudes. A railroad of 36-inch gauge from the mine to Troy enters the lowest adit to receive the ore mined from higher levels. A mill built at Troy in 1916 burned down in May 1927, which was a great loss to the Troy district, because the mill not only concentrated ores from the Snowstorm but treated custom ore as well. Near the portals of adits 6 and 7 are a blacksmith shop, bunkhouses, and other buildings. Near the site of the mill at Troy are two large office and residence buildings.

The ore-bearing veins are in a dark-colored, coarse-grained dike, which strikes N. 20°–35° W. and dips about 75° SW. At two places on the sixth level the dike measured 54 feet in width. On the seventh level the dike is represented by two branches 70 feet apart, one 44 feet and the other 17 feet wide.

[92] Calkins, F. C., and MacDonald, D. F., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, pp. 99–102, 1909.

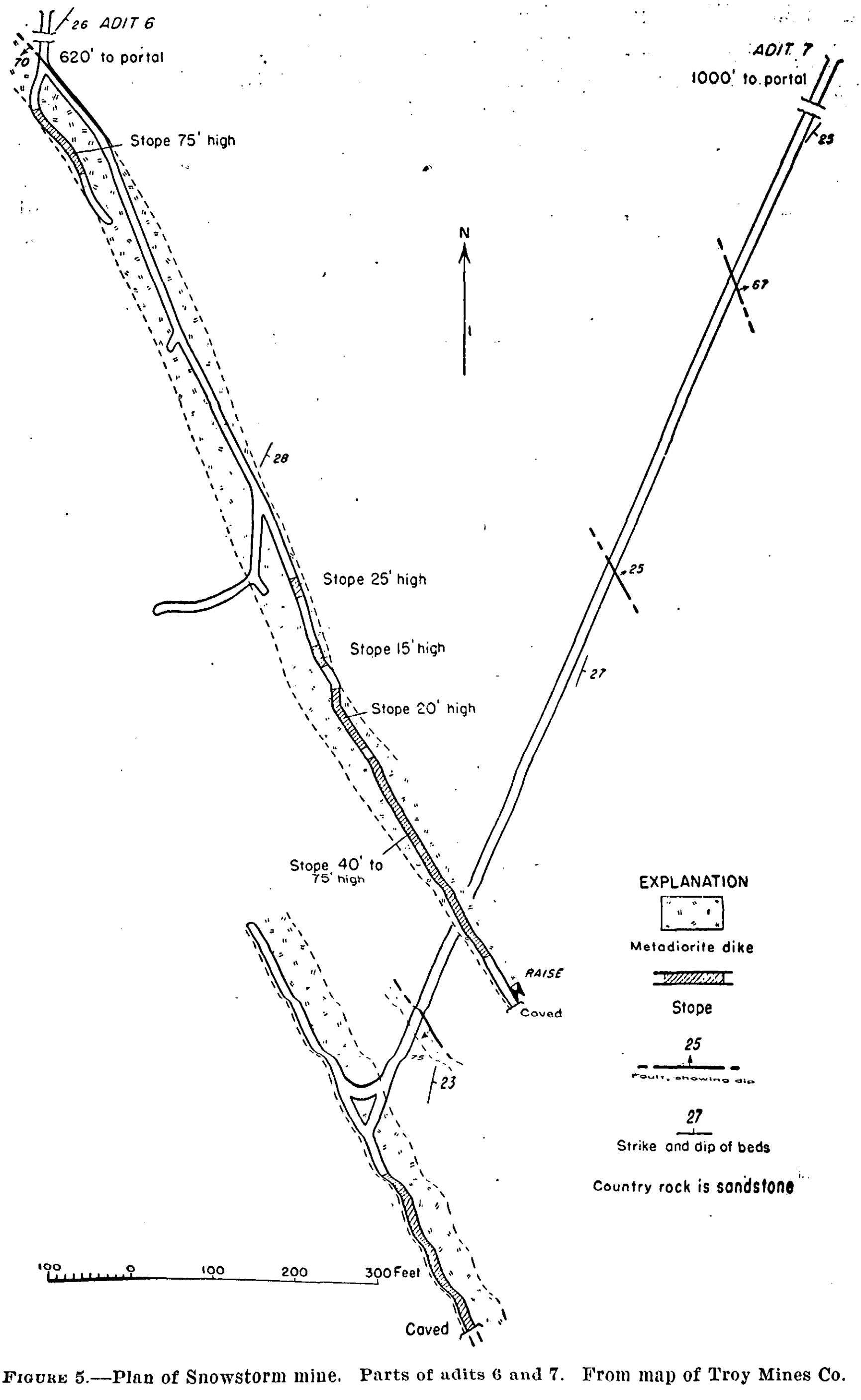

FIGURE 5.—Plan of Snowstorm mine. Parts of adits 6 and 7. From map of Troy Mines Co.

The Prichard formation, which encloses the dike, here consists for the most part of hard, fine-grained secricitic sandstone with so much introduced biotite and chlorite near the contact that it is difficult to distinguish the sedimentary rock from the dike. No veins of any consequence were seen in the Prichard on either level, but small grains of pyrrhotite and pyrite are sparsely disseminated both in the sedimentary rock and in the dike, the pyrite being the less abundant. Disseminated pyrrhotite is found also in the Prichard 500 feet from the dike.

The large veins that have been stoped are partly at or near either contact of the dike with the sedimentary rock and partly in the middle of the dike. They have approximately the attitude of the dike but may dip a little more steeply toward the southwest. Small veins may be seen anywhere in the dike, but they contain only negligible amounts of sulfides. The largest accessible stopes entered were near the southwest contact. The accessible stopes along the sixth and seventh levels are 20 to 260 feet long and 15 to about 100 feet high, and their average width is about 10 feet.

The veins, which were largely formed by replacement, contain the metallic minerals—named in order of abundance—galena, sphalerite, pyrrhotite, pyrite, chalcopyrite, and arsenopyrite, in a gangue of chlorite, amphibole, and quartz with smaller amounts of calcite, garnet, and biotite. Veins a few inches to 6 feet in thickness consist almost entirely of gangue in some places, but in remnants in adjacent stopes consist mainly of galena and sphalerite. Each remnant is at least as wide as the nearby barren part of the vein, and the widest stopes are wider than any of the remnants that were seen. The ore is massive, coarse-grained, and tough. The sulfides are intimately mixed with amphibole and chlorite. They have partly replaced these and, to a less extent, other gangue minerals. Amphibole and chlorite are among the most abundant of the gangue minerals in the ore that is richest in sulfides. The general order of age for the vein minerals is amphibole and garnet, quartz, chlorite, biotite, calcite, pyrite, sphalerite and arsenopyrite, pyrrhotite, chalcopyrite, and galena. A negligible quantity of supergene pyrite is present in some of the ore.

At the northwest end of the long drift on the sixth level the dike is faulted along its footwall, which here dips 70° SW. A lean vein in the fault fissure has been brecciated, so that some of the movement along the fault must be post-ore. A vein in the dike, near and parallel to this fault, attains a width of 6 feet but is chiefly gangue. The only stope near the fault is in the hanging wall of the dike, in another drift southwest of and parallel to the long drift where the fault was seen. In the crosscut on the seventh level another fault, on the footwall of the smaller branch of the dike, striking N. 35°–40° W. and dipping 75° SW., is marked by a good deal of shearing, especially in the adjacent sediments. On the seventh level there are no large stopes in or near this branch of the dike, but a stope was worked on this level in the larger branch, south of the fault, and on the sixth level (fig. 5) a very large stope was worked in this larger branch. Either or both of the faults mentioned above may have been channels for mineralizing solutions.

Several faults in Prichard strata are seen in the long crosscut on the seventh level, but they show no mineralization. They strike northwest and contain a few inches to 2 feet of gouge and breccia. Those northeast of the dike and within a few hundred feet of it dip northeastward; those farther to the northeast dip southwestward. At a few places bedding planes in the sediments continue as joints in the dike for short distances, and minor movement along these planes has very slightly offset some veins.

BIG EIGHT

The Big Eight claims are on both sides of Callahan Creek north of the Snowstorm mine. The property is connected by rail with the nearby narrow-gauge railroad running from the Snowstorm mine to Troy. An adit on the north side of the creek extends about N. 22° W. and one on the opposite side S. 22° E. Both adits are in the Snowstorm dike or have the dike for one wall and sandstone and argillite of the Prichard formation for the other, and both are only a few feet above the creek level. A third adit has been driven northwestward on the north side of the creek, 100 feet above the adit that runs N. 22° W. The workings from this adit are at least 1,000 feet in aggregate length.

A strong vein, in places 7 feet wide, on the west wall of the dike has been stoped in both of the lower adits. This vein strikes about N. 22° W.; part of it is vertical and part of it dips steeply to the southwest. Another vein, roughly parallel to and east of this vein, has been stoped to a less extent. The veins consist mainly of quartz, calcite, actinolite, chlorite, and garnet. Sphalerite is the only abundant ore mineral; galena, pyrrhotite, chalcopyrite, and pyrite are subordinate, and magnetite is scarce. Sulfides are most abundant in those parts of the veins where chlorite and actinolite are present, and the ore minerals replace those silicates.

