AN EVALUATION OF THE HYDROCARBON POTENTIAL OF THE PROPOSED GREAT BEAR WILDERNESS AREA, FLATHEAD, TETON, AND PONDERA COUNTIES, MONTANA

by

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SUMMARY

The proposed Great Bear wilderness study area has very good potential for discovery of natural gas resources and somewhat lesser potential for oil production. The area contains numerous potential hydrocarbon reservoir and source rocks. Structural traps for the accumulation of gas in the subsurface cannot be determined without seismic surveys and possibly drill holes, but structural traps can be inferred from a comparison of the surface geology of the study area with that in gas producing areas to the north in Alberta, Canada. The proposed wilderness study area is in the northern disturbed belt of Montana which contains a structural and stratigraphic history similar to that in the Alberta disturbed belt which contains major reserves of gas and minor amounts of oil.

Successful gas exploration has been conducted a few miles east of the study area, but no seismic or drilling operations have been conducted within the area. Five wells east of the area were drilled in the 1950's. All these wells recovered natural gas but were shut-in, or abandoned, because the region was too remote and the price of gas too low for profitable production. These wells had a total potential productive capacity of 6.3 million cubic feet of gas per day.

The area contains potential hydrocarbon reservoir rocks of Devonian, Mississippian, Jurassic, and Lower Cretaceous ages of which most of them produce oil and/or gas from fields to the east on the Sweetgrass Arch. Some of the potential reservoir units thicken markedly within the study area. All potential reservoir units are overlain by shale, a common cap-rock for hydrocarbons.

Potential hydrocarbon source rocks in the area include Jurassic and Cretaceous marine shales. The results of this study indicate that Upper Devonian and lower Mississippian shales are not potential source rocks. Forty-two samples were collected in and adjacent to the study area from outcrops all of which were partly weathered; most were collected over wide intervals containing rock of both low and high carbon content. They were analyzed for organic content, and thermal analysis (TEA-FID[1]). The analytical results show that most of the samples are somewhat low in organic carbon content, probably as a result of weathering and high thermal conditions due to burial beneath a thick sequence of rocks in numerous thrust plates. The data indicate that the source rocks thermal history is favorable for the generation of gaseous hydrocarbons rather than oil, and suggest that natural gas may have been generated during deep burial after the formation of thrust faults which created suitable structural traps.

Upper Cretaceous marine shales are now thermally mature source rocks that are capable of generating and expelling both oil and gas. Inasmuch as these rocks are probably present beneath the western part of the study area, it may have a potential for both oil and gas.

The type of hydrocarbon structural trap most likely to be found in and near the study area is one that contains the wedge-edge of reservoir rocks. This type of trap occurs just east of the area where three shut-in gas wells penetrate Mississippian reservoir rocks. It is also the most common trap in the gas fields of Alberta.

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[1] Thermal evolution analysis employing a flame ionization detector.

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INTRODUCTION

Recent geologic studies in the northern disturbed belt of northwestern Montana indicate that source and reservoir rocks, favorable for hydrocarbon generation and accumulation, thicken appreciably in the area west and southwest of Swift Reservoir in the eastern part of the Great Bear Wilderness study area (figs. 1 and 2).

The Great Bear Wilderness study area, in the Northern Rocky Mountains, is in the central and western parts of the northern disturbed belt of Montana (fig. 1). The eastern part of the study area is in the Lewis and Clark National Forest, and the western part is in the Flathead National Forest.

The northern disturbed belt of Montana is being evaluated for its hydrocarbon potential by the U.S. Geological Survey. The belt is an arcuate zone of closely spaced thrust faults, folds, and some longitudinal normal faults that extend from the Little Belt Mountains northward for about 185 miles (300 km) to the International Border. The west side of the belt is arbitrarily drawn along the west sides of the Flathead and Whitefish Ranges and along the South Fork Flathead River.

The disturbed belt is 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 Late Cretaceous or very Early Tertiary. The Scapegoat-Bannatyne trend, a linear structure in the Precambrian basement, extends northeast across

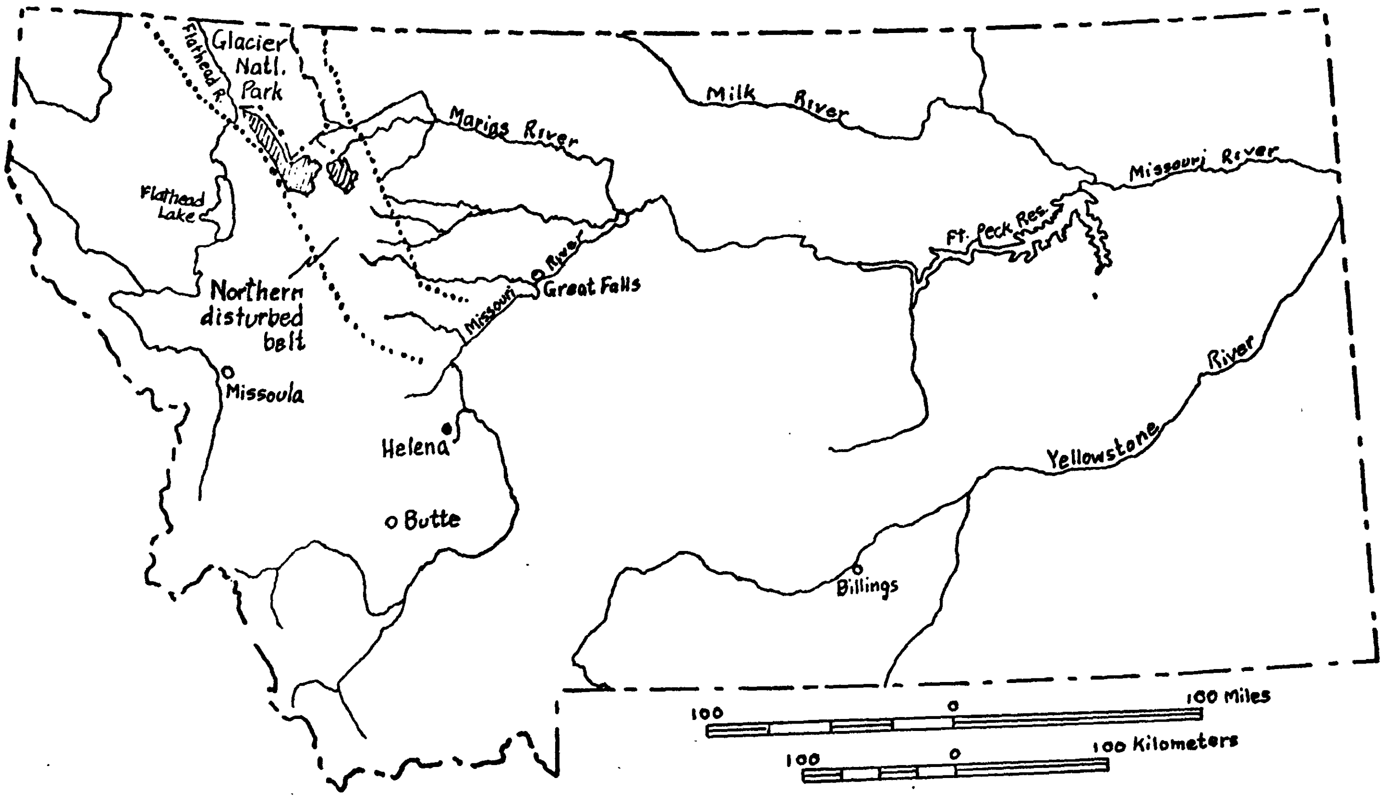


Figure 1.--Index map of Montana showing the location of the Great Bear wilderness study area (patterned).

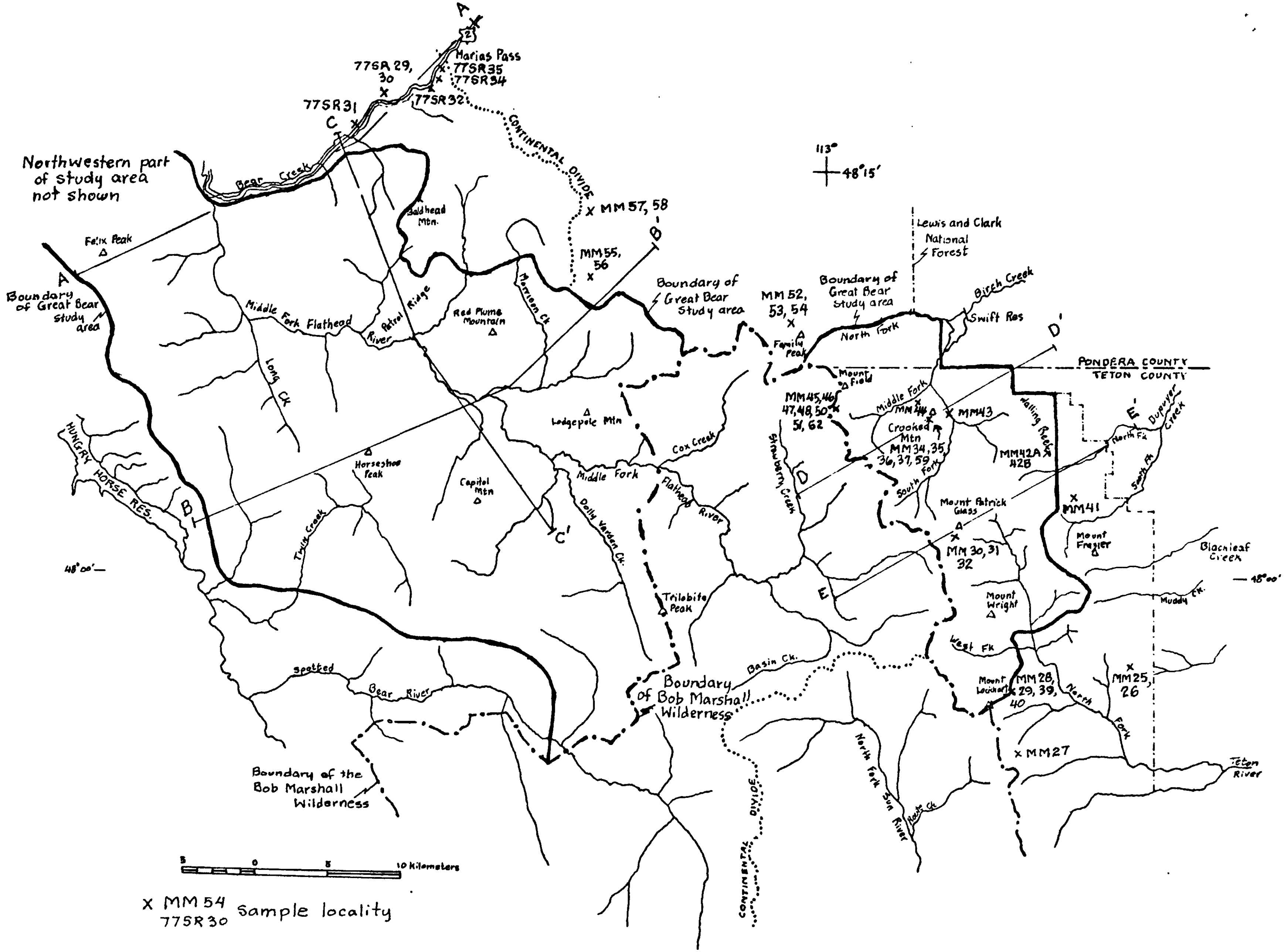


Figure 2.--Index map of the Great Bear wilderness study area in northwestern Montana.

Line sections shown on figures 10 and 11.

the arch (fig. 3). It contains numerous highs, with as much as 1,400 ft (425 m) of 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, and the presence of numerous fields with vast reserves of gas and minor amounts of oil in the Alberta disturbed belt to the north suggest that the disturbed belt of northwestern Montana is a potentially important oil and gas province. The significant fields in Canada (fig. 4) contain ultimate reserves totaling 6 Tcf (Trillion cubic feet) of gas. The structure, stratigraphy, and geologic history of these fields are similar to geologic conditions identified in the disturbed belt of northwestern Montana (Mudge, Earhart, and Rice, 1977).

