UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

MINERAL RESOURCES OF THE BOB MARSHALL WILDERNESS AND STUDY AREAS, LEWIS AND CLARK, TETON, PONDERA, FLATHEAD, LAKE, MISSOULA, AND POWELL COUNTIES, MONTANA

by

U.S. Geological Survey

and

U.S. Bureau of Mines

Open-file report 78-295

1978

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

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STUDIES RELATED TO WILDERNESS

In accordance with the Provisions of the Wilderness Act (Public Law 88-577, September 3, 1964) and the Joint Conference Report on Senate Bill 4, 88th Congress, the U.S. Geological Survey and U.S. Bureau of Mines have been conducting mineral surveys of wilderness and primitive areas. Studies and reports of all primitive areas have been completed. Areas officially designated "wilderness," "wild," or "canoe" when the Act was passed were incorporated into the National Wilderness Preservation System, and some of them are currently being studied. The Act provided that areas under consideration for Wilderness designation should be studied for suitability for incorporation into the Wilderness System. The mineral surveys constitute one aspect of the suitability studies. This report discusses the results of a mineral survey of the Bob Marshall Wilderness, proposed additions to the wilderness, and the proposed Great Bear Wilderness, northwestern Montana.

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Studies related to wilderness

Mineral resources of the Bob Marshall Wilderness and study areas, Lewis and Clark, Teton, Pondera, Flathead, Lake, Missoula, and Powell Counties, Montana

Summary

A mineral survey of the Bob Marshall Wilderness and proposed additions, Montana, was initiated in 1969 and completed in 1975. The total area covers about 2,580 sq mi (6,680 km^2) of the rugged Swan, Flathead, Lewis and Clark, and Sawtooth Mountains; the wilderness covers about 1,480 sq mi (3,830 km^2). The results of the investigations indicate that parts of the area have a high potential for natural gas and a low potential for oil. In addition, the area has a moderate potential for large submarginal deposits of copper and silver, and a low potential for deposits of barite, coal, and limestone. The potential for other mineral commodities and for geothermal resources is very low to nil.

Geologically the area is divisible into two parts. The eastern part is in the disturbed belt of northwestern Montana and consists of Paleozoic and Mesozoic rocks, many northerly-trending and westerly-dipping thrust faults, normal faults, and folds. The central-western part contains Precambrian Belt rocks that locally are overlain by Paleozoic rocks with northerly-trending normal faults, and broad open folds. Clastic rocks of Tertiary age crop out locally along the South Fork of the Flathead River. Igneous rocks in the study area are mostly diorite sills of Precambrian Z age and trachyandesite sills of Late Cretaceous or possibly early Tertiary age; an andesite sill of probable Precambrian Y age is in the north end of the Flathead Range.

Aeromagnetic and gravity data reflect buried structural features and the distribution of near surface crystalline rocks. The buried crystalline rocks that were interpreted from geophysical results could be related to mineralization, but supporting evidence from geological and geochemical studies is necessary to make such a determination. Gravity data provided information on the depth and configuration of the Mississippian carbonate rocks as an aid to interpreting potential structural traps for hydrocarbons. Northeasterly trending gravity features may reflect broad arches or fault zones which could have affected the distribution of hydrocarbons.

The mineral survey consisted of reconnaissance geologic mapping, extensive geochemical sampling, aeromagnetic and gravity surveys, and detailed examination of rocks and mining claims. A total of 4,705 samples were collected: 2,828 were from outcrops, 1,578 from streams, 128 from prospects, 90 from soils, 42 from drill core, 16 from placers, and six from coal beds. The results of 277 samples of carbonate rock and 321 stream-sediment and other rock samples previously collected in

the Sun River Canyon, and 84 samples from the northwest boundary of the Scapegoat Wilderness are included in the evaluation. In addition, 62 stream-sediment samples from the northwestern part of the area were analyzed in the field for acid extractable copper. In the initial reconnaissance of the area, about 1,200 stream pebbles were examined and analyzed.

Two hundred ninety seven mining claims have been located in or adjacent to the Wilderness and proposed additions. None have a record of mineral production. Copper has been produced from a deposit 6.8 mi (11 km) to the southeast of the study area, and coal has been mined about 30 mi (48 km) northeast of the area.

The study area is in the northern disturbed belt of Montana and the structural and stratigraphic history is similar to that in the Alberta Foothills belt which has major proven reserves of gas and minor proven reserves of oil.

The eastern part of the study area (Area A) has a high potential for natural gas and a low potential for oil. The areas with a hydrocarbon potential are shown in figure 1. The boundaries of the areas are arbitrary; much more detailed geologic data including seismic surveys and drilling are necessary to more fully evaluate and delimit areas with hydrocarbon potential. The hydrocarbon potential of Area B is estimated to be moderate. Hydrocarbon source rocks appear to extend under this area beneath the Lewis Thrust Plate, but the presence of structures favorable for trapping hydrocarbons cannot be accurately predicted due to the lack of subsurface data.

Geochemical analyses of potential hydrocarbon source rocks, in and adjacent to the eastern part of the study area, indicate that most marine mudstones of Jurassic and lower Cretaceous ages generated natural gas, whereas those of Upper Cretaceous generated both oil and gas. The primary reservoirs are in Paleozoic carbonate rocks; Mesozoic clastic rocks are potential secondary reservoirs.

The type of structural trap most likely in the study area is one in which a reservoir rock is terminated against an underlying thrust fault. Traps of this type contain gas in shut-in or abandoned wells along the eastern border of the study area. It is also the most common type of trap in the Alberta gas fields.

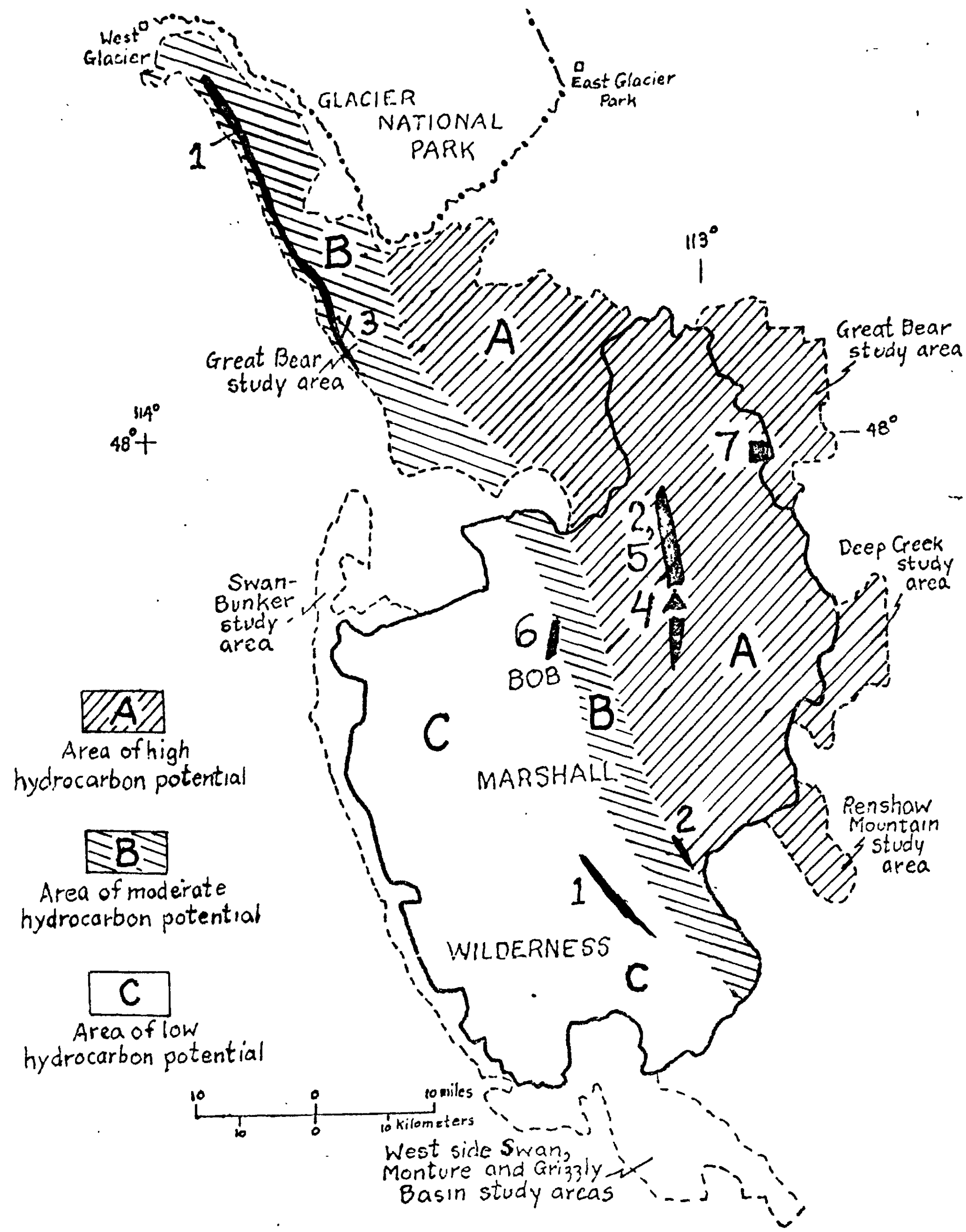
Areas containing other mineral resources are also shown on figure 1. Although no currently minable mineral deposits are known in the area, stratabound deposits in green strata in the Spokane, Empire, and Snowslip Formations (area 1, fig. 1) have a moderate potential for submarginal resources of copper and silver. These deposits in the Spokane and Empire Formations occur in a belt that is 25 mi (40 km) long in the northwest part of the study area. Here prospect workings and associated outcrops were examined along more than 7 mi (11 km) of the strike length of the belt. A deposit on the Corkscrew copper claims

(Hoke Creek prospect) in the Spokane Formation is estimated to contain about 700,000 tons (600,000 t) of disseminated copper and silver averaging 0.15 percent and 0.1 ounce per ton (3.4 g/t), respectively. This part of the study area has a good potential for the discovery of similar deposits. A fault zone on the One Dead Digger and Half Man Claims (area 3, fig. 1) contains more than 100,000 tons of inferred resources that average about 0.39 percent copper and 0.4 oz (13.7 g/t) silver. Numerous other copper and silver occurrences (area 2, fig. 1) are estimated to have a low resource potential because they are small and/or low grade.

Precambrian diorite sills in the area locally contain calcite veins with copper, silver, lead, and zinc minerals as at the Goat Ridge prospect (area 4, fig. 1) but the known deposits are too small to be economically exploited. Lead and silver occurrences are widespread in the Precambrian carbonate rocks of the area; the most extensive occurrence (area 5, fig. 1) is estimated to have a low potential because it is narrow and of low grade. Area 6 (fig. 1) contains massive barite veins of up to 10 ft (3 m) thick. The Bureau of Mines estimates that the barite veins at the Glacier prospect contain 90,000 tons (80,000 t) of resources that average 92 percent barium sulfate. However, the deposit is apparently too small to support large scale mining, and has low potential.

Coal beds in area 7 (fig. 1) are up to 4 ft (1.2 m) thick, but have a low potential because they are low quality, relatively inaccessible, and not amenable to low cost mining.

The area contains deposits of limestone, sand and gravel, and construction stone, but these commodities occur in abundance in more accessible areas of northwest Montana.



1. Moderate potential for submarginal resources of copper and silver in stratabound deposits
2. Low potential for submarginal resources of copper and silver in diorite sills
3. Moderate potential for small submarginal resources of copper and silver in veins
4. Low potential for small resources of copper, silver, lead, and zinc in veins
5. Low potential for submarginal resources of lead and silver in stratabound deposits
6. Low potential for high grade resources of barite in veins
7. Low potential for coal

Figure 1.--Map showing the areas of mineral resource potential in the Bob Marshall Wilderness and adjacent study areas.

CHAPTER A

Geology of the Bob Marshall Wilderness and study areas

by

Melville R. Mudge and Robert L. Earhart

U.S. Geological Survey

INTRODUCTION

The Bob Marshall Wilderness and proposed additions comprise 2,580 square miles (6,680 km^2) of rugged mountainous terrain in Lewis and Clark, Teton, Pondera, Flathead, Lake, Missoula, and Powell Counties, Mont. (fig. 2). The wilderness and proposed additions will be collectively referred to as the study area in much of the following discussion. The Bob Marshall Wilderness comprises about 1,480 square miles (3,830 km^2) whereas the proposed additions comprise about 1,000 square miles (2,850 km^2). The study area is about 110 miles (175 km) long and a maximum of about 47 miles (75 km) wide. The Scapegoat Wilderness adjoins the study area on the southeast and the Mission Wilderness lies about 10 miles (15 km) to the west. The study area is in parts of the Lewis and Clark, Flathead, Lolo, and Helena National Forests. The Continental Divide extends south through the eastern part of the area. Most streams west of the divide area are tributary to the South and Middle Forks of the Flathead River, whereas those east of the Divide are tributary to the Sun, Teton, and Marias Rivers.

The scenery in the study area is spectacular. Deep valleys carved by streams and glaciers form rugged interstream divides of which some are extremely narrow and inaccessible. Total relief is about 5,300 feet (1,600 m) from an elevation of about 4,000 feet (1,220 m) along the northern parts of the South and Middle Forks of the Flathead River to 9,270 feet (2,830 m) at Holland Peak along the Swan Range; most mountain ridges are between 7,000 and 8,500 feet (2,130 and 2,590 m). The Swan Range along the west side of the area affords some of the most spectacular scenery in the area with its very rugged, narrow, snow covered peaks and numerous glacial lakes. The only glaciers in the study area are Grant Glacier at Mount Grant and Stanton Glacier at Great Northern Mountain, both in the Flathead Range.

The most noted scenic feature in the Bob Marshall Wilderness is the Chinese Wall which forms part of the Continental Divide (fig. 3). This prominent cliff of Cambrian rocks has as much as 1,000 feet (300 m) relief; it trends northerly for about 30 miles (48 km), and thus when viewed from the east, it has the appearance of a long massive wall.

Natural lakes and large streams abound in the area. Almost all lakes, of which Big Salmon Lake is the largest, are west of the Continental Divide and on the east flank of the Swan Range. The South Fork of the Flathead, the largest river in the area, drains most of the area west of the Divide (fig. 4). Other large rivers are the Middle Fork of the Flathead to the north, and the Sun River to the east.

Access to the study area is by horse trail; some of the proposed additions are near roads. The nearest road to the wilderness is at Holland Lake on the west side of the Swan Range and it terminates about

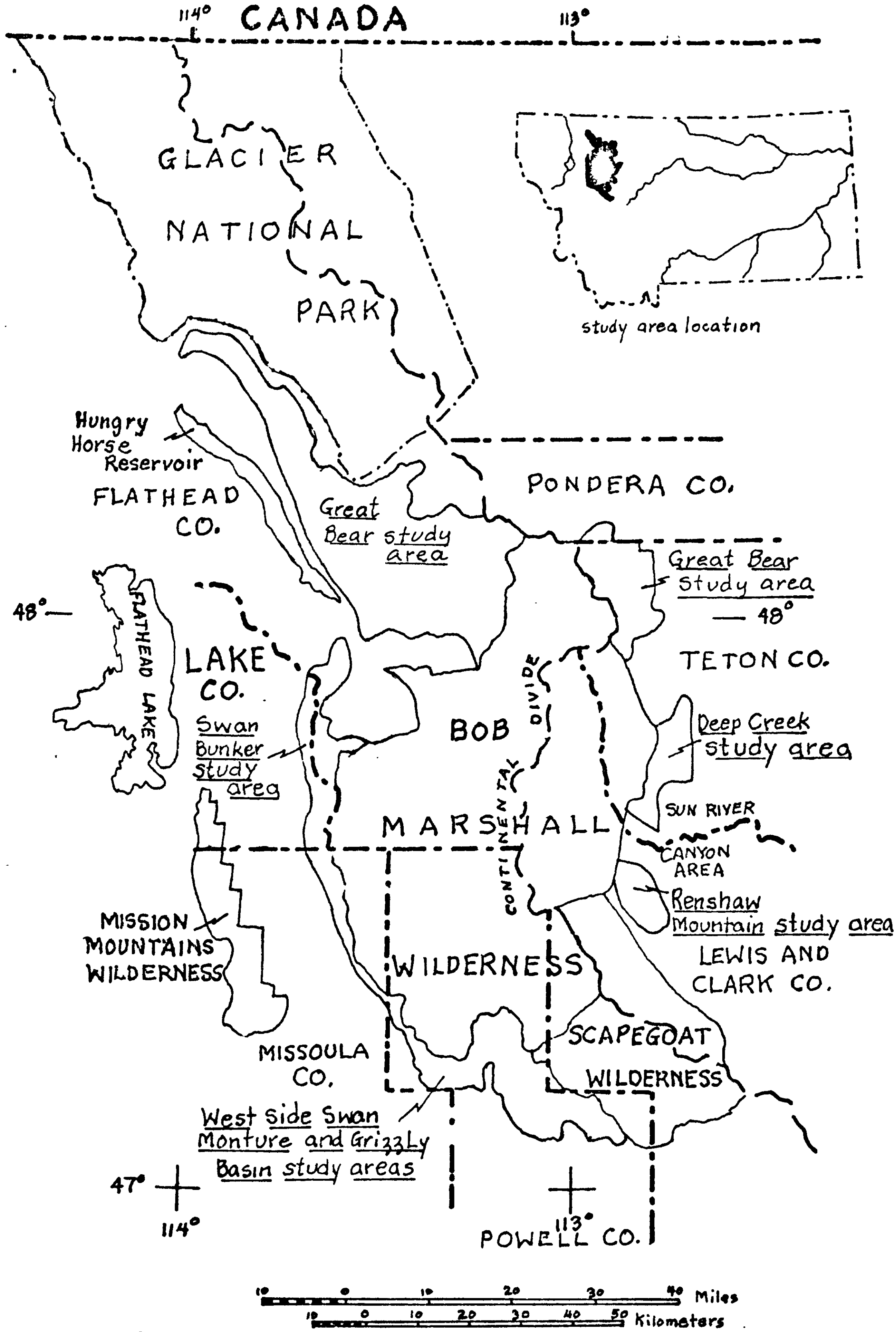


Figure 2.--Index map of part of northwest Montana, showing the location of the Bob Marshall Wilderness and study areas.

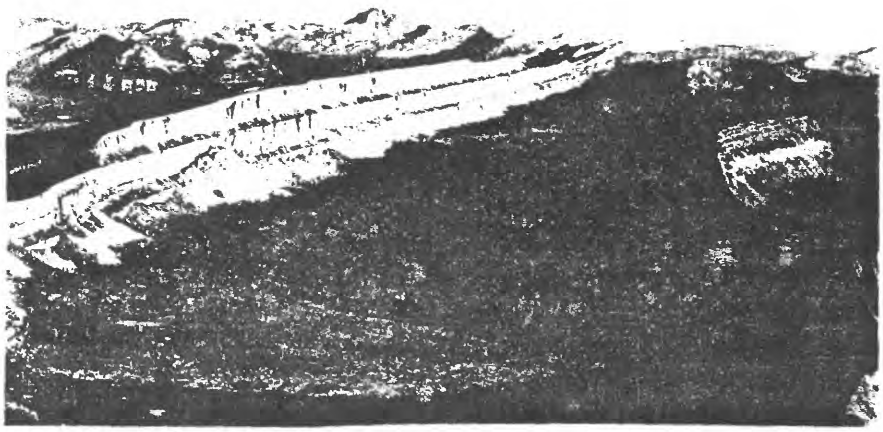


Figure 3.--View northwest showing east face of Chinese Wall (Cambrian rocks) that here is the Continental Divide. The extensive broad syncline, west of the Divide contains local remnants of Mississippian rocks on Devonian strata. The high peak in the center of the photo is Silvertip Mountain. The ridges east of the Chinese Wall contain Bonner Quartzite.

2 miles (3 km) from the boundary. Roads are within a mile (1.6 km) of parts of each addition. Travel in all areas is restricted to foot or horseback and is facilitated by marked Forest Service trails along most valleys and some ridges.

A variety of maps cover the area. Planimetric maps at a scale of 1:125,000 cover the National Forests. In addition, the study area is covered by modern topographic maps at a scale of 1:24,000. The area is also within the Choteau and Cut Bank topographic quadrangles at a scale of 1:250,000. Parts of these maps were enlarged to a scale of 1:125,000 and form the base for plate 1.

Previous studies

The geology of parts of the Bob Marshall Wilderness and additions has been studied by several geologists. Deiss (1933, 1938, 1939, and 1943a and b) described the stratigraphy and structure in the eastern, central, and northern parts. His unpublished reconnaissance geologic maps of part of the area (Ovando, Coopers Lake, Saypo, and Silvertrip quadrangles: scale 1:125,000) were available to us. Childers (1963) mapped in the northern part of area, and McGill and Sommers (1967) mapped and described the Precambrian rocks in the southern part. The Precambrian rocks to the west of the study area, in the Mission Mountains Wilderness, were mapped and studied by Harrison, Reynolds, Kleinkopf, and Pattee (1969). The geology and mineralized localities in the northern and western parts of the area were studied by Johns (1970). The stratigraphy and structure in the eastern part were studied by Mudge (1972a and b). Mudge, Earhart, Watts, Tuchek, and Rice (1974) mapped the geology and assessed the mineral resources in the Scapegoat Wilderness to the south of the study area. A preliminary geologic map of a part of the northern disturbed belt in the eastern part of the area was published in an open-file report (Mudge, Earhart, and Rice, 1977).

Present investigations and acknowledgments

The present investigation began during the summer of 1969, but was recessed in 1970 when field parties of the Geological Survey were reassigned to evaluate the mineral resources of the Lincoln Back County (now Scapegoat Wilderness). Field studies by the Geological Survey in the Bob Marshall Wilderness were resumed in 1971 and completed in 1973. Field studies on the proposed additions were conducted during 1973, 1974, and 1976.

The geologic map (pl. 1) is based mostly on mapping in the field, but in a few places it was supplemented with carefully checked published geologic maps. The geology of the southeastern part of the Bob Marshall Wilderness and parts of the Deep Creek and Renshaw Mountain additions is generalized from geologic maps by Mudge (1966a, b, c; 1967; 1968). For the rest of the study area mapping was done on 1:24,000 maps but compiled on the 1:125,000 map (pl. 1). All mapping was done by foot traverses of two field parties and in places checked by observation from helicopter. Most foot traverses were along the northeastward trending ridges which, for the most part, are at approximately right angles to the strike of the strata. The bedrock is well exposed on most ridges, but poorly exposed in most valleys. Some streams were traversed mainly for stream-sediment samples. The study was greatly aided by helicopter transportation which shuttled the field parties to and from dropoff and pickup points. Horse transportation was used occasionally during each field season.

We are grateful to the many local residents, Forest Service officials, and others whose assistance greatly benefited the mineral survey. In particular, we would like to acknowledge the excellent cooperation of the Forest Service personnel from Region I headquarters at Missoula, Mont., and from the Lewis and Clark, Flathead, Lolo, and Helena Forests. Local residents Bruce Neal, Paul Hazel, and Glenn Roberts provided information on the area.

GEOLOGIC SETTING

The study area is geologically divisible into two parts of contrasting age, rock types and structures; they are best considered separately. The Continental Divide approximately separates the two parts, especially in the Bob Marshall Wilderness (pl. 1).

East of the Divide the study area is in the Sawtooth Range and eastern part of the Lewis and Clark Range (fig. 4). This part of the area is within the northern disturbed belt of northwestern Montana. It typically consists of Paleozoic and Mesozoic rocks which in places are folded and repeated by abundant thrust faults (Mudge, 1972a, b; Mudge, Earhart, and Rice, 1977). The northerly-trending ridges are composed of carbonate rocks of Paleozoic age, whereas the valleys are in clastic rocks of Mesozoic age; most strata dip to the west. The westernmost part of the eastern unit contains a thin sequence of Precambrian rocks overlain by Cambrian rocks that are along the Continental Divide in many places. The Precambrian rocks are thrust mostly on rocks of Cretaceous age.

The unit west of the Divide contains mostly Precambrian Beltian rocks that locally are overlain by Paleozoic rocks (pl. 1). Clastic rocks of Tertiary age are present in a few places along the South Fork of the Blackfoot River. Most strata dip to the east. The area contains northerly-trending normal faults and broad open folds.

Igneous rocks in the study area are an andesite sill of probable Precambrian Y age, diorite sills of Precambrian Z age, and trachyandesite sills of Late Cretaceous or possibly early Tertiary age. The sill of probable Precambrian Y age is in the northern part of the Flathead Range where it intrudes strata of the Empire Formation. The Precambrian Z sills are widespread, and locally intrude all Precambrian formations except the Garnet Range. In the southern part of the area they are commonly in the older Precambrian formations, but in the

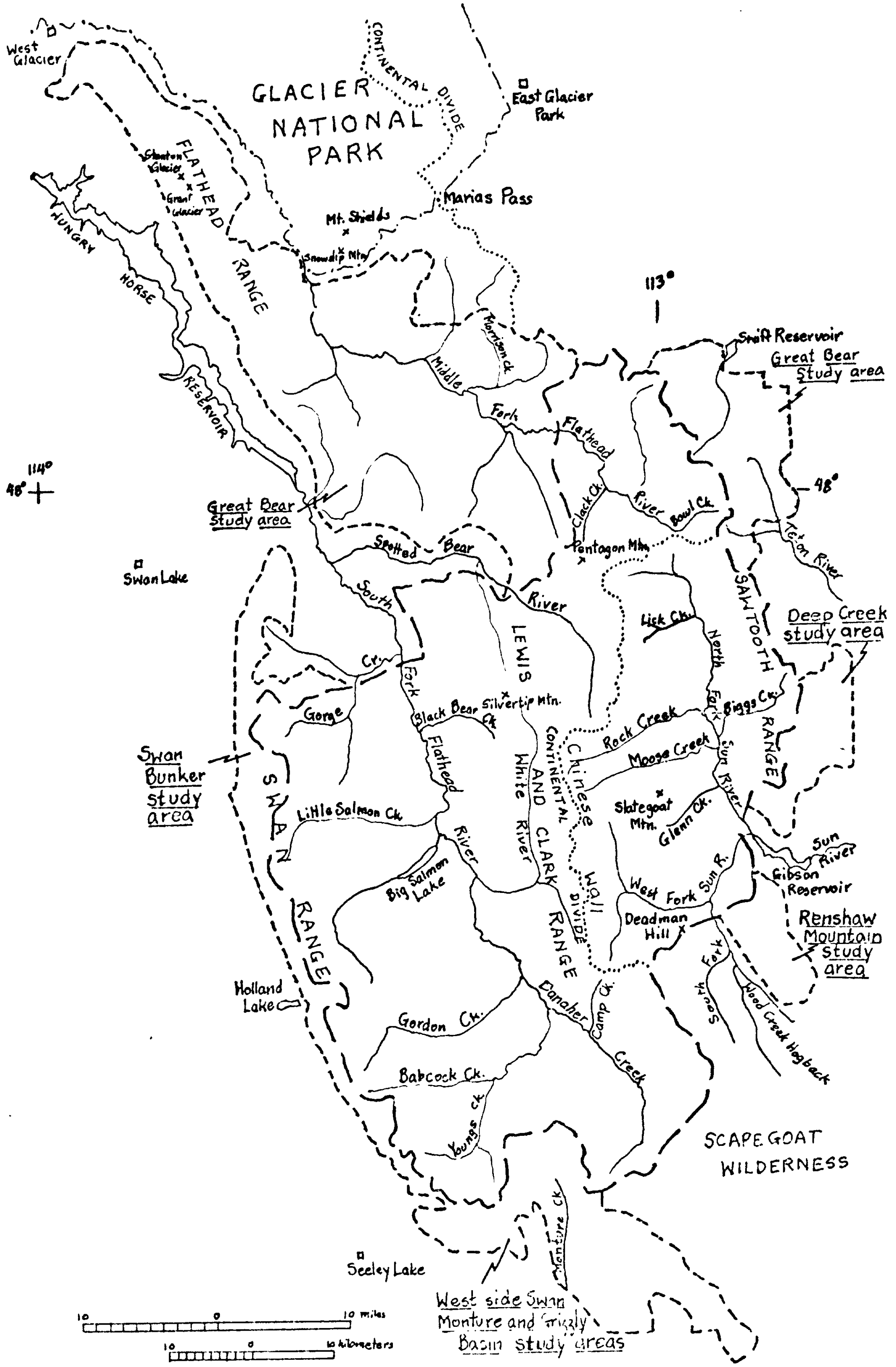


Figure 4.--Bob Marshall wilderness and study areas, northwestern Montana

Northeastern Outcrop 1/	Missoula-Bonner area Clapp and Deiss, 1931 Nelson and Dobell, 1961	Helena area Knopf, 1963	Canyon Ferry area Mertie, Fischer, and Hobbs, 1951
Garnet Range Formation	Garnet Range Formation		
Mc Namara Formation	Mc Namara Formation		
Bonner Quartzite	Bonner Quartzite	Greenhorn Mountain Quartzite	
Mount Shields Formation	Miller Peak Formation	Marsh Formation	
Shepard Formation			
Snowslip Formation			
Helena Formation	"Newland Limestone"	Helena Dolomite	Helena Limestone
Empire Formation	Not exposed	Empire and Spokane Formations	Empire Shale
Spokane Formation			Spokane Shale
Greyson Formation		Not exposed	Greyson Shale
Altyn Formation			Newland Limestone
Thrust faulted			Not exposed

1/ Includes Bob Marshall Wilderness and study areas; Glacier National Park (Childers, 1963; Mudge, 1977); Mission Mountains (Harrison, Reynolds, Kleinkopf, and Pattee, 1969); and Scapegoat Wilderness and adjacent areas (Mudge, Earhart, Watts, Tuchek, and Rice, 1974; Earhart, Grimes, Leinz, and Watts, 1976)

Figure 5.--Correlation of Precambrian Y Belt Supergroup in the eastern outcrop area with other areas in northwestern Montana.

northern part of the area they are mostly in the younger Precambrian rocks. The sills of Late Cretaceous or possibly early Tertiary age locally intruded Lower Cretaceous rocks in the eastern part of the Bob Marshall Wilderness.

PRECAMBRIAN SEDIMENTARY ROCKS

The oldest and most widespread rocks in the study area belong to the Belt Supergroup of Precambrian Y age. These rocks are well exposed in the western two-thirds of the area, from a point a few miles east of the Continental Divide (pl. 1). The lower part of the supergroup is not exposed in the study area. The rocks are divided into ten formations, which are, from oldest to youngest, Greyson, Spokane, Empire, Helena, Snowslip, Shepard, Mount Shields, Bonner, McNamara, and Garnet Range (table 1). The Spokane and Empire Formations are combined as a single map unit in most of their outcrop area, except in the western and northwestern parts of the area where the Empire Formation is easily defined and sufficiently thick to be mapped separately from the Spokane.

The thickness of the Belt rocks increase markedly to the south, west, and northwest. To the east, in the Sun River area, they are about 7,100 feet (2,165 m) thick; west in the Swan Range they are more than 32,000 feet (9,760 m) thick; northwest, near the southwest corner of Glacier National Park, they are about 23,000 feet (7,626 m) thick; and south, in the Scapegoat Wilderness (Mudge and others, 1974), they are as much as 34,000 feet (10,370 m) thick.

Changes in thickness are best demonstrated by the comparison of sections containing the same formations--the sequence from the base of the Helena to the top of the Bonner. The thickness of this sequence is 4,735 feet (1,445 m) to the east in the Sun River area, about 15,550 feet (3,140 m) to the northwest in the vicinity of the southwest corner of Glacier National Park, about 26,000 feet (7,930 m) to the west in the central part of the Swan Range, and about 19,500 feet (5,950 m) to the south in the southern part of the Scapegoat Wilderness.

The Belt Supergroup consists mostly of clastic rocks, except for the Helena Formation and parts of the Shepard Formation, which are predominantly carbonate rock. The clastic rocks are reddish brown argillites, siltites, and quartzites with interbeds of greenish gray and gray units of similar lithologies. The quartzites are commonly very fine to fine grained and rarely contain one or more thin beds that are medium to coarse grained. The carbonate rocks are silty and gray.

The age of the Belt rocks has been determined by potassium-argon and rubidium-strontium isochron methods by Obradovich and Peterman (1968). In the eastern part of the study area they (1968, p. 740-744) determined an average age of 1,100 m.y. for the sequence extending from the Spokane and Empire formations up into the lower part of the McNamara. They (1968, p. 745-746) determined the age of the Garnet Range Formation and the overlying Pilcher Quartzite in the Alberton region of western Montana as 930 m.y.

The correlation of the Belt rocks in the Bob Marshall Wilderness and additions with sections in the Helena area, Glacier National Park, and Missoula is discussed by McGill (1970) and Mudge (1972a, p. A8). The nomenclature used in this report has been adapted to Glacier National Park by Mudge (1977). The correlation of formational nomenclature used here with that used elsewhere in the eastern Rocky Mountains in northwestern Montana is shown on figure 5.

Greyson Formation

The Greyson Formation is the oldest map unit exposed in and near the study area. It has been mapped as the Appekunny Formation in the northern parts of the Swan and Flathead Ranges by Ross (1963) and Johns (1970), in the Marias Pass area by Childers (1963), and in Glacier Park by Ross (1959). Two exposures of the Creyson Formation are in the study area--one is in the area southwest of Marias Pass as mapped by Childers (1963) and the other is in the southeastern part of the southern addition (pl. 1). Near the study area the Creyson is exposed in the lower slopes on the west side of the northern Swan and Flathead Ranges.

In the study area the Greyson is mostly thinly laminated greenish gray to gray argillite. The upper beds of the formation are thickly bedded and weather to a brownish gray. In the Marias Pass area, Childers (1963, p. 142) describes the exposed Appekunny Formation as 1,000 feet (305 m) of dominantly medium green to greenish gray interbedded argillites, quartzites, and some breccia; it also contains thick units of light-gray, light-brown, and white sandstones. In Glacier Park, Willis (1902) lists the total thickness of the Appekunny as about 5,000 feet (1,525 m). As much as 4,500 feet (1,375 m) of the Appekunny is exposed in the Swan Range (Johns 1970, p. 24). Here, Johns notes the rocks weather a light gray to purplish gray.

The upper part of the Greyson is exposed in the mountain ridges northeast of Coopers Lake, in the southeastern part of the West Side Swan, Monture, and Grizzly Basin additions. Here it consists of greenish gray argillite with minor amounts of siltite and quartzite. A thin purplish gray bed is in the lower exposures. In most places the argillite is thick bedded to thinly laminated. In the upper reaches of Dry Creek the lowermost beds are iron stained to a brownish gray.

Purplish-gray to grayish-red strata of the Spokane Formation rest conformably on the thick sequence of greenish-gray strata of the Greyson.

Spokane and Empire Formations

The Spokane and Empire Formations are discussed as a single map unit even though in the western part of the area, and locally in the southern part, they are mapped separately (pl. 1). In the northern part

TABLE 1.–Sedimentary rock units in study area

Quaternary		Alluvial, glacial, colluvial, and landslide deposits	
Tertiary		Gravel	
		Siltstone, sandstone, conglomerate, and minor coal	
Cretaceous	Upper Cretaceous	Two Medicine Formation	
		Virgelle Sandstone	
		Telegraph Creek Formation	
		Marias River Shale	Kevin Member
			Ferdig Member
			Cone Member
			Floweree Member
	Lower Cretaceous	Blackleaf Formation	Vaughn Member
			Taft Hill Member
			Flood Member
		Kootenai Formation	
Jurassic	Upper Jurassic	Morrison Formation	
		Swift Formation	Sandstone member
			Shale member
		Rierdon Formation	
	Middle Jurassic	Sawtooth Formation	Siltstone member
			Shale member
			Sandstone member.
Mississippian	Upper Mississippian	Castle Reef Dolomite	Sun River Member
	Lower Mississippian		Lower member
		Allan Mountain Limestone	Upper member
			Middle member
			Lower member
Devonian	Upper Devonian	Three Forks Formation	
		Jefferson Formation	Birdbear Member
			Lower member
		Maywood Formation	Upper member
	Lower Devonian		Lower member
Cambrian	Upper Cambrian	Devils Glen Dolomite	
		Switchback Shale	
	Middle Cambrian	Steamboat Limestone	
		Pentagon Shale	
		Pagoda Limestone	
		Dearborn Limestone	
		Damnation Limestone	
		Gordon Shale	
		Flathead Sandstone	
Precambrian Y	Belt Supergroup	Garnet Range Formation	
		Mc Namara Formation	
		Bonner Quartzite	
		Mount Shields Formation	
		Shepard Formation	
		Snowslip Formation	
		Helena Dolomite	
		Empire Formation	
		Spokane Formation	
		Greyson Formation	

of the area, the formations were mapped by Ross (1959, 1963), Childers (1963), and Johns (1970, p. 24) as the Grinnell Formation. In the eastern part of the area the unit is locally exposed along the west side of valleys of the South and North Forks of the Sun River to as far north as Clack Creek, and in the upper reaches of the Middle Fork of the Flathead River. The Empire is a distinguishable unit west of an arbitrary line that extends south from the southwest corner of Glacier National Park down to the South Fork of the Flathead River, up Danaher Creek, and eastward through Dry Fork and the North Fork of the Blackfoot River in the Scapegoat Wilderness.

More than 5,000 feet (1,525 m) of strata comprising these formations are exposed in the northwestern part of the area, but only as much as 1,400 feet (425 m) of similar strata are exposed in the Sun River drainage. In the Swan Range, Johns (1970, p. 74) lists these strata as at least 4,600 feet (1,405 m) thick.

The Spokane Formation consists mostly of pale purplish red and grayish red strata with some greenish gray interbeds. The rocks are mostly thinly-bedded siltite with some argillite and thin- to thick-bedded quartzites. Commonly interbedded with the siltites are thin laminae of argillite, which are of a darker hue than the siltite. Minute crossbedding, ripple marks, dessication cracks, and mud chips are locally in the strata. The quartzite beds are micaceous, very fine to medium grained and are thicker and slightly more metamorphosed in the northern exposures than similar beds in the eastern exposures; they commonly weather a very light gray.

A diorite sill of Precambrian Z age intruded the Spokane in the southern part of the West Side Swan-Monture and Grizzly Basin addition, southwest of the Scapegoat Wilderness, and in the Spokane and Empire Formations in much of the eastern outcrop. In these areas strata adjacent to the sills have been altered to dark maroonish-gray, gray-brown, olive green, and medium-gray hornfels.

The overlying Empire Formation and parts of the Spokane Formation are metal bearing units in the eastern part of the Belt Basin in northwestern Montana. Some exposures contain malachite stains, traces of bornite, and rarely galena and sphalerite.

The Empire Formation, as identified by Walcott (1899) and Barrell (1907) and described by Knopf (1963), is mainly a greenish gray argillite with some purplish-weathering dark-red siltite beds. It is equivalent to the upper part of the Grinnell in the area near Marias Pass and in Glacier National Park. In the western and southern exposures of the study area the formation is distinctly greenish gray; it underlies light-brown carbonate rocks of the Helena Formation and overlies pale-red strata of the Spokane. It is mostly argillite and siltite with some thin interbeds of quartzite, dolomite, and locally stromatolitic and oolitic carbonate rock. The quartzites are commonly poorly sorted, ranging from very fine to medium grained, and locally carbonate cemented. In the northwestern part of the study area they are thick bedded, very light gray to almost white, partly recrystallized units.

The formation is as much as 600 feet (180 m) thick in the northwestern exposures, and as much as 2,000 feet (610 m) thick in the southern part of the Scapegoat Wilderness (Mudge and others, 1974, p. B8). In the eastern outcrop area the Empire, if present, cannot be distinguished from the Spokane Formation. Here red beds dominate the sequence of rocks beneath the Helena Formation. Similarly, in the central part of the Scapegoat Wilderness reddish-brown strata underlie the Helena (Mudge, Earhart, Watts, Tuchek, and Rice, 1974, p. B10). No evidence of an unconformity was observed in the Scapegoat and Bob Marshall Wildernesses and proposed additions.

The Empire, where identifiable, is a transitional unit between the Spokane Formation below, and the Helena Formation above. The amount of carbonate in the clastic units and number of thin carbonate beds in the Empire increases upward to the Helena. The contact between the two units is arbitrarily placed at the base of a continuous section of dominantly carbonate beds of the Helena that contain some calcareous or dolomitic siltite and quartzite. These lower beds of the Helena commonly weather light brown, whereas the underlying siltites and associated strata of the Empire weather pale olive to greenish gray.

Helena Formation

The Helena Formation crops out mostly along the western, northern, and southern boundaries of the study area. It is well exposed in the Swan and Flathead Ranges and partly exposed for a few miles along the east side of the South Fork of the Flathead River and Danaher Creek (fig. 6). In the eastern part of the study area, it is exposed in the area east of Deadman Hill (pl. 1, fig. 4). In the northern part of the area, it was mapped as the middle and upper parts of the Siyeh Formation by Childers (1963) and as the lower and middle parts of the Siyeh by Ross (1959) and Johns (1970, p. 28-29). Detailed descriptions of the Siyeh are given for the section in the Camp Creek area (fig. 6) by Sommers (1966, p. 124-132), in the southwest corner of Glacier National Park by Childers (1963, p. 145) and of the Helena in the Sun River Canyon area by Mudge (1972a, p. A77-A78). The stratigraphy and petrology of the formation in the Swan and Mission Ranges is described by O'Connor (1967).

The Helena thickens markedly to the north, west, and south from the Sun River exposure. In the southwestern part of the Sun River area the Helena is about 625 feet (205 m) thick (Mudge, 1972a, p. A10), but it thickens to about 5,450 feet (1,660 m) in the southern part of the Scapegoat Wilderness (Mudge and others, 1974, p. B11), to about 9,400 feet (2,865 m) in the Swan Range, and to about 6,500 feet (1,985 m) in the Flathead Range. The facies of the Helena, however, changes very little between the sections.

The Helena is a distinctive unit that consists of dominantly thin to thick carbonate beds and forms a prominent ridge or cliff below the dominantly reddish clastic strata of the Snowslip Formation and above similar strata of the Spokane and Empire Formations, or locally above the greenish strata of the Empire. A complete section of the Helena is exposed along the crest of the Swan and Flathead Ranges where it forms sharp peaks, cliffs, and irregular ledges.

The formation consists of thin- to thick-bedded silty limestone, dolomite, and calcitic dolomite with some interbeds of dolomitic siltite and argillite. The clastic beds are gray to dark gray and are more widespread in the upper and lower parts of the formation. The carbonate beds are light- to medium-gray and weather yellowish gray to grayish orange. Locally many of the beds contain disseminated and euhedral crystals of pyrite. Joints filled with calcite, and locally dolomite or barite, are common throughout the formation.

Some beds contain stromatolites, oolites, or edgewide conglomerates. The stromatolitic beds are as much as six feet (1.8 m) thick, but most are less than two feet (0.6 m) thick. The oolite and edgewise conglomerate beds are mostly less than one foot (0.3 m) thick. The beds locally contain minute iron-stained laminae or visible amounts of lead and zinc minerals.

Many carbonate beds contain thin laminae, whereas others contain structures described as molar tooth. In the Swan and Mission Ranges, O'Connor (1967) described the molar tooth structures as vertical ribbons and blobs and horizontal mats, lenses, and pods that by differential weathering form crenulating patterns similar to elephants' molar teeth.

The contact between the Helena Formation and Snowslip Formation is sharp and distinct in the central and eastern exposures, but gradational in the northern, western, and southern exposures. Where the contact is sharp, red brown siltite or a greenish gray coarse-grained feldspathic quartzite overlie thick beds of dolomite or gray siltite and argillite that comprise the upper part of the Helena. Where the contact is gradational greenish gray beds overlie the beds characteristic of the upper part of the Helena, but thin beds of dolomite, stromatolitic limestone, oolite, and locally coarse-grained quartzite are interbedded in the lower sequence of greenish gray strata of the Snowslip.

Snowslip Formation

The Snowslip Formation is well exposed along the east side of the crest of the Swan and Flathead Ranges, in the area south of Glacier National Park, along the east side of the upper reaches of the Middle Fork of the Flathead River and Danaher Creek (fig. 6), in the southern part of the area, and along the west side of the Sun River Valley. The Snowslip, along most of its outcrop in the Sun River Valley is hornfelsed by a sill of Precambrian Z age (Mudge, 1972a, p. A12-A13). Less altered strata of the Snowslip are exposed in the area north of

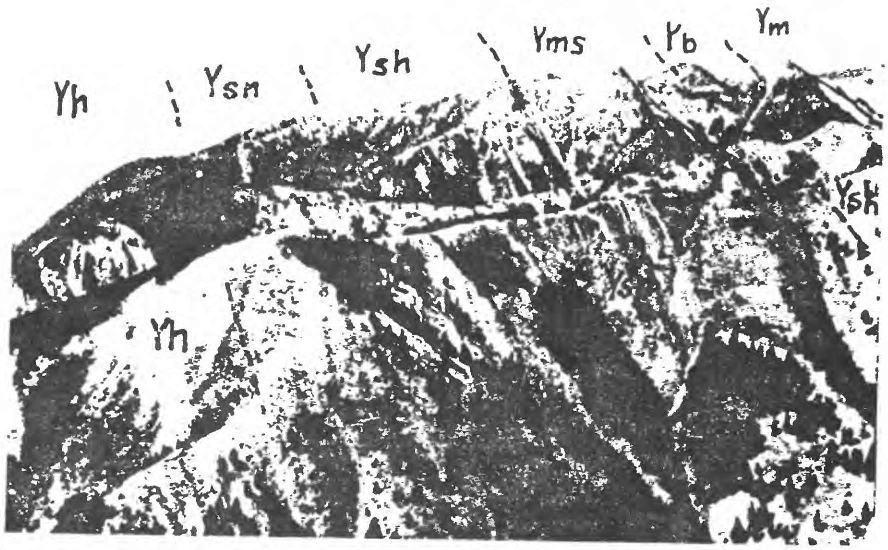


Figure 6.--View north of Precambrian rocks in ridges north of Camp Creek. The section in the ridge in the foreground was measured by Sommers (1966). Yh, Helena Formation; Ysn, Snowslip Formation; Ysh, Shepard Formation; Yms, Mount Shields Formation; Yb, Bonner Quartzite; and Ym, McNamara Formation.

Glenn Creek. Detailed descriptions of measured sections of the formation are given for the Camp Creek section by Sommers (1966, p. 118-124), for the Wood Creek section by McGill and Sommers (1967, fig. 2) and for the type section of the Snowslip in southwestern Glacier National Park by Childers (1963, p. 146).

The Snowslip thickens uniformly to the west from the eastern outcrop; it is about 700 feet (215 m) thick in the east, 2,225 feet (680 m) thick in the central part of the area (Camp Creek section), and 5,450 feet (1,660 m) in the western part of the area (Swan Range). The formation is about 3,200 feet (975 m) thick in the northwestern part of the study area, more than 1,600 feet (490 m) thick at the type section in southwestern Glacier Park, and about 3,600 feet (1,100 m) thick in the southern part of the Scapegoat Wilderness.

The strata comprising the type section of the Snowslip in the southwestern part of Glacier National Park is described by Childers (1963, p. 144) as mostly alternating thick sequences of green and reddish argillites and quartzites. He (1963, p. 144) describes the lower unit as thinly bedded sandy argillite breccias with some coarse quartz grains and small-scale cross stratification and channelling. A stromatolite zone is in the lower part of the unit. Ripple marks, mud cracks, and cross bedding are common features.

Farther west and southwest the lower part of the formation locally contains carbonate beds, some of which are oolitic and stromatolitic, interbedded with grayish green argillite and siltite. Carbonate beds are less common in the lower part of the Snowslip in the Swan Range where beds of gray-green and red argillite and siltite are prevalent.

The central, eastern, and southern outcrop areas consist mostly of pale red to reddish brown strata (Sommers, 1966; Mudge, 1972a; and Mudge and others, 1974). In these areas the quartzites are thin to very thin bedded, very fine to fine grained, and locally form small ledges. Stromatolitic and oolitic limestone, and locally flat pebble conglomerates occur at various horizons. Some stromatolitic beds contain pale-red or light-green laminae, especially in the upper part of the formation. Crossbedding, minute laminae, ripple marks, and mud cracks are common features. Locally, as in the Scapegoat Wilderness (Mudge and others, 1974, p. B14), iron-cross twin pyritohedrons are present. Elsewhere the pyrite is either cubic or disseminated locally in the green strata.

The green to greenish-gray clastic rocks of the Snowslip locally contain minor amounts of copper minerals that are discussed in Chapter C. Occurrences of copper minerals are sporadic but widespread, and are similar to those found in the Snowslip in the Mission Mountains (Harrison, Reynolds, Kleinkopf, and Pattee, 1969, p. D18).

The contact of the Snowslip with the overlying Shepard Formation is everywhere conformable. In the type area in southwestern Glacier

National Park, Childers (1963, p. 144) placed the contact where the dull-red medium-grained quartzites grade up into calcareous argillites of the Shepard. It is similar in the study area except that locally the uppermost strata of the Snowslip are beds of either siltite or argillite, and locally the lowermost bed of the Shepard is a stromatolitic limestone.

Shepard Formation

Exposures of the Shepard Formation are widespread in the western two-thirds of the study area (pl. 1). The Shepard crops out along the east side of the Swan Range, about midway to the valley of the South Fork of the Flathead River; it is also well exposed on the ridges on the east side of the valley (fig. 6). The Shepard is exposed at many places in the area extending east from the south end of the Flathead Range to Morrison Creek, from the Middle Fork of the Flathead River south along the east side of the Continental Divide to the Scapegoat Wilderness, and on the ridges both east and west of Monture Creek, in the southern part of the area.

The formation has been measured and described in detail in a few places in and near the study area. The type section in the southwestern part of Glacier National Park is described by Childers (1963, p. 148). Other detailed descriptions are the Camp Creek sections by Sommers (1966, p. 133-118), the Wood Creek Hogback section by McGill and Sommers (1967, fig. 2), and the South Fork of the Sun River section by Mudge (1972a, p. A78-A80).

The thickness of the Shepard, like other Belt formations, changes appreciably from the eastern outcrop where it is about 815 feet (250 m) to the western outcrop where it is 2,950 feet (900 m). At the type section in southwestern Glacier National Park it is about 1,555 feet (475 m) but thickens in the Swan Range to about 2,950 feet (900 m). It is about 1,990 feet (605 m) thick in the Camp Creek section and about 2,350 feet (715 m) in the southern part of the Scapegoat Wilderness.

The Shepard contains distinctive grayish-yellow strata between the reddish brown Mount Shields Formation above and the reddish brown and grayish green Snowslip below. The Shepard is mostly micaceous siltite, dolomitic siltite, and some silty limestone and argillite. The clastic beds are mostly greenish gray that weather grayish yellow. One or more maroon beds are in the lower half of the formation. The siltites and argillites are very thinly bedded to fissile in places. In the eastern outcrop an edgewise conglomerate a few inches thick is near the base of the formation; elsewhere a stromatolitic limestone occurs near the base, and locally at other stratigraphic positions in the formation. In the northern outcrop, Childers (1963, p. 147) noted distinctive beds of edgewise micrite-pebble conglomerate and calcareous siltstone breccia in the upper part of the formation. In the eastern outcrop Mudge (1972a, p. A13) noted widespread glauconite in thin sandstone lentils in the upper half of the Shepard. Glauconite is sparse in the thicker section of Shepard strata to the west. Abundant sedimentary structures in the eastern exposures of the formation include ripple marks, minute cross laminations, load casts, and mud cracks. Traces of copper, lead, and zinc minerals in some beds of the Shepard are less common than in the Snowslip Formation, and are mostly confined to beds with organic debris.

The contact between the Shepard and the overlying Mount Shields is conformable. In the eastern outcrop area it is gradational over a zone about 100 feet (30 m) thick (Mudge, 1972a, p. A15; Mudge and others, 1974, p. B15). In the central part of the outcrop area, Sommers (1966, p. 113) describes about 50 feet (15 m) of transitional zone. In both areas it consists of yellowish-gray siltstone interbedded with reddish-brown siltstone or quartzite; we place the contact at the top of the uppermost yellowish gray unit.

In the western and northwestern outcrop area, reddish brown beds of the Mount Shields are in sharp contact with yellowish-gray beds of the Shepard.

Mount Shields Formation

Exposures of the Mount Shields Formation are widespread in the western two-thirds of the study area (pl. 1). This distinctive bright reddish-brown unit is well exposed just west of the Continental Divide where it is in thrust contact on Cambrian and Devonian rocks that form the Divide. The unit is also exposed east of the Divide on both sides of the South Fork of the Flathead River (fig. 6), and in the southern and northern parts of the study area. The Mount Shields was formerly named the Shields Formation by Childers (1963, p. 147) from exposures in the southwest part of Glacier National Park. Other measured sections have been described in the Camp Creek section by Sommers (1966, p. 109-113) and in the Wood Creek Hogback by McGill and Sommers (1967, fig. 2).

Like other Beltian units, the thickness of the Mount Shields increases markedly from east to west. The Mount Shields is about 1,820 feet (555 m) thick in the eastern outcrop; about 2,732 feet (835 m) in the central outcrop at Camp Creek; and about 7,150 feet (2,180 m) in the Swan Range. At the type section to the north it is about 2,550 feet (775 m) thick, and in the southern part of the Scapegoat Wilderness, to the south, it is as much as 6,100 feet (1,860 m) thick.

The Mount Shields consists of bright reddish-brown thinly laminated micaceous siltite, argillite, and thin- to thick-bedded quartzite. The quartzite beds are fine to medium grained and are more common in the lower and middle parts of the formation. Thinly bedded siltite and fissile argillite, although present in the lower and middle parts of the formation, are more abundant in the upper part. A grayish green siltite unit with local interbedded dark-gray fissile shale is widespread in the upper part of the formation. In the area south of Sunburst Lake, numerous grayish-green beds are in the lower part of the formation.

A distinctive thick sequence of quartzite beds in the middle part of the formation in the southeastern part of the area diminishes as a prominent unit to the northwest. It was described by Mudge, Earhart, Watts, Tuchek, and Rice (1974, p. B16) in the southern part of the Scapegoat Wilderness as a unit ranging in thickness from 500 (155 m) to 1,000 feet (305 m) and in the Camp Creek area by Sommers (1966, p. 27) as a resistant prominent ledge-forming unit about 550 feet (170 m) thick. The sequence contains quartzite beds less than 2 feet (1 m) thick of which many are separated by thin beds of reddish-brown siltite and argillite. The quartzites are poorly sorted, fine to coarse grained, and pinkish gray to reddish brown.

The quartzite beds of the Mount Shields commonly contain a variety of sedimentary features including minute cross-laminations, ripple marks, and mud crack fillings. In many places the beds contain angular fragments of red argillite and some contain load casts, rill marks, and raindrop impressions. In the eastern outcrop, glauconite is common in the lower beds and locally present in the upper beds. Also in the eastern outcrop, in the area north of Glenn Creek, the lower part of the formation contains light-gray beds of stromatolitic and oolitic limestone. Salt-crystal casts are widespread in the upper part of the formation, beneath the greenish-gray unit. Specularite is locally common on bedding and fracture planes, especially in areas near a diorite sill; it is abundant in the vicinity of Gyp Mountain. The Mount Shields locally contains thin (1/2-4 inch; 2-10 cm) quartz or barite veinlets.