A post-ore fault that strikes northwest and dips 25° NE. has offset the upper segment of the larger vein a few feet to the northwest. Near this fault the dike is sheeted roughly parallel to the bedding planes of the sedimentary rocks, and the fault, whose attitude is close to that of the beds, may be in part a bedding fault. (See fig. 6.)

The mine was idle in 1931, and its total output is not known, but the records in volumes of Mineral Resources show that between 1912 and 1928 more than 6,000 tons of lead-zinc ore containing small quantities of copper, gold, and silver were mined.

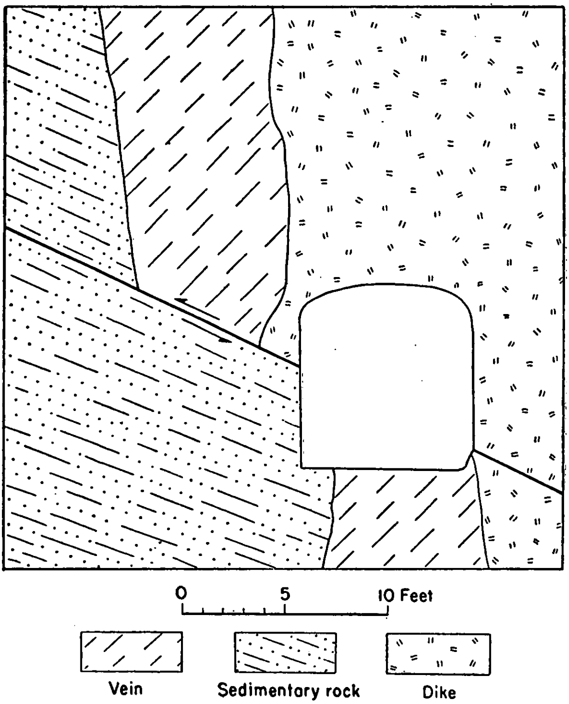

FIGURE 6.—Section at portal of lower adit, Big Eight mine. Upper segment of vein has been moved northwestward along a thrust fault parallel to bedding of sedimentary rock.

BIG FOUR

The Big Four group includes seven unpatented claims on the west side of Gordon Creek a mile north of Callahan Creek. An adit at an altitude of 3,550 feet, with about 1,000 feet of workings, has explored two strong shear zones in the Snowstorm dike. The wall rock of the dike, which is sandstone of the Prichard formation, shows considerable introduced biotite and a small proportion of introduced feldspar. There are some small veins in the dike and in the sedimentary rocks nearby. All these veins are composed chiefly of quartz and calcite and rarely reach a thickness of 6 inches. They contain a little partly oxidized chalcopyrite, galena, and sphalerite.

GIANT SUNRISE

The Giant Sunrise, formerly called the Montana Sunrise, includes 24 unpatented claims in sec. 10, T. 30 N., R. 34 W., on the crest and on the northeast side of Grouse Mountain.

Several hundred feet of workings in five adits have opened up veins on the contact and in the interior of a dike, which strikes N. 35°–40° W. and dips steeply to the northeast. The wall rock of the dike is argillite and sandstone of the Prichard formation, which dips 30°–45° SW. The dike consists of a dark-gray to black fine-grained altered rock composed chiefly of plagioclase, biotite, quartz, carbonate, and sericite, in proportions that differ in different parts of the dike. Small amounts of chlorite, zoisite, sphene, and ilmenite, also are present.

Veins consisting chiefly of quartz and calcite have been formed in sheared parts of the dike or at the contact; these rarely measure so much as 3 feet in thickness and are commonly much less. Pyrrhotite and sphalerite are abundant, galena is less abundant, and chalcopyrite, pyrite, and ilmenite are scarce. A little chlorite is present, especially in slickensided parts of the veins. Sulfides are disseminated in small grains and patches in the dike near veins but are more abundant in the veins, where they appear to replace quartz and calcite.

Renewed movement has taken place within some of the veins. To a less extent some veins have been offset on small faults that follow the bedding in the argillite but extend across the dike.

All of the minerals found in the veins occur in smaller quantities in the contact-metamorphosed shale and sandstone near the dike. As much as 20 feet from the contact, especially in the more sandy laminae of the argillite, there are veinlets and disseminated grains of sulfides and ilmenite, but they are nowhere abundant enough to make ore. Much carbonate, biotite, sericite, and quartz, and a little cordierite, chlorite, epidote, and tourmaline, may be seen under the microscope to have replaced argillite. When the property was visited in 1932, ore minerals were most abundant in the adits highest on the hill, and sulfide mineralization does not increase with depth so far as could be determined in the workings seen at that time.

At the portal of the longest adit, at an altitude of 3,850 feet, are a blacksmith shop and other buildings, with a gasoline engine, a compressor, and other equipment. In 1934 a 100-ton mill with standard equipment was erected. The management reported that an average run for a week in July 1935 contained 6 percent of lead, 8.50 percent of zinc, and 1.20 ounces of silver to the ton. A shipment of lead concentrates yielded 72.20 percent of lead and 16 ounces of silver to the ton, and a shipment of zinc concentrates yielded 50.40 percent of zinc, 4.30 percent of lead, and 1.70 ounces of silver to the ton.

GROUSE MOUNTAIN

The Grouse Mountain group includes 27 unpatented claims on the north side of the North Fork of Keeler Creek, mostly in sec. 10, T. 30 N., R. 34 W. According to K. J. Haugan, who was superintendent in 1932; prospecting on the property began in 1892. Several good cabins, a blacksmith shop, and a large ore bin have been erected on the property. The ore bin was being slowly filled with ore from several veins when the prospect was last seen in 1932, but no stopes had as yet been opened up.

An adit driven northward at an altitude of about 3,900 feet in the Prichard strata encountered the Grouse Mountain metadiorite dike 1,040 feet from the portal. The dike, which strikes northwestward, is at least 145 feet thick, and its northeast contact is a fault. Drifts northwestward and southeastward in the dike have opened up several veins in sheared rock, but none of these veins extend for any great distance, partly because they are lenticular and partly because they are faulted. The maximum width of the veins that were seen is 18 inches, the average 12 inches. The chief vein minerals are quartz and calcite; the dominant sulfides are galena, pyrrhotite, and arsenopyrite, but sphalerite is fairly abundant and a little pyrite and chalcopyrite are invariably present. Chlorite and supergene marcasite are scarcer. The hypogene sulfides were formed in the following order: arsenopyrite, pyrite, pyrrhotite, sphalerite, galena. According to Mr. Haugan, the ore is shown by assays to carry both gold and silver.

Only one fault was seen in the sediments in the adit south of the dike. Many seemingly short, northwestward-trending faults and shear zones cut the dike and the veins, but many of these displace the vein so little that the continuation of a faulted vein can be seen in the back of the drift. These post-ore faults commonly dip to the southwest, but a fault at the northeast contact of the dike, part of the movement along which is probably post-ore, dips to the northeast.

Where seen in the prospect the dike is thoroughly altered at both contacts to a fine-grained homogeneous-looking rock in which no mineral except biotite can readily be identified by inspection. This rock is not easily distinguished from the fine-grained sericitic sandstone in contact with it. In thin sections its chief minerals are seen to be chlorite, carbonate, and sericite.

IRON MASK

The Iron Mask Lead Mining Co. has two claims and two fractions, all patented, on the southwest slope of Grouse Mountain, in secs. 11 and 14, T. 30 N., R. 34 W. Prospecting began in 1892, but up to 1931, when the property was examined, only 200 tons of ore had been shipped. According to Robert Gregg, one of the owners, the chief metal produced was lead, though the ore also contained zinc, silver, and gold.

Two short adits, trending northwestward, in the Grouse Mountain dike have opened up veins of irregular attitude, shape, and size in thoroughly sheared and faulted parts of this dike; not all the sheared zones, however, contain veins. In a gangue of quartz, calcite, chlorite, and hornblende the metallic minerals in order of abundance are galena, sphalerite, arsenopyrite, pyrrhotite, pyrite, and chalcopyrite. The sulfides appear to have replaced calcite or chlorite, or both, and to be most abundant where these minerals are or have been present. Post-ore shearing has occurred within the veins and parallel to their length; there are shear-zones also at the contacts of the veins with the dike rock, and others that cut across the veins. In one place the ore was seen to be cut off by what is called the "spotted porphyry" dike, which is here 3½ feet thick, strikes N. 40° W., and dips 60°–75° SW. Descending ground waters have caused a little replacement of galena by anglesite and of pyrite and arsenopyrite by limonite.

The Grouse Mountain dike has been so thoroughly decomposed by hydrothermal processes that in places a pick can be driven into it without much effort. It here consists chiefly of sericite, chlorite, biotite, carbonate, and minerals of the epidote group. The northeast contact is a fault dipping 55° SW.; this is also the dip of the adjacent argillite of the Prichard formation, so that the fault may be in part a bed fault. At the southwest contact the dike strikes N. 40° W. and dips 60° NE. It attains a thickness of at least 155 feet in this property.

SILVER KING

The Silver King mine comprises three unpatented claims on the North Fork of Keeler Creek, near the junction of the road to the Universal prospect and the county road up the North Fork. There are said to be seven short adits on the property, with a total of 850 feet of workings, but only three, in which the veins were well exposed, were seen and examined. The lowest of these, which is at an altitude of 2,950 feet, trends N. 40° E., is 300 feet long, and has one crosscut driven on a fault zone on the southwest contact of the Silver King sill. There is little mineralization in the fault zone. The fault, which in part follows the bedding, strikes N. 55° W. and dips 50° SW.

