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UNITED STATES DEPARTMENT OF THE INTERIOR
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PETROLEUM POTENTIAL OF WILDERNESS LANDS, MONTANA

By William J. Perry, Jr., Dudley D. Rice, and Edwin K. Maughan

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PETROLEUM POTENTIAL OF WILDERNESS LANDS IN THE
WESTERN UNITED STATES

GEOLOGICAL SURVEY CIRCULAR 902-G

This chapter on the petroleum geology and resource potential of Wilderness Lands in Montana is also provided as an accompanying pamphlet for Miscellaneous Investigations Series Map I-1541

CONTENTS

ILLUSTRATIONS

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ABSTRACT

Wilderness Lands in Montana, totalling 6,930,433 acres, are subdivided for this report into 34 clusters covering 5,066,893 acres for the assessment of petroleum potential based on widely varying geologic conditions; 38,193 acres classified as having unknown potential; and 1,825,347 acres assessed as having zero potential.

The presence or absence of possible source rock, reservoir rock, adequate thermal history, and structural or stratigraphic traps for hydrocarbons are the most critical factors used in qualitatively assigning a high, medium, low, or low to zero oil and (or) gas potential to each of the clusters. Montana encompasses parts of five major geologic provinces. The provinces exhibit a wide range of structural and stratigraphic variations, summarized in this report.

INTRODUCTION

The State of Montana encompasses parts of five major geologic provinces (fig. 1). The first is the southwestern part of the Williston Basin province in eastern Montana. The second is the Northern Montana Foreland (Sweetgrass Arch) province, a complex of domes and arches in the Paleozoic Milk River uplift area of north-central Montana. The third is the Montana Thrust Belt province, that sector of the Cordilleran fold-and-thrust belt located in western Montana. This province, because of its complexity, is subdivided from north to south into (1) disturbed belt and adjoining northern sector of the Montana thrust belt to the west, (2) Helena salient and adjoining central sector to the west, and (3) southwest Montana recess. The fourth is the Central Montana Uplift province, located east of the Helena salient and including Mesozoic uplifts and basins superimposed on the early Paleozoic Central Montana trough and the adjacent northern margin of the Paleozoic Wyoming shelf. The fifth is the southern Montana part of the Wyoming province, a series of major Laramide uplifts and adjoining basins across the southern part of Montana from the southwest Montana recess eastward to South Dakota.

In this report we will first briefly discuss (1) the geologic, particularly structural, framework of these provinces with respect to hydrocarbon accumulations or possible accumulations, (2) Montana stratigraphy, focusing on rocks that have generated hydrocarbons (as source rocks) or yielded hydrocarbons (as reservoir rocks), and (3) the petroleum potential of the clustered Wilderness Lands in Montana (fig. 2). Obscure geologic terminology is eliminated wherever possible; some scientific terms are defined within the text and in the accompanying glossary.

GEOLOGIC FRAMEWORK

WILLISTON BASIN PROVINCE

The Williston basin (fig. 1) is the largest depositional basin of the North American continental interior, preserving the most complete Paleozoic sequence of rocks found in the continental interior (Sandberg and Hammond, 1958; Sandberg, 1962), as much as 16,000 ft of strata, and is one of the

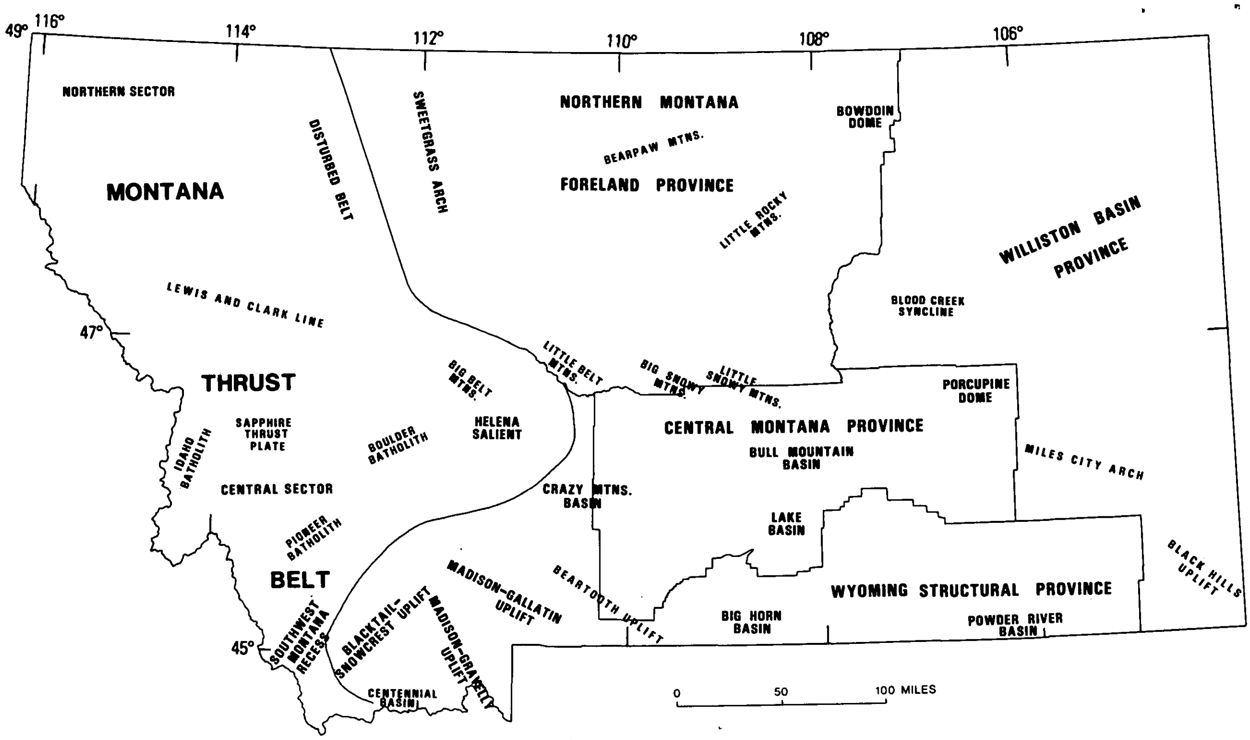

FIGURE 1.—Index map of Montana showing location of principal geologic and geographic features mentioned in text. Boundary lines follow province boundaries as used in U.S. Geological Survey Circular 860 (Dolton and others, 1981): Williston Basin province—Province 94; Northern Montana Foreland (Sweetgrass Arch) province—Province 96; Montana Thrust Belt—Province 98; Central Montana Uplift province—Province 97; and Wyoming Structural province—Provinces 99, 101, and 103.