The contact between the Mount Shields and the overlying Bonner Quartzite is conformable, and in most places it is within a transitional zone a few feet thick. The zone consists mainly of thick beds of poorly sorted pinkish-gray to pale-red quartzite interbedded with reddish-brown siltite and fine-grained quartzite. The contact between the formations is placed at the top of this unit.

Bonner Quartzite

The Bonner Quartzite is a distinctive unit that forms resistant hillside ledges and smooth rounded knobs on ridges (fig. 6). It is prominently exposed on both sides of the South Fork Flathead River and Danaher Creek, along both sides of the Continental Divide, and at Red Plume Mountain (pl. 1). The Bonner is absent in the area between Lookout Mountain and the upper reaches of Clark Creek in the eastern outcrop area where it was eroded prior to Middle Cambrian sedimentation.

The Bonner was called the lower member of the Ahorn Quartzite by Deiss (1943a) and the Red Plume Quartzite by Childers (1963, p. 147). The type section of the Red Plume is described by Childers (1963, p. 150). A section at Camp Creek is described by Sommers (1966, p. 107-109).

The Bonner varies less in its thickness in the study area than other Belt units. It ranges in thickness from 775 to 800 feet (235 to 245 m) along the eastern and northern outcrop area. It is 1,150 feet (350 m) thick on the east side of the Swan Range and 1,270 feet (385 m) thick in the Camp Creek section. The unit attains a thickness of about 1,900 feet (580 m) in the southern part of the Scapegoat Wilderness.

The Bonner consists mainly of pink, pale red, and pinkish gray poorly-sorted quartzite in beds that range in thickness from 1-3 feet (30-75 cm). Locally some beds are mottled pink, lavender, grayish orange, or reddish brown. They are composed of rounded to subrounded fine- to medium-grained quartz with minor amounts of feldspar. Many beds contain cross laminations and some contain ripple marks. In places they contain angular fragments of red argillite. Fracture fillings of white quartz are common.

A conformable contact between the Bonner and the overlying McNamara Formation is within a gradational zone that ranges in thickness from a few feet to as much as 50 feet (15 m). The contact is placed at the base of the lowest maroon or green argillite or siltite bed.

McNamara Formation

The McNamara Formation crops out on ridges on both sides of the South Fork Flathead River and Danaher Creek, and along the central part of the study area extending north from Trident Peaks to Capitol Mountain (pl. 1). It was eroded prior to Middle Cambrian sedimentation in all of the eastern outcrop area, except between Bear Creek and the southern boundary of the study area. The McNamara was called the upper member of the Ahorn Quartzite by Deiss (1943a) and the unnamed sequence by Childers (1963).

Detailed measured sections of the unit are available from three localities in the study area. Two complete sections of the unit are described from the upper reaches of Camp Creek and Brown Sandstone Peak by Sommers (1966, p. 103-106). The lower part of the unit is described at Prairie Reef by Mudge (1972a, p. A81-A82).

The thickness of the McNamara is almost constant in the southern part of the study area but changes markedly toward the north. Southeast of the area, it ranges in thickness from 2,100 to 3,100 feet (640 to 945 m) (Mudge and others, 1974, fig. 2). In the Camp Creek area it is 2,655 feet (810 m) thick, and about five miles (8 km) to the north, at Brown Sandstone Peak, it is 3,070 feet (935 m) thick. From these sections, the unit thickens uniformly northward to about 5,400 feet (1,650 m) at Pivot Mountain.

In the southern part of the study area the McNamara is divisible into two unnamed members, a lower dominantly grayish-green siltite, and an upper dominantly reddish-brown quartzite (Sommers, 1966, p. 36-40); Mudge and others, 1974, p. B18). These units are distinctive north to about Helen Mountain, but farther north and west the entire formation is dominantly a grayish-green siltite. The change in facies is accompanied by a thickening of the formation to the north.

The lower member, although mostly grayish green siltite, also contains thin beds of argillite and quartzite, and locally some reddish gray siltite. The quartzite beds are fine to medium grained, micaceous and thin bedded. Ripple marks, minute crossbedding, and load casts are common. The upper part of the member commonly contains thin beds of glauconitic sandstone that are mostly less than four inches (10 cm) thick and rarely as much as four feet (1.2 m) thick; some beds are silica cemented and contain dark reddish brown mottles and lentils of iron oxide. Also associated with the glauconite beds are thin lenses of vuggy reddish chalcedony; locally some vugs are filled with barite. Grayish green, thin- to thick-bedded firmly cemented argillite beds with a conchoidal fracture are common. In a few places a thin bed of greenish-gray stromatolitic limestone and edgewise conglomerate is in the upper part of the unit.

The upper member mostly contains thin beds of reddish brown quartzite, and minor amounts of interbedded greenish gray siltstone. The quartzites are fine grained, micaceous, thin bedded and resemble quartzite beds in the Mount Shields Formation. Crossbedding and ripple marks are common. The lower part of the member locally contains a few very thin grayish-green glauconitic sandstone beds.

In the northern outcrop the McNamara is dominantly thin bedded, grayish green siltite with some thin beds of greenish gray and reddish brown quartzite. Crossbedding, ripple marks, green chalcedony nodules and lentils, and thin beds of glauconitic sandstone are less common than in the southern outcrop.

Rocks of the overlying Garnet Range Formation rest in conformable contact on those of the McNamara. In most places, gray fine-grained, thin-bedded quartzite of the Garnet Range rest in sharp contact on pale red thin-bedded quartzite or siltite of the McNamara in the southern outcrop, and on grayish-green siltite in the northern outcrop.

Garnet Range Formation

The Garnet Range Formation is the youngest Precambrian Y unit in the study area (pl. 1). It underlies Cambrian rocks on the west side of the South Fork Flathead River and Danaher Creek, on the east side of the South Fork Flathead River between Hodag and Lower Twin Creek, on the west side of the ridge that extends north from Twin Peaks through Rampart and Pagoda Mountains to Dean Ridge and Gunsight Peak. To the east the Garnet Range is locally exposed near the Continental Divide from Wall Creek Cliff south to White River Pass (pl. 1). Elsewhere in the eastern outcrop, it was eroded prior to Middle Cambrian sedimentation.

The Garnet Range is described in detail at the Camp Creek and Brown

Sandstone Peak sections by Sommers (1966, p. 101-102).

A complete thickness of the formation is not present in the study area as everywhere it is overlain unconformably by the Middle Cambrian Flathead Sandstone. The Garnet Range is about 990 feet (300 m) thick at the Camp Creek section and about 825 feet (250 m) thick at the Brown Sandstone Peak section (Sommers, 1966). Elsewhere in the study area it is up to 900 feet (275 m) thick. In the Scapegoat Wilderness it is as much as 1,600 feet (490 m) thick (Mudge and others, 1974, p. B19).

The Garnet Range consists of pale olive to medium gray thin beds of fine-grained micaceous quartzite and interbedded olive gray thin- to thick-bedded micaceous siltite. Beds of siltite appear to be more abundant than beds of quartzite, except along the Scapegoat Wilderness boundary where quartzite is more abundant. A thin quartzose conglomerate noted in the Brown Sandstone Peak section by Sommers (1966, p. 133) was not observed elsewhere.

The quartzite beds range in thickness from one-half to five inches (1.5 to 13 cm), weather flaggy, and contain crossbeds, flute casts, ripple marks, and minute channel-fill features. Most beds are characteristically speckled with hematite or limonite; locally some contain fragments of grayish-green argillite.

CAMBRIAN ROCKS

Rocks of middle and late Cambrian age are widespread in the study area. They are well exposed on the west side of the South Fork Flathead River and Danaher Creek, on the east side of the river in the area between Hodag and Lower Twin Creeks, and in the area extending from Trap Mountain north through the White River drainage (fig. 7) and Silvertip Creek to Gunsight Peak (pl. 1). The most noted exposure of these rocks are along the Continental Divide where they comprise the Chinese Wall (fig. 3). From the Divide they extend north to the Middle Fork of the Flathead River. These rocks are locally exposed in fault blocks in the northeast part of the study area in the Birch Creek drainage, and in the eastern part of the area along the ridge to the north and south of Arsenic Mountain (pl. 1).

The Cambrian rocks in the study area have been thoroughly described and discussed by Deiss (1933, 1939, and 1943a). The outcrops in the eastern part of the area have also been discussed by Mudge (1972a). In the study area Deiss (1933, 1939) describes measured sections at Nannie Basin Ridge, Kid Mountain, Pagoda Mountain, Pentagon Mountain, at Lick Creek and the Continental Divide, at Rock and Baldy Bear Creeks, at Cliff Mountain and the Chinese Wall, at Haystack Mountain and the Chinese Wall, and at Prairie Reef. The lower part of the Cambrian sequence at Nineteen Mountain and Prairie Reef are described in detail by Mudge (1972a, p. A82-A83). Therefore, only a cursory discussion of the Cambrian rocks will be given in this report.

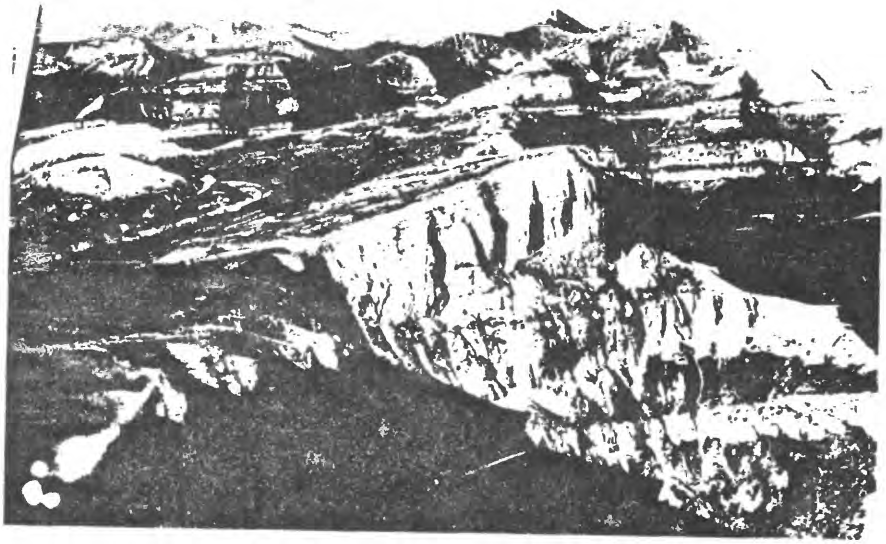


Figure 7.--View north from upper reaches of South Fork of White River showing Fault Peak in foreground (Devonian rocks). Peaks in the center of the photo contain Devonian rock that overlie even-bedded Cambrian rocks.

Cambrian rocks in the study area have been divided into nine formations by Deiss. All Cambrian formations listed in table 1, except the Pentagon Shale, are present in most exposures and are mapped as a single unit on plate 1. As noted by Deiss (1939, p. 42), the Pentagon Shale occurs only in the vicinity of Pentagon Mountain. It extends about 14 miles (25 km) to the south of the mountain (Deiss, 1939, p. 42) and are about 4.5 miles (7.0 m) north of it.

Cambrian rocks thicken to the west and southeast from about 1,625 ft (495 m) at Pentagon Mountain to about 2,335 ft (710 m) at Kid Mountain (Deiss, 1939).

The Cambrian sequence is dominantly carbonate rock; the basal unit is sandstone and moderately thick shale units in the upper and lower parts. The basal Flathead Sandstone and overlying Gordon Shale are in most places covered by talus formed from carbonate rocks. The Flathead is a poorly sorted, fine- to coarse-grained light gray crossbedded sandstone that commonly contains scattered quartz pebbles of quartz.

The Gordon and Switchback Shales are both dark gray shales with some interbedded sandstone and limestone. In the western outcrop the Switchback is mostly limestone. In the eastern outcrop reddish gray mudstone is common in the Switchback. The Switchback commonly contains one or more thin beds of conglomerate (Deiss, 1939; Mudge, 1972a).

The carbonate units are, in ascending order, the Damnation, Dearborn, Pagoda, and Steamboat Limestones, and Devils Glen Dolomite. They are gray and thin bedded, except for the Pagoda and Devils Glen which are thick bedded. In the eastern outcrop the carbonate rocks form steep cliffs, and intervening calcareous shale units form slopes. In the western outcrop the calcareous shale units are mostly absent and the carbonate units blend to form a single massive cliff.

The carbonate units, except the Devils Glen, are mostly impure dolomitic limestone with some dolomite and limestone. The Devils Glen is entirely dolomite.

The Cambrian rocks are overlain unconformably by Devonian rocks. The erosional surface is of extremely low relief and everywhere basal Devonian yellowish-gray beds of siltstone rest on light-gray dolomite beds of the Devils Glen. The variation in the thickness of the Devils Glen, from 179 ft (55 m) in the northern part of the central outcrop to 565 ft (170 m) in the southeastern part, is attributed by Deiss (1939, p. 46) to erosion between late Cambrian and Devonian time. Evidence of local channelling in the top of the Devils Glen was noted in the eastern outcrop by Mudge (1972a, p. A27).

DEVONIAN ROCKS

Exposures of Devonian rocks are widespread in the eastern and central parts of the northerly-trending mountain ridges in the eastern proposed additions and adjacent parts of the Bob Marshall Wilderness, and in the valley of the South Fork Flathead River. They are locally exposed along the Continental Divide and in the drainage of White River (fig. 7). Devonian rocks in the study area were measured by Sloss and Laird (1946) at Slick Creek and Spotted Bear Mountain, Lone Butte, Pentagon Mountain, Slategoat Mountain, and Cabin Creek. The section at Slategoat Mountain, as well as two sections in the Sun River Canyon, east of the study area, have been described in detail by Mudge (1972a, p. A84-A93). Therefore, these rocks will only be briefly discussed in this report.

The Devonian rocks range in thickness from about 950 ft (290 m) in the eastern outcrop area (Mudge, 1972a, p. A29) to more than 1,500 ft (460 m) at Lone Butte in the western outcrop (Sloss and Laird, 1946); they are about 1,500 ft (460 m) thick at Slategoat Mountain.

The grayish-brown to yellowish-gray Devonian rocks contrast with the underlying light-gray Upper Cambrian rocks and the overlying dark to medium gray Mississippian rocks. The Devonian rocks are divided into three formations by Mudge (1972a, p. A28), which are in ascending order, the Maywood, Jefferson, and Three Forks Formations (table 1). Sloss and Laird (1946) gave informal letter designation to these units. The formations are mapped as a single unit on plate 1.

The lower part of the Maywood is mostly greenish gray dolomitic mudstone with some maroon beds. The upper part of the formation consists of thinly bedded gray limestone and dolomitic limestone. The formation ranges in thickness from about 95 ft (30 m) in the eastern outcrop to more than 370 ft (115 m) in the western outcrop.

The Jefferson Formation consists mostly of thin to thick beds of grayish brown limestone, dolomitic limestone, and dolomite. Locally it contains one or more beds of evaporite solution breccia. The amount of limestone in the sequence increases to the west. The formation ranges in thickness from about 800 ft (245 m) in the eastern and western exposures to 625 feet (190 m) in the central exposure at Slategoat Mountain.

The Three Forks Formation consists of beds of evaporite solution breccia (Sloss and Laird, 1945; Mudge, 1972a) and some interbedded dolomite. In the western outcrop the formation is all breccia and contains some fragments from the overlying Mississippan strata. The amount of breccia is less in the eastern outcrop where thin beds of dolomite comprise most of the section. The breccia consists of angular blocks of pale yellowish brown dolomite and dolomitic limestone; locally it is very porous. The formation ranges in thickness from about 50 ft (15 m) in the eastern outcrop to about 600 ft (185 m) in the western outcrop.

The boundary between the overlying Mississippian rocks and the Devonian rocks is placed at a minor disconformity at the base of gray

Mississippian limestone beds. At most places the contact is at the top of the breccia in the Three Forks Formation. In the eastern part of the study area, a thinly bedded siltstone with a 0 to 6 ft (2 m) bed of black shale is locally present at the top. The black shale is correlative to the Exshaw Shale in Alberta.

MISSISSIPPIAN ROCKS

Most exposures of complete sequences of Mississippian rocks are in the north-trending ridges in the eastern part of the area (pl. 1). Parts of the sequence are exposed locally along the east side of the South Fork of the Flathead River, at Jumbo Mountain, from Mid Creek northwest almost to Spotted Bear Mountain, and in the vicinity of Kevan Mountain. In most places, especially in the eastern outcrop, these rocks form prominent ridges and east facing cliffs.

The Mississippian rocks in and near the area have been described by Deiss (1943a), Sloss and Laird (1945), Mudge, Sando, and Dutro (1962), Childers (1963), and Mudge (1972a). All but Deiss and Childers have described detailed measured sections of these rocks. In the study area Sloss and Laird (1945) describe partial sections at Lone Butte, Pentagon Mountain, and Slategoat Mountain, and a complete section at the head of Cabin Creek. They also describe a section at Allan Mountain and Hannan Gulch in the Sun River Canyon area. Mudge, Sando, and Dutro (1962, p. 2005-2008) describe in detail the section on the north side of Gibson Reservoir, east of the study area. Childers (1963) describes the Mississippian rocks exposed southwest of Marias Pass. Mudge (1972a, p. A93-A97 and A100-A102) describes three partial sections to the east in the Sun River Canyon. Therefore, only a brief description of these rocks will be given in this report.

The Mississippian rocks range in thickness from 900 to 1,700 feet (275 to 519 m), attaining the maximum thickness at Cabin Creek.

The Mississippian rocks east of the study area are divided into two formations and five members by Mudge, Sando, and Dutro (1962) but are mapped as a single unit on plate 1. The oldest formation, the Allan Mountain Limestone, is divided into three members; the youngest formation, the Castle Reef Dolomite, is divided into two members (table 1).

The Allan Mountain is mainly medium- to dark-gray limestone with some dolomitic limestone. It ranges in thickness from 535 to 650 ft (163-199 m) (Mudge, 1972a, p. A37). The lower member, which is absent as a result of thrust faulting in many of the eastern ridges, consists of very thinly bedded argillaceous dolomitic limestone and shale. The middle member is mostly a thin-bedded high-calcium limestone in the western part of the Sawtooth Range, but contains some dolomitic limestone in the eastern part. It characteristically contains lenses and nodules of chert (1-4 inches thick; 2.5-10 cm) that are 6-10 inches (15-25 cm) apart (Mudge, 1972a, p. A38), and are most abundant in the western outcrop. The upper member consists of thin- to thick-bedded limestone, magnesium limestone, and dolomitic limestone. More high calcium limestone beds are present in the eastern part of the Sawtooth Range than in the western part. Some beds are coarsely crystalline, porous encrinites; they are more abundant at Slategoat Mountain than in the Sawtooth Range to the east.

The Castle Reef is mostly light gray, thick bedded fine- to coarse-crystalline dolomite with some dolomitic limestone and limestone in the lower part. It ranges in thickness from 250 to 1,000 ft (77-300 m) (Mudge, 1972A, p. A38). The lower member consists mostly of dolomite and some limestone in the western outcrop; limestone beds are increasingly abundant to the east (Mudge and others, 1962). Coarsely crystalline beds with abundant crinoidal debris are at various horizons. Lenses and nodules of chert are common.

The Sun River Member is the uppermost Mississippian unit; it is an important petroleum reservoir unit east of the area. It consists of light-gray, thin to thick beds of very fine- to coarse-crystalline dolomite. Almost all beds are high purity dolomite with more than 40 percent $MgCO_3$. In most places the lower part of the member contains thick lenses of coarsely crystalline encrinite. Chert nodules are common at various horizons.

The Mississippian rocks are everywhere overlain unconformably by Middle Jurassic rocks. Mudge (1972a, p. A42) noted that the variation in thickness of the Castle Reef Dolomite, in a north-south direction is mostly a result of pre-Jurassic erosion.

JURASSIC AND CRETACEOUS ROCKS

Rocks of Middle and Late Jurassic and Early Cretaceous age crop out only in the eastern part of the Bob Marshall Wilderness and the adjacent proposed additions (pl. 1). These rocks have been divided into four formations (table 1), which are in ascending order: the Sawtooth, Rierdon, Swift, and Morrison, but they are shown as a single unit on plate 1. All but the Morrison, the youngest formation, comprise the Ellis Group, and are of marine origin. The Morrison Formation is nonmarine. Unconformities are at the base of each formation of the Ellis Group and at various horizons in the shale member of the Sawtooth.

The Jurassic rocks will be only briefly described in this report. The rocks of the Ellis Group in the area have been described in detail by Cobban (1945), Imlay (1945, 1952, 1953, 1962), Imlay, Gardner, Rogers, and Hadley (1948), and Mudge (1972a). The Morrison Formation in the area has been described in detail by Mudge (1972a). The thickness of the Jurassic and Lower Cretaceous rocks ranges from 485 ft (150 m) in the eastern outcrop to about 1,175 ft (360 m) in the western outcrop (Mudge, 1972a, p. A42).

The marine Ellis Group ranges in thickness from about 285 ft (87 m) in the eastern outcrop to about 675 ft (205 m) in the western outcrop (Mudge, 1972a, p. A42) and more than 615 ft (188 m) in the north (fig. 7a and 7b). The Sawtooth Formation consists of a lower gray fine-grained sandstone member, a middle dark-gray shale member, and an upper yellowish-gray calcareous siltstone member. The shale member, in particular, varies considerably in thickness from 16.5 ft (5 m) in the southeast to more than 255 ft (77 m) in the north (fig. 7a). In many places, such as in the upper reaches of Blacktail Gulch, Deep Creek, and Biggs Creek the sandstone member is absent and the dark-gray shale member rests unconformably on Mississippian rocks. In these areas the lower part of the shale member contains a heavily iron-impregnated zone which ranges in thickness from a few inches in the upper reaches of Blacktail Gulch to more than 4 ft (1.2 m) in Biggs Creek. The zone locally contains some goethite nodules two to three inches (5 to 8 cm) across. Phosphate pellets as much as one inch (2.5 cm) across were observed in the upper siltstone unit between Prairie and Goat Creeks, in the upper reaches of Biggs Creek, north of Route Creek, in Rierdon Gulch, and at Swift Reservoir. Cobban (1945) also reports phosphate pellets in the shale member at Rierdon Gulch and Swift Reservoir.

The Rierdon Formation consists of beds of gray calcareous claystone and siltstone with many thin beds of limestone and numerous barite nodules as much as 6 inches (15 cm) across. It ranges in thickness from 97 to 150 ft (30 to 46 m) (fig. 7a). The Swift Formation consists of a dark gray shale member in the lower part that grades upward to thinly bedded grayish brown sandstone. It ranges in thickness from 97 to 150 ft (30 to 46 m).

The nonmarine Morrison Formation previously included an eastern and western facies as described by Mudge (1972a, p. A49-A52). We now recognize that both facies include rocks of Early Cretaceous age, which we presently refer to as the unnamed formation. It includes most of the western facies of Mudge (1972a, A49-A52) and rests unconformably on the Morrison. Although these formations were mapped as a single unit on plate 1 they will be discussed separately.

The Morrison consists of gray green to olive drab mudstone with some thin beds of very fine grained sandstones. Nodules of gray brown limestone are common and in most places thin lenses of gray brown limestone are in the upper part. In the study area the Morrison ranges in thickness from about 7 to more than 110 ft (2-33 m). Its variation in thickness is a result of pre-unnamed formation erosion.

The nonmarine unnamed formation of Early Cretaceous age comprises most of the western facies of the Morrison in the eastern part of the study area as described by Mudge (1972a). It contains the Cut Bank Sandstone member and Moulton member described by Cobban (1945) in the subsurface in the Cut Bank area. The formation contains a basal sandstone unit (Cut Bank Sandstone member) that ranges in thickness from about 30 to 100 ft (9 to 30 m) (fig. 7c). It is very coarse to medium

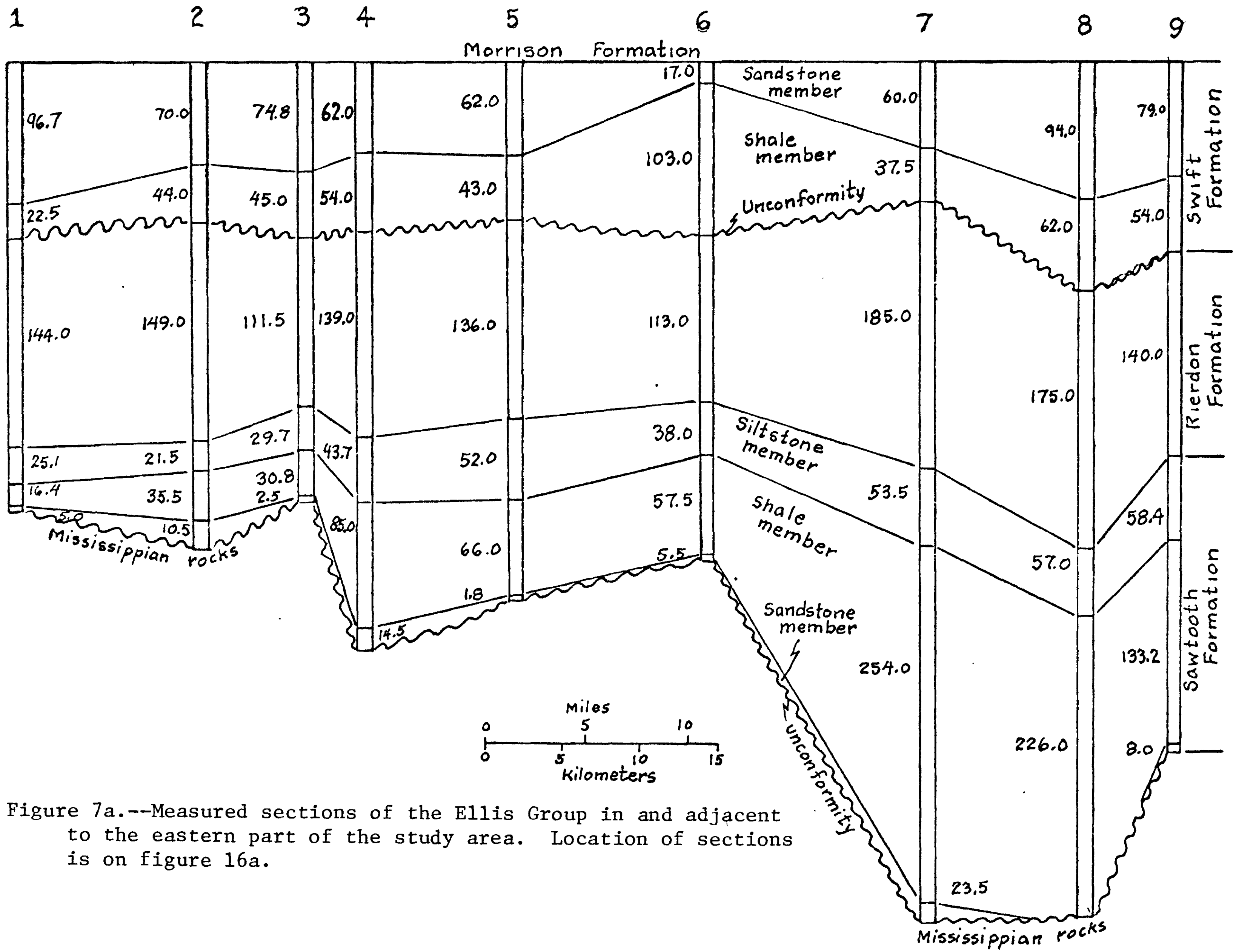


Figure 7a.--Measured sections of the Ellis Group in and adjacent to the eastern part of the study area. Location of sections is on figure 16a.

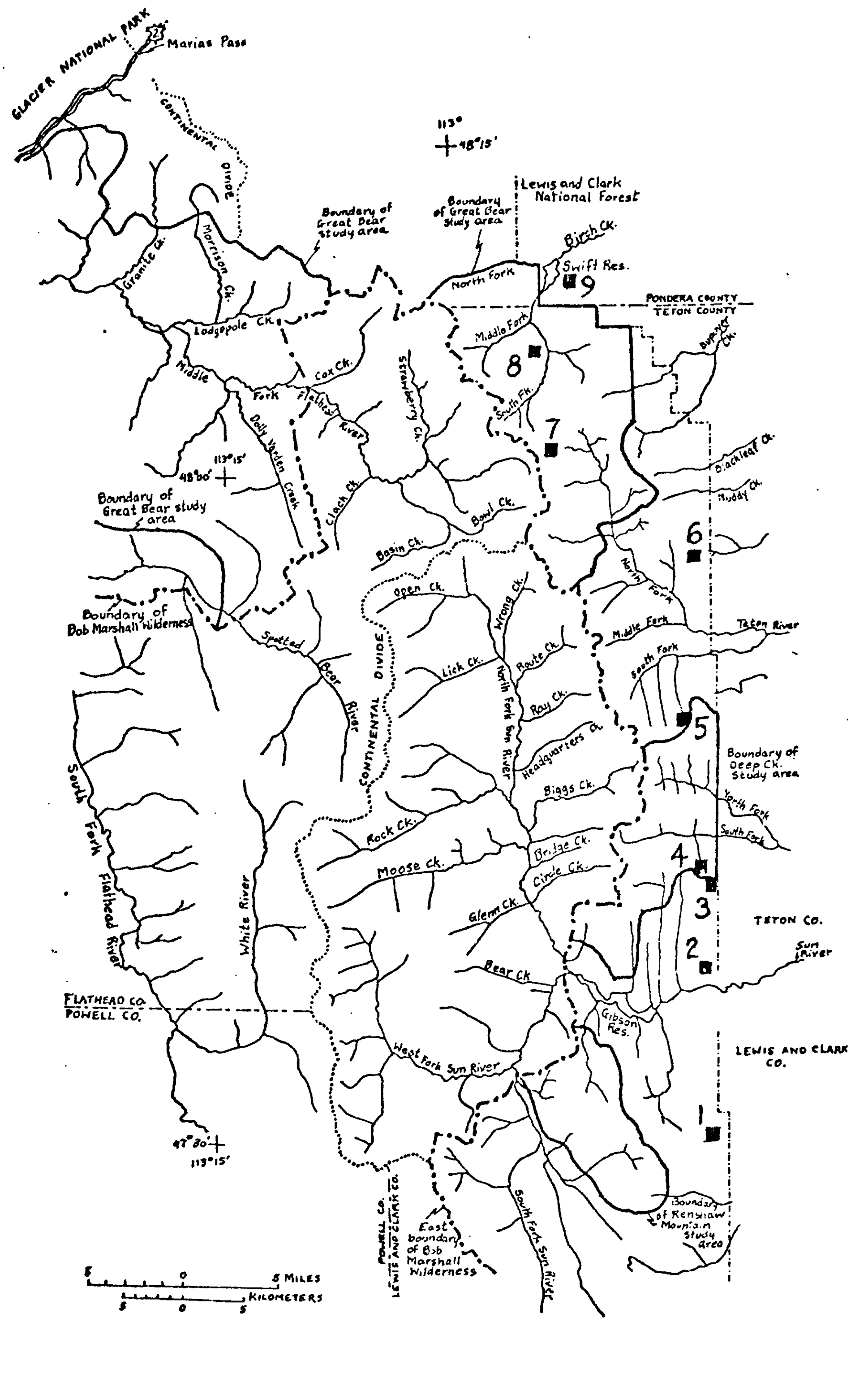


Figure 7b.--Location of measured sections of Ellis Group shown in figure 7a.

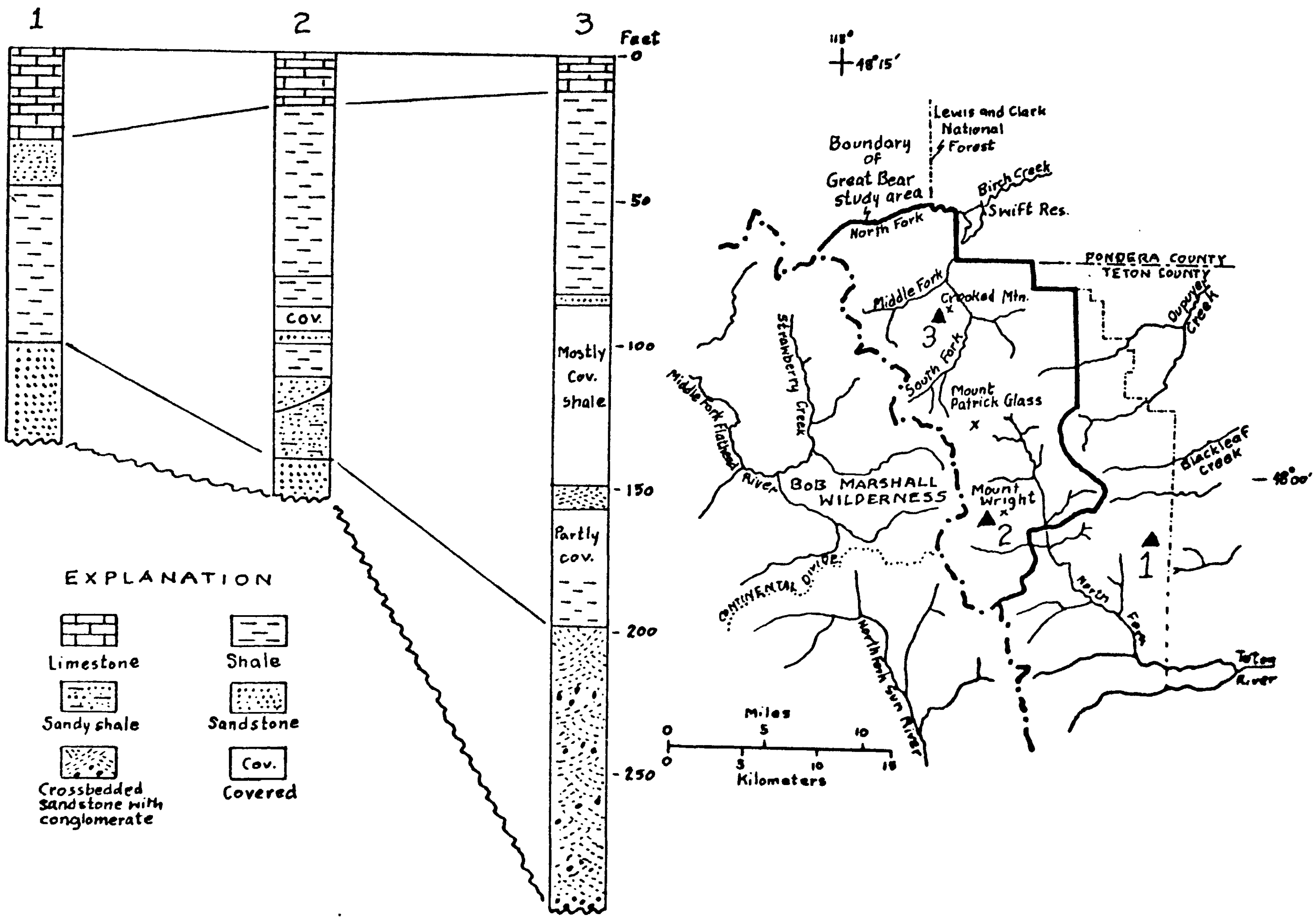


Figure 7c.--Measured sections of the Lower Cretaceous unnamed formation in the eastern part of the Great Bear wilderness study area.

grained, cross-bedded and contains some wood fragments. Conglomerate is common at the base of the unit as well as at various other horizons. The conglomerate has well rounded pebbles of black chert, some limonitic nodules, silicified limestone, and locally some Precambrian Belt rocks in a coarse-grained sand matrix. In places coarse sandy beds grade upward into siltstone. The rest of the formation consists of variegated mudstone with interbedded sandstone. In much of the eastern part of the Bob Marshall Wilderness the mudstones are mostly bright reddish brown. A prominent light gray, thick bedded limestone sequence, 20 to 30 ft (6 to 9 m) thick, is in the upper part of the formation. A second sandstone unit, locally referred to as the "Upper Cut Bank sand," lies about 40 to 60 ft (12 to 18 m) above the basal sandstone unit. It is as much as 20 ft (6 m) of coarse to fine grained medium gray to gray brown cross-bedded sandstone.

The relationship of the contact of the Unnamed formation with the overlying Kootenai Formation has not been fully determined in the study area. The unnamed formation may be overlain by the Kootenai in the eastern part of the area.

CRETACEOUS ROCKS

Cretaceous rocks are exposed principally in the valley of the North Fork Sun River and in the upper drainages of the Middle Fork Flathead River (pl. 1). Locally one or more lower Cretaceous units are exposed in the narrow northerly-trending valleys in the eastern part of the Bob Marshall Wilderness and adjacent proposed additions. As much as 7,000 ft (2,135 m) of Cretaceous rocks comprise six formations and seven members (table 1); only the formations are mapped on plate 1. The Kootenai Formation, Vaughn Member of the Blackleaf Formation, and the Two Medicine Formation are of nonmarine origin. The description of these units in the Sun River Canyon area by Mudge (1972a) is applicable to the present study area and only generalized descriptions will be included in this report.

The nonmarine Kootenai Formation is mainly maroon and grayish-green mudstone with local channel fills of grayish-green sandstone and conglomeratic sandstone. It ranges in thickness from 650-1,000+ ft (198-305+ m). Very thin lentils of magnetite-bearing sandstone are in the formation at Deep Creek. Elsewhere magnetite is commonly scattered through the sandstone beds. The basal unit of the Kootenai is the well-indurated poorly-sorted light-gray Sunburst Sandstone Member. It is up to 50 ft (15 m) thick and is locally absent. It was observed mostly in and south of the Deep Creek drainage. The Sunburst is an important petroleum reservoir unit in the Sunburst oil and gas field east of Cut Bank, Montana.

The Blackleaf Formation consists of three members, which are, in ascending order: Flood, Taft Hill, and Vaughn. The Bootlegger member, described on the Sweetgrass Arch by Cobban, Erdmann, Lemke, and Maugham (1976) is not present in the study area. The formation ranges in thickness from about 665 ft (203 m) in the southeast to about 850 ft (260 m) in the north and 1,600 ft (488 m) in the southwest. The marine Flood, 132 to 300 ft (41-92 m) thick, consists of a thin sandstone unit in the lower part and a relatively thick sandstone unit in the upper part; they are separated by a thick dark gray shale that commonly contains coarsely crystalline phosphatic nodules up to five inches (13 cm) across. The marine Taft Hill, as much as 360 ft (110 m) thick, consists of gray mudstone with interbeds of fine-grained sandstone. Iron-rich manganese nodules, in pods as much as two ft (0.6 m) thick and six ft (1.8 m) long, were observed in the Taft Hill about one mile (1.6 km) north of Sheep Mountain. In the northern part of the area only the lower part of the Taft Hill is present; the upper part appears to interfinger with nonmarine clastics typical of the Vaughn Member. Sandstone units of the Taft Hill are oil and gas reservoirs on the north and east flanks of the Kevin-Sunburst Dome (Cobban and others, 1959, p. 90).

The nonmarine Vaughn Member consists mainly of greenish gray mudstone with thin beds of sandstone, bentonitic shale, and bentonite. It ranges in thickness from 300 to possibly as much as 700 ft (92-214 m). The bentonite beds are up to six inches (15 cm) thick. Locally, the member contains channel fillings of conglomerate and sandstone. Near Teton Pass, above a tributary south of upper Bowl Creek, it contains beds of coal and bituminous shale. On the ridge west of Teton Pass beds of coal, each about 15 inches (38 cm) thick, are separated by about three feet (0.9 m) of sandstone and siltstone. Lower in the section, a bituminous shale bed about 18 inches (45 cm) thick overlies two other coal beds. The beds are about 2 ft (0.6 m) thick and are separated by about 4 ft (1.2 m) of mudstone. About 1,700 ft (520 m) to the northwest, prospect pits expose the coal beds in and at the head of a tributary north of Bowl Creek. These prospects are discussed in Chapter E.

The marine Marias River Shale (about 1,500 ft--460 m-thick) is mostly dark-gray mudstone with some very thin beds of sandstone and bentonite exposed in stream banks of the North and South Forks of the Sun River (Mudge, 1972a). The lowermost member, the Floweree, is 30-40 ft (9-12 m) of noncalcareous dark gray shale. Of particular interest is the Cone Member (about 100 ft--30.5 m-thick) which overlies the Floweree; it contains thin beds of calcarenite that contain minor amounts of oil. A thick bentonite bed about 7 ft (2 m) thick, in the upper part of the Cone was observed in a stream bank exposure along the South Fork of the Sun River, about a half a mile southwest of Furman Creek (Mudge, 1972a, p. A67). The Cone is overlain by the Ferdig Member which is about 350 ft (107 m) thick, and consists of gray noncalcareous mudstone and sandstone with a clayey matrix. The Kevin, the upper member of the Marias River, is about 1,000 ft (305 m) of dark gray calcareous mudstone with abundant bentonite beds up to 1.5 ft (0.5 m) thick.

The marine Telegraph Creek Formation and Virgelle Sandstone are exposed in stream banks along the North Fork of the Sun River (pl. 1). The Telegraph Creek Formation, about 550 ft (170 m) thick, is mainly beds of sandstone and some sandy shale that are crossbedded, ripple marked, and contain mudcracks. The Virgelle Sandstone, about 200 feet (60 m) thick, contains moderately thick beds of light-gray, crossbedded, well-sorted, fine-grained sandstone. In the northern exposures, near Gates Park, the upper beds of the Virgelle contain dark gray brown titaniferous sandstone. The uppermost ilmenite-bearing unit at the top of the Virgelle is about 8 ft (2.4 m) thick. Another zone that contains less ilmenite is a few feet below the upper zone.

The nonmarine Two Medicine Formation is the youngest Cretaceous unit exposed in the study area and it crops out in many places along the North Fork Sun River. Only the lowermost 1,000 ft (305 m) of the formation is present in the area. The Two Medicine consists of gray to green mudstone interbedded with poorly sorted, very coarse-grained sandstone. The lower part of the formation contains a conglomerate bed about 2 ft thick at the junctions of both Lick and Moose Creeks with the North Fork Sun River.

TERTIARY ROCKS

Tertiary sedimentary rocks locally are exposed in stream banks of the South Fork Flathead River and of Twin Creek, just northeast of Horse Ridge (pl. 1). The exposures along the Flathead are in the area between Bartlett and Phil Creeks. The age of the sediments has not been determined but is probably early Miocene, as Rasmussen (1973, p. 30) noted similar strata of that age south of the study area. They may range from late Eocene to late Miocene.

The lithology of the Tertiary rocks varies from one exposure to another. Near the mouth of Burnt Creek, an exposure consists of conglomerate, at least 4 ft (1.2 m) thick, that is composed of rounded to subrounded Beltian and Paleozoic rock fragments as much as 6 inches (15 cm) across. It is interbedded with medium to coarse sandstone. The conglomerate is overlain by about 200 ft (60 m) of gray-brown, crossbedded sandstone that locally fill small channels. The beds strike N. 55° W. and dip 32°. Fragments of similar conglomerates were observed in stream gravel bars in many tributaries of the Flathead from Bartlett Creek north to Damnation Creek.

Tertiary rocks are exposed in stream banks on both sides of the South Fork Flathead River, about midway between Burnt and Bartlett Creeks. The south bank contains the lower part of the stratigraphic sequence which is a very coarse boulder-bearing gravel overlain by siltstone interbedded with granular gravel. The beds strike N. 30° W., and dip 25° NE. The north bank contains a yellowish gray silt about 4 ft (1.2 m) thick which overlies a 4 foot (1.2 m) red brown siltstone. A six in. (15 cm) bed within the yellowish gray silt contains four beds of coaly siltstone, each about one inch (2.5 cm) thick.

Further north on Twin Creek, northeast of Horse Ridge, a Tertiary conglomerate is exposed at stream level beneath a thick channel fill of red-brown clay, silt, and gravel. The conglomerate is gray, heavily iron-stained, and consists of subrounded to rounded fragments of carbonate rocks. Associated with the conglomerate is a thin travertine deposit.

SURFICIAL DEPOSITS

The floors and sides of most valleys are thickly mantled with surficial deposits of Pleistocene and Holocene ages. They include unconsolidated deposits of glacial, landslide, colluvial, and alluvial origin (pl. 1).

The glacial deposits are of the Pinedale and younger glaciations. The glaciers of the Pinedale Glaciation (between 12,000 and 23,000 years ago) filled most valleys and deposited glacial till and outwash. Remnants of these deposits are along the sides of the South Fork Flathead River from Big Prairie north to Damnation Creek (pl. 1). The younger glaciations extended a short distance down valley from cirques and deposited glacial till along the valley sides and outwash gravels on the valley floors. The only remaining glaciers in the study area are Grant Glacier at Mount Grant and Stanton Glacier at Great Northern Mountain in the northwestern part of the area. The thickness of the glacial deposits in the area is probably as much as 500 ft (155 m).

Landslide deposits of rock debris, are widespread in the study area and only the larger deposits are shown on plate 1. Most landslides formed from Cambrian rocks, a few are formed from Precambrian rocks. The largest landslide, containing both younger Precambrian and Cambrian rocks, is on the southwest slope of Dean Ridge (pl. 1). This active slide is about six and one-half miles (10.5 km) long and two miles (3.2 km) wide. The east and north sides of the slide contain large open fractures. The main part of the slide consists of large segments of rotated and slumped rock. The thickness of the landslide deposits in the study area are not accurately determined, but they may be as much as 800 ft (245 m) to 1,000 ft (300 m) thick.

Colluvial deposits are widespread in the study area; they mantle parts of other surficial deposits on most hillsides and include talus deposits along the bases of cliffs. Colluvial deposits shown on plate 1 very likely include some glacial and alluvial deposits. Although most colluvial deposits form a thin veneer on older deposits, some are as much as 200 ft (60 m) thick.

Alluvial deposits, as much as 50 ft (15 m) thick include modern alluvium, and alluvial fan and glacial outwash deposits of Post-Pinedale Glaciation. They are widespread along major streams and many of their tributaries.

Gravel, silt, and brownish stained clay deposits, about 50 ft (15

m) thick, fill an ancient northerly-trending channel of Twin Creek, northeast of Horse Ridge. The degree of weathering and soil formation indicates that they are older than the glaciation in the area and may be as old as Late Tertiary.

IGNEOUS ROCKS

Igneous rocks in the form of sills are widespread, but they underlie only a small fraction of the study area (pl. 1). Some sills are Precambrian and others are latest Cretaceous or Early Tertiary in age. Sills of both ages crop out in the Sun River Canyon area--in the southeastern part of the Bob Marshall Wilderness (Mudge, 1972a, p. A74-A77). A Precambrian sill in the Wood Creek Hogback, southeast of the area, has been described in detail by Knapp (1963). Other Precambrian sills have been described in the Scapegoat Wilderness by Mudge, Earhart, Watts, Tuchek, and Rice (1974).

Precambrian sills

Sills of Precambrian Y and Z ages are in the study area, but only those of Z age are widespread. The sill of Y age crops out only in the northern part of the Flathead Range, whereas those of Z age are widespread (pl. 1). A continuous sill of Precambrian Z age in the eastern outcrop extends from the West Fork of the Sun River north to Lodgepole Mountain, a distance of 41 miles (66 km).

The sills of Precambrian Z age have been dated in the Sun River area, Wood Creek Hogback, and Dearborn Canyon by potassium-argon methods by J. D. Obradovich (oral commun., 1966) as 750±25 m.y. old. A similar date was obtained on a sill adjacent to the south border of the Scapegoat Wilderness by R. F. Marvin (oral commun., 1972). The sill of Precambrian Y age has not been dated, but it is similar in composition to sills in Glacier National Park which have been dated by Hunt (1962) as 1,073 and 1,100 m.y.

The sills of Precambrian Z age intruded older to younger Precambrian rocks from south to north. In the southern part of the study area and the adjacent part of the Scapegoat Wilderness, a sill intruded the Empire and Spokane Formations. In the central part of the area they are locally present in the Helena and Mount Shields Formations. In the Swan Range a sill is in the lower part of the Helena, but to the north it intersected Helena strata at right angles in a stairstep manner up to the lower part of the Snowslip Formation. In the eastern part of the Swan Range a sill intruded the Shepard and Mount Shields Formations, and at the confluence of Gorge and Stadium Creeks, the sill contacts are discordant. Further north it intruded across most of the Mount Shields Formation in a stair-step manner.

The sills of Precambrian Z age also intrude across strata in the eastern outcrop (pl. 1) In the south a sill cut up section from the Spokane and Empire Formations to the Snowslip Formation at the West Fork

Sun River, and up into the Mount Shields Formation as far north as Slategoat Mountain.. At Rock Creek another sill intruded the Spokane and Empire Formations, but toward the north it gradually transgressed up section to the lower part of the McNamara Formation at Lodgepole Mountain. Another sill is in the Mount Shields Formation to the west.

The sills of Precambrian Z age are mostly dark gray diorite but include minor amounts of gabbro and monzonite. They characteristically weather to a moderate-brown to yellowish-brown soil (Mudge, 1972a, p. A75). Knapp (1963) records an average of ten percent magnetite in the sill at Wood Creek Hogback. In the study area magnetite was observed in thin layers parallel to the margin of the sill. The aeromagnetic expression of the sill in the Swan Range indicates that it may have a higher magnetite content than elsewhere in the study area (pl. 3). The sills mostly range in thickness between 200 and 600 ft (61 and 183 m). In the southern part of the Scapegoat Wilderness they are as much as 900 feet (275 m) thick (Mudge and others, 1974, p. B22).

The sedimentary rocks adjacent to the sills are slightly altered to grayish-green and grayish brown hornfels for a distance of about 200 feet (61 m) (Mudge, 1972a, p. A75). Actinolite and epidote crystals are common along bedding planes in the hornfels.

Sills of very Late Cretaceous or Early Tertiary age

Trachyandesite sills intruded lower Cretaceous rocks in the upper reaches of the Middle Fork Flathead River, on both sides of the North Fork Sun River, and from Bear Creek south to the south boundary of the Renshaw Mountain addition (pl. 1). On the east side of the North Fork Sun River a sill forms a distinct grayish-brown ridge for a continuous distance of 19 miles (31 km). The sills in most of the Sun River drainage and Renshaw Mountain addition are discussed by Mudge (1972a) and will only be briefly mentioned here.

The sills intruded only strata of the Blackleaf and Kootenai Formations; in most places they intruded the lower sandstone beds of the Flood Member. Extending north from Black Reef, a sill gradually transgressed strata from the lower part of the Flood Shale Member up into the Vaughn Member at Bridge Creek. Farther north at Headquarters Creek it gradually cut down section into the Kootenai Formation. The sills are fine grained, gray brown, and locally near their margin they contain thin bands of rhyolite that are parallel and adjacent to their contact with the sedimentary rocks. The sills are as much as 600 ft (185 m) thick (Mudge, 1972a, p. A75). In most places the adjacent strata are slightly altered for a distance of only about 10 feet (3 m).

STRUCTURE

The Bob Marshall Wilderness and proposed additions are in the eastern part of the northern Cordilleran geosyncline. The central and eastern parts of the study area are in the northern disturbed belt of

Montana, which is characterized by numerous closely spaced northerly-trending and westerly-dipping thrust faults, many folds, and some longitudinal normal faults (pl. 1). The central and western parts of the belt are characterized by northerly-trending broad open folds and longitudinal and transverse normal faults. Numerous northeasterly-trending lineaments are in the eastern part of the area (fig. 8).

Many structures in the study area have been previously described. Those in the eastern part of the area are discussed by Deiss (1943b) Mudge (1972b) and Mudge, Earhart, and Claypool (1977). The structures in the upper part of the valley of the South Fork Flathead River are evaluated by Sommers (1966), and those in the Marias Pass area by Childers (1963). An hypothesis on the origin of the structures is presented by Mudge (1970).

Most, if not all, faults and folds in the study are a result of an Early Tertiary orogeny (Mudge, 1970, p. 379), i.e., deformation occurred between Paleocene and late Eocene time (Hoffman, Hower, and Aronson, 1975). Following the orogeny, recurrent movement persisted to modern times on at least one of the major normal faults. The easterly tilted Middle Tert[illegible] sediments in the South Fork Flathead River indicate that the major normal fault on the east side of the valley has had recurrent movement.

The closely spaced thrust faults of the Sawtooth Range in the eastern part of the study area dip to the west at a moderately high angle. Most thrust plates have Mississippian rocks at their base, some have Devonian or Cambrian rocks. They overlie Jurassic or Lower Cretaceous rocks. The stratigraphic throw, according to Mudge (1972b, p. B16), ranges between 3,000 and 6,000 ft (915 and 1,830 m). Thrust plates in the western part of the Sawtooth Range are locally folded. A well exposed folded thrust plate in Route Creek (pl. 1) has been discussed by Deiss (1943b, p. 1158). Similar folded plates are both north and south of that area.

The traces of structures in the eastern part of the Great Bear study area form a convex pattern that extends farther northeast than those north and south of the area. Along the eastern border of the Great Bear study area, Mississippian, Jurassic, and Cretaceous rocks have been thrust over northwest plunging folds (fig. 8c, 8d). Here the thrust faults dip west at a relatively low angle. To the west, Cambrian, Devonian, and Mississippian rocks are in relatively steep westerly dipping thrust blocks. The presence of Cambrian rocks in the sole of the thrust block indicate a lower stratigraphic position of the decollement than to the east and a steepening of the thrust plane as it cuts upsection across younger Paleozoic rocks to the east. Farther west, Cretaceous, Jurassic, Mississippian, and Devonian rocks are in moderately steep westerly dipping thrust plates.

Thrust faults of relatively small displacement and a broad open fold are the predominate structures in the North Fork Sun River and the upper reaches of the Middle Fork Flathead River (See geologic cross sections, pl. 5). Cretaceous sedimentary rocks and a sill are in the fault plates. A longitudinal normal fault along the east side of the North Fork Sun River is downthrown to the west and has a minimum displacement of about 200 ft (60 m).

The largest thrust faults in the study area are at and just east of the Continental Divide and they extend north into the drainage of the Middle Fork Flathead River. The thrust plate east of the divide, called the South Fork thrust by Mudge (1972, p. B27), contains a very thin sequence of most of the Precambrian units exposed in the study area. In places they overlie Lower Cretaceous rocks and in other places they overlie Mississippian rocks (pl. 1). The thrust was estimated by Mudge (1972b, p. B28-B30) to have a stratigraphic throw of more than 14,000 ft (4,270 m) and a minimum horizontal movement of four miles (6 km); it dips westerly between 25 and 60 degrees.

The Lewis thrust fault extends south through the study area to the west side of Steamboat Mountain. At the Continental Divide it extends north along the west side of Dolly Varden Creek, and farther north beyond Square Mountain to north of Baldhead Mountain. In the area north of Baldhead Mountain, Childers (1963, p. 154-158) mapped it as a southerly extension of the Lewis thrust of Glacier Park. In the southern part of the study area it was called the West Fork thrust zone by Mudge (1972b). At the south end of Glacier Park, Childers (1963, p. 157) determined the lateral translation of the fault as at least 12 mi (19 km) and it may have moved eastward more than 40 miles (65 km) (Mudge and Earhart, in preparation). In British Columbia and Alberta, movement on the Lewis was more than 32 miles (50 km) northeastward relative to the underlying strata (Price, 1965, p. 124). The amount of movement on the Lewis decreases southward to Steamboat Mountain where it terminates. In most places along its trace the Mount Shields Formation is the basal unit in the fault plate, except to the north where successively older units, down to the Greyson Formation, comprise the basal unit.