We wish to acknowledge the excellent cooperation of the Forest Service personnel from Lewis and Clark and Flathead Forests. D. D. Rice of the U.S. Geological Survey collected the samples along U.S. highway 2 and assisted in the measurement of some of the sections.

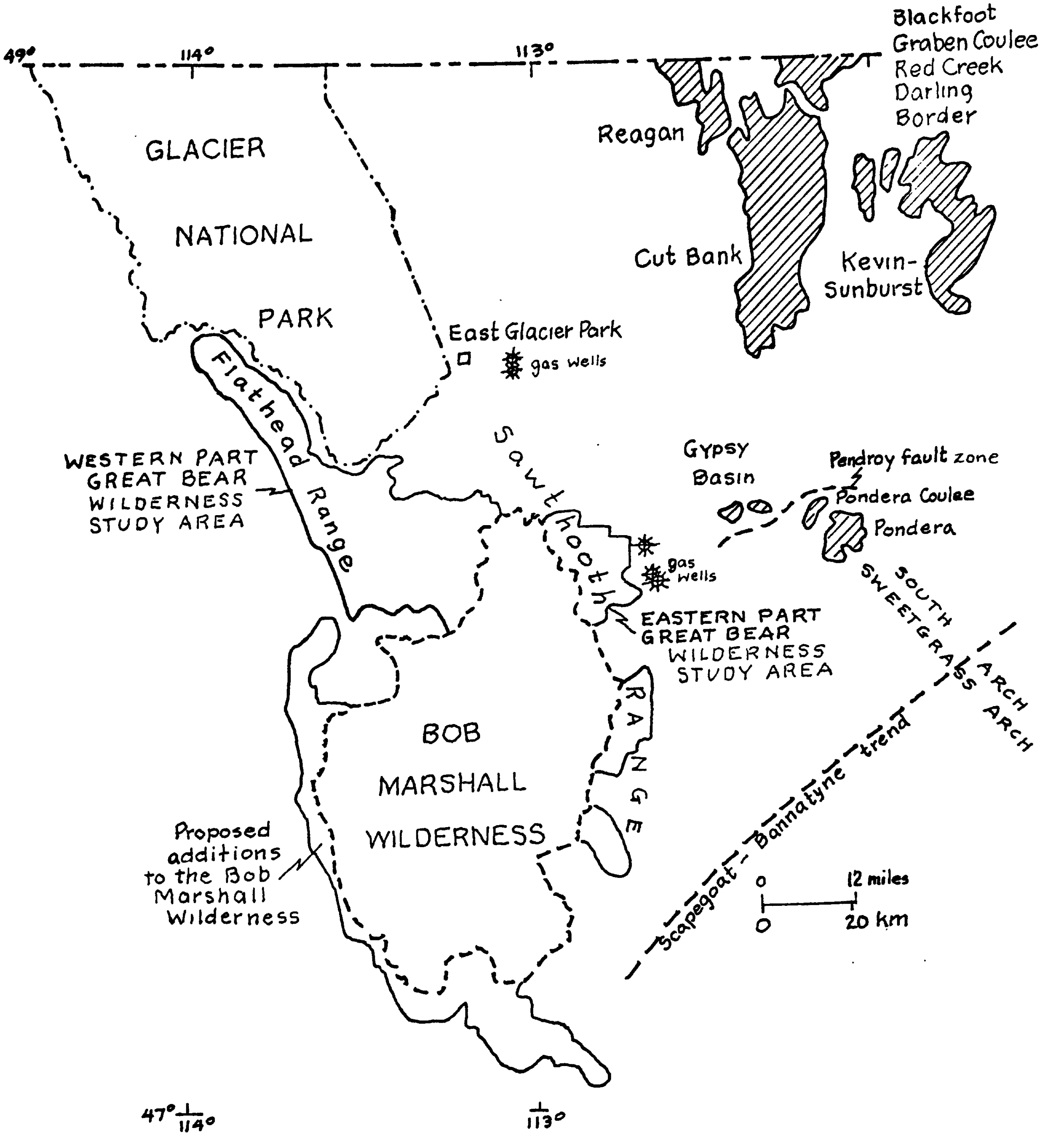


Figure 3.--Map of a part of northwest Montana showing oil and gas fields (Hatchured) and structural features east of the Great Bear wilderness study area.

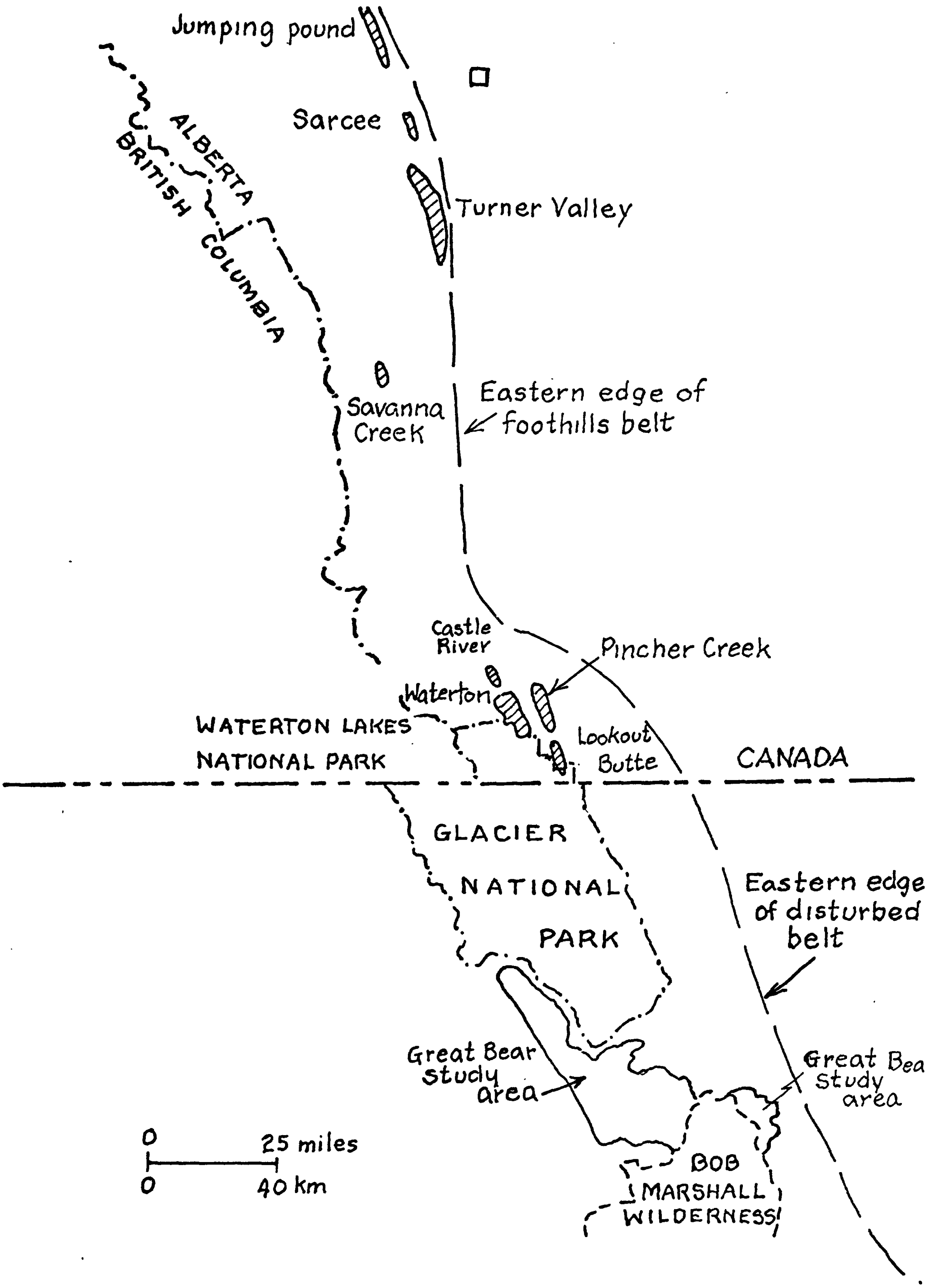


Figure 4.--Map of a part of southern Canada and adjacent Canada showing the location of gas fields (hatchured) in the Foothills of Alberta, Canada.

OUTCROPPING ROCKS

The outcropping rocks and structures in the proposed Great Bear study area are shown on figure 5. The stratigraphic units and their potential role as source and reservoir rocks for hydrocarbons are shown on table 1. The two parts of the proposed Great Bear study area differ geologically and therefore will be discussed separately as the eastern and western parts.

Eastern part.--The eastern part is in the Sawtooth Range and contains closely spaced thrust fault blocks of Paleozoic and Lower Mesozoic rocks. The Paleozoic rocks are carbonates of Cambrian, Devonian, and Mississippian ages. Only the upper three Cambrian formations shown on table 1 crop out in the area. They are at least 600 ft (185 m) thick and consist of thin bedded, gray-brown limestone interbedded with shale that is overlain by a dark gray mudstone and thick, light-gray dolomite. The Devonian rocks are about 1,000 ft (305 m) and consist of dolomitic mudstone in the lower part overlain by thin to thick beds of gray- to gray-brown fetid limestone and dolomite. These strata are overlain by thick beds of porous breccia with some interbedded dolomite. The top of the sequence is thinly bedded siltstone with a 3.0 ft (1.0 m) bed of very dark shale. The shale, referred to as the Exshaw, is locally omitted by thrust faulting.

The Mississippian rocks in the area, which are the primary hydrocarbon reservoir rocks on the Sweetgrass Arch to the east (Chamberlain, 1955) and in Alberta to the north (Gordy and Frey, 1977), are at least 1,400 ft (430 m) thick. In the study area they consist of very thinly bedded dark gray limestone with interbedded shale in the lower part overlain by thin- to thick-bedded, medium gray chert-bearing limestone that grades upward into

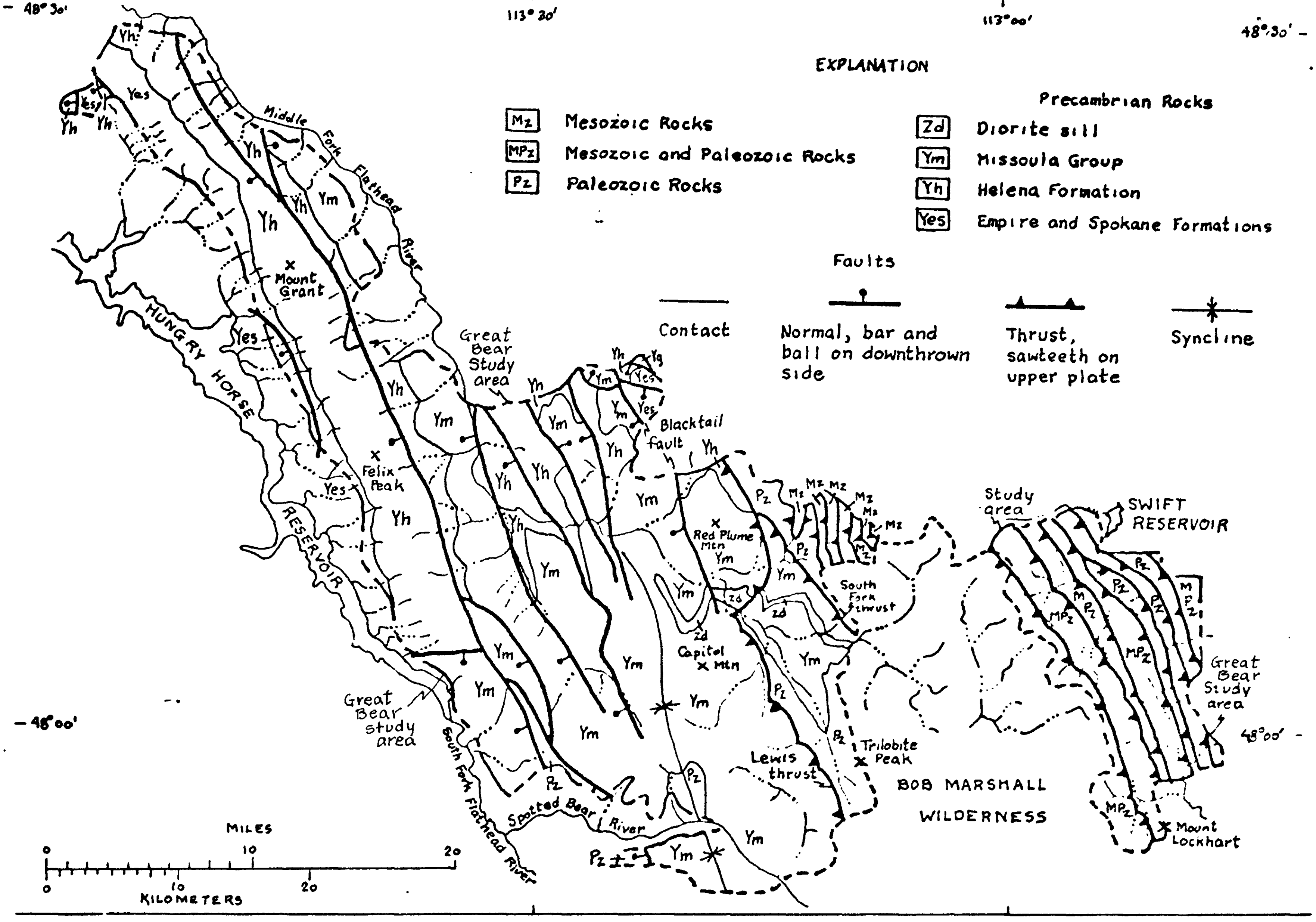


Figure 5.--Generalized geologic map of the Great Bear wilderness study area.

