UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Mineral resource potential and geology of Wilderness Study Areas east of the Bob Marshall Wilderness, Teton and Lewis and Clark Counties, Montana

By

Melville R. Mudge[1], Robert L. Earhart[2], Jerry L. Clayton[2], and K. M. Nichols[2], U.S. Geological Survey
and
Harry W. Campbell[3] and Douglas F. Scott[3], U.S. Bureau of Mines

Prepared in cooperation with the U.S. Bureau of Land Management

Open-File Report 84-0566

1984

This report is preliminary but has been reviewed for conformity with U.S. Geological Survey editorial standards. The stratigraphic nomenclature has been approved previously.

[1]Present address
Lakewood, Colorado

[2]Denver, Colorado

[3]Spokane, Washington

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Bureau of Land Management Wilderness Study Area

The Federal Land Policy and Management Act (Public Law 94-579, October 21, 1976) requires the U.S. Geological Survey and U.S. Bureau of Mines to conduct mineral surveys on certain areas to determine their mineral resource potential. Results must be made available to the public and be submitted to the President and the Congress. This report presents the results of a U.S. Geological Survey geologic and mineral survey of wilderness study areas MT-075-101 through MT-075-110, Headwaters Resource Area, east of the Bob Marshall Wilderness, Teton and Lewis and Clark Counties, Montana. The report also contains the results of a U.S. Bureau of Mines mineral survey of wilderness study areas MT-075-102, 105, 106, 107, and part of 110, Teton and Lewis and Clark Counties, Montana.

MINERAL RESOURCE POTENTIAL
SUMMARY STATEMENT

The 10 U.S. Bureau of Land Management areas have a high potential for hydrocarbon resources, mainly gas. The areas contain potential source and reservoir rocks and are in a structural setting favorable for hydrocarbon generation and accumulation. Seismic data are necessary for each area to determine if potential structural traps are present.

Area 110 has a low potential for lead deposits. A mineral survey conducted by the U.S. Bureau of Mines in 1983 indicated no identified mineral resources are in study areas MT-075-102, 105, 106, 107, and 110.

INTRODUCTION

This study is a synthesis of published and unpublished data from studies made in and adjacent to 10 areas, in the Headwaters Resource Area, in northwestern Montana (fig. 1); these areas are administered by the Bureau of Land Management. The areas, designated 101-110 in this report, adjoin the eastern boundary of the Lewis and Clark National Forest along the eastern side of the northern Rocky Mountains; some of them extend west into the eastern part of the mountains. The northern areas (101-108) are in or adjacent to the Sawtooth Range, whereas the southern areas (109-110) are in the eastern part of the Lewis and Clark Range. All 10 areas total about 23 sq mi. Elevations range from about 5,000 ft in many places east of the mountains to 8,580 ft at Ear Mountain; the total relief is about 3,580 ft.

Only five of the areas are presently under consideration as wilderness study areas: area 102 (Blind Horse Creek), area 105 (Chute Mountain), area 106 (Deep Creek/Battle Creek), area 107 (North Fork of Sun River), and only the part of area 110 (Beaver Meadows) shown on figure 6. These five areas were examined by both the Geological Survey and Bureau of Mines. The five other areas (101, 103, 104, 108, 109, and part of 110) are BLM areas not proposed for wilderness designation and were examined solely by the U.S. Geological Survey.

PRESENT AND PREVIOUS STUDIES

Many reports and maps describe the geology of the 10 areas. All of the areas except 101 are shown on the Choteau $1^{o}x2^{o}$ quadrangle geologic map at a

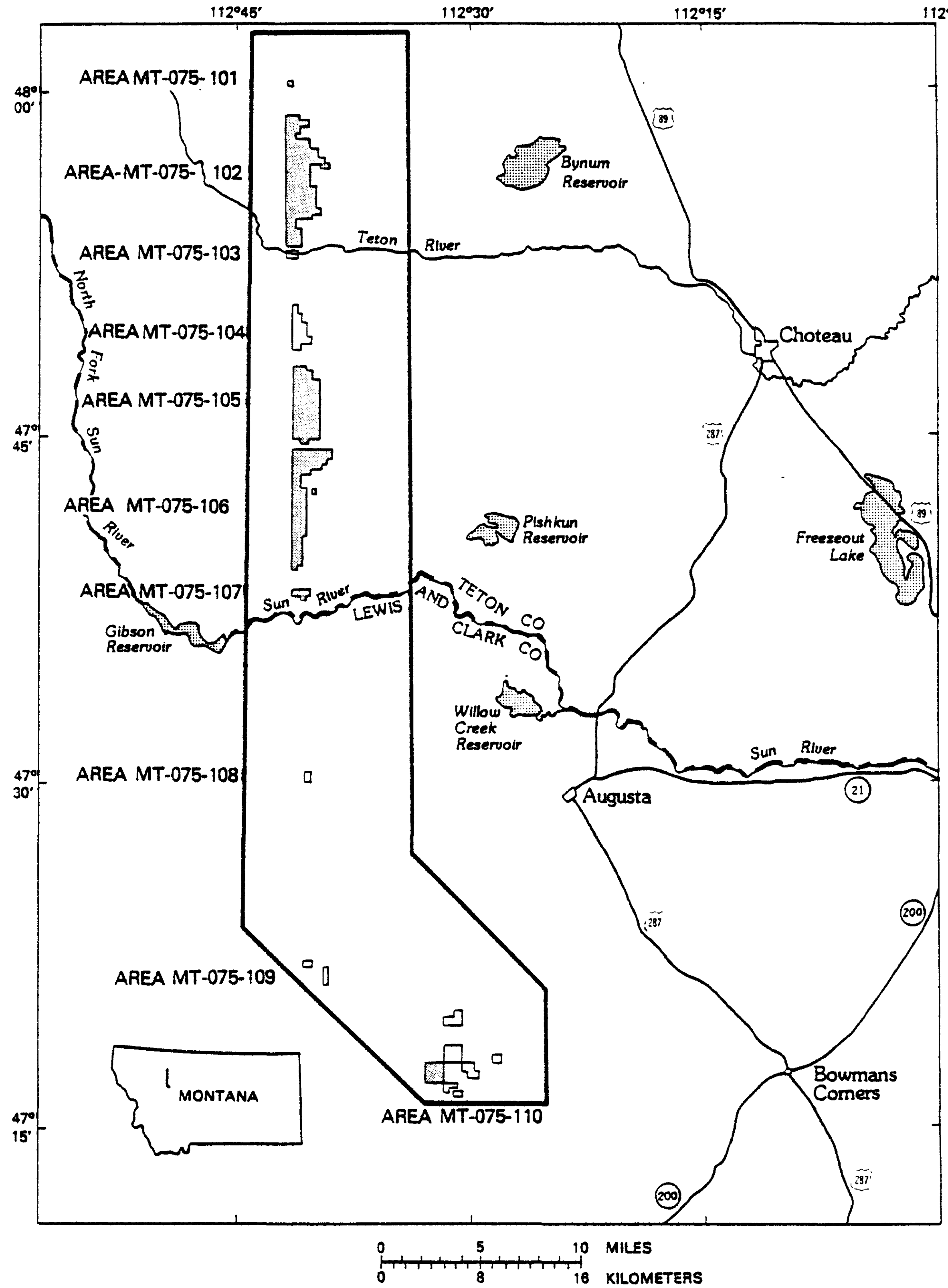

Figure 1.--Index map showing the location of the wilderness study areas east of the Bob Marshall Wilderness, northwestern Montana. Shaded areas were evaluated by both the Geological Survey and the Bureau of Mines.

scale of 1:250,000 (Mudge and others, 1982). Areas 106 and 107 are also shown on bedrock and surficial geologic maps of the Castle Reef quadrangle at a scale of 1:24,000 (Mudge, 1968, 1972c) and in reports on the geology of the Sun River Canyon area by Mudge (1972a, b). Areas 109 and 110 are discussed in a report on the geology, geophysics, and geochemistry of the southeastern part of the Lewis and Clark Range (Mudge and others, 1968). Parts of areas 105 and 106 adjoin a National Forest study area, adjacent to the Bob Marshall Wilderness, which was evaluated for its mineral potential by the U.S. Geological Survey and U.S. Bureau of Mines (1978). Areas 101-107 are included in a regional study on oil and gas geology of the Birch Creek-Sun River area, northwestern Montana, by Stebinger (1918). All of the areas are covered by aeromagnetic and gravity studies by Kleinkopf and Mudge (1972).