The dip of the Lewis thrust plane varies along its trace. Just south of the southeast corner of Glacier National Park it dips between 15°-40°SW (Childers, 1963, p. 158), averaging about 25°. Further south the thrust dips between 20° and 45° W.

The area west of the Continental Divide and east of the South Fork Flathead River contains a broad open northerly-trending syncline. The axial trace extends from the Middle Fork Flathead south into the Scapegoat Wilderness where it is along the Continental Divide. Cambrian and locally Devonian and Mississippian rocks are in the center of the syncline.

West of the syncline, the South Fork normal fault trends northerly along the east side of the valley of the South Fork Flathead River. The fault is downthrown to the west and has about 16,000 ft (4,880 m) of stratigraphic displacement (Sommers, 1966, p. 84). All strata west of it dip moderately to the east.

The largest normal fault in the area is the Swan fault which trends northerly on the east side of the Swan Valley. This fault dips steeply and is downthrown to the west; it has a stratigraphic displacement of at least 20,000 ft (6,100 m) (Mudge, 1970, table 2).

Other normal faults are present in the northern and southern parts of the study area. Some of the faults southwest of Marias Pass are discussed by Childers (1963, p. 159). He (1963, p. 159) named the easternmost fault the Blacktail fault; it extends from a point west of Schafer Meadows in the study area north along the west side of Glacier National Park. In the southern part of the Park, Childers (1963, p. 159) computed the stratigraphic separation on the fault as about 14,000 ft (4,270 m).

In the vicinity of Baldhead Mountain, the normal faults are deflected from northwest to almost east-west (Childers, 1963). Here, he (1963) noted that the normal faults parallel the structures northeast of the Lewis fault and that they may reflect an east-west trend in the structure beneath the Lewis thrust plate.

The normal faults in the southern part of the area form a more complex pattern than those to the north. They trend northwesterly to northeasterly, and most of them have minor displacements of no more than a few hundred feet.

In the eastern part of the area, northeasterly trending lineaments, an alignment of topographic and structural features on LANDSAT photographs__/, (fig. 8) appear to reflect structures older than

__/LANDSAT photographs are those taken of the earth's surface from satellites.

those formed during the Early Tertiary orogeny; they may be structural discontinuities in the crystalline basement. Consequently, they may be important to petroleum exploration because they may have affected the distribution of reservoir and source beds. Most of the lineaments have been noted by Stone (1969, 1974), Sanders, Thomas, Kinsman, and Beatty (1973), and Halbouty (1976). Some of the northeasterly trends discussed in chapter A are also lineaments on the LANDSAT photographs.

The southernmost lineament the Scapegoat-Bannatynne trend, extends southwest from the Sweetgrass Arch across the Scapegoat Wilderness. On the arch it is a Precambrian structural alinement of numerous highs with as much as 1,400 ft (425 m) of relief that formed prior to Cambrian sedimentation (Alpha, 1955).

The central part of the study area contains the Brown Sandstone-

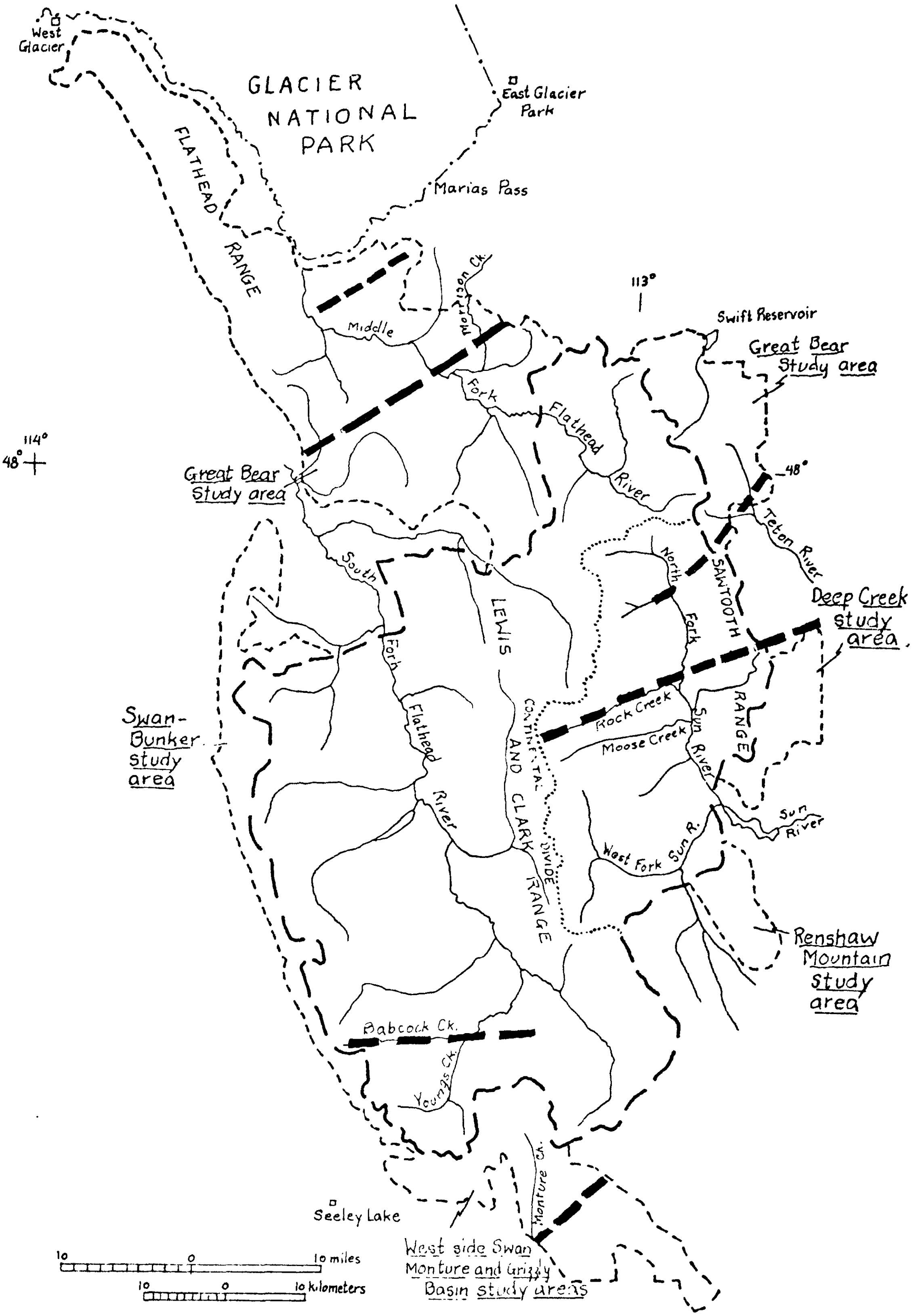


Figure 8.--Lineaments (heavy dashed lines) in the Bob Marshall Wilderness and study areas. From LANDSAT photographs.

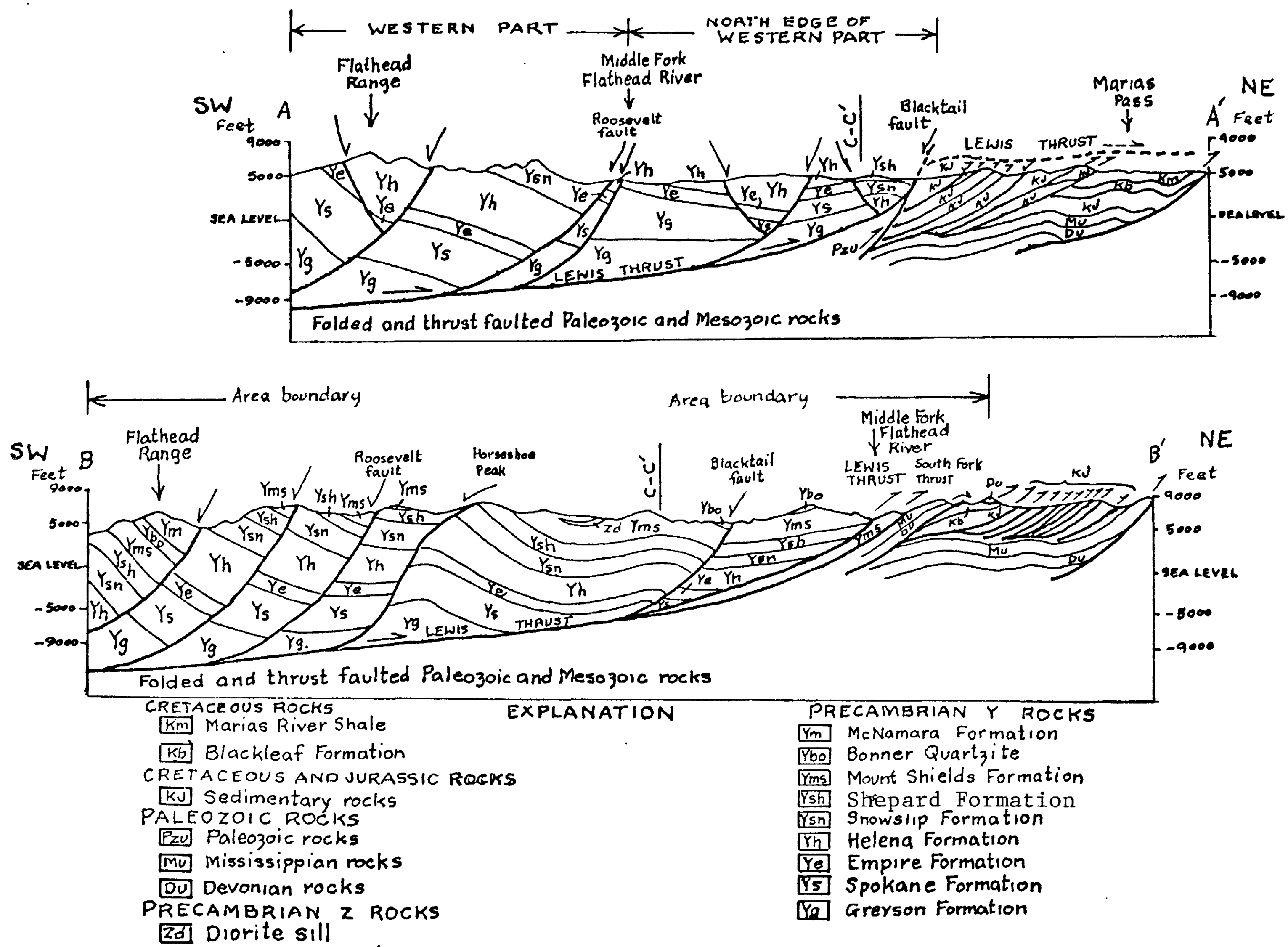


Figure 8a.--Geologic cross sections in the western part of the Great Bear wilderness study area. Line of sections shown on figure 8d. Arrows show direction of movement on faults.

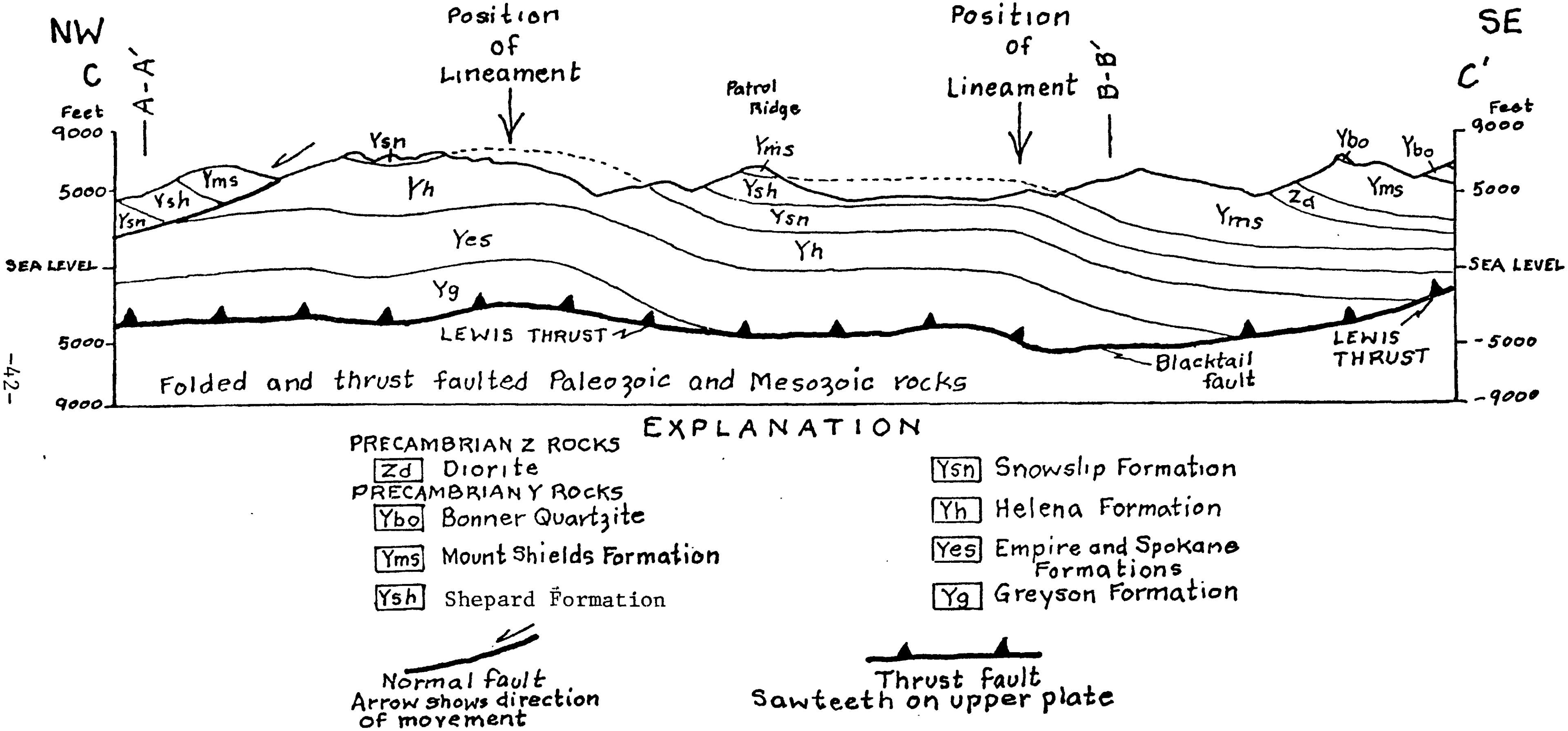


Figure 8b.--Geologic longitudinal section in the western part of the Great Bear wilderness study area. Line of section shown on figure 8d. Point of intersection on Cross section A-A' and B-B' shown on figure 8a.

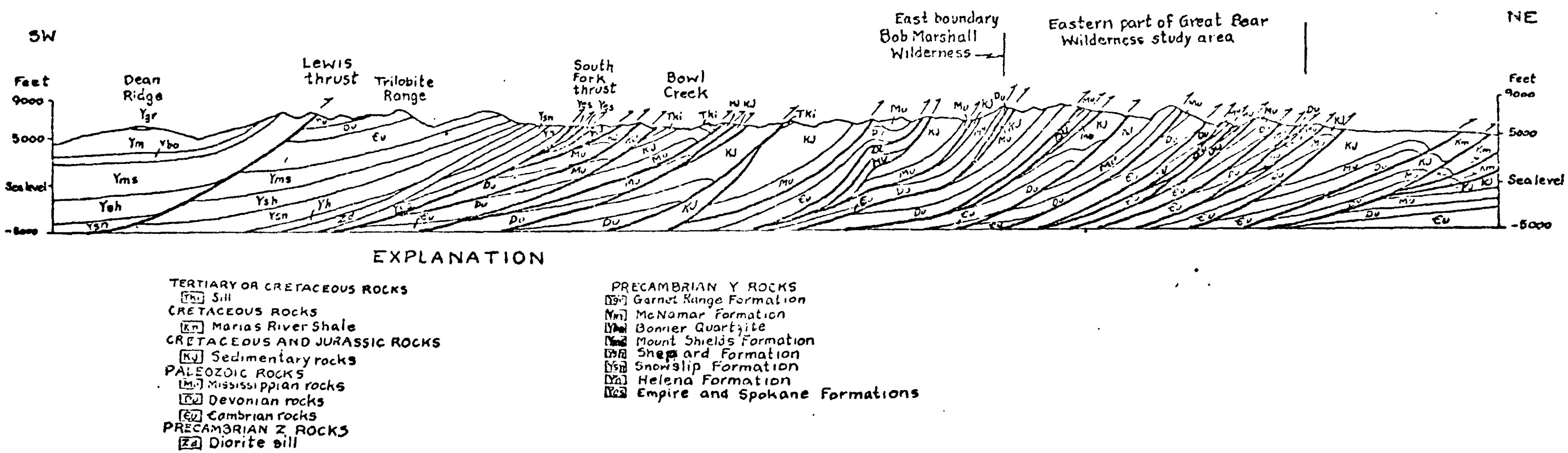


Figure 8c.--Geologic cross section across the eastern part of the Great Bear study area and the northern part of the Bob Marshall Wilderness. Line of section shown on figure 8d.

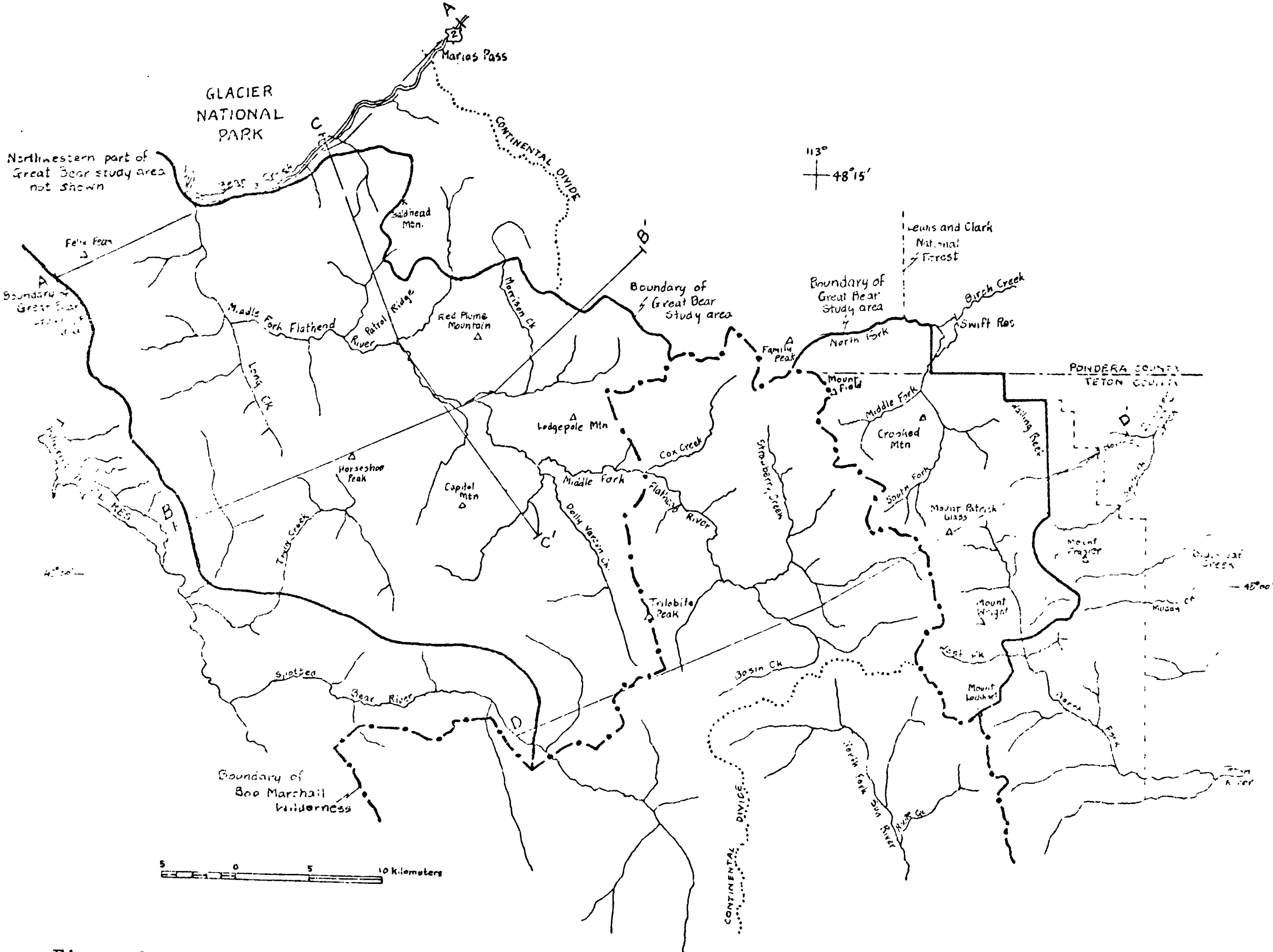


Figure 8d.--Location of cross and longitudinal sections shown in figures 8a, b, c.

Brady trend, Rock Creek-Bynum Reservoir lineament, and the Lick Creek trend. The Brown Sandstone-Brady trend extends northeast from Brown Sandstone Peak, past Sheep Mountain, across the North and South Forks of Deep Creek; it is a series of magnetic highs and lows; gravity data suggest it is basement fault (Kleinkopf and Mudge, 1972). The Rock Creek-Bynum Reservoir lineament is a prominent feature on the LANDSAT photographs but geologic data are insufficient to explain its origin. The Lick Creek trend discussed in Chapter B is reflected by a faint lineament to the northeast that may tie with the Pendroy fault zone in the plains east of the Great Bear study area. It appears to be spatially related to hydrocarbon occurrences.

The northern part of the area contains the Schafer Meadows-Cox Creek trend and two lineaments. The Schafer Meadows-Cox Creek trend is an alinement of gravity and magnetic features that extend from Schafer Meadows northeast past Swift Reservoir. In the Swift Reservoir area it is also reflected by a lineament in the LANDSAT photographs. The geologic significance of the trend is unknown.

Two lineaments are in the western part of the Great Bear study area, south of Glacier National Park (fig. 8). Numerous structural and stratigraphic changes in and east of the study area occur on or between the lineaments (Mudge, Earhart, and Rice, 1977). Evident on plate 1 are: (1) the ridges in the area are between 7,200-7,500 ft (2,200-2,300 m) in altitude; older rocks comprise them to the north; whereas younger rocks comprise them to the south; (2) the normal faults in the northeastern part curve convexly westward, which was noted by Childers (1963), who speculated that they may reflect an east-west structural trend beneath the Lewis plate; (3) in Morrison Creek the Lewis thrust fault cuts abruptly up section omitting more than 6,000 ft (1,800 m) of strata as well as cutting out strata of the South Fork thrust plate; (4) erosion of a fold in the thrust plate containing Paleozoic rocks at Big Lodge Mountain, east of Morrison Creek, resulted in a fenster that exposes Cretaceous rocks; and (5) many northwesterly trending normal faults hinge west of the Lewis thrust and some become major faults to the northwest. The data as shown in figures 8a, 8b, and 8d indicate that the Lewis thrust plate contains a southeast facing monocline. It is similar to a northwest dipping monocline in British Columbia, northwest of Glacier National Park, discussed by Price (1965) who compared it to a "tear fault" that does not cut strata above or below the thrust. He states that the Lewis thrust appears to have discordantly overridden folds and fault plates in the area.

At least two lines of evidence relate the lineaments to structural discontinuities in the basement. First, the lineaments are near the south margin of the deep early Mesozoic basin projected westward from isopach data by Cobban (1945) and indicated from the isopach data on figures 7 and 9 for the Ellis Group and Lower Cretaceous rocks in the eastern part of the study area. Basement structural features such as the Scapegoat-Bannatyne trend (Alpha, 1955; Dobbin and Erdman, 1955) and Pendroy fault zone (Dobbin and Erdmann, 1955) have surface expression because they were accentuated during Tertiary uplift of the basement. Secondly, the convex pattern of some faults and folds in a southwesterly direction may reflect differential strike-slip movement on basement faults which in turn controlled basement configuration.

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CHAPTER B

Aeromagnetic and gravity studies of the Bob Marshall Wilderness and study areas

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INTRODUCTION

Aeromagnetic and gravity studies were made in the Bob Marshall wilderness and adjacent study areas to help delineate subsurface geologic features such as folds, faults, or intrusives that might influence the emplacement of metallic mineral deposits and hydrocarbon accumulation. In this chapter the Bob Marshall Wilderness and proposed additions are referred to as the study area. Geophysical interpretations of the region were previously discussed by Mudge and others (1966, 1969, 1971, 1974); Harrison and others (1969); U.S. Geological Survey (1969, Smith, 1970; Kleinkopf and Mudge, 1972; Bonini and others, 1973; and by Earhart and others, 1976).

The aeromagnetic data (plate 3) were obtained by the U.S. Geological Survey in conjunction with regional studies in northwestern Montana (Mudge and others, 1968; Harrison and others, 1969; and Kleinkopf and Mudge, 1972). The survey elevations, flight line orientations, and spacings are shown on plate 3.

The Bouguer gravity map (plate 4) was constructed from gravity data collected by Peterson and Kleinkopf from 1965 to 1972, and from gravity data made available through the courtesy of the Department of Defense. Stations in the study area were reached by helicopter and horseback. Wilson modeled the gravity profiles. Melville R. Mudge constructed the geologic cross sections and provided the geologic information.

Vertical and horizontal positions for most stations were from benchmarks and spot elevations on 7 1/2-minute topographic maps; some elevations were interpreted from the map contours. However, for a few stations, established before large scale topographic maps were available, elevations were determined by altimeters and positions were located on 1/250,000 scale topographic maps. Those stations along east-west profiles in the drainage of the North Fork Sun River and vicinity were located on aerial photographs. The elevation of each station was determined by photogrammetric methods by the Topographic Division, U.S. Geological Survey.

Observed gravity values were referenced to the North American gravity Control Network at Station WA 124, Great Falls, Montana (Woollard, 1958). The gravity stations were corrected for terrain to a distance of 103.5 miles (166.7 km) using a digital computer by a method described by Plouff (1966). A density of 2.67 g/cm^3 (grams per cubic centimeter) was assumed for the material between sea level and station elevations in reducing the data to the Bouguer anomaly map.

The gravity data, except for detailed profiles, are considered to be of reconnaissance quality because of the wide spacing of stations, extreme topographic relief, and uncertainties of some station positions. The average estimated precision of the gravity data except along the profiles is estimated to be 3 milligals. The precision of the profile data is about 1 milligal.

Aeromagnetic studies

The magnetic features that may reflect subsurface geology are superimposed on the southwesterly dipping gradient of the earth's normal field. This geomagnetic gradient is about 4 gammas/km and is most apparent in the southwestern part of the study area (pl. 3). To the north, the regional magnetic strike is deflected from northwesterly to north-northwesterly by major structures associated with an early Tertiary orogeny.

Magnetic susceptibility measurements by Kleinkopf and Mudge (1972) showed significant differences in magnetic properties among the various crystalline rock types in the region, suggesting that detectable magnetic variations could be expected. Laboratory determinations of magnetic susceptibilities of Tertiary trachyandesite sills showed values averaging 0.001 emu/cm^3 (electromagnetic units per cubic centimeter); the Precambrian diorite-gabbro sills averaged about 0.003 emu/cm^3. Values for typical intrusive rocks such as quartz monzonite from the Boulder batholith varied from 0.0008 to 0.002 emu/cm^3.

The most prominent magnetic feature within the study area is a broad positive anomaly, magnetic peak 4,532, in the central part (pl. 3). It was discussed in earlier reports (Mudge and others, 1968, p. E15 and E16, anomaly 11; and Kleinkopf and Mudge, 1972, p. A13, anomaly 22). Based on their quantitative studies the source of the anomaly may be a large pluton that extends beyond the north edge of the study area. Its hypothetical composition is approximately quartz monzonite and its calculated maximum depth is 10,600 feet (3,230 m) below the ground surface. The postulated pluton may be part of a larger north-trending batholith that is strongly expressed by magnetic peak 4,832, located just north of the study area boundary. The residual magnetic positive feature located just southwest of the Schafer Ranger Station may be an apophysis of the inferred batholith. The southernmost magnetic expression of the batholith is the broad residual positive anomaly in the vicinity of Brown Sandstone Peak which includes magnetic peak 4,172. Along the east side of the postulated batholith the narrow northerly trending band of closely spaced magnetic contours may reflect the extensive diorite sill in the South Fork thrust plate. The sill is almost continuously exposed from the West Fork Sun River north to the vicinity of Schafers Ranger Station (pl. 1). Farther east, two interconnected magnetic lows (4,198 and 4,206) form a trend that reflects deeply buried crystalline basement rocks beneath imbricated thrust plates with relatively non-magnetic Mesozoic sedimentary rocks. The geologic reason for the southeastern deflection of the regional low axis at anomaly 4,198 is unknown; however, a northeasterly magnetic and gravity trend (Kleinkopf and Mudge, 1972, p. A11, anomaly 5) crosses the study area at this point. It is discussed in the section on Northeasterly Trends.

Magnetic peak 4,021, over the west-central part of the Swan Range, has been attributed (Kleinkopf and Mudge, 1972, p. A14, anomaly 25) to a deeply buried pluton in the Precambrian crystalline basement. The feature appears to be part of a large broad magnetic platform extending to the east across Albino Basin. Superimposed on the platform is a narrow elongated positive anomaly which reflects a highly magnetic Precambrian sill and dike complex of dioritic-gabbroic composition exposed along the crest of this part of the Swan Range (Kleinkopf and Mudge, 1972, p. A14, anomaly 26).

In the northwestern part of the study area the magnetic data show a uniform steep gradient, except for a perturbation in the contours in the vicinity of Felix Peak (pl. 3). The form of this residual positive anomaly suggests an igneous intrusion for which there is no recognized surface geologic expression. We estimate the depth to the source of the anomaly may be as much as 6,560 feet (2,000 m).

In the Pretty Prairie area two narrow elongated features are typical of anomalies caused by dikes (pl. 3). Magnetic peak 4,266 reflects a steeply dipping magnetite-rich trachyandesite sill as much as 699 feet (180 m) thick and peak 4,202, near the headwaters of Deer Creek, reflects a diorite-gabbro sill up to 500 feet (150 m) thick. Both sills are repeated many times by faulting (Kleinkopf and Mudge, 1972, p. A13, anomalies 17 and 19A). The elongated narrow magnetic expression of magnetic peak 4,266 extends some 15 miles (25 km) both northwesterly and southeasterly along the sill outcrop.

Reconnaissance gravity studies

Local gravity features trend north and northwest and reflect the gross structural grain, the distribution of less dense sedimentary rocks, and postulated major intrusives (pl. 4). The dikes and sills are too small to be detected by regional gravity surveys. They were detected where the gravity data are more concentrated as in the east-west profiles across the valley of the North Fork Sun River.

The most prominent anomaly on the map is the central gravity high that correlates with the principal magnetic features defined by magnetic peaks 4,832 and 4,532 (pl. 4). The near coincidence of the gravity high supports the interpretation from magnetic data of a buried batholith. The gravity expression over the Swan Range is also an elongated high. Although the station control is sparse, the -150 milligal contour closure corresponds approximately to the magnetic plateau area identified by magnetic peak 4,021. Along the west edge of the Swan range the steep gravity gradient represents the northerly trending Swan fault zone. The coincidence of magnetic peak 4,021 suggests that the emplacement of the postulated pluton may have been controlled by deep faulting.

A gravity low located along the drainage of the South Fork Flathead River (Kleinkopf and Mudge, 1972, p. A13 and A14, anomaly 24) is probably caused by a combination of valley alluvium and sedimentary rocks of Paleozoic age. The station control is too sparse to define the normal fault along the east side of the valley. To the southwest a negative anomaly defined by closed contours -170, -175, and -180 extends into Swan Valley and is interpreted to be caused by a small sedimentary basin (Kleinkopf and Mudge, 1972, p. A14, anomaly 27).

Near the southern border of the study area the gravity anomaly defined by the -150 milligal closure at Jenny Creek Ranger Station is coincident with a weakly expressed magnetic positive anomaly that occurs near the abrupt increase in magnetic gradient along the 3900-gamma contour (pl. 4). The gravity anomaly is poorly controlled and no geologic source is apparent, although a group of normal faults converge in the area of the anomalies. At the south end of the study area along Lake Creek, a small gravity anomaly, -135 mgal (milligal) closure, corresponds to a weak positive magnetic nose. It suggests a shallow intrusive or concentration of sills; according to Mudge (personal commun.) sills are present both north and south of the area and the magnetic expression may reflect a buried sill in a downthrown fault block.

In the northeastern part of the study area a gravity low occurs along the drainage of the North Fork Sun River and is interpreted to reflect Mesozoic rocks. The trace of the South Fork thrust is located along the western edge of the gravity low.

Detailed gravity studies

Detailed gravity surveys along four lines were made in the valley of the North Fork Sun River, and in the upper reaches of the Middle Fork Flathead River (pls. 4 and 5) in order to provide information about the depth and configuration of the top of the Mississippian rocks, which are petroleum reservoirs in the Sweetgrass Arch area to the east and in the foothills of Alberta, Canada. Similar gravity studies have been conducted in southern Alberta by Kanasewich and Clowes (1968), in connection with seismic and magnetic studies. The detailed gravity surveys were established along Moose-Bridge Creeks, section A-A′, Lick-Route Creeks, section B-B′, Basin-Bowl Creeks, section C-C′, and Middle Fork Flathead River-Cox Creek, section D-D′ (pls. 4 and 5).

Computer model studies were made of the gravity data along the four lines. The resulting gravity profiles, the estimated top of Mississippian strata from the model studies, and the geologic sections are shown on plate 5.

Rock densities were measured to aid in preparing the models. Twelve samples of Paleozoic and older rocks yielded an average density of 2.76 g/cm^3, twenty samples of Cretaceous sedimentary rock an average density of 2.61 g/cm^3, and three samples of Cretaceous or Tertiary trachyandesite sills an average density of 2.9 g/cm^3. A single density contrast of -0.15 g/cm^3 between the Cretaceous clastic rocks and the

Mississippian carbonate rocks was assumed for the models along Lick-Route Creek, Basin-Bowl Creek, and Middle Fork Flathead River-Cox Creek (pl. 5). In these models, the short wave-length anomalies, probably due to sills and magnetite-bearing sandstone strata of the Virgelle Sandstone, were removed from the residual gravity profile since they did not directly pertain to the objectives of the study. For the studies along Moose-Bridge Creeks, the effects of some sills that are too small to be detected in the aeromagnetic data could not be readily removed, and three density contrasts were assumed in the modeling.

The actual mass distribution is more complex than could be resolved by the modeling. The top of Mississippian rocks, derived from the models, is based on the assumption of a single constant density contrast between the Mississippian and younger rocks, regardless of varying depth of burial and complex structural relationships. The geologic cross sections were constructed using this simplified gravity model from which the depth and configuration of the Mississippian surface was derived. These sections were then remodeled taking surface geologic features into consideration to check the validity of the assumptions. The resulting calculated gravity profile is shown for comparison with the smoothed observed profile. The minor disparities between observed and calculated profiles are not considered critical to the interpretations.

The geologic cross sections were compiled from 7 1/2 minute field maps and therefore contain more geologic data than is shown on plate 1. The stratigraphic units are discussed in Chapter A and the units that are potential hydrocarbon source and reservoir rocks are discussed in Chapter D. Most thrust faults exposed along the line of sections have small to moderately small stratigraphic displacement; they trend northwest and dip west. The amount of displacement ranges from about 100 ft (30 m) to more than 5,000 ft (1,525 m). The major thrust fault blocks are interpreted to include Paleozoic rocks at depth, most of them extend north from one line of section to another. Ceologic data obtained from plate 1 indicate that Paleozoic rocks are beneath the thrust plate containing Precambrian, Beltian rocks (see sections B-B′, C-C′, and D-D′).

Mississippian rocks are exposed at the east end of each cross section. These rocks are in the east limb of an anticline that is part of an extensive northwest trending zone of folded thrust plates consisting mostly of Paleozoic rocks.

The gravity data and geologic cross sections indicate that potential hydrocarbon reservoir rocks of Mississipian age are in structural traps at relativly shallow depths (less than 10,000 ft-3,000 m).

The interpretations of the detailed gravity data also support the inferred presence, in the subsurface, of other potential structural traps and hydrocarbon source rocks that are discussed in Chapter D.

Northeasterly geophysical trends

Three subtle and somewhat speculative northeasterly trends are inferred from magnetic and gravity data (pls. 3 and 4). They are manifested as a series of aligned high and low anomalies and by parallelism of magnetic and gravity contours. They may reflect buried structures such as northeasterly oriented intrusives, faults, fracture zones, or areas of high relief in the crystalline basement.

The southernmost trend in the study area, the Brown Sandstone Peak-Brady trend, extends northeasterly from Brown Sandstone Peak, past Sheep Mountain and onto the plains. This trend, along with the gravity and magnetic expression of the Scapegoat-Bannatyne feature located farther south has been discussed by Kleinkopf and Mudge (1972).

A second northeasterly trend in the area of Lick Creek is here called the Lick Creek-Pendroy fault trend. It is defined by a saddle between magnetic lows 4,198 and 4,206, and by magnetic high 4,440. The regional gravity data show easterly and northeasterly contour alignments that suggest a possible link to the Pendroy Fault zone northeast on the plains. Of particular note is the thinner section of post-Mississippian sedimentary rocks preserved along Lick-Route Creeks (pl. 5) compared to that to the north (Basin-Bowl Creeks, pl. 5) and to the south (Moose-Bridge Creeks, pl. 5). Perhaps this reflects a broad northeasterly trending arch in this area.

A third possible northeast trend is near the north edge of the study area and is here called the Schafer Meadows-Cox Creek trend. Gravity and magnetic expressions suggest that the trend extends from Schafer Meadows at Schafer Ranger Station past Cox Creek and Swift Reservoir onto the plains. The geologic significance of the trend is unknown.

Conclusions

The aeromagnetic and gravity data provide information about the structural framework and distribution of near surface crystalline rocks. No direct evidence for mineral deposits, such as anomalous magnetic lows that might indicate alteration, was found. The buried crystalline rocks suggested from the interpretations could be sources for mineralization, which are best evaluated by the geochemical studies described in Chapter C of this report. In the evaluation of the petroleum potential of the study area, the gravity model studies provided constraints on the depth and configuration of the top of the Mississippian as an aid to constructing the geologic cross sections. The northeasterly trends may reflect an alignment of mafic intrusive bodies in the crystalline basement. If the alignment is a result of structural discontinuities in the basement such as faults or folds, the trends may reflect a control for the accumulation of hydrocarbons.

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CHAPTER C

A geological and geochemical evaluation of mineral resources of the Bob Marshall Wilderness and study areas

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INTRODUCTION

This chapter discusses the mineral resources, exclusive of oil and gas, and coal, in the Bob Marshall Wilderness and the adjacent wilderness study areas. Oil and gas resources are discussed in Chapter D and coal along with other commodities are discussed in Chapter E. Resources of copper, silver, molybdenum, lead, zinc, and barite are in several parts of the area as shown on fig. 1. None of the known occurrences of these commodities are of sufficient size or grade to be mined. Parts of the area with a potential for large submarginal resources of copper and silver include: (1) along the northwest arm of the study area and east of Hungry Horse Reservoir, where green and gray strata of the Empire and Spokane Formations contain disseminated copper and silver minerals in stratabound deposits, and (2) in the southern part of the area, where copper and silver occur in stratabound deposits in green strata of the Snowslip Formation. The occurrences in the Snowslip also contain subordinate amounts of lead and molybdenum. Small high-grade deposits of barite are in veins in the upper part of Black Bear Creek, in the western part of the area. The deposits are too small and inaccessible to be profitably mined. Precambrian diorite sills locally contain small deposits of copper, silver, lead, and zinc in veinlets and fracture fillings near the sill contacts. Deposits of this type have been prospected in the past, particularly in the vicinity of Goat Ridge near the central part of the study area. The deposits cannot be economically mined because of their small size and limited occurrence.

Most of the anomalous concentrations of base metals and silver are disseminated in green and gray beds of the Belt Formations. This type of mineral occurrence elsewhere in the Belt Basin is well documented (Mudge and others, 1974; Earhart and others, 1976; and Harrison, 1972).

Rocks of similar age and depositional environment to those in the study area contain important sedimentary-type copper deposits elsewhere in the world, particularly in the Rhodesian copper belt (Mendelsohn, 1961). Sedimentary copper-silver deposits of known economic importance in the Belt rocks are in the western part of Montana, near Idaho. The host rocks to these deposits, quartzites of the Revett Formation, are not present in the study area.

The Belt rocks that contain anomalous concentrations of copper and silver in the study area include green quartzite, siltite, and argillite from all the Precambrian formations except the Bonner Quartzite; however, the occurrences in the Empire, Spokane, and Snowslip Formations are more numerous and somewhat more extensive than those in the other formations.

Occurrences of lead with minor amounts of zinc and locally copper and silver are mostly in the Precambrian carbonate rocks, particularly where they contain stromatolites or oolites and where they are in contact with Precambrian diorite sills. These small low grade occurrences have a very low resource potential.

In addition to the above metals, widely scattered rock samples contain weakly anomalous amounts of molybdenum, gold, bismuth, lanthanum, and yttrium. Molybdenum is associated with copper in the stratabound occurrences, particularly with those in the Snowslip Formation. Anomalous molybdenum values are also in shale beds of Jurassic and Cretaceous ages. The occurrences of molybdenum in the Precambrian formations slightly enhances the potential of the stratabound deposits. Very weakly anomalous amounts of gold were detected in a variety of rock types. None suggest a potential for gold deposits. Weakly anomalous amounts of bismuth, lanthanum, and yttrium occur in widely scattered rock samples from a variety of rock types. The area has little to no resource potential for these metals.

The study area contains resources of limestone, sand and gravel, and ornamental stone, but similar extensive deposits of these commodities occur nearer to markets elsewhere in more accessible parts of northwest Montana.

The igneous history of the area suggests that geothermal resources are extremely unlikely. The most recent igneous activity is recorded by trachyandesite sills of Late Cretaceous or Early Tertiary age. All known geothermal fields elsewhere are associated with younger igneous activity.

The mineral evaluation studies were greatly assisted by the close cooperation of Forest Service personnel from the Lewis and Clark, Flathead and Lolo National Forests. Special thanks are due to Bud Powell of the Lewis and Clark National Forest for logistical support and for encouragement, and to Lawrence Prinkki for his insight on the regional geology and for assistance with the field work.

METHODS OF EVALUATION

The mineral resources of the study area were evaluated by geologic mapping and geochemical studies supplemented by geophysical surveys (Chapter B) and by the results of economic studies of prospects (Chapter E). The mineral resource potential is interpreted from the combined data.

The geology of the area was mapped at a scale of 1:24,000 and compiled at a scale of 1:125,000 (pl. 1). During mapping, the rocks were closely examined for indications of mineral deposits. Mapping traverses were on about one mile (1.5 km) spacings and closer where justified. Most were along mountain ridges; however, mapping traverses combined with stream-sediment traverses were made along the bottoms of many of the valleys. The foot traverses were supplemented by geologic mapping from a helicopter.

Stream-sediment and rock samples were collected mostly during geologic mapping of the area. The total number of samples collected by the U.S. Geological Survey field parties was 4,423, of which 1,578 are stream sediment and 2,828 are outcrop samples. In the northwestern part of the area 62 stream sediment samples were analyzed in the field for acid extractable copper. In the initial reconnaissance about 1,200 stream pebbles were examined and analyzed. However, the analytical data on them are not included in this report nor in the tapes open filed with the U.S. Dept. Commerce National Technical Information Service, Springfield, Virginia.

Geochemical studies consisted of rock and stream-sediment sampling, spectrographic and chemical analyses, and the interpretation of the results. Sample numbers and localities are shown on plate 2. Stream sediments were collected from fine material in the major streams and tributaries on about one mile (1.5 km) spacings. Where possible, approximately .7 to 1.2 lb (.3 to .5 kg) of sediments was taken from the most active part of the stream. In many cases, the most active part of larger streams was inaccessible and the material at the edge of the stream channel was sampled. Stream sediments were screened, and the minus 80 mesh fraction was analyzed. Rock samples are from all of the lithologic types of all formations or rock units that crop out in the area. Most are grab samples of about 1.2 to 1.5 lb (.5 to .7 kg), half of which was analyzed, and the other half was retained as a hand specimen. About 80 percent of the samples have no basis of selection; they were collected and analyzed to determine the background and anomalous values of the various elements in the unmineralized rocks. In this report, these are termed "unbiased samples." The remaining 20 percent of the rock samples contained indications of mineralization or had some other basis for selection. These are termed "biased samples." Indications of mineralization included visible sulfide minerals or their oxidation products, and altered rocks. Where mineralized rock was found, the highest grade material was usually selected. Evaluated with the samples are 84 samples from the northwest boundary of the Scapegoat Wilderness and unpublished analytical data on 321 stream and rock samples collected previously in the Sun River drainages by M. R. Mudge and R. E. Erickson. Also Ca/Mg analyses of 277 samples of carbonate rock previously collected by Mudge are used in this report; most of them were published previously (Mudge, 1972a). The distribution of rock samples by type and source is given in table 2. About 61 percent of the rock samples are from the Precambrian rocks.

Table 2.--Distribution of rock samples by geologic units or by geologic age

Sedimentary and Metasedimentary Rocks

Sample source	Unbiased samples	Biased samples	Total
Tertiary rocks	9	5	14
Middle and Upper Cretaceous rocks	60	10	70
Lower Cretaceous rocks	239	15	254
Cretaceous and Jurassic rocks			
Morrison Formation	54	18	72
Jurassic rocks			
Ellis Group	54	12	66
Paleozoic rocks			
Mississippian rocks	145	9	154
Devonian rocks	179	5	184
Cambrian rocks	222	6	228
Precambrian rocks			
Garnet Range Formation	45	--	45
McNamara Formation	227	58	285
Bonner Formation	144	41	185
Mount Shields Formation	298	50	348
Shepard Formation	98	50	148
Snowslip Formation	183	99	282
Helena Formation	188	39	227
Empire and Spokane Formations	59	49	108
TOTAL	2204	466	2670

Igneous Rocks and Veins

Cretaceous sills	32	12	44
Preambrian sills	102	12	114
Veins		61	
TOTAL	134	85	158

TOTAL ROCK SAMPLES -- 2828

All samples were analyzed for 30 elements by a semiquantitative emission spectrographic technique (Grimes and Marranzino, 1968). These elements and their lower limits of detection by this technique are given in table 3.

In addition, all samples were analyzed for gold and a few for silver and copper by atomic absorption methods. Most samples were analyzed for mercury by a mercury detector method (Vaughn and McCarthy, 1964) and most were scanned for radioactivity by a gamma ray detector.

All stream-sediment samples were analyzed for copper extracted in a 6-normal hydrochloric acid solution and for cold extractable heavy metals by colorimetric methods. Stream sediments at 62 localities in the northwest part of the area were analyzed on-site for copper extracted in a 6-normal hydrochloric acid solution by a colorimetric method (Canney and Hawkins, 1958) that was adapted for field use. This method was applied in order to evaluate a copper anomaly detected by other methods in that part of the area.

Many analysts contributed to the analyses of the samples. Spectrographic analyses were by D. J. Grimes and J. A. Domenico and a few by J. C. Hamilton. Atomic absorption determinations of gold and silver were by R. M. O'Leary, C. A. Curtis, J. Mitchell, E. Welsch, J. D. Hoffman, and R. L. Miller. Atomic absorption copper determinations were by J. Mitchell and R. W. Leinz. Citrate-soluble heavy metals and acid extractable copper were determined by J. Mitchell, J. D. Hoffman, and J. D. Sharkey. Mercury was determined by J. G. Frisken, R. L. Turner, R. B. Carten, and R. L. Miller. Calcium was determined volumetrically and magnesium determined gravimetrically by E. J. Fennelly and I. C. Frost.

Table 3.--Elements determined by the semiquantitative spectrographic technique, and the lower limits of detection.

[All values are in parts per million except iron, magnesium, calcium, and titanium, which are given in percent.]

Element	Lower limit of detection	Element	Lower limit of detection
Iron	0.05	Copper	5
Magnesium	.02	Lanthanum	20
Calcium	.05	Molybdenum	5
Titanium	.002	Niobium	20
Manganese	10	Nickel	5
Silver	.5	Lead	10
Arsenic	200	Antimony	100
Gold	10	Scandium	5
Boron	10	Tin	10
Barium	20	Strontium	100
Beryllium	1	Vanadium	10
Bismuth	10	Tungsten	50
Cadmium	20	Yttrium	10
Cobalt	5	Zinc	200
Chromium	10	Zirconium	10

During the course of the project, a source of copper contamination was discovered in the spectrographic analytical method, which affected over half of the samples collected from the area. Corrective measures were taken to eliminate the contamination, and the analyses of the copper-contaminated samples were spot checked by replicate spectrographic analyses and by atomic absorption. Replicate analyses showed that the samples most affected were those that contained amounts of copper in the range of the lower reporting steps (5, 7, 10, 15, and 20 ppm). The actual copper in a large number of these samples were 2 to 3 reporting steps lower than indicated by the analyses of the contaminated sample. In the higher reporting steps (30, 50, 70 ppm and more), the amount of contamination was usually insufficient to have a marked effect on the analytical results. Thus the contamination probably has not resulted in creating significant "false-anomalies." However, the copper background values given in this report for most rock types and stream sediments, which are in the range of the lower reporting steps, are probably somewhat high. The affect of the analytical error on the evaluation of the copper potential is indeed minimal.

The results of the aeromagnetic and gravity geophysical surveys, while important to the evaluation of the oil and gas potential, are of limited value to the interpretation of the potential for other mineral resources in the area. The types of mineral occurrences in the study are not usually directly reflected by regional aeromagnetic and gravity surveys. The geophysical results do indicate that it is unlikely that the area contains mineral deposits associated with buried intrusive rocks at depths considered reasonable for exploration and mining. One possible exception to this is in the northwest part of the area where stratabound deposits and associated vein deposits in the Empire and Spokane Formations could be enriched by an intrusive, interpreted from an aeromagnetic anomaly (Chapter B), to be emplaced at a depth of about 6,500 ft (2,000 m). It is remotely possible that the intrusive may have contributed metals to the deposits, or it may have provided a source of heat that remobilized the metallic minerals and concentrated them in fractures and in favorable sedimentary horizons.

INTERPRETATION OF GEOCHEMICAL DATA

The geochemical data are interpreted with respect to geologic environments. The compilation and interpretation of the analytical and rock data required the aid of a computer because analytical determinations number nearly 150,000. Variables are further increased with the input of geologic data. The analytical data from unbiased rock samples and from stream sediments provided the basis for determining mean and threshold (the upper limit of background) values for the elements of interest in the sample categories shown in table 4.

The elements of principal interest, as indicated by the analytical

Table 4.--Geometric mean, threshold, and percentage of anomalous values of copper and lead in selected categories of unbiased samples

Sample category	Geometric mean values		Threshold values		Percent of samples with anomalous values	
	Cu	Pb	Cu	Pb	Cu	Pb
Red quartzite from Yes, Ysn, Ysh, Yms, Ym	18	11	30	15	12	<2
Red quartzite from Ybo	15	N	30	N	12	N
Green quartzite from Yes, Ysn, Ysh, Yms	14	14	30	22	15	<2
Green quartzite from Ym	21	14	70	17	<2	4
Red siltite from all Precambrian formations	15	13	25	30	10	<2
Green siltite from all Precambrian formations	19	13	30	20	13	5
Red argillite from all Precambrian formations	10	16	30	30	<2	<2
Green argillite from all Precambrian formations	15	16	30	22	13	<2
Precambrian carbonate rocks 1/	15	16	30	20	<2	15
Precambrian carbonate rocks 2/	22	25	24	20	21	35
Paleozoic carbonate rocks	10	N	30	N	<2	N
Jurassic sandstone	15	N	30	N	9	N
Lower Cretaceous sandstone	18	N	30	N	13	N
Lower Cretaceous siltstone	25	N	50	N	4	N
Lower Cretaceous shale	25	16	>50	20	<2	15
Upper and middle Cretaceous shale	21	15	>30	>20	0	0
Precambrian diorite sills 3/	315	13	500	17	3	10
Cretaceous sills	72	N	150	N	0	N
Stream sediments	25	17	30-70 4/	30	(?)-2	8

1/ Excludes those with stromatolites and/or oolites

2/ With stromatolites and/or oolites, also includes biased samples

3/ Based on 45 representative samples from 2 sections

4/ At least two anomalous populations

N = Not determined because of insufficient unqualified values

Yes-Empire and Spokane Formations, Ysn-Snowslip Formation, Ysh-Shepard Formation, Yms-Mount Shields Formation, Ybo-Bonner Formation, Ym-McNamara Formation data and by geological observations, are copper, lead, and silver. Silver is omitted from table 4 because most of the samples contained less than 0.5 ppm, the lower detection limit. Therefore, any sample with detectable silver is considered anomalous. The threshold values for copper and lead in the various sample categories were determined by plotting the cumulative percent frequency distribution of analytical values on log probability graphs after the method described by Sinclair (1974). Values greater than threshold are considered anomalous.

Geometric mean values are given in table 4 for comparison with the threshold values. The geometric mean values are computed using only unqualified values. Most sample categories had at least a few samples with analytical results below the limits of detection. As a result, the geometric mean values given in the table are somewhat higher than the actual values. For this reason, the determination of an anomalous value by the cumulative frequency plot is probably more valid than a method based on the geometric mean such as twice the geometric mean or the geometric mean plus two standard deviations.

The geometric mean value of lead in carbonate rocks with stromatolites or oolites (table 4) is actually higher than the threshold value. This is because this sample category includes both unbiased and biased samples, many of which are highly anomalous in lead. Both biased and unbiased samples are included in the geometric mean calculation, but the threshold value reflects only the upper limit of the "normal" lead values.

In general, the rock types with the higher percentages of anomalous values (the last two columns in table 4) in the unbiased samples are the most favorable for deposits of copper and lead, as determined by geologic studies. These studies indicate that the Precambrian green strata are most favorable for copper deposits and Precambrian carbonate rocks are most favorable for lead deposits, and these sample categories have a relatively high percentage of anomalous values. However, this association must be evaluated in context with geological observations. Precambrian red quartzites and siltites are considered to have no potential for copper deposits although they have a relatively high percentage of unbiased samples with anomalous amounts of copper.

Green quartzites of the McNamara Formation, considered in a separate category in table 4, contain highly variable amounts of glauconite. The copper content of these rocks commonly varies with that of glauconite. As a result, the background values of copper cover a broader range than that in quartzites of other formations.

The interpretation of the distribution of copper in stream sediments is problematic, because the copper values represent more than one, and probably multiple, populations. They must be evaluated in the context of the geology of the drainage basin. For example, the sediment in streams whose drainage contains diorite sills commonly contains 70 ppm copper. Although this value is normal in the vicinity of the sills,

Table 5.--Analytical results of selected anomalous stream sediment and rock samples from the Bob Marshall Wilderness and study areas.