most important oil-productive basins in North America (Dow, 1974; Rice, 1979). The northern part of the Williston basin lies in Canada, the southwestern part in Montana, and the remainder in North and South Dakota. Precambrian to Mississippian paleotectonics of the Williston basin are summarized by Sandberg (1964). A composite stratigraphic section (fig. 3*A* and 3*B*) for northeastern Montana illustrates the stratigraphic units involved in the thick Cambrian, Ordovician, Silurian, Devonian, and Mississippian rock sequence of the Williston basin, many of which yield oil and gas (Glaze, 1971; Rice, 1979). The distribution and thickness of many of these rocks, as well as Mesozoic rock units, were controlled by intermittent movements of structural features already in existence by the close of Precambrian time (Sandberg, 1962). The Blood Creek syncline (fig. 1) is herein included within the Williston Basin province. This broad, shallow downwarp extends westward from the southwestern edge of the Williston basin, along the older northeastern margin of the upper Paleozoic Big Snowy trough.

NORTHERN MONTANA FORELAND (SWEETGRASS ARCH) PROVINCE

The Northern Montana Foreland province (fig. 1) lies between the western part of the Williston basin and the Montana thrust belt. During much of Paleozoic time, this province was part of the broad Milk River uplift, a southern extension of the Paleozoic Alberta shelf (Schwartz, 1983, fig. 3). The Paleozoic Milk River uplift separated the Williston basin to the east from the Cordilleran miogeoclinal wedge, the eastward-thinning wedge of sedimentary rocks deposited on the continental margin to the west, remnants of which are preserved west of the disturbed belt in extreme northwestern Montana. This broad positive area was partitioned in Mesozoic and early Tertiary time, from east to west, into the Bowdoin dome, igneous intrusive complexes of the Little Rocky Mountains, Bearpaw Mountains and Highwood Mountains and the Sweetgrass Arch (Alpha, 1955; Glaze, 1971; Lorenz, 1983). The Sweetgrass Arch and Sweetgrass Hills area just east of the north-