TABLE 1.–Sedimentary rock units

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	Unnamed Fm. ✱ Ⓡ
		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 ✱

Ⓡ Hydrocarbon reservoir rock; Ⓢ Hydrocarbon source rock; and
✱ Rocks outcropping in the study area

TABLE 1.- Sedimentary rock units

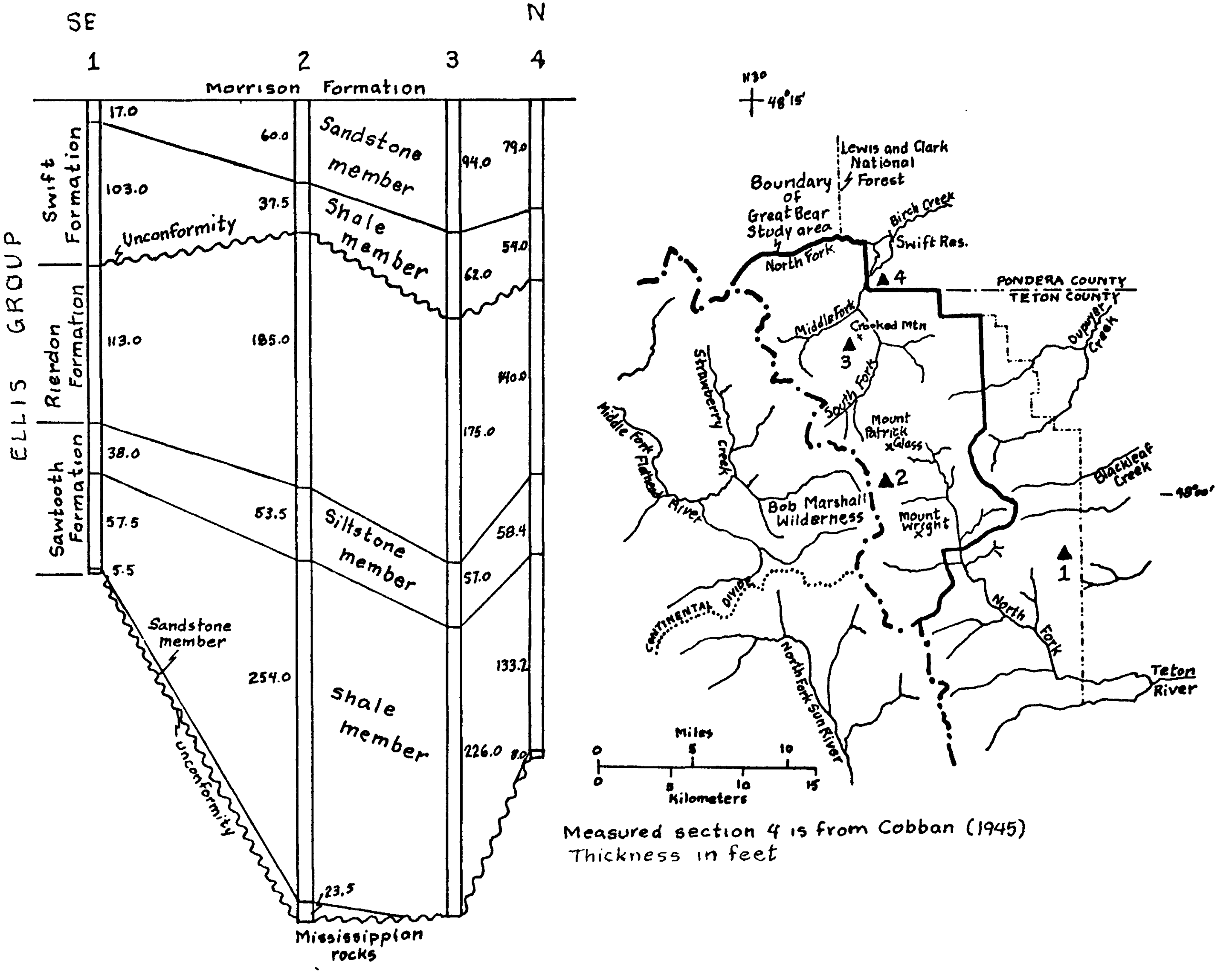
Cambrian	Upper Cambrian	Devils Glen Dolomite *
		Switchback Shale *
	Middle Cambrian	Steamboat Limestone *
		Pentagon Shale *
		Pagoda Limestone *
		Dearborn Limestone *
		Damnation Limestone *
		Gordon Shale *
		Flathead Sandstone *
Precambrian Y	Belt Supergroup	Garnet Range Formation
		Mc Namara Formation *
		Bonner Quartzite *
		Mount Shields Formation *
		Shepard Formation *
		Snowslip Formation *
		Helena Dolomite *
		Empire Formation *
		Spokane Formation *
		Greyson Formation *

*, Rocks outcropping in the study area

relatively thick-bedded dolomitic limestone. Beds of crinoidal debris are at several horizons in the middle and upper parts. Oil residue is locally present at and near the top of the Mississippian rocks.

The outcropping Mesozoic rocks are the marine Ellis Group and the nonmarine Morrison and Kootenai Formations which are overlain by the lower member of the Blackleaf Formation. The Ellis Group is over 600 ft (183 m) thick in the study area, twice as thick as it is a few kilometers to the south. It consists of three formations, which are, in ascending order: the Sawtooth, Rierdon, and Swift. The thickness of these formations and their members in the study area are compared with that in sections in adjacent areas to the east on figure 6. The shale member of the Sawtooth Formation is a very dark gray marine shale more than 255 ft (77 m) thick. From the study area it thins to the east and south (fig. 7). It is about 17 ft (5 m) thick in the southern part of the Sawtooth Range to the south. It ranges in thickness from less than 10 ft to 45 ft (3 to 18 m) thick in the subsurface near Cut Bank, Montana, to the northeast (Cobban, 1945, p. 1273).

Oil impregnated, dark gray thinly bedded, very fine-grained sandstone, 5.5 ft (1.6 m) thick, in the lower part of the member about one mile south of Mount Patrick Glass (section 2, fig. 6) is about 18 ft (5 m) above the base of the unit. A coquina, about 20 ft (6 m) thick, and about 25 ft (8 m) above the base of the shale member at the head of the Middle Fork Birch Creek, has a distinct petroliferous odor on a fresh surface.



Measured section 4 is from Cobban (1945)
Thickness in feet

Figure 6.--Measured sections of the Ellis Group (Jurassic) in and near the eastern part of the Great Bear wilderness study area.

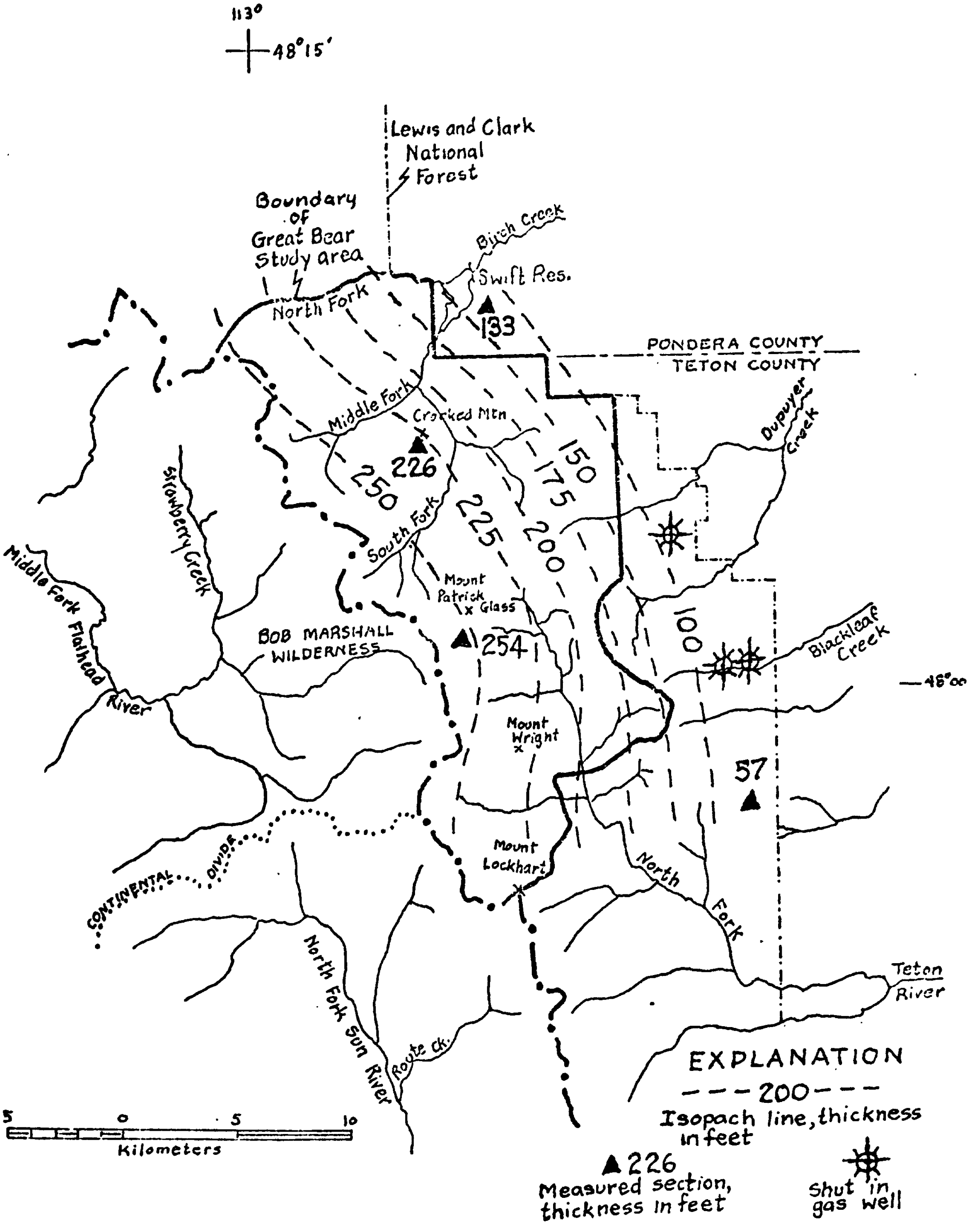


Figure 7.--Isopach map of the shale member of the Sawtooth Formation in the eastern part of the Great Bear wilderness study area.

The Rierdon Formation, a gray calcareous marine mudstone, attains its maximum thickness of 185 ft (56 m) in the eastern part of the study area (figs. 6 and 8); it thins to 140 ft (43 m) to the east at Swift Reservoir, and to 136 ft (41 m) to the south in Rierdon Gulch, a tributary of the Teton River. The Rierdon is considered the main source rock for the hydrocarbons in the oil and gas fields of the Sweetgrass Arch to the east (Leskela, 1955; Rice, 1977).