Adjacent to and west of the BLM wilderness study areas are National Forest lands that have been studied for mineral resource potential. These areas include the Scapegoat Wilderness (Mudge and others, 1974), Bob Marshall Wilderness (U.S. Geological Survey and U.S. Bureau of Mines, 1978), and the southeastern part of the Lewis and Clark Range (Mudge and others, 1968).

U.S. Geological Survey personnel did geologic mapping, geochemical sampling, and geophysical surveys. During these studies, rock samples were collected from formations that crop out in and near the study areas, and sediment samples were taken from streams that drain the areas. Float samples collected consisted of pebbles and cobbles from stream gravel. All samples were analyzed by a semiquantitative spectrographic method for 30 elements. In addition, samples collected near area 110 were analyzed for lead and zinc by chemical methods, stream-sediment samples were analyzed for citrate-soluble heavy metals, and rock and sediment samples collected near area 110 were analyzed for mercury. Analyses were by D. J. Grimes, G. C. Curtin, A. P. Marranzino, H. W. Knight, J. H. McCarthy, J. R. McHugh, and G. H. Van Sickle.

In 1983, Bureau of Mines personnel gathered data concerning mines, prospects, and mineralized areas by searching literature and courthouse records and making a field examination of the five wilderness study areas (Campbell and Scott, 1984). The field examination required 12 worker-days. Nine rock samples were collected and analyzed for copper, lead, zinc, gold, silver, calcium, magnesium, iron, aluminum, silicon, uranium, sodium, potassium, manganese, phosphorous, titanium, and sulfur by atomic absorption, inductively coupled plasma analysis, or fire-assay methods. At least one sample from each prospect was analyzed for 40 elements[1] by semiquantitative spectrographic methods to determine the presence of unsuspected elements. Excluding coal, sample preparation was done by the Western Field Operations Center, Spokane, Wash., and analyses were made by the bureau's Reno Research Center, Reno, Nev. The U.S. Department of Energy's Pittsburgh Energy Technology Center, Pittsburgh, Pa., determined heat value and moisture, ash, carbon, sulfur, and other abundances in a coal sample.

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[1]Aluminum, antimony, arsenic, barium, beryllium, bismuth, boron, cadmium, calcium, chromium, cobalt, copper, gallium, gold, iron, lanthanum, lead, lithium, magnesium, manganese, molybdenum, nickel, niobium, palladium, potassium, phosphorus, platinum, scandium, silicon, silver, sodium, strontium, tantalum, tellurium, tin, titanium, vanadium, yttrium, zinc, and zirconium.

GEOLOGY

The rocks in the 10 areas are predominantly sedimentary and range in age from Precambrian (Belt Supergroup) to Late Cretaceous (table 1). A diorite sill of Proterozoic Z age (750 m.y.) near area 110 (fig. 2) is the only igneous rock exposed in or near the areas. Upper Cretaceous sedimentary rocks crop out at several localities to the east of the study areas. Quaternary deposits locally mantle parts of each area.

The Proterozoic Y (Belt Supergroup) sedimentary rocks in area 110 comprise the Greyson (oldest), Spokane, Empire, Helena, Snowslip, Shepard, and Mount Shields (youngest) Formations (Mudge and Earhart, 1978). The Precambrian rocks have an aggregate thickness of about 9,000 ft and are overlain unconformably by Cambrian rocks. In the Steinbach thrust plate, east of Beaver Meadows, Cambrian rocks rest unconformably on the Greyson, whereas in the Eldorado thrust plate in the upper reaches of Elk Creek, Cambrian rocks rest unconformably on the lower part of the Mount Shields. The Belt Supergroup consists mostly of clastic rocks, except for the Helena Formation and parts of the Shepard Formation, which are mostly carbonate rock.

The diorite sill of Proterozoic Z age is exposed near area 110 at Beaver Meadows (fig. 2) where it intrudes the Greyson Formation. The exact thickness of the sill at this location is unknown. Elsewhere it ranges in thickness from 196 to 607 ft (Mudge and Earhart, 1978). The sill is dark-gray diorite that characteristically weathers to a medium brown.

Rocks of Middle and Late Cambrian age are exposed in areas 109 and 110. They are about 2,231 ft thick near the south boundary of area 110 where they are divided into eight formations. These are, in ascending order: the Flathead Sandstone, Gordon Shale, Damnation Limestone, Dearborn Limestone, Pagoda Limestone, Steamboat Limestone, Switchback Shale, and Devils Glen Dolomite (Deiss, 1939). The Flathead is a poorly sorted, fine- to coarse-grained, light-gray, crossbedded sandstone. The Gordon and Switchback are both dark-gray shales that contain some interbedded sandstone and limestone. The other formations are gray, thinly bedded carbonates except for the Pagoda and Devils Glen, which are thick-bedded carbonates (Mudge and Earhart, 1978). The carbonate rocks form steep cliffs, and the intervening calcareous shales form slopes. The carbonate units, except for the Devils Glen, are mostly impure dolomitic limestone containing some dolomite and limestone. The Devils Glen is entirely dolomite.

Devonian rocks crop out only at Sheep Mountain in area 110. Here they are repeated by thrust faults, and therefore a complete section is not exposed. The total thickness of the Devonian sequence near area 107 in the Sun River area is about 951 ft (Mudge, 1972a). The Devonian is divided into three formations which are, in ascending order: the Maywood, Jefferson, and Three Forks. The Maywood consists mostly of greenish-gray dolomitic mudstone in the lower member and thinly bedded gray limestone and dolomitic limestone in the upper member. The lower member of the Jefferson consists mostly of thin to thick beds of grayish-brown limestone, dolomitic limestone, and dolomite. Locally it contains one or more thin beds of evaporite-solution breccia. The Birdbear Member of the Jefferson is light-grayish-brown, thinly bedded dolomite, calcitic dolomite, and limestone. The Three Forks Formation consists of evaporite-solution breccia and some thin beds of dolomite.

Mississippian rocks assigned to the Madison Group are exposed in areas 102-106, 108, and 109. They range in thickness from about 902 to 1,198 ft. The Madison Group is divided into two formations, the Lower Mississippian

Table 1.--Sedimentary rock units in wilderness study areas east of the Bob Marshall Wilderness

Quaternary	Alluvial, glacial, colluvial, and landslide deposits and gravel	
Upper Cretaceous	St. Marys River Formation Horsethief Sandstone 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	
	Mount Pablo Formation	Cut Bank Sandstone Member
Upper Jurassic	Morrison Formation	
Upper and Middle Jurassic	Ellis Group Swift Formation	Sandstone member Shale member
Middle Jurassic	Rierdon Formation	
	Sawtooth Formation	Siltstone member Shale member Sandstone member
Upper and Lower Mississippian	Castle Reef Dolomite	Sun River Member Lower member
Lower Mississippian	Allan Mountain Limestone	Upper member Middle member Lower member
Upper Devonian	Three Forks Formation	
	Jefferson Formation	Birdbear Member Lower member
Upper and Middle Devonian	Maywood Formation	Upper member Lower member
Upper Cambrian	Devils Glen Dolomite	
Upper and Middle Cambrian	Switchback Shale	
Middle Cambrian	Steamboat Limestone Pagoda Limestone Dearborn Limestone Damnation Limestone Gordon Shale Flathead Sandstone	
Proterozoic Y	Belt Supergroup Missoula Group Mount Shields Formation Shepard Formation Snowslip Formation Helena Formation Ravalli Group Empire Formation Spokane Formation Greyson Formation	

