Geology of the Clark Fork Quadrangle Idaho-Montana

By J. E. HARRISON and D. A. JOBIN

CONTRIBUTIONS TO GENERAL GEOLOGY

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A descriptive report with emphasis on structure and on stratigraphy of the Belt series

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By J. E. HARRISON and D. A. JOBIN

ABSTRACT

The Clark Fork quadrangle, in the panhandle of Idaho, is underlain by more than 38,000 feet of low-grade metasedimentary rocks of the Precambrian Belt series. This series includes the Prichard and Burke formations, the Revett quartzite, and the St. Regis, Wallace, Striped Peak, and Libby formations. These rocks have been intruded by the Precambrian (?) quartz diorite that forms the Purcell sills of the area and by Cretaceous (?) granodiorite stocks or plugs, granodiorite porphyry sills, and diabase dikes and sills. Near the larger intrusive bodies the rocks of the Belt series have been mildly contact metamorphosed.

The only other rocks are thin Quaternary alluvial and glacial deposits in the valleys.

The structural setting in the quadrangle is one of simple folds and complex fractures. The entire area is on the west flank of a northward-trending syncline whose axis appears to be near the east edge of the quadrangle south of the Hope fault. Small drag folds, generally only a few tens of feet in either wave length or amplitude, are associated with faults. Other small folds occur in a zone a few hundred feet wide around a granodiorite plug exposed along Lightning Creek.

Three main parts of the fracture system are here called the Hope fault, block faults, and mineralized faults. The Hope fault is by far the most prominent in the area. It is a northwestward-trending, steeply southward-dipping normal fault along which the apparent strike slip is right lateral about 16 miles, and the apparent dip slip is southwest side down about 22,000 feet. The block faults form a complex mosaic pattern south of the Hope fault and a simpler pattern north of it. These faults are all high-angle normal or reverse dip-slip faults along which movement has been a few hundred feet. Mineralized faults include a group of high- and low-angle normal, reverse, and strike-slip faults that have wallrock alteration and traces of ore minerals along them. Movement along these faults was at most a few tens of feet.

The geologic history is imperfectly known because of large gaps in the stratigraphic column and a current lack of radiometric age determinations. A partial history begins with shallow-water deposition of the Belt series as fine-grained clastic and carbonatic sediments in a Precambrian geosyncline. The Belt rocks were intruded by Purcell sills, gently folded, and then offset by right

lateral movement along the Hope fault in late Precambrian (?) time. No record of Paleozoic or early Mesozoic time exists in the area. In late Mesozoic (?) time, large bodies of granodiorite were intruded, the country rocks were shattered by block mosaic faulting, and minor faults were mineralized and filled by lamprophyre dikes. A period of extensive erosion in the early Cenozoic was probably interrupted in the late Cenozoic by major normal movement on the Hope fault. Pleistocene glaciation, first continental and then alpine, was followed by Recent erosion of part of the glacial deposits and construction of the Clark Fork delta.

The quadrangle has both metallic and nonmetallic mineral deposits of considerable value. Veins in the Clark Ford district have yielded about $1.5 million worth of silver and lead. Though they were being mined sparsely in 1960, they have not been exhausted. The nonmetallic deposits are natural cement rock and construction materials, which includes rock mined for sand and gravel, building stone, riprap, and railroad ballast.

INTRODUCTION

The Clark Fork quadrangle is on the east side of the Idaho panhandle and about 50 miles south of the Canadian border (fig. 1). Altitudes ranges from about 2,070 feet on the delta of the Clark Fork River to 7,009 feet on the top of Scotchman Peak. Almost all the area is heavily forested, and most of it is included within the Kaniksu and Cabinet National Forests.

Previous geologic work in the area includes reconnaissance by Calkins (1909), reconnaissance by Campbell and others (1915) along the Northern Pacific Railway route, reconnaissance mapping of part of the quadrangle and a study of the Clark Fork mining district by Anderson (1930), and a detailed restudy of the Clark Fork district by Anderson (1947). A reconnaissance map of the Pend Oreille district made by Sampson (1928) almost joins the Clark Fork quadrangle on the west, and the quadrangle is joined on the east by the Libby 30-minute quadrangle (fig. 1) mapped by Gibson (1948).

The mapping for this report was done during the summers of 1957, 1958, and 1959, and field checked by Harrison during July 1960. Work on three adjacent quadrangles north and west of the Clark Fork quadrangle fig. 1) was in progress at the time of this writing. This report is designed to give a brief description of the geology in the first quadrangle completed.

We thank Mr. Robert Gregson, ranger of the U.S. Forest Service, for his generous cooperation and aid with logistic problems during our mapping. We are particularly grateful to S. Warren Hobbs and Arthur B. Campbell, U.S. Geological Survey, for field conferences on Belt stratigraphy in the Coeur d'Alene, Superior, and Clark Fork areas.

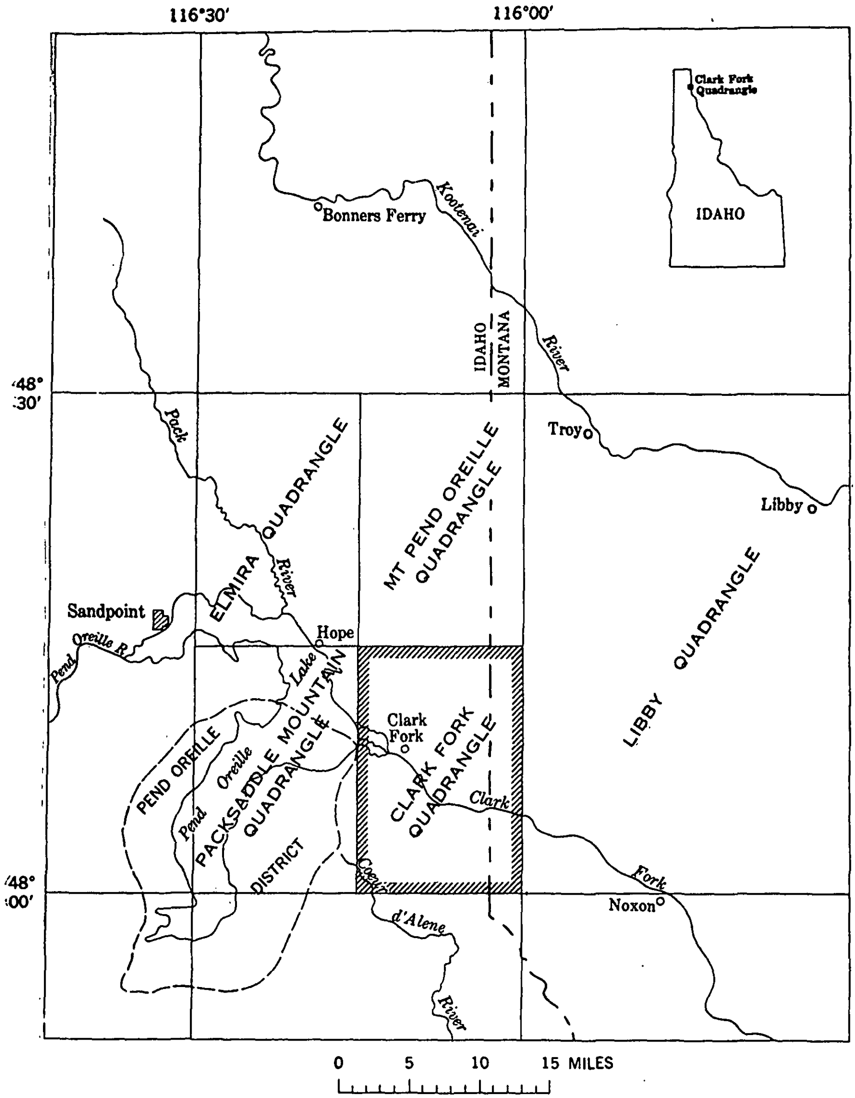

FIGURE 1.—Index map of northern Idaho-Montana.

GEOLOGIC HISTORY

The geologic history of the area, extrapolated from available data, is moderately complex. More than 38,000 feet of fine-grained sand, silt, clay, and carbonatic sediments accumulated as shallow-water deposits in a Precambrian geosyncline. Early life is represented by fossil algae (stromatolites) that lived on some of the Precambrian mud flats. At a later Precambrian time, when the sediments had become indurated, quartz diorite sills were intruded into the lower part of the geosynclinal sequence. These sills and their host sedimentary rocks were gently folded; perhaps regional metamorphism began with these first tectonic movements, and perhaps the Hope fault was first formed during this late Precambrian tectonism. A major right lateral movement along the Hope fault offset the Precambrian folds, possibly at the end of Precambrian time but perhaps during Paleozoic time.

No certain geologic record of Paleozoic or most of Mesozoic time exists in the area.

Near the end of the Mesozoic, large bodies of granodiorite were intruded into the bedrock and caused metamorphism in the biotite zone of Belt rocks adjacent to the intrusive bodies. This intrusion was accompanied by block mosaic faulting and differential vertical adjustment of the blocks over the intrusive mass. A final phase of this late Mesozoic tectonism included small-scale shearing, thrusting, and normal faulting that was accompanied by intrusion of thin lamprophyre dikes and mineralization along the young fractures.

A period of erosion was interrupted, perhaps in late Tertiary time or perhaps as late as early Pleistocene, by major vertical movement along the Hope fault. The prominent scarp formed at that time is the most striking topographic feature of the quadrangle even today.

An advance of a continental ice sheet in Pleistocene time presumably dammed the flow of the Clark Fork River. A lobe of the sheet advanced eastward from the Lake Pend Oreille area to somewhere near the Idaho-Montana line. This formed Glacial Lake Missoula and also dammed most of the tributaries to the Clark Fork River in the quadrangle. Thick deposits of lacustrine and glaciofluvial silts, sands, and gravels accumulated in the lake, and filled the Clark Fork Valley to a level of at least 3,400 feet. A second stage of glaciation, probably strictly alpine, followed the continental glaciation. The prominent cirques and U-shaped valleys north of the Hope fault were deepened and extended during this time. Some of the major glaciers probably flowed out into the Clark Fork valley and northeastward toward Lake Pend Oreille (fig. 1). Retreat of these alpine glaciers led to a further accumulation of glaciofluvial debris in the Clark Fork valley.

The Recent geologic history principally involves streams downcutting through Pleistocene deposits to their prefill levels and construction of the Clark Fork River delta. The preglacial topography in the Clark Fork valley has been partly exhumed. The Hope fault scarp is being gradually cut back, but the scarp is still rounded back rather gently from the original trace of the fault.