The Lower Cretaceous Kootenai and unnamed formations contain units that are lithologically and stratigraphically equivalent to the reservoir rocks in the producing oil and gas fields in the vicinity of Cut Bank, Montana, to the northeast. The lower unnamed formation contains the Cut Bank sand and Moulton zone described by Cobban (1955) in the subsurface of that area. The formation ranges in thickness from 160 ft (49 m) south of the study area to more than 300 ft (92 m) in the area (fig. 9). It rests unconformably on mudstone of the Jurassic Morrison Formation.

In the eastern part of the study area the unnamed formation contains a basal sandstone unit (Cut Bank sand) that ranges in thickness from about 30 to 100 ft (9 to 30 m). It is very coarse to medium 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 unnamed formation consists of variegated mudstone with interbedded sandstone. 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,"

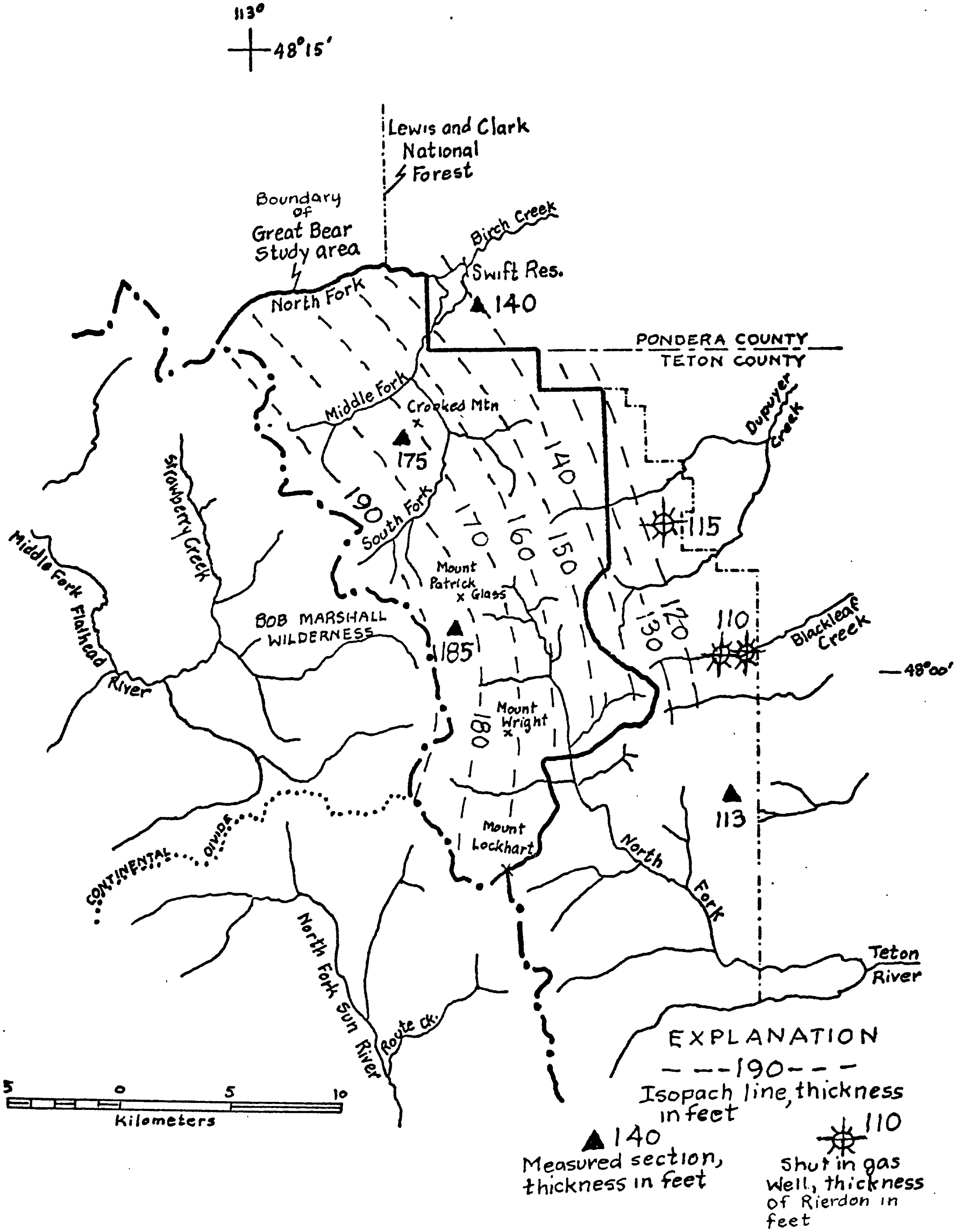


Figure 8.--Isopach map of the Rierdon Formation in the eastern part of the Great Bear wilderness study area.

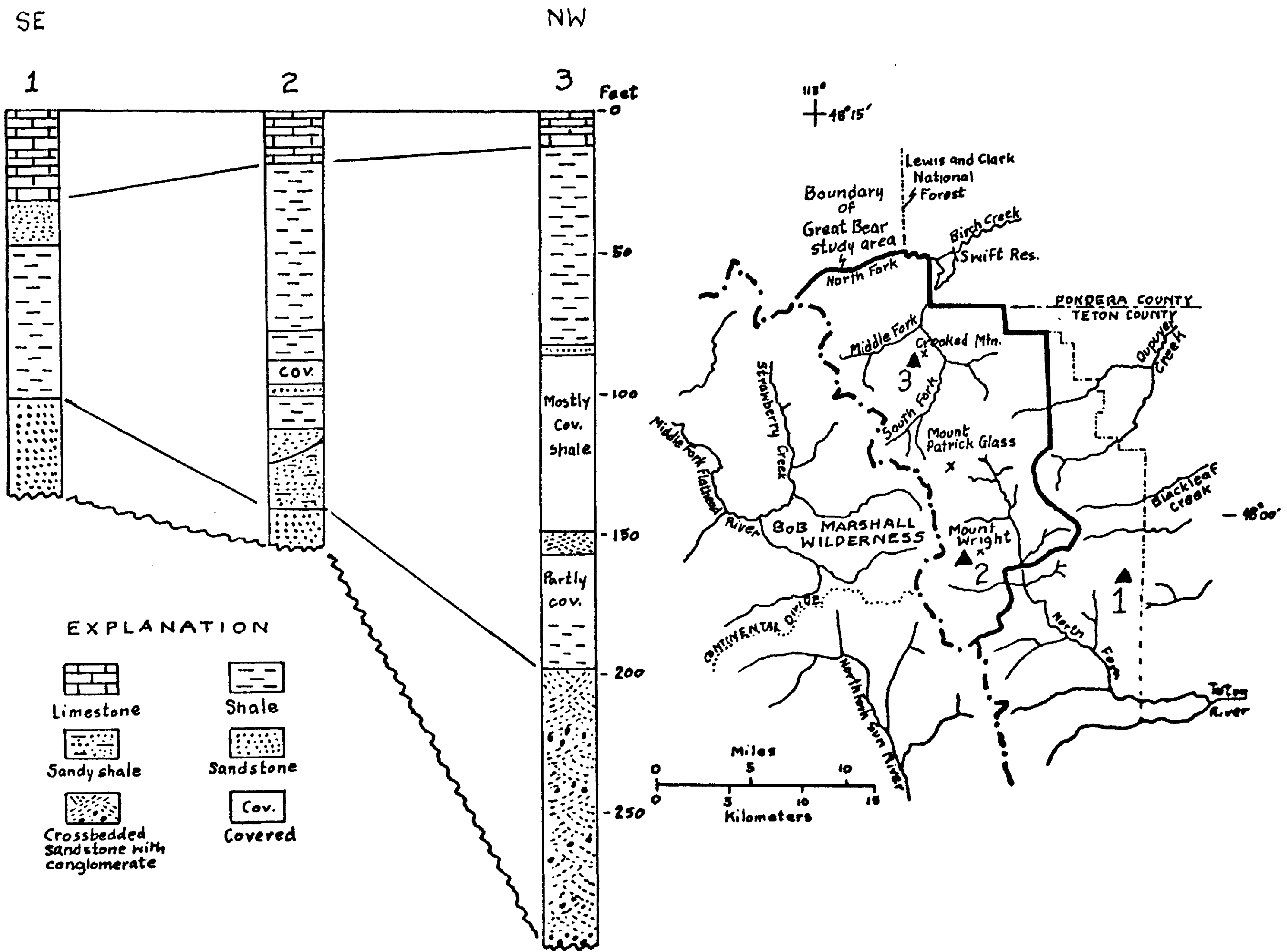


Figure 9.--Measured sections of the Lower Cretaceous unnamed formation in the eastern part of the Great Bear wilderness study area.

lies about 40 to 60 ft (12 to 18 m) above the basal sandstone unit. It is 8 ft (2 m) to almost 20 ft (6 m) of coarse to fine grained medium gray to gray brown cross-bedded sandstone.

The Kootenai Formation ranges in thickness from 650 to 1,000+ ft (198 to 305+ m). It consists of gray-green and maroon mudstone with numerous poorly sorted, greenish gray sandstone beds that are loally cross-bedded and contain lenticular basal conglomate s (Mudge and Sheppard, 1968). The "Sunburst sandstone," a hydrocarbon reservoir rock in the Kootenai in the oil and gas fields of the Kevin-Sunburst Dome to the northeast, was not recognized in the study area.

Western part--The outcropping rocks in the western part are mostly formations of the Precambrian Y Belt Supergroup (table 1). Paleozoic rocks are in the southern part of the area and Mesozoic rocks in the eastern part (fig. 5). A thick Precambrian diorite sill is in the east-central part.

The Precambrian rocks are in the Lewis and South Fork thrust plates. The Lewis plate ranges in thickness from 0 on the east to about 10,000 ft (3,050 m) at the Middle Fork of the Flathead River east of Felix Peak and to more than 17,000 ft (5,185 m) at the crest of the Flathead Range. The aggregate thickness of the formations in the Lewis plate is more than 16,000 ft (4,880 m) in the east to as much as 27,000 ft (8,235 m) in the west, whereas those in the South Fork thrust plate are about 4,200 ft (1,281 m). The South Fork thrust plate is as much as 5,000 ft (1,525 m) thick in the southeast corner of the area where it includes Cambrian rocks.

The Precambrian units are mostly reddish brown and greenish gray argillite and siltite with some quartzite except for the Helena and Shepard Formations which are mostly carbonate rocks.

The Paleozoic rocks are mostly carbonate units of Cambrian, Devonian, and Mississippian ages that represent a somewhat deeper water marine facies than the Paleozoic rocks in the eastern part of the study area.

Mesozoic rocks along the east side of the western part of the study area include the Kootenai Formation and the Flood Member of the Blackleaf Formation. The Kootenai thickens from 650 ft (198 m) to as much as 1,000 ft (305 m) in the western part of the study area. The Flood Member of the Blackleaf Formation is a dark-gray, marine fissile shale with a moderately thick sandstone unit in the upper part and in places a thin sandstone unit in the lower part. The member ranges in thickness from 130 to 300 ft (39-91 m).

STRUCTURE

The study area is structurally complex. The predominant structures in the eastern part are closely spaced thrust faults (figs. 5 and 10), whereas those in the western part are normal faults and broad open folds in the Lewis thrust plate (figs. 5 and 11). Two periods of structural deformation occurred in the area; both are important to the petroleum evaluation. The structures exposed on the surface are a result of an early Tertiary orogeny. These are superimposed on pre-existing structures that formed in Late Cretaceous or very early Tertiary, and may reflect structures formed during or soon after Precambrian time.

The eastern part of the study area contains closely spaced westerly dipping thrust plates to the east and folded thrust plates to the west (fig. 10). The southeast part of the area lies in the structurally high part of the disturbed belt (Mudge, Earhart, and Rice, 1977). The high area may reflect a southwesterly trending structural discontinuity in the crystalline basement rocks that extends from the Pendroy Fault, southwest through the mountain front in the upper reaches of Blackleaf Creek and in the southern part of the study area. The three wells containing gas shown on figure 3 are on the high area. Folds plunge northwest and south from the structural high (Mudge, Earhart, and Rice, 1977).