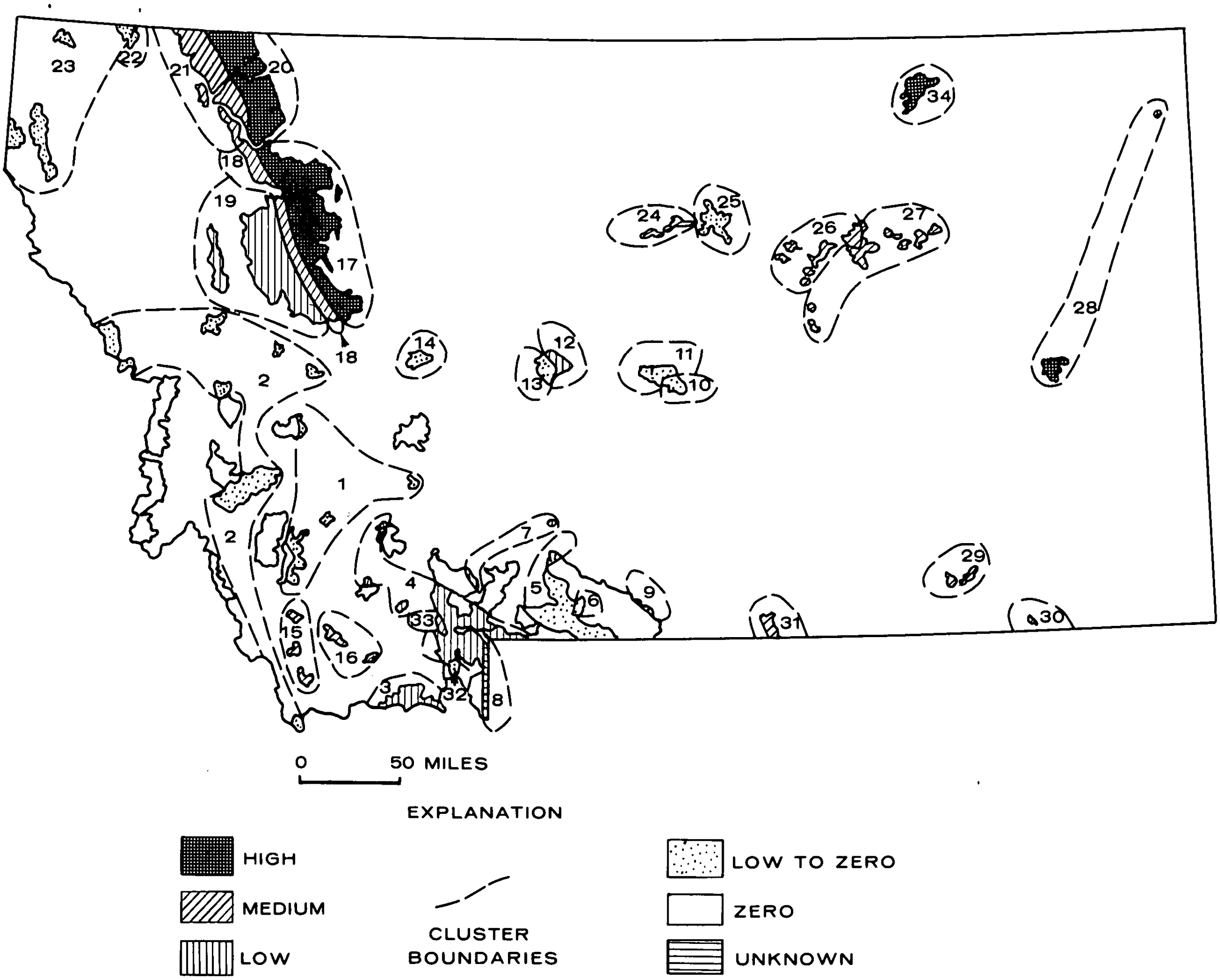

FIGURE 2.—Index map of Federal Wilderness Lands in Montana. Cluster boundaries shown by dashed lines; numbers refer to clusters as described in text. Ratings (high, low, etc.) refer to oil and gas potential.

ern part of the arch have yielded significant amounts of oil and gas, particularly the giant Cutbank oil and gas field on the western flank of the Sweetgrass Arch. A stratigraphic summary of the western flank of the Sweetgrass Arch is provided (fig. 4). Common to the northern Montana Foreland province and disturbed belt to the west is a major unconformity between Mississippian and Jurassic rocks in which the thick Pennsylvanian through Triassic sequence of sedimentary rocks of southern Montana and the Williston basin is omitted by erosion or nondeposition (figs. 3 and 4, also Rice, 1979). The Bearpaw Mountains laccolith is the only major igneous complex in Montana with associated hydrocarbon production; the flanking, chiefly Cretaceous, sedimentary rocks contain numerous accumulations of natural gas. Both the Bowdoin dome and Bearpaw Mountains yield shallow biogenic gas (Rice and Claypool, 1981). In the Bearpaw Mountains, gas is trapped by gravity slide blocks on the flanks of the uplift.

MONTANA THRUST BELT PROVINCE

The Montana sector of the Cordilleran thrust belt, commonly designated the Montana thrust belt (fig. 1), is geologically more complex than either that of adjoining Alberta and British Columbia to the north or the Wyoming-Utah-Idaho sector to the south. The complexities are due in part to inherited very old (Precambrian) structural elements, which have been reactivated at

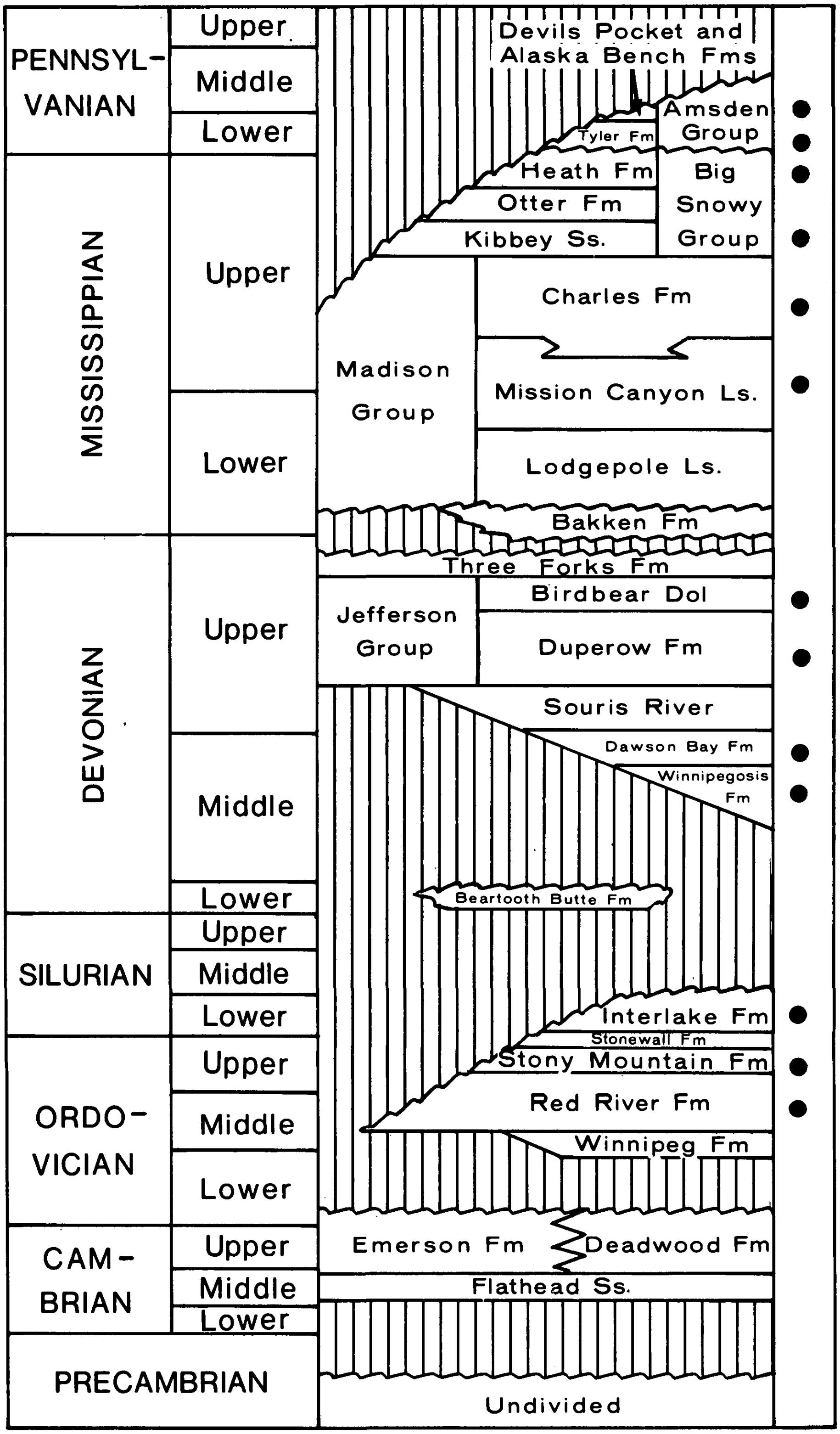

FIGURE 3A.—Correlation chart of Paleozoic rocks for east-central and northeastern Montana. Solid circle in right-hand column indicates oil productive.