In two other adits higher on the hill the same fault is exposed in crosscuts, where there are stopes that have yielded 6 cars of ore. Galena and quartz are the chief minerals, chalcopyrite and pyrite are scarce, and no sphalerite was seen in any of the specimens examined. The ore occurs in patches in the fault breccia, the ore-bearing part of which was nowhere much more than 2 feet wide in any of the stopes that were entered. The stopes are not far from the surface, and the fault has afforded a permeable channel for descending oxidizing waters, which have formed anglesite, cerussite, copper carbonates, covellite, and limonite in the ore.

Six carloads of ore have been produced from this property, the average smelter returns for which, according to W. P. Bromley, were 60.9 percent of lead, 1.0 percent of zinc, and 0.19 ounce of gold and 12.3 ounces of silver to the ton.

LIBERTY METALS

The Liberty mine, part of the Liberty Metals holdings, is 6 miles by road south of Troy, in sec. 35, T. 31 N., R. 34 W., and may be reached by a good road from Troy. The property, which consists of 8 patented claims, has been developed by means of three adits and a shaft. Most of the 2,100 feet of underground workings are on one level and may be reached through the principal adit, which trends southeastward. From this adit, which is partly in sandstone and argillite of the Prichard formation and partly in a coarse-grained metadiorite sill, several crosscuts have been turned off in search of ore. The principal adit cuts the Lenia fault and continues a short distance into the Wallace formation east of the fault. The fault, along which there is a crushed zone about 20 feet wide, here strikes nearly north and is vertical. No ore was seen within 100 feet of the fault, but the fault zone contains a few thin barren veins of quartz.

Most of the ore consists of galena, with less sphalerite and pyrite, in an abundant gangue of quartz and carbonate. The ore forms irregular small veins and replacement masses along joints and near irregular shear zones in quartzitic sandstone. All the ore seen in the quartzitic sandstone was near the sill contact, but none of the mine openings were extended very far into the Prichard rocks in search of ore. Horizontal drill holes driven into the sandstone near the northeastern contact of the sill revealed disseminated galena in patches or small veins between 6 and 28 feet from the contact. In addition to the ore in sandstone a smaller quantity occurs in the sill, where it forms very irregular veins and patches related to discontinuous shear zones. Quartz and carbonate are the most abundant vein minerals, and galena, sphalerite, pyrrhotite, pyrite, and chalcopyrite are rather scarce. The ore from the sill is said to be richer in gold, according to the assays, than that from the quartzite.

According to J. F. Powers, mine superintendent, the only shipment of ore made thus far yielded $142 per ton, chiefly in lead and silver. This ore came from locally mineralized parts of the sandstone and probably was carefully picked. There are no stopes in the mine.

The camp is well equipped with bunkhouses, blacksmith shop, and mill buildings. In 1934 equipment for a 100-ton mill was being installed.

Liberty Metals Tunnel No. 11, the portal of which is on property of the Giant Sunrise prospect on Grouse Mountain, has been driven southwestward for 1,800 feet in the Prichard formation in the hope of finding the veins exposed in the Little Spokane, Silver Strike, and Cabinet Queen prospects or other veins like them. All these veins are in the Grouse Mountain dike, on the southwest side of Grouse Mountain, in the Liberty Metals property. No ore had been encountered in the tunnel when it was visited in 1934.

BIMETALLIC

The Bimetallic group includes 14 unpatented claims on the north side of the North Fork of Keeler Creek, about a mile northwest of its junction with the South Fork. Four short adits have been driven northward or northwestward, at altitudes of 3,560 to 3,800 feet, to explore veins in the Grouse Mountain dike. As a rule the veins strike northwest, dip about 50° SE., and are in sheared parts of the dike. The sheared zones are as much as 3 feet wide, but few of the veins are more than 8 inches wide, and most of them are less. The chief vein mineral is quartz, which in many places exhibits a ribbon structure; galena, the only abundant sulfide, is extremely irregular in its distribution and at best may make up 80 percent of a 6-inch vein; arsenopyrite is less abundant than galena, and pyrite, chalcopyrite, and sphalerite are scarce.

Post-vein faulting has sheeted the veins and has in places offset them a little, but the veins do not persist far even where they are not faulted. The ore is everywhere more or less oxidized; the commonest supergene minerals developed are anglesite and cerussite, and a little pyromorphite was seen in nearly every specimen that was examined with care. A little limonite and a very little manganese oxide are present, and covellite and chalcocite were seen under the microscope. The dike where seen in the Bimetallic is altered chiefly to sericite, chlorite, carbonate, and quartz, accompanied by small amounts of other minerals.

In a small valley about half a mile east of these adits and three-quarters of a mile west of Lime Butte, an adit has been driven 850 feet westward in the Prichard formation, its ultimate goal being to intercept these veins.

BLACK HORSE

The Black Horse adit, formerly the Highland Chief, is near the south brow of Grouse Mountain, southeast of the Iron Mask. It extends southeastward for 120 feet in the Grouse Mountain dike, and has opened up one strong vein in a brecciated zone that strikes northwest and dips 40° NE. The vein consists chiefly of calcite, quartz, and chlorite, with very little arsenopyrite, pyrite, sphalerite, pyrrhotite, and chalcopyrite.

BLUE BIRD

The Blue Bird is a little north of the main forking of Keeler Creek, at an altitude of 2,800 feet. An adit about 300 feet long with two short crosscuts has been driven northward to explore the Grouse Mountain dike. Small faults and shear zones in the dike are practically barren, containing, so far as observed, only a little coarsely crystalline calcite with thin seams of pyrite. A little higher on the hill, in an open cut in the Prichard formation near the dike, a little galena can be seen in a bed vein of quartz. The Silver King fault is intercepted in the adit, but, so far as could be seen in that narrow opening, the fault is dying out and does not appreciably offset the dike.

CABINET QUEEN

The Cabinet Queen prospect, later called the Liberty Metals No. 5, is north of the North Fork of Keeler Creek, in sec. 10, T. 30 N., R. 34 W., at an altitude of 4,025 feet. An adit 550 feet long was started in the Grouse Mountain dike and extended on with many turnings into argillite of the Prichard formation. The southwestern contact of the dike and the argillite is a fault, and within the dike there has been much shearing, some of it in a horizontal direction.

The best ore seen was in a small stope on the southwest side of the largest shear zone in the dike, where a vein 3 feet in thickness had been opened up. The vein consists chiefly of quartz and calcite, with much arsenopyrite and slightly less pyrite and sphalerite. Polished sections of the ore showed small quantities of galena and chalcopyrite.

The dike rock, whether near or remote from the ore, is much altered, chiefly to chlorite, carbonate, and quartz, and contains a little residual plagioclase.

HIAWATHA

The Hiawatha is north of the North Fork of Keeler Creek, at an altitude of about 3,800 feet, near the boundary between secs. 10 and 11, T. 30 N., R. 34 W. The outer part of an adit on the property is in the Grouse Mountain dike, but when visited, the adit was caved 30 feet from the portal. A little ore containing partly oxidized galena in a quartz gangue was seen on the dump.

LITTLE SPOKANE

The Little Spokane, later a part of the Liberty Metals group of claims, is north of the North Fork of Keeler Creek, in the central part of sec. 10, T. 30 N., R. 34 W., at an altitude of about 4,525 feet. An adit started in the Prichard formation penetrated the Grouse Mountain dike on the northeast side of a fault that strikes northwest and dips 55° SW. This adit is partly caved. There are other small prospect adits nearby, and according to Joseph Powers the workings have a total length of 250 feet.

Small seams of iron-stained galena partly altered to anglesite contain the only ore minerals in the veins, in which the gangue is chiefly quartz and carbonate. These veins, irregular in attitude, are in sheared zones as much as 16 inches across in the dike. Near the veins, and near the fault at the southwest contact of the dike, the dike rock is altered to a soft, brown, pulverulent material.

SILVER STRIKE

The Silver Strike prospect, formerly known as the Molyneaux claim and later under control of the Liberty Metals Co., is on the north side of the North Fork of Keeler Creek, in the central part of sec. 10, T. 30 N., R. 34 W., at an altitude of about 4,100 feet. It has a single adit, 160 feet long, which starts in the Prichard formation but enters the Grouse Mountain dike and cuts several northwestward-trending shear zones, most of which are in the dike. Some of the shear zones, affected by post-vein faulting as well as by earlier movement, are as much as 30 inches wide. The sheared rock contains a little iron-stained galena, partly altered to anglesite and pyromorphite, in a quartz gangue.

UNIVERSAL

The Universal is on the northeast side of the North Fork of Keeler Creek, in sec. 11, T. 30 N., R. 34 W., at an altitude of 3,950 feet. An adit about 250 feet long starts in argillite of the Prichard formation and penetrates the Grouse Mountain dike, which is faulted along both contacts by northwestward-trending faults, which dip southwestward into the sediments. Like other faults that dip in a direction opposite to that of the dike and make off along the bedding, they show little mineralization. Shear zones in the dike enclose lenticular quartz veins, irregular in size and attitude, most of which have a northwesterly strike. The largest vein seen was 6 inches in maximum thickness. The veins contain a little carbonate, galena, and sphalerite and still smaller quantities of chalcopyrite, pyrrhotite, pyrite, and marcasite. Oxidation has hardly affected the sulfides.