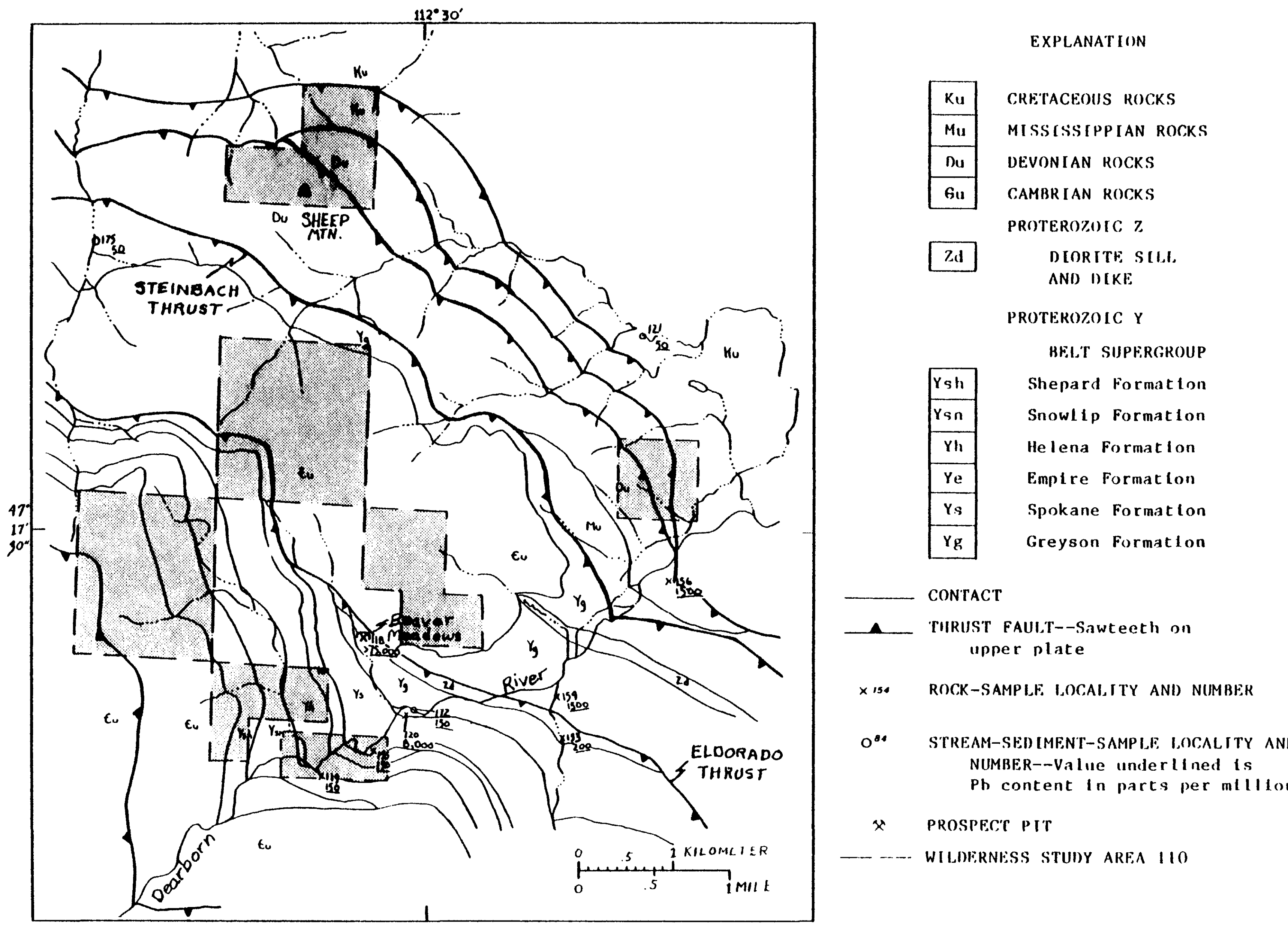


Figure 2.--Geologic map of area 110 showing sample localities and distribution of anomalous lead in rocks and stream sediments. Shaded areas were evaluated by both the Geological Survey and the Bureau of Mines.

Allan Mountain Limestone and the Lower and Upper Mississippian Castle Reef Dolomite (Mudge and others, 1962). The Allan Mountain is mainly medium- to dark-gray limestone and some dolomitic limestone, whereas the Castle Reef is mostly light-gray, thick-bedded dolomite, dolomitic limestone, and limestone. The largest potential hydrocarbon reservoir in the Madison Group is the dolomitized crinoidal grainstone unit that locally forms the upper part. This unit, included by Mudge and others (1962) in the Sun River Member of the Castle Reef, is the main oil and gas producer in several fields to the east on the Sweetgrass Arch (Chamberlain, 1955).

In surface exposures, the grainstone unit at the top of the Madison has a vuggy and intercrystalline porosity (4-12 percent) and is permeable (6-12 millidarcies). Many of the pores are filled with oil residue. Calcite cement partly occludes some of the pore space and developed after migration of liquid hydrocarbons into the grainstone unit.

Variations in thickness of the grainstone unit are mainly the result of pre-Jurassic erosion. In places the grainstones are completely eroded beneath the Jurassic rocks, but where present they thicken to more than 328 ft, as observed in a north-south direction along the strike of imbricate thrust slices. A pre-Jurassic high erosional remnant is centered in areas 101 and 102, where 328 ft of grainstone is exposed. The reservoir in a potentially commercial gas field near area 101 is this grainstone unit. The grainstone unit thins southward to area 108, where the top of the Madison is an underlying nonporous packstone-wackestone unit.

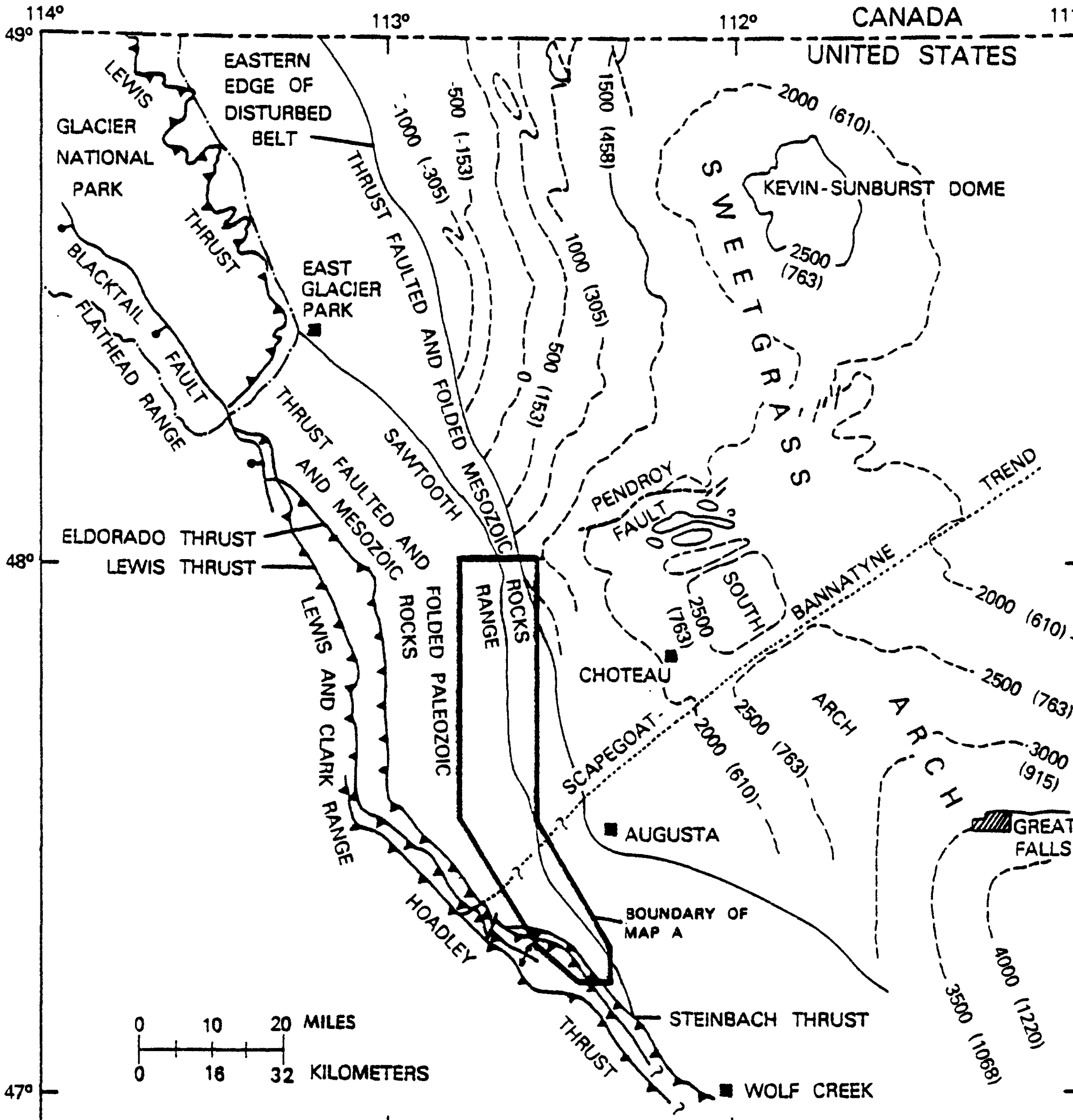
Crinoidal grainstone beds in the upper part of the Allan Mountain Limestone have minor potential as a hydrocarbon reservoir. These beds have a surface porosity of 2 to 5 percent and are relatively impermeable (0.01-3 millidarcies).