[Samples included in table contain equal to or greater than 100 ppm Cu, or 100 ppm Pb, or 200 ppm Zn, or 5 ppm Mo, or 1 ppm Ag. Analyses are by a semiquantitative emission spectrographic method and by atomic absorption methods. The elements As, Au, Be, Bi, Nb, Sb, Sn, and W were analyzed but are not listed in the table because all samples contained undetected or insignificant amounts.]

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
						Rock Samples								
						Empire and Spokane Formations								
H007	55,725	104,350	3.00	3.00	2.00	.150	700	20.0	50	200	N	30	30	20,000
H007B	55,725	104,350	1.50	.70	10.00	.030	1,500	50.0	<10	200	N	<5	7	10,000
H007C	55,725	104,350	1.50	1.50	1.00	.070	500	15.0	70	500	N	<5	7	15,000
HS431	67,050	151,675	3.00	2.00	3.00	.100	1,500	N	50	2,000	N	100	20	1,500
B241B	91,075	146,475	2.00	.30	.10	.200	50	.5	150	700	N	5	15	100
H235	109,600	145,125	2.00	1.50	.50	.070	1,500	N	10	1,500	N	1,000	10	1,000
H514B	92,775	92,775	.70	1.50	3.00	.030	500	.7	N	2,000	N	N	20	3,000
H514C	92,775	92,775	2.00	3.00	1.50	.200	200	.7	30	150	N	7	30	500
H521A	105,875	91,000	3.00	5.00	3.00	.500	1,000	7.0	70	500	N	15	50	5,000
B715	139,700	94,900	1.50	.70	.07	.300	150	1.0	30	300	N	7	50	150
B715A	139,700	94,900	3.00	.50	.15	.300	500	<.5	20	300	N	20	50	700
B715B	139,700	94,900	1.50	.20	.07	.150	150	3.0	N	700	N	5	20	700
B715C	139,700	94,900	3.00	.30	.15	.300	500	30.0	N	3,000	N	20	30	7,000
B715D	139,700	94,900	3.00	1.00	.07	.300	200	N	20	200	N	10	70	150
B716	139,600	95,200	.70	.07	.10	.030	200	20.0	N	>5,000	N	5	N	15,000
B716D	139,600	95,200	1.50	.30	.05	.150	30	70.0	50	>5,000	N	<5	30	20,000
B716E	139,600	95,200	2.00	.70	<.05	.500	70	1.5	50	300	N	5	70	500
B716F	139,600	95,200	3.00	.20	<.05	.200	500	1.0	N	300	N	30	20	700
B716I	139,600	95,200	1.50	.15	.30	.100	200	1.0	N	3,000	N	15	<10	500
B716J	139,600	95,200	1.50	.70	.05	.300	100	2.0	30	500	N	7	70	700
B721	132,000	97,300	3.00	.20	<.05	.200	50	100.0	150	300	N	5	50	>20,000
H829	147,975	92,750	3.00	3.00	5.00	.100	1,000	1.0	10	5,000	N	5	<10	300
H830	147,500	92,425	3.00	3.00	3.00	.150	700	N	50	300	N	7	30	150
B735	159,400	87,400	1.00	2.00	.50	.200	200	N	50	300	N	5	30	150
B293	16,875	144,300	1.50	2.00	3.00	.200	1,500	.7	30	1,500	N	7	30	700
B914	20,875	137,050	10.00	1.50	3.00	1.000	1,000	N	10	300	N	50	15	300
B929	19,875	130,875	7.00	2.00	5.00	1.000	1,500	N	N	150	N	50	50	300
B973	166,325	76,000	1.50	1.00	5.00	.150	1,500	N	70	>5,000	N	7	30	15
B982	138,825	96,300	1.00	.30	.15	.200	70	2.0	70	300	N	10	N	1,000
B933	129,775	98,300	1.50	1.00	2.00	.070	500	.7	70	1,000	N	15	N	300
B933A	129,775	98,300	1.50	.30	.07	.500	150	3.0	150	700	N	7	50	1,500
						Helena Formation								
H002A	65,950	102,725	7.00	.70	5.00	.100	300	N	20	300	N	30	20	10
H002C	65,950	102,725	7.00	1.00	2.00	1.000	1,000	N	<10	50	N	100	30	500
H002D	65,950	102,725	10.00	1.00	1.50	1.000	1,500	N	<10	70	N	70	30	300
H004	75,375	99,725	1.50	2.00	5.00	.150	300	<.5	15	300	N	50	15	7
HS657	64,650	153,650	1.50	1.50	2.00	.200	100	<.5	50	300	<20	<5	50	7
B155B	95,000	145,675	1.50	3.00	15.00	.070	700	N	200	200	N	N	<10	70
B159B	98,675	146,525	2.00	7.00	10.00	.030	1,000	.7	30	70	N	N	N	15
B159C	98,675	146,525	1.50	7.00	15.00	.020	700	<.5	20	30	N	10	N	7
HS645	64,650	153,650	1.00	3.00	15.00	.030	700	N	N	30	N	<5	N	10
HS648	64,650	153,650	1.00	5.00	5.00	.030	1,500	N	<10	50	N	<5	N	5

Table 5.--continued

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
						Empire and Spokane Formations								
H007	20	2,000	30	300	7	N	30	50	N	100	4.50	N	--	--
MC07B	N	15	7	500	N	300	10	30	N	15	.11	N	--	--
MC07C	N	70	15	700	<5	<100	20	15	N	50	.65	.20	--	--
HS461	20	10	50	10	10	100	50	20	N	200	.10	--	2,200	--
B241B	30	15	15	20	5	<100	100	10	N	200	.07	<.02	130	--
M235	30	N	700	<10	10	150	50	30	N	100	.04	<.02	--	--
M5143	30	70	5	200	N	N	10	15	N	30	1.40	.05	--	--
M514C	30	N	20	200	7	N	70	30	N	200	.13	N	--	--
M521A	70	N	30	30	20	N	70	70	300	500	.06	N	--	--
B715	70	N	20	15	15	N	100	30	N	150	.06	N	--	<.50
B715A	30	N	30	10	15	N	70	30	N	150	.04	N	--	N
B715B	70	N	10	15	5	<100	30	20	N	100	.04	N	--	2.00
B715C	70	N	30	20	10	<100	70	30	N	150	.04	N	--	22.00
B715D	70	N	20	15	15	N	150	50	N	150	.04	N	--	N
B716	20	N	5	30	<5	700	10	15	N	70	.04	N	--	28.00
B716D	50	N	15	15	10	150	70	20	N	100	.04	N	--	.74
B716E	70	N	20	15	15	N	100	30	N	150	.02	N	--	.50
B716F	N	N	30	15	7	N	30	20	N	150	.02	N	--	.50
B716I	20	N	20	15	5	100	20	30	N	150	.04	N	--	1.00
B716J	70	N	20	20	15	N	100	30	N	150	.02	N	--	1.00
B721	50	N	15	N	15	<100	70	30	N	150	.60	.10	--	[illegible]
M829	70	15	10	100	10	100	20	30	N	100	.08	N	--	1.00
M830	50	N	20	10	15	N	70	30	N	100	.04	N	--	N
B735	30	N	15	15	5	N	50	15	N	150	.02	N	--	N
B898	20	N	15	15	5	100	20	15	N	200	.14	N	--	--
B914	<20	N	30	15	30	150	300	70	N	150	N	<.05	--	--
B920	<20	N	50	<10	30	150	300	30	N	150	N	<.05	--	--
B973	30	20	15	N	10	100	30	30	N	100	--	--	--	--
B982	50	N	15	<10	10	100	50	30	N	200	--	--	--	--
B983	20	N	20	15	7	500	30	30	N	50	--	--	--	--
B983A	50	N	10	15	10	300	70	30	N	200	--	--	--	--
						Helena Formation								
H002A	<20	N	30	200	<5	N	20	30	N	150	--	--	--	--
H002C	N	N	50	<10	50	100	500	30	N	50	--	--	--	--
H002D	N	N	30	<10	50	100	500	30	N	150	--	--	--	--
H004	70	<5	30	150	5	N	15	50	<200	200	--	--	--	--
HS657	20	7	10	10	<5	<100	70	<5	<200	30	--	--	--	--
B155B	<20	N	N	200	<5	N	15	15	<200	30	.02	<.02	--	--
B159B	<20	N	<5	1,500	N	N	10	10	N	20	.01	<.02	--	--
B159C	N	N	20	>20,000	N	<100	10	10	3,000	20	.04	<.02	--	--
HS645	<20	N	N	20	N	100	N	15	500	20	.02	<.02	15	--
HS648	<20	N	N	15	N	N	<10	10	300	20	.04	<.02	10	--

Table 5.--continued

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
HS650	64,650	153,650	1.50	5.00	7.00	.007	1,500	N	N	<20	N	N	N	20
HS656	64,650	153,650	1.50	5.00	5.00	.030	1,000	N	<10	50	N	N	N	30
HS603	64,650	153,650	.70	1.50	10.00	.050	200	N	N	50	N	5	N	15
M227	100,975	146,350	1.50	5.00	10.00	.010	500	1.0	20	70	N	<5	N	<5
M227A	100,975	146,350	2.00	5.00	15.00	.010	700	1.5	20	<20	N	5	N	7
M515	93,300	94,575	2.00	3.00	20.00	.200	300	N	30	300	N	7	30	15
M517A	92,275	95,000	3.00	3.00	>20.00	.100	1,000	N	30	500	N	70	30	20
B560A	73,650	100,000	1.50	5.00	10.00	.300	700	2.0	500	500	N	7	30	700
M545	72,000	126,900	1.50	5.00	15.00	.050	500	<.5	50	700	N	20	15	15
M712	156,000	85,750	7.00	1.50	.50	.300	700	N	100	1,000	N	20	50	20
B677	128,900	102,100	1.50	3.00	>20.00	.050	500	N	30	100	N	N	10	10
M771	130,650	100,550	3.00	7.00	10.00	.070	1,000	N	30	300	N	N	30	7
M772	129,700	101,275	3.00	7.00	>20.00	.150	1,000	N	100	500	20	10	20	30
M773	123,100	101,975	2.00	2.00	15.00	.070	700	N	30	100	20	5	15	20
M813	145,000	94,750	.70	1.00	1.00	.200	500	N	30	300	N	<5	30	20
B714	148,350	100,700	1.50	3.00	15.00	.070	700	1.5	50	500	N	10	20	10
M239	153,300	95,150	1.50	1.00	>20.00	.030	1,000	1.5	N	300	N	20	10	500
B723	152,000	99,200	3.00	7.00	5.00	.200	1,000	N	70	300	N	7	50	300
B724	153,200	90,150	2.00	10.00	15.00	.150	1,000	2.0	70	3,000	N	7	30	300
B759	140,000	124,200	1.00	2.00	5.00	.015	1,500	.7	N	300	N	15	N	70
B759B	140,000	124,200	1.50	1.50	1.50	.070	1,000	10.0	30	200	N	20	10	5,000
B900A	17,550	144,600	3.00	1.50	15.00	.150	300	N	50	500	100	30	30	300
B950	28,025	135,850	1.50	2.00	20.00	.050	700	.7	<10	150	N	N	30	1,000
B999	170,300	82,275	2.00	5.00	10.00	.100	700	N	100	300	N	N	50	7
Snowslip Formation														
M014B	58,875	138,250	1.50	1.00	.10	.300	200	10.0	70	500	N	20	50	3,000
M015A	58,575	138,150	1.00	1.50	.15	.200	150	15.0	50	700	N	20	15	7,000
M015B	58,575	138,150	1.50	2.00	.30	.300	150	10.0	70	700	N	20	20	2,000
L143	41,200	149,400	.70	.20	7.00	.150	2,000	N	10	70	N	<5	15	300
L145	40,870	149,120	1.50	1.00	.70	.200	300	7.0	50	500	N	10	30	2,000
B154B	94,775	145,700	2.00	.70	1.00	.200	200	N	50	200	N	20	30	500
M232	109,025	144,675	3.00	3.00	2.00	.300	1,500	3.0	<10	150	N	50	20	2,000
M232A	109,025	144,675	3.00	3.00	1.50	.300	1,500	7.0	<10	200	N	70	15	2,000
M232B	109,025	144,675	3.00	2.00	1.00	.300	1,000	2.0	20	700	N	30	30	700
B271A	106,750	144,925	2.00	5.00	7.00	.150	1,000	N	<10	700	N	<5	<10	300
B375	62,400	131,025	1.50	.70	.20	.200	200	15.0	70	700	N	20	30	5,000
B376	62,275	131,075	1.50	1.00	.07	.150	100	15.0	50	300	N	15	20	7,000
M349	60,450	134,650	.70	.70	10.00	.050	2,000	N	15	300	N	5	15	150
M349D	60,450	134,650	3.00	1.00	.50	.300	700	N	70	300	N	15	30	200
M349E	60,450	134,650	1.00	.50	1.00	.300	700	5.0	70	200	N	10	30	1,500

Table 5.--cont.

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	[illegible]N	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
HS650	N	N	N	15	N	N	N	10	700	<10	.30	<.02	25	--
HS656	<20	N	N	<10	N	N	10	10	500	50	.40	<.02	15	--
HS683	20	N	5	20	N	100	10	15	300	30	.24	.04	30	--
M227	N	N	15	5,000	N	<100	<10	<10	N	15	.05	<.02	10	--
M227A	N	N	15	1,500	N	N	<10	<10	N	10	.10	<.02	10	--
M515	50	20	20	30	10	N	70	50	N	150	.06	N	--	--
M517A	50	N	50	150	7	100	70	70	N	150	.02	N	--	--
B560A	70	N	15	30	15	100	70	100	N	150	.10	N	--	--
M545	30	N	15	70	5	100	70	30	700	70	.22	N	--	N
M712	70	15	50	10	15	<100	100	50	300	200	.02	N	--	N
B677	50	N	5	10	5	100	50	15	500	30	.40	N	--	N
M771	N	N	10	10	5	N	30	20	1,000	70	.12	N	--	N
M772	30	N	20	700	10	100	70	30	500	100	.06	N	--	N
M773	20	N	10	300	7	100	100	20	N	50	.40	N	--	N
M818	20	N	10	10	7	N	30	20	500	70	.02	N	--	N
B714	30	30	15	1,000	5	100	30	15	N	50	.06	N	--	1.00
M339	50	N	5	70	<5	300	70	30	N	20	.10	N	--	1.00
B723	70	N	20	20	15	N	50	30	N	150	.02	N	--	N
B724	30	N	10	70	15	200	50	30	N	100	.10	N	--	1.00
B759	N	N	10	300	N	N	30	10	N	30	.22	N	--	1.00
B759B	20	N	30	30	<5	N	30	15	<200	70	>10.00	N	--	5.00
B900A	20	N	20	200	7	N	50	20	5,000	100	3.00	N	--	--
B950	50	N	N	20	N	200	20	30	N	20	.06	N	--	--
B959	30	20	10	<10	10	100	30	15	N	100	--	--	--	--
Snowslip Formation														
MO14B	50	15	20	70	10	N	70	20	N	200	--	<.02	5,000	6.00
MO15A	30	7	20	30	7	N	50	30	N	150	--	<.02	3,000	14.00
MO15B	50	N	20	30	10	N	50	30	N	100	--	<.02	5,000	9.00
L143	20	N	10	<10	5	100	20	30	N	100	.03	N	--	--
L145	<20	100	15	20	7	N	50	20	N	200	.22	N	--	--
B154B	20	N	15	N	10	N	50	20	N	200	.02	<.02	--	--
M232	70	N	20	50	15	<100	70	50	N	200	.06	<.02	--	--
M232A	50	N	30	50	15	N	70	50	N	150	.06	.02	--	--
M232B	30	30	20	50	10	<100	50	20	N	150	.02	<.02	--	--
B271A	<20	N	7	100	5	N	30	20	N	100	.02	<.02	--	--
B375	20	N	20	300	10	N	100	20	N	150	.11	N	--	--
B376	30	200	15	500	7	N	70	20	N	100	.46	N	--	--
M349	30	N	5	30	5	200	100	30	N	70	.06	N	--	--
M349D	30	N	20	10	10	N	70	30	N	300	<.01	N	--	--
M349E	20	N	10	10	7	N	70	30	N	200	.07	N	--	--

Table 5.--continued

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
M350	60,275	134,200	2.00	1.00	2.00	.100	700	1.5	30	1,000	N	20	15	1,500
M369	26,075	120,225	1.50	.50	.10	.150	300	15.0	50	700	N	5	15	7,000
M369A	26,075	120,225	1.50	1.00	.07	.300	200	50.0	300	5,000	N	15	70	15,000
B397	56,375	141,600	1.50	.50	15.00	.200	1,500	N	30	70	N	5	20	300
B397A	56,375	141,600	3.00	2.00	3.00	.500	150	7.0	150	1,500	N	30	30	7,000
B398A	56,075	141,400	3.00	1.50	1.50	.300	1,000	N	100	150	N	10	20	300
B399	55,825	141,225	2.00	2.00	.15	.300	150	15.0	100	150	N	15	20	7,000
M416	24,050	125,625	2.00	2.00	.30	.500	500	N	150	200	N	50	50	500
M448	39,875	115,475	2.00	3.00	1.00	.300	500	N	50	300	N	10	50	70
M452	47,450	111,750	1.50	1.00	.30	.300	150	2.0	50	300	N	10	30	100
M452A	47,450	111,750	2.00	1.00	.10	.300	300	5.0	70	300	N	10	50	3,000
M453	47,900	112,150	1.50	.70	.07	.150	100	.5	15	300	N	5	15	1,000
M454	48,025	112,850	1.50	.70	.10	.300	200	3.0	50	200	N	7	30	300
M455	48,125	113,750	2.00	.70	.05	.300	200	N	50	300	N	7	30	20
M527A	86,725	102,600	1.50	1.00	2.00	.200	700	N	10	300	N	N	15	200
B552	92,425	101,625	2.00	1.00	10.00	.150	1,500	.5	20	150	N	N	20	15
B553	92,275	101,925	2.00	.70	<.05	.200	70	.7	50	300	N	N	30	30
B561	90,250	102,000	2.00	2.00	.15	.300	150	3.0	100	300	N	10	50	700
B571	101,600	99,825	2.00	1.00	.10	.300	200	10.0	100	2,000	N	15	50	7,000
M664A	101,300	97,400	3.00	2.00	7.00	.150	1,000	1.5	50	300	N	15	30	30
M682	105,100	97,600	3.00	5.00	5.00	.300	1,500	1.5	100	300	N	15	50	100
B687A	129,100	106,200	3.00	2.00	20.00	.200	>5,000	N	100	300	N	15	70	700
P688	128,575	106,600	3.00	1.50	.05	.300	200	<.5	150	700	N	7	100	30
M776A	126,200	103,000	3.00	2.00	7.00	.150	700	1.5	30	500	N	7	30	50
M779	125,225	103,400	3.00	1.50	3.00	.300	5,000	<.5	200	500	N	20	50	7,000
M780	124,375	103,400	5.00	1.50	.10	.300	500	N	150	300	N	10	30	200
M781	124,600	103,700	3.00	1.00	.70	.150	3,000	7.0	50	700	N	7	15	5,000
M801	136,475	104,150	1.50	1.50	7.00	.150	700	1.0	50	700	N	7	20	7,000
M805	135,600	105,750	1.50	.70	7.00	.070	1,500	3.0	20	700	N	5	<10	2,000
B705	142,200	103,600	1.00	.20	1.00	.020	1,000	N	N	300	N	5	N	300
M842	153,600	96,075	7.00	2.00	.30	.200	200	15.0	150	700	N	20	70	30
M872A	136,975	112,675	2.00	2.00	1.00	.100	500	<.5	20	150	N	15	15	1,000
B889	24,050	143,750	5.00	2.00	.05	.500	200	<.5	300	>5,000	N	10	70	15
B889A	24,050	143,750	1.50	.70	3.00	.200	2,000	1.5	50	300	N	<5	20	700
B891	23,850	144,425	3.00	2.00	.15	.200	200	<.5	100	500	N	10	50	500
Sheppard Formation														
L141	41,580	149,610	2.00	1.00	10.00	.100	300	[illegible]	30	>5,000	N	N	30	200
HS549	93,900	148,275	2.00	1.50	1.50	.150	200	[illegible]	70	1,500	N	7	30	3,000
B270	106,725	144,775	3.00	2.00	3.00	.100	50[illegible]	[illegible]	70	5,000	N	7	30	2,000
M243A	112,375	141,925	3.00	2.00	3.00	.200	[illegible]	[illegible]	20	>5,000	N	15	50	1,500
M302	46,650	107,150	3.00	1.50	15.00	.150	[illegible]	[illegible]	50	150	N	30	70	200

Table 5.--continued

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
M350	20	100	10	500	5	100	20	30	N	70	.06	N	--	--
M369	20	70	15	N	5	100	50	30	N	200	1.40	N	--	--
H369A	30	70	15	N	15	N	150	30	N	200	.64	.05	--	--
B397	20	N	15	500	5	150	50	50	N	200	.04	N	--	--
B397A	70	N	50	N	15	N	70	50	N	300	.05	N	--	--
B398A	50	N	30	N	7	N	70	70	N	300	<.01	N	--	--
B399	30	20	30	50	7	N	70	20	N	500	.02	N	--	--
M416	50	N	30	30	30	N	70	50	N	300	.06	N	--	--
M443	30	7	20	50	10	N	70	20	N	300	.02	N	--	--
M452	30	30	15	700	15	N	70	20	N	150	.08	<.05	--	--
M452A	30	N	20	<10	15	N	100	30	N	150	.06	<.05	--	--
M453	20	N	15	50	7	N	30	20	N	150	.02	<.05	--	--
M454	20	N	15	N	15	N	20	15	N	200	.02	<.05	--	--
M455	30	15	15	20	10	N	70	20	N	150	.02	N	--	--
M527A	N	N	7	N	5	N	10	15	N	150	.02	N	--	--
B552	20	5	10	500	7	100	30	15	N	100	.08	N	--	--
B553	30	20	7	200	10	N	70	15	N	150	.10	N	--	--
B561	30	N	15	20	15	N	100	30	N	150	.12	N	--	--
B571	30	N	30	200	15	200	70	30	N	150	.45	N	--	11.00
H664A	30	15	15	200	7	150	70	30	N	150	.10	N	--	1.00
M682	70	50	30	500	15	<100	100	30	N	150	.06	N	--	.50
B657A	100	N	10	20	10	200	70	50	N	500	.02	N	--	N
B683	50	N	15	150	15	N	100	20	N	200	<.02	N	--	N
M776A	30	15	15	70	5	N	50	30	N	200	.02	N	--	1.00
M779	100	15	20	30	15	N	100	70	N	300	.12	N	--	1.00
M780	50	N	30	10	10	N	70	30	N	700	.02	N	--	N
M781	30	N	20	10	7	N	50	30	N	150	.14	N	--	<.50
M801	20	N	15	150	7	100	70	20	N	150	.08	N	--	1.50
M805	20	N	7	50	5	100	50	30	N	70	.10	N	--	N
B705	30	N	5	15	<5	N	15	20	N	70	.02	N	--	N
M842	70	N	30	10,000	15	N	100	30	N	200	.10	N	--	15.00
M872A	20	N	15	70	5	N	50	20	N	70	.02	N	--	N
B859	70	10	20	70	15	<100	150	20	N	200	.10	N	--	--
B839A	50	N	10	10	7	<100	30	70	N	100	.10	N	--	--
B891	50	N	50	70	10	N	50	30	N	500	.08	N	--	--
Shepard Formation														
L141	30	N	15	70	7	700	30	70	N	150	<.01	N	--	--
HS549	20	N	10	<10	5	100	70	15	N	150	.05	<.02	5,500	--
B270	20	N	15	10	7	150	100	20	N	150	.02	<.02	--	--
M243A	70	N	15	10	5	1,000	100	30	N	300	.12	<.02	--	--
M302	20	15	30	70	15	150	70	30	N	70	.06	N	--	--

Table 5.--continued

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
M34SE	60,975	135,225	1.00	.70	10.00	.100	500	N	30	100	N	10	30	500
B393	57,300	141,400	3.00	7.00	10.00	.300	1,000	N	50	200	N	5	30	150
B395	56,925	141,575	2.00	2.00	20.00	.200	500	N	50	5,000	N	5	20	15
M462	51,200	115,650	1.50	1.00	20.00	.200	2,000	N	10	200	N	15	50	300
M472A	43,400	120,400	5.00	1.00	5.00	.020	300	N	<10	>5,000	N	N	10	70
M523A	86,775	102,950	1.00	.70	10.00	.150	2,000	N	10	150	N	50	30	1,000
M529	87,150	103,175	1.50	1.50	10.00	.200	1,500	N	30	200	N	15	30	700
M529A	87,150	103,175	1.50	1.50	20.00	.500	2,000	N	10	300	N	15	30	1,500
B554	92,125	102,200	1.50	2.00	20.00	.100	500	N	10	200	N	N	20	15
M542	72,900	127,375	2.00	2.00	20.00	.300	1,500	N	50	500	N	15	70	7,000
M542A	72,900	127,375	3.00	3.00	>20.00	.150	3,000	N	30	700	N	N	50	1,500
M543	72,650	127,100	3.00	3.00	15.00	.300	5,000	N	70	500	N	30	50	300
M674	103,475	100,850	3.00	7.00	7.00	.150	1,500	N	70	1,500	N	5	50	700
M674A	103,475	100,850	3.00	3.00	1.50	.100	700	.7	70	700	N	15	10	300
M675	103,750	100,500	1.50	1.50	2.00	.100	1,500	N	50	>5,000	N	N	10	300
B664	121,400	110,600	3.00	5.00	5.00	.150	700	N	70	700	N	5	30	300
M736	126,100	116,500	3.00	2.00	.07	.150	50	<.5	30	500	N	15	30	20
B669	129,175	116,900	3.00	3.00	1.50	.300	500	5.0	100	300	N	20	70	1,500
B703	132,700	107,100	3.00	2.00	20.00	.150	2,000	1.0	50	300	N	10	50	50
B933	31,400	122,500	3.00	3.00	5.00	.200	700	N	70	300	N	7	30	200
B974	156,200	96,575	2.00	2.00	.10	.300	50	N	150	1,000	N	30	70	150
Mt. Shields Formation														
MS514	77,475	148,550	2.00	1.00	.70	.150	500	2.0	20	500	<20	10	20	7
M26A	67,675	144,875	2.00	.70	.10	.150	100	1.0	70	300	N	20	15	500
B21A	63,650	146,450	2.00	1.50	.70	.300	500	20.0	70	500	N	15	70	15,000
B29	65,000	144,375	1.00	.50	.05	.070	100	N	20	500	N	N	10	200
B44A	73,375	139,425	2.00	1.00	.10	.300	200	1.5	50	300	N	15	70	1,000
MS492	73,700	149,700	10.00	1.50	1.50	1.000	700	N	20	300	N	50	20	200
B257	103,975	145,675	2.00	2.00	2.00	.100	200	2.0	50	1,500	N	10	30	7,000
M242	112,325	141,700	1.50	7.00	15.00	.030	3,000	2.0	15	50	N	15	N	20
M253	113,100	140,400	1.00	.30	.30	.070	500	N	30	500	N	10	N	150
B354	66,175	131,175	5.00	3.00	2.00	.300	700	.5	100	300	N	30	30	1,500
B367B	64,450	132,425	.30	.70	<.05	.070	70	1.0	50	100	N	30	20	50
M347	61,500	135,375	5.00	5.00	7.00	.150	5,000	N	30	70	N	15	50	1,000
M417	25,225	125,325	3.00	1.50	.10	.200	1,500	N	50	150	N	7	70	20
B456	46,225	131,950	2.00	1.50	.30	.200	700	N	50	700	N	15	50	150
M540A	73,000	120,400	2.00	2.00	.10	.300	300	.5	100	300	N	30	70	500
B638	93,975	106,600	1.00	3.00	3.00	.070	700	.7	70	700	N	7	20	300
M615	102,650	122,550	1.50	1.50	2.00	.150	700	5.0	50	300	N	5	20	15
M638	107,400	120,375	2.00	2.00	1.00	.200	700	1.5	200	2,000	N	20	70	1,500
M661	104,300	101,800	2.00	2.00	.15	.200	300	1.0	70	500	N	10	30	300
M702	118,200	130,075	2.00	2.00	.15	.200	300	3.0	200	500	N	10	70	7,000

Table 5.--continued

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
M348E	20	N	7	20	7	100	30	30	N	70	.02	N	--	--
B393	30	N	20	15	10	N	70	30	N	150	.01	N	--	--
B395	50	20	10	30	7	300	70	700	N	150	.02	N	--	--
M462	50	N	10	50	5	200	50	30	N	300	.10	N	--	--
M472A	N	10	5	N	5	500	100	70	N	10	.08	N	--	--
M528A	70	N	5	100	5	100	20	20	N	70	<.02	N	--	--
M529	70	N	15	N	7	100	30	30	N	50	N	N	--	--
M529A	70	N	5	10	5	150	30	50	N	300	.02	N	--	--
B554	20	N	10	300	5	300	50	15	N	50	N	N	--	--
M542	70	N	15	20	10	300	100	50	N	300	.14	N	--	N
M542A	70	N	20	20	10	300	100	50	N	150	.12	N	--	N
M543	70	N	20	20	15	150	100	70	N	200	.12	N	--	N
M674	20	N	30	10	15	N	70	20	N	100	.08	N	--	N
M674A	70	N	15	100	7	N	70	20	N	150	.04	N	--	1.00
M675	30	N	5	10	5	200	70	50	N	150	.02	N	--	N
B664	30	N	20	20	7	<100	70	30	N	100	.04	N	--	N
M736	N	15	30	30	7	N	50	15	N	100	.02	N	--	.50
B669	70	N	50	10	15	N	150	30	N	150	.14	N	--	8.00
B703	30	N	20	3,000	10	300	70	20	N	100	.06	N	--	1.00
B933	50	N	20	20	10	<100	50	20	N	150	.06	N	--	--
B974	30	N	50	20	10	N	70	20	N	200	--	--	--	--
Mt. Shields Formation														
MS514	<20	<5	15	10	7	500	50	15	<200	200	--	--	--	--
M26A	<20	N	15	15	5	N	30	15	N	200	.14	<.02	--	--
B21A	30	N	15	15	15	<100	70	70	N	500	.07	<.02	--	--
B29	N	N	<5	20	N	N	20	10	N	100	.02	<.02	--	--
B44A	30	N	15	<10	10	N	70	30	N	700	.10	<.02	--	--
MS492	N	N	50	<10	30	300	150	30	N	150	.08	<.02	330	--
B257	20	<5	20	15	7	<100	50	15	N	70	.02	<.02	--	--
M242	N	N	7	10	N	<100	20	20	N	20	.08	<.02	--	--
M253	N	N	5	10	N	N	20	15	N	70	.10	<.02	--	--
B354	30	N	70	50	15	N	100	30	N	150	.12	N	--	--
B367B	N	10	30	30	7	N	70	20	N	70	.13	N	--	--
M347	30	N	30	10	10	N	70	70	N	150	.02	N	--	--
M417	N	10	50	N	5	N	50	10	N	150	.04	N	--	--
B456	50	N	30	10	15	N	70	30	N	300	.02	<.05	--	--
M540A	<20	N	30	10	10	<100	100	30	N	100	.10	N	--	.50
B638	N	N	15	10	7	N	50	15	N	100	.10	N	--	.50
M615	30	N	10	10	7	N	50	20	N	150	.04	N	--	<.50
M638	70	N	30	100	15	<100	100	30	N	150	.07	N	--	1.00
M661	30	N	30	15	10	N	70	30	N	150	.05	N	--	.50
M702	70	N	30	15	15	N	70	50	N	150	.13	N	--	2.00

Table 5.--continued

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
M719	125,800	124,775	3.00	2.00	1.00	.200	300	10.0	100	2,000	N	15	70	5,000
B663	121,700	111,000	2.00	3.00	2.00	.150	700	3.0	30	700	N	10	20	30
B672B	130,300	117,975	7.00	7.00	7.00	.070	>5,000	N	20	150	N	30	30	700
B672C	130,300	117,975	5.00	1.50	.20	.100	200	.7	20	1,500	N	30	<10	3,000
B766	136,100	119,500	3.00	1.50	.70	.150	1,000	2.0	50	500	N	10	50	70
B938	28,800	125,800	3.00	2.00	.07	.300	200	1.0	100	1,500	N	30	100	700
B970	28,650	122,800	3.00	3.00	.10	.300	70	N	50	100	N	30	70	500
McNamara Formation														
MS730	71,900	146,300	7.00	2.00	2.00	.200	500	1.5	500	2,000	<20	20	15	2,000
M016	72,275	146,925	3.00	3.00	15.00	.010	>5,000	<.5	10	>5,000	<20	<5	<5	30
L120	35,610	141,950	3.00	2.00	1.00	.150	500	N	100	2,000	N	5	50	500
L135	43,130	151,240	1.50	.70	1.00	.150	300	.7	30	200	N	5	30	150
L136	43,160	151,080	1.50	1.00	1.00	.150	700	N	50	500	N	5	30	200
B341E	56,170	147,800	1.50	.70	<.05	.200	200	N	15	300	N	7	<10	200
M32A	68,425	139,975	.50	.30	5.00	.050	1,500	1.5	10	1,500	N	N	N	300
M33A	68,550	140,425	2.00	.70	.50	.150	1,000	N	70	700	N	7	<10	300
M39	71,350	137,850	1.50	.50	.10	.200	70	.7	20	300	N	5	30	100
B87	80,375	139,900	3.00	.70	.10	.150	200	N	100	>5,000	N	N	20	150
M72A	84,375	139,200	2.00	1.00	1.50	.150	700	5.0	100	1,500	N	<5	15	2,000
M73	84,775	139,925	2.00	.50	2.00	.100	1,500	1.0	150	>5,000	N	15	15	150
M318	105,325	134,950	5.00	2.00	.30	.200	500	N	150	>5,000	N	10	N	1,000
M269	95,350	135,750	1.50	1.00	15.00	.030	3,000	N	10	1,500	N	N	N	200
M270	95,725	136,075	3.00	2.00	1.50	.150	700	N	150	500	N	5	N	700
M272	95,825	136,975	2.00	1.50	.30	.200	500	N	70	1,500	N	10	20	300
M281	97,850	137,250	3.00	1.50	2.00	.100	1,500	1.0	150	>5,000	N	20	N	1,000
B325	100,025	133,275	1.50	1.00	.50	.150	1,000	1.5	70	200	N	5	20	300
M379A	25,175	132,775	3.00	1.50	.50	.100	300	10.0	150	1,000	N	5	20	7,000
M379	26,225	132,475	2.00	1.50	1.50	.100	500	N	150	1,000	N	5	30	500
M381	29,250	131,925	2.00	1.50	.70	.300	300	7.0	100	500	N	5	50	5,000
B335A	59,725	140,550	3.00	2.00	5.00	.100	700	3.0	100	3,000	N	10	30	3,000
M413	25,650	129,200	5.00	3.00	.30	.500	300	N	150	200	N	30	150	15,000
B464	55,175	116,975	3.00	1.50	.20	.150	700	<.5	70	300	N	10	20	300
B602	95,400	119,375	5.00	2.00	.10	.150	200	N	50	300	N	30	30	200
B628	87,800	125,800	1.50	.50	2.00	.100	700	N	70	1,500	N	<5	30	5
B650	114,500	119,750	5.00	2.00	3.00	.100	1,500	N	150	300	N	10	30	200
M721	123,475	125,400	3.00	1.50	1.50	.100	700	<.5	70	1,500	N	10	15	30
B862	30,975	139,825	1.50	2.00	2.00	.200	700	N	150	700	N	10	30	200

Table 5.--continued

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
M719	70	50	30	15	15	100	150	30	N	150	.02	L	--	8.00
B663	20	<5	20	10	7	<100	50	15	N	100	.04	N	--	N
B672B	30	N	30	300	7	N	70	70	N	100	.14	N	--	<.50
B672C	30	20	20	<10	5	N	50	20	N	150	.22	N	--	<.50
B766	30	N	20	15	10	N	70	20	N	200	.04	N	--	N
B938	<20	N	70	15	10	<100	70	20	N	300	.40	N	--	--
B970	30	N	30	10	10	N	50	20	N	200	1.30	N	--	--
McNamara Formation														
MS730	20	<5	15	50	7	100	70	50	<200	150	--	--	--	--
M016	<20	<5	<5	300	<5	1,000	10	15	<200	10	--	--	--	--
L120	70	N	15	N	10	<100	100	30	N	150	.01	N	--	--
L135	20	N	10	100	5	N	30	30	N	150	<.01	N	--	--
L136	<20	N	15	10	7	N	30	20	N	150	<.01	N	--	--
B541Z	30	N	10	<10	<5	N	20	15	N	300	<.02	<.02	--	--
M32A	30	30	<5	200	N	<100	30	30	N	150	.01	<.02	--	--
M33A	20	N	15	10	5	N	30	20	N	150	.04	<.02	--	--
M39	20	30	10	20	7	<100	70	15	N	150	.01	<.02	--	--
B87	30	N	<5	20	10	500	70	30	N	300	<.01	<.02	--	--
M72A	20	N	5	20	<5	N	50	20	N	150	.05	<.02	--	--
M73	20	N	10	50	7	700	100	50	N	150	.08	<.02	--	--
B318	50	N	20	20	10	700	70	70	N	150	.10	<.02	--	--
M269	50	N	5	10	N	100	30	70	N	30	.03	<.02	--	--
M270	50	N	15	20	10	N	70	30	N	150	.02	<.02	--	--
M272	N	N	20	10	5	N	30	30	N	200	.06	<.02	--	--
M281	N	N	20	50	10	5,000	70	50	N	70	.04	<.02	--	--
B325	N	N	15	10	5	N	50	30	N	150	.03	<.02	--	--
M378A	70	N	10	N	5	N	70	50	N	150	.07	N	--	--
M379	N	50	10	N	5	N	70	50	N	300	.34	N	--	--
M381	50	N	10	20	10	N	70	50	N	300	.06	N	--	--
B395A	N	15	15	7,000	10	N	70	100	N	200	.02	N	--	--
M413	70	N	5	10	30	N	100	70	N	500	.65	N	--	--
B464	30	N	10	30	7	N	30	30	N	200	.02	N	--	--
B602	30	N	30	20	10	N	70	50	N	150	.04	N	--	N
B628	30	N	7	200	7	100	70	30	N	150	.08	N	--	N
B650	30	N	15	50	15	N	150	70	N	100	.02	N	--	N
M721	30	10	15	10	7	N	30	30	N	100	.02	N	--	<.50
B862	30	N	20	10	7	N	30	30	N	200	.04	N	--	--

Table 5.--continued

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
M48	73,225	145,725	.50	1.00	15.00	.007	300	N	N	N	N	N	N	7
B266	105,425	143,075	.70	.50	15.00	.020	300	N	N	50	N	N	N	7
M295	102,350	142,850	.70	1.00	20.00	.015	500	N	N	30	N	N	N	5
CM181	84,700	161,875	20.00	.10	.20	.010	20	<.5	<10	50	<20	5	<10	50
MS328	89,575	164,050	15.00	.10	5.00	.070	700	5.0	50	100	<20	100	50	200
B169C	109,000	156,025	15.00	3.00	7.00	.010	300	N	N	70	N	N	20	N
MS594	79,200	145,875	.70	.70	15.00	.070	700	N	<10	70	N	20	15	70
B114	98,575	158,775	1.50	.50	15.00	.100	100	2.0	70	70	N	N	500	100
CM165	87,500	165,600	20.00	.30	.50	.030	100	<.5	30	50	<20	<5	20	10
CM164	86,700	164,500	15.00	.50	10.00	.010	100	<.5	20	50	<20	<5	30	30
M697	111,350	134,800	<.05	.70	>20.00	.015	70	N	N	N	N	N	N	5
B009	111,475	151,900	1.50	.10	N	.500	50	N	15	700	N	5	10	<5
Mississippian rocks														
B010	111,475	151,900	1.50	.07	N	.500	150	N	15	700	N	5	15	7
Morrison Formation														
B011	111,475	151,900	3.00	.07	N	.500	15	.5	30	700	N	N	70	15
B013	109,325	152,675	2.00	.15	.05	.500	100	N	30	300	N	7	70	15
B015	109,825	152,675	3.00	.07	N	.200	150	N	20	3,000	N	7	30	15
B016	109,825	152,675	15.00	.07	N	.200	300	N	<10	100	N	70	70	150
B017	109,825	152,675	1.50	.07	N	.300	50	N	20	1,500	N	10	70	7
M206	122,925	141,625	.50	3.00	20.00	.030	3,000	N	N	70	N	N	N	N
CM167	89,875	166,175	15.00	.70	3.00	.100	200	<.5	50	100	<20	10	50	10
MS277	80,400	164,625	1.00	.70	.70	.300	50	2.0	150	1,000	<20	<5	100	70
Cambrian rocks														
M019	77,050	157,950	5.00	.20	5.00	.150	100	<.5	10	200	<20	5	20	<5
CM-420	92,725	161,900	7.00	1.00	>20.00	.015	3,000	<.5	<10	200	<20	10	150	15
M89A	96,025	161,375	5.00	.10	.70	.030	100	N	15	100	N	N	15	20
M89D	96,025	161,375	10.00	.30	.70	.070	30	N	10	150	N	N	50	10
M98A	98,700	161,375	20.00	.50	3.00	.200	500	N	10	300	N	20	300	20
M100A	101,200	160,225	2.00	3.00	10.00	.010	150	3.0	<10	150	N	<5	15	30
M100B	101,200	160,225	1.00	5.00	10.00	.150	200	3.0	50	5,000	N	N	150	20
M100C	101,200	160,225	20.00	.30	7.00	.030	150	7.0	<10	1,000	N	15	15	150
B199A	125,350	149,375	10.00	1.50	.70	.300	100	N	200	200	N	30	300	15
CM169	88,275	167,275	15.00	.50	.70	.200	500	<.5	100	500	<20	30	50	20

Table 5.--continued

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
H48	N	N	N	N	N	200	N	N	700	N	.02	<.02	—	—
B266	N	N	N	N	N	300	N	<10	500	15	.02	<.02	—	—
H285	N	N	<5	20	N	300	30	N	700	20	.06	<.02	—	—
CH181	<20	30	50	50	<5	<100	100	10	3,000	<10	—	—	—	—
HS828	500	100	3,000	70	<5	3,000	200	>200	3,000	150	—	—	—	—
B169C	N	N	15	20	N	100	30	N	500	N	.10	<.02	—	—
HS594	30	N	7	1,500	<5	150	70	15	N	70	.06	<.02	110	—
B114	70	N	150	N	5	300	70	70	300	100	.55	<.02	—	—
CH165	20	100	30	50	<5	<100	50	10	300	5	—	—	—	—
CH164	<20	20	200	50	<5	500	100	10	1,000	<10	—	—	—	—
H697	20	N	N	700	N	150	30	N	N	10	.02	N	—	N
B009	30	7	<5	10	5	<100	20	20	N	>1,000	—	<.02	<10	.40
Mississippian rocks														
B010	20	7	7	10	<5	<100	20	<10	N	150	—	<.02	<10	.40
Morrison Formation														
B011	200	20	<5	70	10	500	100	30	N	500	—	<.02	<10	.80
B013	30	7	15	10	10	N	100	15	N	200	—	<.02	12	.20
B015	<20	15	10	10	10	<100	100	<10	N	100	—	<.02	14	.60
B016	N	N	70	30	15	N	70	15	700	70	—	<.02	93	1.40
B017	<20	10	10	10	7	<100	100	10	N	150	—	<.02	11	.60
H206	N	7	N	N	N	300	10	N	N	10	.14	<.02	35	—
CH167	<20	100	70	30	<5	50	70	10	200	100	—	—	—	—
HS277	50	30	200	70	10	700	700	10	<200	100	—	—	—	—
Cambrian rocks														
H019	<20	10	20	30	5	200	20	<10	<200	50	—	—	—	—
CH-420	<20	50	30	10	<5	100	150	70	500	<10	—	—	—	—
H29A	N	10	70	<10	N	300	30	100	<200	15	.15	<.02	—	—
HS9D	N	15	10	<10	5	500	100	20	<200	70	.35	<.02	—	—
H93A	150	N	50	30	20	150	300	100	300	200	.11	<.02	—	—
H190A	20	15	70	10	N	300	30	20	N	30	.15	<.02	—	—
H190B	100	7	50	10	10	700	50	100	N	100	.06	<.02	—	—
H190C	70	20	300	50	<5	500	50	100	500	50	.50	<.02	—	—
B199A	50	N	70	20	20	<100	300	20	300	200	.12	<.02	20	—
CH169	50	5	30	30	15	50	70	10	700	200	—	—	—	—

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU
HS780	78,300	160,175	1.00	.05	.20	.050	100	N	<10	150	N	N	N	<5
Kootenai Formation														
B008	111,475	151,900	5.00	.15	.05	.300	70	N	30	1,000	N	N	70	30
B109	99,075	160,000	3.00	.70	.70	.300	500	N	10	700	N	10	50	30
B192	114,600	150,400	.70	.20	15.00	.010	1,500	N	N	70	N	7	N	N
B220	116,950	144,625	3.00	.70	.50	.200	700	N	10	1,000	N	15	50	10
H205	122,575	140,800	1.00	7.00	15.00	.030	700	N	N	100	N	N	N	5
H212	128,375	136,975	3.00	.70	.50	.300	1,000	N	10	500	N	15	150	20
H213	123,025	136,300	5.00	.50	.50	.300	300	N	<10	700	N	10	300	20
B227	120,400	147,900	2.00	.30	15.00	.100	1,500	N	N	300	N	N	15	5
H216	131,225	136,225	3.00	1.00	.30	.300	700	N	10	300	N	20	100	15
HS829	83,225	165,425	15.00	1.00	1.00	>1.000	1,500	<.5	30	200	<20	30	150	30
HS533	85,775	163,900	5.00	1.00	.50	.300	700	<.5	<10	200	<20	<5	50	20
Blackleaf Formation														
H130	126,725	143,250	3.00	.30	.07	.200	100	N	20	700	N	10	30	15
B250	92,175	150,175	5.00	.70	.30	.300	700	N	20	1,000	N	15	50	15
HS826	87,125	164,400	3.00	1.50	7.00	.300	300	2.0	150	200	--	5	300	50
HS827	88,125	164,400	2.00	1.00	5.00	.200	200	1.0	100	150	--	5	300	50
HS774	80,700	152,525	>20.00	.05	.50	.050	50	<.5	30	200	<20	<5	<10	10
Marias River Shale														
HS765A	89,300	155,825	<.05	5.00	>10.00	<.002	N	N	70	200	N	N	<10	<5

sample	S-LA	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P
HS780	20	100	10	<10	N	N	50	N	N	70	.08	N	--	--
Kootenai Formation														
B008	50	300	5	20	10	100	100	10	N	70	--	<.02	35	.80
B109	<20	30	30	10	15	300	150	15	N	150	.12	<.02	--	--
B192	N	15	5	N	N	300	N	N	N	N	.14	<.02	25	--
B220	N	7	30	N	15	700	100	15	N	70	.05	<.02	25	--
H205	N	20	N	N	N	300	10	N	N	10	.05	.02	30	--
H212	20	10	50	10	15	300	100	15	N	150	.04	.02	30	--
H213	30	15	30	15	15	300	150	15	N	150	.08	.02	30	--
B227	20	150	10	N	5	300	20	15	N	70	.09	<.02	30	--
H216	30	15	50	<10	15	200	150	15	N	100	.11	<.02	20	--
HS329	300	5	50	<10	10	200	500	20	700	500	--	--	--	--
HS333	20	100	20	15	10	200	200	10	<200	70	--	--	--	--
Blackleaf Formation														
H150	30	7	30	<10	10	N	70	20	N	150	.06	<.02	15	--
B250	20	7	30	10	15	100	100	15	N	150	.06	<.02	10	--
HS826	30	3	150	20	5	300	150	30	700	150	--	--	--	--
HS827	50	2	100	10	5	200	100	30	500	150	--	--	--	--
HS774	<20	10	<5	20	<5	100	10	5	200	20	--	--	--	--
Marias River Shale														
HS765A	N	20	N	N	N	10,000	N	N	N	N	--	--	--	--

Table 5.--continued

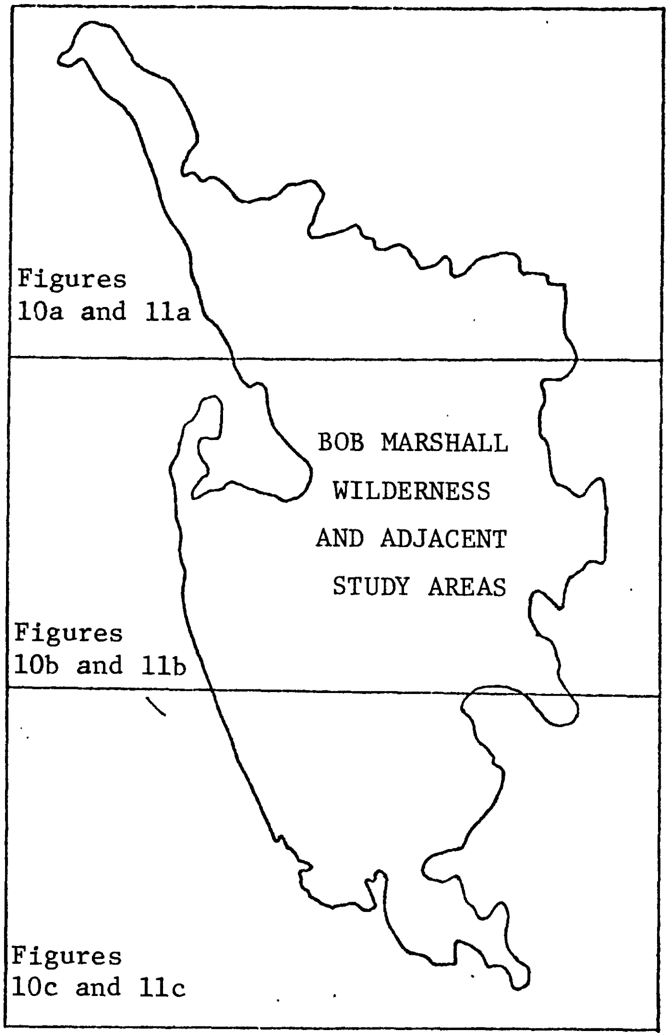
sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU	S-LA
							Stream sediments								
201	116,275	139,350	1.5	1.5	3.00	.30	700	N	70	500	N	15	50	150	30
274	48,325	124,275	2.0	1.0	.05	.50	200	N	70	200	N	15	30	150	30
308	95,675	110,900	3.0	1.0	1.00	1.00	700	N	70	500	N	30	50	300	50
CH181	84,700	161,850	20.0	.1	.20	.01	20	<.5	<10	50	<20	5	<10	50	<20
500	118,425	145,300	3.0	1.5	2.00	.30	500	N	50	700	N	15	70	30	20
695	54,200	109,200	3.0	1.5	.70	.70	2,000	N	150	1,000	N	20	50	50	70
725	93,200	95,200	3.0	3.0	15.00	.30	300	N	100	300	N	5	30	30	20
887	90,000	119,975	2.0	2.0	5.00	.20	200	N	100	1,000	N	7	70	10	50
936	88,700	116,300	3.0	1.0	3.00	.30	500	.7	50	700	N	15	150	500	50
954	112,875	130,400	3.0	1.5	.10	.20	200	1.0	70	700	N	7	15	200	30
984	138,300	94,600	3.0	1.5	1.50	.30	1,500	N	100	1,000	N	15	50	200	70
1057	129,900	124,625	2.0	1.5	3.00	.50	300	1.5	70	500	N	10	30	70	30
1061	130,575	121,625	2.0	1.5	1.50	.50	500	1.5	50	500	N	7	30	50	20
1082	134,300	106,325	3.0	1.5	1.00	.30	700	N	70	500	N	10	30	30	20
1106	161,200	80,750	3.0	1.0	.50	.50	700	N	50	500	N	15	30	50	20
1125	154,500	98,900	3.0	2.0	.20	.50	200	N	150	700	N	15	70	50	50
1163	143,100	127,675	3.0	.7	.70	.50	700	N	50	700	N	15	70	30	30
1202	124,150	154,425	3.0	3.0	10.00	.30	500	2.0	100	500	N	15	70	20	20
1266	135,700	127,725	3.0	1.5	5.00	.30	500	N	150	700	N	15	70	30	50
1353	25,425	138,975	2.0	1.5	.30	.30	700	N	100	700	N	10	50	300	30

sample	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P	CM-CX-CU	CM-CX-HM
							Stream sediments								
201	N	30	10	10	<100	50	20	N	150	.03	--	20	--	--	--
274	N	20	15	10	N	50	30	N	200	.10	--	10	--	--	--
308	N	20	15	20	N	200	30	N	200	.02	--	55	--	--	--
CH181	30	50	50	<5	<100	100	10	3,000	<10	--	--	--	--	--	--
500	7	30	20	10	100	100	20	N	150	.08	<.02	30	--	--	--
695	7	20	50	30	N	100	100	N	500	.30	N	50	--	--	--
725	N	30	30	15	N	70	50	300	200	.10	N	--	--	--	--
887	N	20	150	10	N	70	30	N	300	.10	--	--	N	--	--
936	N	30	15	15	N	70	30	N	200	.24	N	--	1.5	--	--
954	N	15	<10	7	N	50	30	N	150	.45	--	--	1.5	--	--
984	N	20	30	10	N	50	20	N	200	.06	--	25	N	--	--
1057	N	20	10	7	100	150	30	N	150	.06	N	35	<.5	--	--
1061	N	15	150	10	100	70	30	N	150	<.02	--	--	N	--	--
1082	N	20	150	10	N	70	30	N	150	.08	--	--	<.5	--	--
1106	N	30	150	15	<100	150	30	N	150	.10	--	--	<.5	--	--
1125	N	30	70	15	N	100	30	300	300	.04	N	--	<.5	--	--
1163	N	30	300	15	100	150	20	N	200	.08	N	--	<.5	--	--
1202	N	50	150	15	150	70	30	N	200	.06	N	--	<.5	--	--
1266	10	70	30	15	100	150	30	N	300	.04	N	--	<.5	--	--
1353	N	20	20	10	N	70	30	N	200	.14	N	50	--	--	--

Table 5.--continued

sample	X-COORD.	Y-COORD.	S-FE%	S-MG%	S-CA%	S-TI%	S-MN	S-AG	S-B	S-BA	S-CD	S-CO	S-CR	S-CU	S-LA
1365	20,675	136,725	5.0	2.0	2.00	1.00	1,000	N	70	700	N	30	30	200	<20
1417	138,300	97,175	3.0	.7	.70	.30	700	N	70	1,000	N	15	150	20	50
1422	139,050	132,725	5.0	.7	.70	.50	500	N	70	700	N	20	100	20	20

sample	S-MO	S-NI	S-PB	S-SC	S-SR	S-V	S-Y	S-ZN	S-ZR	INST-HG	AA-AU-P	AA-CU-P	AA-AG-P	CM-CX-CU	CM-CX-HM
1365	N	30	20	20	100	300	20	N	200	.08	N	170	--	--	--
1417	10	70	20	10	N	70	50	N	300	--	--	--	--	--	--
1422	10	70	N	15	200	150	20	N	200	--	--	--	--	--	--



EXPLANATION

Geochemical data on Distribution Maps

70 ppm and more copper in stream sediments

50 ppm and more lead in stream sediments

0.5 ppm and more silver in stream sediments

70 ppm and more copper and 0.5 ppm ar more silver from the following Precambrian Formations:

McNamara
Mount Shields
Snowslip
Empire and Spokane

50 ppm and more lead and 0.5 ppm and more silver from the Helena Formati

700 ppm and more copper and 0.5 ppm a more silver from Precambrian diorit sills

TKi	Trachyandesite
Mz	Mesozoic rocks
MPz	Mesozoic and Paleozoic rocks
Pz	Paleozoic rocks

Precambrian Z

Zd	Diorite

Precambrian Y

Yu	Precambrian Y undifferentiated
Ym	Missoula Group--includes Garnet Range, McNamara, Bonner, Mount Shields, Shepard and Snowslip Formations
Yh	Helena Formation
Yes	Empire and Spokane Formations
Yg	Greyson Formation

Normal fault

Thrust fault

Anticline

Syncline

× Sample locality with 70 ppm copper or more where value is given

○ Sample locality with 50 ppm lead or more where value is given

Sample locality wit 0.5 ppm silver or more where value is given

Figure 9.--Index and explanation to the geochemical maps (figs. 10a, b, c, and 11a, b, c)

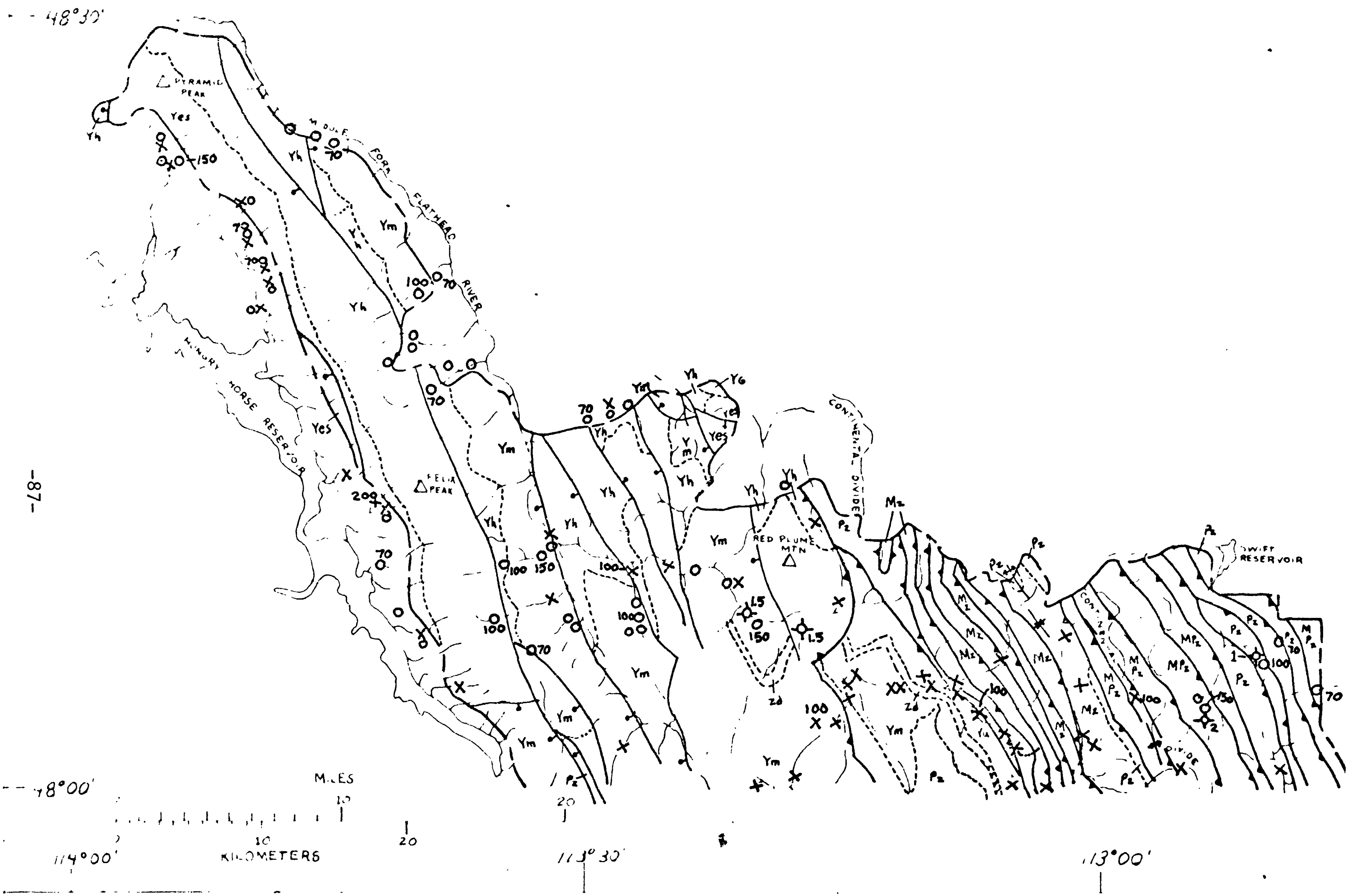


Figure 10a.--Distribution map of selected anomalous values of copper, lead, and silver in stream sediments, showing the generalized geology.