AMERICAN EAGLE

The American Eagle group (formerly the Federal Silver Lead) includes 17 claims in secs. 27 and 34, T. 31 N., R. 34 W., on the north fork of Iron Creek about 3 miles southwest of Troy. The chief workings consist of an adit 1,300 feet long, which trends northwest, with several hundred feet of crosscuts. The adit is partly in argillite of the Prichard formation and partly in a metadiorite sill 700 feet thick, the largest in the quadrangle, which strikes northwest and dips steeply southwest. In this and in three other adits visited the sheared parts of the sill enclose quartz veins 2 to 12 inches thick. The quartz is stained with iron oxide and copper carbonate in places, and a little pyrite, galena, and chalcopyrite are said to have been found in the veins. In the longest adit a crosscut has been driven on a strong fault trending northwestward in the sill. The fault zone contains at least 4 feet of breccia and gouge, but no ore was seen in this crosscut.

BLACKTAIL

The Blacktail prospect, owned by Charles and William Drake, includes three unpatented claims at an altitude of 3,500 feet on the east side of Hale Creek, in sec. 17, T. 31 N., R. 34 W. One adit, caved at the portal, is reported to be 300 feet long. Another adit 400 feet long, in a dike, has opened up a number of discontinuous veins, none of them more than 18 inches thick, in shear zones that strike northwest and dip northeast. The veins consist chiefly of quartz and calcite with minor quantities of galena, sphalerite, pyrrhotite, chalcopyrite, pyrite, and marcasite. There are faults within most of the veins or along their walls.

A selected specimen of ore, lean in sulfides, from one of the veins was assayed and found to contain a trace of gold and 3.20 ounces of silver to the ton.

KEELER MOUNTAIN

The Keeler Mountain prospect, owned by H. C. Weidner and J. M. Smith, is at the base of Keeler Mountain, close to the boundary line between secs. 24 and 25, T. 30 N., R. 34 W., at an altitude of 2,500 feet. An adit 120 feet long in argillite of the Prichard formation has opened up several quartz veins, striking northeast, the largest of which is 8 inches thick. Pyrrhotite, the only abundant sulfide, has replaced fractured and slickensided quartz. The pyrrhotite in turn has been fractured and has been replaced to a very small extent by galena, pyrite, chalcopyrite, and sphalerite.

MONTANA MORNING

The Montana Morning prospect is in the southeastern part of sec. 28, T. 31 N., R. 34 W., near the head of Iron Creek. It is connected by secondary roads with the Snowstorm narrow-gage railway on Callahan Creek, where an ore bin has been erected, and with the road that extends up Iron Creek to the Liberty mine. The workings consist of an adit with several short crosscuts, almost wholly within a dike but near its east wall, and of a shorter adit in the Prichard sediments. The dike strikes about N. 10° W. and dips steeply to the east, but its attitude is not constant.

Irregular small veins commonly less than 2 inches in thickness, consisting chiefly of quartz and carbonate, have been formed along shear zones both in the dike and in the sediments east of it. Pyrite, chalcopyrite, pyrrhotite, galena, and sphalerite, all of them scarce, occur in the veins, and small patches of them replace the sericitic sandstone several feet from the dike. In one small stope in the dike, ore had been mined from a vein or series of veins in a shear zone that strikes northwest and dips steeply northeast. Remnants of the vein indicate that it was at least 24 inches thick in places and that the chief ore mineral was galena. Small quantities of sulfides were seen on the dump.

In the short adit in sandstone and argillite beds of the Prichard formation, which here strike N. 25° W. and dip 50° SW., a little sulfide was seen in irregular shear zones, which trend northwest and dip either southwest or northeast more steeply than the sediments. At a place where several shear zones coalesce, the sheared ground was explored by a raise to the surface and by a winze.

SILVER GROUSE

The Silver Grouse group of nine unpatented claims is on the northeast side of Grouse Mountain, in sec. 11, T. 30 N., R. 34 W. An adit 300 feet long, at an altitude of about 3,525 feet, has opened up several quartz veins in shear zones in gray sandstone of the Ravalli formation, which strikes northwest and dips southwest. The veins strike N. 35°–80° W. and commonly dip northeastward. They have been displaced, though nowhere to any great extent, by faults parallel to them and by cross faults. Some of the crosscutting faults are bed faults; others strike northwest and dip southwest more steeply than the beds. The last movement occurred along the faults that dip southwest.

The veins, which are 4 to 17 inches wide, consist mainly of quartz, but contain some pyrrhotite and a little chalcopyrite, pyrite, and biotite. Galena and carbonate are present in small quantity, and according to Mr. C. H. Curtis, one of the owners, selected samples especially rich in galena gave assays of 4 to 71 ounces of silver to the ton. A little sudfide and biotite are disseminated in the wall rock. The ore in the veins and on the dump shows a little iron oxide.

SNOWSHOE FAULT AREA

SNOWSHOE

The Snowshoe mine is on the south side of Snowshoe Creek, about 3 miles above its confluence with Big Cherry Creek. The mine has been idle for many years, and its workings are largely inaccessible. Most of the following historical and statistical information was kindly supplied by C. H. Foot of Kalispell, Mont., one of the present owners of the property.

The Snowshoe group comprises four patented claims, the Chinook, Snowshoe, Rustler, and Porcupine. The first prospecting was done in 1892, and the first important development began about 1900, when the group was taken over by an English syndicate, the Pacific Northwest Mining Corporation, Ltd. The total output to date has been about 130,000 tons of ore, containing lead, silver, and gold, the net smelter returns for which have amounted to $1,086,000. There is 11,000 feet of development work in the mine, and in 1934 it was said that 110,000 tons of ore had been proved or partly blocked out. According to MacDonald,[93] who visited the mine in 1905 when it was active, development work had then opened the lode to a depth of 300 feet or more, showing it to have an average width of about 7 feet.

Mr. Foot believes that at times as much as 40 percent of the concentrates was lost by inefficient milling, and MacDonald[94] remarks that a large proportion of the gold, probably as much as $400 per day, was lost in milling.

The vein material occurs in the fissured and sheared zone of the Snowshoe fault, which here strikes N. 12° W. and is about vertical. The country rock on the east side of the fault is dark bluish-gray sandy argillite and sandstone of the Ravalli formation; that on the west side is thick-bedded white limestone and calcareous shale of the Wallace. The strike of the beds on both sides of the fault is about N. 30° W., but the dip east of the fault is toward the east whereas the dip west of the fault is toward the west. The angles of dip vary greatly.

As seen in the mine, the shear zone attains a maximum width of 12 feet, though most of it is less than half as wide. This zone is made up of sheared and sheeted country rock enclosing quartz veins a fraction of an inch to a foot in width, which contain carbonate and sulfides. The most abundant sulfides are galena and blende; pyrite is a little less abundant; chalcopyrite and arsenopyrite are rather scarce. A little disseminated pyrrhotite was found in limestone west of the ore zone.

The sulfides are irregularly distributed in the quartz but most commonly form veins and stringers several inches thick, which are parallel with the local surface of shearing. The sulfides also spread out from the veins and form patches in the quartz. Thick and thin slices of country rock alternate with the quartz veins and are commonly parallel to them. Quartz and carbonate are the most abundant introduced minerals in these horses of wall rock.

The shattered and brecciated condition of the quartz, as seen under the microscope, and the preference of sulfides for the shattered quartz

[93] Calkins, F. C., and MacDonald, D. F., A geological reconnaissance in northern Idaho and northwestern Montana: U. S. Geol. Survey Bull. 384, p. 104, 1909.

[94] MacDonald, D. F., Economic features of northern Idaho and northwestern Montana; U. S. Geol. Survey Bull. 285, p. 50, 1906.

indicate that movement took place along early formed quartz veins before the introduction of the metallic minerals. Slickensided masses of sulfides and gangue show that further faulting occurred after the formation of the sulfides.

GLACIER SILVER-LEAD

The Glacier Silver-Lead Mining Co. owns several claims and prospects near the confluence of Shaughnessy and Granite Creeks, 6 miles southwest of Libby, from which town they may be reached over a first-class road. According to officials of the company, the property includes a total of not less than 2 miles of underground workings, but these were partly inaccessible at the time of examination because of caving and bad air. The Glacier mine, formerly called the Lukens-Hazel, is being developed through the No. 4 level, an adit that runs northwestward through a disturbed mass of sandstone and shale of the Wallace formation.

The ore occurs in two lodes, referred to at the mine as the "West vein" and the "East vein," each in a strong shear zone that strikes northwestward and dips 45°-60° NE. As shown on the company's mine maps, the lodes are 400 to 440 feet apart on the third level. The ore shoots pitch to the southeast.

The West vein, which has thus far been the more productive, has been explored for 2,000 feet along the strike. It is 2 to 10 feet thick and consists of sheared quartz containing variable amounts of pyrite, galena, sphalerite, and carbonate, named in order of abundance. In the country rock near the principal vein are small quartz veins of different thicknesses and attitudes, some of which occupy faults of small displacement. Some of these fault veins contain only barren quartz, whereas others contain small quantities of the same sulfides as are found in the large vein. Movements along these veins have offset the large vein a few feet in some places.