DESCRIPTION OF ROCK TYPES

Most of the rocks exposed in the Clark Fork quadrangle are low-grade metasedimentary rocks of the Belt series of Precambrian age (pl. 1). These rocks have been intruded by minor amounts of quartz diorite, granodiorite and related rocks, and diabase. Glacial deposits fill the high cirques and major valleys. Alluvium, alluvial fans, and deltaic deposits occur in a few of the largest valleys.

METASEDIMENTARY ROCKS

Most previous descriptions of the Belt rocks of this area used only two lithologic terms for the clastic rocks—argillite and quartzite. A threefold breakdown of these rocks is used here: "quartzite" for metamorphosed sandstone, "siltite" for slightly metamorphosed siltstone, and "argillite" for slightly metamorphosed claystone.

Descriptive data on sedimentary and low-grade metasedimentary rocks are based on the terms proposed by McKee and Weir (1953) for describing layered rocks (table 1) and on the Wentworth scale of grain size. Grain size in the Belt rocks was determined by measurement of the average grain size in thin sections of the least metamorphosed rocks.

TABLE 1.—*Quantitative terms used in describing layered rocks*

[By McKee and Weir (1953)]

Stratification		Cross-stratification		Thickness		Splitting property
				Centimeters	Inches (approx)	
Beds	Very thick bedded	Crossbeds	Very thickly crossbedded	>120	>48	Massive.
	Thick bedded		Thickly crossbedded	120–60	48–24	Blocky.
	Thin bedded		Thinly crossbedded	60–5	24–2	Slabby.
	Very thin bedded		Very thinly crossbedded	5–1	2–½	Flaggy.
Laminae	Laminated	Cross laminae	Cross laminated	1–0.2	½–1/12	Shaly (claystone, siltstone). Platy (sandstone, limestone).
	Thinly laminated		Thinly cross laminated	<0.2	<1/12	Papery.

BELT SERIES

The Precambrian Belt series in the Clark Fork quadrangle has a minimum thickness of about 38,000 feet. Included in the series are the Prichard (at the base) and Burke formations, the Revett quartzite,

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and the St. Regis, Wallace, Striped Peak, and Libby formations. All were named by Ransome (1905) except the Libby formation, which was named by Gibson (1948). Neither the bottom of the Prichard formation nor the top of the Libby formation is exposed in the quadrangle.

The Belt series is made up of five fundamental rock types which are (a) very fine grained to fine-grained quartzite and arkosic quartzite; (b) siltite and argillitic siltite; (c) laminated black argillite and white or green siltite; (d) argillite and silty argillite; and (e) carbonate rocks. Nearly identical rock types commonly appear in several formations or in at least two members of a single formation. Green to gray-green thin-bedded to laminated siltite or argillitic siltite is abundant throughout most of the series and is the least useful of all rock types for identification of stratigraphic position. Differences among other similar rock units are subtle, though some are apparently real and useful for mapping—at least within the Clark Fork quadrangle.

Cyclic sedimentation characterizes the series. Cyclic pairs can be identified in thinly laminated graded beds, in layers that are several feet thick, or in entire map units (pl. 2).

All formations or members are conformable and gradational by interlayering. Most of the gradation or transition takes place within a few tens of feet, but between some units the zone of transition is 100 to 200 feet thick. Where the transition zone between formations exceeds 300 feet in thickness, it has been mapped as a separate unit and arbitrarily placed in one of the formations.

The only fossils are in a few thin beds or scattered colonies of stromatolites. These fossils are of little value in correlation, because they have a wide vertical range.

Small-scale sedimentary structures are common throughout the series, but they are either more abundant or better preserved in the upper part. Mud-crack casts, ripple marks, and graded bedding are the most common features; cross-lamination and crossbedding are common. Mud-chip breccia is abundant in the carbonatic siltites and argillites. Salt casts are common only in one member of the Striped Peak formation.

Because the formations are transitional and lack diagnostic fossils, structural and stratigraphic measurements are necessarily imprecise. The thickness of a unit and the stratigraphic throw on faults commonly can be measured only to the nearest 50 feet, and at some places, only to the nearest 100 feet. Because of these limitations, all thicknesses of units have been computed from the map rather than measured in the field.

We have attempted to follow current practice in the Coeur d'Alene district (established by Ransome and Calkins in 1908) in defining formations and placing their contacts; we have followed Gibson (1948) in identifying the Libby formation, a formation not exposed in the Coeur d'Alene area. The subdivision of the formations into members is our own.

The least metamorphosed rocks of the Belt series are composed of a simple suite of minerals. Average modes, determined by X-ray analysis, of the five principal rock types are given in table 2, based on 6 to 14 analyses of each of the five main rock types of the Belt series. This grouping is based primarily on grain size, but certain unusual clastic rocks containing laminations of black argillite are separately considered, as are the carbonate-rich rocks. Of special interest in table 2 is the relative abundance of feldspar not previously reported. The general correlation between grain size and mineral proportions is also indicated in figure 2.

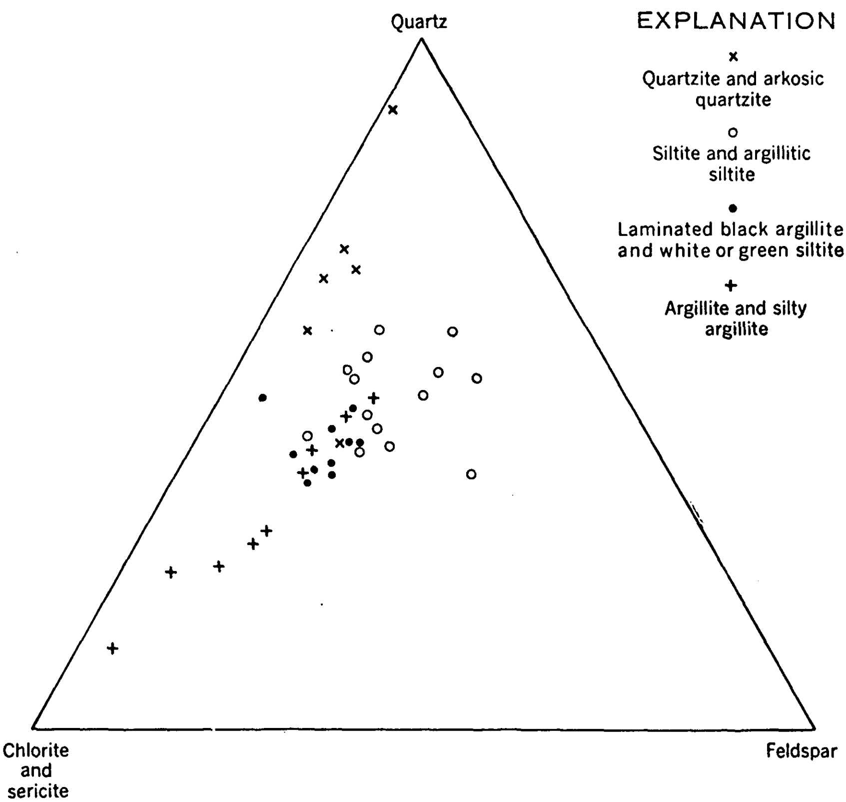

FIGURE 2.—Triangular diagram showing variations in modes, in volume percent, of some noncarbonate rocks of the Belt series.

TABLE 2.—*Some average modes, in volume percent, of Belt rocks*

[Numbers in parentheses indicate number of samples analyzed; numbers in small type indicate range of modes]

Component	Average mode and range for indicated number of samples and rock type.				
	Quartzite and arkosic quartzite (6)	Siltite and argillitic siltite (14)	Laminated black argillite and white or green siltite (10)	Argillite and silty argillite (9)	Carbonate bearing rocks (6)
Quartz	51 38–61	44 34–52	33 27–38	32 14–42	25 19–28
Potassium feldspar	6 3–9	3 0–12	4 0–10	2 0–4	4 1–11
Albite-oligoclase	14 1–20	13 3–20	10 2–13	9 0–12	7 0–10
Chlorite	3 0–9	11 0–32	21 5–30	17 0–28	3 0–9
Sericite	23 9–30	27 10–52	31 21–36	39 14–85	12 0–22
Carbonate minerals	3 0–11	2 0–27	1 0–14	1 0–7	49 38–78

PRICHARD FORMATION

Assigned to the Prichard formation are about 18,000 feet of quartzite, siltite, and argillite; the bottom of the formation is not exposed. Three members are mapped as follows: A lower member of interlayered quartzite, siltite, and argillite; a middle member of thinly laminated black and white or green argillite interlayered with a few scattered beds, less than 10 feet thick, of quartzite or siltite; and an upper member of laminated black and white argillite interlayered with dark-gray siltite that is typical of the overlying Burke formation (pl. 2). Weathered outcrops of the siltites and argillites of the Prichard formation commonly are coated by a rusty film.

The Prichard formation crops out only north of the Hope fault, and is well exposed on the ridge crests and in the glaciated valleys on both sides of Lightning Creek (pl. 1).

QUARTZITE, SILTITE, AND ARGILLITE MEMBER

The lowest exposed member of the Prichard formation contains interlayered beds of siltite and two varieties each of quartzite and argillite. The strata range in thickness from 2 to 200 feet, but average about 15 feet. The dominant rock type is greenish-gray quartzite that is micaceous and slightly argillitic; it is progressively more abundant toward the lower part of the member (pl. 2). A second kind of quartzite is light gray to white and speckled with magnetite; it is the least abundant rock type. The siltite is dark gray, argillitic, and commonly contains abundant pyrrhotite as disseminated crystals or as films. Argillite varieties include laminated dark- and light-gray silty argillite and laminated black argillite and white silty argillite, which is more abundant in the upper part of the member. Both varieties of argillite at places contain scattered crystals and films of pyrrhotite. The member is well exposed on the ridgetops and in the cirques west of Lightning Creek (pl. 1).

The total thickness of the lower member is unknown because the bottom is not exposed; even the thickness of the exposed part cannot be measured accurately because it is cut by faults of undetermined throw. If the throw on the faults is not more than a few hundred feet, the thickness of the lower member is about 15,000 feet.

The upper part of the member contains a series of layers, 50 to 100 feet thick, of greenish-gray micaceous quartzite. On plate 2, the contact with the overlying argillite member has been drawn at the top of the uppermost of these quartzite layers. The thick layers of quartzite at and below the contact form a series of cliffs on ridge crests and a series of falls in the sharp valleys tributary to Lightning Creek.