Rocks of Middle and Late Jurassic and Early Cretaceous age consist of the Middle and Upper Jurassic Ellis Group, comprising the Sawtooth (lower), Rierdon, and Swift (upper) Formations; the Upper Jurassic Morrison Formation; and the Lower Cretaceous Mount Pablo and (or) Kootenai Formations. Where the Lower Cretaceous rocks are differentiated, they include the Mount Pablo (lowest), Kootenai, and Blackleaf (uppermost) Formations.

The Ellis Group crops out in areas 102-106 where it is about 673 ft thick. The Sawtooth Formation consists of a lower gray, fine-grained sandstone member, a middle dark-gray shale member, and an upper tan-gray siltstone member. The Rierdon is a dark-gray mudstone with many thin beds of limestone. The Swift contains dark-gray shale in the lower part and thinly bedded grayish-brown sandstone in the upper part.

The Morrison Formation is as thick as 196 ft and consists of gray-green to olive-drab mudstone and some thin beds of fine-grained sandstone. In areas 102-106 it is overlain unconformably by the Cretaceous Mount Pablo Formation. Further south, in the vicinity of the Sun River, the Morrison is overlain unconformably by the Kootenai Formation.

The Lower Cretaceous Mount Pablo Formation is exposed in areas 101-106. It was formerly called the western facies of the Morrison Formation in the Sun River Canyon area by Mudge (1972a). The unit is a hydrocarbon reservoir rock in and near the Kevin-Sunburst dome to the northeast (fig. 3). There it consists of the Cut Bank Sandstone Member in the lower part and an unnamed member in the upper part. The formation ranges in thickness from about 180 to 210 ft. The Cut Bank Sandstone Member contains a basal sandstone that is very coarse to medium grained and crossbedded. A conglomerate is common at its base. The rest of the member consists of gray-green mudstone overlain by a



EXPLANATION

- —1000(305)— STRUCTURE CONTOUR--Shown east of disturbed belt. In feet (meters in parentheses). Dashed where inferred. Datum is restored base of Colorado Group (from Dobbin and Erdman, 1955)
- FAULT--Dashed where inferred. Bar and ball on downthrown side of normal fault
- THRUST FAULT --Sawteeth on upper plate; queried where uncertain
- ANTICLINE

Figure 3.--Tectonic and structure contour map of part of northwestern Montana.

fine- to coarse-grained sandstone. The upper member consists of variegated mudstone containing some thin beds of sandstone and a light-gray limestone unit near the top.

The Kootenai Formation is exposed in areas 101-109 where it is about 656 ft thick. It is mainly maroon and grayish-green mudstone and local channel fill of grayish-green sandstone and conglomeratic sandstone.

The Blackleaf Formation is exposed in areas 101-109 and is about 656 ft thick. It consists of the Flood Member (lowest), Taft Hill Member, and Vaughn Member (uppermost) (Cobban and others, 1976). The Flood contains 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, fissile shale. The Taft Hill consists of gray mudstone with interbeds of fine-grained sandstone (Mudge, 1972a). The Vaughn is mainly greenish-gray mudstone and some thin beds of sandstone, bentonitic shale, and bentonite. Channel fillings of conglomerate are locally present at the base of some of the sandstone beds (Mudge and Sheppard, 1968). The bentonite beds are less than 6 in. thick.

A variety of Quaternary deposits are in the study areas. The deposits in areas 106, 107, 108, and the southern part of 105 have been mapped in detail by Mudge (1967, 1972c) and serve as an example of the type of Quaternary deposits common along the mountain front. They are locally derived alluvial, colluvial, landslide, talus, and glacial deposits of various ages. The alluvial and glacial deposits are common in and near the mouths of the canyons. Talus and landslide deposits are widespread in the interstream areas along the mountain front. Colluvial deposits are common on the slopes adjacent to the drainages.

All of the areas are in the northern disturbed belt of Montana (fig. 3), an arcuate zone of numerous closely spaced, northerly trending, and westerly dipping thrust faults, many folds, and some longitudinal normal faults. These structures resulted from an orogeny that occurred between Paleocene and late Eocene time (Mudge, 1970; Hoffman and others, 1976). Several major structures east of the disturbed belt bear indirectly on this study. The Sweetgrass Arch is a northwesterly trending, structurally high area, consisting of the South Arch and the Kevin-Sunburst dome (fig. 3), that has been tectonically active since the Precambrian (Mudge, 1972b). Its present configuration was established by Late Cretaceous time (Mudge, 1972b). The Scapegoat-Bannatyne trend is an alinement of structural highs and lows having more than 1,394 ft of relief on the Precambrian surface (Alpha, 1956). It shows as a pronounced lineament on Landsat photographs that coincides with mapped northeasterly trending faults and folds in and east of the eastern part of the disturbed belt (Mudge and Earhart, 1979). The eastern part of the disturbed belt of Montana is equivalent to the Foothills subdivision of the Alberta disturbed belt to the north.

Areas 101-109 contain structures characteristic of the eastern part of the disturbed belt (for example, thrust plates contain Cretaceous rocks that have been translated eastward a short distance), whereas area 110 contains major structures characteristic of the western part of the belt (for example, thrust plates containing Precambrian and Paleozoic sedimentary rocks that have been translated eastward many miles).

The structures in all the study areas are thrust faults and some folds; in areas 101-108 they trend mostly north, whereas in areas 109 and 110 they trend northwest. Most thrust faults in areas 101-108 dip 45° to 60° west and have a stratigraphic throw of 492 to 1,198 ft (Mudge, 1972a). In areas 109 and 110 the thrust faults mostly dip between 20° and 45° and have a stratigraphic throw of many miles. The folds are associated with the thrust faults, and most of them plunge south. The Teton anticline, in and south of the forks of the Teton River, is a symmetrical open fold that plunges southward from the North Fork Teton River. Another group of large folds plunges southward from the vicinity of Ear Mountain (area 104) and extends across the South Fork Deep Creek (area 106). Ear Mountain is the east limb of an anticline containing Mississippian rocks.

Areas 101 and 102 are structurally higher than are the areas to the south, as they are adjacent to the westerly projection of the structurally high South Arch of the Sweetgrass Arch (fig. 3). Areas 104 to 108 are in the structural depression southwest of the South Arch. In area 108, structures of the Sawtooth Range plunge to the south into a structural depression that is on the southwesterly projection of the Scapegoat-Bannatyne trend (fig. 3). Area 109 is in the south part of that depression.

Area 110 (fig. 2) contains two major thrust blocks consisting of Proterozoic Y and Cambrian sedimentary rocks and a Proterozoic Z diorite sill and dike. The easternmost major thrust is the Steinbach and the westernmost is the Eldorado (fig. 2). In the Beaver Meadows area, the Eldorado thrust placed Precambrian rocks of the Greyson, Spokane, and Empire Formations and the Proterozoic Z sill onto Cambrian rocks. The Steinbach thrust placed rocks of the Greyson Formation onto Devonian rocks. The amount of easterly translation of these thrust plates has not been determined, but it is probably many miles. The Eldorado thrust plate contains about 5,167 ft of Belt rocks which in the Steinbach thrust plate were eroded prior to Middle Cambrian sedimentation. This difference suggests that the Eldorado thrust has major translation.

Thrust faulting in all 10 areas helped develop structural traps that have potential for hydrocarbons. Mississippian rocks in the subsurface have been repeated by thrust faults and form potential traps similar to those of the gas fields in the foothills of Alberta (Bally and others, 1966; Gordy and Frey, 1977). In area 101, the Blackleaf field (fig. 4), the structural trap containing natural gas is analogous to the traps common in the Alberta gas fields.

GEOCHEMISTRY

Three properties are important for the evaluation of sedimentary rocks as possible source rocks of petroleum: (1) organic-matter content, (2) organic-matter type, and (3) burial and temperature history (thermal maturity). The combination of organic-carbon pyrolysis and solvent extraction/gas chromatography allow preliminary evaluation of these properties.