The East vein is similar in many respects to the West vein, though it has not been so extensively developed. It varies in thickness from a few inches to 10 feet and consists predominantly of sheared quartz containing the same sulfides that occur in the West vein. A little scheelite has been found in the East vein.

In both veins quartz and pyrite, which were deposited early, have been crushed and brecciated by subsequent movement along the veins. A second generation of quartz, pyrite, and other minerals was then deposited.

A mill with a capacity of about 325 tons per day has been erected at a cost of $65,000. Equipment in the mill includes a 200-horsepower motor, a Hardinge conical ball mill, a Dorr classifier, and Fahrenwald flotation machines. In the spring of 1930 the mill was not running to capacity. According to Mr. John Johanson, one of the officials of the company, concentrates shipped to the smelter in the early part of 1930 averaged 47.4 percent of lead, 1.74 ounces of gold, and 60.8 ounces of silver to the ton. The reported assay value of a later run of concentrates was 49.8 percent of lead, 2.61 ounces of gold, and 84.9 ounces of silver to the ton.

SILVER MOUNTAIN

The Silver Mountain group includes one patented claim and two and a fraction unpatented claims on the south side of Granite Creek, about 2 miles by road above the Glacier mine. Three adits, one above the other, have opened up veins along the Snowshoe fault and a fault that runs parallel to it on the west. The two upper adits were caved at the time of examination. The lowest, which is on the Snowshoe fault, extends S. 3° W. The wall rock on the west is light-colored calcareous shale of the Wallace formation dipping westward; that on the east side of the fault is light-gray quartzite of the Ravalli formation dipping eastward. The Snowshoe fault, which is here about vertical, consists of breccia, gouge, small horses of country rock, and vein quartz. Its average width is about 3 feet, but in places it is as much as 6 feet wide. Pyrite, arsenopyrite, galena, sphalerite, with less chalcopyrite and pyrrhotite, occur in streaks, bands, and disseminated grains in the quartz, mostly near the walls of the fault zone. A little carbonate and sericite are present. Diopside and actinolite have replaced the wall rock near the fault to a slight extent. Flat-lying to steeply dipping quartz veins as much as 20 inches in thickness branch from the main vein and penetrate the country rock, but they are not rich enough to follow. In many places the quartz is sheeted, and it there contains sulfides. Shearing continued or was repeated after the deposition of the pyrite, for the microscope shows that scattered pyrite was partly replaced by quartz, carbonate, and sulfides.

Specimens of ore collected from the dumps of the two upper adits indicate that the ore they encountered is similar in character to that just described. According to Frank Pival, present owner of the property, at least one shipment of ore, consisting of 22 tons of concentrates, has been made from the lowest adit. Assays of selected samples have shown 8 to 18 percent of lead, 8 to 21 ounces of silver, and 0.4 to 1.2 ounces of gold to the ton.

MONTANA SILVER-LEAD

The Montana Silver-Lead prospect, which includes eight unpatented claims, is on the north side of Leigh Creek, about 2 miles upstream from the county road. Two cabins, a small blacksmith shop, and a powder house have been erected on the property. The group is developed by two adits with a total of about 1,500 feet of workings, mainly along the Snowshoe fault. The fault strikes north in the lower adit and N. 7° E. in the upper adit; in both places it is nearly vertical. The maximum width of the fault zone is 6 feet. The breccia and gouge in the fault are tight, and there is very little water in either adit. The wall rock on the east side of the fault is white quartzite and sandstone, gray argillite, and gray calcareous sandstone of the Ravalli formation; the rock in the west wall is gray calcareous shale and brownish-red siliceous limestone of the Wallace formation. On both sides of the fault the wall rocks are strongly sheared.

Quartz veins carrying sulfides are more abundant in both walls than in the fault zone itself. Sheared veins exposed in short crosscuts and in the back and walls on either side are cut off at the fault. Other quartz veins appear to have passed out from the fault into the wall rock on both sides. Pyrite, galena, and sphalerite occur sparingly in the quartz; the quartz in the wall rocks contains more sulfide than that in the fault zone. The only gangue minerals other than quartz are calcite, ankerite, and a little sericite. A little chalcopyrite, pyrrhotite, and arsenopyrite were found on the dump, besides the sulfides already mentioned. Oxidation has produced small quantities of anglesite, cerussite, limonite, and copper carbonates.

A selected specimen of ore lean in sulfides from one of the veins assayed 0.01 ounce of gold and 12.4 ounces of silver to the ton.

VICTOR-EMPIRE

The Victor-Empire prospect is on the north side of Granite Creek, 2 miles above the Glacier mine. A compressor, run by water power from Granite Creek, supplies air for the drills and for the drill-sharpening equipment in the blacksmith shop.

The mine is opened by an adit, which runs N. 51° W. for about 50 feet. A drift continues N. 7°–15° W. for at least 1,300 feet along the Snowshoe fault, which is here almost vertical. The drift was inaccessible beyond 1,300 feet but is said to be 2,000 feet long. The rocks in the west wall of the fault are gray calcareous sandstone and sandy, calcareous shale of the Wallace formation. The east wall is quartzite and sandstone of the Ravalli. Near the fault the wall rocks have been replaced to some extent by tremolite, sphene, and zoisite. Pyrite, pyrrhotite, and galena, partly enclosed in the quartz veins and partly disseminated or forming small irregular streaks, occur in the crushed wall rock and gouge of the fault zone, which is 2 to 5 feet wide, but they are more abundant in the rock alongside the fault zone. A steeply dipping branch fault in the Ravalli was encountered about 1,100 feet north of the portal of the adit and was followed northwestward for a short distance. The gouge and breccia along this fault is nowhere more than 30 inches thick, and it is no more strongly mineralized than the main fault zone.

A horizontal diamond drill hole driven from the end of the 2,000-foot drift along the larger fault, in a direction a little north of east, is said to have passed through high-grade gold-silver-lead ore at about 940 feet.

FAIRBAULT

The Fairbault Mining Co. has five claims on the south side of Cherry Creek, about a mile above the Copper Reward group of prospects. An adit 335 feet long, at an altitude of 4,100 feet, has been driven S. 5° E. on the Snowshoe fault. The fault, which here dips 65° NE., separates fine-grained white to gray calcareous argillite of the Wallace formation, on the west from fine-grained rusty-gray, sericitic, sandy argillite of the Prichard on the east. Galena, pyrrhotite, and chalcopyrite are sparsely disseminated in the brecciated vein quartz along the fault. Assays of selected samples shown the writer by Isak Ludvikson, one of the owners of the property, indicate that the ore carries a little gold and silver.

SILVER CABLE

The Silver Cable prospect includes two or three short adits on the south side of Cable Creek, at altitudes of about 5,500 feet, on the Snowshoe fault. East of the fault are dark-colored argillite and gray sandstone of the Prichard formation; west of it is gray sandstone of the Ravalli. One adit has been driven 75 feet southward on the fault zone, which here strikes nearly north, dips 80° east, and is about 4 feet wide. A quartz vein 3 feet wide, enclosing small patches of pyrite and a little galena, may be seen at the face. The vein minerals on the dump are chiefly quartz, pyrite, and carbonate; galena and pyrrhotite occur less abundantly, and a little chalcopyrite was seen in a polished section of the ore.

Milling machinery, including boiler, crusher, screens, and bins, in decayed buildings near the foot of the slope appears never to have been used.

SILVER TIP

A continuation of the Snowshoe vein on the north side of Cherry Creek has been prospected by several open pits and adits on the Silver Tip group of claims. The principal opening follows the Snowshoe fault for a distance of 250 feet. Here the fault strikes N. 10° W. and dips 84° NE.; several hundred feet higher on the hill it strikes north and is vertical. The wall rock west of the fault is shale of the Wallace formation; that east of it is brownish sandy argillite of the Prichard formation. Fault breccia, gouge, and vein quartz have in places an aggregate thickness of 3 feet. The metallic minerals are galena, altering to anglesite and cerussite, and pyrite, altering to limonite.

STATESMAN

The Statesman prospect, on the south side of Poorman Creek, at an altitude of about 6,300 feet, is the southernmost prospect on the Snowshoe fault, which has been traced only about 3 miles farther south. Here the fault strikes N. 8° W. and dips 80° NE. The fault zone is 3 feet wide and, as seen in open cuts, contains quartz veins as much as 7 inches in thickness. East of the fault are Prichard strata dipping eastward; west of the fault are Ravalli strata that dip westward and southwestward. Some of the veins pass out into the sandstone and argillite wall rocks on either side, and 40 feet west of the fault a 12-inch quartz vein was opened up. The veins are not conspicuously mineralized; they contain a little arsenopyrite and galena and still smaller quantities of chalcopyrite, pyrrhotite, sphalerite, and pyrite.