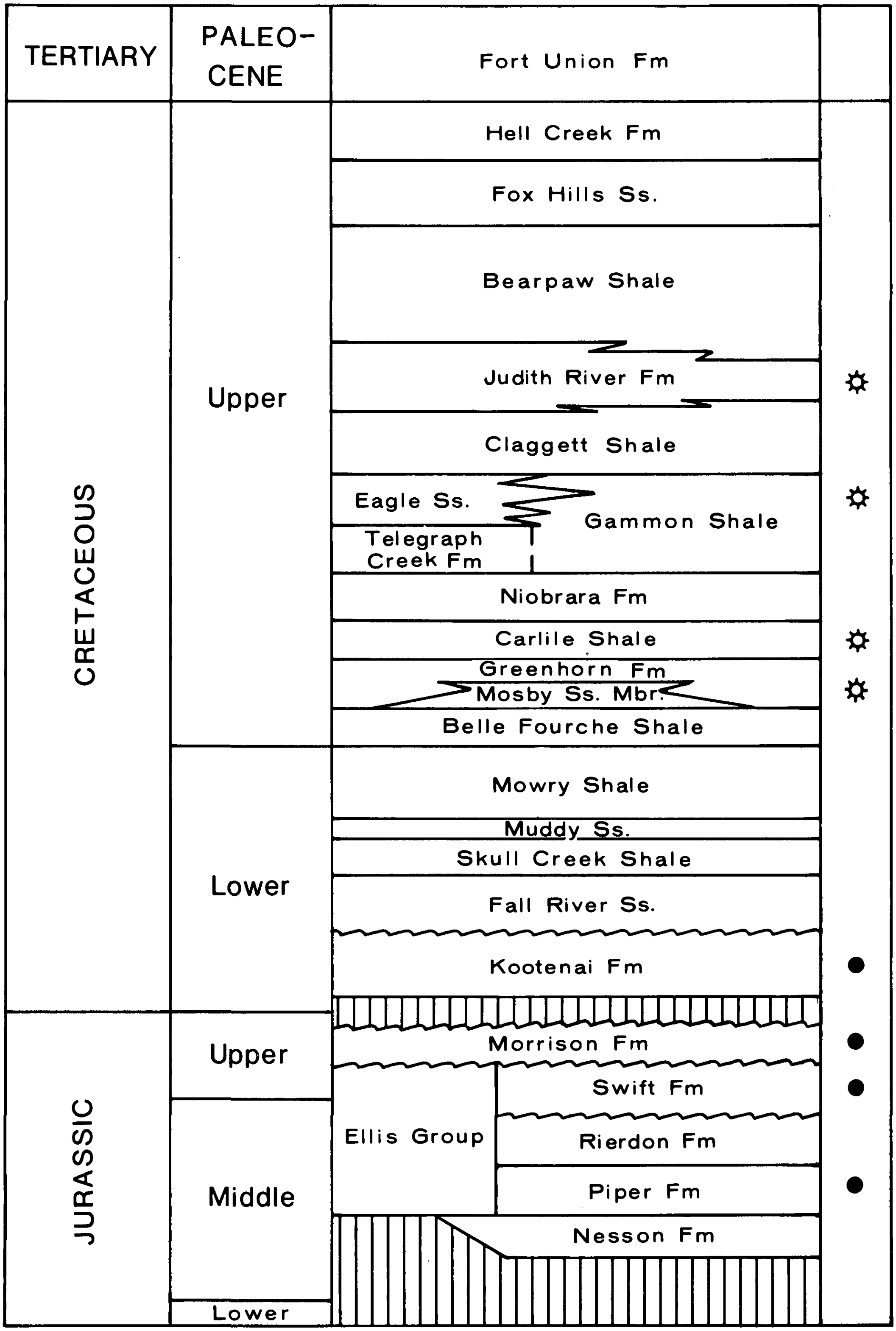

FIGURE 3*B*.—Correlation chart of Mesozoic rocks for east-central and northeastern Montana. Symbols in right-hand column: solid circle—oil productive; open circle with rays—gas productive.