These properties are useful for source-rock evaluation because hydrocarbons are generated from certain types of organic matter as a result of increased temperature and time related to deep burial of the host rocks. Organic-carbon content is a measure of the amount of organic matter deposited and preserved in the rock. Shales worldwide contain an average of about 1.14 weight percent organic carbon (Hunt, 1961), and 0.5 percent is the approximate lower limit for a potential source rock. The amount of hydrocarbons already generated and present in the rock is indicated by the volatile hydrocarbon yield from pyrolysis and solvent extraction. Thermal maturity of the organic matter can be estimated from the temperature of maximum pyrolysis yield. In addition, the ratio of pyrolitic hydrocarbon yield to organic carbon reflects both the type of organic matter and the thermal maturity. The ratio of

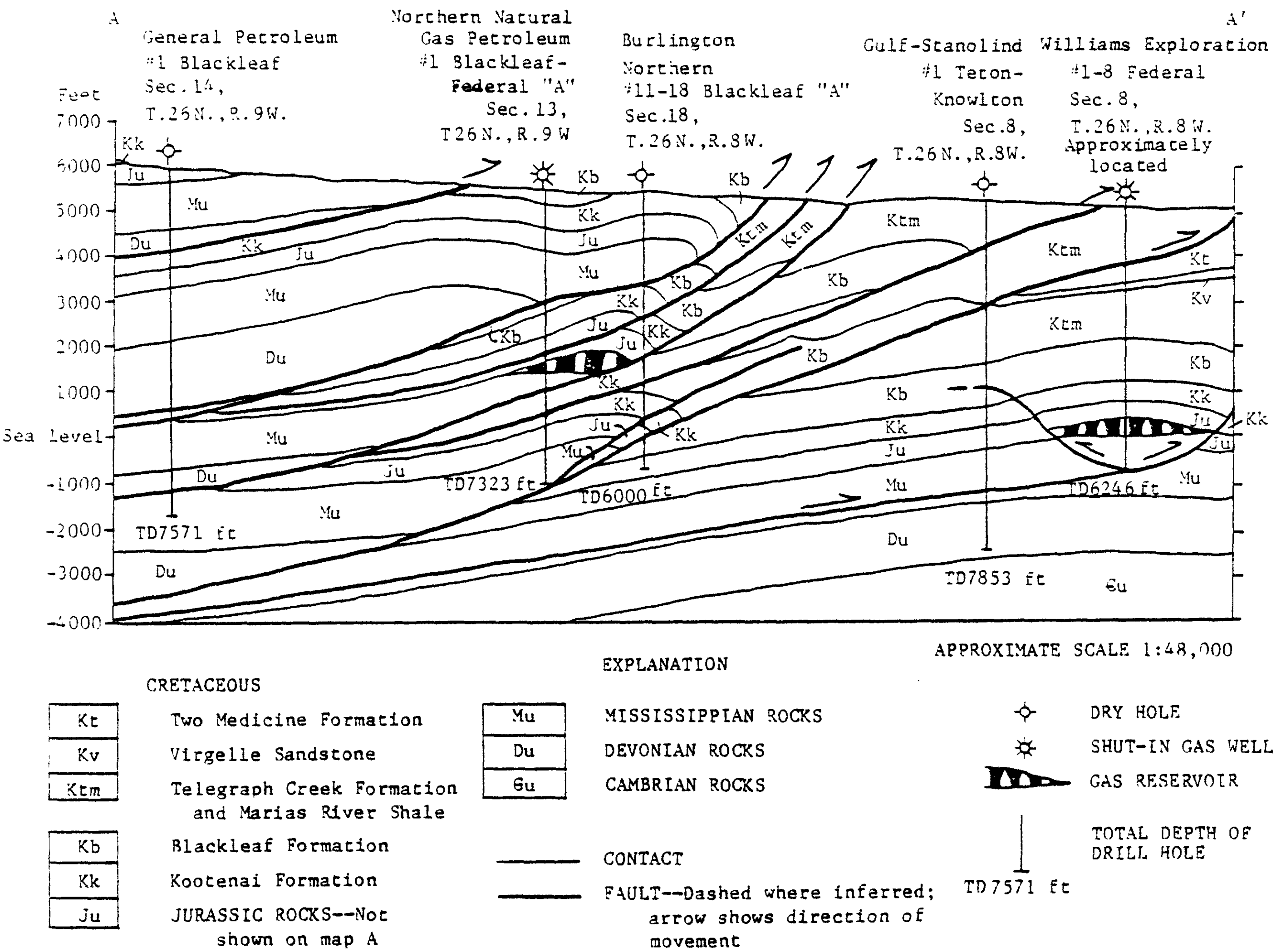


Figure 4.--Cross section through the Blackleaf gas field in the vicinity of areas 101 and 102. Modified from Montana Geological Society (1979).

extractable hydrocarbons to organic carbon and the molecular distribution of saturated hydrocarbons as determined by gas chromatography are sensitive to thermal alteration.

For a given type of organic matter, temperature is the single critical factor in generation of hydrocarbons, although once the critical temperature has been reached, a long period of time may have the same effect on generation as a higher temperature for a shorter time. Sedimentary rocks classified as immature have never been exposed to temperatures sufficiently high to promote thermal generation of hydrocarbons, although biogenic gas may be present (Rice, 1977). Mature rocks are those in which liquid hydrocarbons or gas have been generated, depending upon the type of contained organic matter. In the postmature stage, liquid hydrocarbons do not occur in significant quantities because they have been cracked to yield mainly gas (chiefly methane).

The evaluation of petroleum source rocks consisted of analyzing samples collected from 10 to 15 cm below the weathered surface of outcrops in and near the study areas. On the basis of previous studies (Leythaeuser, 1973; Clayton and Swetland, 1976), we know that the organic content of outcrop samples may have been reduced to as little as one-half of the amount in equivalent unweathered rocks in the subsurface. Moreover, this loss of material may be selective for hydrocarbons. Therefore, the outcrop samples provide minimum values for organic-matter-content measurements. A few samples collected in this study were composites, representative of a greater thickness of each rock unit. Accordingly, the organic-content measurements obtained are average values in which the contribution from high-grade intervals has been lowered by inclusion of material from organic-lean intervals, in approximate proportion to their thickness in the section sampled.

The analyses of the samples are shown in table 2. Organic carbon was measured by a direct, wet oxidation method (Bush, 1970). Thermal-evolution analysis using a flame ionization detector was carried out as described by Claypool and Reed (1976), except that the response of the flame ionization detector was calibrated by analysis of known amounts of eicosone ($n\text{-}C_{20}H_{42}$) coated on alumina. In this analysis the rock is heated at 104°F per minute, increasing from 122°F to 1,292°F, and the hydrocarbons evolved are quantitatively measured.

The pre-Upper Cretaceous rocks analyzed generally contain below-average amounts of organic matter compared to shale in general. Furthermore, the organic-matter type contained in these rocks cannot be converted to liquid hydrocarbons upon pyrolysis as indicated by the low pyrolitic hydrocarbon yields (pyrolitic hydrocarbon to organic carbon ratios generally less than 10 percent). There are three possible reasons why the organic matter in these rocks does not generate significant quantities of liquid hydrocarbons upon pyrolysis: (1) the original organic matter contained in the rocks was hydrogen deficient, (2) the rocks had a high thermal history due to deep burial or some other heat source, or (3) the rocks were intensely weathered.

Of the three possibilities, the second, high thermal history, is the most likely explanation for the low pyrolitic hydrocarbon yields. This interpretation is supported by the temperatures of maximum pyrolysis yield, which are consistently near or above 932°F. Mudge and others (1978) reported similar findings in their study of the Bob Marshall Wilderness and adjacent areas. In addition, surface weathering may have reduced the organic content somewhat compared to equivalent unweathered rocks in the subsurface. However, some of the outcrop samples from the Upper Cretaceous, especially the Cone

Member of the Marias River Shale, are recognizable as above average in organic-matter content despite the possible effects of weathering.

In contrast to the other pre-Upper Cretaceous rocks studied, most of the shale samples from the Devonian Three Forks Formation yielded large amounts of pyrolitic hydrocarbons relative to organic carbon. Most of these samples contain somewhat low amounts of organic carbon (<0.40 percent) to have generated economically significant quantities of oil or gas. However, Mudge and others (1978) reported much higher amounts of both organic carbon and pyrolitic hydrocarbons in Devonian and Mississippian Exshaw Formation samples from the Lewis thrust plate just southwest of study area 109.

These results suggest that the potential for generation of liquid hydrocarbons from possible source rocks of pre-Upper Cretaceous rocks in the study area has largely been spent (except possibly in the Exshaw Formation from the Lewis plate, mentioned above), but there is a potential for natural-gas accumulations. It is unlikely that any major oil accumulations generated from source rocks of Early Cretaceous age or older will be found in the area, because any oil generated from these rocks, and not lost due to breaking of traps and conduit beds during thrust faulting, would have been converted to gas and condensate by the elevated temperatures associated with subthrust burial. In addition to gas formed by thermal cracking of preexisting oil accumulations, these pre-Upper Cretaceous rocks could also have generated natural gas during the transition from the mature to the postmature stage.