TEXAS RANGER

The Texas Ranger group comprises four claims on the south side of Leigh Creek, about 2 miles west of the county road. An adit has been driven S. 3° W. for 300 feet along the Snowshoe fault zone, which here dips 86° SE. and has a maximum width of about 3 feet. The wall rock east of the adit is argillite and sandstone of the Ravalli; that west of the adit is dolomitic limestone of the Wallace formation. Material on the dump shows that the ore consists of galena, sphalerite, pyrrhotite, pyrite, and chalcopyrite in a gangue of quartz and carbonate. No large bodies of sulfides were seen in the adit, but quartz veins a few inches to 3 feet thick, containing sulfides in moderate amount, were seen in the country rock near the portal of the adit.

COPPER REWARD

The Copper Reward group of five claims is on the north side of Big Cherry Creek. A strong vertical mineralized shear zone, striking northwest, in quartzite of the Ravalli formation has been prospected by several shafts and adits at altitudes between 3,500 and 4,000 feet. The principal opening, an adit, which according to G. W. Walker, who owns the claims, was driven for 440 feet along the shear zone, was closed by caving at the portal when visited.

As shown by open cuts, veins 3 to 6 inches wide of sulfides in a gangue of quartz and carbonate occur in the shear zone, and the quartzite wall rock has been replaced to a slight extent by sulfides. The more abundant metallic minerals are pyrite, arsenopyrite, and galena; less abundant are chalcopyrite and sphalerite. Where the ore has been oxidized, limonite, anglesite, malachite, and azurite have been deposited.

D. AND W.

The D. and W. group, owned by Messrs. Clark, Wakefield, and others, includes the Last Turn, Wakefield, and 12 other claims on Prospect Creek. It may be reached by a secondary road leading from the county road to the Glacier mine and Granite Creek. An excellent cabin and blacksmith shop are conveniently located at the end of the road, near the Ida V. adit.

The Ida V. adit extends about 500 feet on a quartz vein, which strikes northwest and dips 80° NE., in shale, sandstone, and quartzite of the Wallace formation. The quartz has been sheared, and pyrite, with less galena and sphalerite, have been introduced along closely spaced parallel shear planes and disseminated in the quartz. The sulfides were then shattered by later movements, and the fragments were cemented by a new generation of quartz. An adit driven westward near the Ida V. penetrated, about 350 feet from the portal, a strong shear zone, which strikes N. 10°–20° W. A drift 160 feet long on this shear zone shows small veins of galena. Similar mineralization may be seen in several other openings on this group.

MOUNTAIN ROSE

The Mountain Rose prospect, comprising five unpatented claims, is on Granite Creek, near the west line of sec. 7, T. 29 N., R. 31 W. A small aerial tram for transporting ore connects the adit with the camp on Granite Creek, which includes a blacksmith shop and other cabins. A good road up Granite Creek runs through the property.

The principal opening is an adit running S. 14° E. for 98 feet along the strike of the quartzite of the Ravalli, which here dips 62° NE. At 88 feet a crosscut 770 feet long has been driven S. 50°–70° W. to cut a number of northwestward-striking veins of quartz and sulfides. Most of these veins are along bedding faults, though in places they break across the beds at a small angle. The veins are 1 to 12 inches thick and contain, at the most, about 2½ inches of sulfides, including pyrite, galena, sphalerite, and subordinate pyrrhotite and chalcopyrite. The gangue contains a little ankerite and sericite. Movement has recurred along the fault planes since the veins were formed.

ST. PAUL

The St. Paul group of seven claims is owned by Mrs. S. N. Plummer, Sam Ratekin, and Mike Shanahan. Its northwest end is on the south side of Snowshoe Creek east of the Snowshoe mine, and its southeast end is on the slope north of Cherry Creek. A cabin and a small blacksmith shop have been built on Cherry Creek near the adit, and a new road running past the property was being constructed in the summer of 1930. The claims on Snowshoe Creek are connected by road with the Snowshoe mine.

An adit on the Cherry Creek side follows for 600 feet a fault that strikes N. 62°–72° W. and dips 65° SW. The wall rock on both sides consists of sandstone, argillite, and white quartzite belonging to the Ravalli formation. The fault zone contains 3 feet of breccia and 2 to 3 inches of gouge, both stained with limonite but containing little sulfide. On the south side of Snowshoe Creek, east of the Snowshoe mine, three adits have been driven on what is presumed to be the same fault, which here strikes N. 57°–60° W. and dips 70° SW. In the two adits, with a total of 400 feet of workings, that were examined by the writer, the fault zone is 18 to 42 inches wide. The ore minerals, consisting of fine-grained pyrite, galena, and sphalerite with less chalcopyrite, are enclosed in quartz, where they form both veinlets and disseminated patches. Where the ore has been oxidized, abundant limonite and a little azurite, malachite, cerussite, gypsum, and manganese oxide have been formed. A good deal of sericite and a very little calcite are present both in the ore and in the wall rock.

DEMONSTRATOR

Several small quartz veins in thin-bedded sandy shale of the Wallace formation, locally much disturbed, on the north fork of Prospect Creek have been prospected by Henry Brink and Timothy Miller, who own a group of nine claims. On one of these claims, the Demonstrator, there are several shallow openings, which reveal small amounts of galena, pyrite, and sphalerite disseminated in a gangue of massive quartz. Near these cuts a thin brown sill, composed chiefly of plagioclase, biotite, and iron oxide, is exposed for a short distance. The sill is cut by tiny barren quartz veins.

DOUBLE MAC

The Double Mac prospect is on the north side of Granite Creek, about 1½ miles southwest of the Glacier (Lukens Hazel) mine. Two short adits and several pits have opened up several groups of small closely spaced quartz veins in gray quartzitic sandstone of the Ravalli formation, which here strikes N. 28° W. and dips 83° NE. A few thin beds of magnesian limestone have been replaced by tremolite. In general the veins lie parallel to the bedding, but they pinch and swell and locally coalesce to form larger veins. In addition to quartz the veins contain pyrite, sphalerite, galena, and arsenopyrite, which together may make up, in places, fully 90 percent of a 6-inch vein. Shearing is indicated in places by as much as 2 inches of gouge and breccia, and the shattered condition of the pyrite and arsenopyrite, as seen under the microscope, shows that at least a part of the movement took place after the sulfides were deposited. The sulfides are also disseminated through much of the country rock, and according to Edward Boyes, one of the owners of the property, a fair sample taken horizontally across 45 feet of veins and country rock assayed $12 per ton in gold, silver, lead, and zinc.

LOYAL

The Loyal prospect is on the north side of Horse Creek, at an altitude of about 2,400 feet, a mile northwest of the Glacier mine. An adit 85 feet long has been driven northward on a vertical fault in a sill in light-colored, thin-bedded, sandy calcareous shale of the Wallace formation. The fault contains a little quartz and still less pyrite, galena, and sphalerite, all partly oxidized.

MISSOURI

The Missouri group of seven claims is on the north side of Leigh Creek about 2 miles above its junction with Cherry Creek. Several short adits, at altitudes between 3,600 and 4,400 feet, have been driven on quartz veins along a shear zone striking northwestward in quartzite of the Ravalli.

The sulfides seen in the adits and on the dumps are galena, pyrite, arsenopyrite, and chalcopyrite. Parts of the vein are more or less oxidized, pyrite and arsenopyrite being replaced by limonite and galena by anglesite. The most abundant gangue mineral is quartz, though ankerite, altering to iron and manganese oxides, is conspicuous in one of the upper adits. As may be seen in polished sections, arsenopyrite was one of the first of the primary metallic minerals to be deposited; it is replaced in part by galena, chalcopyrite, and pyrite. Though most of the quartz is earlier than the sulfides, tiny veinlets of later quartz cut through shattered pyrite and arsenopyrite.

SEATTLE

A persistent quartz vein in argillite and quartzite of the Ravalli has been prospected at several places on the Seattle group of five claims, two of which are on the north side and three on the south side of Cherry Creek. The vein, which is a few inches to 4½ feet in width, contains variable quantities of quartz, galena, blende, chalcopyrite, and pyrite, the last altering in places to limonite. For the most part the vein is parallel to the beds, which here strike N. 45°–50° W. and dip 35° NE., but in many places the vein and apophyses from it cut across the bedding, and where this occurs the crosscutting bodies commonly have a steeper dip than the wall rock.

OUTLYING SILVER-LEAD MINES AND PROSPECTS

BLUE CREEK

The Blue Creek mine is on the East Fork of Blue Creek, at an altitude of 3,150 feet, about 2 miles north of Fatman Mountain. Two short adits have been driven eastward to the Blue Creek fault, which here is a crushed zone at least 4 feet wide in sandstone and argillite of the Ravalli. The fault is sinuous, its strike ranging from N. 18° W. to N. 30° W. and its dip from 55° to 85° W. In most places the dip approaches the higher figure, and in one place the fault is vertical. In a prospect northwest of the mine the same fault strikes nearly north and dips 75° W.

Patches and streaks of ore as much as 18 inches wide occur in the fault zone, especially near the footwall, and to some extent in both walls. In places, however, the fault zone contains only breccia and gouge and is practically barren of vein material. Galena, sphalerite, pyrite, and pyrrhotite are the chief sulfides and quartz and calcite the chief gangue minerals in the ore. Chalcopyrite, arsenopyrite, and hornblende also are present but are very scarce. Most of the ore is exceedingly fine-grained, and the sulfides as a rule are intimately mixed, though in some parts of the vein they tend to be separately deposited in layers.