This member has a few characteristics that help distinguish it from other units of the Belt series. It is the only Belt unit that contains pyrrhotite; the weathering of this sulfide causes the rustiest looking rocks in the Belt series. Only the micaceous greenish-gray quartzites of the Prichard formation and the dark-gray siltites of the Burke formation have ellipsoidal concretions, many of which are 3 to 4 inches long, consisting of chlorite-biotite-vermiculite pods in a granular quartz matrix cemented by quartz and carbonate minerals. An abundance of micaceous greenish-gray concretionary quartzite, therefore, is diagnostic of the lowest member of the Prichard formation. Light-gray to white magnetite-speckled quartzite that is laminated and about 10 feet thick occurs only in this member; however, parts of these layers have silt-sized particles, and a small exposure of this siltite could easily be confused with similar siltite in the Burke formation.

LAMINATED ARGILLITE MEMBER

The laminated argillite member of the Prichard formation is 2,000 to 2,200 feet thick and consists principally of interlaminated white or pale-green and black flaggy argillite. The dark laminae are argillite, and the light laminae are argillite or silty argillite. Scattered through the lower part of the unit are a few beds of micaceous greenish-gray quartzite that are generally less than 10 feet thick. The upper part of the unit contains a few thin beds of dark-gray siltite. Thus, this member is a very thick sequence of nearly pure argillite. The best exposures of this member are on the spurs and valley walls about halfway between Lightning Creek and Scotchman No. 2 (pl. 1).

The upper contact has been placed at the bottom of the lowest thick layer of dark-gray siltite.

The argillite member is distinguished from the other members of the Prichard formation by its relative homogeneity. Except near its contacts, it contrasts sharply with the nonhomogeneous units above and below. Black and white or green argillite in the Prichard formation differs from similar rocks in the Wallace, Striped Peak, and Libby formations in that (a) adjacent pairs of laminae in the Prichard are nearly always gradational, (b) the Prichard is evenly laminated whereas the younger rocks are commonly thinly and unevenly laminated, (c) light colored laminae in the younger formations are commonly carbonatic siltite, and (d) the younger rocks at many outcrops contain deformed mud-crack casts unknown in the Prichard.

ARGILLITE AND SILTITE MEMBER

The upper member of the Prichard formation is transitional between the middle member and the Burke formation. The entire member consists of alternating layers of laminated black and white or green argillite and very thin bedded dark-gray siltite; the siltite layers gradually increase in number toward the top of the unit. Particularly good exposures of this member can be seen between Goat Mountain and Scotchman Peak, as well as on the lower part of the south spur of Scotchman Peak (pl. 1). The thickness of this member ranges from 800 to 1,000 feet, depending mainly on where the lower contact is placed.

The upper contact can be readily identified at the base of the lowest layers of dark-gray siltite that are 70 to 100 feet thick, in contrast to the layers in the transition zone that are only 20 to 30 feet thick.

BURKE FORMATION

The Burke formation, consistently about 3,200 feet thick, is mainly dark-gray siltite interlayered with gray-green silty argillite (pl. 2). Layers of each of these rock types range in thickness from 1 to 100 feet, but average about 10 feet. Beds are generally less than 1 inch thick, but outcrops weather into rounded flaggy to slabby units that are 2 to 12 inches thick. The dark-gray siltite of the Burke formation consistently has a light clear-gray rind in weathered outcrops, which distinguishes it from any other siltite in the Belt series of the Clark Fork quadrangle. The lower part of the formation contains a few thin layers of laminated black and white argillite, the middle and upper parts contain a few layers of thinly laminated argillitic quartzite as much as 10 feet thick, and the upper part contains a few layers of white or light-gray thinly laminated or thinly cross-laminated quartzite as much as 4 feet thick. Purple streaking, some of which is confined to the outer one-sixteenth inch of weathered outcrops and is not everywhere parallel to bedding, is common in the coarser grained beds of the formation. The Burke formation is well exposed on the ridgetops and mountain peaks east of Lightning Creek, especially between East Fork Peak and Savage Mountain (pl. 1).

The upper contact is placed at the base of a thick layer of white to buff, blocky, very thinly crossbedded quartzite that is typical of the Revett quartzite. Below the contact are a few layers of thin-bedded or very thinly crossbedded quartzite, 1 to 4 feet thick, that are similar to part of the Revett quartzite but that are interlayered with the typical dark-gray siltite of the Burke.

The Burke formation is readily distinguished from other Belt rocks by the interlaying of distinctive dark-gray, but light-gray-weathering, siltite with gray-green silty argillite or purple-streaked argillitic quartzite.

REVETT QUARTZITE

The Revett quartzite is about 2,000 feet thick and consists of white to gray or buff, blocky, thin-bedded or very thinly crossbedded quartzite interlayered with laminated green siltite that at places is argillitic or contains thin layers of silty argillite (pl. 2). At the base, near the middle, and at the top of the formation are layers of blocky very thinly crossbedded quartzite that are as much as 200 feet thick; most of the quartzite, however, is in layers about 20 feet thick that alternate with siltite layers also about 20 feet thick. Some of the quartzite is streaked with purple, most of it contains abundant octahedra of magnetite, and a very small amount of it has black laminae and lenses of heavy minerals. The formation at a few outcrops is slightly calcareous or dolomitic. Excellent exposures of this formation can be seen on the ridge crests and cirques at the head of Sparr Creek and in a nearly complete section through the formation exposed in roadcuts along U.S. Highway 10A at the west end of Howe Mountain (pl. 1).

The contacts have been selected to include all the thick layers of white to buff blocky very thinly crossbedded quartzite. The upper contact is placed at the top of the highest layer of this quartzite. Care is required in identifying the upper contact because the upper layer of quartzite is underlain by about 150 feet of irregularly bedded purple or green interlaminated argillite and siltite that is similar to much of the St. Regis formation. Below these beds similar to the St.

Regis is about 100 feet of interlayered white quartzite and green siltite that is underlain by another thick layer of quartzite. In areas of poor exposure the contact between the Revett and St. Regis could mistakenly be placed between the beds similar to the St. Regis near the top of the formation and the uppermost of the middle quartzites.

The Revett quartzite has some diagnostic sedimentary structures. Its very thin crossbedding within layers 2 to 3 feet thick is unique in the Clark Fork quadrangle. Unique, too, are some features of the blocky quartzite where it is not crossbedded. Much of the rock is a mass of wedge- or lens-shaped layers which have a maximum thickness of about 3 feet. The thicker quartzite layers are also characterized by the presence of sparse contorted cylindrical masses, 1 to 2 feet in diameter, that have an irregularly layered internal structure which resembles a jelly roll; these masses probably were layers of thin-bedded sandstone that slumped, or were rolled by storm waves, when the beds were only partly consolidated.

ST. REGIS FORMATION

The St. Regis formation consists mostly of flaggy irregularly interlaminated purple or green argillite and green siltite which alternates with laminated but blocky purple or green argillitic siltite that has scattered argillite partings (pl. 2). The interlaminated argillite and siltite layers are a few inches to several tens of feet thick and are interlayered with argillitic siltite layers that have a similar range in thickness. In general, siltite is more abundant near the base and argillite more abundant near the top of the formation, although both varieties appear in most outcrops that expose at least 20 feet of section. The upper part of the formation is dolomitic or sideritic at many places. Mud cracks, ripple marks, and mud-chip breccia are common throughout. A complete section of the St. Regis formation is exposed in roadcuts along U.S. Highway 10A at the west end of Howe Mountain (pl. 1).

The thickness of the St. Regis formation ranges from 600 to 1,100 feet. The formation thins to the north; the thickest section is exposed on the west end of Howe Mountain and the thinnest on the ridges and cirque walls south and east of Little Sparr Lake (pl. 1).

The upper contact has been placed at the base of the lowest waxy green argillite in the basal member of the Wallace formation. The St. Regis formation contains, therefore, only argillite or siltite beds, and it contrasts sharply with the quartzite-bearing formation below and the limestone- and dolomite-bearing formation above.

Much of the St. Regis formation is distinctly purple or has a marked purplish cast. This color has been used by some geologists as an aid in identifying the unit. The purple color is characteristic of the St. Regis formation in most of the Clark Fork quadrangle; however, in some places, such as in the exposures on the spur southeast of Wiggletail Creek (pl. 1), much of the formation is green and other parts show only scattered purplish blotches, some of which cross bedding planes. A few layers in the upper part of the Revett and in the lower part of the Wallace also have this same distinctive purple color. Thus, purple color is neither limited to, nor consistent throughout, the St. Regis rocks in this area, and therefore is not regarded as a definitive feature.

WALLACE FORMATION

The Wallace formation is about 10,200 feet thick and is the principal carbonate-bearing formation of the Belt series in the quadrangle. The formation is here subdivided into five members, all of which contain beds that are markedly calcareous or dolomitic (pl. 2). In the southwest corner and at the middle of the east side of the quadrangle (pl. 1) the Wallace formation has not been divided, because structural complexities and (or) lack of outcrop do not allow specific identification of members. Rock types, in order of decreasing abundance, are (a) black and white or green thinly interlaminated argillite and siltite; (b) green siltite commonly very thinly interbedded with argillitic green siltite; (c) blue-gray laminated dolomitic limestone; (d) greenish-gray very thin bedded dolomitic or calcareous siltite and dolomitic or calcareous argillitic siltite; (e) black laminated silty argillite; (f) white laminated dolomitic quartzite; and (g) laminated waxy green argillite. Good exposures of the Wallace formation occur in roadcuts along the south side of Howe Mountain and on the spurs on the east side of Johnson Creek (pl. 1).

LOWER CALCAREOUS MEMBER

The lower calcareous member of the Wallace formation consists of a lower part that is transitional to the St. Regis formation, and an upper part that is mostly limestone or greenish carbonate-bearing siltite and argillite. About a dozen beds of waxy green argillite, each about 6 feet thick, occur in the lower 200 feet of this member, and beds of dolomitic white quartzite that generally are about a foot thick are scattered sparsely through the lower 1,000 feet. The best exposure of this unit is in roadcuts along U.S. Highway 10A on the south side of Howe Mountain (pl. 1). Its thickness on the west end of Howe Montain is about 2,500 feet.

In the lower part of the member are interlayered waxy green argillite, green carbonate-bearing siltite, irregularly laminated purple argillite and siltite, and sparse white dolomitic quartzite. Purple beds like those of the St. Regis formation are limited to the lower 100 feet. From about 500 feet above the base to the top of the member, the beds are mostly interlayered blue-gray dolomitic limestone and greenish-gray very thin bedded carbonate-bearing siltite. About 100 feet below the top of the member, beds of black argillite thinly interlaminated with green or white silty argillite appear, and increase in abundance upward. The contact with the overlying argillite member is placed approximately where about half the layers are dolomitic limestone or siltite and half are black and green argillite.