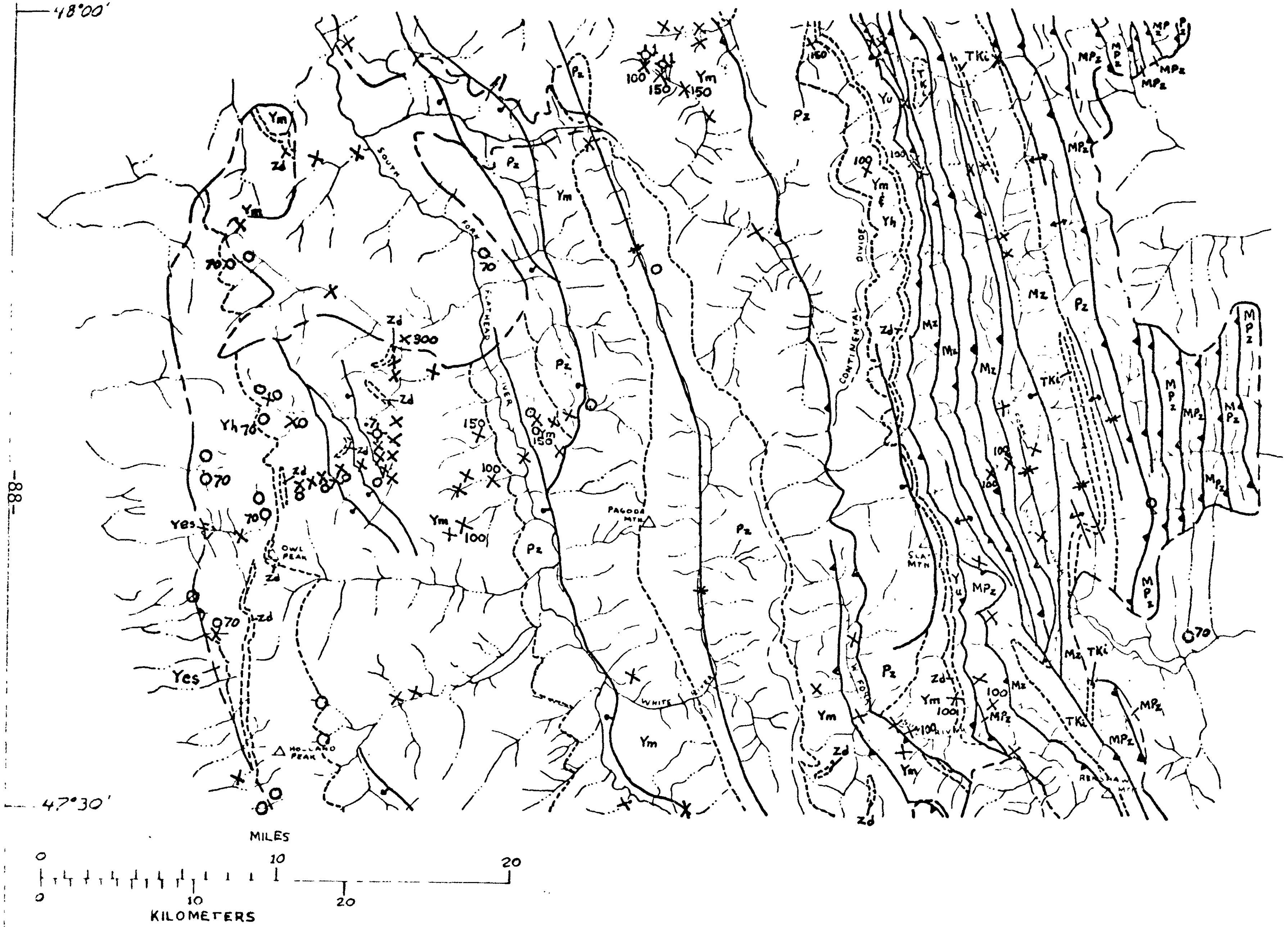


Figure 10b.--Distribution map of selected anomalous values of copper, lead, and silver in stream sediments, showing the generalized geology.

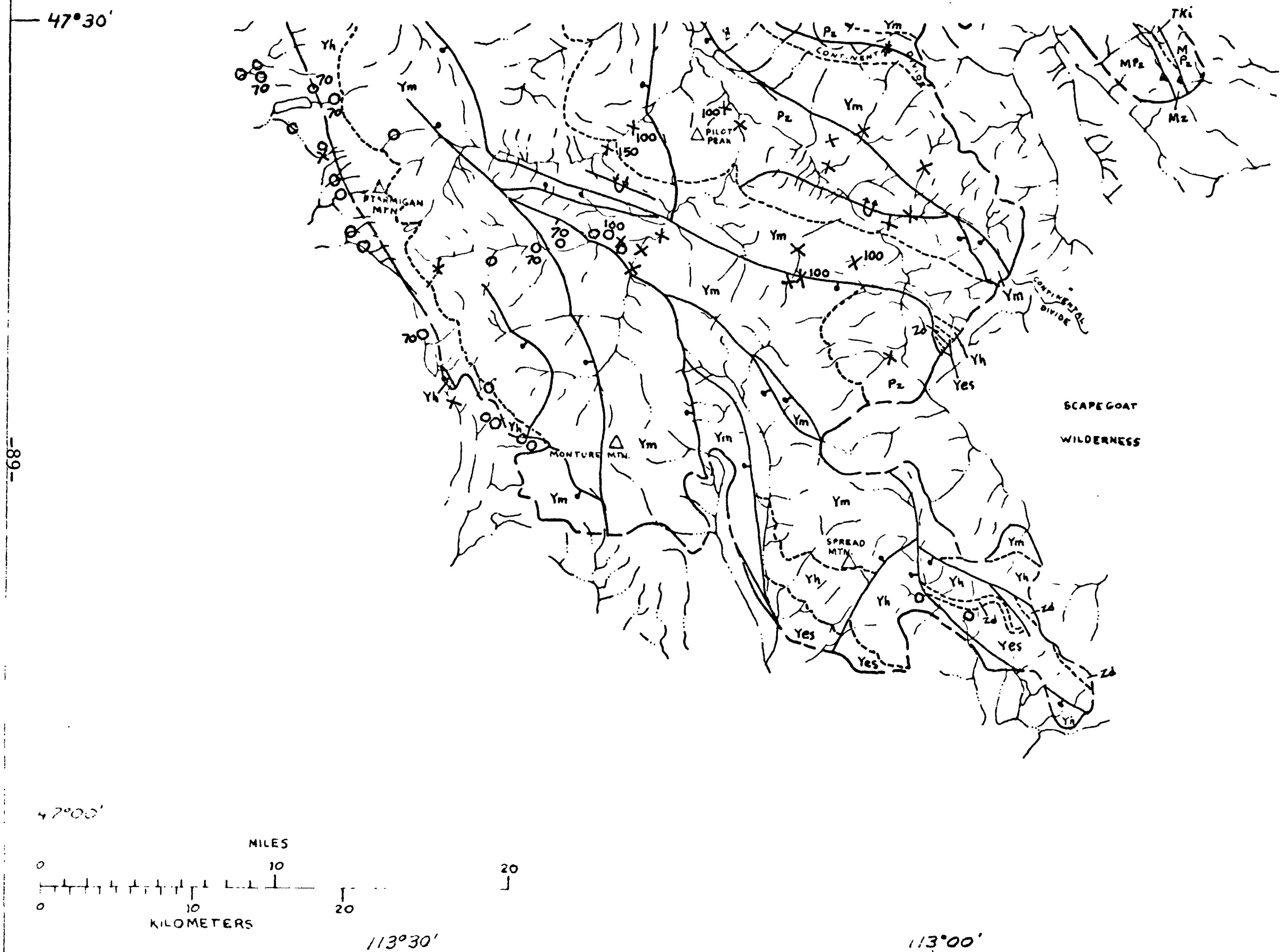


Figure 10c.--Distribution map of selected anomalous values of copper, lead, and silver in stream sediments, showing the generalized geology.

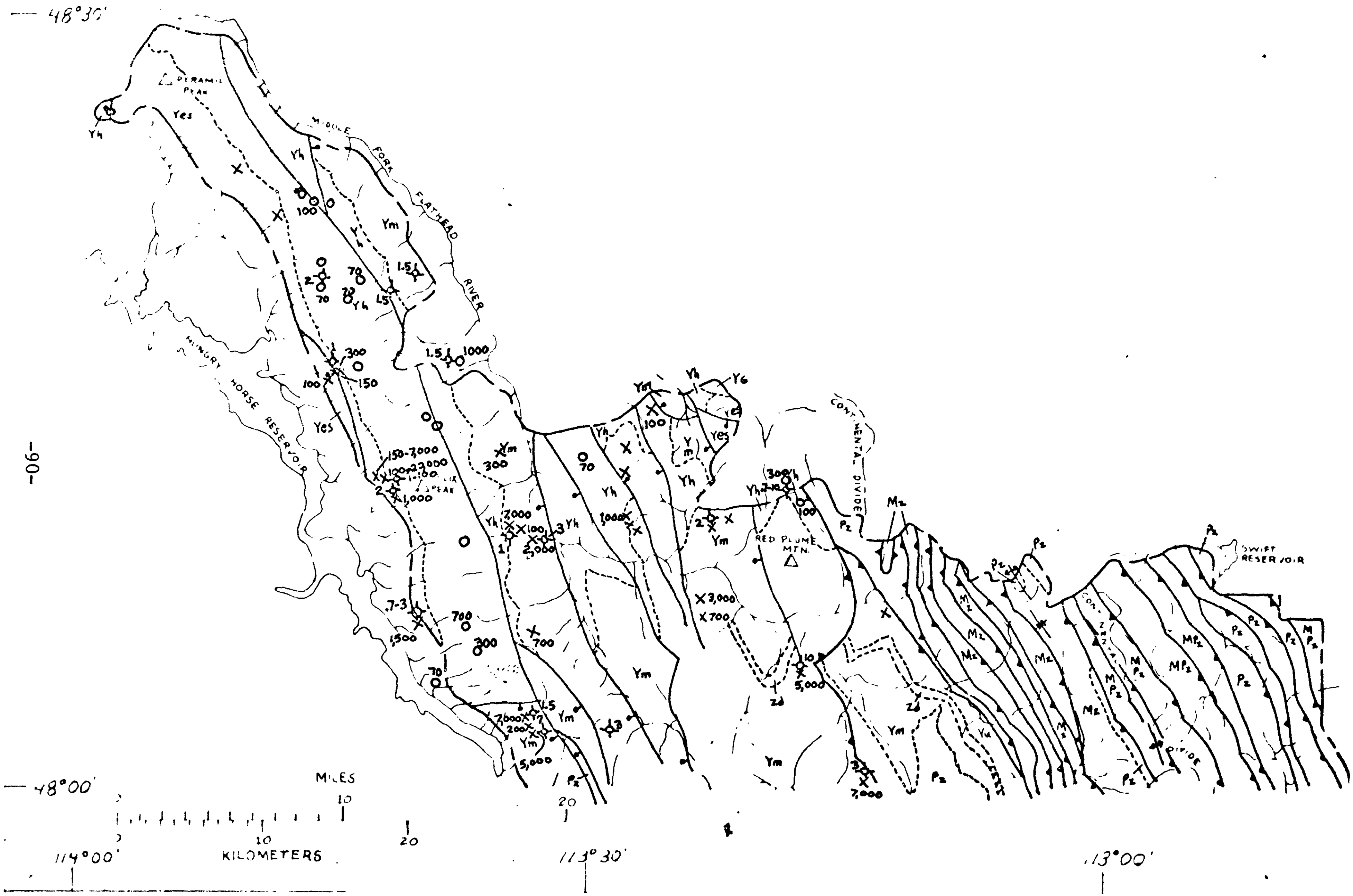


Figure 11a.--Distribution map of selected anomalous values of copper, lead, and silver in rocks, showing the generalized geology.

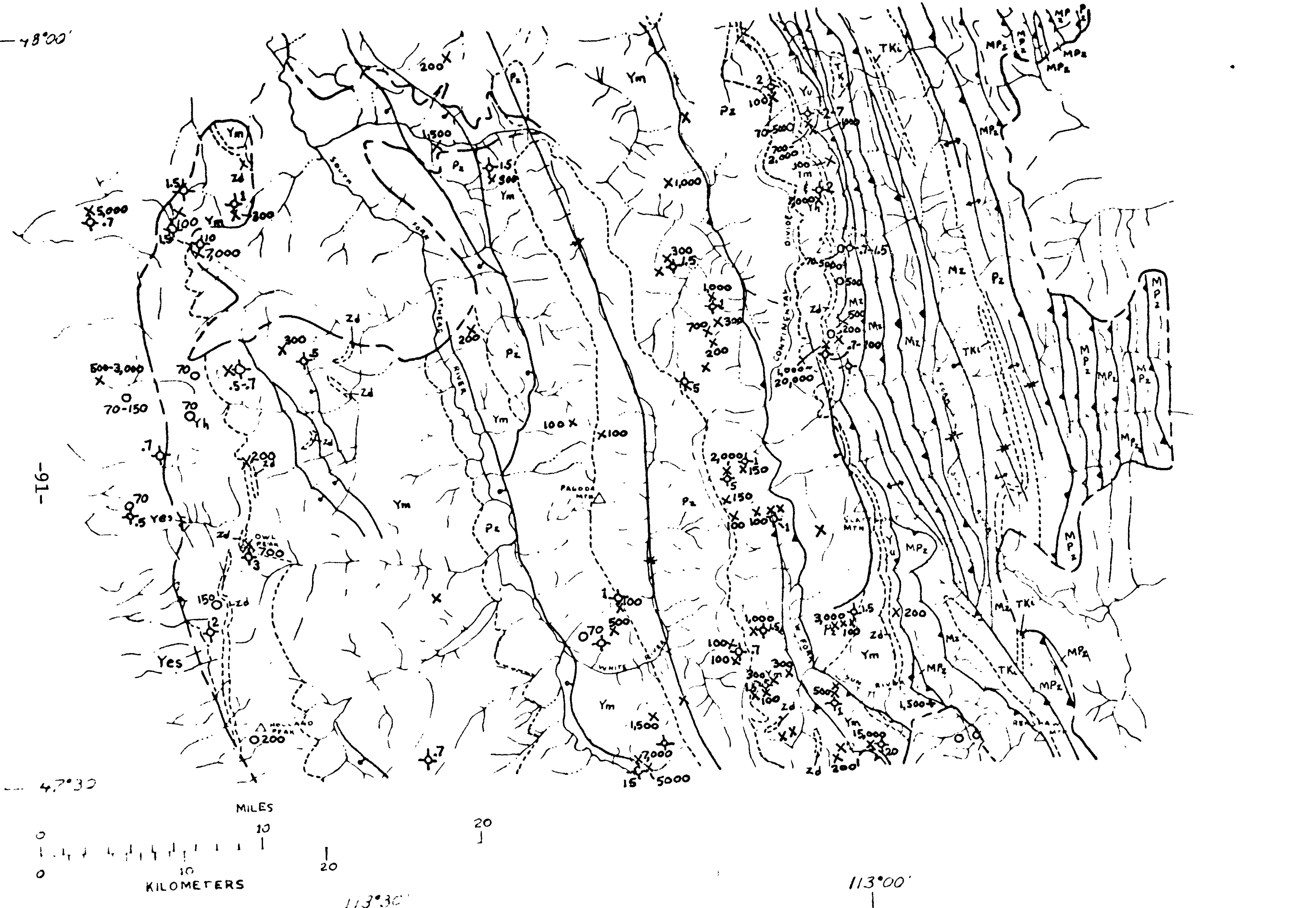


Figure 11b.--Distribution map of selected anomalous values of copper, lead, and silver in rocks, showing the generalized geology.

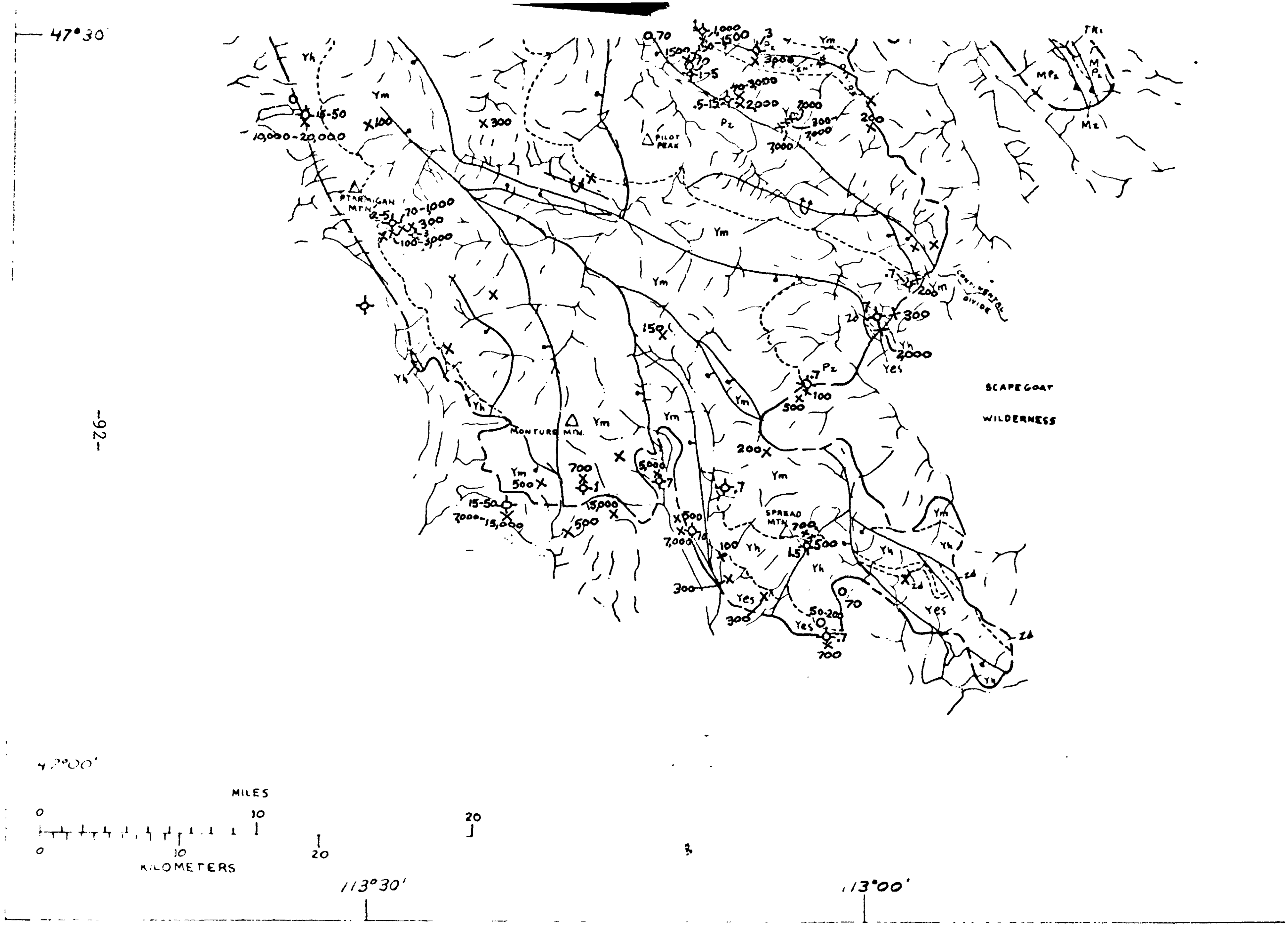


Figure 11c.--Distribution map of selected anomalous values of copper, lead, and silver in rocks, showing the

it is anomalous in drainage basins where the diorite sills are absent. In the other extreme, the dilution effect of carbonate rocks, which have a relatively low background amount of copper, can mask copper anomalies derived from the Precambrian green clastic rocks. The interpretation of the distribution of lead and silver in stream sediments is less problematic. Widespread lead anomalies are derived principally from the Precambrian carbonate rocks and to a lesser extent from occurrences in green beds and from mineralized parts of diorite sills. For the most part, the distribution pattern of anomalous lead values in stream sediments closely follows the outcrop pattern of the Helena Formation. Only a few stream-sediment samples contain anomalous amounts of silver. The anomalous silver values are interpreted to reflect a nearby source.

An index and explanation to the geochemical distribution maps are given in fig. 9. In addition to geochemical data on the distribution of copper, lead, and silver, the maps also show the generalized geology so that anomalies can be evaluated with respect to their geologic setting. The distribution of stream sediment samples with copper and lead values that are one or more reported analytical steps higher than the threshold values (table 4), or with detectable amounts of silver are shown in figs. 10a, 10b, and 10c. The values of copper, lead, and silver in rock samples, as shown in figs. 11a, 11b, and 11c, are selected on the basis of the geologic source of the samples. Anomalous values from geologic units that are interpreted to have little or no resource potential--such as copper in Cambrian carbonate rocks--are excluded from the geochemical distribution maps. The minimum values plotted are 2 to 3 steps higher than the threshold values in table 4. By showing only the more highly anomalous values in favorable geologic units, the target areas for resources of copper, lead, and silver are more clearly depicted. A listing of all analytical data from selected samples with anomalous amounts of one or more of the metals copper, lead, silver, zinc, or molybdenum are given in table 5. The analytical data from all the samples collected in the study area are available on tape from the National Technical Information Service (McDanal, S. K., and Wilch, L. O., 1977).

The association of the various valuable elements is an important consideration in evaluating the resource potential of metallic deposits in the study area. The potential of some occurrences is enhanced by the presence of anomalous amounts of two or more of the elements of principal interest, copper, lead, and silver. In addition, some occurrences contain anomalous amounts of molybdenum. Zinc is probably associated with occurrences that contain appreciable amounts of lead, but the lower limit of detection of zinc by the spectrographic method (200 ppm) is too high to demonstrate the association with the present data.

Table 6 shows the frequency of anomalous pairs of metals in samples from the Precambrian formations. The younger rocks are excluded because they do not appear to have a potential for metallic resources. The most frequent association is copper and silver. Over half the

Table 6 .--Samples from the Precambrian formations with anomalous amounts of copper, silver, lead, and molybdenum, and number of anomalous element pairs. Ranges of values in ppm, L = less than, G = greater than.

	Number of rock samples with anomalous amounts of copper, silver, lead, and molybdenum, and ranges of values								Number of samples with anomalous element pairs				
Formation	Cu	Ranges of values	Ag	Ranges of values	Pb	Ranges of values	Mo	Ranges of values	Cu+Ag	Cu+Pb	Pb+Ag	Cu+Mo	Pb+Mo
Garnet Range	4	70-150	0	--	0	--	0	--	--	--	--	--	--
McNamara	51	70-15,000	19	.5L-10	16	50-7,000	7	5-50	16	9	5	4	3
Bonner	10	70-100	0	--	0	--	0	--	--	--	--	--	--
Mount Shields	32	70-15,000	22	.5L-20	6	50-300	6	5-50	14	3	3	2	0
Shepard	35	70-7,000	11	.5L-5	15	50-3,000	6	5-20	7	6	3	2	1
Snowslip	54	70-15,000	41	.5L-50	37	50-10,000	21	5-200	30	22	25	13	14
Helena	17	70-5,000	20	.5L-10	46	50-20,000G	4	7-30	7	7	17	0	1
Empire and Spokane	35	70-20,000G	22	.5L-100	8	50-700	7	15-2,000	20	6	6	7	5

samples from the Snowslip, Empire, and Spokane Formations, that contain anomalous amounts of copper, also contain anomalous amounts of silver. The metallic mineral occurrences in these formations are almost entirely in clastic rocks. In the Helena Formation, which consists mostly of carbonate rocks, lead, and silver show a high frequency of association. Table 6 shows that metallic mineral occurrences in the Snowslip Formation, more than any in the other Prcambrian formations, commonly contain associations of all the elements considered in the table. From the geochemical associations, the Snowslip appears to be the most favorable prospecting target of the Precambrian formations.

TYPES OF DEPOSITS

The types of non fuel deposits in the Bob Marshall Wilderness and adjacent study areas are, in order of importance: (1) stratabound copper-silver deposits in green and gray clastic metasedimentary rocks of the Precambrian formations and related vein deposits, (2) stratabound lead-silver-zinc deposits and copper-silver deposits in shelf-facies carbonate rocks of the Precambrian formations, (3) vein or fissure copper-lead-zinc-silver deposits in Precambrian diorite sills, (4) vein barite deposits, and (5) limestone and dolomite deposits in the Paleozoic formations. Deposits of sand, gravel, and ornamental stone are present in the area, but abundant resources of equal or better quality occur in more accessible parts of northwest Montana. Oil and gas are discussed in Chapter D, and coal and other commodities are discussed in Chapter E of this report.

The non fuel mineral occurrences of possible economic importance, except for limestone, are all in the Precambrian formations which occupy most of the western two thirds of the area. The eastern third is underlain by Paleozoic and Mesozoic rocks.

Stratabound copper-silver deposits.--The study area contains numerous copper and silver occurrences in green and grav quartzite, siltite, and argillite of the McNamara, Mount Shields, Shepard, Snowslip, Empire, and Spokane Formations. The mineralized zones are generally concordant to the enclosing strata. In detail, they have discordant features such as concentrations of copper minerals along fractures that cross-cut bedding planes. The character of these mineral occurrences varies with rock type. Those in quartzite are mostly disseminations of copper minerals in the matrix of the rock. The siltite occurrences are similar to those in quartzite except that the copper minerals are more concentrated along laminae of the coarser-grained beds and along the contact with argillite interbeds. Cross-cutting fractures coated with copper minerals are more abundant in siltite than in quartzite. Most copper minerals in the argillite occur in fractures and microfractures; locally they are along discrete laminae. Commonly, the tenor of the copper and silver increases with the grain size of the rocks.

The copper sulfide minerals are, in order of abundance, bornite, chalcocite, and chalcopyrite. Locally the sulfides are coated with or completely oxidized to malachite. No silver mineral has been identified. The small amounts of lead, zinc, and molybdenum are mostly in mineralized parts of the Snowslip Formation (table 6).

The stratabound copper-silver occurrences are widely distributed in the Precambrian terrane, but most of them are too small, low grade, or discontinuous to be of economic importance. The only locality in the study area where they have been extensively prospected is in the Flathead Range where mineralized zones are exposed in prospect workings and in logging road cuts near the western boundary. All copper-silver occurrences in this area are in the Empire and Spokane Formations and the most extensive and better grade occurrences are in the Spokane Formation. Here the Spokane, like elsewhere, is mostly maroon argillite, but it contains more green and gray quartzites, siltites, and argillites than in its eastern and southern outcrop. Argillite and siltite are the dominant lithologies in the green bed sections. In addition, the formation in the northwestern outcrop contains numerous light-gray beds of relatively pure, fine to medium grained, massive quartzite. The beds are up to 3 ft (1 m) thick and are overlain and underlain by maroon siltite and argillites. The "green bed" sections in the Spokane are up to about 100 ft (30 m) thick in the upper and middle parts of the formation; the lower part is not exposed. Quartzite units included in the green bed sections are in part lenticular and in part planar where they form the base of a graded-bed sequence. Commonly the green-bed sections contain several repetitions of graded beds that are locally interrupted by lenticular beds of quartzite or siltite.

Copper and silver minerals are locally in the green bed sections and rarely in gray quartzites in maroon beds. Isolated occurrences are along a belt about 12 miles (20 km) long, but the most continuous zone is in the vicinity of Hoke Creek which is about 5 miles (9 km) south of Felix Peak (fig. 11a). Here a roadcut exposure contains copper minerals, chalcocite and malachite in a green bed section over a width of about 10 feet (3 m) (fig. 12). Similar occurrences are noted in scattered roadcut exposures and float along strike for a total estimated distance of about 40 feet (125 m). Prospects exposing copper minerals on extensions of this trend suggest the possibility that the zone may be even longer. Representative chip samples collected at the locality shown in fig. 11a indicated the most highly mineralized part of the section contains 1500 ppm copper and 3 ppm silver in quartzite which makes up less than 25 percent of the exposure. A chip sample of argillite and siltite contained 300 ppm copper and 0.7 ppm silver. Representative samples along probable extensions of this zone were collected by the U.S. Bureau of Mines and the results along with tonnage and grade estimates are included in Chapter E.

All mineralized exposures in the vicinity of Felix Peak (fig. 11a) appear to be higher in the stratigraphic section than the zone described above and it is unlikely that any of those exposures represent a continuity of the mineralized zone at Hoke Creek, 6 miles (9 km) to the

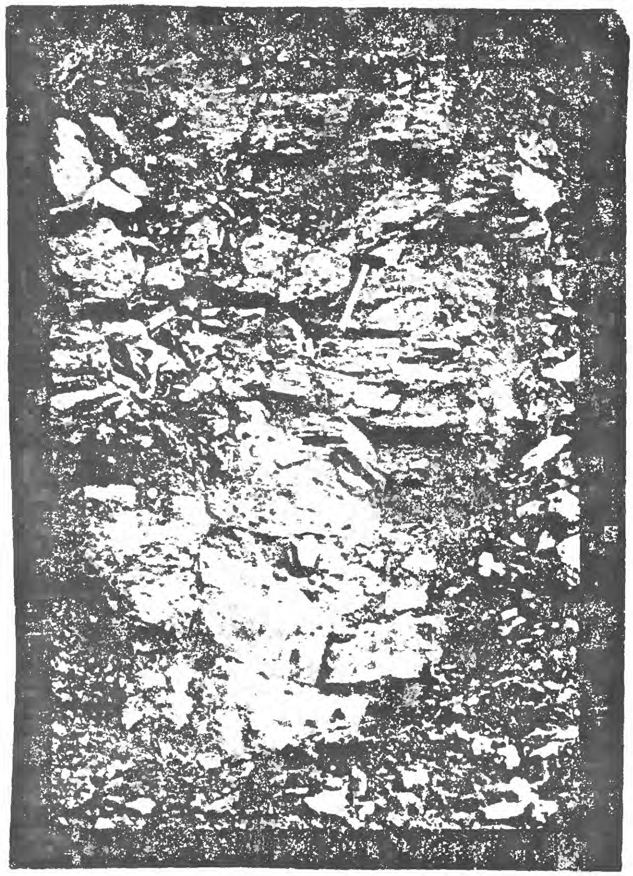


Figure 12.--Mineralized green beds in the Spokane Formation near Hoke Creek in the northwestern part of the study area at sample site B-983 (plate 2). Quartzite (lower part of photo) grades to siltite and to argillite (thin beds in center of photo). Graded sequence contains some thin lenticular quartzite beds.

south.

The Felix Peak-Hoke Creek area is underlain by an aeromagnetic anomaly that is interpreted to reflect an intrusive body buried at a depth of as much as 6,500 feet (2,000 m). The anomaly is discussed in Chapter B. The proximity of the copper-silver mineralized zone to the magnetic anomaly suggests a possible relationship. It is unlikely that a buried intrusive was the source of metals in the metasedimentary rocks because occurrences of a similar type and origin elsewhere in the area are far removed from intrusive bodies. The buried intrusive may have provided a heat source that remobilized and concentrated the metallic minerals in fractures, such as that on the One Digger claim described in Chapter E, but the sedimentary rocks of the area are not highly fractured and they were rendered relatively impermeable by metamorphism to greenschist facies prior to the injection of the diorite sills in Precambrian Z time. Therefore, unless the buried intrusive is of Precambrian Y age, which is extremely unlikely, the remobilization effect would be minimal.

Sediments collected from the streams that drain the belt of rocks with the stratabound occurrences locally contain weakly anomalous amounts of copper, none contain anomalous amounts of silver. Farther south, in the Scapegoat Wilderness (Mudge and others, 1974) and in the Scapegoat Additions (Earhart and others, 1976), significant occurrences of copper and silver in similar type deposits are strongly reflected by copper and silver anomalies in the stream sediments. On the basis of this comparison, it would appear that the occurrences along the northwest part of the study area are very low grade. The results from the acid-extractable copper tests tend to confirm this interpretation. Only two samples from Felix and Hoke Creeks contained 7 and 15 ppm copper extracted in 6 normal hydrochloric acid. All other samples along the 12 mile (20-km)-long zone contained less than 5 ppm. In contrast, a mineralized zone in the Scapegoat additions (Earhart and others, 1976, fig. 4) in which a 0.8 normal hydrochloric acid solution was used as a leach, the results reflected a 4 mile (6 km) extension of a shallow buried mineralized zone from the southeast of the Cotter Basin mine. There, extractable-copper values were consistently greater than 18 ppm. Even though a more concentrated acid solution was used in determining the extractable copper in the study area, the results are considerably lower. To further confirm these results, on -site analyses of extractable copper in a 6 normal hydrochloric acid solution were made from sediments in all the streams that drain the 12 mile (20 km) belt along the northwest arm of the area. The on-site analysis of acid extractable copper was successfully applied in the Scotchman Peak area (Grimes and others, 1975) as an exploration guide for a shallow buried stratabound copper-silver deposit. In that area, the stream sediments consistently contained greater than 40 ppm extractable copper; many contained several hundred ppm. In contrast, the copper extracted from stream sediments in a 6 normal hydrochloric acid solution along the northwest part of the study area were mostly between 1 and 3 ppm copper, and they confirmed the low values obtained from the laboratory analyses.

Elsewhere in northwest Montana the acid extractable method of stream-sediment analysis strongly reflect shallow buried copper-silver deposits. Therefore, results from these tests in the northwest part of the study area suggests that the area does not contain major copper-silver deposits at the surface or at shallow depth. The lack of detectable amounts of silver in any of the stream sediments from this area tends to confirm this conclusion. The Spokane Formation from the vicinity of Felix Peak to about 7 mi (11 km) south may be the most favorable part of the mineralized belt, but even here it is unlikely that the zone has adequate continuity or is of sufficient grade to be mined in the forseeable future.

Other copper-silver occurrences are in the Spokane and Empire Formations near the western boundary to as far south as Holland Lake. The Empire Formation has been prospected by small workings on Goat Creek, outside of the study area, and a short distance to the southeast of Holland Lake on the western boundary.

Most stratabound copper-silver occurrences in the study area are in the Missoula Group rocks, particularly in the Snowslip Formation which is more widely distributed than the Empire and Spokane Formations in the study area. The most common copper minerals in these occurrences are bornite and malachite; chalcocite and chalcopyrite are less common. Individual occurrences can be continuously traced for only a few feet, but in some parts of the area such as from Basin Creek for 6 miles (10 km) to the northwest (fig.11b, northern part), copper-bearing outcrops were observed in all ridges that trend approximately normal to the strike of the formation. The apparent lack of stratigraphic continuity of the occurrences in the Snowslip may be due to the fact that unlike the mineralized zones in the Spokane and Empire they have not been opened up by prospect workings, nor have they been exposed by road cuts. The type, setting, and the tenor of the occurrences in the Snowslip are greatly similar to those in the Empire and Spokane, except that those in the Snowslip more frequently contain anomalous amounts of lead and molybdenum (table 6). In addition to the Basin Creek locality, scattered mineralized zones in the Snowslip follow the outcrop pattern of the formation in the western part of the area from southeast of Ptarmigan Mountain to the north edge of the study area, a distance of over 37 miles (60 km) (figs. 11a-11c). The thin near shore facies of the Snowslip on and east of the Continental Divide also contains zones with anomalous amounts of copper, silver, lead, and molybdenum. Regardless of the widespread occurrences, it is unlikely that the Snowslip contains copper and silver deposits that could be profitably mined in the foreseeable future. The potential for submarginal copper and silver resources in the Snowslip, particularly in the area to the north of Basin Creek, is at least equal to the potential for these commodities in the Empire and Spokane Formations.

Stratabound copper-silver occurrences in the other Missoula Group formations appear to have a low potential. In order of decreasing importance, these include: (1) occurrences in the Mount Shields Formation near the West Fork Sun River (fig. 11b), and south and southwest of Red Plume Mountain (fig. 11a) and (2) widespread occurrences with generally low copper and silver values in glauconitic rocks of the McNamara Formation in the central part of the area. The distribution of anomalous values of copper and silver from stratabound occurrences in the other formations are not shown on the geochemical distribution maps because they are relatively few and apparently unimportant.

Stratabound lead-silver-zinc deposits and copper-silver deposits in carbonate rocks.--The Precambrian carbonate rocks of the area locally contain stratabound occurrences of lead, silver, and zinc: locallv. copper minerals are more abundant than either lead or zinc minerals These occurrences are mostly in the Helena and Shepard Formations, those in the Helena are more widespread than those in the Shepard. As a result, only those occurrences in the Helena are evaluated in this report.

The lead-silver-zinc and copper-silver occurrences are commonly associated with algal deposits in the Helena. The algal material consists of stromatolites and oolites in beds up to about 3 feet (1 m) thick, but they are more commonly less than 1.5 feet (.5 m) thick. Locally, carbonate beds over a thickness of several feet contain fairly abundant fragments of stromatolitic debris. The algal material was deposited in a shelf or tidal flat environment that represents a transition to reducing conditions; this environment is favorable for the precipitation of sulfide minerals.

Very low-grade occurrences that contain megascopically visible amounts of galena and locally copper sulfide minerals are erratically distributed in the algal beds, but most algal beds contain low amounts of these metals.

Numerous samples containing anomalous amounts of lead (greater than 50 ppm) were collected from Helena carbonate rocks that apparently lack algal debris, but these values are too low to represent a potential lead resource except possibly where the Helena is in contact with a Precambrian diorite sill. Such is the case in the eastern part of the area near and south of Lick Mountain (fig. 11b) where the Helena contains visible disseminated galena within 6 feet (2 m) of a sill. The mineralized zone may be nearly continuous over a strike length of 4 miles (6 km); however, it is not well enough exposed to establish continuity. The lead values ranged from 70 to 5,000 ppm in the rock samples from the mineralized zone. Anomalous lead values in the sediments from streams to the north of Lick Mountain may reflect a northward continuation of the mineralized zone (fig. 10b). This occurrence has a low resource potential because the mineralized zone is thin and lead values are low and erratic. Other base metal and silver occurrences in the Helena in the study area also have low resource potential.

Vein deposits with copper-lead-zinc-silver in Precambrian diorite sills.--Vein deposits with base and precious metals are spatially and probably genetically related to the Precambrian diorite sills. These deposits are mostly restricted to the vicinity of Goat Ridge in the east-central part of the area where they have been prospected. Similar occurrences in a Precambrian diorite sill about 3 miles (5 km) south of Red Plume Mountain can be inferred from the anomalous amounts of silver and lead in the sediments of streams that drain the sill (fig. 10a). The veins are as much as a few inches thick and occur in the upper part of the sill. In the prospects at Goat Ridge area the diorite contains small fracture fillings and vugs filled with limonite, pyrite, malachite, azurite, bornite, covelite, chalcopyrite, galena, and sphalerite in a calcite matrix. Fractures in the diorite host rock are commonly coated with malachite. Locally, malachite and sulfide minerals are disseminated in the diorite groundmass between sulfide-bearing calcite veinlets. Sulfide occurrences associated with the Precambrian diorite sills have a low resource potential because they are very small.

Deposits of vein barite.--Barite-bearing veins are widespread in the study area, but the only ones of possible economic importance are in the upper part of Black Bear Creek where they are up to 10 ft (3 m) thick and contain relatively pure barite. Elsewhere, small veinlets and veins of barite of up to a few inches thick occur in most of the Precambrian formations, but none of these represent a potential resource of barite.

The barite veins in the upper part of Black Bear Creek at sample locality B-3 (pl. 2) are in the McNamara Formation and consist of almost pure light gray to pinkish-gray barite with very minor limonite after pyrite. The principal vein is exposed by outcrops and prospect trenches over a slope distance of 300 feet (100 m) or so. It strikes northerly and is steeply dipping. The thickness of the vein ranges from 2 feet (0.6 m) in the northern outcrop area to 10 feet (3 m) in the central outcrop area and to about 8 feet (2.5 m) at the southern extremity. At least one other vein, up to 3 feet (1 m) thick is near and parallel to the principal vein. The wall rocks of the veins are fractured, chloritic, and contain disseminations, vugs, and lenticular inclusions of barite and minor limonite; the hanging wall of the principal vein is highly convoluted. About 500 feet (150 m) downslope from the southern outcrop limit of the vein, the McNamara Formation is continuously exposed across the strike projection of the vein. The absence of the vein in this outcrop indicates that the vein very likely terminates; it is doubtful that its strike changes radically. The termination point of the vein to the north is less certain; however, the vein does not crop out on a ridge about 1.5 miles (2 km) north of the northernmost exposure. Neither the vein nor the fractured wall rocks contain unusual amounts of valuable metals. The dimension of the veins are described in greater detail in Chapter E along with a grade and tonnage estimate. The barite veins in the study area apparently do not contain recoverable amounts of metals; in addition, the barite veins are relatively inaccessible. Therefore, although they are high grade, these deposits are considered to be a paramarginal resource.

Limestone and dolomite deposits in the Paleozoic formations.--The Paleozoic formations in the eastern part of the area contain large deposits of high-quality limestone and dolomite. These deposits are of no value currently because of their inaccessibility and distance from potential markets. Deposits of at least equal size and quality occur in more accessible localities outside of the study area. Carbonate rocks in the Precambrian formations are of much lower quality.

High-calcium limestone and high-purity dolomite are the most valuable of the carbonate rocks because of the great variety of uses in the chemical and metallurgial industries. High-calcium limestone must contain at least 95 percent $CaCO_3$ by weight and high-purity dolomite must have at least 40 percent $MgCO_3$ (Brobst and others, 1973). Analytical data on samples from Paleozoic carbonate rocks are included in table 7. The results indicate that the middle member of the Allan Mountain Limestone of Mississippian age contains a 12-foot (36-m) thickness of high-calcium limestone. The Devils Glenn Dolomite of Cambrian age and the Sun River Member of the Allan Mountain Limestone of Mississippian age contains 155 and 255 feet (47 and 78 m) thicknesses of high purity dolomite, respectively. The high-calcium limestone deposits are widely distributed in the eastern third of the area. The bulk of the high-purity dolomite resources are in the east-central and southeastern parts.

Table 7. Average calcium and magnesium content of some Paleozoic carbonate rocks in and near the Bob Marshall Wilderness and adjacent study areas, Montana (from measured sections described by Mudge, Sando, and Dutro, 1962, and by Mudge, 1972); values in percent.

Cambrian rocks			
Formation	--	Devils Glenn Dolomite	Damnation Limestone
Thickness	--	154 feet (47 meters)	144 feet (44 meters)
No. Samples	--	4	4
Av. Ca	--	22.3	35.5
Av. $CaCO_3$	--	55.6	63.5
Av. Mg	--	12.9	1.2
Av. $MgCO_3$	--	44.7	3.9

Devonian rocks			
Formation	--	Maywood (Upper Member)	Jefferson (Lower Member)
Thickness	--	149 feet (45 meters)	577.5 feet (166 meters)
No. Samples	--	6	25
Av. Ca	--	26.0	26.6
Av. $CaCO_3$	--	64.9	66.2
Av. Mg	--	7.8	9.1
Av. $MgCO_3$	--	26.9	31.4

Mississippian rocks			
Formation	--	Allan Mountain Limestone (Middle Member)	Allen Mountain Limestone (Upper Member)
Thickness	--	118 feet (36 meters)	209.6 feet (64 meters)
No. Samples	--	3	7
Av. Ca	--	38.5	36.9
Av. $CaCO_3$	--	95.8	92.2
Av. Mg	--	0.3	1.2
Av. $MgCO_3$	--	1.1	4.2
Formation	--	Castle Reef Dolomite (Lower Member)	(Sun River Member)
Thickness	--	442.7 feet (135 meters)	256 feet (78 meters)
No. Samples	--	14	6
Av. Ca	--	32.9	21.6
Av. $CaCO_3$	--	82.1	53.7
Av. Mg	--	4.5	12.9
Av. $MgCO_3$	--	15.4	44.8

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CHAPTER D

Petroleum evaluation of the Bob Marshall Wilderness and study areas

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INTRODUCTION

The eastern part of the Bob Marshall Wilderness, the Deep Creek and Renshaw Mountain study areas, and most of the Great Bear study area has a high potential for natural gas accumulations and somewhat lesser potential for oil accumulations. The area has hydrocarbon source and reservoir rocks and very likely contains structural traps. The western part of the Bob Marshall Wilderness, the West side Swan, Monture, and Grizzly Basin study areas, the Swan-Bunker study area, and the Flathead Range part of the Great Bear study area is estimated to have a low potential for exploitable hydrocarbon accumulations because these areas contain a thick sequence (as much as 32,000 ft-9,760 m) of Precambrian rocks which overlie potential reservoir and source rocks.

The eastern part of the study area is in the structurally complex northern disturbed belt of Montana, an arcuate belt of closely spaced thrust faults, folds, and some longitudinal normal faults. The west boundary of the disturbed belt is arbitrarily drawn along the South Fork of the Flathead River and the west side of the Flathead Range. The following discussion will pertain almost entirely to the part of the study area within the disturbed belt.

The disturbed belt lies west of the Sweetgrass Arch, a broad northwest plunging flexure that consists of the south arch and the Kevin-Sunburst dome. The Sweetgrass Arch has been tectonically active during various periods, beginning in Precambrian time; its present form was attained in the Late Cretaceous or very Early Tertiary. The Scapegoat-Bannatyne trend, a linear structure in the Precambrian basement, extends northeast across the arch (fig. 13). It contains numerous highs, with as much as 1,400 ft (425 m) of structural relief, that formed prior to Cambrian deposition (Alpha, 1955). The Pendroy Fault, a northeasterly trending arcuate fault zone at the northwest end of the south arch of the Sweetgrass Arch and the Scapegoat-Bannatyne trend, are reflected as pronounced lineaments on LANDSAT photographs.

Recent prolific oil and gas discoveries in the overthrust belt of Wyoming, Idaho, and Utah to the south (Powers, 1977), and the presence of numerous fields with vast reserves of gas and minor amounts of oil in the analogous Alberta foothills to the north suggest that the disturbed belt of northwestern Montana is a potentially important oil and gas province. The fields in Alberta, Canada, shown on table 9 contain in-place reserves totaling greater than 15 Tcf (Trillion cubic feet) of gas. Fox (1959) and Wells (1968) provide detailed summaries of the petroleum geology of this province. The structure, stratigraphy, and geologic history of the productive foothills are similar to the disturbed belt of northwestern Montana (Mudge, Earhart, and Rice, 1977).

The study area is virtually unexplored for hydrocarbons. No exploratory wells have been drilled and only one seismic survey extended into the area along the South Fork of Deep Creek in the Deep Creek study area. East of the study area gas was discovered in wells drilled in the 1950's near the southeast boundary of the Great Bear study area and in the vicinity of East Glacier Park (table 8 and fig. 13). These wells never produced because the region was too remote from markets and the price of gas was too low for economic production; one well had a flow potential as great as 6.3 million cubic feet of gas per day (MMCFD). The inaccessibility of the mountains to the west and the structural complexity of the disturbed belt may have discouraged early exploration in the study area. Recent discoveries in the Idaho-Wyoming- Utah Overthrust Belt have renewed interest in the northern disturbed belt of Montana.

Many geologic factors are considered in an evaluation of the hydrocarbon potential of an area, such as: potential source and reservoir rocks, structural and stratigraphic traps, seals for the traps, and timing of each factor relative to hydrocarbon generation and migration.

The hydrocarbon evaluation of the study area is based on: (1) surface mapping, (2) analyses of rock samples and limited stratigraphic studies, and (3) geologic comparisons with analogous productive areas in the southern Alberta Foothills to the north, and on the Sweetgrass Arch to northeast and east.

The authors thank Mr. C. G. Maio of the Montana Board of Oil and Gas Conservation, who granted permission to sample cores from nearby wells for source rock studies. The investigations were also aided by personnel from Shell Canada Resources, Ltd., who furnished natural gas samples from the Jumping Pound field in Alberta. C. Threlkeld, of the U.S. Geological Survey, did carbon-isotope analyses on the natural gases.

OUTCROPPING ROCKS

The eastern part of the study area contains outcropping Paleozoic and Mesozoic rocks Precambrian and Paleozoic rocks crop out in the western part. The outcropping rocks and structures in the study area are shown on plate 1. The stratigraphic units and their potential as source and reservoir rocks for hydrocarbons are shown in figure 14. Only those units pertinent to hydrocarbon evaluation will be briefly discussed.

Eastern part.--The eastern part covers most of the area east of the Continental Divide to the south, and the area drained by the upper tributaries of the Middle Fork Flathead River to the north. It includes the Sawtooth Range which contains closely spaced thrust fault blocks of Paleozoic and Mesozoic rocks, and the valley of the North and South Forks of the Sun River and the upper reaches of the Middle Fork Flathead River which contain thrust faulted and folded Mesozoic rocks.