The traces of structures in the eastern part of the study area form a convex pattern that extends farther northeast than those north and south of the area as is evident on the geologic map by Mudge, Earhart, and Rice (1977). Along the eastern border of the study area, Mississippian, Jurassic, and Cretaceous rocks have been thrust over northwest plunging folds (fig. 10). 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. The westernmost plates are in a folded thrust zone that extends northwest along the eastern part of the Bob Marshall Wilderness (fig. 10).

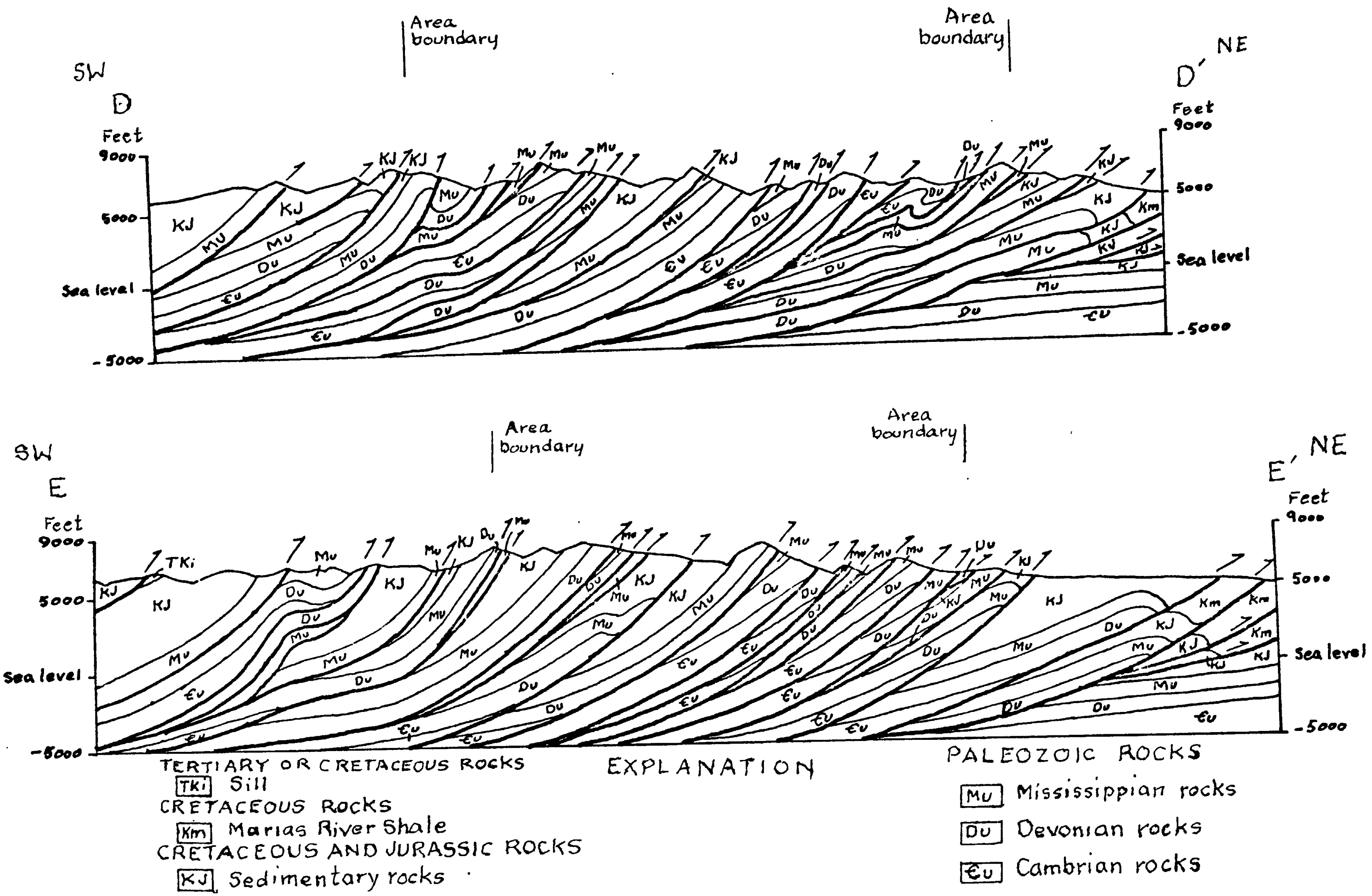


Figure 10.--Geologic cross sections through the eastern part of the Great Bear wilderness study area. Line of sections shown on figure 2. Arrows show direction of movement on faults.

The western part of the study area contains normal fault blocks and folds that comprise the Lewis thrust plate (figs. 5 and 11). The ridges in the eastern half of the area are at about the same elevation--between 7,200 and 7,500 ft (2,200-2,300 m). Older rocks comprise the ridges to the north, whereas younger rocks comprise them to the south.

In the area between U.S. Highway 2 and the northern boundary of the Bob Marshall Wilderness, two southwest trending lineaments formed by aligned topographic, and in part, structural features are evident on LANDSAT photographs. One lineament extends southwest into the area, south of U.S. Highway 2, in the vicinity of Baldhead Mountain; the other extends southwest through the area of Red Plume Mountain.

Structural changes on or near the lineaments and the interpretation of these structures are critical to the petroleum evaluation as they appear to represent paleofeatures that formed prior to the early Tertiary faults and folds. Pre-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).

The Lewis thrust dips at a low angle to the west (fig. 11) and along its outcrop to the east it cuts across many thousand feet of strata. West of Trilobite Peak the Lewis rests on Upper Mississippian strata. To the north it gradually cuts down through those strata as well as all Devonian and Cambrian strata. East of Red Plume Mountain the Lewis thrust abruptly cuts up section in its plate--omitting more than 6,000 ft (1,800 m) of strata. In the same area, the Lewis cuts out strata of the South Fork thrust plate. To the east, the erosion of folded Paleozoic rocks in a thrust plate has exposed a fenster of lower plate Mesozoic rocks.

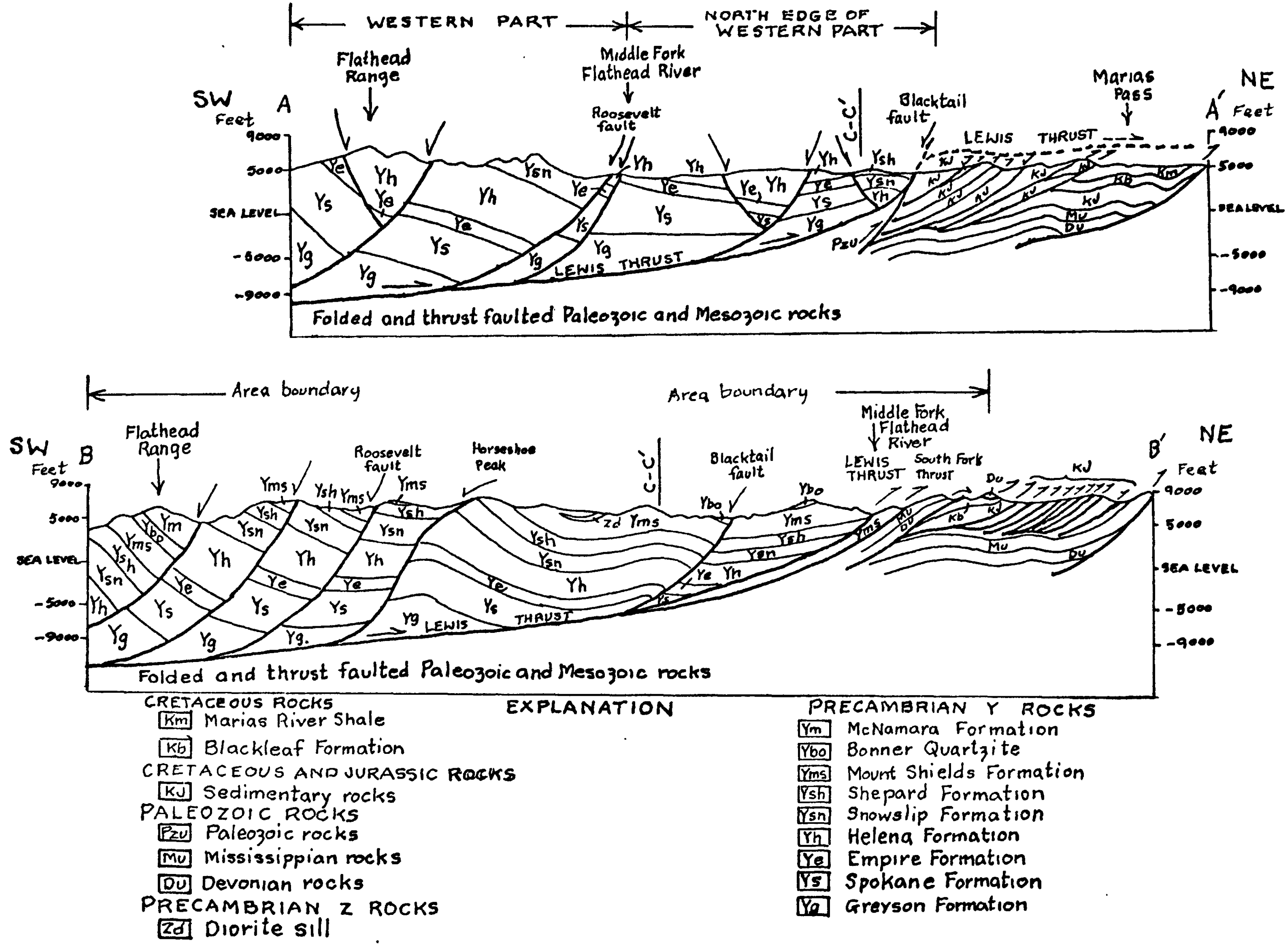


Figure 11.--Geologic cross sections in the western part of the Great Bear wilderness study area. Line of sections shown on figure 2. Arrows show direction of movement on faults.

The northwest trending normal faults in the area are listric and antithetic faults. The listric faults are interpreted to connect at depth with the Lewis thrust (fig. 11). This interpretation is supported by the presence of the easterly dipping antithetic faults that formed during the downward movement of the listric faults. Most of the normal faults originate in the southern part of the study area, and their stratigraphic displacement increases northwestward. The Blacktail fault, for example, originates south of Red Plume Mountain, but according to Childers (1963, p. 159) it has about 14,000 ft (4,270 m) of stratigraphic displacement at the north edge of the study area. The fault extends to the north into Alberta where it is called the Flathead fault by Bally, Gordy, and Stewart (1966, p. 355) who interpret it to be a listric fault. Childers (1963, p. 162) noted, in the vicinity of Baldhead Mountain, the normal faults are deflected from northwest to almost east-west. In this zone of deflection he (1963, p. 162) 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 simplified southwest to northeast cross sections (fig. 11) give a third dimension concept of the structural features, but without seismic or drill hole data they provide little insight as to the nature of the southwesterly trending lineaments at depth. An interpretation of the structure in the Paleozoic and Mesozoic rocks beneath the Lewis plate is tenuous due to the lack of seismic data.

The longitudinal section (fig. 12) aids in the interpretation of the lineaments at depth. The Lewis plate contains southeast-facing monoclines at depth that very likely reflect structures formed prior to the easterly translation of the Lewis plate.