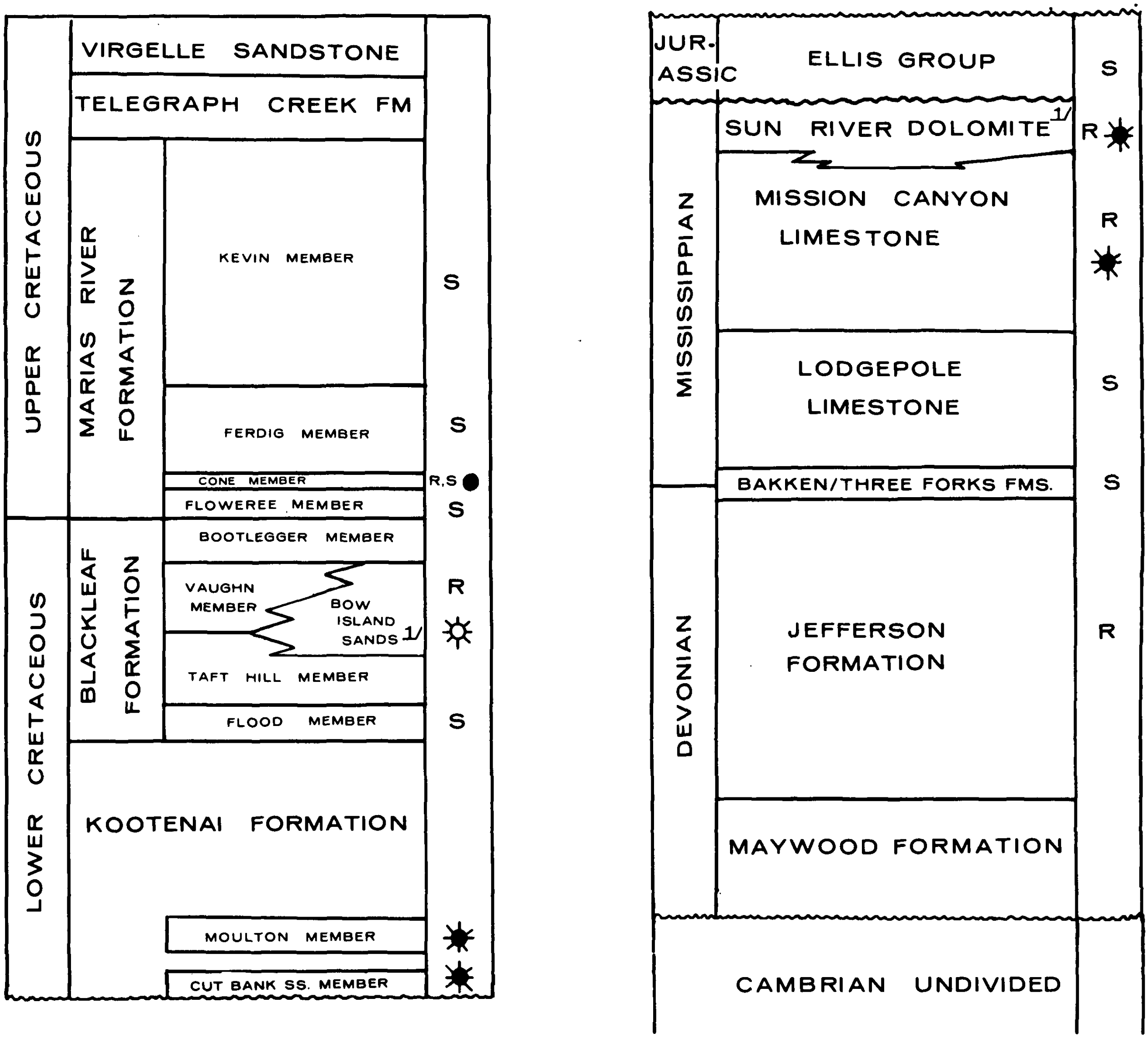

FIGURE 4.—Correlation chart of pre-Tertiary stratigraphic units of the western flank of the Sweetgrass arch and adjacent eastern disturbed belt, northwest Montana. A superscripted 1 denotes informal drillers terms in this area. Abbreviations and symbols in right-hand column are as follows: S—known or potential source rock; R—known or potential reservoir rock; solid circle—oil productive; open circle with rays—gas productive; and solid circle with rays—both oil and gas productive. *Within* the disturbed belt, Mississippian rocks are divided into the Allan Mountain Limestone, equivalent to the Lodgepole Limestone and overlying Castle Reef Dolomite which includes the Sun River Dolomite Member (Mudge, 1972a).

various times and which have influenced the geologic framework of the Montana thrust belt (Harris, 1957; Harrison and others, 1974; and many other workers). The Cordilleran thrust belt, which extends from Alaska to Mexico (Powers, 1983), is characterized by west-to-east displacement of sheets of chiefly sedimentary rocks (thrust sheets) detached from the underlying crust and moved on successively more eastward or northeastward located west-dipping thrust faults (low-angle, map-scale contraction faults) during Jurassic to early Tertiary time. The total horizontal contraction or shortening (west to east) of the sedimentary wedge is estimated by many workers to exceed 100 miles.

The disturbed belt, the northern subdivision of the Montana thrust belt, is an extension of the Foothills and Front Range structural subdivisions of the Cordilleran thrust belt in southern Alberta (Willis, 1902; Mudge and Earhart, 1980; Mudge, 1983). The Foothills region of Canada has yielded prolific amounts of gas and condensate (Rice, 1977). Exploration has not yet discovered such giant accumulations in the Montana thrust belt, but the possibility of the existence of such accumulations, particularly within the disturbed belt, should not be discounted. Oil and gas exploration of the disturbed belt, particularly west of the mountain front, has been restricted from exploration. Glacier National Park is located chiefly on the major Lewis thrust sheet in the northern part of the disturbed belt (Mudge and Earhart, 1980) and is probably underlain by imbricate thrust slices of Mississippian carbonate rocks, beneath the Lewis thrust sheet, similar to and coextensive with hydrocarbon-producing structures in southwestern Alberta (Kulik, 1983). The Bob Marshall Wilderness and associated Wilderness Study Areas occupy much of the disturbed belt south of Glacier Park, and these areas are considered to have significant hydrocarbon potential (Mudge and others, 1977; Rice, 1977; Mudge and others, 1978). The stratigraphy and structure of much of this area were carefully detailed by Mudge (1965, 1966, 1967, 1972a, 1972b) and excellent regional geologic maps are available (Mudge and others, 1982; Mudge and Earhart, 1983). Principal stratigraphic units east of the mountain front are illustrated (fig. 4). The region is characterized by a complex of imbricated thrust sheets, folded thrust faults, and other structural features closely similar to those north of the International Boundary. West of the disturbed belt the northern sector may be subdivided from east to west into the Rocky Mountain trench, the Purcell anticlinorium, and Purcell trench along the Idaho-Montana State boundary. Both the disturbed belt and northern sector to the west are bounded on the south by the Lewis and Clark line, a linear zone of crustal weakness described by Reynolds (1979).