Two kinds of rock help identify this map unit. The green argillite near the base has a distinct conchoidal fracture and a waxy appearance that is unlike that of any other rock in the Belt series. The blue-gray dolomitic limestone layers commonly have irregular patches and veinlets of dark-blue calcite in a 3-dimensional swirled pattern. Differential weathering removes the calcite and leaves a surface that has swirled furrows; this surface resembles the bumps and furrows on the molar teeth of elephants, whence the name "molar tooth" structure or "molar tooth" limestone. "Molar tooth" limestone is limited to the Wallace formation and, within the formation, occurs only in the lower and upper calcareous members.

ARGILLITE MEMBER

The argillite member of the Wallace formation consists mainly of black argillite, either in thick sequences or thinly interlaminated either with green silty argillite or with white silty argillite or siltite. All the rock types are slightly calcareous or dolomitic. The best exposures are in roadcuts along U.S. Highway 10A on the south side of Howe Mountain and along a new logging road on the west side of Johnson Creek near the mouth of the creek (pl. 1). The thickness of the member on the south side of Howe Mountain is about 2,800 feet.

The upper contact has been selected within a transitional zone, about 200 feet thick, where the black argillite and silty argillites begin to be interlayered with beds of green, slightly calcareous or dolomitic, argillite or siltite about 6 to 8 feet thick, and with beds of green argillitic or silty dolomitic limestone of similar thickness.

The argillite member is easily recognized in large exposures because of the abundance of black argillite. In small exposures, the unit can be mistaken for any other map unit that contains much thin-bedded black argillite; the other units include the member above it, the member at the top of the Wallace formation, and parts of the Striped Peak and Libby formations.

ARGILLITE, SILTITE, AND LIMESTONE MEMBER

The third member of the Wallace formation consists of a sequence of alternating layers that average about 20 feet thick. The principal rock types are green calcareous argillite or siltite, interlaminated black argillite and olive or white siltite, and green to tan silty dolomitic limestone or dolomitic siltite. A few thin beds of oolitic limestone occur in this unit. The best exposures of this member are on the spurs on the east side of Johnson Creek (pl.).

The thickness of this member is the least certain of all the Belt map units. Not only are the contacts difficult to identify, but also nowhere in the quadrangle is an unfaulted section of this member exposed. The minimum thickness estimated after reconstructing prefault bedding attitudes is about 3,500 feet.

The argillite, siltite, and limestone member contains, throughout its thickness, layers of rock that are similar to rocks that are abundant in, and characteristic of, the overlying and underlying members. The upper transition zone is about 300 feet thick, and the contact between the argillite, siltite, and limestone member and the overlying upper calcareous member is placed about in the middle of this zone. Here, dolomitic limestone and carbonate-bearing siltite become more abundant than black argillite.

The argillite, siltite, and limestone member has no small scale features that are distinctive. The member can be identified positively only in large exposures where the interlayering of the various rock types is apparent. Nevertheless, the gross aspect of the member is markedly different from that of the black argillite member below and the highly calcareous member above; so it is a useful though troublesome map unit.

UPPER CALCAREOUS MEMBER

The upper calcareous member of the Wallace formation consists principally of blue-gray laminated dolomitic limestone, much of which has molar-tooth structure; it also includes greenish-gray to bluish-gray very thin bedded carbonate-bearing siltite and laminated green calcareous argillite. The color of the siltite and argillite is related to the abundance of carbonate minerals; the blue rocks have more carbonate minerals than the green rocks. At many outcrops the siltite and argillite are interbedded in layers that range in thickness from ¼ to 1 inch. Good exposures of this member can be seen in roadcuts along U.S. Highway 10A at the southeast end of Howe Mountain (pl. 1). The thickness of this member in the area between Derr and Johnson Creeks is about 1,000 feet.

The upper 50 feet of this member consists of beds of blue-gray dolomitic limestone interlayered with beds of thinly laminated black argillite and white siltite. The contact is placed at the top of this interlayered zone.

The upper calcareous member of the Wallace formation is similar to the upper 1,500 feet of the lower calcareous member and cannot be distinguished from it in outcrop. Both of these members contain "molar tooth" limestone, which is limited to these two map units. Determining which calcareous member of the Wallace formation is exposed in a given outcrop depends upon detailed mapping.

LAMINATED ARGILLITE AND SILTITE MEMBER

The laminated argillite and siltite member of the Wallace formation is mainly black argillite thinly interlaminated with green siltite or white calcareous siltite. Scattered throughout the upper part of the unit are lenses as much as 3 feet thick and pods as much as 6 inches thick containing green argillitic siltite. Cross sections of the pods are strikingly similar to cross sections of what Granger and Raup (1959, p. 437; fig. 55) called pseudochannels in the Dripping Spring quartzite of Precambrian age in Arizona. Near the top of this member are a few beds of blue-gray dolomitic limestone that are 2 to 20 feet thick and a few beds of dolomitic stromatolites that average about 1 foot thick. Bedding planes in the laminated argillite and siltite are wavy owing, at least in part, to differential compaction and bending around siltite lenses and pods and around stromatolite colonies. Deformed mud-crack casts (Bradley, 1930) are abundant at many outcrops. This member is well exposed in road and railroad cuts on the west end of Antelope Mountain (pl. 1), where it is about 400 feet thick.

The upper contact is placed at the top of the highest thinly laminated black argillite and siltite layer. Layers of green argillitic siltite occur both above and below the contact and define a zone of transition between the Wallace and the overlying Striped Peak formations.

The laminated argillite and siltite member of the Wallace formation cannot be distinguished in outcrops from other similar units of the Belt series. Positive identification of this member depends upon detailed mapping of the stratigraphic section.

STRIPED PEAK FORMATION

The Striped Peak formation consists of about 2,000 feet of red and green quartzite, argillite, and siltite, and light-gray silty dolomite (pl. 2). The formation is divided into four members which, from the base to the top, are (a) argillite, siltite, and quartzite member; (b) a dolomite member; (c) a laminated argillite and siltite member; and

(d) a quartzite member. Ripple marks, mud cracks, mud-chip breccia, and salt casts are more common in this formation than in any other rocks in the quadrangle.

In the Clark Fork area, Anderson (1930, 1947) mapped all Belt rocks above the Wallace formation as Striped Peak formation. In the Libby quadrangle, Gibson (1948) subdivided the Belt rocks above the Wallace formation into the Striped Peak formation and the overlying Libby formation. We have followed Gibson and have placed the contact at the top of a prominent red arkosic quartzite.

Excellent exposures of the Striped Peak formation can be seen on Antelope Mountain and on the spurs on the north side of the West Fork of Elk Creek (pl. 1).

ARGILLITE, SILTITE, AND QUARTZITE MEMBER

The argillite, siltite, and quartzite member of the Striped Peak formation is about 600 feet thick and can be subdivided in a few places into three distinct rock units. But at most places the subdivisions cannot be mapped accurately and all three are placed in a single member. The lower 150 feet consists of red and green coarse siltite interlayered with laminated green siltite and red argillite. The layers are from 3 to 15 feet in thickness. The middle 150 feet of the member is mainly thin-bedded but slabby red to pink quartzite that is interlayered with laminated red argillite in beds that range from paper thin to 2 feet thick. Some thin layers in the quartzite contain carbonate minerals that weather tan, so that some outcrops are striped red and tan. Large detrital (?) muscovite flakes are conspicuous on bedding surfaces in the quartzite. The upper 300 feet of the member consists of laminated but blocky red, bluish-purple, and dark-green argillite, silty argillite, and argillitic siltite. Some of the silty layers are cross laminated and (or) calcareous. The upper part of this upper unit characteristically contains small vugs that are filled by quartz and calcite. Red argillite partings in green argillitic siltite commonly show salt casts. At a few outcrops on the west side of Buckskin (Blackskin) Creek the apparently massive blocky bluish-purple argillite weathers to a thinly laminated pink and green blocky argillite. One thin stromatolite bed occurs in the lower part of the red and green argillite. Good exposures of this member can be seen in roadcuts and cliffs along U.S. Highway 10A on the south side of Antelope Mountain (pl. 1).

The upper contact is placed at the top of the uppermost bed of red and green argillite in the middle of a zone of transition about 50 feet thick between this member and the overlying dolomite member.

Several features of this member are aids in identifying it. The quartz-calcite vugs and salt casts in the upper part of the member have been seen only in this map unit. The red arkosic quartzite in the middle of this member is found only in the Striped Peak formation, but similar quartzite also forms the upper member of the formation. Identification of members is readily determined, however, if rocks overlying or underlying the red arkosic quartzite can be seen, because laminated black and white argillite and siltite occurs just above and below the red arkosic quartzite of the upper member but not of the lower member (pl. 2).

DOLOMITE MEMBER

The dolomite member of the Striped Peak formation consists of blue-gray to tan dolomite and dolomitic limestone, greenish- or bluish-gray silty dolomite, and green dolomitic siltite. Most of the rock is very thin bedded, but slabby to blocky. Much of it is dolomitic siltite thinly interbedded with silty dolomite, and it commonly has films of quartz along closely spaced joints that are at a large angle to the bedding. The quartz films and some of the siltier thin beds resist weathering and form a distinctive network or boxwork on many outcrops. A few thin beds of stromatolites or oolites are scattered throughout this member. Most of the rocks weather readily to a brown powdery soil containing scattered rock fragments. Good exposures are scarce; the best of these are along a logging road (constructed in 1952) that switchbacks down the head of Dry Creek and joins the Dry Creek road to the road junction at Delyle Campground (pl. 1). The thickness of the dolomite member on the northeast end of Delyle Ridge and on Antelope Mountain is about 400 feet.

Because the dolomite weathers so readily, its contacts in most places must be mapped on the basis of float and color of soil. The upper contact is placed at the top of the highest dolomite layer in a zone about 50 feet thick that is transitional to the overlying laminated argillite and siltite member.

The dolomite member of the Striped Peak formation is similar to much of the rock in the lower and upper calcareous members of the Wallace formation. At some outcrops the dolomite of the Striped Peak shows boxwork structure not seen in the calcareous members of the Wallace, but at most places the dolomite member of the Striped Peak must be distinguished by its stratigraphic position.

LAMINATED ARGILLITE AND SILTITE MEMBER

The laminated argillite and siltite member of the Striped Peak formation is about 300 feet thick and consists principally of black argillite interlaminated or thinly interlaminated with olive to white siltite. At a few outcrops the white siltite is slightly calcareous. At some places the black argillite laminae are partings in very thin bedded siltite or argillitic siltite. Good exposures of this member occur on the northeast end of Delyle Ridge and on the spurs north of the West Fork of Elk Creek (pl. 1).

The contacts are placed so that this member contains only laminated argillite and siltite. The upper contact is placed at the bottom of the lowest quartzite layer in the upper transition zone, which is about 50 feet thick.

In a small outcrop, rocks of this member of the Striped Peak formation can be mistaken for rocks of the Wallace or Libby formations.