Liquid-hydrocarbon occurrence cannot be completely ruled out in the study areas because a few of the Upper Cretaceous samples have characteristics of mature oil source rocks. In particular, samples JC123 and JC124, from just east of area 102, have high pyrolitic hydrocarbon yields and temperatures of maximum pyrolysis in the range of those observed for mature source rocks in other Rocky Mountain areas.

Two samples of the Cone Member (JC67 and SR5) near area 107 contained organic carbon well in excess of average shales, but yielded relatively low amounts of hydrocarbons upon pyrolysis. The temperatures of maximum pyrolysis yield of 932°F and 914°F, respectively, suggest that these two samples may have been subjected to high temperatures, probably as a result of subthrust burial. However, it is noteworthy that samples of the Cone Member from other areas in and adjacent to the disturbed belt yield large quantities of pyrolitic hydrocarbons and have good petroleum-source potential (Mudge and others, 1978).

Carbonate rocks are abundant in the Montana disturbed belt, and large limestone[2] occurrences are in the wilderness study areas. Analytical results of limestone samples collected by the Bureau of Mines from the study areas (fig. 5, nos. 1-3, 5, and 7) are shown in table 3.

A chip sample from a lens of impure coal exposed in an irrigation ditch (fig. 5, no. 4) had a heating value of 782 Btu/lb and an ash content of 85 percent. This coal is in Cretaceous rocks and is probably part of the Blackfeet-Valier coal belt, which is characterized by coal in beds which are generally thin and discontinuous (Averitt, 1963, p. 49, fig. 10). No coal was found in any of the wilderness study areas.

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[2]In commercial usage, the word "limestone" is a general term for rocks containing at least 80 percent calcium and magnesium carbonate.

Table 2.—Organic-carbon and thermal-evolution analyses of hydrocarbon source-rock samples, U.S. Bureau of Land Management areas 101-110

[ND, no data; ~, about; wt., weight; pct, percent; fm, formation; mbr, member; ppm, parts per million]

Sample No.	Sample interval (ft)	Organic carbon (wt. pct)	Pyrolitic hydrocarbon yield (wt. pct)	Volatile hydrocarbon (ppm)	Pyrolitic hydrocarbon / organic carbon (pct)	Temperature of maximum pyrolysis yield (°C)
UPPER CRETACEOUS HORSETHIEF SANDSTONE/BEARPAW SHALE TRANSITION						
MM73——	Grab———	1.03	0.04	73	4.0	502
UPPER CRETACEOUS VIRGELLE SANDSTONE						
JC70——	Grab———	1.49	0.45	211	30.4	492
UPPER CRETACEOUS TELEGRAPH CREEK FORMATION						
JC69——	Grab———	0.84	0.12	218	14.3	512
UPPER CRETACEOUS MARIAS RIVER SHALE						
JC35——	Grab———	1.19	0.15	105	12.7	486
JC57——	--do———	.84	.03	16	4.1	492
JC58——	--do———	1.36	.10	49	7.0	484
JC59——	--do———	.59	.02	8	4.2	476
JC60——	--do———	.44	.02	7	5.4	502
JC62——	ND———	1.13	.04	17	3.2	504
JC67——	Grab———	2.91	.38	349	13.1	500
JC68——	--do———	1.11	.08	124	7.6	502
JC123——	--do———	.70	.23	172	32.3	496
JC124——	--do———	.99	.26	185	26.4	484
MM77——	--do———	1.65	.15	318	9.2	512
MM80——	--do———	1.18	.12	112	10.4	523
MM82——	--do———	.76	.00	147	11.0	497
MM83——	--do———	1.60	.06	193	3.7	498
MM76,SR4, SR5,SR6.	--do———	1.05	.56	95	5.4	~520
SR11——	--do———	.6	.03	20	4.3	494
MM72——	--do———	14.55	.50	131	3.5	486
LOWER CRETACEOUS BLACKLEAF FORMATION						
JC63——	Grab———	1.25	0.04	36	3.1	ND
JC65——	--do———	.80	.06	95	7.9	510
JC66——	--do———	1.17	.06	119	3.2	506
JC90——	--do———	.90	.04	14	4.2	505
JC93——	--do———	.72	.03	12	3.8	501
JC102——	--do———	.76	.04	87	4.6	544
MM13——	40———	1.16	.05	93	3.9	504
MM14——	65———	.95	.04	73	3.9	504
MM15——	15———	.33	.02	41	6.7	502
MM16——	50———	.93	.03	55	3.0	ND
MM17——	15———	.96	.03	39	2.8	512
MM74——	Grab———	.87	.04	32	4.6	518
MM75——	--do———	1.49	.14	51	9.6	487
MM81——	--do———	.60	.02	72	3.5	520
SR1——	--do———	.68-.86	.06	57	7.3	508
SR2——	--do———	.87	.05	46	5.3	514
SR3——	--do———	1.43	.08	104	5.8	506
LOWER CRETACEOUS KOOTENAI FORMATION						
MM22——	Grab———	0.69	0.02	28	3.4	540
MM18——	Grab———	.55	.02	34	4.3	508

Table 2.—Organic carbon and thermal evolution analyses of hydrocarbon source-rock samples, U.S. Bureau of Land Management areas 101-110—Continued

Sample No.	Sample interval (ft)	Organic carbon (wt. pct)	Pyrolitic hydrocarbon yield (wt. pct)	Volatile hydrocarbon (ppm)	Pyrolitic hydrocarbon / organic carbon (pct)	Temperature of maximum pyrolysis yield (°C)
UPPER JURASSIC MORRISON FORMATION						
JC61----	Grab--------	0.90	0.05	8	5.3	480
UPPER AND MIDDLE JURASSIC SWIFT FORMATION						
JC101---	Grab--------	1.52	0.11	108	7.6	517
MM10----	40----------	.80	.05	69	6.8	506
SR12----	Grab--------	.65-.88	.05	17	5.4	494
MIDDLE JURASSIC RIERDON FORMATION						
JC106---	Grab--------	0.37	0.01	28	3.3	520
JC100---	--do--------	.41	.04	74	8.8	499
JC110---	--do--------	.28	.02	42	6.2	522
JC112---	Grab--------	.21	.01	25	6.0	528
MM1-----	Lower 6-----	.25	.01	28	5.6	488
MM2-----	Lower 10----	.30	.02	22	6.8	479
MM8-----	Lower 55----	.32	.01	29	4.4	509
MM9-----	Upper 55----	.23	.02	40	7.7	504
MM21----	Whole fm----	.22	.01	26	5.3	520
MM26----	113---------	.31	.01	14	3.2	506
SR13----	Upper 20----	.27-.46	.02	12	3.8	491
MIDDLE JURASSIC SAWTOOTH FORMATION						
JC91----	Grab--------	0.37	0.02	16	4.3	~520
JC103---	--do--------	.67	.02	46	3.8	520
JC104---	--do--------	.56	.02	27	2.8	550
JC105---	--do--------	.84	.01	27	1.1	560
JC111---	--do--------	.27	.01	26	4.0	530
MM7-----	Whole mbr---	.31	.02	43	7.3	502
MM19----	Lower 50----	.61	.02	39	2.9	520
MM20----	Upper 10----	.39	.02	71	5.8	500
MM25----	57----------	.41	.02	38	4.9	492
SR19----	Grab--------	ND	ND	ND	ND	ND
LOWER MISSISSIPPIAN ALLAN MOUNTAIN LIMESTONE						
MM23----	Lower 50----	1.08	0.019	24	1.8	558
SR26----	Grab--------	ND	ND	ND	ND	ND
DEVONIAN THREE FORKS FORMATION						
JC87----	Grab--------	0.32	0.06	71	18.3	499
JC88----	--do--------	.11	.03	36	28.1	492
JC89----	--do--------	.36	.08	94	22.3	491
JC97----	--do--------	1.03	.02	31	2.1	~600
CAMBRIAN GORDON SHALE						
MM6-----	Grab--------	0.08	0.01	30	129	ND

Table 3.--Analyses of limestone samples, wilderness study areas east of the Bob Marshall Wilderness

[Values in percent; N, none detected]

Sample No. (fig. 2)	CaO[1]	MgO[2]	Fe_2O_3	Al_2O_3	SiO_2	Na_2O	K_2O
1	35.4	15.4	0.09	0.17	6.6	N	0.17
2	32.5	19.4	.10	.14	3.5	N	.09
3	35.9	2.5	.12	.23	22.0	N	N
5	28.8	19.7	.15	.48	9.1	N	.09
7	49.6	2.6	.42	.91	4.0	0.05	.21

[1]If all the calcium in the sample is assumed to be in the form of carbonate molecules, the content of $CaCO_3$ in the analysis may be obtained by multiplying the CaO content by the factor 1.785.