The central sector of the Montana thrust belt, located south of the Lewis and Clark line and west of the Helena salient, provided the locus for large Mesozoic igneous intrusions (Pioneer, Philipsburg, and Boulder batholiths) and appears to be a region of relatively thin crystalline crust and high heat flow. This sector is also the locus of most of the hot springs in Montana (Chadwick and Leonard, 1979). All of these factors are negative with respect to oil and gas possibilities. The Helena salient, east of the Boulder batholith (fig. 1), parallels and structurally overprints the Precambrian Belt embayment and the western part of the Paleozoic Central Montana trough (Harris, 1957; Bregman, 1976). The Precambrian Belt embayment is probably not a depositional embayment of Belt age but a later pre-Middle Cambrian structural depression (M. K. Reynolds, oral commun., 1983). The Helena salient of the thrust belt, comprehensively discussed by Woodward (1981), is bounded to the southeast by the Battle Ridge monocline (Garrett, 1972), a northeast-trending linear structural feature intermittently active since Mississippian time, and to the south by the southwest Montana transverse zone (Schmidt and O'Neill, 1983).

The structure and petroleum potential of the southwest Montana recess is discussed by Perry and others (1981, 1983). Here the intersection of foreland and thrust belt structural trends (Scholten, 1967; Beutner, 1977) has generated a complex structural style that is currently being deciphered (Perry, 1982; Perry and Sando, 1983). Middle Tertiary to recent extension faulting and formation of extension-fault-bounded basins (grabens and half-grabens) have profoundly modified much of western Montana and are responsible for much of the present topographic relief in southwestern Montana. The presence of the three principal requirements for hydrocarbon accumulations—thermally mature, kerogen-rich source beds (possible source rock) for hydrocarbons, possible reservoir rocks, and structural traps in this sector of the Montana thrust belt (Perry and others, 1983)—offers many potential exploration targets.

CENTRAL MONTANA UPLIFT PROVINCE

The Central Montana Uplift province includes from west to east, the Crazy Mountains basin, Bull Mountain basin, Lake Basin, intervening uplifts, anticlines, synclines, and Porcupine dome on the east (fig. 1). The Crazy Mountains basin (Garrett, 1972) has been modified by intrusion of a major early Tertiary laccolith (Bonini and others, 1972) and associated radial dike swarms, forming the Crazy Mountains. The Little Belt Mountains, Big Snowy Mountains, and Cat Creek anticline (from west to east) lie along the northern boundary of this province (Thom, 1923). The southern boundary is the northern limit of the Beartooth uplift and Big Horn basin and uplift—major structural features of the Wyoming province to the south. Numerous small oil fields, mainly in structurally enhanced stratigraphic traps, have been found in the Central Montana Uplift province, along the eastward extension of the Laramide (Late Cretaceous to early Tertiary) Big Snowy uplift. The northern part of this province is within the area of the upper Paleozoic Big Snowy trough, an area previously uplifted during Devonian time.

MONTANA PORTION—WYOMING STRUCTURAL PROVINCE

Between the southwest Montana recess of the thrust belt and the southeastern corner of Montana lies a complex of structurally yoked Laramide uplifts and basins that may have developed sequentially from west to east. Parts of the Archean (early Precambrian) basement-cored uplifts have been thrust over adjacent basins above thrust faults that involve the entire upper part of the earth's crust (Gries, 1981, 1983; Perry and Kulik, 1982). Of note are relatively or completely untested basins and thrust-fault traps associated with the Blacktail-Snowcrest and Madison-Gravelly uplifts northwest of Yellowstone Park as well as the northern and eastern margin of the Beartooth uplift just west of the northern Big Horn basin (fig. 1) to the east. The southeastern margin of the Blacktail-Snowcrest uplift incorporates the sequence of rocks deposited in the axial part of the Upper Paleozoic Snowcrest trough (fig. 5), much thicker than that of the Centennial (upper Tertiary to Holocene) basin immediately to the south. It is likely that the Paleozoic Snowcrest trough was separated from the Wyoming shelf Paleozoic sequence of the Centennial basin (figs. 1 and 5) by a system of down-to-the-northwest extension faults along which displacement occurred during the period of more rapid deposition in the trough than on the adjacent shelf.

Tertiary, possibly Laramide, faults with associated drape folds are present along the Beartooth and Bighorn Mountain fronts, similar to other areas of the Wyoming Structural province. This province is typified by major northeast- and northwest-trending lineaments (Maughan, 1983a) that are also present farther north (Thomas, 1974). These features are linear zones of crustal fracturing or faulting, active during the late Paleozoic and selectively reactivated during late Mesozoic to early Tertiary thick-plate thrust faulting of the Rocky Mountain foreland (Gries, 1983; Kulik and others, 1983). The Montana portions of the Powder River and Big Horn basins have not yielded hydrocarbons as prolifically as those portions in adjacent Wyoming, but exploration for petroleum in these areas is still active. The stratigraphic sequence in these basins is similar to that in adjoining Wyoming and not greatly different from that of the Centennial basin (fig. 5). Possible structural traps for hydrocarbons, associated with thick-plate thrust faulting within the Wyoming structural province, are among the most controversial exploration targets currently being drilled.