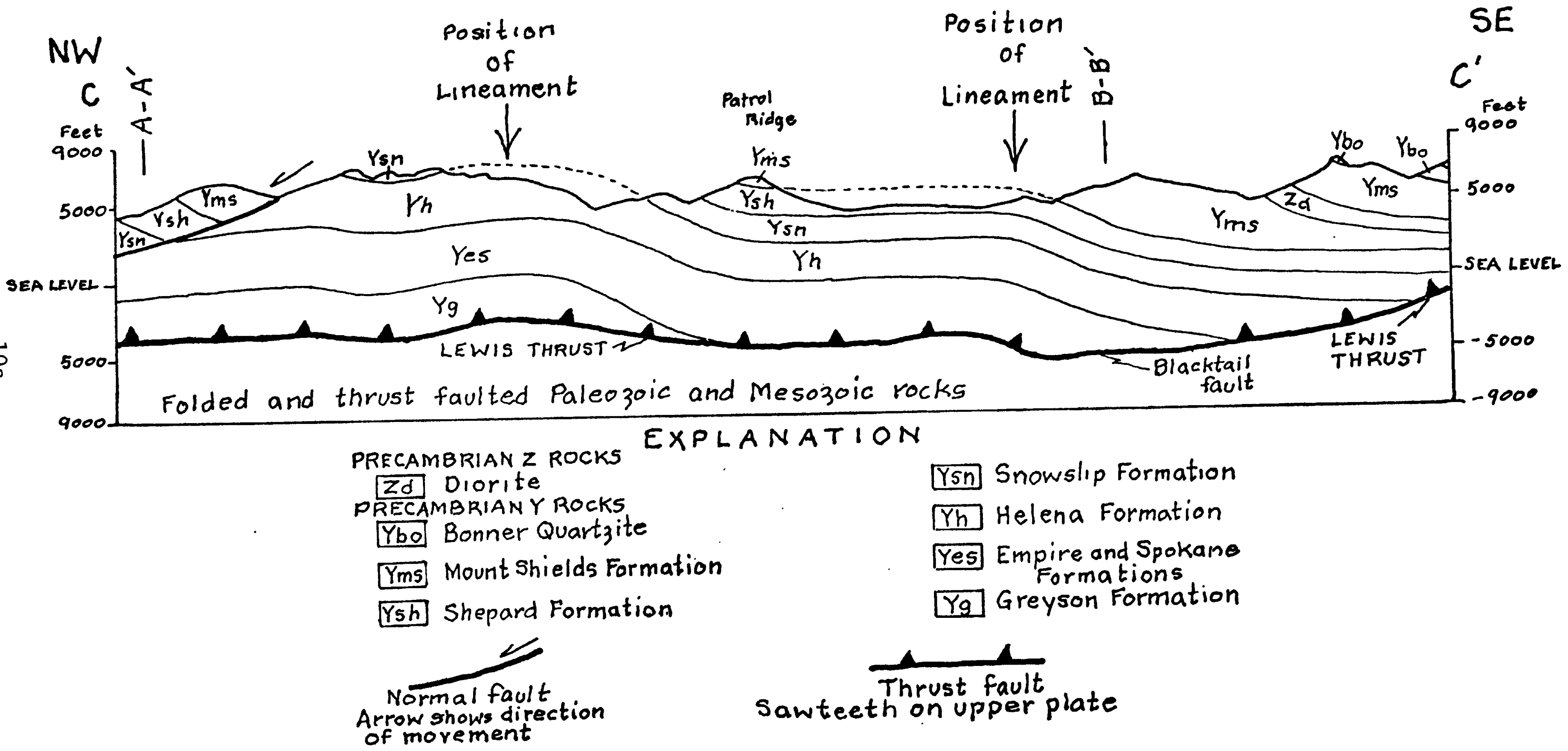


Figure 12.--Geologic longitudinal section in the western part of the Great Bear wilderness study area. Line of section shown on figure 2. Point of intersection on Cross section A-A^1 and B-B^1 shown on figure 11.

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 (1955) 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. The strike-slip movement doesn't appear to affect the Early Mesozoic paleo-environment, but it may reflect vertical movement on basement faults which in turn controlled basement configuration.

OIL AND GAS EVALUATION

The potential for discovery of oil and gas, mainly gas, is very good for most of the Great Bear study area. Excellent source, reservoir, and cap rocks are present in the area. Surface mapping of structures suggest that subsurface features favorable for hydrocarbon accumulation may be at depth, but they cannot be determined without seismic surveys.

The mountainous part of the disturbed belt of Montana is essentially unexplored for hydrocarbons. The belt contains the eastern part of the Bob Marshall and Scapegoat Wildernesses and some of the proposed wilderness study areas, the Great Bear wilderness study area, the Tuchek-Mt. Thompson Seton wilderness study area, and Glacier National Park. Seismic studies have not been conducted in any of these areas.

Successful gas exploration has been conducted a few kilometers east of the eastern part of the Great Bear Study area. The wells are shown on figure 3 and their rates of flow are shown on table 2. These wells have not produced gas as they were drilled in the 1950's and were shut-in or abandoned because the region was too remote and the price of gas was too low for profitable production (Mudge, Earhart, and Rice, 1977). These wells along with the two wells east of East Glacier Park are capable of producing 6.3 million cubic feet of gas per day (MMCFD). Numerous dry holes east of the wells in Blackleaf and Dupuyer Creeks missed the gas-bearing reservoir and therefore indicate that the area of greatest hydrocarbon potential is westerly from the wells containing gas.

Table 2.--Shut-in gas wells in the northern disturbed belt of Montana

(from Rice, 1977, table 8)

Name	Location	Producing formation and depth	Initial potential flow
Northern Natural gas 1 Blackleaf - Federal "B"	NE¼ SW¼ 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"	SE¼ NE¼ 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	SW¼ SW¼ 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	SW¼ SW¼ 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	SE¼ NW¼ 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.

The configuration of potential gas fields in the area will very likely be linear in a northwest direction, based on the configuration of gas fields in the Foothills of Alberta and from the structural setting in the study area. In the eastern part of the study area the northwest plunging folds and drill hole data along the east side of the mountains indicate the leading edge of Mississippian rocks in a thrust block at depth will trend more northwest than the trend of the surface structures. Therefore, here, the linear trend of a field will be more northwesterly than the trend of the surface structures.

Hydrocarbon source rock evaluation.--Forty-two outcrop samples from in and near the Great Bear wilderness study area were analyzed for purposes of petroleum source rock evaluation. The results suggest that the organic matter in rocks of Jurassic and Lower Cretaceous age had the capacity for generating large volumes of natural gas. Burial of these rocks beneath thrust plates provided sufficient overburden to elevate temperatures that would have generated significant amounts of gas at a time favorable for entrapment. The results also suggest that oil occurrences from these same rocks will probably not be found in reservoir rocks in the study area. Therefore, paleotemperatures were sufficiently high to have resulted in the destruction of oil with consequent generation of rich gas. However, possible thermally mature oil-source rocks of Upper Cretaceous age are present in the western part of the study area, and oil generation in the area may have occurred when these rocks were deeply buried by thrust plates with thick rock sequences.

The analysis of the samples are shown on Table 3 and the location of the samples is shown in figure 2. Organic carbon content was measured by a direct, wet oxidation technique (Bush, 1970). Thermal evolution

Table 3, Organic carbon and thermal evolution analysis of outcrop samples (See fig. 3 for location of samples except for sample 77SR33 which is from about 2 miles east of Marias pass)

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						
77SR35	Grab	2.54	0.37	570	14.6	486
Ferdig Member						
77SR34	Grab	0.79	0.062	71	7.8	498
Cone Member						
77SR33	Grab	1.84	0.094	34	5.1	488
LOWER CRETACEOUS FLOOD MEMBER, BLACKLEAF FORMATION						
77SR32	Grab	0.81	0.086	74	10.6	504
77SR28	Grab	1.08	0.056	43	5.2	479
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
77SR31	Grab	0.85	0.044	54	5.2	512
MM56	50′	1.28	0.17	71	13.2	476
UPPER JURASSIC SHALE MEMBER, SWIFT FORMATION						
MM58	60′	0.75	0.044	40	5.9	496
77SR30	Grab	0.65	0.032	32	4.9	500
MM50	lower 30′	0.70	0.036	39	5.1	500
MM51	upper 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
UPPER JURASSIC RIERDON FORMATION						
MM57	upper 80′	0.62	0.070	67	11.3	494
77SR29	Grab	0.24	0.104	140	43.3	494
MM47	lower 100′	0.34	0.017	19	5.0	502
MM48	upper 30′	0.61	0.045	54	7.4	502
MM36	175′	0.24	0.013	22	5.4	516
MM29	125′	0.24	0.010	13	4.2	504
MM26	113′	0.31	0.010	14	3.2	506
MM31	175′	0.30	0.008	8	2.7	520
MIDDLE JURASSIC SHALE MEMBER, SAWTOOTH FORMATION						
MM55	Grab	0.60	0.096	57	16.0	488
MM25	57′	0.41	0.020	38	4.9	492
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
MM62	lower 5′	0.92	0.053	84	5.8	502
MM35	220′	0.51	0.021	50	4.1	498
MM46	upper 80′	0.40	0.017	22	4.3	500
MM45	lower 75′	0.62	0.031	56	5.0	502
MM34	lower 5′	2.68	0.14	88	5.2	506
MM44	lower 50′	0.61	0.017	56	2.8	506
MM28	upper 20′	0.36	0.012	16	3.3	504
MM59	lower 10′	1.92	0.12	101	6.3	508
LOWER MISSISSIPPIAN LOWER MEMBER, ALLAN MOUNTIAN LIMESTONE						
MM27	20′	0.44	0.010	13	2.3	—
MM53	65′	1.27	0.023	20	1.8	560
DEVONIAN THREE FORKS FORMATION (Exshaw shale)						
MM52	Channel 3′	6.57	0.030	18	0.5	580
(Siltstone)						
MM54	Grab	0.16	0.002	7	1.3	—
CAMBRIAN SWITCHBACK SHALE						
MM43	100′	0.08	0.002	5	2.5	—

analysis employing a flame ionization detector (TEA-FID) was carried out in the manner described by Claypool and Reed (1976), except that the response of the flame ionization detector was calibrated by analysis of known amounts of eicosane ($n\text{-}C_{20}H_{42}$) coated at 4.24 percent on alumina. In this analysis the rock is heated at 40°C/min. from 50 to 700°C and the hydrocarbons evolved are quantitatively measured.

The samples were collected from exposed rock at depths of four to six inches. Based on previous studies (Leythaeuser, 1971; Clayton and Swetland, 1976) we know that the organic content of samples collected in this manner may have been reduced to as little as one-half the amount in equivalent unweathered rocks. Moreover, this loss of material may be selective for hydrocarbons or hydrocarbon precursors. In addition, the samples analyzed were for the most part composites representative of a greater thickness of each rock unit. Accordingly the organic content measurements obtained are average values in which the contribution from darker, high-grade intervals has been lowered by inclusion of lighter-colored organic-lean intervals, in approximate proportion to their thickness in the section represented by the sample.

Three properties are important for the evaluation of sedimentary rocks as possible source rocks of petroleum: (1) percent organic matter present, (2) organic matter type, and (3) burial and temperature history, or thermal maturity of organic matter. The combination of organic carbon and TEA-FID analyses permits preliminary evaluation of these properties.

These properties are important because hydrocarbons are generated from certain types of organic matter in sedimentary rocks under the influence of increased temperature and time, most commonly brought about by deep burial. Given sufficient amounts of the right type of organic matter, temperature history is the critical factor. Rice (1977) discusses three stages of thermal maturity: 1) immature sedimentary rocks are capable of generating only bacterial methane; (2) mature sedimentary rocks are capable of yielding both oil and gas; (3) post-mature sediment rocks are commonly associated with the occurrence of natural gas because organic matter continues to generate methane after oil generation has stopped, and because liquid hydrocarbon compounds formed during earlier stages can be converted to methane gas when subjected to higher temperatures.

Organic carbon in shales is a measure of the amount of organic matter deposited and preserved in the rock. Type of organic matter, in terms of capacity to generate hydrocarbons, is indicated by pyrolitic hydrocarbon yield. The amount of hydrocarbons already generated and present in the rock is indicated by the volatile hydrocarbon content. Thermal maturity of 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 types of organic matter and thermal maturity.

Results of these analyses are given in Table 3 for samples from the proposed Great Bear wilderness area. Before consideration of these results, example analyses of "typical" source rocks are shown in Table 4. These are rocks generally considered to be important petroleum source

Table 4, 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	$\frac{\text{Pyrolytic hydrocarbon}}{\text{Organic carbon}}$ %	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

rocks in the Rocky Mountain region. The Devonian Bakken Shale is exceptionally rich in organic matter, and geochemical evidence indicates that this rock is the source of the oil in Mississippian rocks in the Williston Basin in eastern Montana (Williams, 1974). The Phosphoria Formation is a widespread rock unit of Permian age which is believed to be the source of the oil in upper Paleozoic rocks of western Wyoming (Sheldon, 1967; Stone, 1967). The Frontier Shale has only average organic richness (in the case of the particular sample shown in table 4) but it is reputed to be a major contributor to oil occurrences in rocks of Cretaceous age in the Powder River basin (Hunt, Jamieson, 1956). The Graneros Shale is likewise a major source for oil in the Denver basin (Clayton and Swetland, 1977). The Pierre Shale may have significance as a source rock for fracture shale accumulations, and is not presently a major contributor to oil occurrence in the Denver basin (Swetland and Clayton, 1976).