[2]If all the magnesium in the sample is assumed to be in the form of carbonate molecules, the content of $MgCO_3$ in the analysis may be obtained by multiplying the MgO content by the factor 2.0915.

MINES AND PROSPECTS

In 1983, Bureau of Mines personnel examined mines and prospects in the five BLM proposed wilderness study areas (MT-075-102, 105, 106, 107, and 110), and searched literature and courthouse records.

No current mining claims or activity were found in the wilderness study areas in 1983. Prospects examined during this study are shown on figure 6 and described in table 4. Evidence of mining activity was found only inside the Deep Creek/Battle Creek Wilderness Study Area at one prospect, where narrow quartz veins in limestone contain no significant metal values. Previous mining activity near the study areas occurred at about the turn of the century when early settlers prospected for coal east of the Chute Mountain Wilderness Study Area, operated a small lime kiln on the Dearborn River, and prospected for lead east of the Beaver Meadows Wilderness Study Area (Lewis and Clark County mining claim records; James Salmond, personal commun., 1983). Titaniferous-magnetite deposits near Lake Theboe were prospected for iron during World War II.

Bureau of Land Management records indicate that 7,025 acres[3] within the five wilderness study areas were leased for oil and gas exploration. Several oil companies were exploring for oil and gas near the wilderness study areas in 1983. Oil and gas have been produced from wells of the Blackleaf field north of the Blind Horse Creek Wilderness Study Area (Montana Oil and Gas

[3]Beaver Meadows, 595 acres; Blind Horse Creek, 4,784 acres; Chute Mountain, 159 acres; Deep Creek/Battle Creek, 1,291 acres; North Fork of Sun River, 196 acres.

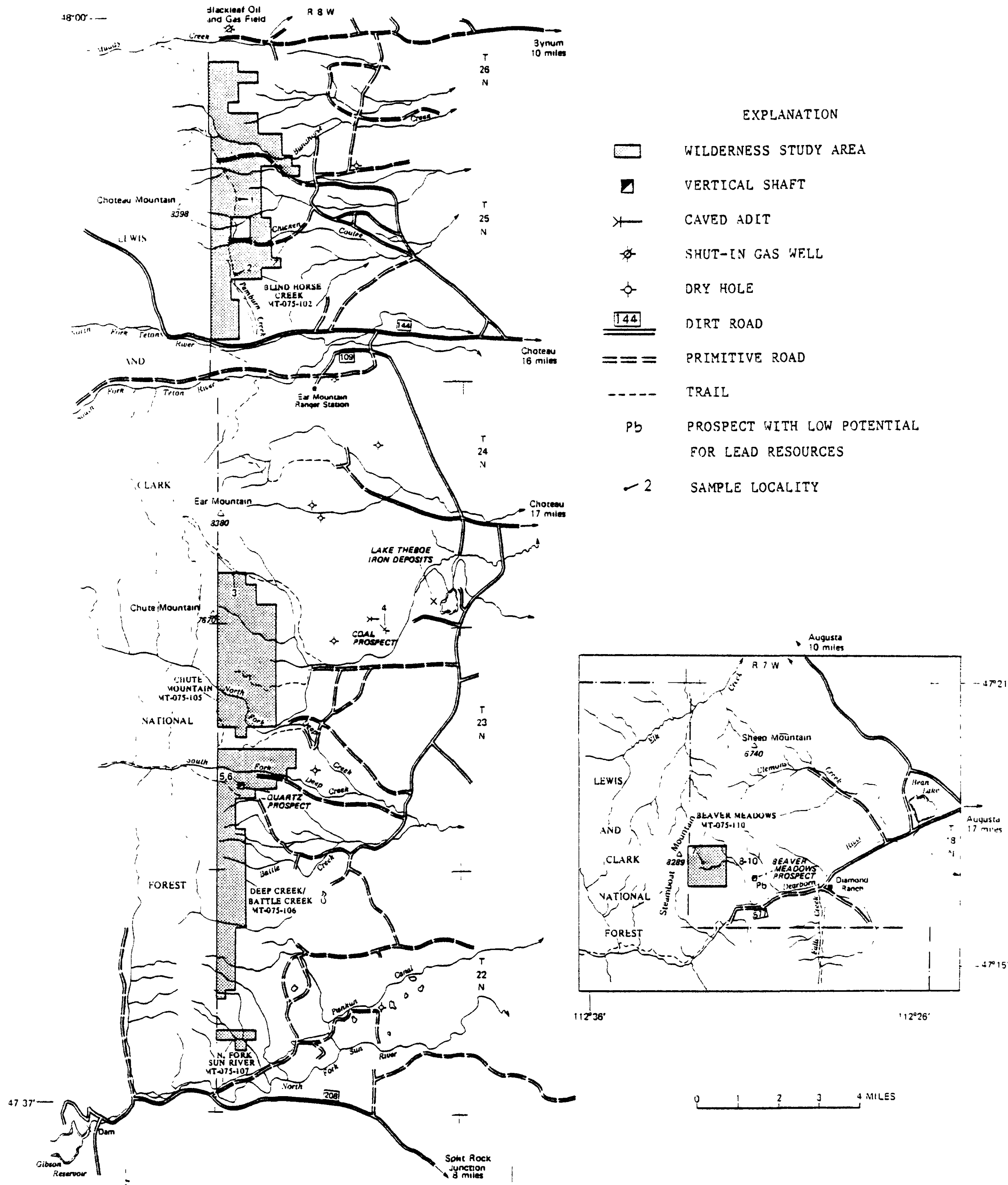

Figure 5.--Prospects and Bureau of Mines sample localities in and adjacent to the wilderness study areas east of the Bob Marshall Wilderness, Montana.