STRATIGRAPHIC SUMMARY

Strata ranging in age from Precambrian to Holocene are present in Montana. The most complete stratigraphic section is within the portion of the Williston basin that lies in the northeastern part of the State. Thick Precambrian and Paleozoic sedimentary rock accumulations, which were deposited on the ancient continental shelf, occur in western Montana. Montana was repeatedly inundated by shallow inland seas throughout much of the Phanerozoic, until Late Cretaceous time. Major gaps are present in the stratigraphic record, particularly the Late Cambrian to Late Devonian hiatus in central and western Montana and Late Mississippian to Jurassic hiatus in the disturbed belt and Northern Montana Foreland province (the Paleozoic Milk River uplift area). Thick Cretaceous deposits occur locally within the thrust belt, in the foreland of central and southwestern Montana, and in various Laramide basins. Thick Tertiary deposits, locally up to 16,000 ft thick, occur in extension-fault-bounded basins in western Montana (Fields and Petkewich, 1967; Reynolds, 1979). Marine Paleozoic rocks, enriched in kerogen, are generally thermally mature throughout the State, whereas thermally mature Cretaceous source rocks are primarily present only in western Montana. Tertiary source rocks for hydrocarbons have not yet been identified but may be present in the deeper parts of Tertiary basins in western Montana. Reservoir or possible reservoir rocks for petroleum are widely distributed throughout the stratigraphic column.

The names of principal pre-Tertiary rock units and their relative placement in the stratigraphic sequence are shown for the Williston basin and north-central Montana (fig. 3*A* and 3*B*), the Sweetgrass Arch and eastern disturbed belt (fig. 4), and southwestern Montana (fig. 5). Correlations between geological regions are shown in figures 3*A*, 3*B*, and 5. We briefly describe the sedimentary rocks that compose each system, beginning with the oldest and omitting the younger, post-Cretaceous rocks and sediments.

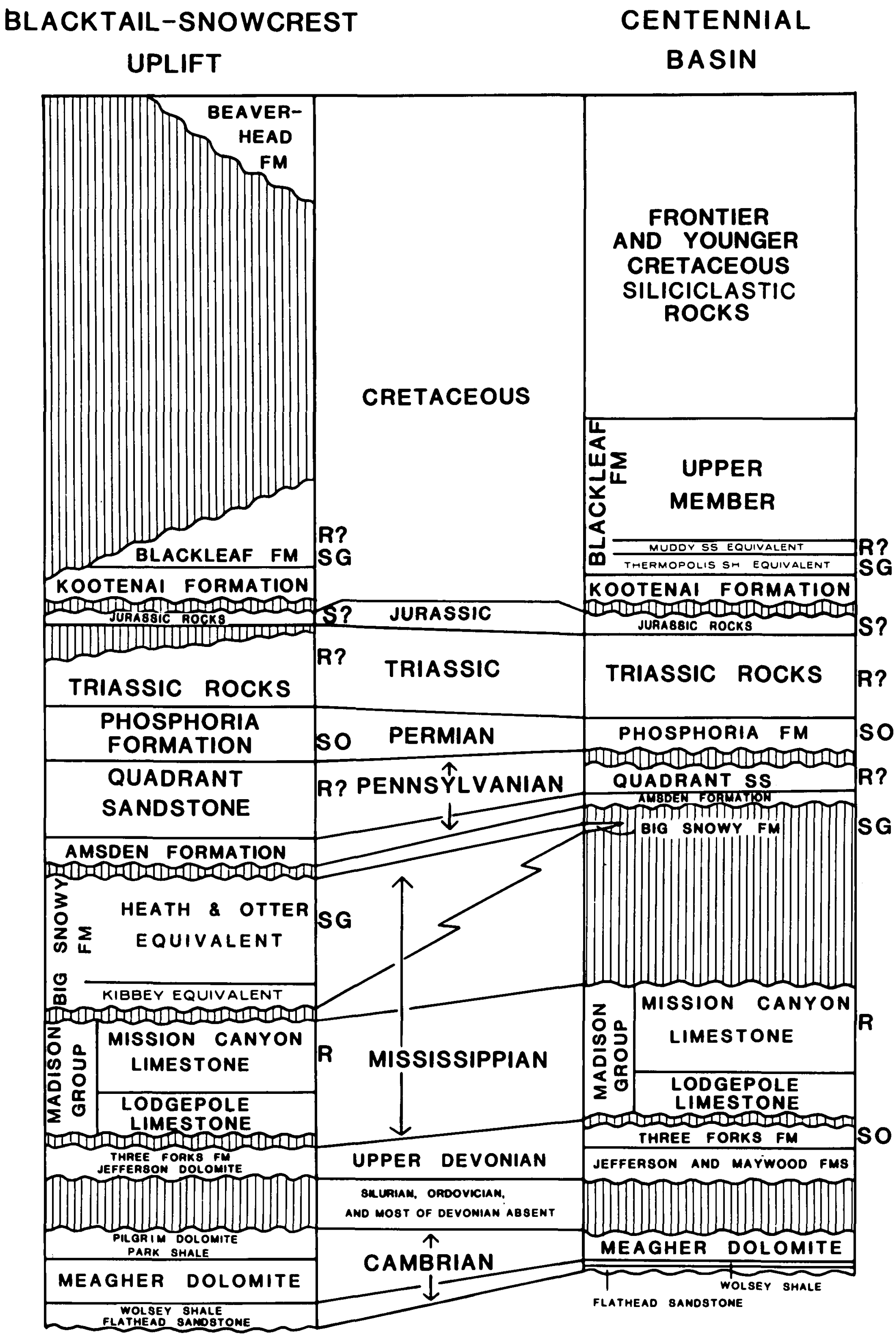

FIGURE 5.—Correlation chart of pre-Tertiary formations of Blacktail-Snowcrest uplift and Centennial basin in southwestern Montana. R?—possible reservoir rocks, S?—possible source rocks, SG—indicated gas-prone source rock, SO—indicated oil-prone source rock (from Perry and others, 1983).