The analyses in Table 4 are presented for comparison with analyses of rock samples from the study area, given in Table 3. In addition to providing some feeling for the significance of the values reported, these "known" petroleum source rock units have stratigraphic equivalents in the study area, except for the Phosphoria Formation. These analyses of the Phosphoria Formation are included because they demonstrate that reliable results can be obtained by analysis of outcrop samples; and because they illustrate the effects of degree of thermal maturity, as indicated by combined organic carbon/TEA-FID analyses. As shown on Table 4, the original organic richness of the Phosphoria Formation was variable as indicated by the organic carbon content. The principal effects of increasing maturity are to decrease the pyrolitic hydrocarbon yield relative to organic carbon content (from 43 to 1 percent), and to increase the temperature of maximum pyrolysis yield (from 453 to 570°C).

In comparison with the typical oil source rocks shown in Table 4, the samples from the proposed Great Bear wilderness area (with a few exceptions) are generally lower in organic content. Moreover, the organic matter present in most of these rocks is not of the type which can be converted to liquid hydrocarbons upon pyrolysis. There are three possible reasons why the organic matter in these rocks does not generate significant liquid hydrocarbons when heated: (1) because of the original composition of the organic matter (i.e., woody plant material), (2) because of high thermal history due to deep burial or some other cause, (3) because of extreme effects of weathering at the outcrop.

Of the three possibilities, the second, high thermal history, is the most likely explanation for the generally low pyrolitic hydrocarbon yields. This interpretation is supported by the temperatures of maximum pyrolysis yield which are consistently near or above 500°C. In addition, it is likely that weathering has reduced the organic content somewhat, compared to equivalent rock units in the subsurfaces.

These results suggest that the potential for generation of liquid hydrocarbons from possible source rocks of pre-upper Cretaceous age in the proposed Great Bear wilderness area has largely been spent, probably prior to the Early Tertiary orogeny. If this is the case, then it is unlikely that any major oil accumulations generated from source rocks of Lower Cretaceous or older age will be found in reservoir rocks in the Lower Cretaceous and older part of the section in the proposed Great Bear study area.

This interpretation of a high thermal history due to subthrust burial is also 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 by burial beneath thrust plates.

However, it is not possible to completely rule out liquid hydrocarbon occurrence, because possible oil source rocks of Upper Cretaceous age are present near the northwest part of the study area (e.g., sample MM35). These rocks probably were thermally immature prior to thrusting. Additional sub-thrust burial might have caused these and similar Upper Cretaceous rocks to generate and expel liquid petroleum. If this coincided with the development of trapping structures in the conduit and reservoir beds in adjacent or overthrust parts of the section, oil occurrences could have developed.

Sub-thrust burial of thermally immature source rocks of Upper Cretaceous age with consequent generation and expulsion of oil may have accounted for a liquid petroleum occurrence in the Swift Current Valley, discovered in the period 1902-1906 (Darrow, 1955). Production was from a depth of 500 feet, possibly from Virgelle Sandstone, or sandstones in the lower part of the Two Medicine Formation. The source of the oil was very likely from the Marias River Shale, which when "blanketed" by the Lewis thrust plate, became heated to a mature shale source bed.

Excluding the Upper Cretaceous Marias River Shale, the rest of the Mesozoic section is much more favorable for the occurrence of gaseous hydrocarbon deposits rather than oil. The organic matter in Mesozoic rocks of pre-Upper Cretaceous age still has the capacity for generating light hydrocarbons, especially methane. Burial of these rocks beneath thrust plates should have generated significant amounts of natural gas at a time favorable for trapping, because of simultaneous creation of structures associated with the faulting. Similar conclusions were reached by Rice (1977) in his evaluation of the petroleum potential of the Bob Marshall Wilderness and adjacent wilderness study areas.

In addition to the sample of the Kevin Member of the Marias River Shale (77SR34) mentioned above as an example of a mature possible oil source rock, other samples are also worth more detailed consideration. The sample of the Cone Member of the Marias River Shale analyzed in this study (77SR33) had an organic carbon content of 1.84 percent, which is above average for shales and more than adequate for consideration as a possible source rock. Rice (1977) reported the analysis of a sample of the Cone Member which had 4.90 percent organic carbon. Although the pyrolitic hydrocarbon yield reported in Table 3 for sample 77SR33 is not exceptionally high, other reports note that distillation tests on this same rock unit yielded between one and two gallons of oil per ton (Stebinger, 1918, p. 162). For average oil and rock densities this is equivalent to an oil yield of from 0.2 to 0.4 percent.

Seven samples of the Lower Cretaceous Flood Member of the Blackleaf Formation were analyzed. Only two samples have organic carbon content in excess of one percent (77SR28 and MM50). Pyrolitic hydrocarbon yields are generally low, ranging from 0.02 to 0.09 percent. An exception is sample MM56 which yields 0.17 percent hydrocarbons on pyrolysis and contains 71 ppm of volatile hydrocarbons. If this sample is more characteristic of the Flood Member in the subsurface, then Lower Cretaceous units may also be prospected for oil occurrence in the study area.

Analysis of samples of the Upper Jurassic Swift Formation from six localities indicates uniformly low hydrocarbon yields. Organic carbon contents are fairly high, ranging from 0.7 to 0.9 percent with one sample at 1.8 percent. Samples MM32 and MM37 have temperatures of maximum pyrolysis yield of 528 and 522°C, suggesting that the hydrocarbon generating potential of the organic matter in this unit has been reduced by burial metamorphism at these localities.

The eight samples of Upper Jurassic Rierdon Formation collected for this study have uniformly low organic contents, with a range of 0.24 to 0.62 percent organic carbon. Samples MM31 and MM36 have maximum pyrolytic yield temperatures of 520 and 516°C. These samples are from the same localities as the samples of the Swift Formation discussed above, and have likewise had their pyrolytic oil yield reduced by burial metamorphism. The possibility that these samples may not reflect the character of the organic matter in these rocks throughout the area is suggested by an analysis of the Rierdon Shale containing 1.51 percent organic carbon reported by Rice (1977), and by the analysis of sample 77SR29 reported in Table 3. Although the organic carbon content for this sample appears to be inadequate for consideration as a possible petroleum source rock, the pyrolytic oil yield relative to organic carbon, 43 percent, was the highest of any sample analyzed in this study. This sample also contained the highest content of volatile hydrocarbons. These findings may indicate that some hydrocarbon-generating potential remains in the Rierdon Formation at these localities.

The Middle Jurassic shale member of the Sawtooth Formation was the most extensively sampled unit in the present study. At the base of this unit, samples of the lower 5 to 10 feet (MM62, MM34, MM59) contained 0.92, 2.68, and 1.92 percent organic carbon. The pyrolytic oil yields for these samples are still high in comparison with most of the other rocks analyzed in this study, but have probably been reduced by a combination of original burial metamorphism and recent surface weathering. The lower part of the Sawtooth shale member may be the most important hydrocarbon source rock in the Mesozoic section as it is volumetrically extensive in the study area and is favorably situated with respect to conduit and reservoir beds. As shown on figure 6, the member attains its greatest thickness in the study area and it overlies Mississippian reservoir rocks.

The samples from the upper part of the Sawtooth Formation are more similar to the Rierdon and Swift Formations in their organic character. One particular grab sample (MM55) contains organic matter suggesting a more favorable (lower) temperature history at this locality, although at 0.60 percent the organic carbon content is only marginally adequate for consideration as a petroleum source rock.

The Paleozoic section is represented in this study by five samples: two samples of the Lower Mississippian Allen Mountain Limestone, two samples from the Devonian Three Forks Formation, and a single sample of the Cambrian Switchback shale. All of these samples show evidence of a more extreme high temperature history, and are metamorphosed to the point that they are essentially incapable of yielding additional hydrocarbons. The sample of Devonian Exshaw Shale (MM52), equivalent to the Bakken Shale in Table 4, contains about 6.6 percent organic carbon, and prior to metamorphism probably had 10 percent or more total organic carbon content. This organic matter has been metamorphosed to a stage approximately equivalent to anthracite coal rank, and may have experienced maximum depth of burial and its highest temperature at some time prior to thrusting, because of the apparent discontinuity in the estimate of thermal history between these Paleozoic rocks and the overlying Mesozoic units. If this is the case, then these Paleozoic units can probably be eliminated from consideration as possible source rocks for additional oil or gas. The analyses of Lower Mississippian Allen Mountain Limestone, especially sample MM53, suggest a burial and temperature history similar to that of the underlying Exshaw Shale. The organic carbon content of the Allen Mountain limestone is high for limestones (0.44, 1.27), especially considering that organic matter in carbonate rocks is typically converted to hydrocarbons with relatively high efficiency, and this portion of the original organic matter was removed from the rock at a much earlier stage. This interpretation of extremely high temperature history for Paleozoic rocks is based on temperatures of maximum pyrolysis yield of 560 and 580°C for two samples (MM52, MM53) from the same locality. Other samples of Paleozoic age contained insufficient pyrolyzable organic matter to give a distinct pyrolysis peak. The prospectiveness of Paleozoic rocks as hydrocarbon sources in this area depends on how representative these two samples are of regional character of organic matter in these units.

Reservoir rocks.--Numerous potential reservoir rocks in the study area are indicated on Table 1. Most of them should underly the eastern and western parts. All reservoir rocks appear to thicken westward and northwestward. The westward thickening is evident in Cambrian, Devonian, Mississippian, Jurassic, and Lower Cretaceous rocks. Cambrian rocks are not known as reservoir rocks in the region.

Potential reservoir rocks in the Devonian sequence are the Birdbear Member of the Jefferson and the Three Forks Formation. The Birdbear consists of thin irregularly bedded porous dolomite about 55 ft (16 m) thick in the eastern part of the study area. The Three Forks, about 200 ft (61 m) thick, consists of porous to cavernous evaporite-solution breccia with interbedded dolomite. Both units underly the study area and are capped by the black (Exshaw) shale.

The upper part (Sun River Member) of the Mississippian sequence is the main reservoir rock on the Sweetgrass Arch and in the Foothills of Alberta. The Sun River Member of the Castle Reef Dolomite, more than 350 ft (106 m) thick in the eastern part of the study area, is a light gray dolomitic limestone with some thick beds of porous coarse crinoidal debris. The rest of the underlying 490 ft (149 m) of the Castle Reef Dolomite also contains interbeds of coarse crinoidal debris 1 to 3 ft (30 cm to 1 m) thick. These rocks underly the study area and are capped by mudstones of the Sawtooth Formation--potential source rocks.

The Jurassic Swift Formation consists of an upper sandstone member and a lower shale member (fig. 6). The sandstone member was correlated with the "Ribboned" sandstone in the subsurface by Cobban (1955), which is a reservoir rock for oil and gas on the Sweetgrass Arch (Gribi, 1959).

In the eastern part of the study area, the sandstone member of the Swift attains a thickness of 94 ft (28 m) on the west side of Crooked Mountain; it thins to 60 ft (18 m) south of Mount Patrick Glass and to 17.0 ft (5 m) southeast of the area. It continues to thicken northwest from the east part to possible more than 100 ft (30 m). In the eastern part of the study area the Swift is overlain by 11.0 ft (3 m) to more than 35 ft (10 m) of mudstone of the Morrison Formation. Both of these units are in the subsurface of the study area. The thickness of Morrison mudstone above the Swift increases to the northwest from the eastern part of the study area.

The lower sandstone unit of the Lower Cretaceous unnamed formation, the Cut Bank sand, is a well known hydrocarbon reservoir rock in the subsurface near Cut Bank, Montana, where it is the main producing reservoir (Lynn, 1955). In the eastern part of the study area it is as much as 100 ft (30 m) thick (figs. 8 and 9). The unit is in the subsurface of the study area where it is capped by a mudstone sequence 25 to 40 ft (7-12 m) thick.