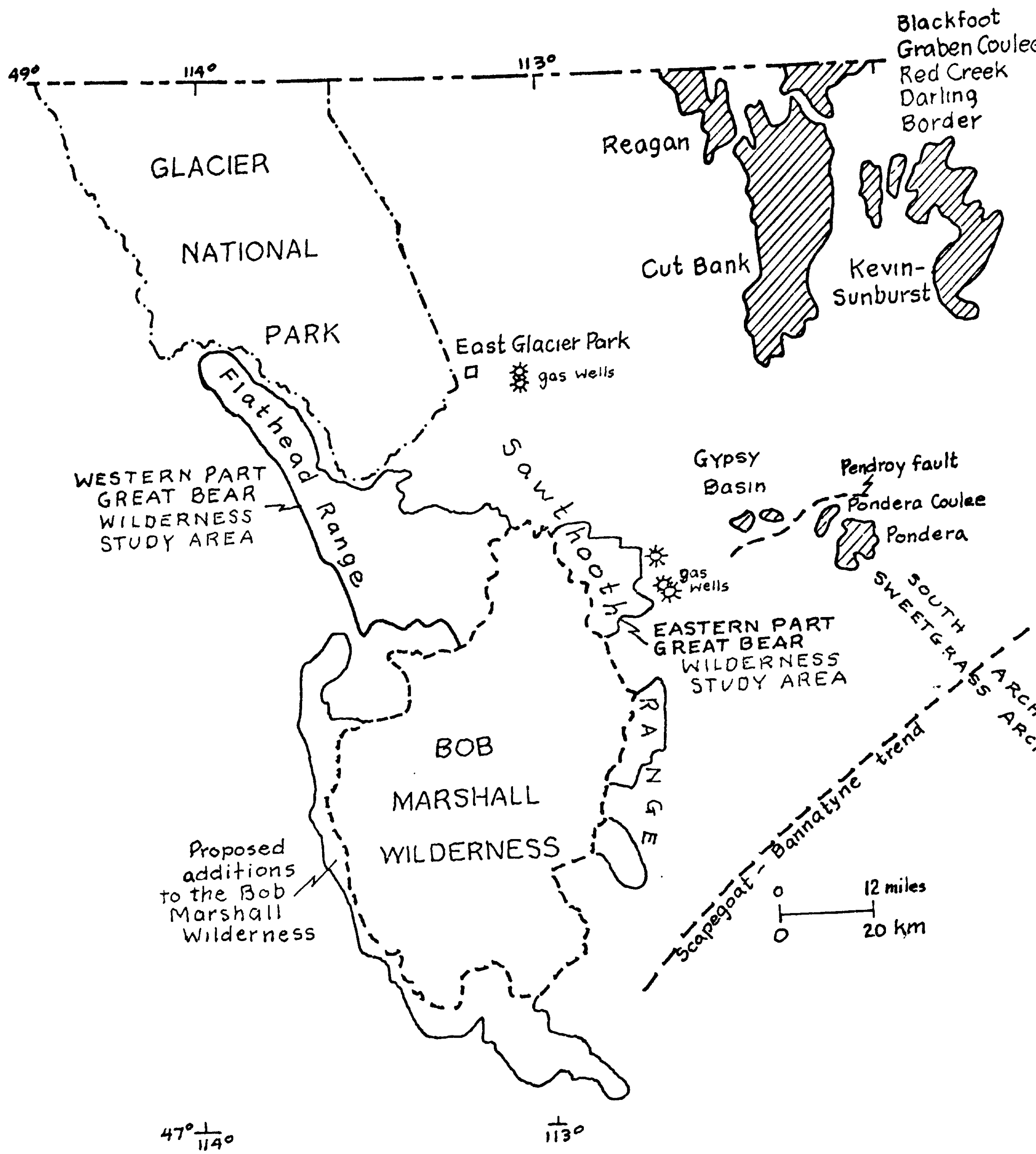

Figure 13.--Map of a part of northwest Montana showing oil and gas fields (Hatchured), abandoned or shut-in gas wells, and structural features east of the Great Bear wilderness study area.

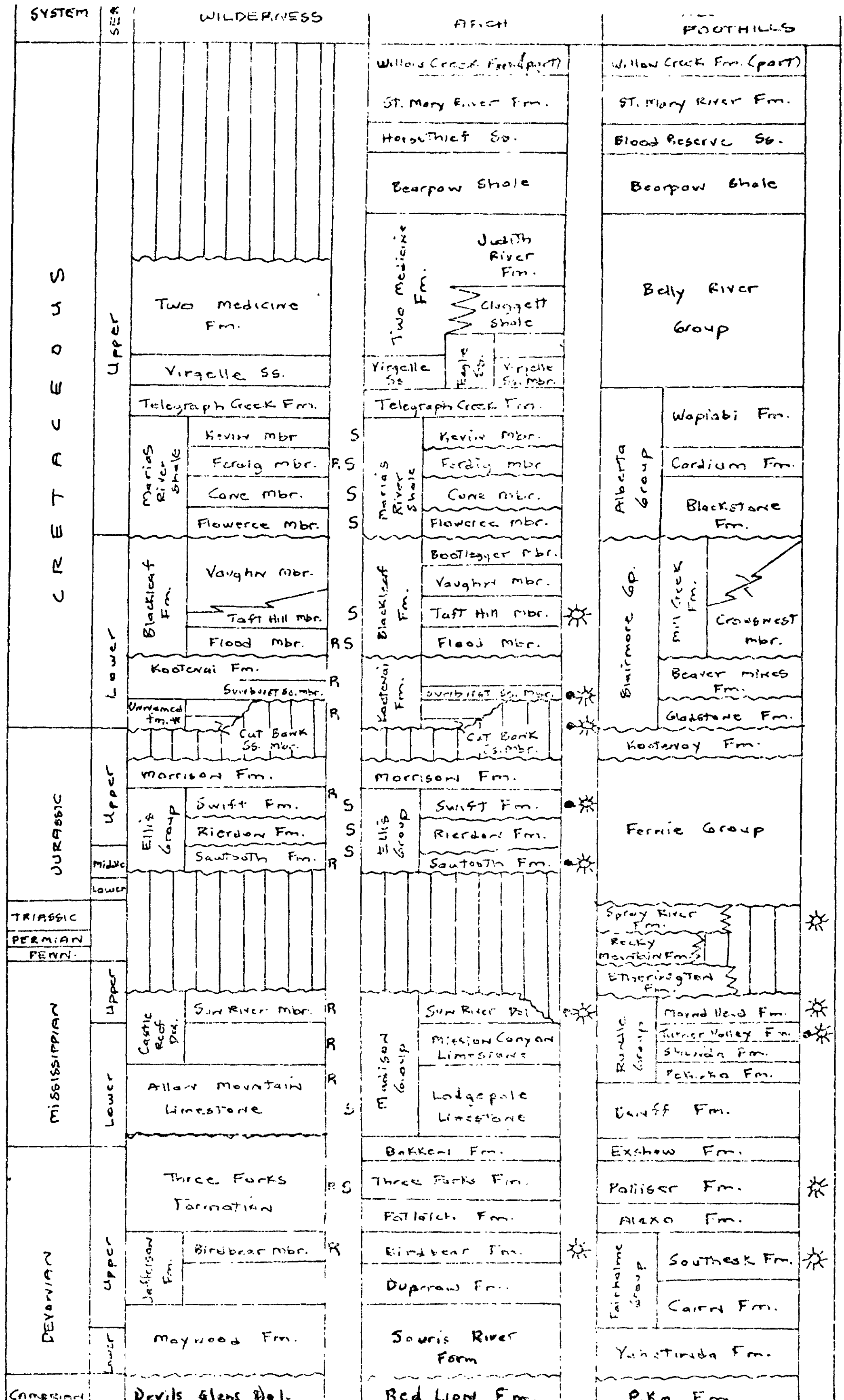

Figure 14 Correlation chart for Bob Marshall Wilderness, Sweetgrass arch, and southern Alberta Foothills showing productive intervals. ● oil ☼ gas R Reservoir from S source rock.

* Unnamed formation crops out northeast of the study area and may be present in the subsurface to the north.

Mississippian rocks are locally exposed along the west side of the area. All potential hydrocarbon source and reservoir rocks appear to thicken westward and northwestward in the eastern part of the area.

The Paleozoic rocks in the Sawtooth Range are of Cambrian, Devonian, and Mississippian ages. Only the upper three Cambrian formations shown on table 1 Chapter A, crop out in the eastern area; however, the entire Cambrian sequence underlies the area. The exposed formations are at least 600 ft (185 m) thick and consist of thin bedded, gray-brown limestone and interbedded shale which are overlain by a dark gray mudstone and thick dolomite. Cambrian rocks are not known as hydrocarbon reservoir or source rocks in the region.

Devonian rocks in the eastern part of the study area are about 1,000 ft (305 m) thick. The Birdbear Member of the Jefferson ranges in thickness from 150 to 235 ft (46-72 m) and consists mostly of thin beds of dolomite that pinch and swell. The Three Forks Formation, as much as 590 ft (180 m) thick, is mostly porous breccia with some interbedded dolomite. The upper part of the sequence contains Lower Mississippian-Upper Devonian black shale. This is part of the Exshaw Shale in the subsurface of southeastern Alberta and part of the Sappington Member of the Three Forks Formation in Montana (Macqueen and Sandberg, 1970). It is considered the principal hydrocarbon source bed in the Williston basin (Dow, 1974). In the eastern part of the study area this shale is as much as 3.0 ft (1.0 m) thick.

Natural gas is produced from Devonian reservoir rocks in the southern foothills of Alberta and on the Sweetgrass Arch, east of the study area (figs. 13 and 15). In southern Alberta these reservoir rocks are in the upper part of the Fairhome group (Birdbear Member of the Jefferson Formation) and the Pallister Formation (Three Forks Formation) (fig. 14). On the Kevin-Sunburst Dome, a part of the Sweetgrass Arch, gas is produced from the Birdbear Membr. In the 1950's natural gas was recovered in a test well from the Jefferson and the lower part of the Three Forks Formations east of the Great Bear study area.

Mississippian rocks in the area are the primary hydrocarbon reservoir rocks on the Sweetgrass Arch to the east (Chamberlin, 1955) and in Alberta to the north (Gordy and Frey, 1977). The shut-in or abandoned wells east of the study area (table 8) tested natural gas from the Sun River Member of the Castle Reef Dolomite (uppermost Mississippian). Gallup (1951, p. 814) considered the Banff Formation (Lower Mississippian) and the upper part of the Rundle (Upper Mississippian) as the source beds of oil and gas in the Turner Valley field in Alberta. In the eastern part of the study area numerous relatively thick beds of porous coarsely crystalline crinoidal debris occur at various horizons in the middle and upper parts of the Mississippian sequence. These potentially important hydrocarbon reservoir beds thicken westward. Oil residue is locally at and near the top of the Mississippian sequence at the southeast end of Diversion Lake and in the upper reaches of Birch Creek. A well developed joint system

Table 8.--Gas fields of the Alberta Foothills (north to south)

	Initial in-place reserves billion cu. ft.	billion cu. mtrs.	Recovery rate
Mountain Park	21	0.6	0.90
Lovett River	72	2	0.80
Brown Creek	59	1.7	0.85
Stolberg	550	15.6	0.80
Nordegg	34	1	0.85
Hunter Valley	78	2.2	0.85
Burnt Timber	780	22	0.85
Panther River	201	5.7	0.75
Wildcat Hills	1070	30.3	0.85
Jumping Pound	2817	79.7	0.85
Sarcee	190	5.4	0.90
Moose Mountain	50	1.4	0.80
Turner Valley	2870	81.2	0.75
Savanna Creek	240	6.8	0.85
Waterton	4137	117.1	0.80
Pincher Creek	1590	45	0.30
Lookout Butte	530	15	0.55

Source: Reserves of crude oil, gas, natural gas liquids, and sulfur, Province of Alberta: Energy Resources Conservation Board 1975.

Table 9.--Shut-in gas wells in the northern disturbed belt of Montana

Name	Location	Producing formation and depth	Initial potential flowing
Northern Natural gas 1 Blackleaf - Federal "B"	NE° SW° sec. 19, T. 26 N., R. 8 W.	Sun River Mbr. Castle Reef Dol. 5280-5300 ft (1609-1615 m)	969 MCFGPD (27 MCMGPD)
Northern Natural Gas 1 Blackleaf - Federal "A"	SE° NE° sec. 13, T. 26 N., R. 9 W.	Sun River Mbr. Castle Reef Dol. 3794-3830 ft (1156-1167 m)	6293 MCFGPD (178 MCMGPD)
Texaco 1 Government - Pearson	SW° SW° sec. 26, T. 27 N., R. 9 W.	Three Forks Fm. Jefferson Fm. 2068-3360 ft (630-1024 m)	280 MCFGPD (8 MCMGPD)
Union Oil 1 Morning Gun	SW° SW° sec. 18, T. 31 N., R. 11 W.	Sun River Mbr. Castle Reef Dol. 8962-9087 ft (2732-2770 m)	500 MCFGPD (14 MCMGPD) 13 bbls. condensate
Great Northern Drilling 1 Two Medicine	SE° NW° sec. 19, T. 31 N., R. 11 W.	Sun River Mbr. Castle Reef Dol. 8895-9018 ft (2711-2749 m)	771 MCFGPD (22 MCMGPD) 13.6 bbls. condensate

MCFGPD - thousand cubic feet of gas per day.
MCMGPD - thousand cubic meters of gas per day.
bbls. - barrels.

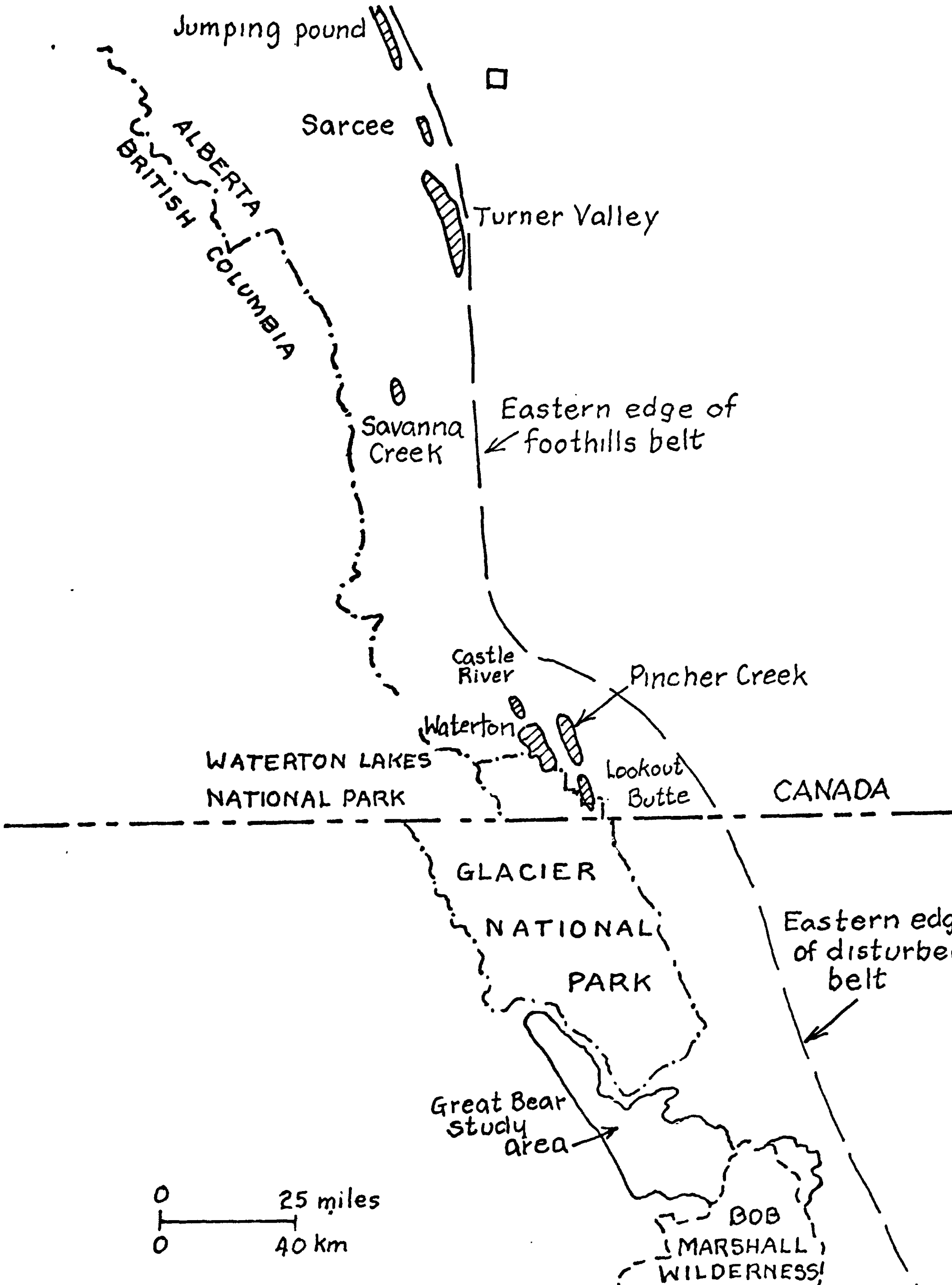

Figure 15.--Map of a part of southern Canada and adjacent Montana showing the location of gas fields (hatchured) in the Foothills of Alberta, Canada.

was formed in the upper part of these rocks prior to Jurassic sedimentation (Mudge, 1972a, p. A41). The joints were widened by ground water and filled with sand to depths of 20 feet or more during Middle Jurassic sedimentation. Sand was also transported laterally along some bedding planes resulting in local occurrences of sand lenses in the upper part of the Mississippian strata, especially along the west side of the valley of the North Fork of the Sun River. The lower member of the Allan Mountain Limestone (Lower Mississippian) contains interbedded gray shales that are also considered potential source rocks.

Mesozoic rocks are exposed in the eastern part of the study area (fig. 14), and some of them are important hydrocarbon source and/or reservoir rocks. The oldest and probably the most important of these rocks occur in the Middle Jurassic Ellis Group which are, in ascending order: the Sawtooth, Rierdon, and Swift Formations (fig. 7a, Chapter A). As noted in Chapter A, these formations increase considerably in thickness from the southeast outcrop (285 ft - 87 m) to the southwest outcrop (675 ft - 205 m) and to the north (more than 615 ft -188 m). The thickest southwest sections are in the eastern part of the Bob Marshall Wilderness and the thickest northern sections are in the eastern part of the Great Bear study area. As shown on figure 7a, Chapter A, the thickening of these formations is due mainly to thickening within their shale units, which are the hydrocarbon source rocks. The shale member of the Sawtooth Formation, in particular, thickens markedly from the southern part of the Sawtooth Range (16.5 ft - 5 m) northward (more than 255 ft - 77 m). It ranges in thickness from less than 10 ft to 45 ft (3 to 18 m) in the subsurface in the Cut Bank oil and gas field to the northeast (Cobban, 1945). In the eastern part of the Great Bear study area an oil impregnated, dark gray, thinly bedded, very fine-grained sandstone 5.5 ft (1.6 m) thick occurs in the lower part of the shale member of the Sawtooth about one mile south of Mount Patrick Glass. A coquina, about 20 ft (6 m) thick lies about 25 ft (8 m) above the base of the unit at the head of the Middle Fork Birch Creek. Here it has a distinct petroliferous odor on a freshly broken surface. The Rierdon Formation thickens northwest from about 110 ft (34 m) in the southeast part of the Sawtooth Range to possibly more than 185 ft (56 m) to the northwest.

The Swift Formation contains potential hydrocarbon source and reservoir rocks. The lower shale member, a potential source rock, ranges in thickness from about 22 ft to 103 ft (7 to 32 m), attaining its maximum thickness in the eastern part of the Great Bear study area. The sandstone member contains oil-reservoir beds in the Flat Coulee oil field in Liberty County, Montana (Radella and Galuska, 1966), and in the Bannatynne field in the southern part of the Sweetgrass Arch (Gribi, 1959). It is correlated with the "Ribboned" sandstone in the subsurface by Cobban (1955). In the eastern part of the study area it ranges in thickness from 17 to 97 ft (5 to 30 m). The thickest part of the Swift Formation is adjacent to the northeast corner of the western part of the Great Bear study area.

The Lower Cretaceous Kootenai and unnamed formations contain units that are lithologically and stratigraphically equivalent to reservoir rocks that produce oil and gas in the vicinity of Cut Bank, Montana, to the northeast. The lower unnamed formation includes the Cut Bank Sandstone Member and the Moulton Member described by Rice (1975). The unnamed formation is from 113.0 to about 300 ft (34-92 m) thick in the eastern part of the Great Bear study area (fig. 7c, Chapter A). A basal sandstone unit, the lower Cut Bank sand, attains its maximum thickness of 100 ft (30 m) in the eastern part of the Great Bear study area. Conglomerate is common at the base and at various horizons within this coarse to medium grained sandstone. A second porous sandstone unit, referred to locally as the upper Cut Bank member, lies about 40 to 60 ft (12 to 18 m) above the basal sandstone. It is 3 to almost 20 ft (1-6 m) of coarse to fine-grained sandstone.

Sandstone units in the Kootenai Formation produced oil and gas in the Cut Bank and other fields on the Sweetgrass Arch where the Cut Bank and Moulton members are included in the Kootenai. The Sunburst Sandstone Member, a hydrocarbon reservoir rock in the Kootenai in oil and gas fields in the Kevin-Sunburst Dome to the northeast, persists only near Deep Creek in the study area. The Kootenai in the study area contains two to five poorly sorted sandstone units which locally contain channel-fill deposits of sandstone and conglomerate as much as 50 ft (15 m) thick (Mudge and Sheppard, 1968); they are considered as potential reservoir rocks.

The Blackleaf Formation includes the marine Flood and Taft Hill Members and the nonmarine Vaughn Member. A medial shale unit and two sandstone units in the Flood are potential source and reservoir rocks. The sandstone units are as much as 30 ft (10 m) thick; the upper unit is thicker and more widespread. The shale unit is dark gray and as much as 195 ft (59 m) thick. Gas has been produced from shallow wells in marine sandstones in the Taft Hill Member in several fields to the east. In addition, although the Taft Hill is a prominent marine unit in the southern part of the Sawtooth Range, it grades northward into nonmarine rocks of the Vaughn Member of the Blackleaf Formation. The dark gray, marine shales in the Taft Hill in the southern part of the Range are potential hydrocarbon source rocks. The Vaughn Member locally contains lenticular channel deposits of poorly sorted sandstone and conglomerate as much as 20 ft (6 m) thick which are potential reservoir rocks but of limited areal extent. Igneous sills of very Late Cretaceous or Early Tertiary age, which average 500 ft (152 m) thick, intruded strata of the Kootenai and Blackleaf Formations in the area of the North and South Fork of the Sun River (pls. 1 and 5). The lack of intense metamorphism associated with the intrusion of the sills suggests that they probably did not affect potential hydrocarbon accumulations.

The marine Marias River Shale is mostly dark gray shale as much as 1,300 ft (397 m) thick. It is exposed in the valleys of the North and South Forks of the Sun River in the eastern part of the Bob Marshall Wilderness. The four members of the Marias River Shale (fig. 14) contain potential hydrocarbon source rocks and the Ferdig Member contains potential reservoir rocks. The source rock characteristics of the Cone Member east of the mountains was noted by Stebinger (1918, p. 161-162) who reported that distillation tests on the unit yielded the equivalent of 1 to 2 gallons of oil per ton (4.2 to 8.3 liters per tonne).

The Ferdig Member of the Marias River Shale includes a western sandstone facies that may be present beneath the Lewis thrust plate in the western part of the study area. This sandstone facies in the western part of the Sun River area is correlated with the Cardium Sandstone, a petroleum reservoir rock in Alberta (Mudge, 1972). In the Sun River Canyon area the western facies of the Ferdig is about 280 ft (85 m) thick; it increases in thickness northward to about 350 ft (106 m). It consists mostly of fine grained sandstone beds which are nodular in the lower part, thin bedded in the middle, and massive and somewhat crossbedded in the upper part. This unit in the eastern part of the study area trends northwest beneath the South Fork and Lewis thrust plates; it may be present beneath the Lewis plate in the western part of the Great Bear study area. The Ferdig is overlain by thick dark gray shale of the Kevin Member.

The Telegraph Creek and Virgelle Sandstone, prominent marine sandstone units in the valley of the North Fork of the Sun River, are potential hydrocarbon reservoir rocks in and west of that area. The Telegraph Creek is about 550 ft (168 m) thick and consists mostly of thick bedded fine-grained sandstone (Mudge, 1972a). The Virgelle consists of thick beds of poorly sorted sandstone about 200 ft (61 m) thick.

The nonmarine Two Medicine Formation is about 2,000 ft (610 m) thick in the North Fork of the Sun River (Mudge, 1966). Thick sandstone units, locally conglomeratic, occur in the lower 550 ft (168 m) of the formation.

Central and Western part.--The outcropping rocks in the central and western part of the study area are mostly formations of the Precambrian Y Belt Supergroup (table 1, Chapter A). Paleozoic rocks overlie them in the central part of the area (pl. 1). A thick Precambrian diorite sill occurs along the eastern, western, and southern margins of the area.

Precambrian Belt and Paleozoic rocks are involved in the Lewis and South Fork thrust plates. In the Lewis thrust plate these rocks are more than 17,000 ft (5,185 m) along the Flathead Range, and more than 32,000 ft (9,760 m) thick along the Swan Range to the west. They are as much as 34,000 ft (10,370 m) thick in the Scapegoat Wilderness to the southeast. The thickness of the Precambrian, as shown on the cross section on plate 1, is more than 18,000 ft (5,490 m) at the South Fork Flathead River.

Precambrian strata in the South Fork thrust plate are about 4,200 ft (1,281 m) in the northern part of the area, and as much as 8,800 ft (2,684 m) thick in the south.

Hydrocarbon source and reservoir rocks of Paleozoic and Mesozoic ages extend an unknown distance westward beneath the South Fork and Lewis thrust plates.

STRUCTURAL CONSIDERATIONS

Because the area is structurally complex the location and configuration of buried structural traps that are favorable for the accumulation of hydrocarbons are difficult to interpret without the aid of seismic records and drill hole data. The importance of seismic records in the interpretation of subsurface structures in the disturbed belt was stressed by Gordy and Frey (1977) who stated:

> "It was not until the Forties, when seismic exploration techniques were used extensively, that commercial production was established and the hydrocarbon potential of the area [southwest Alberta] began to be fully realized. Since the discovery of Pincher Creek in 1948, five gas accumulations have been found with total ultimate reserves of marketable gas in the order of 2800 billion cubic feet ($79x10^9m^3$)."

The rocks in the study area were deformed during at least two tectonic events. The exposed structures are a result of an Early Tertiary orogeny, and consist of closely spaced thrust faults in the eastern part and normal faults and broad open folds in the Lewis thrust plate in the central and western parts (pl. 1). These structures are superimposed on pre-existing structures that may originally have formed during or soon after Precambrian time, and were reactivated in Late Cretaceous or very early Tertiary time.

Pre-Early Tertiary structures were a control for hydrocarbon accumulation in Alberta (Gallup, 1955), on the Sweetgrass Arch east of the disturbed belt (Alpha, 1955; Leskela, 1955), and in eastern Montana (Thomas, 1974). In the study area, older structures may be reflected by northeasterly-trending lineaments and trends. The lineaments, discussed briefly in Chapter A, are an alinement of topographic and structural features. Most of the trends, as discussed in Chapter B, are an alinement of gravity and magnetic features that are spatially related to the lineaments.

The Scapegoat-Banntynne trend and Pendroy fault zone (extension of the Lick Creek trend of Chapter B) are spatially related to known hydrocarbon occurrences. An abandoned oil field as well as other wells containing oil shows are located along the Scapegoat-Bannatyne trend on the Sweetgrass Arch (Alpha, 1955). The Pondera oil field is in the upthrown block (south side) of the Pendroy fault zone. Farther west, shut-in gas wells, just east of the Creat Bear study area, are probably near the southwesterly extension of this fault zone. This area includes the westerly extension of the Sweetgrass Arch which forms a structurally high part of the disturbed belt. Folds plunge northwest and south from the structural high (Mudge, Earhart, and Rice, 1977). Farther southwest, along Lick and Route Creeks in the eastern part of the Bob Marshall Wilderness, the trend appears to reflect a broad unnamed structural arch (Chapter B).

Farther north the Schafer Meadows-Cox Creek trend and the two lineaments that extend across and north of Morrison Creek (fig. 8, Chapter A) appear to reflect northeasterly trending structural features in the subsurface (see Chapters A and B). These trends and lineaments are in an area where stratigraphic data (Chapter A) on early Mesozoic rocks indicate a marked change northward from a shallow basin to a deep basin or trough. This part of the area may contain both structural and stratigraphic traps that are favorable for the accumulation of hydrocarbons.

Two northeasterly-trending lineaments are in the western part of the Great Bear study area, south of Glacier National Park. Here Precambrian metasedimentary strata are exposed in normal fault blocks and folds that comprise the Lewis thrust plate. The structural features in the plate, related to the lineaments, are discussed in Chapter A; they are part of southeasterly dipping monoclines. The monoclines reflect a pre-Lewis thrust fault structure that may have originated in the Precambrian crystalline basement, similar to the Scapegoat-Bannatyne trend and Pendroy fault zone. The lineaments are also near the south margin of a deep early Mesozoic basin. Subsurface data in the area are insufficient to infer the nature or extent of the structure.

Three types of structural traps should be considered in hydrocarbon studies in the northern disturbed belt according to Hurley (1959). Type 1 is the wedge-edge of Paleozoic rocks that terminate against an underlying fault, and we would include also the wedge-edge of potential reservoir rocks of Mesozoic age in thrust plates. Type 2 is drag folding formed by thrust faulting, and Type 3 is folded thrust plates.

The structural trap most likely in the study area is Type 1; this type contains gas in the area of the shut-in or abandoned wells in Blackleaf Creek (fig. 17, Hurley, 1959). Structures of this type probably extend northwest into the eastern part of the Great Bear study area. It is also the most common type of structural trap in the gas fields in the foothills of Alberta (Bally, Gordy, and Stewart, 1966). An example of this trap, shown on figure 18, is the thrust fault blocks with Paleozoic rocks in the Waterton field in the southern Foothills Belt of Alberta which is one of Canada's largest gas producers (Gordy and Frey, 1977). They (1977) note that interpretation of seismic data disclosed a complex stack of at least three major thrust plates containing Paleozoic carbonate rocks. Development drilling confirmed the seismic interpretation, and disclosed internal structures that were complicated by folding and by subsidiary thrust faults (Gordy and Frey, 1977).

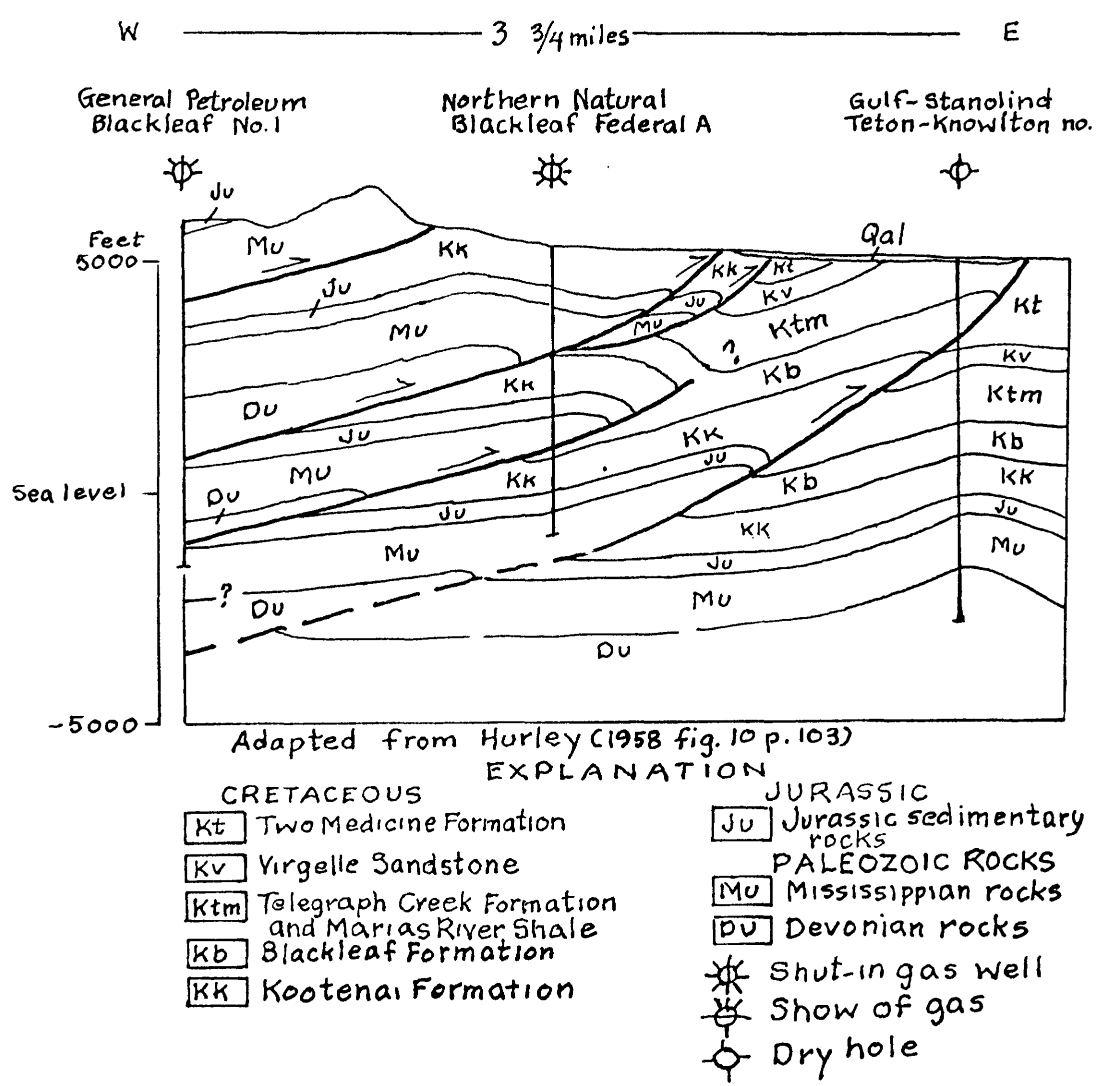

Figure 16.--Geologic cross section in Blackleaf Creek, east of the Great Bear wilderness study area. Arrows show direction of movement on faults. Qal, alluvial deposits.

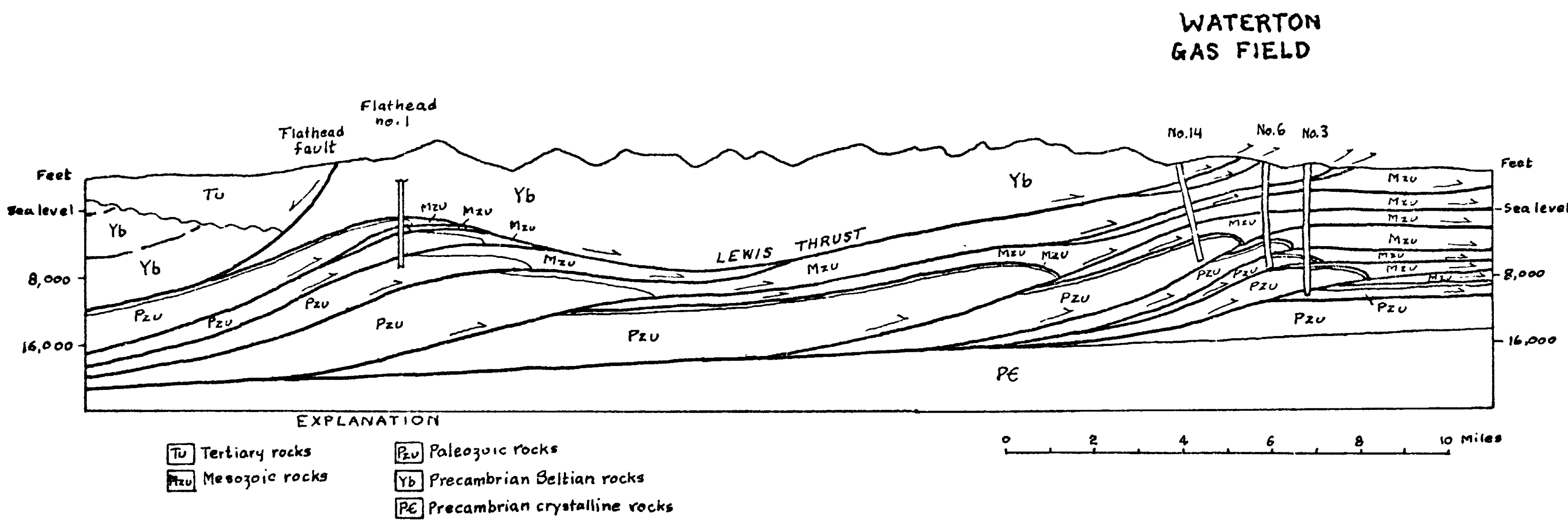

Figure 17.--Geologic cross section of Waterton gas field in southern Alberta and adjacent area in Columbia, northwest of Glacier National Park. Adapted from Bally, Gordy, and Stewart (1966, pl. 5). Arrows show direction of movement on faults.

Type 1 traps were very likely formed in many places in the eastern part of the study area. In the North Fork Sun River and in the eastern tributaries of the Middle Fork Flathead River, detailed gravity studies indicate that potential Devonian, Mississippian and Lower Mesozoic reservoir rocks are in a structural trap type 1 setting (pl. 5). Numerous fault blocks with thrust faulted wedge-edges of potential reservoir rocks closely associated with potential hydrocarbon source rocks are interpreted on the geologic cross sections on plate 5.

Similar traps may also exist in the western part of the Great Bear study area beneath the eastern part of the Lewis and South Fork thrust plates. In the eastern part of British Columbia, a few miles north of the International border, seismic surveys supplemented by drill hole data show stacked thrust plates with the wedge-edges of Paleozoic carbonate rocks beneath the Lewis thrust plate (west part of fig. 18). Although surface data alone is insufficient to determine if the same type of structures are beneath the Lewis and South Fork thrust plates in the study area (fig. 8a, b, c, Chapter A), we infer that thrust faulted and possibly folded Paleozoic and Mesozoic rocks are beneath these plates.

Type 2 structures (drag folds) are exposed in the eastern part of the study area, and structures of this type very likely form traps in the subsurface. The strata in these structures include potential hydrocarbon reservoir rocks. In most places the folds are not broad or extensive, but the overturned strata in the West Fork of the Sun River (Mudge, 1972a, fig. 29), and the broken anticline shown on section A-A′, plate 5, west of the North Fork Sun River represent large type 2 structures.

Type 3 structural traps, folded thrust plates, are in the eastern part of the study area; this type is common in the Alberta Foothills (Scott, 1951; Jones, 1971). They form an extensive complex structural belt about 35 mi (56 km) long and 2-4 mi (3-6 km) wide along the west side of the Sawtooth Range northward from the vicinity of the Sun River through the upper reaches of Cox Creek at the north end of the Bob Marshall Wilderness. The structurally highest point of the belt is in the vicinity of the fenster at Route Creek (pl. 1) which is also on the northeasterly trending Lick Creek-Pendroy trend and lineament. In addition, two complexly folded thrust plate sequences on Circle Creek and north of Arsenic Mountain are interpreted on the east end of the geologic cross sections on plate 5 and along the west side of the Sawtooth Range on figure 8c. The configuration of these very complex structures cannot be fully interpreted without seismic data.

HYDROCARBON SOURCE ROCK EVALUATION

Hydrocarbon source rock evaluation is an interpretation of the capability of certain sedimentary rocks in and adjacent to the study area to generate hydrocarbons in sufficient quantity to form economic accumulations. The evaluation is based on the results of chemical analyses that measure the richness, chemical type, and thermal maturity of the preserved organic matter in samples collected from the localities shown on figure 18. The geological processes responsible for hydrocarbon generation are briefly reviewed to provide a framework for interpreting the analytical data.

Petroleum hydrocarbons (oil and gas) are generated from sedimentary rocks in which a sufficient amount of hydrocarbon-generating type of organic matter has been deposited and preserved. After deposition and initial modification during early diagenesis, the hydrocarbon-precursor organic matter is converted to petroleum hydrocarbons at elevated temperature, which is usually controlled by depth of burial. In young sedimentary basins (i.e., less than 70 million years old) temperatures of 120 to 150°C are required for significant hydrocarbon generation (Philippi, 1965). To some extent, longer time can substitute for high temperatures. A number of studies have shown that temperatures corresponding to depths of burial of about 7,000 ft (2,100 m) are required for significant hydrocarbon generation from source rocks of late Paleozoic (250 m.y.) to Cretaceous (100 m.y.) age, in the northern Rocky Mountain region (Nixon, 1973; Dow, 1974; Claypool, Love, and Maughan, 1978). Assuming a normal geothermal gradient, the subsurface temperature under a burial of 7,000 ft (2,100 m) is about 65°C.

In addition to the thermal history, the generation of hydrocarbons is dependent on the type and amount of the original organic matter in the rock. Sedimentary organic matter is either first cycle or recycled carbonaceous material. Recycled organic matter commonly is present at low levels in sedimentary rocks, but usually has lost all capacity for generating hydrocarbons. First cycle organic matter retains hydrocarbon-generating capacity, and is composed of variable proportions of the two end-member types: sapropelic and humic. Sapropelic organic matter is derived from the remains of aquatic organisms (either marine or lacustrine) while humic organic matter is derived from remnants of higher, terrestrial plants. Sapropelic organic matter is hydrogen-rich and has the capacity for generation of liquid hydrocarbons (oil) at early stages of maturity. Humic organic matter is hydrogen-deficient and generates only gas in economically significant quantities.

In addition to organic type, the amount of organic matter preserved in a sedimentary rock is important in source rock evaluation. A value of 0.4 weight percent organic carbon, which is equivalent to about 0.5 percent organic matter, is often cited as a lower limit, below which a rock should not be considered as a possible source rock of petroleum (Ronov, 1958; Dow, 1977). Rocks with greater than 0.4 percent organic carbon possibly are adequate as petroleum source rocks if other criteria regarding type and thermal maturity are met. The maximum temperature to which a rock and its contained organic matter has been exposed is also an important factor limiting the occurrence of hydrocarbons, especially oil. In simplest terms, stages of thermal maturity are designated as immature, mature, post-mature, and metamorphosed. Thermally immature sedimentary rocks can generate only biogenic methane (marsh gas) or

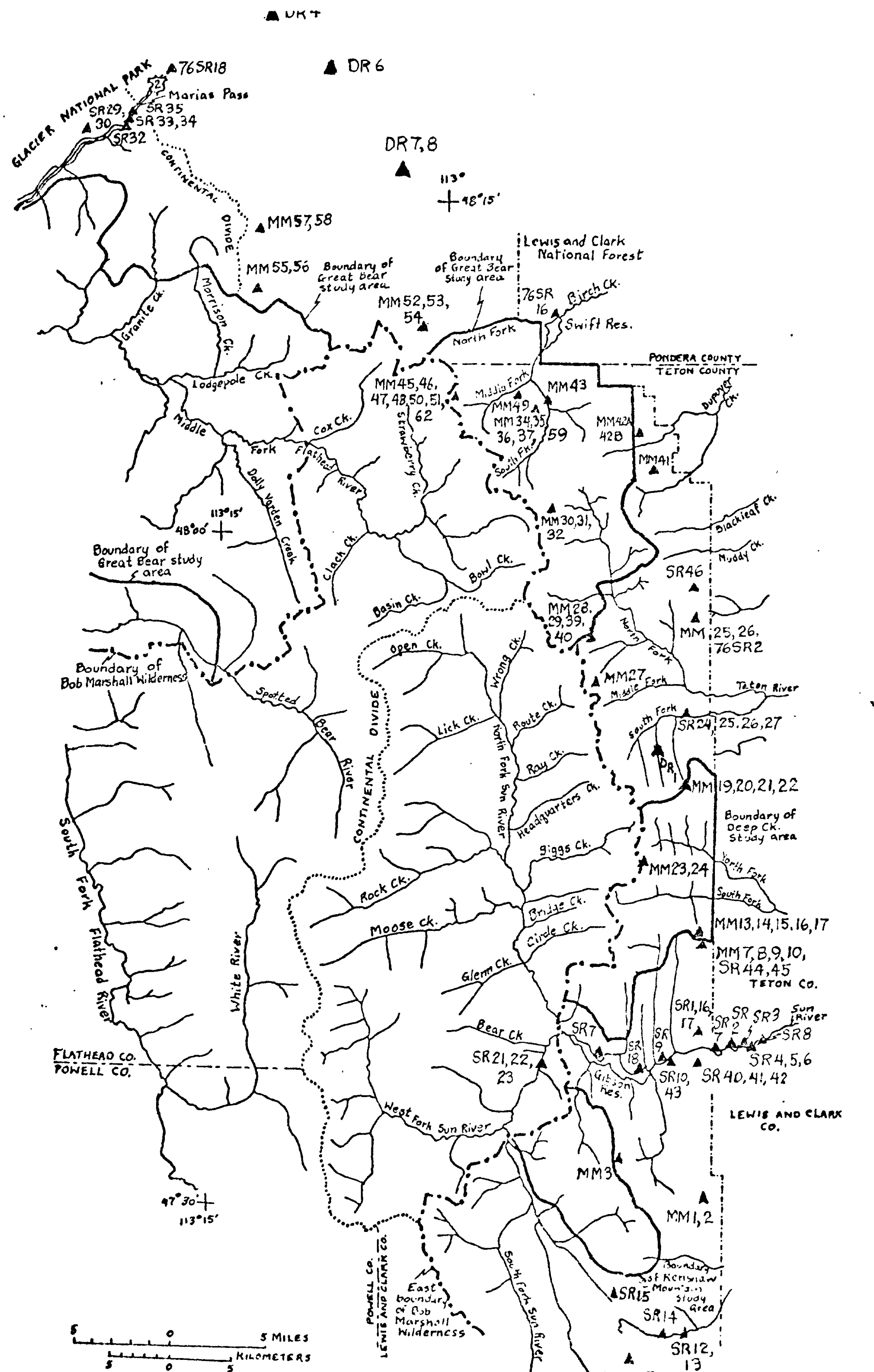

Figure 18.--Location of hydrocarbon source rock samples in and adjacent to the eastern part of the Bob Marshall Wilderness and study areas.

[illegible]

[- Indicates data not known]

Sample number	Sampled interval in feet	Organic carbon wt, %	Pyrolytic hydrocarbon yield, wt %	Volatile hydrocarbon content in ppm	Pyrolytic hydrocarbon / organic carbon, %	Temperature of maximum pyrolysis yield, °C
UPPER CRETACEOUS MARIAS RIVER SHALE						
Kevin Member						
DR5	Grab	4.90	-	-	-	-
SR35	Grab	2.54	0.37	570	14.6	486
SR8	Lower 50'	1.16-1.46	0.21	510	14.1	503
SR23	Lower 50'	1.18-1.20	0.18	170	14.8	484
Ferdig Member						
SR34	Grab	0.79	0.062	71	7.8	498
SR6	Lower 20'	1.03	0.08	127	7.8	507
SR22	Lower 100'	.78-1.31	0.056	73	5.9	487
SR11	Grab	0.6	0.025	20	4.3	494
Cone Member						
DR4	Grab	4.90	-	-	-	-
SR33	Grab	1.84	0.094	34	5.1	488
SR4	Upper 15'	.4-.49	0.026	43	6.7	480
SR5	Lower 85'	2.35-2.92	0.18	152	7.9	490
SR21	Entire member	1.28-3.96	1.50	1960	37.9	480
LOWER CRETACEOUS BLACKLEAF FORMATION						
Taft Hill Member						
MM17	15'	0.96	0.026	39	2.8	512
MM16	50'	0.93	0.027	55	3.0	-
SR2	Grab	0.87	0.046	46	5.3	514
SR1	Grab	.68-.86	0.062	57	7.3	508
Flood Member						
DR6	Grab	0.95	-	-	-	-
SR28	Grab	1.08	0.056	43	5.2	479
SR31	Entire member	0.85	0.044	54	5.2	512
SR32	Grab	0.81	0.086	74	10.6	504
MM55	Grab	0.6	0.096	57	16.0	488
MM56	50'	1.28	0.17	71	13.2	476
MM41	Lower 100'	0.67	0.018	20	2.7	490
mm40	20'	0.72	0.025	36	3.5	508
MM39	50'	0.86	0.027	46	3.1	508
MM15	15'	0.33	0.022	41	6.7	502
MM14	65'	0.95	0.036	73	3.9	504
MM13	40'	1.16	0.045	93	3.9	504
SR3	Grab	1.43	0.083	104	5.8	506
SR10	Grab	1.19	0.087	42	7.3	490
SR14	Grab	1.68	0.079	15	4.7	496
LOWER CRETACEOUS KOOTENAI FORMATION						
MM18	Grab	0.55	0.023	34	4.3	508
UPPER JURASSIC SWIFT FORMATION						
Transition to Morrison						
SR9	Grab	1.64	0.082	20	5.0	492
Shale Member						
MM58	60'	0.75	0.044	40	5.9	496
SR30	Grab	0.65	0.032	32	4.9	500
MM50	Lower 50'	0.70	0.036	39	5.1	500
MM51	Lower 25'	1.77	0.064	35	3.6	504
MM37	60'	0.85	0.033	41	3.9	522
MM32	80'	0.91	0.045	53	4.9	528
MM10	40'	0.80	0.054	69	6.8	506
MM22	40'	0.69	0.023	28	3.4	540
SR12	Grab	.65-.88	0.047	17	5.4	494
MIDDLE AND UPPER JURASSIC ELLIS GROUP (UNDIVIDED)						
DR14	Core	2.44	-	-	-	-
DR12	Core	3.55	-	-	-	-

UPPER JURASSIC RIERDON FORMATION

SR29	Upper 20'	0.24	0.104	140	43.3	494
DR7	Grab	1.51	-	-	-	-
MM57	Upper 80'	0.62	0.070	67	11.3	494
MM36	175'	0.24	0.013	22	5.4	516
MM47	Lower 100'	0.34	0.017	19	5.0	502
MM48	Upper 30'	0.61	0.045	54	7.4	502
MM31	175'	0.30	0.008	8	2.7	520
MM26	113'	0.31	0.010	14	3.2	506
MM29	125'	0.24	0.010	13	4.2	504
MM8	Lower 55'	0.32	0.013	29	4.4	504
MM9	Upper 55'	0.23	0.017	40	7.7	504
SR16	Entire fm.	.13-.45	0.016	19	3.6	505
MM21	Entire fm.	0.22	0.011	26	5.3	520
MM3	Lower 10'	0.37	0.038	40	10.6	476
MM1	Lower 6'	0.25	0.014	28	5.6	488
MM2	Lower 10'	0.30	0.020	22	6.8	479
SR15	Grab	0.09	0.011	21	12.9	-
SR13	Upper 20'	.27-.46	0.017	12	3.8	491
			MIDDLE JURASSIC SHALE MEMBER, SAWTOOTH FORMATION			
DR8	Grab	0.52-0.56	-	-	-	-
DR10	Core	0.37	-	-	-	-
DR11	Core	0.77	-	-	-	-
MM45	Lower 75'	0.62	0.031	56	5.0	502
MM46	Upper 80'	0.40	0.017	22	4.3	500
MM62	Lower 5'	0.92	0.053	84	5.8	502
MM44	Lower 50'	0.61	0.017	56	2.8	506
MM34	Lower 5'	2.68	0.14	88	5.2	506
MM35	220'	0.51	0.021	50	4.1	498
MM59	Lower 10'	1.92	0.12	101	6.3	508
DR15	Core	0.66	-	-	-	-
MM42A	Lower 100'	0.66	0.042	76	6.4	490
MM42B	Upper 50'	0.35	0.020	28	5.7	494
MM30	50'	0.23	0.005	6	2.2	508
MM25	57'	0.41	0.020	38	4.9	492
MM28	Upper 20'	0.36	0.012	16	3.3	504
DR1	Grab	0.76	-	-	-	-
MM19	Lower 50'	0.61	0.017	39	2.9	520
MM20	Upper 10'	0.39	0.022	71	5.8	500
MM7	Entire member	0.31	0.021	43	7.3	502
			LOWER AND UPPER MISSISSIPPIAN CASTLE REEF DOLOMITE			
DR9	Core	0.62	-	-	-	-
DR13	Core	1.88-1.92	-	-	-	-
			LOWER MISSISSIPPIAN LOWER MEMBER, ALLAN MOUNTAIN LIMESTONE			
MM53	65'	1.27	0.023	20	1.8	560
MM27	20'	0.44	0.010	13	2.3	-
MM23	Lower 50'	1.08	0.019	24	1.8	558
DR2	Grab	1.39	-	-	-	-
SR7	50'	.18-.45	0.028	65	6.3	502
MM5	Lower 10'	0.17	0.020	30	12.0	484
			DEVONIAN THREE FORKS FORMATION (EXSHAW SHALE)			
MM52	3'	6.57	0.030	18	0.5	580
MM54	Grab	0.16	0.002	7	1.3	-
DR3	Grab	7.23-7.29	-	-	-	-
MM4	5'	3.36	1.18	257	35.2	468
			CAMBRIAN SWITCHBACK SHALE			
MM43	100'	0.08	0.002	5	2.5	-
			CAMBRIAN GORDON SHALE			
MM6	Grab	0.08	0.010	30	12.9	-

Table 11.--Data on wells from which core samples were analyzed and listed on table 10.

Sample number	Location	Core interval
DR 9	sec. 19, T. 37 N., R. 8 W.	5785-5790 ft (1763-1765 m)
DR 10	sec. 11, T. 29 N., R. 6 W.	3425 ft (1044 m)
DR 11	sec. 28, T. 29 N., R. 7 W.	4121-4125 ft (1256-1257 m)
DR 12	sec. 11, T. 31 N., R. 12 W.	9555-9567 ft (2912-2916 m)
DR 13	sec. 18, T. 31 N., R. 11 W.	8959-8960 ft (2731 m)
DR 14	sec. 14, T. 37 N., R. 15 W.	12,315-12,319 ft (3754-3755 m)
DR 15	sec. 1, T. 27 N., R. 7 W.	3308 ft (1008 m)

Table 12, Example analyses of "typical" source rocks, Rocky Mountain region

Age, formation, and location	Sample type	Organic carbon Wt, %	Pyrolytic hydrocarbon yield Wt %	Volatile hydrocarbon content ppm	Pyrolytic hydrocarbon / organic carbon %	Temperature of maximum pyrolysis yield °C	Interpretation of thermal maturity
Devonian Bakken Shale, Williston basin	core	8.76	2.45	3400	28.0	486	Mature
Permian Phosphoria Fm., SW Montana	Outcrop	11.9	5.16	3400	43.4	453	Immature
Permian Phosphoria Fm., SE Utah	Outcrop	1.9	0.61	520	32.1	477	Mature
Permian Phosphoria Fm, Western Wyoming	Outcrop	3.2	0.44	900	13.8	495	Early postmature
Permian Phosphoria Fm., Eastern Idaho	Outcrop	2.9	0.027	24	0.9	570	Late postmature
Cretaceous Frontier Fm, Powder River Basin Wyo.	core	0.96	0.13	420	13.3	500	Early postmature
Cretaceous Graneros Shale, Denver Basin Colo.	Cuttings	2.3	0.35	1000	15.2	487	Mature
Cretaceous Pierre Shale, Denver Basin Colo.	Outcrop	0.97	0.10	170	10.4	490	Mature

minor occurrences of oil. Mature rocks generate oil and/or gas, depending on the type of organic matter. During the post-mature stage, additional gas is generated and any oil that remains with the rocks at this stage may be converted to gas. Metamorphosed rocks are not prospective for either oil or gas.

In this study, organic carbon content is used to evaluate organic richness, and thermal analysis is used to estimate type of organic matter and thermal maturity. In addition, the reflectance of vitrinite (an optical measurement on recognizable particles of a coal constituent) was determined on four samples. Coal rank and vitrinite reflectance have been correlated with the degree of thermal maturity required for hydrocarbon generation (Vassoyevitch and others, 1970). The stable carbon isotope ratio of methane in natural gas samples from Alberta was measured to determine the degree of thermal maturity at which the gas was generated.