QUARTZITE MEMBER

The quartzite member of the Striped Peak formation consists mainly of distinctive red arkosic quartzite that is very thin bedded to laminated, flaggy to slabby, and contains partings and thin interlayers of thinly laminated red argillite. Detrital(?) muscovite flakes are scattered throughout the quartzite and are particularly abundant on bedding surfaces. Some of the quartzite layers are cross laminated, and many are pink or thinly banded red and white on a fresh surface. Interlayers of green micaceous quartzite and some green argillite and siltite occur at the top and bottom of the member. This green quartzite has an average grain size of fine sand and is the coarsest grained relatively unmetamorphosed rock of the Belt series in the quadrangle. The member is resistant to erosion, and good exposures can be seen almost everywhere that it has been mapped in the quadrangle. Complete sections are well exposed on some of the spurs north of the West Fork of Elk Creek and on the east valley wall of the main southward-trending fork of Dry Creek (pl. 1).

The thickness of the quartzite member ranges from about 650 to about 700 feet. This difference appears to depend on the amount of green quartzite and argillite at the base, which is about 50 feet in the Antelope Mountain area but about 100 feet in the Elk Creek area.

The contact between the quartzite member and the overlying Libby formation is exceptionally distinct. The upper 10 feet of the quartzite member is micaceous green quartzite, readily distinguished from the basal rocks of the Libby formation, which consists of green quartzite and siltite interlayered with laminated black argillite and white siltite.

The red arkosic quartzite of the Striped Peak formation is not like any other Belt rock. This quartzite occurs both in the middle part of the basal member and in the uppermost member. An easy way of recognizing the two has been described for the Striped Peak formation in this report. (See "Argillite, Siltite, and Quartzite Member.")

LIBBY FORMATION

The part of the Libby formation exposed in the Clark Fork quadrangle consists of laminated black argillite and white siltite, green to gray cherty argillite and siltite that contain carbonate minerals, green to tan silty limestone and dolomite, and a few thin beds of calcareous and cherty stromatolites and oolites (pl. 2). Mud cracks and ripple marks are abundant throughout the formation, and mud-chip breccia is characteristic of the carbonate-bearing siltites and argillites. Chert occurs as pale-green layers and lenses in laminated green argillite and siltite, as pale-green chips in some of the mud-chip breccias, and as black layers or irregular patches that cut across layering in the stromatolites and oolites. Oolites, where present, are in beds just below beds of stromatolites.

Three members of the Libby formation have been mapped: (a) the laminated argillite and siltite member; (b) the calcareous member; and (c) the argillite, siltite, and dolomite member.

Only about 1,800 feet of the formation is exposed in the Clark Fork quadrangle, but Gibson (1948, p. 18) reported at least 6,000 feet of the formation in the Libby quadrangle. The top of the formation has been removed by erosion in both quadrangles. Excellent exposures can be seen on Antelope Mountain and on the east valley wall of the main southward-trending fork of Dry Creek (pl. 1). A small quarry on the north side of U.S. Highway 10A about half a mile west of the Carpie mine yields good samples of nearly all varieties of rock in the Libby formation as well as excellent samples of stromatolites and oolites.

LAMINATED ARGILLITE AND SILTITE MEMBER

The laminated argillite and siltite member of the Libby formation is about 230 feet thick and consists of black argillite thinly interlaminated with olive or white siltite that is locally argillitic or slightly calcareous. Deformed mud-crack casts, thin cross-lamination, and graded or interrupted graded bedding are common in this rock. Near the top are a few layers of carbonate-bearing gray siltite and a few thin beds of stromatolites. Some of the best exposures are in cuts along the Northern Pacific Railway tracks about half a mile west of Cabinet, Idaho (pl. 1).

This member includes all the laminated black argillite and white siltite in this part of the stratigraphic sequence. The upper contact is placed at the top of a transition zone about 30 feet thick that contains interlayered beds of stromatolites, gray carbonate-bearing siltite, and interlaminated black argillite and white siltite.

This member, which is similar to other black-and-white sequences in the Belt series, can only be identified because of its stratigraphic position above the distinctive red arkosic quartzite member of the Striped Peak formation.

CALCAREOUS MEMBER

The calcareous member is about 600 feet thick and consists principally of cherty argillite and siltite, silty limestone and dolomite, and a few thin beds of stromatolites and oolites. The cherty argillite and siltite is gray to green, very thin bedded but slabby, and is commonly calcareous. The silty limestone and dolomite is green but weathers tan and is commonly interlayered, in beds a few feet thick, with the cherty argillite and siltite. Most of the stromatolites and oolites are black or mottled bluish black and white; all of them are calcareous and cherty. Mud cracks, ripple marks, and mud-chip breccia are common. Pale-green chert in the very thin bedded argillite and siltite has the same appearance in hand specimen as much of the green argillite, but it can be identified readily by a scratch test. This member is well exposed in cliffs along U.S. Highway 10A west of the Carpie mine (pl. 1).

The contacts are placed to exclude laminated black and white rocks from the calcareous member. The upper contact is placed at the base of the lowest laminated black argillite and white siltite layer in the upper transition zone. About a dozen beds of stromatolites occur in the upper 50 feet of the calcareous member and the lower 100 feet of the overlying argillite, siltite, and dolomite member. These beds, which are as much as 3 feet thick, are actually lenses that pinch out or become isolated small colonies in the same stratigraphic interval. Whether or not the beds occupy identical stratigraphic positions from outcrop to outcrop could not be determined, but it is certain that they are in approximately the same interval. Many of the stromatolite beds have oolitic layers just beneath them, but the stromatolite beds are more persistent than the oolitic ones. The abundance of stromatolite and oolite beds in the transition zone is an aid in locating the contact between the middle and upper members of the formation.

The only Belt rocks in the quadrangle that contain abundant chert are in the middle and upper members of the Libby formation, but the upper member also contains layers of laminated black argillite and white siltite and can thus be distinguished from the middle member.

ARGILLITE, SILTITE, AND DOLOMITE MEMBER

The argillite, siltite, and dolomite member of the Libby formation consists of interlayers of the rock types characteristic of the lower and middle members of the Libby formation. This upper member includes layers of laminated black argillite and white siltite, green to gray, calcareous or cherty, very thin bedded to laminated argillite and siltite, silty limestone and dolomite, and a few layers of stromatolites and oolites. These rocks have the small-scale sedimentary features described for similar layers in the lower and middle members. The upper member is not well exposed; among the better exposures are those on Antelope Mountain and in the steep cliffs a few hundred feet north of the Carpie mine (pl. 1).

The top of the Libby formation has been removed by erosion. The thickest exposure of the remaining part of the upper member is on the east side of the main southward-trending fork of Dry Creek where the thickness is about 1,000 feet.

The argillite, siltite, and dolomite member contains chert, which serves to distinguish it from members of other Belt formations. Because the upper member of the Libby formation consists of interlayers of rocks characteristic of both the lower and middle members, the upper member can easily be mistaken in small outcrops for either of the other two members and can be positively identified in outcrop only where the exposure is large enough to show the characteristic interlayering.

SURFICIAL DEPOSITS

Surficial deposits in the area are presumably of Quaternary age and include deposits of glacial, glaciofluvial, glaciolacustrine, and alluvial origin. These deposits are in a variety of forms and contain rock fragments that range in size from boulders to clay. The most abundant type of deposit is composed of poorly to moderately well sorted and stratified silt, sand, and gravel. Such deposits fill much of the valley of the Clark Fork River (pl. 1).

GLACIAL DEPOSITS

Deposits of glacial origin in the area include till, outwash, and moderately well-sorted even-bedded to crossbedded silts, sands, and gravels that probably were deposited in Glacial Lake Missoula (Pardee, 1910). The till, on the north side of the Hope fault, forms sheets covering most of the high valley floors and the valley walls for a few hundred feet above the floor. Little Sparr, Still, and Porcupine Lakes are dammed by moraines. Till, in the form of a creeping deposit, occurs on the south valley wall of the East Fork of East Fork Creek; the trail to Scotchman No. 2 leaves the creek level and climbs about 800 feet through uprooted trees and moist hummocky surficial debris on this deposit.

Glaciofluvial and glaciolacustrine deposits fill most of the valley of the Clark Fork River as well as the lower parts of many valleys tributary to the Clark Fork. The silts, sands, and gravels that make up these deposits are several hundred feet thick at places. A series of terraces has been cut in these deposits in the Clark Fork valley; the highest terrace remnant is at 3,400 feet, which is about 1,200 feet above the level of the Clark Fork River. Most of the major stream valleys contain at least remnants of these deposits to at least 3,400 feet in altitude along their courses. The streams are currently cutting down to their prefill level by removing the debris deposited in them when the valleys were inundated by Glacial Lake Missoula. A 2,800-foot terrace level is represented by terraces in the Clark Fork valley and by gravel fill along Johnson Creek.

The 4,200-foot level of Glacial Lake Missoula, a level that has been identified and studied by Pardee (1910) near Missoula and downstream for many miles, is not apparent in the Clark Fork quadrangle. Alden (*in* Gibson, 1948) has suggested that a lobe of ice accompanying continental glaciation moved up the Clark Fork valley and formed an ice dam for Glacial Lake Missoula "near the Idaho-Montana line." If this is so, no wave-cut benches such as those at Missoula could have formed in the Clark Fork area. Hanging valleys along Blue Creek at altitudes of 4,400 to 4,600 feet record the presence of ice at high levels near the Idaho-Montana line and perhaps support Alden's concept of a high dam for Glacial Lake Missoula near that area. The few places in the Clark Fork valley where glacial striae are accompanied by pluck structures to give evidence of ice movement, however, record motion from north of the Hope fault into the Clark Fork valley and westward in the valley toward Lake Pend Oreille. These striae are only a few hundred feet above the present level of the Clark Fork River, and they may record ice movement of an alpine stage of glaciation that is younger than the main stage of Glacial Lake Missoula. An alternative explanation is that the valley glaciers from north of the Hope fault actually contributed the ice that formed the dam of Glacial Lake Missoula. Further detailed examination of the surficial deposits in the area is required before any conclusion can be drawn regarding this point.

ALLUVIAL DEPOSITS

The alluvial deposits are mainly deltaic deposits and valley alluvium reworked from the glacial deposits. The deltaic deposits are in the valley of the Clark Fork River, which enters Lake Pend Oreille just west of the quadrangle. The reworked glacial debris occurs in the bottom of the U-shaped valley of Lightning Creek in the Cabinet Mountains and along its braided channel between the front of the Cabinet Mountains and the Clark Fork River. Reworked glacial debris also forms small cones and fans at the base of the steep mountain fronts that bound the Clark Fork valley at points where a number of the steep mountain streams enter the relatively flat valley of the Clark Fork.