Another potential reservoir unit is a lenticular coarse to fine-grained cross-bedded 8 to 17 ft (2-5 m) thick, that overlies the above mudstone. This unit is referred to in the subsurface to the east as the upper Cut Bank sand or as part of the Moulton zone. The unit is overlain by more than 20 ft (6 m) of mudstone and it is present in the subsurface in the study area.

Other potential reservoir rocks include from two to five sandstone units in the Kootenai Formation that are from 25 ft (7 m) to 85 ft (26 m) thick. They yield hydrocarbons to the east (Rice and Cobban, 1977). The most widespread and thickest units are in the upper and lower parts of the formation. They are fine- to coarse-grained cross-bedded, and in places contain a basal conglomerate that ranges in thickness from about 1 ft (30 cm) to at least 50 ft (15 m) (Mudge and Sheppard, 1968). Where observed the conglomerate is always a channel-fill and is very lenticular in cross section. It consists of pebbles, and in places cobbles, that are in a coarse-grained sandy matrix. Two or more of these sandstone units are locally present in the subsurface in the study area, and are capped by variegated mudstones.

Sandstone units of the Blackleaf Formation and Marias River Shale have a low or unknown potential as reservoir rocks. A sandstone of the Flood Member of the Blackleaf Formation is as much as 35 ft (10 m) thick in the study area, and consists of fine- to medium-grained crossbedded sandstone (Rice and Cobban, 1977). It overlies a black shale that is a potential source for hydrocarbons and it underlies a 2 ft (61 cm) coal bed to the north and dark gray shales to the south (Rice and Cobban, 1977). The sandstone probably underlies part of the study area.

Sandstones of the Taft Hill Member are not considered potential reservoir rocks even though according to Rice (1977) they have produced gas in shallow wells to the east. The marine Taft Hill sediments are replaced by nonmarine sediments of the Vaughn Member to the north from the Sun River area (Mudge, Earhart, and Rice, 1977), and to the northwest from the Sweetgrass Arch (Rice and Cobban, 1977). Therefore, the sandstone units of either the Vaughn or Taft Hill are not extensive in the subsurface rocks of the study area.

The Ferdig Member of the Marias River Shale has a western sandstone facies that may be present beneath the Lewis thrust plate in the western part of the study area. This sandstone facies was studied in the western part of the Sun River area by Mudge (1972) where he correlated it with the Cardium Sandstone, a petroleum reservoir rock in Alberta. 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 part, and massive and somewhat crossbedded in the upper part. The unit 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. It is present in the eastern part of the study area. The Ferdig is overlain by thick dark gray shale of the Kevin Member.

Structural traps.--An accurate interpretation of structural traps in the subsurface cannot be made in this structurally complex area without the aid of seismic surveys and drill hole data. The importance of seismic surveys 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 ($79x10^9m^3$)."

According to Hurley (1959) three types of structural traps should be considered in hydrocarbon studies in the northern disturbed belt. Type 1 is the wedge-edge of Paleozoic rocks in thrust plates, and we would include also the wedge-edge of potential Mesozoic reservoir rocks in thrust plates. Type 2 is the drag folds formed as a result of thrusting and Type 3 is folding west of the zone of drag folding.

The structural trap most likely to be found in the study area will be Type 1; this type contains gas in the area of the shut-in wells in Blackleaf Creek and it is shown on figure 13 (Hurley, 1959). It is also the most common structural trap in the gas fields in the foothills of Alberta (Bally, Gordy, and Stewart, 1966). An example of these structures is shown on figure 14. The Waterton field in the southern Foothills belt of Alberta 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 involving Paleozoic carbonate rocks. Development drilling confirmed the seismic interpretation, but it disclosed that the internal structures were even more complicated by folding and subsidiary thrust faults (Gordy and Frey, 1977).

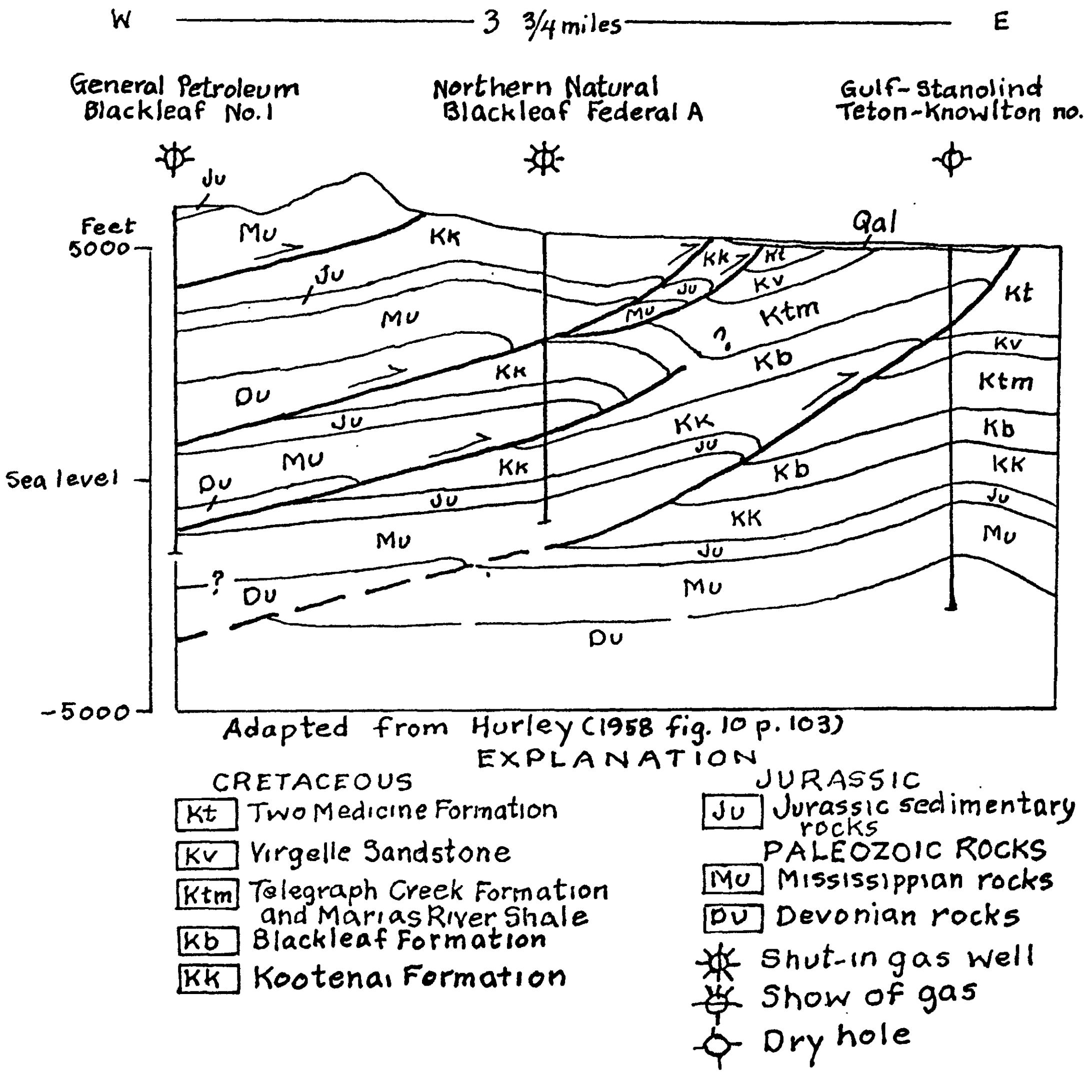


Figure 13.--Geologic cross section in Blackleaf Creek, east of the Great Bear wilderness study area. Arrows show direction of movement on faults. Qal, alluvial deposits

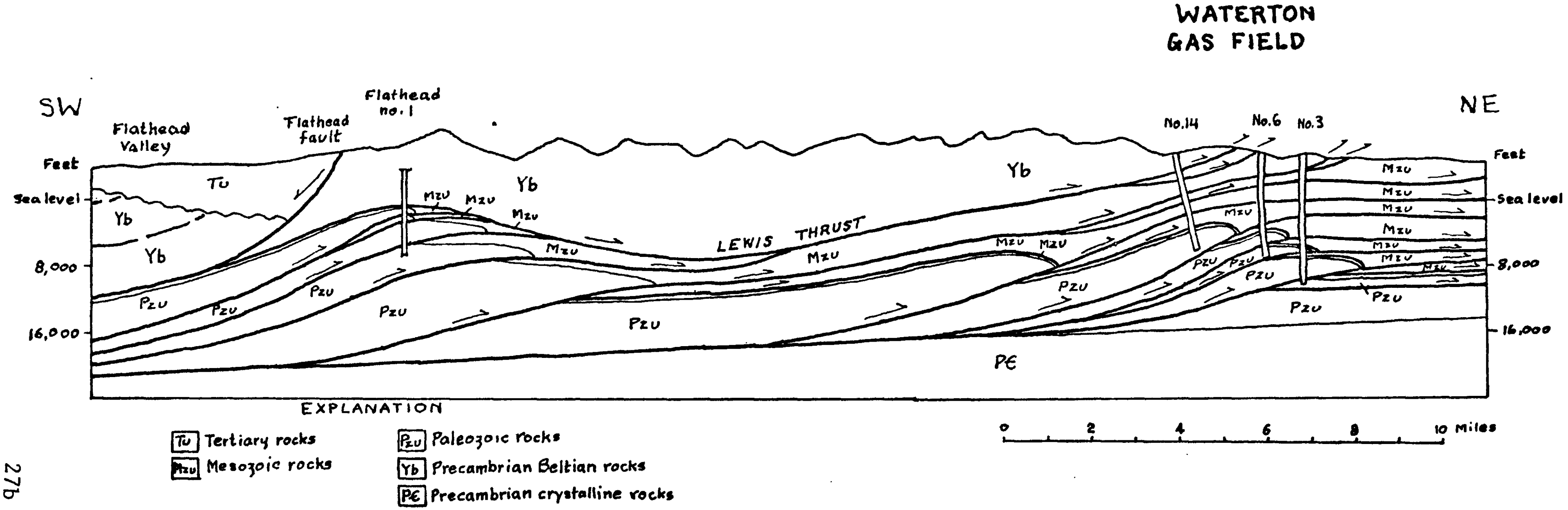


Figure 14.--Geologic cross section of Waterton gas field in southeastern British Columbia and northwest of Glacier National Park. Adapted from Bally, Gordy, and Stewart (1966, pl. 5). Arrows show direction of movement on faults.

The structure in Blackleaf Creek (type 1) probably extends northwest into the eastern part of the study area. Elsewhere in this part of the study area, surface data are inadequate to demonstrate similar structural traps, although some are inferred on figure 10.

Similar traps may also exist in the western part of the study area. In the eastern part of British Columbia, a few miles north of the International border, seismic surveys supplemented by a drill hole show a stacking of thrust plates with the wedge-edges of Paleozoic carbonate rocks present beneath the Lewis thrust plate (west part of fig. 14) (Bally, Gordy, and Stewart, 1966). Again surface data alone is insufficient to determine if these structures exist beneath the Lewis thrust plate in the western part of the study area (fig. 11). However, we can confidently predict that thrust faulted and possibly folded Paleozoic and Mesozoic rocks are beneath the Lewis plate.

Type 2 structural traps are on the surface in the eastern part of the study area and very likely exist in the subsurface, possibly in both parts of the area. The folds are not broad or extensive. Should they exist in the subsurface they will, by folding, form a wedge-edge of Paleozoic rocks.

Type 3 structural traps, in the form of folded thrust plates exist along the west side of the Sawtooth Range. Wedge-edges of Paleozoic rocks are involved in a folded thrust plate and similar structures may extend into the west part of the eastern study area. These are very complex structures whose nature and extent cannot be fully interpreted in the subsurface from the present data. They are common structures in the Alberta Foothills (Scott, 1951; Jones, 1971).

In the western part of the area, southeasterly facing monoclines are related to paleostructures that may reflect discontinuities in Precambrian crystalline basement as suggested by their northeasterly alinement. Subsurface data are insufficient to infer the nature and extent of the paleostructures. Older structures were important in the formation of stratigraphic and structural traps for hydrocarbons on the Sweetgrass Arch and in eastern Montana.

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