The organic carbon contents of some potential source rocks east of the study area have been reported by Rice (1977) and Mudge, Earhart, and Claypool (1977). These analyses plus additional results compiled for the present study are all combined and reported in tables 10 and 11. Our samples may reflect effects of weathering at the outcrop. In extreme cases of weathering organic carbon contents can be deleted by thirty percent relative to equivalent unaltered rocks (Leythaueser, 1973; Clayton and Swetland, 1978). Samples were analyzed from nine major stratigraphic units, ranging in age from Upper Cretaceous to Cambrian. Of these only the Upper Jurassic Rierdon Formation and the Cambrian units had generally less than 0.4 percent organic carbon. The Cambrian mudstones are somewhat metamorphosed and were not expected to contain much organic carbon. The upper Rierdon contains 0.32-0.57 percent organic carbon in core samples from the Cut Bank field to the east. On the basis of these organic carbon values, the Rierdon Formation has a low potential as a source rock. Of the other major stratigraphic units analyzed (Upper Cretaceous Marias River Shale, Lower Cretaceous Blackleaf Formation, Upper Jurassic Swift Formation, Middle Jurassic Sawtooth Formation, Lower Mississippian Allen Mountain Limestone, and the Devonian Three Forks Formation) all contained a large proportion of samples with organic carbon well in excess of 0.4 percent. Thus, regardless of possible weathering effects, these units are of adequate organic richness to be potential source rocks.

All rock samples were also analyzed by a thermal analysis technique (Claypool and Reed, 1976) to evaluate type of organic matter and thermal maturity. The use of this analysis for source rock evaluation is also discussed by Barker (1974), Espitalie and others (1977), and Claypool and Threlkeld (1978). In brief, this technique permits measurement of 1) petroleum-like substances present in a rock (volatile hydrocarbon content in ppm); 2) petroleum-like substances produced by thermal decomposition (pyrolysis) of solid organic matter in the rock (pyrolytic hydrocarbon yield in wt. percent); and 3) the amount of heat required to cause thermal decomposition of the solid organic matter, measured as the

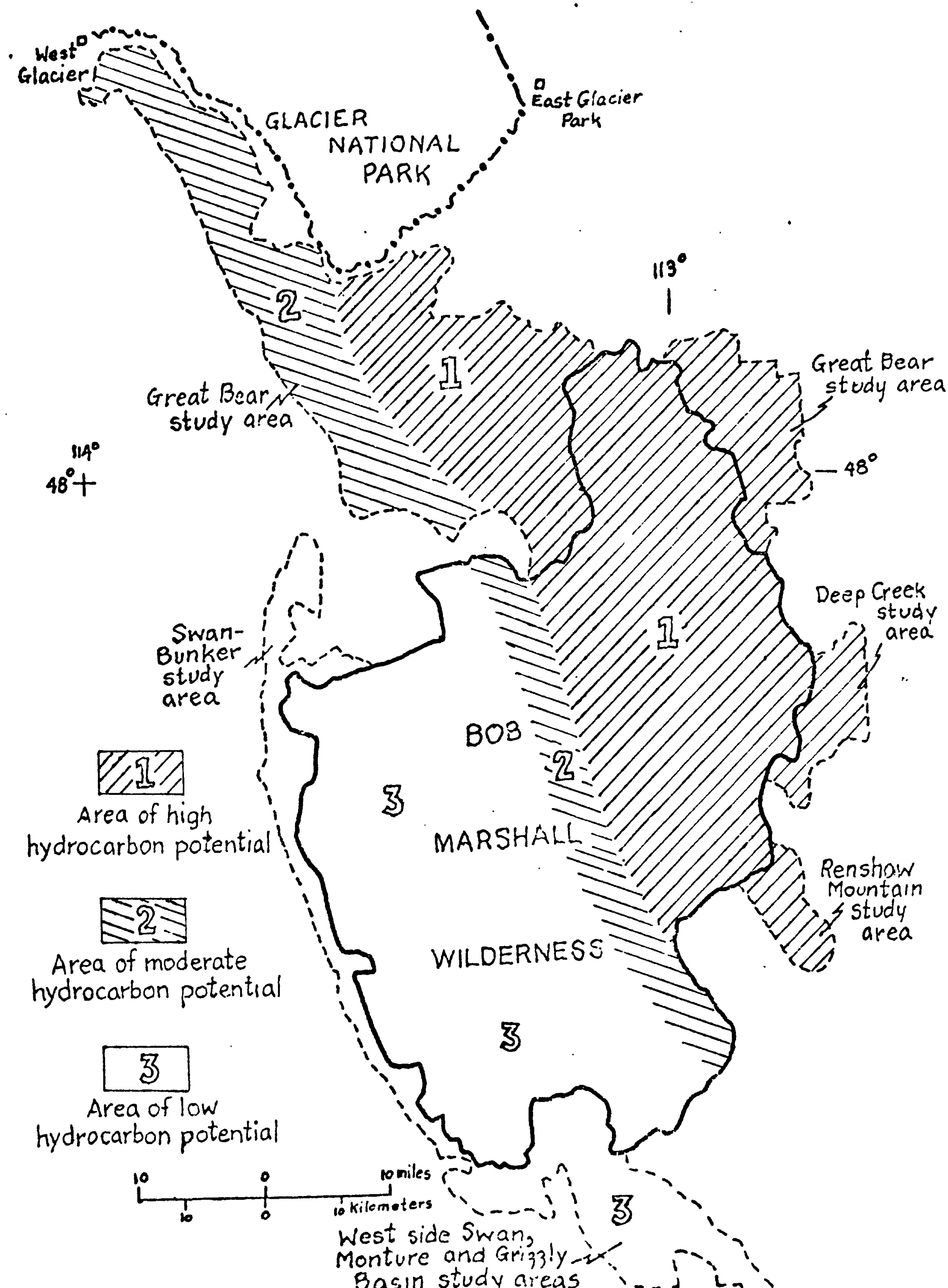

Figure 19.--Hydrocarbon potential of the Bob Marshall Wilderness and study areas.

temperature at which the pyrolysis yield is at a maximum (temperature of peak 11 in centigrade). These properties are reported in table 10, along with the ratio of the pyrolytic hydrocarbon yield to the organic carbon content. In general, possible mature oil source rocks have volatile hydrocarbon contents in excess of about 100 ppm, a pyrolytic hydrocarbon-to-organic carbon ratio of 20 to 40 percent, and a temperature of maximum pyrolysis yield in the range of 470 to 495°C. Sedimentary rocks which have pyrolytic hydrocarbon-to- organic carbon ratios of 3 to 10 percent and temperatures of maximum pyrolysis yield of 500 to 540°C can be considered thermally post-mature with respect to liquid hydrocarbon (oil) generation. If the organic carbon content of such rocks is sufficiently high, it is likely that they have generated liquid hydrocarbons at a previous stage of their burial history; however, it is unlikely that any oil would be found in reservoirs contiguous to thermally post-mature rocks. Previously generated oil would have had to migrate to cooler rocks in order to be preserved. The post-mature stage may be optimum for the occurrence of gaseous hydrocarbons because intense gas generation occurs later in the burial history of source rocks than does oil generation (Teichmuller and Teichmuller, 1968; Harwood, 1977). In addition, any oil buried with post-mature rocks is converted to gas by thermal cracking. Temperatures of maximum pyrolysis yielding above about 560°C suggest low-grade metamorphism, and occurrence of either oil or gas in such rocks is unlikely. These criteria for hydrocarbon source rock evaluation on the basis of thermal analysis presume sufficient organic matter to provide a pyrolysis response. This means that the technique is much less reliable for samples with less than about 0.5 percent organic carbon; however, these samples generally would be eliminated from consideration as source rocks on the basis of inadequate organic richness. Table 12 shows example analyses of "typical" source rocks in the Rocky Mountain region with an interpretation of their thermal maturity.

Considering the results of thermal analysis reported in table 10, several samples of the Upper Cretaceous Marias River Shale and one sample (MM 4) of the Devonian Exshaw Shale have properties characteristic of mature oil source rocks. One sample of the Jurassic Rierdon Formation (SR 29) has some of the characteristics of a mature oil source rock (140 ppm volatile hydrocarbon content, 43 percent pyrolytic hydrocarbon-to-carbon ratio); however the organic carbon content is so low (0.24 percent) for this sample and for others in this formation that it has a low potential as a possible oil source rock on the basis of inadequate organic richness. The Upper Cretaceous rocks, that crop out near the northwest part of the study area, probably were thermally immature prior to thrusting. Additional sub-thrust burial should have caused these and Upper Cretaceous rocks of similar organic richness to generate and expel liquid petroleum (oil). If expulsion and migration coincided with the development of trapping structures in the conduit and reservoir beds in adjacent or overthrust parts of the section, oil accumulations could have developed.

Sub-thrust burial of thermally immature source rocks of Upper

Cretaceous age with consequent generation and expulsion of oil may account for an oil occurrence in the Swift Current Valley, where it was produced during 1902-1906 (Darrow, 19550. Production was from a depth of 500 feet, possibly from the Virgelle Sandstone, or sandstones in the lower part of the Two Medicine Formation. The source of the oil was very likely the Marias River Shale which was probably heated sufficiently to generate and expel oil when buried by the Lewis thrust plate.

The Exshaw Shale has characteristics of a mature oil source rock in the southeastern part of the study area where it is in the Lewis thrust plate (fig. 16, table 10). This is in contrast to the post mature character of the organic matter in this same unit about 60 miles to the north in the study area, where Paleozoic strata appear to have undergone low-grade metamorphism by possible burial by strata of the Lewis and South Fork thrust plates. This discontinuity of thermal maturity in the Exshaw Shale (and in the overlying Allen Mountain Limestone) is consistent with their position in respect to the major thrust plates, and confirms the interpretation that burial beneath thrust plates is a major factor in controlling thermal history and consequent hydrocarbon generation in the Montana Disturbed Belt.

Except for the mature oil source rocks of the Marias River and Exshaw Shales, and the apparently metamorphosed samples of Exshaw Shale (MM 52), Allen Mountain Limestone (MM 23, MM 53), and the Gordon and Switchback Shales of Cambrian age (MM 6 and MM 43, respectively), most of the samples for which analytical results are reported in table 10 are in the early to late post-mature stage with respect to hydrocarbon generation. This is evidenced by pyrolytic hydrocarbon-to-organic carbon ratios in the range of 3 to 10 percent, and temperatures of maximum pyrolysis yield generally above 500°C in samples of rocks that are Middle Jurassic to Lower Cretaceous in age. This includes the Sawtooth Formation, Rierdon Formation, Swift Formation, and the Flood and Taft Hill Members of the Blackleaf Formation. Local exceptions within this group of samples appear to have undergone a slightly milder temperature history. Examples of such local exceptions occur within each of the above-named formations of Mesozoic age, and are concentrated in the northeastern and southeastern parts of the study area, again suggesting that the position of sedimentary rocks within major thrust plates is the major control on their history in this area.

If these analyses properly characterize the rocks in the subsurface of the study area, then the generation of oil from source rocks of pre-Upper Cretaceous age in the Bob Marshall Wilderness and the proposed additions, has been largely spent, probably prior to the Early Tertiary orogeny. Any oil generated from these rocks, and not lost due to breaching of traps and conduit beds during thrust faulting, would have been converted to gas and condensate by the elevated temperatures associated with sub-thrust burial. In addition to gas formed by thermal cracking of pre-existing oil accumulations, these pre-Upper Cretaceous source rocks should have generated abundant natural gas during the transition from the mature to the post-mature stage. The possibility of economically significant natural gas accumulations from this later episode of gas generation is made more favorable by the concurrent development of structural traps associatd with thrust faulting.

This interpretation of a high thermal history due to subthrust burial is supported by mineralogical and chemical analyses of shales and bentonites reported by Hoffman and others (1976), who concluded that Mesozoic strata were subjected to temperatures of up to 175°C in the Disturbed Belt as a result of burial beneath thrust plates. Similar conclusions (based primarily on measurement of vitrinite reflectance and carbon isotope ratios of methane) were reached by Rice (1977) in his evaluation of the petroleum potential of the study area. Rice (1977) reported vitrinite reflectance for four samples. We have tabulated organic carbon values (table 10) and vitrinite reflectance (table 13) for three of these samples. Hacquebard (1975) studied the correlation between reflectance of vitrinite in coals of the Lower Cretaceous Mannvile Formation and occurrence of oil and gas in reservoirs of both Mesozoic and Paleozoic age in Alberta. He found that Mesozoic oil occurrences correlates with a vitrinite reflectance range of 0.4 to 0.8 percent R_o. Except for immature gas of the Cretaceous, most of the gas in Alberta is in Paleozoic reservoirs. Hacquebard (1975) found that 47 percent of gas reserves are in regions where vitrinite reflectance of the overlying Cretaceous coals was in the range of 0.8 to 1.2 percent R_o. The three samples for which vitrinite reflectance is reported in table 13 are to the northeast of the study area. The sample which is closest to the study area (DR 7) has an average vitrinite reflectance of 0.91 percent R_o, which is within the gas occurrence range for Alberta (Hacquebard, 1975). The other two samples, which are somewhat further to the north and east of the study area (DR 6, DR 11), have vitrinite reflectance average values of 0.75 and 0.70 percent R_o, respectively. These limited data on vitrinite reflectance, when taken together with the interpretation of thermal maturity based on thermal analysis of within or adjacent to the study area, support the conclusion that Mesozoic rocks (except for the Upper Cretaceous) within the study area are prospective for gas occurrences rather than oil because of a thermal history unfavorable for oil.

Carbon isotope ratios of the methane component of natural gas are useful in determining the origin and thermal history of a gas accumulation. Gases sampled from the gas pipeline and one well in the Jumping Pound field (fig. 15) in the southern Alberta foothills were produced from the Mississippian Turner Valley Formation. The methane in this gas has a stable carbon isotope ratio, expressed as delta-C^{13}, of -42 permil. Stahl and Cary (1975) from studies of gas in Paleozoic rocks in West Texas and many other gas-producing areas (Stahl, 1974), concluded that gases within this range occur in the late mature stage, and are generated from source rocks which have vitrinite reflectance values of 0.8 to 0.9 percent R^o. The carbon isotope ratio of gas from the Alberta Foothills indicates a stage of thermal maturity similar to that in West Texas, which is about the same as that observed in the study area of Montana. This suggests that the hydrocarbon potential of the study area may be similar to that of the Alberta Foothills, and that the potential for gas is somewhat higher than that for oil.

Table 13.--Vitrinite reflectance, values for selected samples

Sample number	Vitrinite reflectance (%R_o)		
	minimum	maximum	average
DR 6	0.52	1.03	0.75
DR 7	0.77	1.01	0.91
DR 11	0.44	0.79	0.60

CONCLUSIONS

The eastern part of the study area has a very good potential for discovery of natural gas accumulations and a somewhat lesser potential for oil accumulation. This area contains good potential source and reservoir rocks and very likely contains structural traps. The presence and extent of subsurface structural traps can only be determined by seismic studies, which were not part of this investigation.

The areas with hydrocarbon potential, based on present geologic data, are shown numerically in decreasing order of importance of figure 19. We wish to stress that boundaries between areas are not intended to be sharply defined. Detailed exploration, including seismic surveys and drilling, will be necessary to evaluate the petroleum potential of the areas.

Area 1 includes all the area east of the Lewis thrust plate in the Bob Marshall Wilderness, but northwest of the wilderness it also includes part of the Lewis plate east of a line that extends south from the southwest corner of Glacier National Park along the Middle Fork of Flathead River, Long Creek, and the upper reaches of Spotted Bear River.

Area 1 is estimated to have high hydrocarbon potential because it contains hydrocarbon source and reservoir rocks, and possible structural traps. The northern and central parts of the area contain northeasterly-trending lineaments (older structures) which may have affected petroleum accumulations. Northwest-trending folded thrust plates are along the east and west sides of the Sawtooth Range, and very likely are west of the present eastern edge of the Lewis and South Fork thrust plates in the Lewis and Clark Range.

Present geologic data indicate that the areas of the northeasterly-trending lineaments (fig. 8) have a potential for hydrocarbons. In the east-central part of the area the northeastern extension of the northern lineament appears to connect with the Pendroy fault zone east of the study area. The Pondera oil field lies on the south side of the fault. Three wells containing gas are on this lineament, along the east side of the study area, between Blackleaf Creek and the North Fork of Dupuyer Creek. The lineament extends southwest to Lick Creek in the Bob Marshall Wilderness. The gravity survey in Lick and Route Creeks indicates the area is structurally high, and the first Mississippian sequence may be at relatively shallow depth (Chapter B and pl. 5). Folded thrust plates extend northwest through the upper reaches of Route Creek where they are structurally higher than in adjacent areas.

The northern part of area 1 also contains a northeast-trending lineament, excellent source and reservoir rocks, as well as northwesterly-plunging folded thrust plates. A northeastern extension of the area contains gas wells, east of East Glacier Park. In the western part of the area, east of the crest of the Flathead Range, potential reservoir rocks underlie a thick Precambrian sequence, and deep drilling would be necessary to penetrate them. The thickness of the Precambrian strata ranges from a few meters near the exposed Lewis thrust fault to more than 12,000 ft (3,658 m) in the Flathead Range.

Elsewhere in the Sawtooth Range, Mississippian and Devonian rocks are in narrow linear thrust fault blocks. This close spacing may break up the continuity of potential reservoirs at depth, and reduce the size of hydrocarbon accumulations. Seismic studies are necessary to determine if potential structures lie beneath the imbricate surface structures of the range.

The gravity survey along Cox Creek indicates the area may contain potential structures with Mississippian rocks at relatively shallow depths (Chapter B, pl. 5). Favorable reservoirs may very likely be present in other fault blocks at greater depth, as folded thrust plates are present in the eastern part of the area.

The hydrocarbon potential of area 2 is considered to be moderate because data are not available on the structures beneath the Lewis thrust plate We believe hydrocarbon and source rocks extend beneath the thrust plate for many miles to the west. Potential petroleum accumulations would lie beneath at least 12,000 ft (3,658 m) of Precambrian rocks present in the Lewis thrust plate.

Area 3 is classified as having a low hydrocarbon potential because of the thick sequence of Precambrian rocks in the Lewis thrust plate, and the lack of known reservoir rocks in the subsurface in most of the area. Precambrian rocks range in thickness from more than 10,000 ft (3,048 m) near the Continental Divide in the central part of the Wilderness, where there are two thrust plates, to more than 32,000 ft (9,754 m) in the Swan Range. Paleozoic and Mesozoic rocks probably do not extend more than a few miles beneath these thrust plates, and no known reservoir or source rocks are present in the Precambrian sequence.

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CHAPTER E

ECONOMIC APPRAISAL OF THE BOB MARSHALL WILDERNESS AND STUDY AREAS

by

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Introduction

Previous studies

The Montana Bureau of Mines and Geology investigated mineral deposits in Flathead County, Montana (Johns, 1970). The bulletin describing the work refers to several mineralized areas within the wilderness and proposed additions.

Present studies and acknowledgments

U.S. Bureau of Mines investigations were made in 1971, 1973, 1974, and 1976 by Lawrence Y. Marks, assisted by Fredrick A. Spicker, Donald B. Kennedy, Randal W. Cross, Steven W. Schmauch, David W. Lockard, and Gordon D. Clarke. About 200 mandays were spent in field investigations. About 300 miles (480 km) of foot and 250 miles (400 km) of horseback traverses were made in search of mines, prospects, and mineralized areas. A helicopter was used to reach a few remote places. Bureau of Mines personnel reviewed all available information, examined mining claim records, and mapped and sampled all known mines and prospects. Three shallow, SPO-size core holes were drilled with a small diamond drill, yielding core with about 1-inch (2.5-cm) diameter. Lode sample analysis was directed by Howard H. Heady, U.S. Bureau of Mines, Reno, Nevada. Placer samples were analyzed by Dean C. Holt, U.S. Bureau of Mines, Spokane, Washington. Coal samples were analyzed at the U.S. Bureau of Mines Coal Preparation and Analysis Laboratory, Pittsburgh, Pennsylvania. Paul McIlroy, U.S. Bureau of Mines, Spokane, Washington, furnished production cost data for barite and copper deposits. Forest Service personnel and local residents, including Bruce Neil, Paul Hazel, Charles Shaw, Glenn Roberts, Richard Klick, Montana J. Barnard, Vern Moulton, Norman Rousselle, and James Salmond, provided information which aided investigations.

Methods of evaluation

Previous mineral studies in and near the wilderness and proposed additions provided some background information on production, history, reserves, and geology. Bureau of Mines personnel searched county records to determine the location of mining claims and visited all claims that could be found. The deposits were mapped and sampled. Where underground workings were inaccessible, samples were taken from nearby outcrops and mine dumps. Property owners were contacted when possible, and in some cases they pointed out places where their best samples were taken. Deposits are classified according to the resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey (U.S. Geol. Survey, 1976). Production cost estimates are based on the operation of similar properties.

Setting

The Bob Marshall Wilderness and proposed additions have no record of mineral production. However, oil and gas shows were found in wells within 3 miles (4.8 km) of the study area (Hurley, 1959). Barite was produced near Greenough, Montana, about 20 miles (32 km) to the south of the area (Carrillo, 1966). Copper was produced from Precambrian strata and gold from Recent gravels about 7 miles (11 km) east and 8 miles (13 km) southeast of the study area, respectively (Earhart, et al, 1976). Coal has been mined from Cretaceous sedimentary rocks near Valier, Montana, about 30 miles (48 km) northeast of the study area (Averitt, 1963).

Mining claims

County records indicate that 297 mining claims have been located in the wilderness and proposed additions since about 1890. Some claim descriptions are vague, and some of these claims may have been outside the area. As described, 275 are lode claims, 10 are coal claims, 8 are petroleum placer claims, and 4 are metallic placer claims. Annual assessment work was being maintained on at least 100 claims at the time of this investigation. Two of the lode claims have been patented; their exact position cannot be determined. The oil and gas and coal claims were located prior to passage of the Mineral Leasing Act of February 25, 1920. Since that time oil and gas and coal rights can only be appropriated on Federal lands by leasing.

Sampling and analytical methods

During examination of mines, prospects, and mineralized outcrops, Bureau of Mines personnel collected 128 lode, 90 soil, 42 drill core, 16 placer, 6 coal, and 1 bentonite samples. Lode samples and drill core were fire assayed for gold and silver, and analyzed by atomic absorption methods for copper. Selected lode samples were analyzed for lead and zinc by atomic absorption methods, and at least one sample from each prospect or occurrence was analyzed by emission spectrograph for 40 elements. Panned concentrates from gravel deposits were further concentrated on a Wilfley table and analyzed for gold and other heavy detrital minerals. Coal samples were analyzed for percentages of moisture, volatile matter, fixed carbon, ash, hydrogen, total carbon, nitrogen, oxygen, sulfur, and for heating values. The bentonite sample was tested for degree of swelling, calcium-to-sodium ratio, acidity, salt, and grit content. All lode and placer samples were checked for radioactivity and fluorescence. The minus 80 mesh fractions of soil samples were analyzed for copper by atomic absorption methods and spectrographically for other elements.

Resource classification

Resources have been classified according to the following definitions (U.S. Geol. Survey, 1976) in this report:

Resource--A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible.

Identified resources--Specific bodies of mineral-bearing material whose location, quality, and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category.

Reserve--That portion of the identified resource from which a usable mineral and energy commodity can be economically and legally extracted at the time of determination. The term ore is used for reserves of some minerals.

Indicated--Reserves or resources for which tonnage and grade are computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout.

Inferred--Reserves or resources for which quantitative estimates are based largely on broad knowledge of the geologic character of the deposit and for which there are few, if any, samples or measurements. The estimates are based on an assumed continuity or repetition, of which there is geologic evidence; this evidence may include comparison with deposits of similar type. Bodies that are completely concealed may be included if there is specific geologic evidence of their presence. Estimates of inferred reserves or resources should include a statement of the specific limits within which the inferred material may lie.

Identified-Subeconomic--Resources that are not Reserves, but may become so as a result of changes in economic and legal conditions.

Paramarginal--The portion of Subeconomic Resources that (1) borders on being economically producible or (2) is not commercially available solely because of legal or political circumstances.

Submarginal--The portion of Subeconomic Resources which would require a substantially higher price (more than 1.5 times the price at the time of determination) or a major cost-reducing advance in technology.

Mineral commodities and economic considerations

Mineral commodities for which resources are estimated in the study area are, in order of decreasing importance, natural gas, oil, copper, barite, silver, coal, stone, and sand and gravel. No mineral production has been recorded from the wilderness and proposed additions.

The following sections contain some generalizations for familiarization with ore values, production costs, and market conditions. Production costs have a wide range, and may differ two- or three-fold for different deposits. Unit production costs are relatively low where high-grade ore bodies are mined near the surface.

Oil and gas

In 1977, an estimated 2.99 billion barrels of crude oil were produced and 5.165 billion barrels were consumed in the United States. The nation is greatly dependent upon imported oil. The average wellhead price was about $8.50 per barrel. In the same year, an estimated 19.1 trillion cubic feet (0.540 trillion m^3) of natural gas was produced and 19.2 trillion cubic feet (0.544 trillion m^3) was consumed domestically. The estimated average price at the wellhead was 77.9 cents per thousand cubic feet ($27.53 per thousand m^3) (U.S. Bur. Mines, 1978).

Barite

While most barite ($BaSO_4$) is used for weighting drilling mud, some is used in the production of chemicals, glass, paints, and rubber. Barite used in drilling mud must be fine-ground, free of soluble salts, and have a specific gravity of 4.2 or higher. Chemical grade barite must contain at least 94 percent $BaSO_4$, and no more than 1 percent iron-oxide and 1 percent strontium sulfate (Fulkerson, 1975). In 1977, an estimated 1.549 million tons (1.405 million t) of barite was produced, and an estimated 2.5 million tons (2.68 million t) was consumed in the United States. The average price for crude barite was about $23.30 per ton ($25.70/t) in 1977 (U.S. Bur. Mines, 1978). Average price for dry-ground, drilling-mud-grade barite was from $71 to $78 per ton ($78 to $86/t) in February 1978. Chemical- and glass-grade barite sold from $46.50 to $55.00 per ton ($51.30 to $60.66/t) during the same period (EMJ, March 1978). Demand is expected to increase at an annual rate of 2.2 percent through 1985 (U.S. Bur. Mines, 1978).

Mining a 90,000-ton (80,000-t) vein deposit in the study area and transporting crude barite to the nearest railroad and/or major highway would cost about $30 per ton ($33/t).

Copper

In 1977, an estimated 1.490 million tons (1.352 million t) of copper were mined, and an estimated 2.290 million tons (2.077 million t) of copper were consumed in the United States. The estimated average price paid to domestic producers in 1977 was 66.7 cents per pound ($1.47/kg) (U.S. Bur. Mines, 1978). McIlroy et al (1974) estimated $11.47 per ton ($12.64/t) operating costs for room and pillar mining of lead ore at 500 tons (450 t) per day, and flotation milling of 600 tons (540 t) per day in 1971. This is equivalent to $16.86, using the January 1977 Marshall and Stevens cost index. Costs for mining and milling copper ore was probably similar. Current smelting and refining cost for copper (oral communication, Paul McIlroy, 1977) is more than 20 cents for each pound (0.45/kg) of contained copper, and would add more than $2 per ton ($2.20/t) for each 0.5 percent copper in the ore. Therefore, under present economic conditions, the cost of underground mining and subsequent milling and smelting for the size of disseminated copper ore deposit which might be found in the study area is on the order of $19 per ton ($20/t).

Silver

In 1977, domestic mines produced an estimated 37.4 million troy ounces (1.16 million kg), and an estimated 165 million troy ounces (5.13 million kg) were consumed domestically. The estimated average New York price in 1977 was $4.60 per troy ounce ($0.15/g) (U.S. Bur. Mines, 1978). Silver is associated with copper and zinc in the study area.

Coal

The present fuel shortage has increased demand for coal. The price of bituminous coal and lignite produced in the United States in 1977 averaged an estimated $21.00 per ton ($23.14/t) f.o.b. the mine. An estimated 685 million tons (621 million t) was produced and 638 million tons (579 million t) consumed domestically in 1977 (U.S. Bur. Mines, 1978). Production costs are highest in underground mines. Most underground coal mines are highly mechanized. An efficient operation requires the beds to be nearly horizontal, and at least 30 inches (76 cm) thick. Average recovery in underground mines is about 57 percent of the coal in place (Lowrie, 1968, p. 11). Transportation is a major factor in the delivered price, and deposits near the point of use compete most favorably.

Sand and gravel and stone

Sand and gravel, quartzite, limestone, and dolomite occur in large deposits in the wilderness and proposed additions. Although some deposits are suitable for use as construction materials, deposits of equal or better quality are available closer to major markets. Transportation costs are significant in determining minability of these high-bulk, low-unit-value commodities; therefore, the deposits in and near the Bob Marshall Wilderness are not considered to be reserves.

Mines, prospects, and mineralized areas

Figure 20 shows mines, prospects, and mineralized areas examined in and near the Bob Marshall Wilderness and proposed additions.

Felix Creek - Hoke Creek area

Low-grade disseminated copper-bearing lenses were examined at prospect workings and associated outcrops along more than 7 miles (11 km) of strike length in the Spokane Formation and, less commonly, in the Empire Formation. These occurrences are scattered from north of Felix Creek to south of Hoke Creek (fig. 20, Nos. 3-6). A quartz-rich fault zone above South Fork Logan Creek contains higher concentrations of copper and silver minerals than those in disseminated occurrences. The Felix Creek-Hoke Creek area (fig. 21) is reached from U.S. Highway 2 at Martin City, Montana, by about 35 miles (56 km) of oiled road. Dirt roads lead to within 1 airline mile (1.6 km) of each group of copper occurrences, but 1 to 3 miles (1.6 to 5 km) of steep trail must be used to reach some prospects.

Argillites and quartzites strike N. 40° E. to N. 40° W., dip 25° to 50° east, and locally contain as much as 0.52 percent disseminated copper. At least 16 copper-bearing lenses were sampled. The copper content of cross-cutting chip samples ranged from 0.13 percent over 60 feet (18.3 m) to 0.35 percent over 6 feet (1.8 m) and 0.52 percent over 2 feet (0.6 m). One disseminated copper deposit on the Corkscrew Copper claims (fig. 21, Nos. 74-77) contains about 700,000 tons (600,000 t) of resources averaging 0.15 percent copper and 0.1 ounce silver per ton (3.4 g/t).

In places, chip samples of quartz veins and shear zones above South Fork Logan Creek contained as much as 1.9 percent copper and 1.1 ounces silver per ton (37.7 g/t) and selected vein material had as much as 34.4 percent copper and 13.0 ounces silver per ton (446 g/t). Copper-bearing veins, however, are relatively scarce in this area. A fault zone on the One Dead Digger and Half Man prospects (fig. 21, Nos. 18-28 and 29-33) contains more than 100,000 tons (90,000 t) of resources with averages of about 0.39 percent copper and 0.4 ounce silver per ton (13.7 g/t).

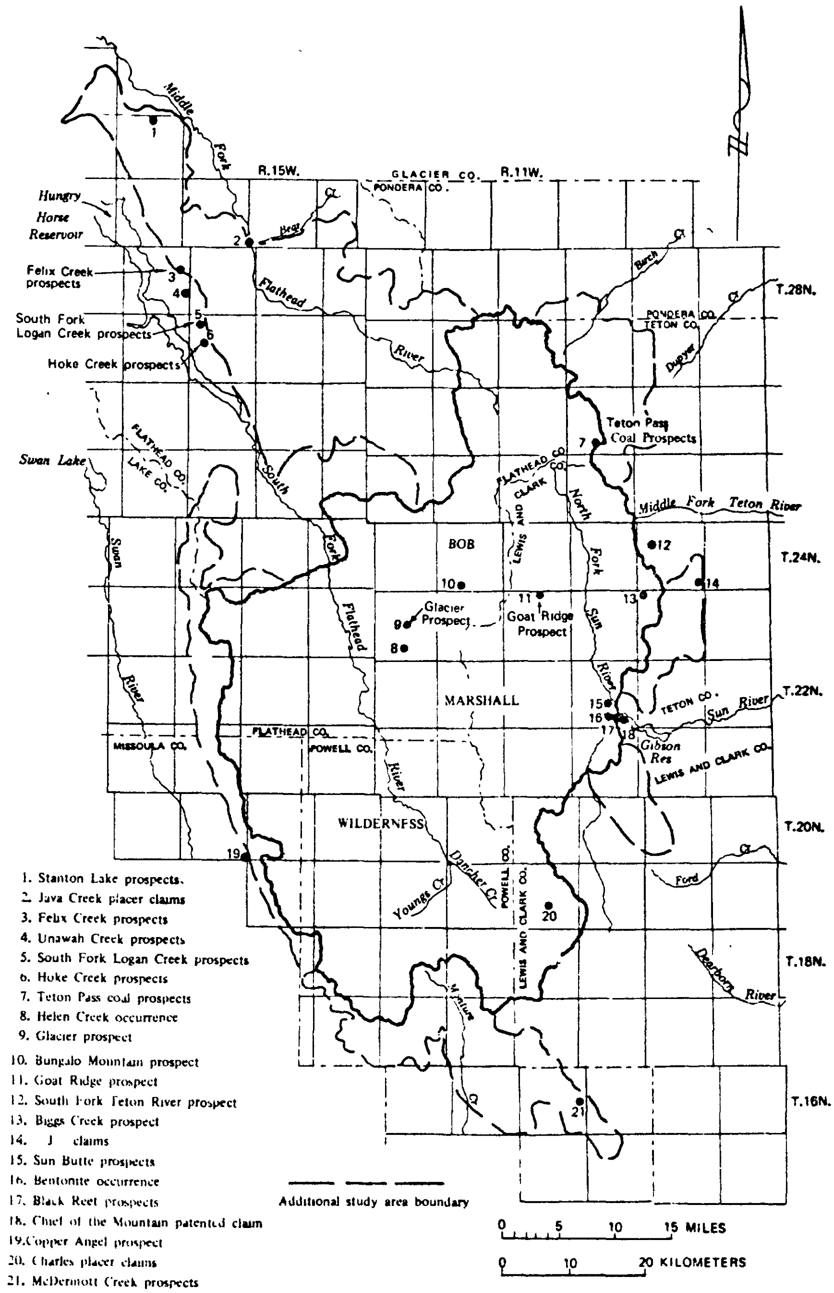

Figure 20.--Mines, prospects, and mineralized areas.

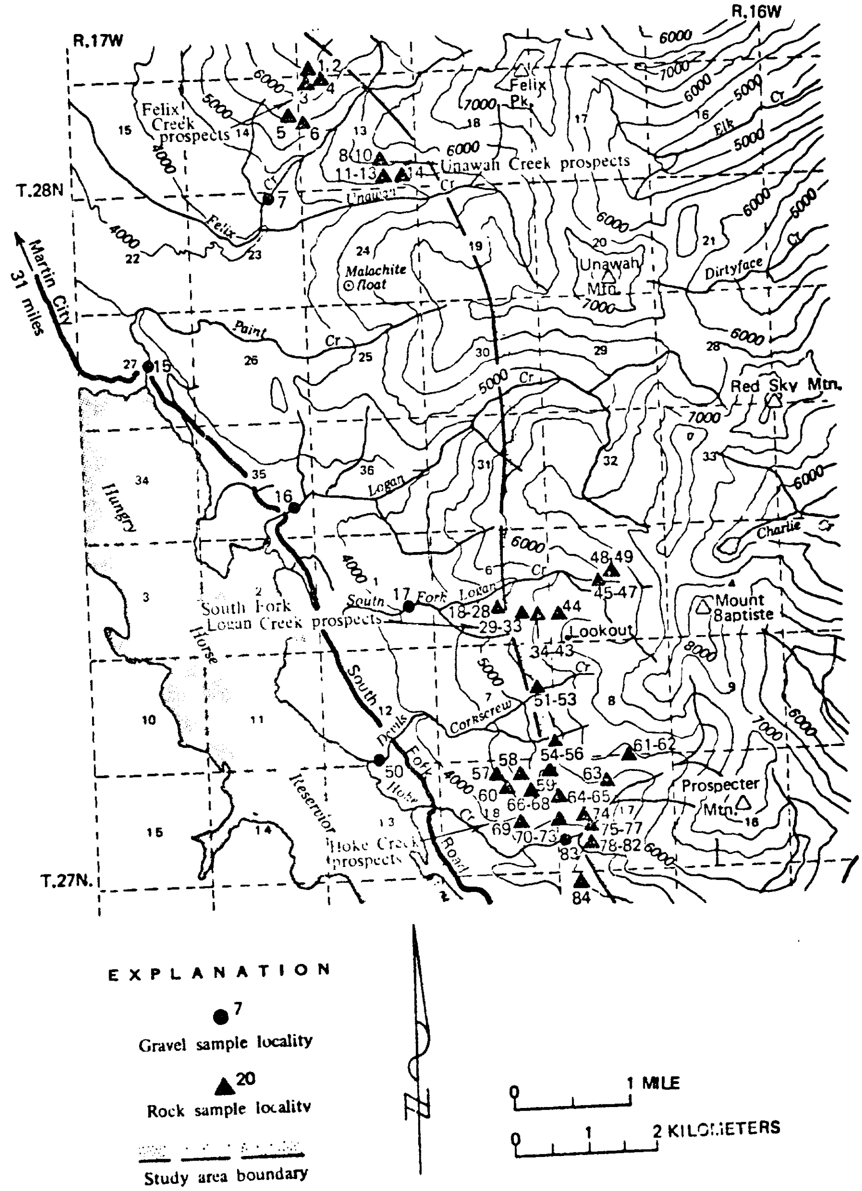

Figure 21.--Felix Creek-Hoke Creek area.

Data for samples shown on figure 21

[Tr, trace; N, not detected; N.d., not determined]

Sample				Gold (ounce per ton) 1/	Silver (ounce per ton) 1/	Copper (percent)
No.	Type	Length (feet) 1/	Description			
1	Chip	2.0	Across malachite-stained quartzite in pit-----------	Tr	0.1	0.31
2	Grab	Select	Malachite-stained quartzite on pit dump-------------	Tr	1.6	2.69
3	do--	--	Quartzite on pit dump------------------------------	Tr	N	.13
4	Chip	2.0	Across malachite-stained quartzite in pit-----------	Tr	.2	.52
5	do--	5.0	Across quartzite and argillite in pit---------------	Tr	N	.088
6	do--	4.0	Across quartzite in pit-----------------------------	Tr	N	.06
7	Grab	Gravel	Pan concentrate-------------------------------------	N	N	N.d.
8	Chip	10.0	Diagonally across argillite and quartzite in trench	N	.3	.07
9	do--	10.0	Below No. 8---	Tr	.4	.36
10	do--	10.0	Below No. 9---	N	.3	.25
11	do--	6.0	Along 3-inch-thick quartz vein, 10 feet from adit portal--	Tr	.4	.16

Data for samples shown on figure 21--continued

Sample				Gold (ounce per ton)1/	Silver (ounce per ton1/	Copper (percent)
No.	Type	Length (feet)1/	Description			
12	Grab	--	Argillite country rock in adit, 10 feet from portal	N	0.3	0.057
13	Chip	20.0	Across argillite at outcrop-----------------------	Tr	.3	.038
14	do--	4.0	Across argillite and quartzite in trench------------	Tr	.3	.038
15	Grab	Gravel	Pan concentrate------------------------------------	N	N	N.d.
16	do--	do----	do--	N	N	N.d.
17	do--	do----	do--	N	N	N.d.
18	Chip	.5	Poorly exposed vein quartz-------------------------	Tr	.4	1.2
19	Grab	Select	Vein quartz from stockpile-------------------------	0.02	4.2	23.7
20	Chip	2.1	Across iron-oxide-stained sheared argillite---------	Tr	.2	.18
21	do--	3.0	Across quartz-rich mineralized shear zone-----------	N	Tr	1.0
22	do--	5.0	Argillite and quartzite with some vein quartz pods---	Tr	2.4	.47
23	do--	2.2	Across quartz-rich mineralized shear zone-----------	Tr	.3	.49
24	do--	4.3	Across iron-oxide-stained sheared argillite---------	Tr	Tr	.10
25	do--	5.0	Interval above quartz vein; principally sheared argillite---	.01	.3	.66

Data for samples shown on figure 21--continued

No.	Sample			Gold (ounce per ton) 1/	Silver (ounce per ton) 1/	Copper (percent)
	Type	Length (feet) 1/	Description			
26	Chip	0.8	Across mineralized quartz vein in fault zone---------	0.01	1.1	1.9
27	do--	7.0	Across argillite-------------------------------------	.01	.1	.43
28	do--	15.0	Across sheared argillite above adit portal-----------	N	.1	.11
29	Grab	--	Dump at caved adit-----------------------------------	N	N	.20
30	do--	Select	Vein quartz with copper minerals; on stockpile at caved adit---	.03	13.0	34.4
31	Grab	do----	Malachite-rich pod above caved adit------------------	.01	4.9	9.7
32	Chip	3.0	Argillite and quartzite above sample 31--------------	Tr	Tr	.14
33	do--	4.0	Argillite and quartzite below sample 31--------------	Tr	.1	.17
34	do--	5.0	Quartzite and argillite beside caved adit portal-----	N	N	.008
35	do--	6.0	Quartzite and argillite in pit-----------------------	N	N	.004
36	Grab	Select	Vein quartz coatings from open fractures in trench---	Tr	N	.024
37	Chip	6.0	Quartzite and argillite in cave----------------------	N	N	.007
38	do--	6.0	Quartzite inside adit; 10 feet from portal-----------	N	N	.004
39	do--	6.0	Quartzite and argillite in trench--------------------	N	N	.007

Data for samples shown on figure 21--continued

No.	Sample: Type	Sample: Length (feet) 1/	Description	Gold (ounce per ton) 1/	Silver (ounce per ton) 1/	Copper (percent)
40	Chip	5.0	Quartzite and argillite in trench-------------------	N	N	0.006
41	do--	5.0	do---	N	N	.013
42	Grab	Select	Vein quartz coatings from open fractures in trench---	Tr	N	.025
43	do--	--	Quartzite in pit---------------------------------------	N	N	.012
44	Chip	3.0	Quartzite and argillite in small pit, possibly caved adit---	N	N	.004
45	do--	5.0	Quartzite at face in 43-foot-long adit---------------	N	0.2	.33
46	do--	5.0	Quartzite along east rib of adit, 26 feet from portal	N	Tr	.14
47	do--	8.0	Quarztite along west rib of adit, 9 feet from portal	N	.1	.029
48	Grab	Select	Quartz from 1-inch-thick vein in pit-----------------	Tr	N	.009
49	Chip	10.0	Along 8-inch-thick quartzite bed with malachite stain, in pit--	Tr	N	.12
50	Grab	Gravel	Pan concentrate---------------------------------------	N	N	N.d.
51	Chip	14.0	Across siltite and quartzite outcrop-----------------	N	.1	.07
52	do--	14.0	Similar, but 37 feet N. 42° W. from No. 51-----------	N	.1	.088
53	do--	36.0	Twenty-eight feet N. 42° W. from No. 52; more quartzite in section---------------------------	N	.1	.077

Data for samples shown on figure 21--continued

No.	Sample Type	Sample Length (feet)1/	Sample Description	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)
54	Chip	7.0	Across quartzite outcrop with some siltite----------	N	0.1	0.093
55	do--	30.0	Similar, but 80 feet S. 20° E. from No. 54----------	N	.1	.076
56	do--	20.0	Similar, but 215 feet S. 20° E. from No. 55---------	N	Tr	.064
57	Grab	--	Argillite and quartzite at outcrop in roadcut-------	N	.1	.052
58	do--	--	Siltite in pit--------------------------------------	N	.1	.048
59	Chip	6.0	Across quartzite in short inclined shaft------------	N	.2	.35
60	do--	6.0	Along argillite outcrop in road ditch---------------	0.01	.1	.084
61	do--	39.0	Along quartzite at south rib of adit----------------	Tr	N	.007
62	Grab	Select	Malachite stained quartzite from adit dump----------	Tr	1.1	4.36
63	Chip	2.0	Across quartzite bed near caved adit portal---------	Tr	.1	.027
64	do--	10.0	Across argillite in trench -------------------------	N	.1	.052
65	do--	10.0	Argillite, below No. 64 ----------------------------	.01	Tr	.12
66	do--	6.0	Argillite at outcrop in roadcut---------------------	N	N	.0022
67	do--	3.0	Argillite, below No. 66-----------------------------	N	.1	.21
68	do--	5.0	Argillite, below No. 67-----------------------------	N	.1	.071
69	Grab	--	Argillite and quartzite in outcrop------------------	N	.2	.046

Data for samples shown on figure 21--continued

No.	Sample Type	Sample Length (feet)1/	Description	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)
70	Chip	10.0	Across argillite and quartzite at outcrop-----------	N	Tr	0.044
71	do--	6.0	Across argillite along north rib of inclined shaft, 22 feet from collar----------------------------------	N	N	.11
72	do--	5.0	Argillite with quartzite lenses, near shaft collar---	N	N	.12
73	do--	8.0	Argillite and quartzite at outcrop above shaft collar--	N	N	.14
74	do--	10.0	Across quartzite and argillite in pit---------------	N	N	.12
75	do--	3.5	Along 1-foot-thick argillite and quartzite zone in 33-foot-long adit--------------------------------	Tr	0.2	.32
76	do--	60.0	Composite of two samples; diagonally across argillite and quartzite outcrop in creek bed---------	Tr	.2	.13
77	do--	35.0	Diagonally across beds at outcrop; similar to No. 76	Tr	.1	.18
78	do--	6.0	Across quartzite in trench; 100 feet S. 72° W. from portal of adit at Nos. 79-81------------------	N	.2	.003
79	do--	2.0	Across quartzite in adit, 43 feet from portal--------	N	.3	.26
80	do--	1.5	Across quartzite 31 feet from portal----------------	N	.4	.44
81	do--	2.0	Across quartzite 10 feet from portal----------------	N	.3	.28
82	do--	6.0	Across argillite at outcrop near portal of caved adit---	N	.2	.057

Data for samples shown on figure 21--continued

Sample				Gold (ounce per ton) 1/	Silver (ounce per ton) 1/	Copper (percent)
No.	Type	Length (feet) 1/	Description			
83	Grab	Gravel	Pan concentrate	N	2/	N.d.
84	do--	--	Argillite in pit	Tr	0.3	0.057

1/ Metric conversion factors:
Feet x 0.3048 = meters
Ounces (troy) per ton x 34.285 = grams per tonne
Cubic yard x 0.7646 = cubic meter

2/ Original gravel contained the equivalent of 23 mg. silver per cubic yard.

None of the individual copper occurrences seem to have sufficient size or grade for profitable mining; however, there is potential for minable deposits in the area. Large tracts are untested; and no samples have been taken more than 56 feet (17.1 m) below the surface. At the Corkscrew Copper prospect, chip sample analyses suggest that some copper has been leached from outcrops. Results of core drilling to sample unoxidized rock are inconclusive; holes did not reach the water table, although they sampled rocks several feet below the surface.

Prospects and mineralized areas in the Felix Creek - Hoke Creek area are described in order of their distribution, from north to south.

Felix Creek prospects

Three shallow pits and three shallow trenches are in an area about 1 mile (1.6 km) long, near the head of Felix Creek (fig. 21, Nos. 1-6). Quartzite, argillite, and siltite of the Empire Formation strike N. 30° to 40° W. and dip 35° to 50° NE. Malachite and possibly traces of chalcocite are visible, particularly in quartzite layers. Copper in chip samples representing thicknesses of 2 to 5 feet (0.6-1.5 m) of quartzite, ranged from 0.06 to 0.52 percent, which was the highest disseminated copper content noted by the Bureau of Mines in the study area. The average copper content in four chip samples weighted by sample length is 0.18 percent. Similar copper content may extend below the bottom of some excavations.

Unawah Creek prospects

A caved adit, two trenches, and an outcrop were sampled above Unawah Creek (fig. 21, Nos. 8-14) on the B. C. B. claims located by M. J. Barnard, K. O. Caverly, and M. J. Barnard, Jr. in September 1974. Country rock is quartzite and argillite of the Empire Formation; it strikes N. 30° to 40° W. and dips 25° to 40° NE. Copper minerals are visible in these workings and adjacent outcrops along one-half mile (0.8 km) of strike length. The average copper content in six chip samples weighted by sample length is 0.14 percent. A 10-foot (3.05-m)-thick section in one trench averaged 0.23 percent copper.

South Fork Logan Creek prospects

Several old prospect workings and one new open pit are near South Fork Logan Creek. Quartz veins and associated shear zones on the One Dead Digger (fig. 21, Nos. 18-28) and Half Man (fig. 21, Nos. 29-33) claims contain the highest concentrations of copper and silver found by the Bureau of Mines in the study area. The average copper content in ten chip samples from the pit weighted by sample length is 0.39 percent. Mineralized sheared argillite and quartzite may extend more than 500 feet (150 m), between a pit and caved adit.

The most extensive workings are an open pit at the site of an older caved shaft on the One Dead Digger claim (fig. 21, Nos. 18-28). The pit is about 4,950 feet (1,510 m) above sea level on a steep hillside, approximately 200 feet (61 m) above South Fork Logan Creek, the nearest source of surface water. There has been no production. More than 100,000 tons (90,000 t) of resources of about 0.39 percent copper and 0.4 ounce per ton (13.7 g/t) silver are inferred between the open pit on the One Dead Digger claim and a caved adit on the Half Man claim. The One Dead Digger, Half Man, and other claims above South Fork Logan Creek are held by L & M Enterprises of Kalispell, Montana, owned by Vern Moulton and Alfred Luciano.

One Dead Digger prospect

An open pit on the One Dead Digger claim is at the site of an older caved shaft. The access road was constructed in 1976, after preliminary excavation. An adit driven southeasterly along the principal fault zone is caved about 20 feet (6.1 m) from the portal. The argillite near the fault is sheared and is very unstable; it requires considerable support.

The intensely-sheared zone, along the fault, locally more than 10 feet (3.0 m) thick, is in light tan to gray argillite of the Spokane Formation which strikes N. 45° E. and dips 20° SE. The zone contains quartz veins and pods, 4 to 10 inches (10 to 25 cm) thick, and malachite, chalcocite, bornite, chalcopyrite, azurite, and chrysocolla. At least two minor faults strike northeasterly (fig. 22).

Eleven samples were collected (fig. 22, Nos. 18-28); analyses are listed on the accompanying table.

The principal fault strikes N. 45° W. and dips 56° SW. along the northeast side of the open pit (fig. 22). The hanging wall, southwest of the fault, contains about 9 feet (2.7 m) of sheared argillite. Vein quartz and copper minerals are concentrated in the 2-foot (0.6-m) interval nearest the fault. Copper minerals are disseminated throughout the adjacent sheared argillite.

Samples of mineralized sheared argillite that is exposed intermittently for 60 feet (18.3 m) contain an average of 0.39 percent copper and 0.4 ounce per ton (13.7 g/t) silver. About 1300 tons (1200 t) of resources are indicated in the hanging wall to a depth of 30 feet (9.1 m) below the pit. An additional 700 tons (600 t) of similar grade resources are inferred to extend 30 feet (9.1 m) to the southeast along the shear zone.

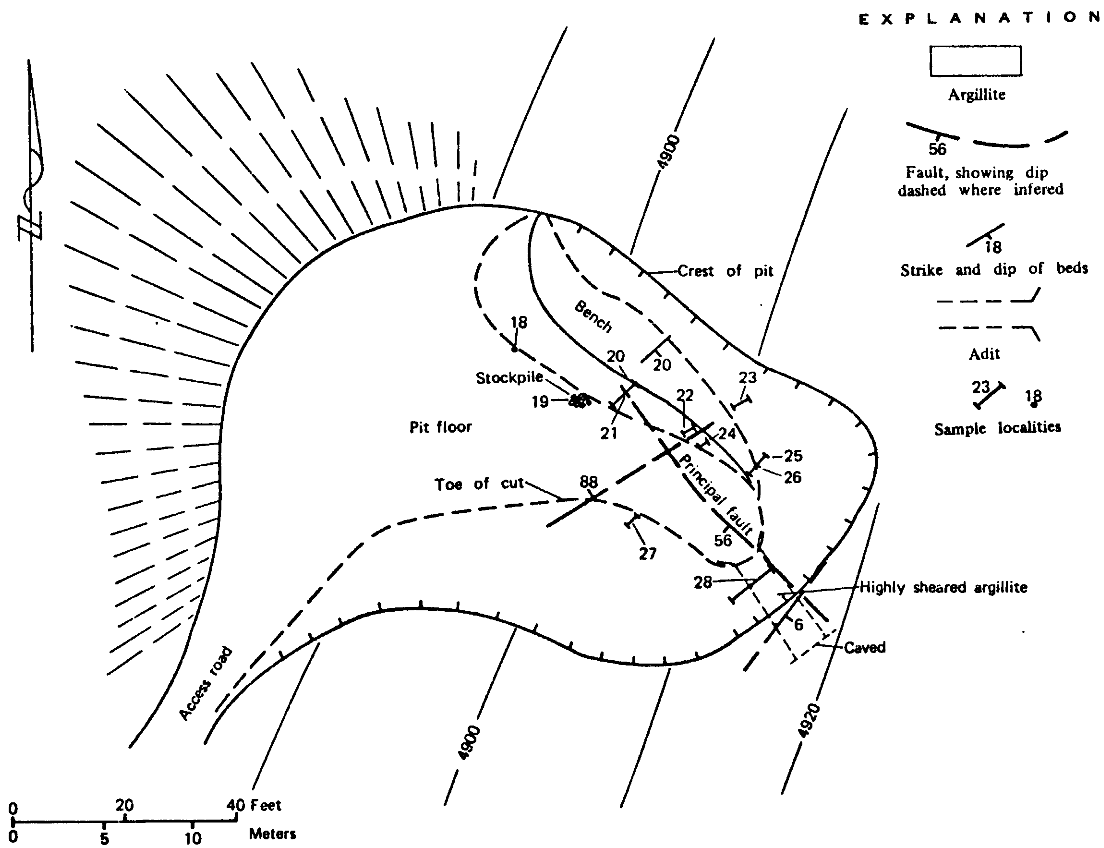

Figure 22.--One Dead Digger prospect.

Data for samples shown on fig. 22

[Tr, trace; N, not detected]

Sample				Gold (ounce per ton) 1/	Silver (ounce per ton) 1/	Copper (percent)
No.	Type	Length (feet) 1/	Description			
18	Chip	0.5	Poorly exposed quartz vein------------------------	Tr	0.4	1.2
19	Grab	Select	Vein quartz from stockpile------------------------	0.02	4.2	23.7
20	Chip	2.1	Across iron-oxide-stained sheared argillite--------	Tr	.2	.18
21	do--	3.0	Across quartz-rich mineralized shear zone----------	N	Tr	1.0
22	do--	5.0	Argillite and quartzite with some quartz pods------	Tr	2.4	.47
23	do--	2.2	Across quartz-rich mineralized shear zone----------	Tr	.3	.49
24	do--	4.3	Across iron-oxide-stained sheared argillite--------	Tr	Tr	.10
25	do--	5.0	Interval above quartz vein; principally sheared argillite---	.01	.3	.66
26	do--	.8	Across mineralized quartz vein in fault zone-------	.01	1.1	1.9
27	do--	7.0	Across argillite-----------------------------------	.01	.1	.43
28	do--	15.0	Across sheared argillite above adit portal---------	N	.1	.11

1/ Metric conversion factors: Feet x 0.3048 = meters; ounces (troy) per ton x 34.285 = grams per tonne

The 2.3-foot (0.7-m)-thick quartz-rich zone nearest the fault averages 0.74 percent copper and 1.2 ounces per ton (41.1 g/t) silver. Adjacent sheared argillite is about 6.7 feet (2.04 m) thick; it averages 0.26 percent copper and 0.13 ounce per ton (4.46 g/t) silver. The higher grade zone comprises about one-fourth of the 2,000-ton (1,800-t) indicated and inferred resource.