IGNEOUS ROCKS

Igneous rocks in the quadrangle are all intrusions. They include quartz diorite of Precambrian(?) age, granodiorite and related rocks of Cretaceous(?) age, and diabase of Cretaceous(?) age. The most abundant and widespread are the granodiorite and related rocks.

QUARTZ DIORITE

Three sills of quartz diorite intrude the lowest member of the Prichard formation in the northwest corner of the quadrangle (pl. 1). The rock is medium to coarse grained, greenish black or mottled greenish black and white. It consists principally of hornblende, plagioclase, quartz, and biotite, with minor amounts of potassium feldspar, calcite, sphene, apatite, pyrite, and magnetite.

The age of the quartz diorite is not certain. Schofield (1914) and most later workers believe that the rocks are equivalent to the Purcell lava and are, therefore, Precambrian; Clapp (1932, p. 28) suggested, however, that some of these diorite masses may be late Mesozoic in age. Pending radiometric age determinations, a Precambrian age is tentatively accepted for these rocks.

GRANODIORITE AND RELATED ROCKS

The granodiorite and related rocks consist of fine- to coarse-grained, gray to mottled black and white granodiorite, gray and white granodiorite porphyry, and a small amount of white pegmatite. The granodiorite and granodiorite porphyry consist principally of andesine, quartz, microcline, biotite, and hornblende; the pegmatite consists principally of plagioclase, quartz, and microcline. The granodiorite porphyry has a granophyric groundmass, and much of the fine-grained gray granodiorite is either granophyre or granophyric. These rocks have internal structure in places, as shown by planar alinement of tabular feldspar crystals and streaks of mafic minerals in the coarser grained rocks and by planar alinement of biotite flakes and hornblende needles in the finer grained rocks.

The largest body of coarse-grained granodiorite is an oval plug about 2½ miles long and 1½ miles wide in the valley of Lighting Creek (pl. 1). This body has a few pegmatite dikes at its margin. The internal structure is generally steep and markedly discordant to the general attitude of the enclosing Prichard formation, which has been deformed into a series of small folds that wrap around the plug.

Within about 700 feet of the plug the host rocks are hornfelsed; some are spotted with clots of coarse-grained biotite, and some have developed a gneissic structure that has partly or completely destroyed the bedding but is subparallel to it.

A small knob of coarse-grained granodiorite sticks out through glacial debris about halfway between Antelope and Sugarloaf Mountains (pl. 1). This small exposure is atypical because it is cut by a vein and is deeply weathered.

The fine- to medium-grained gray granodiorite forms a series of pinch-and-swell sills, only a few of which are mappable. The sills range in thickness from about 6 to about 20 feet. All the sills seen are north of the Hope fault. The most persistent and thickest is the middle of the upper member of the Prichard formation; this sill caps Goat Mountain and can be traced almost continuously south to the Hope fault and north to the fault in the valley of the East Fork of the East Fork Creek. The rocks within a few feet of the sills are hornfelsed.

The granodiorite porphyry, in sills generally less than 3 feet thick, crops out mainly on Bee Top Mountain. These sills show no noticeable metamorphic effects on the enclosing rocks of the Prichard formation.

DIABASE

Dark-green or greenish-black, fine- to medium-grained diabase forms small dikes and sills in the quadrangle. Most of the rock is altered, consisting principally of chlorite, biotite, calcite, sericite, and some augite. According to Anderson (1947, p. 48), the fresh rock is mainly labradorite and augite. All the samples we collected have at least traces of relict diabasic texture, which may explain why Anderson (1930), who originally called these basic rocks lamprophyres, later (1947) called them diabase.

The diabase sills and dikes generally are less than 10 feet thick and, because they are altered and easily weathered, are difficult to trace. Perhaps 30 small outcrops have been seen, but only the two shown on the geologic map (pl. 1) were traced for more than a few feet. The diabase described by Anderson (1947, p. 48, 96) along the Dike fault in the workings of the Hope Mine crops out at three places along the surface trace of the mineralized fault; two of these are in small exposures on the hillside north of Mosquito Creek and the third is in a bulldozer cut on the south end of Sugarloaf Mountain. Anderson (1930, p. 36) noted that the basic dikes cut outcrops of granodiorite in the Purcell trench and the Cabinet Mountains.

The diabase is younger than the granodiorite; otherwise, its age is uncertain. Anderson (1930) originally accepted Sampson's (1928) view that the dikes were a late stage of the granodiorite, were related in time to the metalliferous deposits of the area, and were probably Cretaceous in age. Anderson (1947) suggested that the dikes were not related to the granodiorite but still accepted their relation to ore deposition, which he suggested was early Tertiary. We have no new evidence to help solve this problem, other than to note that our reconnaissance work in the Packsaddle Mountain quadrangle corroborates the fact that diabase dikes cut granodiorite. Preferring Sampson's synthesis, we, therefore, tentatively consider the diabase to be of Cretaceous(?) age.

METAMORPHISM OF THE BELT SERIES

Study of 150 thin sections shows that all the Belt rocks are metamorphosed; most of the metamorphism seems to be regional, but some is contact metamorphism adjacent to intrusive rocks. In the least metamorphosed rocks, original clay minerals have been converted to sericite or chlorite. At somewhat higher metamorphic grade, quartz and feldspar grains have become sutured; coarse muscovite flakes, biotite flakes, and tourmaline crystals have grown across bedding planes; and laminated argillitic rocks have become slaty. The highest grade of metamorphism is shown by former argillitic rocks that are now spotted with clots or strings of clots of biotite ¼ to ½ inch in diameter and that have scattered andalusite crystals in them.

The various effects of metamorphism are unevenly distributed in the quadrangle. Most of the Belt rocks are only slightly metamorphosed, but at several places the rocks have been metamorphosed in the biotite zone. All the Prichard and Burke rocks of original pelitic composition now contain at least traces of metamorphic biotite. The highest grade rocks are in an aureole about 700 feet wide around the granodiorite plug in the valley of Lightning Creek and in an area about half a mile in diameter around the lookout on the State line southwest of Beaver Peak (pl. 1). Rocks that contain conspicuous metamorphic biotite, but that are not spotted, are widespread north of the Hope fault except in the northeast corner of the quadrangle. They are also on both sides of Twin Creek near the mouth of Delyle Creek, in outcrops within about a mile south and east of the small granodiorite exposure between Antelope and Sugarloaf Mountains, and on the west end of Howe Mountain. Because the exposed granodiorite bodies are bordered by rocks of the biotite zone, a fair inference is that each of the local areas of biotite zone rocks is also underlain by an intrusive body at relatively shallow depth (see cross sections on pl. 1), and that the biotite is a contact metamorphic product. Data are not yet sufficient to demonstrate clearly either that all the metamorphism is contact metamorphism, or that some of it in the lowest grades is of regional type. The available data suggest that contact metamorphism of the albite-epidote hornfels facies (Fyfe and others, 1958) has been superimposed on regional metamorphism of the greenschist facies that ranges from the quartz-albite-muscovite-chlorite subfacies in the upper part of the thick section of Belt rocks to the quartz-albite-biotite subfacies in the lower part.

STRUCTURE

The structural setting in the quadrangle is one of simple folds but complex fractures. The entire area is on the west flank of a large syncline, and dips of beds gradually increase from east to west away from the fold axis. Small drag folds, generally less than 50 feet across but exceptionally as large as 1 mile across, are adjacent and subparallel to faults. A few small folds surround the granodiorite plug cut by Lightning Creek. The major syncline has been offset several miles along the Hope fault, and it has been further disrupted by a series of block faults that form a block mosaic. On the south side of the Hope fault, where the mosaic is best developed, the beds tend to step down to the west and to the north. In addition, the Belt rocks are cut by a series of steep to flat faults that have been mineralized but along which movement has been only a few feet. The rocks are also broken by five conspicuous and widespread sets of joints.

FOLDS

The only major fold in the area is a syncline whose axis, south of the Hope fault, is at or near the east edge of the quadrangle. The axial region of this fold is so broad and gentle that the trace of the axial plane cannot be located closely. Disorientation of the rocks by faulting further complicates any attempt to locate the axis and determine its bearing and plunge; the amount of tilt in the fault blocks is only a few degrees, but it is enough to deflect a low dip significantly. The axis of the syncline appears to trend generally north and to be nearly horizontal or gently northward-plunging.

Small folds adjacent to faults are common. The folds indicated on the geologic map by fold symbols are all structures that can be seen and measured in a small outcrop. These folds generally are limited to within a few tens of feet of a fault, are subparallel to the fault in bearing, and plunge at low angles. In the best exposures, they are seen to be drag folds; at places, several parallel folds of low amplitude and small wavelength are adjacent to a fault. If the exposure is large enough to show the entire dragged zone, the gross attitude of the bedding can be seen as a drag structure whose motion sense is in agreement with that determined by stratigraphic offset.

Most of the dragged zones are less than 200 feet wide, but along some faults the zone of folds may be as much as 1,000 feet wide. Section *D–D′* (pl. 1) was constructed across the largest fold found in a dragged zone where the Striped Peak formation abuts against the south branch of the Hope fault. The only cleavage is in the drag-folded rocks adjacent to faults.

Small folds also occur around the margin of the granodiorite plug in the valley of Lightning Creek. Here the beds are crumpled and deflected from the regional strike and dip in a zone about 500 feet wide around the plug. This pattern of disturbance of beds combined with the steep internal structure of the granodiorite body (described above) indicates that the igneous mass was forcibly intruded into relatively coherent rocks.

FAULTS

The faults in the area are divided for convenience into the Hope fault, block faults, and mineralized faults. This division is also probably a general chronological sequence, from oldest to youngest.

HOPE FAULT

The Hope fault is a normal and strike-slip fault that strikes northwest and dips steeply southwest. It has by far the largest throw of any fault in the quadrangle, and its scarp is one of the most striking topographic features in the area. The fault splits near the point where it is crossed by Lightning Creek; the south branch probably swings more to the east at the quadrangle boundary and rejoins the main branch in the Libby quadrangle. The Hope fault is actually exposed only where the west fork of Cascade Creek enters the Clark Fork valley. This exposure is only about 30 feet wide, which is less than the full width of the broken zone along the fault at that place.