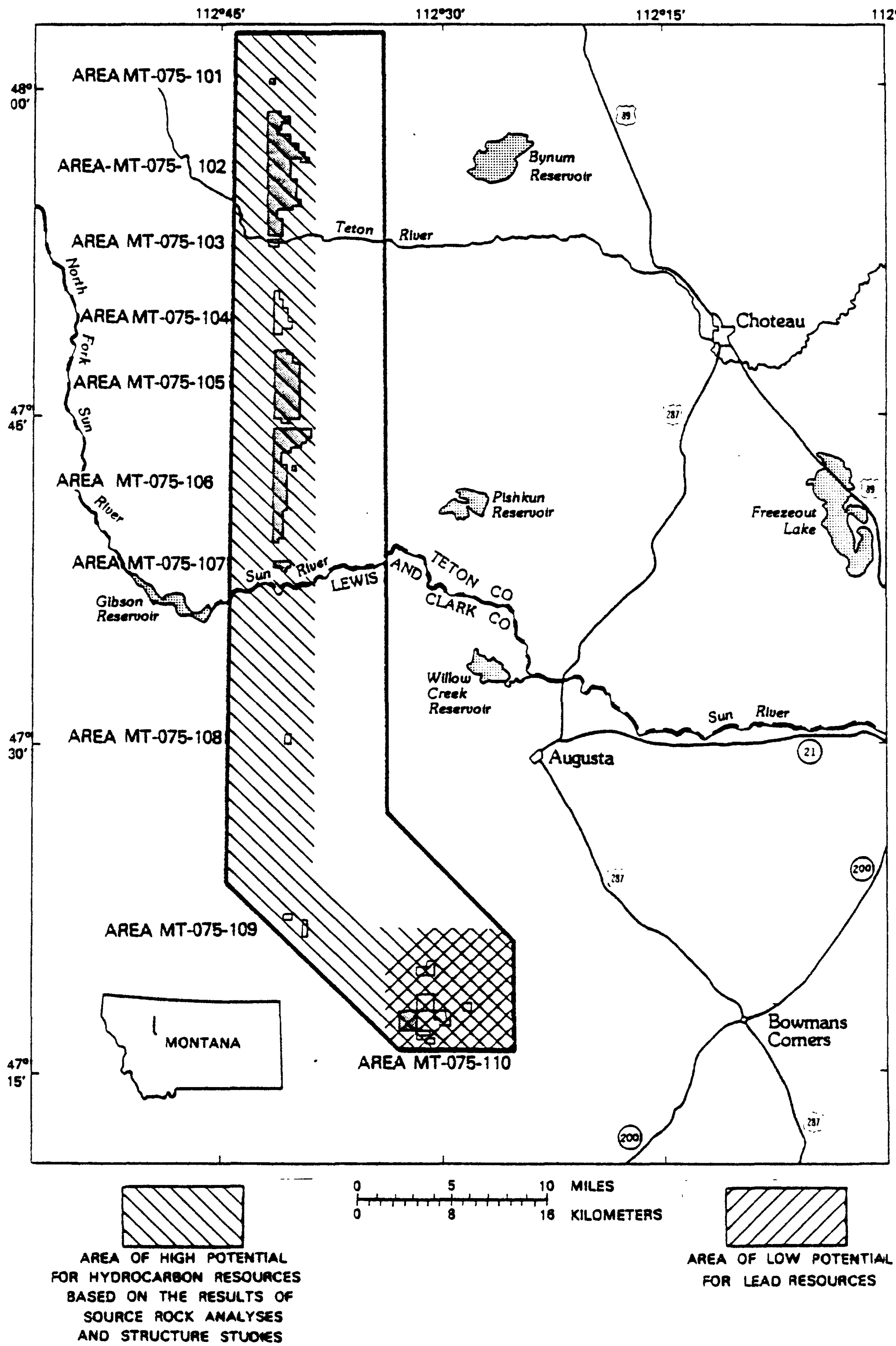

Figure 6.--Map showing the mineral resource potential of wilderness study areas east of the Bob Marshall Wilderness, northwestern Montana.

Table 4.--Prospects in and adjacent to wilderness study areas east of the Bob Marshall Wilderness

[*, prospects outside wilderness study areas. Prospects shown on fig. 6]

Name	Geology	Workings	Sample data and resource estimate
Coal prospect*	Impure coal lens 20 ft long and 3 ft thick strikes N. 65° W. in shale and thinly bedded pyritic, limonite-stained sandstone.	Two caved adits and several shallow trenches.	One 3-ft chip sample of impure coal had a heating value of 782 BTu/lb and an ash content of 85 percent.
Quartz prospect	Milky quartz veins as much as 3 in. thick in massive, gray limestone.	One shaft 4 by 6 by 11 ft deep.	One select sample of milky quartz contained no significant mineral values. Analyses of a limestone sample are shown in table 5.
Beaver Meadows prospect	Finely disseminated galena in fine-grained quartzite along contact with north-trending diorite dike. Manganese-oxide stain on fracture surfaces in quartzite and diorite.	One 25-ft-deep shaft and six prospect pits.	Two select samples of galena-bearing quartzite contained 6.1 and 1.7 percent lead. One grab sample of diorite contained 0.019 percent lead. Prospect has low potential for lead resources.

Table 5.--Analytical results of samples of anomalous rocks collected near U.S. Bureau of Land Management area MT-075-110

[Analyses are spectrographic, by G. C. Curtin and A. P. Marranzino, except: Pb and Zn analyses are chemical, by J. R. McHugh and G. H. Van Sickle; and Hg analyses are atomic absorption, by H. W. Knight and J. H. McCarthy. Values are in parts per million except Ca, Mg, and Fe, which are in percent. ND, not determined; >, greater than amount shown; <, less than amount shown]

Sample No.	Ca	Mg	Fe	Ti	Mn	Ag	B	Ba	Cd	Co	Cr	Cu	Ga	Hg	Mo	Ni	Pb	Sr	V	Y	Zn	Zr
118	<20	0.7	2	3,000	5,000	<1	<10	300	<20	7	20	20	10	0.02	<2	5	>75,000	150	150	50	200	20
119	2	1	7	1,500	200	1	50	300	<20	15	20	50	20	.19	15	20	150	50	50	30	<200	150
120	.2	.5	15	ND	2,000	5	100	200	<20	<5	15	30	20	.07	20	2	8,000	50	20	15	1,500	150
153	1	.3	>20	5,000	2,000	5	150	300	ND	20	5	1,500	50	ND	<2	15	200	<50	100	30	<200	50
154	3	1.5	5	1,000	5,000	5	150	50	30	<5	5	50	<10	ND	<2	<2	1,500	<50	30	10	7,000	150

Statistical Bulletin, 1983); exploration wells have been drilled near some of the wilderness study areas (fig. 5).

The Beaver Meadows Prospect (fig. 5, no. 8) is east of the Beaver Meadows Wilderness Study Area in a northwest-trending zone containing anomalous lead values. Quartzite at the prospect contains finely disseminated galena along a contact with a diorite sill; no evidence was found that this occurrence extends into the wilderness study area. Other prospects in the zone are 3.5 mi northwest of the wilderness study area, north of Elk Creek.

ASSESSMENT OF MINERAL RESOURCE POTENTIAL

The evaluation of the mineral resource potential exclusive of oil and gas is based on data obtained by geological, geochemical, and geophysical studies of adjacent areas (fig. 6). These areas include the Scapegoat Wilderness (Mudge and others, 1974), Bob Marshall Wilderness (U.S. Geological Survey and U.S. Bureau of Mines, 1978), and the southeastern part of the Lewis and Clark Range (Mudge and others, 1968). During these studies, rock samples were collected from formations that crop out in and near the study areas, and sediment samples were taken from streams that drain the areas. Float samples collected consisted of pebbles and cobbles from stream gravel. All samples were analyzed by a semiquantitative spectrographic method for 30 elements. In addition, samples collected near area 110 were analyzed for lead and zinc by chemical methods, stream-sediment samples were analyzed for citrate-soluble heavy metals, and rock and sediment samples collected near area 110 were analyzed for mercury. Analyses were by D. J. Grimes, G. C. Curtin, A. P. Marranzino, H. W. Knight, J. H. McCarthy, J. R. McHugh, and G. H. Van Sickle. The U.S. Bureau of Mines examined mines and prospects in and near five of the wilderness study areas (fig. 5).

Areas 101-109 are apparently devoid of occurrences of economic minerals. The geochemical results do not indicate any unusual concentration of valuable elements, and the geophysical surveys do not indicate any aeromagnetic or gravity anomalies that may reflect buried deposits. These areas contain limestone and dolomite deposits, possibly of commercial grade; however, larger deposits of these commodities are abundant in more accessible areas of northwestern Montana.

Area 110 is in a northwesterly trending zone that locally contains visible amounts of lead and zinc minerals (Mudge and others, 1968). The mineralized zone extends for 19.9 mi to the northwest of area 110, and recent geochemical studies by D. J. Grimes and R. W. Leinz (oral commun., 1980) show that the zone continues well to the southeast of the area. The geology of the area and the distribution of anomalous lead at a few localities along the Dearborn River near area 110 are shown in figure 2. The thresholds for anomalous lead values in stream sediments and rock samples, as determined from the analyses of samples from the adjacent Bob Marshall Wilderness, are 30 and 20 ppm, respectively (Earhart, 1978, p. 69). The complete analyses of rock samples containing anomalous lead are given in table 5. At many localities, several rock samples were collected; only the samples from each locality having the greatest amounts of lead are shown in figure 2 and table 5. Seven rock samples and three stream-sediment samples from near area 110 contain highly anomalous amounts of lead. Five of these samples (table 5) contain anomalous amounts of zinc (more than 200 ppm), or silver (0.5 ppm or more), or copper (20 ppm or more). The highest lead values are from a prospect pit (sample 118) near the contact of a diorite sill with limestone. Elsewhere near area 110, anomalous amounts of lead are in a variety of sedimentary rock types ranging in age from Precambrian to Devonian. Several of the anomalous samples were collected near thrust faults, which suggests that lead and the associated metals were either introduced or remobilized along thrust faults and were deposited in host rocks in the upper plates. Parts of area 110 are cut by thrust faults that in the Beaver Meadows area contain highly anomalous amounts of lead.

Individual occurrences of lead and zinc along the mineralized trend are small and confined to a narrow zone. None of the known occurrences contain minable quantities of ore-grade material. However, the mineralized zone in area 110 has not been tested by drilling, and the area is considered to have a low potential for lead resources with associated zinc, silver, and copper.

Titaniferous magnetite occurs near Lake Theboe in Cretaceous beach placer deposits (fig. 5). No evidence of titaniferous magnetite occurrences was found in any of the wilderness study areas.

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