The fault zone may extend between the pit and a caved adit about 500 feet (150 m) to the southeast, on the Half Man claim. Copper-bearing vein quartz, similar to mineralized rock at the pit, is stockpiled outside the caved adit. Therefore, an additional 100,000 tons (90,000 t) of similar grade resources is inferred between the pit and the caved adit.

Half Man prospect

The caved adit on the Half Man claim (fig. 21, Nos. 29-33) trends about S. 65° E. along a fault zone in beds of light gray quartzite and argillite which strike N. 15° E. and dip 7° SE. Volume of waste on the dump indicates the adit was more than 200 feet (60 m) long. About 300 pounds (140 kg) of vein quartz containing abundant malachite, and seams as thick as one-eighth inch (3 mm) containing chalcocite, is stockpiled near the dump. Fault gouge 6 inches (15 cm) thick and 12 inches (30 cm) long exposed above the portal contains abundant malachite. Copper minerals extend more than 3 feet (0.9 m) from the gouge into adjacent quartzite and argillite. Quartzite and argillite above the caved adit average 0.16 percent copper over a thickness of at least 7 feet (2.1 m). Sample analyses are on the table accompanying figure 21. Similar copper bearing quartz along a fault on the One Dead Digger claim suggests resources between the two prospects.

Other L & M prospects

L & M Enterprises explored several old prospect workings in Secs. 5 and 6, T. 27 N., R. 16 W. at Nos. 34-49 (fig. 21).

At sample locality 34-43 (fig. 21), trenches, adits, and pits in quartzite and argillite expose an easterly trending fracture zone. Some fracture surfaces are coated with quartz, with occasional copper minerals.

A trench 30 feet (9.1 m) long trends S. 35° E. in quartzite at sample locality 34-43 (fig. 21). A pit in quartzite and argillite is at locality 44. No mineralized rock was found at either locality.

An adit at sample locality 45-47 (fig. 21) trends S. 12° W. for 45 feet (13.7 m) in quartzite which strikes N. 10° E. and dips 25° SE. Malachite, and possibly chalcocite, are in seams as much as one-fourth inch (6 mm) thick along some bedding planes and in thin quartz veinlets.

Data for samples shown on fig. 23

[Tr, trace; N, not detected; N.d., not determined]

No.	Sample Type	Sample Length (feet)1/	Description	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)
50	Grab	Gravel	Pan concentrate	N	N	N.d.
51	Chip	14.0	Across siltite and quartzite outcrop	N	0.1	0.07
52	do--	14.0	Similar, but 37 feet N. 42° W. from No. 51	N	.1	.088
53	do--	36.0	Twenty-eight feet N. 42° W. from No. 52; more quartzite in section	N	.1	.077
54	do--	7.0	Across quartzite outcrop with some siltite	N	.1	.093
55	do--	30.0	Similar, but 80 feet S. 20° E. from No. 54	N	.1	.076
56	do--	20.0	Similar, but 215 feet S. 20° E. from No. 55	N	Tr	.064
57	Grab	--	Argillite and quartzite at outcrop in roadcut	N	.1	.052
58	do--	--	Siltite in pit	N	.1	.048
59	Chip	6.0	Across quartzite in short inclined shaft	N	.2	.35
60	do--	6.0	Along argillite outcrop in road ditch	0.01	.1	.084
61	do--	39.0	Along quartzite at south rib of adit	Tr	N	.007

Data for samples shown on figure 23--continued

Sample				Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)
No.	Type	Length (feet)1/	Description			
62	Grab	Select	Malachite stained quartzite from adit dump------	Tr	1.1	4.36
63	Chip	2.0	Across quartzite bed near caved adit portal-----	Tr	.1	.027
64	do--	10.0	Across argillite in trench---------------------	N	.1	.052
65	do--	10.0	Argillite, below No. 64------------------------	0.01	Tr	.12
66	do--	6.0	Argillite at outcrop in roadcut----------------	N	N	.0022
67	do-	3.0	Argillite, below No. 66------------------------	N	.1	.21
68	do--	5.0	Argillite, below No. 67------------------------	N	.1	.071
69	Grab	--	Argillite and quartzite in outcrop-------------	N	.2	.046
70	Chip	10.0	Across argillite and quartzite at outcrop-------	N	Tr	.044
71	do--	6.0	Across argillite along north rib of inclined shaft 22 feet from collar----------------------	N	N	.11
72	do--	5.0	Argillite with quartzite lenses, near shaft collar---	N	N	.12
73	do--	8.0	Argillite and quartzite at outcrop above shaft collar-------------------------------------	N	N	.14
74	do--	10.0	Across quartzite and argillite in pit----------	N	N	.12

A pit about 10 feet (3 m) long at locality 48-49 (fig. 21) exposes nearly vertical quartz veins, 1 inch (2.5 cm) thick, that roughly parallel the quartzite beds which strike N. 10° W. The quartz veins are relatively barren of metallic minerals, but an 8-inch (20-cm)-thick quartzite bed contains malachite.

Jeanette and Little Darling claims

The Jeanette and Little Darling patented claims (Patent No. 34005) are near the head of South Fork Logan Creek, but their exact position could not be determined. Norman Rousselle of Kalispell, Montana, and others, are the owners.

Hoke Creek prospects

At least 67 claims are in the Hoke Creek area. M. J. Barnard, M. J. Barnard, Jr., and K. O. Caverly of Pablo, Montana, located the Corkscrew Copper 1-48, Unknown, and Unknown 1-18 lode claims between July 1971 and September 1975 (fig. 21, Nos 51-84). The claims were being actively prospected at the time of this investigation.

The country rocks consist of argillite, quartzite, and siltite of the Spokane Formation; they strike from N. 25° E. to N. 40° W. and dip about 25° eastward.

Workings consist of 8 adits, 2 inclined shafts, 3 pits, and 1 trench; some adits are caved and inaccessible (fig. 23). Disseminated copper minerals are along bedding planes and joint surfaces in argillite, quartzite, and siltite beds. Malachite and other metallic minerals are concentrated locally in seams one-fourth inch (6 mm) thick. Copper minerals are principally in light green to gray argillite lenses. Adjacent purple argillite and quartzite are typically barren of copper minerals. Samples from malachite-bearing lenses were taken between localities 51 and 84, which are 9,000 feet (2,700 m) apart; the average copper content in chip samples is 0.1 percent. Stratigraphic thicknesses of 2 to 36 feet (0.6 to 11 m) are represented by these samples. Copper minerals can be traced in outcrops of a light-green to gray lens for as far as 300 feet (91 m) at locality 51-53. The highest copper contents in chip samples were 0.35 and 0.32 percent (samples 59 and 75, respectively), in an inclined shaft and an adit. The lower content of surface samples from the same vicinity suggests that copper has been leached from outcrops. Core holes were drilled to determine whether copper content is higher in unoxidized rocks at depth. Core holes A, A-2, and B (fig. 23) were 5, 56, and 43 feet (1.5, 17.1, and 13.1 m) deep, respectively. Drilling results were inconclusive; cores were taken several feet below the surface, but none of the holes extended below the water table into unoxidized rocks. Analyses of core assays are listed in tables 14-16.

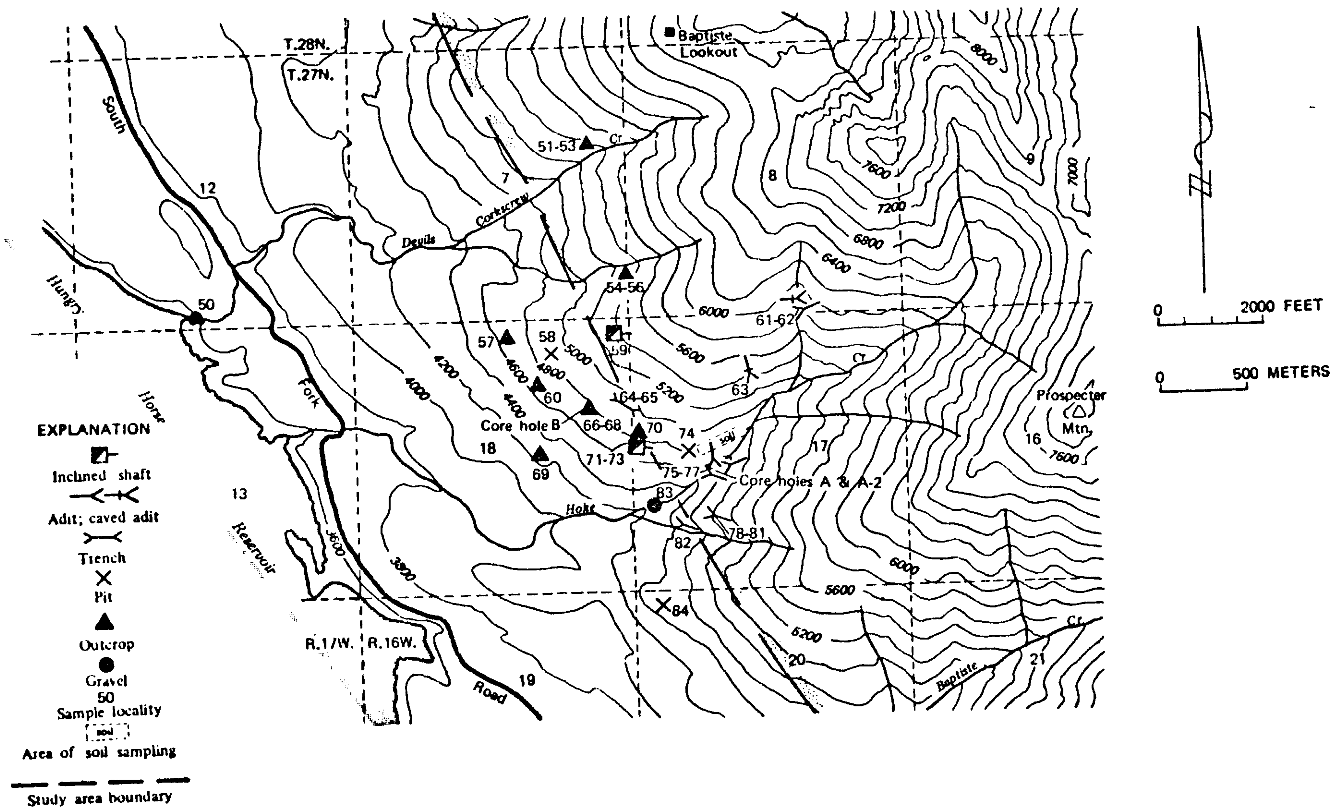

Figure 23.--Hoke Creek prospects.

Data for samples shown on figure 23.--continued

No.	Sample Type	Sample Length (feet)1/	Description	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)
75	Chip	3.5	Along 1 foot thick argillite and quartzite zone in 33 foot long adit----------------------	Tr	0.2	0.32
76	do--	60.0	Composite of two samples; diagonally across argillite and quartzite outcrop in creek bed----	Tr	.2	.13
77	do--	35.0	Diagonally across beds at outcrop; similar to No. 76--	Tr	.1	.18
78	do--	6.0	Across quartzite in trench; 100 feet S. 72° W. from portal of adit at nos. 79-81--------------	N	.2	.003
79	do--	2.0	Across quartzite in adit, 43 feet from portal---	N	.3	.26
80	do--	1.5	Across quartzite 31 feet from portal------------	N	.4	.44
81	do--	2.0	Across quartzite 10 feet from portal------------	N	.3	.28
82	do--	6.0	Across argillite at outcrop near portal of caved adit--------------------------------------	N	.2	.057
83	Grab	Gravel	Pan concentrate---------------------------------	N	2/	N.d.
84	do--	--	Argillite in pit--------------------------------	Tr	.3	.057

1/ Metric conversion factors: Feet x 0.3048 = meters; ounces (troy) per ton x 34.285 = grams per tonne; cubic yard x 0.7646 = cubic meter.
2/ Unprocessed gravel contained 23 mg. silver per cubic yard.

Core hole A contained 5 feet (1.5 m) of argillite and quartzite averaging 0.22 percent copper. The 25.2-foot (7.62-m) interval between 3.8 and 29 feet (1.16 and 8.84 m) in hole A-2 averaged 0.14 percent copper. The 7-foot (2.1-m) interval between 3.5 and 10.5 feet (1.07 and 3.20 m) in hole B averaged 0.18 percent copper. Silver content was as high as 1.8 ounces per ton (61.7 g/t) in hole A-2, and 1.7 ounces per ton (58.3 g/t) in hole B. Some silver concentrations occurred in the purple argillite and quartzite zones of core holes A-2 and B. Core recovery, in the intervals for which copper content has been summarized, ranged from 17 to 100 percent and averaged 59 percent. Therefore, average copper content is only an approximation.

A deposit of copper-bearing argillite and quartzite on the Corkscrew Copper claims between sample localities 74 and 75-77 (fig. 23) contains beds about 35 feet (10.7 m) thick which average 0.15 percent copper. Eighty-five samples of the "B" soil horizon, or subsoil, were taken at 25-foot (7.62-m) intervals in lines normal to the strike of the formation, and 100 feet (30.4 m) apart north of localities 75-77. They contained 5 to 1,000 parts per million (ppm) copper. The mean copper content for samples with less than 100 ppm copper is 20 ppm. Samples with more than 40 ppm copper are more than one standard deviation above the mean, and are considered anomalous. Distribution of soil samples with greater than 40 ppm copper indicates that copper-bearing quartzite and argillite extends 750 feet (230 m) northwest from localities 75-77 to a pit at locality 74. If similar rock is inferred downdip for 375 feet (114 m) (one-half the distance between samples 74 and 77), and if the zone averages 30 feet (9 m) in thickness, about 700,000 tons (600,000 t) of copper-bearing rocks can be inferred. Weighted average copper content in four rock samples is 0.15 percent; silver averages about 0.1 ounce per ton (3.4 g/t). Other low-grade disseminated copper occurrences are in the 9,000-foot (2,700-m)-long area from 7,000 feet (2,100 m) north of locality 74 at localities 51-53, to 2,000 feet (610 m) south at locality 84.

Glacier prospect

The Glacier Nos. 1 and 2 barite claims were located by L. A. Gaustad, M. W. Myers, and B. C. Trosper of Kalispell, Montana, in May 1957. They can be reached from U.S. Highway 2 at Martin City, Montana, by 55 miles (88 km) of gravel road and 22 miles (35 km) of pack trail (fig. 20, No. 9). The deposit is on a steep hillside about 900 feet (270 m) above Black Bear Creek, the nearest source of surface water (fig. 24). Prospect workings consist of a pit and a trench. No production from the claims has been reported.

Table 14. - Core hole A.

[N, none detected; Tr, trace]

Depth Interval (feet)1/	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)	Core Recovery (percent)	Description
0-1.5	N	0.2	0.41	90	Light gray to greenish argillite with some quartzite; contains red-brown layers and bands with red-brown flecks, visible specks and seams of chalcocite, and some malachite stain. Bottom of hole at 5 feet.
1.5-3.0	Tr	.1	.12	90	
3.0-5.0	Tr	.2	.16	90	

1/ Metric conversion factors: Feet x 0.3048 = meters; ounces (troy) per ton x 34.285 = grams per tonne.

Table 15. - Core hole A-2.

[N, none detected; Tr, trace]

Depth Interval (feet)1/	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)	Core Recovery (percent)	Description
0-3.8	Tr	0.1	0.0034	60	Light green silty argillite with white to orange quartzite layers. Trace of chalcocite and malachite.
3.8-5.9	Tr	.1	.11	92	
5.9-8.7	Tr	.1	.13	71	Gray to brownish quartzite with some light green argillite; thin seams of chalcocite and malachite along fractures.
8.7-14.	Tr	.2	.21	53	
14.-16.	Tr	.3	.19	90	Gray to brownish quartzite and argillite; lower two thirds mostly quartzite; thin seams of chalcocite and malachite.
16.-20.	N	N	.15	46	
20.-29.	Tr	N	.087	17	
29.-32.	Tr	Tr	.0058	53	Light green silty argillite with some brown quartzite; lower portion mostly quartzite; traces of chalcocite (?)
32.-36.	Tr	.1	.0074	50	
36.-38.	Tr	Tr	.014	100	Interbedded light green to gray quartzite and argillite; lower portion mostly argillite
38.-42.	Tr	Tr	.0044	85	Change at 40 feet to purple argillite and gray to purple quartzite containing limonite specks.
42.-43.	Tr	.1	.0020	76	

Table 15--continued

Depth Interval (feet)1/	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)	Core recovery (percent)	Description
43.-46.5	Tr	0.1	0.0020	76	Purple argillite with about 20 percent quartzite layers containing traces of limonite and pyrite.
46.5-50.	Tr	1.8	.0020	51	
50.-52.	Tr	.6	.0032	70	
52.-54.	Tr	.1	.0020	90	
54.-56.	Tr	.1	.0020	75	Purple argillite with about 30 percent quartzite. Bottom of hole at 56 feet.

1/ Metric conversion factors: Feet x 0.3048 = meters; ounces (troy) per ton x 34.285 = grams per tonne.

Table 16. - Core hole B.

[N, none detected; Tr, trace]

Depth Interval (feet)1/	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)	Core Recovery (percent)	Description
1.-3.5	Tr	N	0.024	36	No sample from 0 to 1 foot depth. Gray quartzite with limonite blebs and light green argillite. Traces of malachite.
3.5-6.	Tr	0.2	.38	44	Change at 4.5 feet to light green argillite with some gray quartzite which contains limonite and traces of chalcocite and malachite.
6.-7.5	Tr	.2	.11	100	Gray quartzite with limonite and chalcocite blebs, and minor light green argillite
7.5-9.	Tr	1.6	.062	100	
9.-10.5	Tr	.1	.056	87	
10.5-12.	Tr	Tr	.015	93	
12.-14.	Tr	.1	.0084	75	
14.-16.	N	N	.0026	37	Gray vuggy quartzite and some light green argillite. Abrupt change at 15 feet to purple and gray argillite with vuggy limonitic bands.
16.-19.	N	Tr	.0028	17	

Table 16--continued

Depth Interval (feet)1/	Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)	Core Recovery (percent)	Description
19.-21.	N	Tr	0.0010	95	Purple to gray argillite with some interbedded light-green argillite. Fractured zone at about 21 feet.
21.-24.	N	Tr	.0020	50	
24.-26.5	N	N	.0024	92	Thinly laminated purple to gray argillite; more massive in center of interval; scattered limonite specks.
26.5-29.	Tr	0.3	.0020	30	Purple massive argillite with scattered vuggy limonite bands.
29.-31.	N	Tr	.0018	75	Purple to gray massive argillite and impure quartzite. Abrupt color change to light green limonite bearing argillite at about 31.5 feet.
31.-32.	N	.1	.0014	75	
32.-34.	N	N	.0022	55	Light green argillite and quartzite with bands of limonite stain.
34.-37.	N	N	.0014	80	Abrupt color change at 35 feet. Interbedded pink to purple quartzite and purple argillite. Blebs of limonite in quartzite layers.
37.-39.	N	Tr	.0020	65	
39.-41.	Tr	Tr	.0012	88	Purple massive argillite with a few limonite stained impure quartzite bands.
41.-43.	0.01	1.7	.0016	55	Bottom of hole at 43 feet.

1/ Metric conversion factors: Feet x 0.3048 = meters; ounces (troy) per ton x 34.285 = grams per tonne.

A barite vein that strikes N. 65° to 78° E. and dips 83° N. to 85° S., is in the McNamara Formation. The barite is white to pink, massive, and has closely spaced fractures which facilitate breaking. Country rock at the prospect consists of gray, green, and reddish-brown argillite and quartzite beds that strike N. 17° to 35° W. and dip about 45° NE. (fig. 25).

Prospect workings consist of a pit 15 feet (4.6 m) long across the east barite vein outcrop, and a trench 75 feet (23 m) long along the west barite outcrop (fig. 24). The pit exposes sharp contacts between barite and the argillite, but the trench exposes a gradational vein contact at least 3 feet (0.9 m) wide. The thickness of pure barite in the trench is as much as 10 feet (3 m), and averages 7.5 feet (2.3 m) over a distance of 75 feet (23 m).

Probable vein length, including covered sections, is about 430 feet (131 m), and thickness averages 9 feet (3 m). If barite is inferred to an average depth of 170 feet (52 m), the deposit contains a resource of about 90,000 tons (80,000 t). The barite is suitable for drilling mud use; six samples averaged 92 percent $BaSO_4$, 0.14 percent iron, 0.06 percent strontium, and 4.36 specific gravity.

This resource is paramarginal at current barite prices, considering reasonable return on investment. The cost of mining and transporting crude barite from the Glacier prospect to the railroad at Martin City, Montana, would probably be about $30 per ton ($33/t). Crushing, beneficiation, and transportation to points of use in Montana, Wyoming, or Utah would probably add about $40 per ton ($43/t). Total production and shipping costs would be on the order of $70 per ton ($77/t). Average price for dry-ground drilling-mud-grade barite was $71 to $78 per ton ($78 to $86/t) in February 1978 (EMJ, March 1978).

Teton Pass coal prospects

The Teton Pass coal prospects consist of the Black Diamond, Marble Heart, Sky Pilot, Phoenix, and Klondike claims, which were located between 1907 and 1914. They are described as being near the headwaters of the Sun, Teton, and Big Rivers, near the Continental Divide, and near the boundary between Teton and Flathead Counties. The Phoenix claim is further described as being north of Bowl Creek. Position of these claims could not be determined, but they probably are on coal outcrops at locality 7 (fig. 20). The coal prospects are accessible from Choteau, Montana, by 37 miles (60 km) of road and 6 miles (10 km) of pack trail.

Coal beds 0.5 to 4.0 feet (0.15 to 1.2 m) thick occur in the Vaughn Member of the Cretaceous Blackleaf Formation. The member consists of gray to brown mudstone and sandstone which strike about N. 15° W. and dip about 40° SW. A fault has thrust Mississippian carbonate rocks over the coal-bearing Cretaceous rocks west of the prospects (fig. 26).

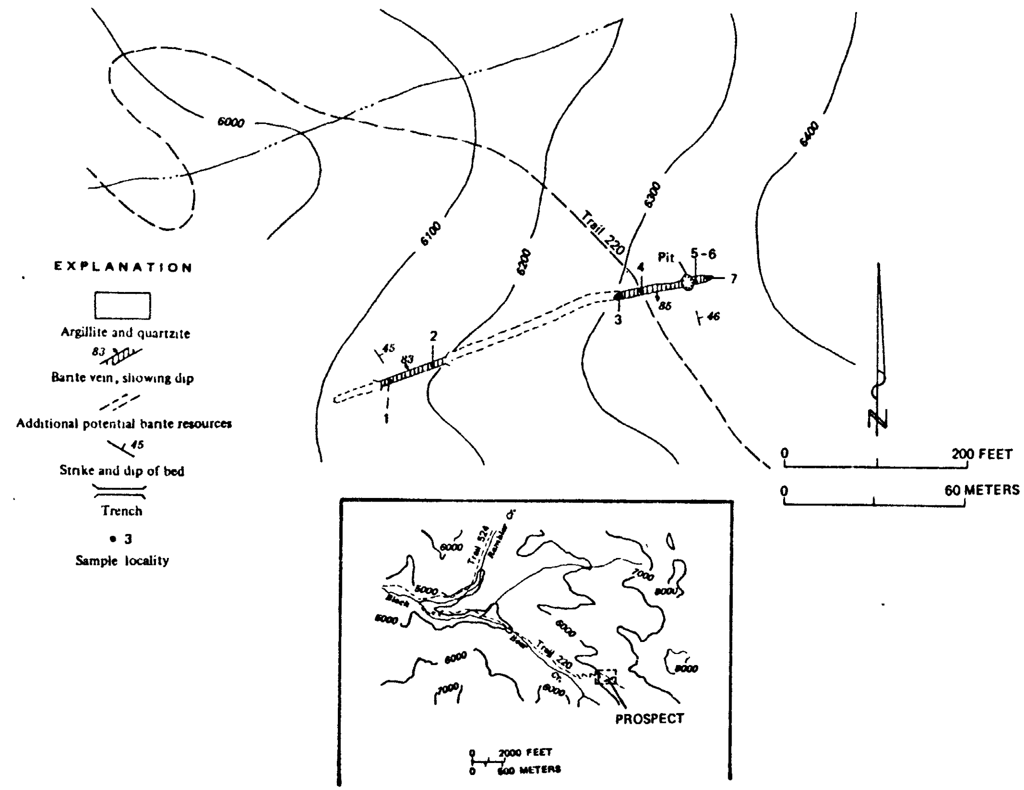

Figure 24.--Glacier prospect.

Data for samples shown on figure 24.

[N.d., not determined]

Sample				Barium Sulfate ($BaSO_4$)	Iron	Strontium	Specific gravity
No.	Type	Length (feet)1/	Description	(percent)	(percent)	(percent)	
1	Chip--	7.5	Across vein------------------------	94.4	0.11	0.037	4.44
2	do----	6.0	Vertically along vein--------------	88.5	.15	.068	4.36
3	do----	12.0	Across vein------------------------	92.0	.14	.027	4.38
4	do----	11.0	do---------------------------------	96.2	.039	.029	4.43
5	do----	13.0	do---------------------------------	90.0	.25	.13	4.24
6	do----	13.0	Sample taken across vein by Montana Bureau of Mines and Geology (Johns, 1970, p. 152)---------------------	88.0	N.d.	N.d.	N.d.
7	do----	5.0	Across vein------------------------	94.6	.08	.034	4.38

1/ Metric converstion factors: Feet x 0.3048 = meters.

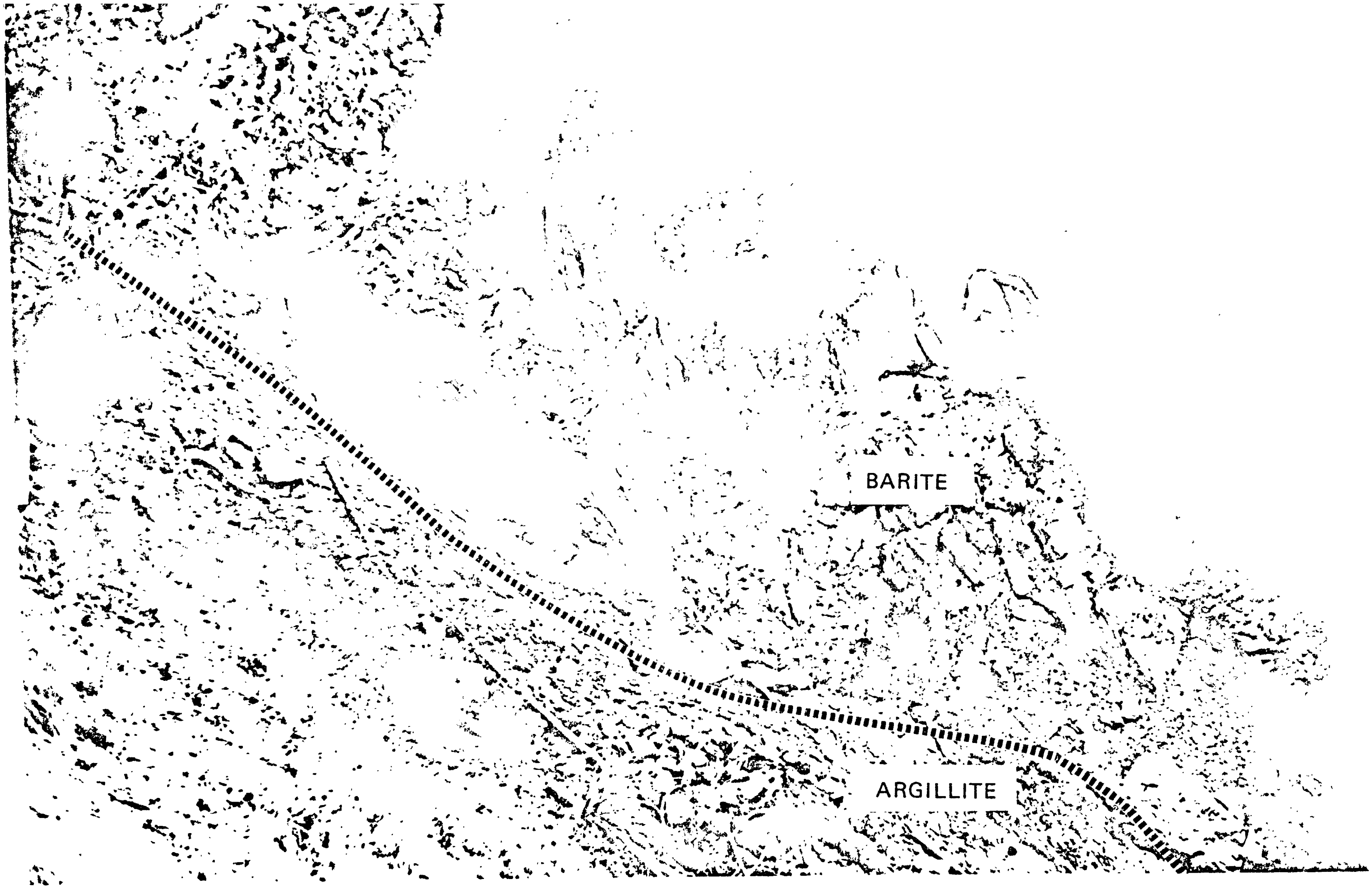

Figure 25.--West barite outcrop; view looking southerly.

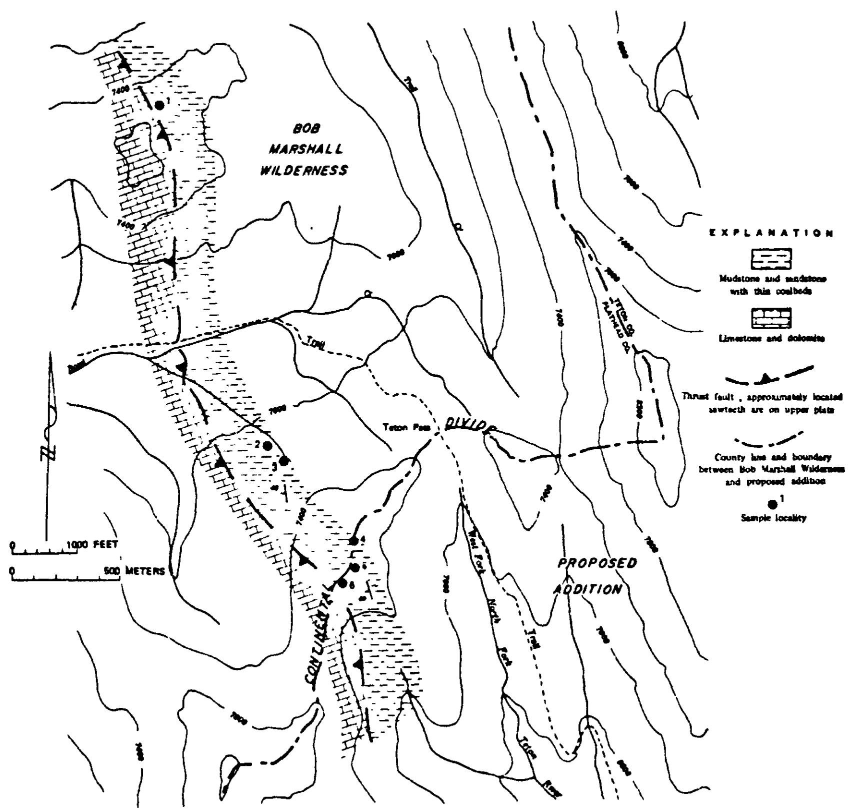

Figure 26.--Teton Pass coal prospects.

Data for samples shown on figure 26

Chip Sample		Across Bed	Proximate Analysis (percent)				Ultimate Analysis (percent)					
No.	Length (feet)1/	Condition	Moisture	Volatile Matter	Fixed Carbon	Ash	Hydrogen	Total Carbon	Nitrogen	Oxygen	Sulfur	Heating Value (Btu per lb)1/
1	2.0	As received	15.7	12.6	9.1	62.6	2.9	12.8	0.2	21.4	0.1	1,750
		Moisture free		14.9	10.8	74.3	1.4	15.2	.3	8.7	.1	2,070
2	4.0	As received	21.7	23.5	44.8	10.0	5.3	53.1	.9	30.3	.4	8,820
		Moisture free		30.0	57.2	12.8	3.7	67.8	1.1	14.1	.5	11,270
		Mois. & ash free		34.4	65.6		4.3	77.8	1.3	16.1	.5	12,930
3	4.5	As received	27.8	18.8	21.9	31.5	4.6	28.3	.4	35.0	.2	4,290
		Moisture free		26.1	30.3	43.6	2.1	39.2	.6	14.2	.3	5,940
		Mois. & ash free		46.2	53.8		3.7	69.5	1.1	25.1	.6	10,520
4	1.0	As received	10.1	15.3	27.7	46.9	3.2	32.7	.5	16.5	.2	5,320
		Moisture free		17.0	30.9	52.1	2.3	36.4	.6	8.3	.3	5,920
		Mois. & ash free		35.6	64.4		4.8	75.9	1.2	17.5	.6	12,370
5	.5	As received	17.4	22.2	30.2	30.2	4.3	38.1	.6	26.4	.4	6,120
		Moisture free		26.9	36.5	36.6	2.9	46.1	.7	13.3	.4	7,410
		Mois. & ash free		42.4	57.6		4.5	72.7	1.2	20.9	.7	11,690
6	1.0	As received	14.0	18.7	26.0	41.3	3.7	31.8	.5	22.4	.3	5,120
		Moisture free		21.7	30.3	48.0	2.5	37.0	.5	11.7	.3	5,950
		Mois. & ash free		41.8	58.2		4.8	71.1	1.0	22.5	.6	11,440

1/ Metric conversion factors:
Feet x 0.3048 = meters
Btu per pound x 2.326 = joules per kilogram

Only surface coal samples were taken at these prospects; analyses of such oxidized samples show lower heat value than those of unoxidized coal at depth. Surface contamination results in higher ash content.

A 75-foot (23-m)-long depression at locality 1 (fig. 26) may be an old prospect pit. The depression exposes a 1.5-foot (0.46-m)-thick black carbonaceous mudstone bed. A 2-foot (0.6-m)-thick impure coal bed crops out about 20 feet (6 m), stratigraphically, above the pit. The bed is slumped, and an uncontaminated sample was not obtained. Analysis of a chip sample across the bed indicated 74.3 percent ash (moisture free) and had a heating value of only 2,070 Btu per pound (4,820 joules/kg). At depth, the quality of this coal bed is probably higher than the surface sample indicates.

At locality 2 (fig. 26) a coal bed about 4 feet (1.2 m) thick is poorly exposed in an easterly-trending pit about 30 feet (9.1 m) long. Analysis of a chip sample taken across the bed indicated 12.8 percent ash (moisture free); the heating value was 11,270 Btu per pound (26,210 joules/kg). The sample may have been contaminated by overlying material.

The most extensive working is a northwesterly-trending pit 80 feet (24 m) long at localilty 3 where a 4.5-foot (1.4-m)-thick coal bed with two 3-inch (8-cm)-thick claystone partings is exposed. On a moisture-free basis, a sample from this bed, excluding the claystone, contained 43.6 percent ash; the heating value was 5,940 Btu per pound (13,800 joules/kg).

Seven or more carbonaceous beds crop out in the 400-foot (120-m) stratigraphic interval between localities 4 and 6 (fig. 26). Three beds with highest coalified wood content were sampled. Samples across the coal contained from 36.6 to 52.1 percent ash (moisture free), and the heating values ranged from 5,920 to 7,410 Btu per pound (13,770-17,240 joules/kg).

Thin and impure coal beds such as those in the Teton Pass area commonly grade laterally into carbonaceous mudstone beds. Although discontinuous, there may be an average of one 2-foot (0.6-m)-thick, 8,000-foot (2,400-m)-long coal bed between sample localities 1 and 6. If the bed extends 4,000 feet (1,200 m) downdip, about 3 million tons (2.7 million t) of coal may be inferred in the area. Average recovery in underground coal mines is about 57 percent (Lowrie, 1968). This bed probably could not be mined profitably under present economic conditions because (1) it is generally low quality and would require beneficiation, (2) thickness is erratic and averages less than 30 inches (76 cm), making mining expensive, (3) the dip is about 40°, further increasing the probable cost of mining, and (4) the area is relatively inaccessible.

Goat Ridge prospect

The Old Hickory, High Land, Mable, Lucky Strike, and Evening Star lode mining claims were located in June 1919 by Otto Waddell, N. S. Dobbs, and Harry Marks. These claims are described as being 1 mile (1.6 km) from the base of Red Shale Mountain (probably Lookout Mountain, shown on pl. 1), on the south slope of Red Shale Creek, 1.5 miles (2.4 km) east of Mount Carrie (one of the Three Sisters peaks, pl. 1), and in the Miners Creek (unorganized) mining district. Old prospect workings on Goat Ridge (fig. 20, No. 11) appear to be on these claims. The workings are reached from the boat landing northwest of Gibson Dam by about 32 miles (52 km) of trail.

The Goat Ridge workings are near the contact between limestone of the Helena Formation and an underlying diorite sill which strikes northerly and dips about 15° W. (fig. 27). The sill is about 500 feet (150 m) thick, and is composed of dark gray fine-grained diorite which is cut by white calcite veins as much as 2 inches (5 cm) thick.

The most extensive development is a westerly-trending adit (Nos. 5 and 6, fig. 27) which is caved. The size of the dump indicates the adit was about 30 feet (9 m) long. The portal is 10 feet (3 m) below the contact between the diorite and the Helena Formation. Fracture surfaces in diorite are coated with limonite and malachite, and the rock contains bornite and chalcopyrite. Smithsonite, sphalerite, and auricalcite have been identified in samples.

A pit (Nos. 3 and 4) 15 feet (4.6 m) long had been dug on the upper contact of the sill 300 feet (90 m) north of the adit. Here, the gray thin-bedded shaley limestone, overlying the diorite, strikes N. 5° W., dips 16° W., and is limonite stained to within a few inches of the contact.

On the hilltop to the northeast a pit in diorite with malachite (No. 1) is 18 feet (5.5 m) long and trends N. 50° E. (fig. 28). White calcite veins generally are one-eighth inch (3 mm) thick or less, and rarely are 2 inches (5 cm) thick. They contain sparsely disseminated pyrite and chalcopyrite crystals as long as 0.1 inch (3 mm).

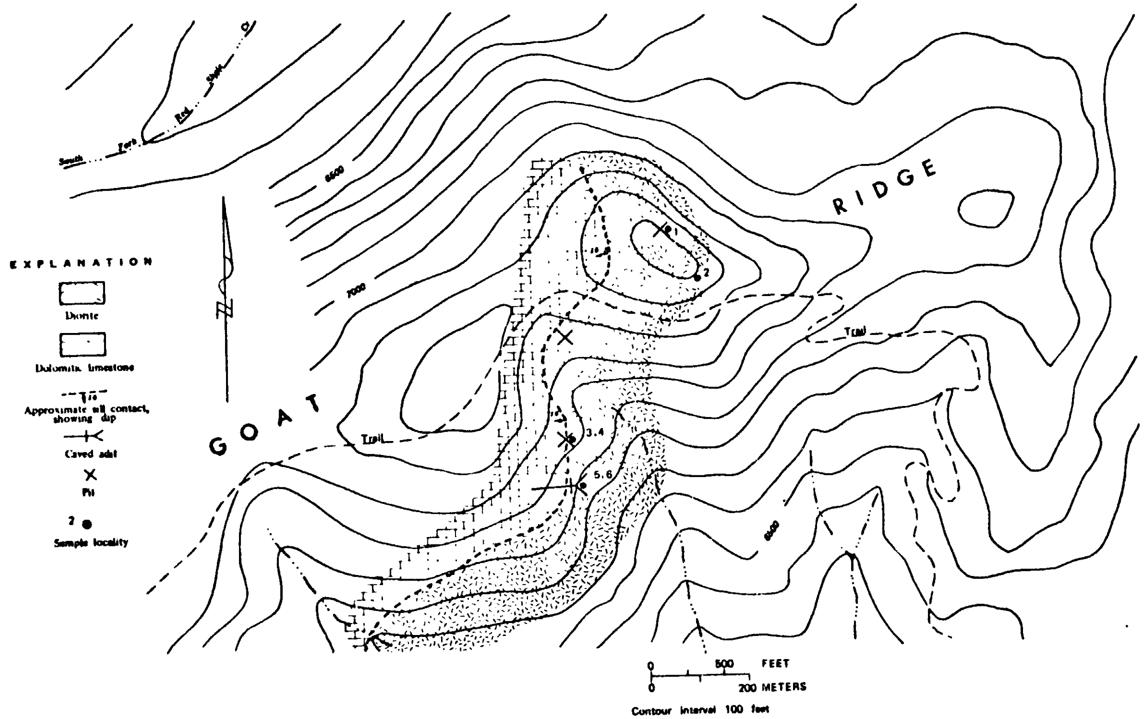

Figure 27.--Goat Ridge prospect.

Data for samples shown on figure 27.

[Tr, trace; N, not detected]

Sample				Gold (ounce per ton)1/	Silver (ounce per ton)1/	Copper (percent)	Lead (percent)	Zinc (percent)
No.	Type	Length (feet)1/	Description					
1	Chip--	18.0	Diorite from pit--------------------------	N	N	0.12	Tr	0.13
2	do----	12.0	Diorite from outcrop----------------------	N	0.1	.03	Tr	.02
3	do----	1.0	Across diorite-limestone contact in pit----	N	N	.01	0.02	.02
4	do----	9.0	Diorite from pit--------------------------	N	.2	.03	Tr	.05
5	do----	3.0	Diorite with visible iron and copper minerals, above caved adit----------------	N	.2	.36	Tr	1.10
6	do----	Select	Diorite with calcite veins and visible chalcopyrite, bornite, malachite, and specular hematite------------------------	N	.5	1.92	Tr	3.40

1/ Metric conversion factors:
Feet x 0.3048 = meters
Ounces (troy) per ton x 34.285 = grams per tonne

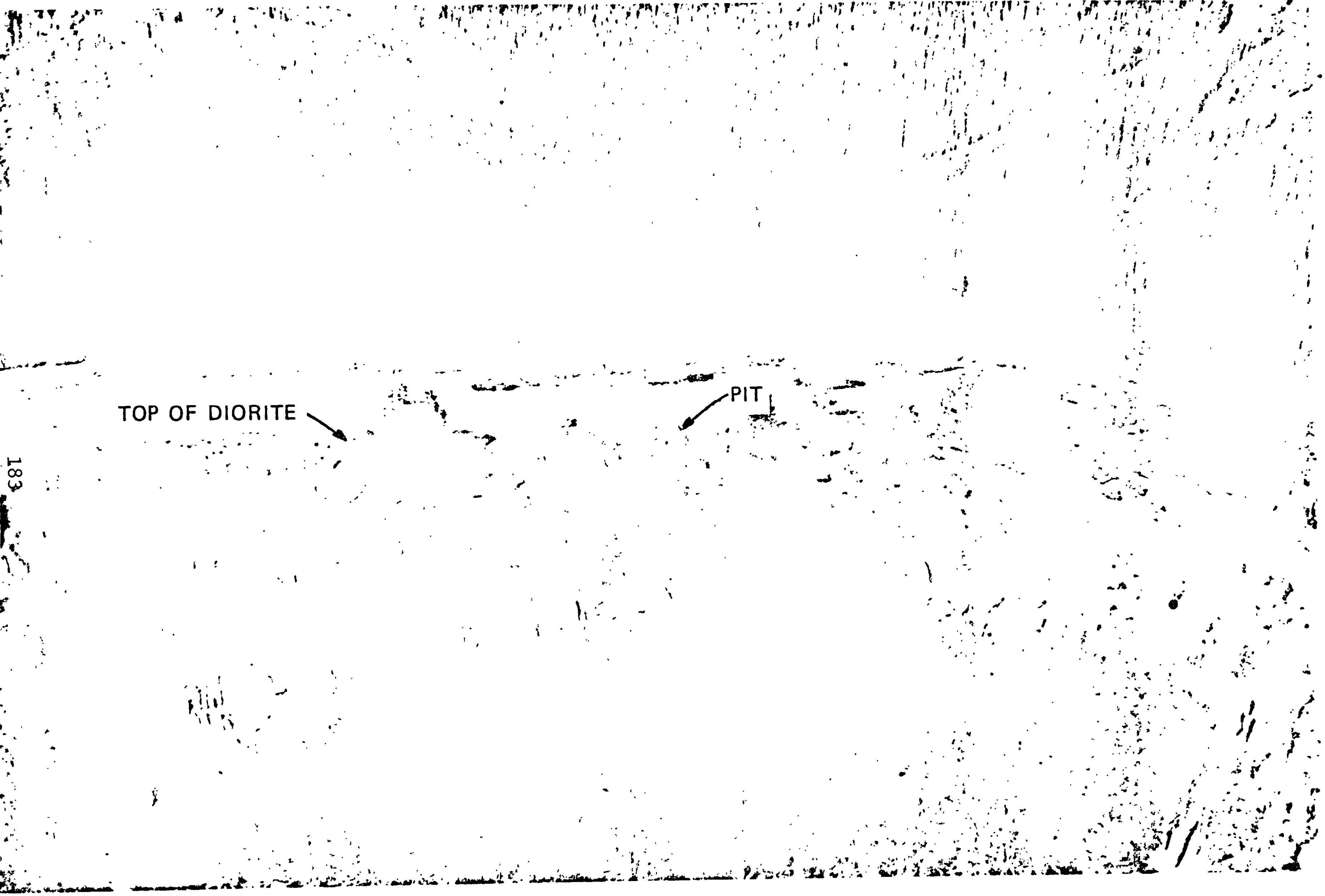

Figure 28.--Diorite sill at Goat Ridge prospect; view looking westerly to pit at sample locality 1.

All samples from the Goat Ridge prospect contained zinc and copper, and some contained silver. The zinc, copper and silver values extend at least 10 feet (3 m) below overlying carbonate rocks into the diorite at the caved adit, but the concentrations of metallic minerals are discontinuous and do not appear high enough to mine under present or anticipated economic conditions. Average grade of the diorite exposed in the area of the Goat Ridge workings is probably less than 0.1 percent zinc, 0.1 percent copper, and 0.05 ounce silver per ton (1.7 g/t). These prospects are in a geologic setting similar to the South Fork thrust zone in the Wood Canyon area from 18 to 48 miles (29 to 77 km) to the southeast, where Mudge, Erickson, and Kleinkopf (1968) found weak lead and zinc mineralization.

Oil and gas prospects

The Bald Head, C.C.A., Defender, Joe Berry, Little Black, Neff, Old Tom, Spokane, and War Eagle oil placer claims were located in 1904 on Birch Creek inside the study area. The Rocky Mountain Petroleum placer claim was located near the mouth of Danaher Creek in the Bob Marshall Wilderness, in 1905. No workings were found on these claims.

Johns (1970, p. 156) observed a 0.75-inch (1.9-cm)-wide asphalt dike in Devonian dolomite along the east side of South Fork Flathead River 2 to 2.5 miles (3.2 to 4.0 km) north of Black Bear Creek. Forest Service personnel reported other asphalt veins in areas of Devonian and Cambrian rocks along White River, below its south fork (oral commun., Robert Manchester, 1971). Asphalt is a petroleum residue.

Other prospects and occurrences

The following table summarizes other prospects and occurrences which appear to have little potential for development of a minable deposit, or are not well enough exposed to determine the potential (table 17). Metal values are lacking, low, or the deposit is too small to constitute a resource under present or anticipated economic conditions.

Table 17.--Summary of other prospects and occurrences. 1/

[Tr, trace; N, not detected; N.d., not determined]

Map No. (fig. 1)	Prospect or occurrence	Country rock	Description of deposit	Development	Sample Type	Sample Analyses: Gold (ounce per ton)	Silver (ounce per ton)	Copper (percent)	Zinc (percent)	Other
1	Stanton Lake prospects	Fractured quartzite and argillite; strike N. 30° to 57° W., dip 47° to 65° NE.; contain quartz veins to 3 in. thick.	Disseminated copper minerals in quartzite beds.	One caved adit trending N. 35° E.; 4 pits.	Select chips of vein quartz from caved adit.	Tr	N	0.0038	N.d.	N.d.
					Random chips from dump at caved adit.	Tr	N	.0034	N.d.	N.d.
					5-ft. chip across prospect pit.	Tr	N	.0046	N.d.	N.d.
					Grab from dump at sloughed pit.	Tr	N	.02	N.d.	N.d.
					Grab from pit walls.	Tr	N	.026	N.d.	N.d.
2	Java Creek placer claims	Principally argillite and quartzite.	Alluvium near confluence of Java Creek and Middle Fork Flathead River.	None.	Gravel samples from favorable areas.	N N N	N N N	N.d. N.d. N.d.	N.d. N.d. N.d.	N.d. N.d. N.d.
8	Helen Creek occurrence	Quartzite and argillite; strike N. 10° E., dip 22° SE.; contains discontinuous quartz-barite veins.	Quartz-barite veins 1 to 4 in. thick; strike N. 80° E., dip 68° SE.; contain calcite and specular hematite.	None.	Select of vein outcrop.	N	Tr	N	0.19	12.2 percent $BaSO_4$
10	Bungalo Mountain prospect	Thin-bedded quartzite and argillite; strike N. 15° E., dip 11° NW.; contains barite-quartz veins.	Barite-quartz veins 2 to 3 in. thick; strike N. 80° E., dip vertically.	Pits.	3-ft. chip along 0.25-ft. thick barite vein in pit.	N	0.2	Tr	.25	37.7 percent $BaSO_4$ Tr lead
					Select from stockpile?	N	Tr	Tr	.38	56.5 percent $BaSO_4$ Tr lead
12	South Fork Teton River prospect	Black shale; strike N. 10° W., dip 75° SW.; contains belemnites(?), fossil fragments; a fault strikes N. 32° W., dips 80° SW.	No visible metallic mineralization indicated.	None.	Three random grab samples.	N N N	N .1 .1	.0036 .0034 .0032	.011 .0096 .0072	Spectrographic analyses indicates no other metal concentrations.
13	Biggs Creek prospect	Sandstone and shale unconformably overlying dolomite and limestone; strike north-northwest, dip westerly.	Concentration of iron-rich minerals along the unconformity which strikes N. 12° W., and dips 65° SW.; the 4-ft. thick zone is altered carbonaceous shale with local dolomite breccia and chert nodules.	Caved adit which trends southward near base of carbonaceous shale and sandstone unit.	Grab along 300 feet of outcrop.	N	N	Tr	.11	1.6 percent iron; Tr lead
					Select from dump at caved adit.	N	.1	Tr	.10	12 percent iron; Tr lead
					4-ft. chip across outcrop.	N	Tr	Tr	.11	20 percent iron; Tr lead
					3-ft. chip across outcrop.	N	.1	Tr	.12	22 percent iron; Tr lead
14	J Claims	Limestone and carbonaceous shale; strike northerly, dip westerly.	None known.	None found, but lode claims filed in August 1954.	Not sampled.	N.d.	N.d.	N.d.	N.d.	N.d.
15	Sun Butte prospects	Mudstone and sandstone; overlain by glacial till.	Poorly sorted gravel, sand, and clay.	Four pits.	3-ft. chip along pit wall.	N	.2	N	.16	.02 percent lead
					3-ft. chip along pit wall.	N	N	.01	.11	.02 percent lead
16	Bentonite occurrence	Fissile shale distorted by thrust fault; contains bentonite layers.	Bentonitic clay layers as much as 4 feet thick and 100 feet wide that strike northerly and dip 80° westerly.	None.	Select of 0.3-ft. thick bentonite(?) bed.	N.d.	N.d.	N.d.	N.d.	Non-swelling calcium-rich clay with some Fuller's earth properties; pH = 7.8; salt content = 1440 ppm; sand content = 15.6 percent
17	Black Reef prospect	North-trending shale and sandstone, dip 45° westerly; trachyandesite porphyry sill to east.	Contact of shale and trachyandesite porphyry.	Two pits.	Select chips of trachyandesite porphyry from pit.	N	N	N.d.	.12	N.d.
18	Chief of the Mountains patented claim	Sandstone and shale; strike N. 55° W., dip 46° SW. east of unconformity and strike N. 40° E., dip 40° SE. west of unconformity.	"Medicine minerals" along unconformity; evaporite "bloom" of salts beneath overhanging cliff.	None.	25-ft. chip along massive sandstone with crust of salts.	N	N	N.d.	N.d.	Spectrographic analysis and petrographic study indicates iron-bearing carbonate minerals.
					1-ft. chip across unconformity.	N	N	N.d.	N.d.	
					Grab of sandstone above unconformity.	N	N	N.d.	N.d.	

Map No. (fig. 1)	Prospect or occurrence	Country rock	Description of deposit	Development	Sample Type	Sample Analyses: Gold (ounce per ton)	Silver (ounce per ton)	Copper (percent)	Zinc (percent)	Other
19	Copper Angel prospect	Massive, dolomitic limestone above thin-bedded, partly calcareous argillite and quartzite; strike N. 20° E., dip 15° SE.	Shear zones 0.5 to 10.0 feet thick striking N. 20° to 30° W., dipping 44° to 62° S.; subordinate shear zone 1 to 2 inches thick, partly quartz filled, strikes N. 77° E., dips 70° SE.	One adit driven 27 feet N. 77° E., then 15 feet N. 55° E. in base of dolomitic limestone.	4-ft. chip along 1-in. thick quartz vein in adit.	Tr	0.9	0.13	N.d.	N.d.
					2-ft. chip along 1-ft. thick shear zone in adit.	Tr	.3	.36	N.d.	N.d.
					5-ft. chip along 0.5-ft. thick shear zone in adit.	0.02	.4	.91	N.d.	N.d.
20	Charles placer claims	Principally metasedimentary rocks.	Alluvium along Rapid Creek.	None.	Gravel samples from favorable areas.	N	Tr	N.d.	N.d.	N.d.
						Tr	Tr	N.d.	N.d.	N.d.
						Tr	Tr	N.d.	N.d.	N.d.
21	McDermott Creek prospects	Argillite and quartzite intruded by a diorite sill 500 feet thick; strike N. 68° W., dip 41° NE.	Malachite coatings on joint surfaces in argillite and quartzite; also calcite lenses in diorite.	A 42-ft. long adit trending N. 25° E., about 50 feet above the diorite sill; a caved adit trending about N. 3° E., and a small pit.	7-ft. chip vertically across face in adit.	N	N	.021	N.d.	N.d.
					2.5-ft. chip across malachite-stained quartzite bed in adit.	N	Tr	.12	[illegible]	[illegible]
					3-ft. chip across calcite lens.	N	N	.14	N.d.	[illegible]
					Grab from dump at caved adit.	N	N	.025	N.d.	N.d.
					3-ft. chip across calcite lens in pit.	Tr	N	.012	N.d.	N.d.

1/ Metric conversion factors: Feet x 0.3048 = meters; inches x 2.54 = centimeters; ounces (troy) per ton x 34.285 = grams per tonne.

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