The mine has not been worked for some time, but according to Anderson [95] at least one car of ore was shipped in 1927.

BROKEN HILL

The Broken Hill mine is on the east side of the East Fork of Blue Creek, at an altitude of 4,200 feet. Two adits, one of which was caved at the portal, have been driven eastward in sandstone of the Ravalli formation to a mineralized shear zone along the Blue Creek fault, which strikes northwest and dips steeply northeast. Eighty feet from the portal of the upper adit is a stope about 60 feet high, which probably yielded a few carloads of ore. Remnants of ore seen in this stope indicate that the chief metallic minerals are fine-grained galena and sphalerite; pyrite occurs less abundantly, and a few grains of pyrrhotite and chalcopyrite were seen in polished sections. The gangue is quartz. The ore body is exceedingly irregular and pinches within a short distance from a maximum width of 30 inches to 9 inches or less. The form of the stope indicates that the ore was in a shoot pitching to the northwest. A winze said to be 116 feet deep, which was inaccessible when the property was visited, connects with the lower adit. The ore is said to have pinched out at or above the

95 Anderson, A. L., Geology and ore deposits of the Clark Fork district, Idaho: Idaho Bur. Mines and Geology Bull. 12, p. 106, 1930.

level of the lower adit, though the shear zone is still well marked at that depth.

BLACK DIAMOND

The Black Diamond group of three unpatented claims is north of the Libby quadrangle, on Pine Creek, about 5 miles above the main road along the Yaak River. Several adits, one of them 500 feet long, have been driven in faulted and sheared white quartzite similar to that of the Ravalli formation, in order to explore a number of veins near a dike. The veins, which are in or near shear zones, commonly strike northeast and dip steeply to the southeast or are vertical. They are 4 to 29 inches in thickness. The gangue is mainly quartz, and the most abundant sulfides are galena and pyrite, but they also contain some pyrrhotite, chalcopyrite, and sphalerite. Irregular patches and disseminated grains of the sulfides occur in the wall rock near the veins. The average width of solid sulfide for several veins is 7 inches.

It is reported that a 100-ton mill has been erected on the property since the writer's visit and that concentrates were being shipped in 1935.

CRATER

The Crater prospect is a mile east of Savage Lake, at an altitude of 3,050 feet on the steep mountain front. An adit has been driven northeastward for 100 feet to explore an exceedingly irregular quartz vein in the breccia of a large fault zone, called the Savage Lake fault, which here strikes north and stands vertical. The fault zone is 40 feet wide in places, and rock fragments in the breccia differ widely in size.

The wall rocks, which are gray to buff dolomitic limestone and shale of the Wallace formation, strike northwest and dip 90°–28° NE. The vein pinches and swells abruptly, ranging in width from 8 to 30 inches, and is sheared, especially at the margins. It contains a little pyrite, tetrahedrite, and galena. It is but slightly oxidized, though in places the quartz and sulfides are thinly coated with limonite, azurite, and malachite.

PRICE

The R. J. Price Mining Co. has 12 unpatented claims north and east of Rock Creek Meadows, at the head of Rock Creek. An open cut at an elevation of 5,200 feet exposes the Rock Lake fault, a shear zone 6 feet wide that cuts quartzite of the Ravalli. The fault strikes northwest and is vertical. Lower on the slope a crosscut adit extending N. 20° E. was being driven in August 1932. This adit was then 343 feet long but had not yet reached the fault zone. A thin section of the sheared quartzite shows about 35 percent of calcite and a little sericite. The shear zone contains a little partly oxidized pyrite and a very little galena in thin seams.

The Rock Lake fault continues under and beyond Rock Lake, and on the southwest side of the lake, in a disturbed area near the fault, open cuts reveal small veinlets and disseminated grains of sphalerite and galena with a little pyrite and chalcopyrite. The sulfides have replaced Ravalli quartzite and are sparsely distributed through a zone 8 feet wide.

REMP

The Remp prospect is on the northwest side of Cedar Creek, half a mile below the lower Cedar Lake, and may be reached by a horse trail up Cedar Creek. The altitude of the cabin on the property is 5,650 feet. A quartz vein, striking N. 46° W. and dipping 50° SW., in limestone of the Wallace formation has been prospected by several short adits, the largest of which was caved at the time of examination. Ore collected on the dumps indicates that the chief sulfide is tetrahedrite; galena is second in abundance, and very small quantities of pyrite and pyrrhotite are present.

TRIO

The Trio prospect includes two unpatented claims on Emma Creek half a mile west of Bull Lake. An adit and crosscut with a total of 200 feet of workings have been driven in light-colored sandstone and argillite of the Ravalli formation. In most places the beds dip westward and southwestward at low angles, but in some places east of the prospect they are horizontal. The ore forms irregular patches in a large fault zone that strikes north. The dip of the fault is uncertain, as the ground is much disturbed, but it appears to be about 55° westward. The beds west of the fault are strongly sheared.

The chief metallic minerals, none of them very abundant, in the vein and on the dump are pyrrhotite, pyrite, galena, and sphalerite; magnetite and chalcopyrite are present in minor quantity, and a little supergene marcasite and limonite were seen. The gangue is chiefly quartz but includes a little chlorite and carbonate.

As a result of movement along the fault later than the mineralization the veins have been broken into segments, and under the microscope it is seen that some mineral grains have been shattered and partly replaced by other minerals.

WEYERHAEUSER

The Weyerhaeuser prospect is in the NW. ¼ sec. 5, T. 31 N., R. 34 W., on the western slope of Preacher Mountain, at an altitude of about 4,500 feet. Several open cuts and an adit 270 feet long have been made in a metadiorite sill intruded in the Prichard formation, which is here composed of white quartzitic sandstone and dark-gray argillite dipping southeastward. The sandstone has been so altered in appearance by the introduction of hornblende, epidote, and biotite that it cannot easily be distinguished from the rock of the sill. In places these minerals, together with subordinate feldspar, make up 40 percent of the metamorphosed rock, and there is evidence also that some feldspar has been replaced by epidote.

The workings mentioned expose several quartz veins, in shear zones in the sill, which strike N. 45°–55° W. and dip 70°–80° NE. and which have a maximum thickness of 12 inches. Faulting has slightly offset some of the veins. Sulfides are not abundant and are confined to the quartz in the veins. Galena predominates, but very small quantities of chalcopyrite, pyrrhotite, and pyrite are present. Oxidation has produced some limonite and a very little malachite, covellite, pyromorphite, cerussite, and anglesite.

COPPER PROSPECTS

FREEMAN

The Freeman prospect is just above Copper Lake, in Copper Gulch, at an altitude of 5,600 feet. The country rock is the Ravalli formation. Two short adits about 20 feet apart have opened up a quartz vein 6 feet thick, which occupies a shear zone that strikes N. 48° E. and dips 46° NW. An inclined winze at least 80 feet deep was partly filled with water when the prospect was examined.

The chief ore mineral is chalcopyrite, which is disseminated through the quartz. A little bornite is intergrown with the chalcopyrite, and both minerals are veined with chalcocite, malachite, and limonite. A selected sample of quartz high in chalcopyrite assayed 0.01 ounce of gold and 0.60 ounce of silver to the ton.

MONTANA PREMIER

The Montana Premier group includes eight claims on the west slope of Copper Mountain between an altitude of 2,800 feet and the top of the ridge, chiefly in sec. 12, T. 30 N., R. 34 W. Several northeastward-trending veins that dip steeply to the southeast and one strong vein that strikes N. 60° W. and dips northeast, all of them in sandstone and shale of the Wallace formation, have been opened up by short trenches and adits. The veins range in thickness from 18 to 60 inches. They are composed chiefly of quartz and calcite but contain a little barite and a very little chalcopyrite and pyrite. In all the exposures the sulfides are partly altered to oxides and carbonates. The prospect is interesting to the owners chiefly because of the barite.

ULLEY

The Ulley prospect is on Squaw Peak, at an altitude of about 5,250 feet, half a mile northeast of the lookout station on the summit, and is reached by a trail up Star Gulch. A short crosscutting adit has been driven to explore a quartz vein that has a maximum thickness of 12 inches. The vein strikes north and dips 50° W., and it cuts white quartzite of the Ravalli that dips 50° SE. A second crosscut adit, 100 feet below the first, had not penetrated the vein when the property was visited in 1934. In places, more than half of the vein consists of metallic minerals, chiefly magnetite and chalcopyrite. The vein is much brecciated, but there is no evidence of large displacement. Slight oxidation has produced a little limonite and malachite and caused parts of the ore to be honeycombed.

PLACER MINES AND PROSPECTS

NUGGET PLACER

The Nugget Placer Mining Co. holds several claims on Libby Creek, about a mile below the mouth of Bear Creek and a short distance east of the eastern border of the Libby quadrangle. According to Sidney M. Logan, president of the company, these claims were formerly worked with crude equipment, and much of the gold was lost. A small production in 1916 is reported in the volume of Mineral Resources for that year.

In 1932, gravel in the present stream channel and that in a former channel, very close to the present stream, were being worked by means of a dragline and scraper bucket, which dumped the gravel through a grizzly into a sluice. The water of Libby Creek, dammed a short distance above, was carried in an open ditch to the sluice. The gravels were not well sorted, and many boulders were too large to go through the grizzly and were carried away in a truck. Drifting in low bench gravel was attempted, but this operation proved to be too expensive. There is a little concentration of gold at the surface on these claims, but the pay streak, where present, is close to bedrock.