The apparent displacement along the Hope fault can be measured fairly well. The apparent horizontal displacement, based on the offset of the Revett-St. Regis contact, is about 16 miles right lateral. The apparent vertical displacement, based on offset of the contact between the argillite and siltite, and of quartzite members of the Striped Peak formation on Middle Mountain and the upper part of the argillite, quartzite, and siltite member of the Prichard formation across the fault, is about 22,000 feet; this measurement agrees with the total apparent vertical displacement between the upper part of the argillite, siltite, and dolomite member of the Libby formation unit on the south end of Sugarloaf Mountain and the contact between the laminated argillite and argillite and siltite members of the Prichard formation on the Hope fault scarp west of Blue Creek. At the Sugarloaf Mountain area the north branch of the Hope fault has about 16,500 feet of apparent vertical displacement, and the south branch has about 5,500 feet. Near the west edge of the quadrangle, the apparent vertical displacement between the St. Regis-Wallace contact on Howe Mountain and the lower part of the Prichard formation on the fault scarp is about 24,000 feet; the extra 2,000 feet of apparent displacement here is approximately equivalent to the amount of down stepping on the block faults between the east end of Middle Mountain and the west end of Howe Mountain. Gibson (1948, p. 47) reported at least the Libby quadrangle, which suggests that the two branches, which 18,000 feet of apparent vertical displacement along the Hope fault in together have a total apparent vertical displacement of about 22,000 feet in the Clark Fork quadrangle, have rejoined in the Libby quadrangle, for neither branch by itself has the minimum displacement measured by Gibson.

The Hope fault thus has major strike and dip-slip components. The amount of each cannot, however, be measured accurately. Right-lateral movement is demonstrated by the displacement of the major synclinal axis, which must have been shifted relatively east on the north side of the Hope fault. Additional faulting plus the existence of a series of synclinal axes in the Libby quadrangle make positive matching of axes impossible, though the most likely match requires a strike slip of about 8 miles. A true dip-slip movement is indicated by small-scale horizontal drag folds on the fault scarp, by a large gently plunging drag fold subparallel to the fault on Middle Mountain (see section D–D', pl. 1), and perhaps by vertical offset of 1,000 to 1,500 feet of a Cretaceous or Tertiary erosion surface represented by the difference in accordance levels of peaks north and south of the fault (Anderson, 1930; Pardee, 1950).

The age of the Hope fault is not known with certainty. It surely was in existence at the time of the block faulting, for the block fault pattern abuts against the Hope fault and in no way can be matched across it in either the Clark Fork or Libby quadrangles. The block faulting probably accompanied intrusion of the granodiorite; the early movement on the Hope fault, therefore, can be dated only as pre-Cretaceous(?) and may be as old as Precambrian(?). The high scarp near the trace of the fault suggests that a vertical movement along the fault has occurred fairly recently. We infer that the Hope fault is an old structural break along which movement has occurred at several different times. We suggest that major strike-slip movement occurred in Precambrian time and that major dip-slip movement occurred during Laramide or post-Laramide pre-Pleistocene time.

BLOCK FAULTS

One of the striking features of the geologic map is the pronounced grid pattern of small faults south of the Hope fault, and a similar but less pronounced pattern north of the Hope fault (pl. 1, fig. 3).

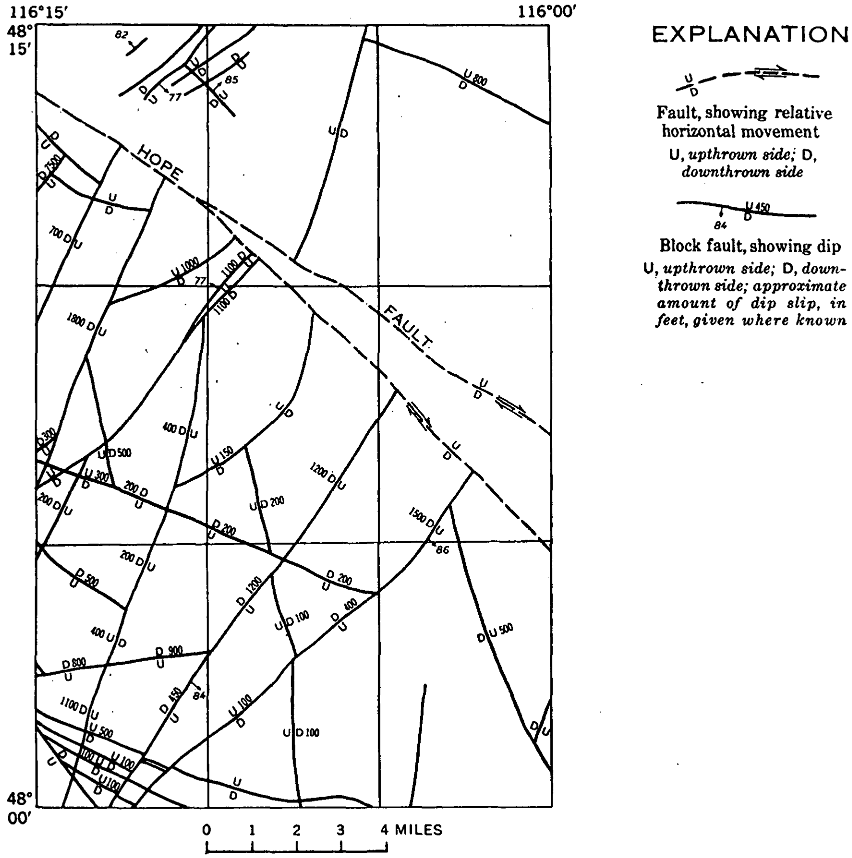

FIGURE 3.—Sketch map of block fault system.

These faults can be located and traced in the field by several of their characteristics. The faults are expressed by a zone of brecciated and gougy rock commonly 30 to 50 feet wide. This zone is soft and weathers readily so that the topographic expression of the zone is a depression, such as a notch on a spur, a saddle in a ridge, or a valley. The rock for a few tens of feet on each side of most faults is dragged into a series of shallow folds that are generally subparallel to the fault and have a low angle of plunge. Stratigraphic offset and abrupt changes of rock type are apparent across many of these faults. The faults commonly intersect at large angles, and the apparent horizontal offset, if any is present, is less than the width of the broken zones along the faults. Thus, in the best exposures of such fault intersections, two broken zones intersect and neither is appreciably offset by the other. At a few places, one block fault has noticeably offset another. At the few places where exposures permit good measurements, the faults dip 77° or more. The poorly exposed faults must also be nearly vertical in dip because the rugged topography they commonly traverse has little effect on their trend.

Block faulting is defined by Hills (1953, p. 70) as dip-slip faulting that has divided an area into a series of differentially elevated or depressed blocks; if such movement occurs on two or more sets of intersecting faults, he suggests that the pattern be called a block mosaic. The grid pattern of faults in the area fits the definition of a block mosaic, and the faults in the mosaic are here called block faults to distinguish them from other types of faults.

Differential movement of the blocks has resulted in a general stepping down of the beds from east to west and from south to north (fig. 3), although the motion of a few individual blocks was in a contrary sense. Tilting of the blocks was generally small (see sections *B–B′*, *C–C′*, and *D–D′* on pl. 1), but west of the Packsaddle fault, tilting down to the east has accented the synclinal fold structure. The attitudes of the St. Regis formation and Revett quartzite north and south of the Hope fault are markedly different. The steep dips in these formations south of the fault are not reflected in the same nor the underlying formations north of the fault. The principal reason for this difference is presumably due to eastward tilting of the blocks south of the Hope fault and west of the Packsaddle fault.

The block faults seem to be related to intrusion of the granodiorite. Sampson (1928) first recognized the relation of some of the faults to granodiorite in the Pend Oreille district where the abundance of the block faults increases over stocks, and where many blocks have either been pushed up or have foundered in the magma. He borrowed the term "intrusion faults" from Ransome (1903, 1919) to describe faults that were believed to be directly related to the intrusion of an igneous body. Sampson also used the term "post-intrusion faults" for parts of this block-fault system along which movement occurred after the granodiorite solidified or for long faults not obviously related to the granodiorite. Anderson (1930) extended Sampson's classification scheme into the Clark Fork area. Both Sampson and Anderson suggested that some of the "post-intrusion faults" probably began as "intrusion faults." We accept Sampson's and Anderson's data on the association of block faulting and known intrusive bodies as evidence of the age of "intrusion faults" in this general area, and propose to extend the concept to faults in similar patterns where no intrusive rocks are exposed. The distribution of metamorphic rocks of the biotite zone, previously described in this report, supports the idea that intrusive bodies at relatively shallow depths are scattered throughout the quadrangle. All the block faults are therefore interpreted to be intrusion faults in the sense that they represent adjustment of overlying rocks to the intrusion of an extensive mass of granodiorite, only a small part of which has been exposed by erosion. The age of the block faults is, therefore, considered the same as that of the granodiorite, which is probably Cretaceous.

MINERALIZED FAULTS

Faults that have zones of hydrothermal alteration along them or that contain ore minerals are shown on the geologic map as veins. These mineralized faults or veins include fractures that are high-angle normal or reverse faults, strike-slip faults, and low-angle reverse faults. In general, movement along these faults has been only a few feet, and the offset of contacts along them is too small to show on the geologic map. Mineralized faults are most abundant in the block-faulted ground along the south side of the Hope fault.

Anderson (1930, 1947) studied the mineralized faults in many mine workings that are no longer accessible and presented detailed descriptive data on them.

The mineralized faults as a group contrast rather sharply with the block faults. Although fractures of either group may be traced for miles, at every exposure of a mineralized fault altered country rock is strikingly apparent and contains at least traces of pyrite, chalcopyrite, or galena. By contrast, the block faults are filled by gouge and (or) mylonitic breccia and have zones of altered wallrock and sulfides only where joined or cut by mineralized faults. The style of faulting offers further contrasts: mineralized faults are both high and low angle, normal and reverse, and many have strike-slip components, but none have more than 40 feet of relative displacement; the block faults are all nearly vertical dip-slip faults with displacements generally of more than 100 feet. All this suggests that the area contains two classes of faults, and our structural synthesis is based on this interpretation.

The scant data obtained from surface mapping of the mineralized faults suggest that the faults formed after the block faulting. At the few places where veins cross block faults in surface exposures, the vein alteration cuts across the broken zone of the block fault.

The mineralized faults probably represent final adjustment of the rocks to stresses set up by movement on the Hope fault, intrusion and cooling of granodiorite, and block faulting. Anderson (1947, p. 59–60) concluded that the mineralized faults were related to a single regional stress that also formed the Hope fault. His reconnaissance map was not detailed enough to reveal the block faulting to him; consequently, he was not concerned with it in his structural synthesis, although he included some of the unmineralized block faults in his fracture-pattern analysis. The close association of intrusion of basic dikes and mineralization of faults has been stressed by Sampson (1928) and Anderson (1930), and movement on these faults is described by them as both earlier and later than the emplacement of the dikes and the ore. If the block faulting is related to the intrusion of the granodiorite, but the intrusion of basic dikes and mineralization of the faults is postgranodiorite, then probably the great variety of faults containing dikes and ore minerals (as contrasted to the single variety of block faults) are products of some stress field other than that associated with the block faulting. In addition, the great variety of mineralized fault types and the association of thrusts (compression) and normal faults (tension) suggest that a series of limited local stresses rather than one broad stress field created the jumble of strains in the rocks. We infer, therefore, that the mineralized faults are younger than the block faults, that they represent a final phase of strain associated with Cretaceous(?) intrusion of granodiorite and block faulting, and that they were formed contemporaneously with basic dike intrusion and mineralization in the area. We suggest that this last stage of adjustment was localized in blocks of rock that had been deformed previously along the Hope fault, or that were near the Hope fault as it too adjusted during or following the block faulting.

JOINTS

Joints are conspicuous in all the Belt and intrusive rocks of the area. Few joint measurements were made in the intrusive rocks that form a very small part of the exposed bedrock. Sufficient measurements of joints in Belt rocks were made to allow a brief discussion of them, and the following remarks concern only joints in the Belt rocks.

Five sets of joints are conspicuous. These are shown on the contour diagram (fig. 4) and have average attitudes of N. 40° E., 81° NW.; due north, 80° W.; N. 20° W., 75° SW.; N. 60° W., 80° SW.; and N. 87° W., vertical. These sets control the boxwork structure on weathered surfaces in the dolomite member of the Striped Peak formation. Spalling of blocks along these sets of joints has helped produce a

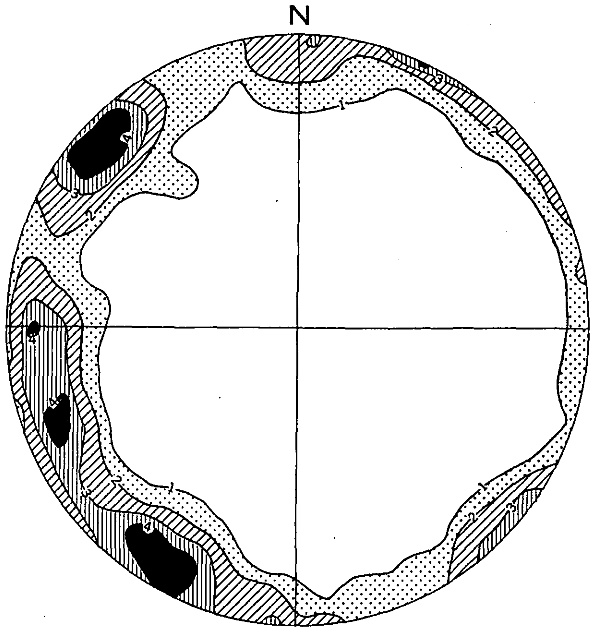

FIGURE 4.—Contour diagram of joints in Belt rocks, upper hemisphere equal-area net plot of 1,326 poles. Contoured in percentage of poles.

series of stepped cliffs along several valleys in the quadrangle; many marked lineaments on the topographic map and particularly on aerial photographs of the quadrangle are joint controlled.

Structural analysis of the joints is not feasible, because of the lack of data on major fold patterns and a consequent lack of information on which, if any, of the conspicuous joint sets are related to folding.

ECONOMIC GEOLOGY

The quadrangle contains both metallic and nonmetallic mineral deposits. The metallic deposits are in fissure fillings; the principal metals produced from these veins are lead and silver, but minor amounts of copper, zinc, and gold also have been produced. Nonmetallic deposits include sand and gravel, building stone, natural cement rock, riprap, and railroad ballast.

METALLIC DEPOSITS

The metallic deposits are in veins that occur chiefly on Howe, Middle, and Antelope Mountains—an area that is called the Clark Fork mining district. Anderson made studies of the general area (1930) and of the Clark Fork mining district (1947). Only a small amount of mining has been done since Anderson's last study, and most of the mines are now partly or completely inaccessible because of caving or flooding. The following brief description of the ore deposits is summarized largely from Anderson's reports, but it includes a few of our observations.

The veins in the quadrangle are fault fissures that contain a few shoots, stringers, and pods of sulfide ore in a quartz-carbonate gangue. Two more or less distinct kinds of veins occur in the area: lead-silver veins and copper veins. About $1.5 million worth of ore has been produced from these veins, chiefly from the lead-silver veins in the Whitedelf, Hope, and Lawrence mines. The principal metals produced are lead and silver, which occur mainly in the minerals galena, argentiferous galena, pyrargyrite, and freibergite. A minor amount of copper, gold, and zinc has come from these veins, and some copper has been produced from the veins that contain copper but little lead or silver. Lead-silver veins are concentrated primarily on the low hills around Clark Fork; copper veins, with or without small amounts of lead and silver, are scattered throughout the quadrangle.

Many of the copper veins can be identified readily in surface exposures. Some of the copper veins have a gangue of brecciated quartz, calcite, and a little feldspar, cemented by jasper; scattered through the gangue are crystals and veinlets of specular hematite, pyrite, and chalcopyrite or malachite. These vein fillings pinch and swell; the thicker parts are as much as 14 feet thick. The filling is resistant to erosion and forms ridges that are as much as 20 feet high and several hundred feet long. Even where the quartzose vein filling is thin, the altered wallrock has a red cast—presumably from disseminated specks of jasper or hematite—and much of the altered zone shows traces of copper bloom. All the veins around Cabinet, on the east end of Antelope Mountain, and in the Bitterroot Range are of this jasper-hematite type. The close association of this copper vein type with the ferruginous red arkosic quartzite of the Striped Peak formation suggests that some of the gangue and ore minerals in these veins may have been derived from the country rock.

Some of the veins are in faults that also contain diabase dikes. At most places the dikes are cut by the veins or by stringers of ore minerals, but at a few places (Anderson, 1930, p. 124) the dikes cut the veins.

The existing data on the age of faulting and intrusion of diabase have been summarized in this report in "Mineralized Faults," and "Diabase." The age and origin of the ore deposits is involved with the age and origin of the mineralized faults and the diabase. We can only repeat here that Sampson's (1928) synthesis, which suggests that the diabase and ores are a late stage of the intrusion and cooling of granodiorite, seems reasonable.

NONMETALLIC DEPOSITS

The nonmetallic deposits are construction materials of various kinds. Sand and gravel, riprap, and railroad ballast have been produced at times since 1950. Different varieties of building stone were being quarried at the time of our fieldwork. Some layers of natural cement rock in the Wallace and Striped Peak formations have never been developed.

The glacial deposits in the Clark Fork River valley afford abundant supplies of sand and gravel.

Various parts of the Wallace formation have been quarried for riprap. The argillite member has been used most extensively and has provided most of the riprap used along the Clark Fork River and its distributaries on its delta.

Both the upper member of the Wallace formation and the red arkosic quartzites of the Striped Peak formation have been crushed and used as ballast along the tracks of the Northern Pacific Railway.

Two kinds of rock have been quarried for building stone, and a third kind is a potential building stone. Black stone has been taken from the Libby formation, largely from laminated black argillite and green siltite layers in the upper member. Although many rocks similar to these layers occur throughout the Belt series, those rocks in the upper part of the Libby formation will split into slabs 2 to 3 inches thick, but those in other formations tend to split into much thinner pieces. Red stone has been quarried from the red arkosic quartzite layers of the Striped Peak formation; most of the stone has come from the upper member, but some has come from the red arkosic quartzite layers in the middle of the lowest member. The red quartzite does not split well, but many layers about 2 to 3 inches thick are sandwiched between red argillite layers or partings. The quartzite, therefore, can be quarried in slabs of convenient thickness. The clear gray siltite of the Burke formation is a slabby rock that could be used for building stone, but probably because outcrops are not accessible by road, no attempt has yet been made to use it.

Certain layers in the Wallace and Striped Peak formations meet the general requirements for natural cement. As a first measure of potential cement resources, 2 samples of the dolomite member of the Striped Peak formation and 3 samples of the upper calcareous member of the Wallace formation have been analyzed (table 3). Two of these 5 samples, 1 from the Striped Peak formation (CF–8–70) and 1 of molar-tooth limestone from the Wallace formation (CF–3–1a), fall within the chemical range of natural cements. (See Dolbear, 1949, p. 161.) Systematic sampling to determine tonnage and grade of these deposits has not been done but molar-tooth limestone, which is one variety of indicated cement rock in the area, is relatively abundant in both the upper and lower calcareous members of the Wallace formation.

TABLE 3.—*Chemical analyses of some calcareous and dolomitic rocks in the Wallace and Striped Peak formation*

[Analysts: P. L. D. Elmore, S. D. Botts, I. H. Barlow, and Gillison Chloe. Rapid rock analyses by methods similar to those described by Shapiro and Brannock (1956)]

	1	2	3	4	5
SiO_2	27.5	54.2	54.2	29.0	44.8
Al_2O_3	6.6	10.9	13.2	4.6	6.6
Fe_2O_3	.9	1.2	1.1	.9	1.6
FeO	1.4	2.5	3.1	.65	.55
MgO	3.3	5.3	6.0	14.0	9.2
CaO	30.3	8.8	5.6	18.7	12.7
Na_2O	.68	1.6	.80	.55	1.1
K_2O	1.7	2.6	3.8	1.4	1.5
H_2O	1.4	2.2	2.6	1.1	1.0
TiO_2	.23	.46	.56	.20	.29
P_2O_5	.07	.11	.14	.06	.08
MnO	.12	.08	.14	.06	.22
CO_2	26.2	9.9	8.6	28.2	19.8
FeS_2 [1]	.31	.76	.31	.43	.09
Total	101	101	100	100	100

[1] Sulfur soluble in aqua regia calculated as FeS_2.

1. Field No. CF-3-1a. Laboratory No. 155260. Molar-tooth limestone, upper calcareous member, Wallace formation; from small quarry on southeast end of Howe Mountain.
2. Field No. CF-3-1b. Laboratory No. 155261. Calcareous interlaminated green siltite and argillite, upper calcareous member, Wallace formation; same locality as CF-3-1a.
3. Field No. CF-7-28. Laboratory No. 155262. Blue-gray interlaminated dolomitic siltite and dolomitic argillite, upper calcareous member, Wallace formation; from outcrop at west edge of quadrangle along road from Summit Campground.
4. Field No. CF-8-70. Laboratory No. 155263. Blue-gray silty dolomite, dolomite member, Striped Peak formation; from botttom of spur between Dry Creek and main south branch of Dry Creek.
5. Field No. CF-9-18. Laboratory No. 155264. Gray-green interlaminated dolomitic argillite and dolomitic argillaceous siltite that shows boxwork structure, dolomite member, Striped Peak formation; from spur opposite Jacks Gulch in southeast corner of the quadrangle.

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