RED GULCH PLACER

In 1931, hydraulic mining under the direction of James Mahoney was in progress on the west side of Libby Creek, just below the mouth of Little Cherry Creek, on claims belonging to the Red Gulch Mining Co. Water was brought by ditch from Cable and Bear Creeks. Gravels in an old channel of Libby Creek, about 20 feet above the present creek level (Fig. 7), were being washed, with a reported yield of 60 cents to $1 a yard. The deposit, as exposed, includes 3 to 10 feet of tightly packed and partly cemented stream gravel, which lies on bedrock and contains the pay streak. This is overlain by 6 to 10 feet of finely laminated silt, containing a few lenses of gravel, and above this is 1 to 6 feet of soil mixed with striated boulders and pebbles, which had rolled down from a deposit of till higher on the slope to the west.

Along the bank of Little Cherry Creek, west of the present workings, pits which had been sunk through till found some gold at bedrock.

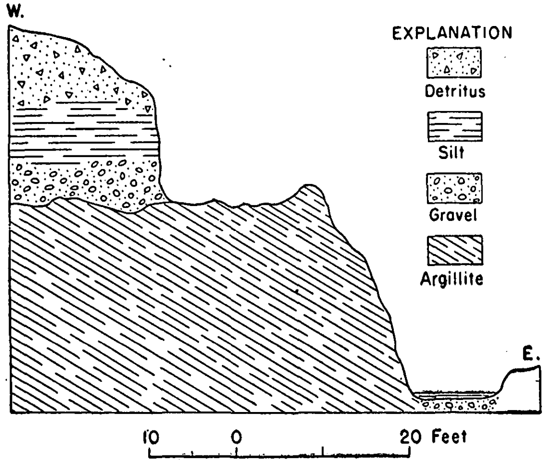

FIGURE 7.—Cross section at Red Gulch placer mine on Libby Creek, showing gravel deposit on bench above present drainage level.

LIBBY CREEK GOLD MINING CO.

The claims of the Libby Creek Gold Mining Co. are on Howard Creek and Libby Creek near their junction.

A pit on the Howard Creek claims, formerly known as the Vaughan and Greenwell mine, is said to have been productive for 20 years prior to Schrader's visit [96] and to have yielded about $5,000 a year from 1904 to 1908. Schrader describes the deposit as follows:

> The lower opening is on the east side of the creek. * * * From the creek the deposit rises gently eastward for about an eighth of a mile to a height of about 150 feet; its extent parallel with the creek is somewhat greater. It rests upon a streamward-sloping bench or roughly eroded surface of quartzite which dips gently east away from the range. The deposit seems to be ground moraine. It is nowhere much over 30 feet in thickness and probably averages 15 feet. Two periods of deposition are apparently present. The basal part of the section is consolidated and cemented somewhat like hardpan, and its gravels are decidedly subangular. * * * The gold is distributed more or less irregularly throughout the deposit.

Most of the work in recent years has been done in a pit a little farther upstream, where gravels in the present stream bed and the till that lies above the hardpan have been prospected. A rather fine gravel below the hardpan is said not to pay.

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[96] Schrader, F. C., Gold-bearing ground moraine in northwestern Montana: U. S. Geol. Survey Bull. 470, pp. 62–74, 1911.

The till is lean except at the very top, where there is a surface concentration of gold. Over the entire pit the ground is said to average about 22.5 cents a cubic yard, but reports as to the richness of this ground are conflicting.

On Libby Creek not far above the mouth of Howard Creek are old pits of the Libby Placer Co., formerly known, according to Schrader,[97] as the Goldhill-Montana-Kootenai group. Output was reported from this group for every year from 1902 to 1908 except one, the total value being more than $30,000.

In 1932 hydraulic mining was being carried on a short distance up Libby Creek from these old pits and a quarter of a mile above the road to Howard Lake. A tough, rather firmly cemented hardpan containing subangular pebbles, exposed a few feet above the present stream, is overlain by till containing subangular pebbles and boulders as much as 8 feet in diameter. There is till beneath the hardpan also, and in one place the total thickness of till and hardpan is more than 50 feet. A short distance above the workings, eastward-dipping quartzite of the Ravalli is exposed in the bed of Libby Creek. There appears to be a very little gold in the body of the till and on the top of the hardpan, though there has been some concentration of gold near the surface.

"DIKE" ON LIBBY CREEK

A mineralized layer in the Ravalli formation that is commonly spoken of as a "dike" crops out on Libby Creek between Libby Creek Falls and the mouth of Howard Creek. There has been some placer mining on Libby Creek below this layer, and it has been regarded as a probable source of the gold. In the summer of 1932 the Libby Creek Gold Mining Co. was placer mining in the vicinity of the "dike" and indicated its intention of also exploring the "dike" itself.

Along the stream bed a short distance below Libby Creek Falls, beds in the Ravalli formation are exposed at several places in a distance of about 300 feet. These beds, which dip 44° NE., consist of hard quartzitic sandstone with an average grain size of 0.20 millimeter, stained buff by iron oxide and showing dendrites of manganese oxide along the joints. Under the microscope it is seen that one-tenth to one-fourth of some beds is made up of feldspar, part of which is altered to sericite. Other fine-grained sericite, formerly clay material, fills interstices between the grains. A few well-rounded grains of zircon are present.

The sandstone is cut by small, irregular quartz veins, which before oxidation contained a little sulfide. As the solutions that deposited the quartz soaked into the sandstone in some places and replaced other minerals or filled interstices, the quartz veins are not everywhere well

[97] Schrader, F. C., op. cit.

defined. Under the microscope tiny veinlets of quartz a fraction of a millimeter in width can be discerned. From the distribution of the iron oxide stains it seems clear that most of the sulfide was associated with the introduced quartz.

Some prospectors assert that colors of gold can be panned from some of the sandstone beds, but others disagree. Assays of specimens taken at intervals for a distance of 300 feet across the mineralized sandstone exposed in the creek bed showed only a very little gold and silver.

COMET PLACER

Several placer claims that were staked about 1890 on Little Cherry Creek near its confluence with Libby Creek were bought by the Comet Mining Co. in 1908 and worked until 1916. A small production in 1910 and 1911 from a hydraulicking operation on this property is reported in Mineral Resources; and a little gold is also said to have been obtained by ground sluicing of stream gravel in 1921. Since then the property has been idle. Part of this production came from gravel and till in the valley of the present stream and part of it from bench gravel on the south side of the valley. According to one of the placer miners who had prospected this property, the heavy overburden of till overlying the stream gravels which contain the pay streak is lean in gold and so thick that the cost of its removal would eat up any possible profit from the pay streak.

LIBBY PLACER (BROPHY PLACER)

The largest placer pit seen in the area is on the east bank of Libby Creek near its confluence with Ramsey Creek. It is about 1,600 feet long and 400 feet wide and appears to be chiefly in till. No record of the output from this placer can be found, but it may have been included in that reported for the Libby Placer Co., described in this report under the heading Libby Creek Gold Mining Co.

In the summer of 1931 J. L. Devol, Ed. Leary, and Frank Denton were prospecting on the west bank of Libby Creek a quarter of a mile below Ramsey Creek on ground reported to be owned by the same Libby Placer Co. that mined in the pit mentioned above. These miners were working the present stream gravels by shoveling them into about 45 feet of sluices carrying water from Libby Creek. The deposit being mined is near bedrock, which is here a calcareous shale of the Wallace formation dipping gently to the northeast. The experience of these operators showed that, with the methods they were using, only material that was on or very close to bedrock was rich enough to work. Away from the gravels of the present creek the prospects are not encouraging. Panning at the surface 20 feet above the present stream shows the usual surface concentration of gold, which is less marked, however, than the concentration near bedrock.

MONTANA PLACER

The Montana placer, which includes 10 claims on Cherry Creek near its confluence with Snowshoe Creek, was opened about 1905. In 1915 the claims were taken over by J. E. Leary, M. Neary, Sam Miller, and associates, who spent a considerable sum in developing the property. A small production was made, but the project, according to Mr. Leary, was given up as unprofitable.

It is said that placer gold has been found throughout the 4 miles along Cherry Creek extending from a point 1½ miles above the mouth of Snowshoe Creek to Harry Howard's placer, a quarter of a mile below Smearl Creek. At the Montana placer and elsewhere on Cherry Creek the older placer workings are confined to comparatively narrow deposits along the present stream channels.

HARRY HOWARD PLACER

In the summer of 1929 Harry Howard of Libby was working the crevices in the creek bed, together with a few feet of the overlying gravel, on his claims along Cherry Creek near the mouth of Smearl Creek, in secs. 27, 33, and 34, T. 29 N., R. 31 W. He estimated that the gravel he was working yielded about 50 cents to $1 per yard and that he had cleaned up about $700.

GETNER PLACER

In the summer of 1929 J. L. Getner and an associate were preparing to work the Recent stream gravels near the creek level on the east side of Libby Creek, a short distance below Crazyman Creek and about 1 mile east of the Libby quadrangle. No report has been obtained regarding the success of whatever was done here.

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