PRECAMBRIAN

Sedimentary rocks of the Belt Supergroup in northwestern Montana were deposited more than 1 billion years ago in a major basin near the outer edge of the ancient continental margin and in a narrow embayment or aulacogen, which extended eastward (landward) from this basin. This embayment is now the area of the Helena salient of the thrust belt and extends through much of the Central Montana Uplift province (Harris, 1957) to the Porcupine dome (fig. 1). The Belt sequence is composed dominantly of clastic rocks, although carbonate rocks are important components low within this sequence. The rocks thicken westward; an aggregate thickness of over 30,000 ft has been estimated for far northwestern Montana (Harrison and others, 1974). Coarse conglomeratic rocks occur on the southern margin of the Precambrian Belt embayment (McMannis, 1963) or pre-Middle Cambrian structural depression, along the southern margin of the Helena salient. The Belt Supergroup locally contains very thin beds of carbon-enriched dark gray shale or siltstone. These beds are not presently known to contain source rock for hydrocarbons, but they have not been thoroughly studied. Fractured Precambrian rocks may locally provide fractured reservoirs for hydrocarbons, but such reservoirs have not yet been identified in Montana.

CAMBRIAN

Rocks deposited during the Cambrian Period record the progressive eastward inundation of Montana by the sea over an irregular erosion surface (Sandberg, 1962; Peterson, 1981a, 1981b). Cambrian rocks are as much as 2,000 ft thick in western Montana and 1,200 ft thick northeast of the Bearpaw Mountains (Glaze, 1971). These rocks thin eastward toward the continental interior from a thickness of more than 1,100 ft on the west side of the Williston Basin province to less than 600 ft in northeasternmost Montana (Sandberg, 1962). An east- to northeast-trending zone of thicker Cambrian rocks extends into the Williston basin from the central Montana uplift area, from the area of the Precambrian Belt embayment (Sandberg, 1962). The oldest sedimentary rocks are sandstone and, locally, conglomerate deposited as the sea transgressed eastward toward the continental interior. These coarse-grained rocks grade upward into finer-grained siliciclastic rocks (siltstone and shale), which grade upward in turn into limestone and dolomite, the dominant components of the Cambrian rocks in western Montana (Lochman-Balk, 1972). Mudstone, siltstone, and claystone are the dominant components of the rock strata in central Montana where the inland sea was shallow. Sandstone is the dominant component in the east. Although possible reservoir rocks, both sandstone and dolomite, of Cambrian age are widespread, petroleum production from reservoirs of Cambrian age are restricted to the North Dakota part of the Williston basin. Substantial thicknesses of porous dolomite of Cambrian age are known to be present in western Montana (Peterson, 1981b). Cambrian source rocks, however, are unknown in Montana.

ORDOVICIAN

In Montana, the Ordovician System comprises parts of two depositional sequences (Sandberg, 1962; Foster, 1972) that are generally restricted to the Williston basin. The older Ordovician strata comprise fine clastic and carbonate rocks in Montana and are a continuation of the Upper Cambrian depositional sequence. These Lower Ordovician rocks have a maximum thickness of about 600 ft in the Williston basin in northeastern Montana, but they were erosionally thinned west of the Williston basin and removed west of a roughly north-south line between the Bearpaw Mountains and the western part of the Big Horn basin (Foster, 1972).

A second depositional cycle, involving Middle and Upper Ordovician strata, extends farther west but pinches out between the Bearpaw Mountains and the Sweetgrass Arch (fig. 1). Farther south, the irregular line of pinchout swings eastward into the ancestral central Montana uplift and then southwestward through the Crazy Mountain basin (fig. 1) into southwest Montana as shown by Sandberg and Mapel (1967). This cycle consists of a basal sandstone near the Bearpaw Mountains in the west and sandstones and shales (Winnipeg Formation) in the Williston basin overlain by dolomites or limestones of the oil-productive Red River Formation and younger Ordovician carbonate units (Sandberg, 1962). Dow (1974) identified the medial shale of the Winnipeg Formation as the source rock for most lower Paleozoic oil in the Williston basin.

In southern Montana, Ordovician rocks are over 600 ft thick in the northeastern Powder River basin (Kinnison, 1971), 400 ft thick in the northern Big Horn basin, and pinch out westward beneath the Crazy Mountain basin (Stauffer, 1971). Locally they persist as far west as the Madison-Gravelly uplift (Hadley, 1960). Kerogen-rich Ordovician source rock of the Winnipeg Formation (Dow, 1974) and important Ordovician reservoir rocks for petroleum are present in, but generally restricted to, the Williston basin in Montana. Important hydrocarbon production has been established from structural and stratigraphic traps, principally in the Red River Formation of the Williston basin (Ballard, 1969; Kohm and Louden, 1978).

SILURIAN

Silurian rocks, primarily dolomite, in the Williston basin have a maximum thickness of 700 ft in northeastern Montana (Gibbs, 1972). They thin westward to an erosional edge in the eastern part of the Northern Montana Foreland province, onto the Paleozoic Milk River uplift, and thin southward into the eastern part of the Wyoming province, where they pinch out in the northern Powder River basin. During latest Ordovician and Silurian time, the Williston basin became a deeply subsiding subcircular depression surrounded by a broad, stable shelf (Sandberg, 1962). Silurian rocks are absent in central and western Montana. Production from reservoirs of Silurian age is restricted to limited areas of the Williston basin.

DEVONIAN

Deposition during the Devonian Period resulted in five sequences, of which the middle three are principally dolomitic rocks (Sandberg and others, 1983). A summary report describing these rocks in Montana and adjacent areas by Sandberg and Mapel (1967) was incorporated into the work of Baars (1972). The earliest Devonian rocks consist of conglomerates and sandstones deposited in channels and associated red beds, probably deposited as soils on an upland surface formed in Early Devonian time when all of Montana was elevated above sea level (Sandberg, 1961; Glaze, 1971). Some of these channels are located along fracture zones in the underlying Silurian rocks (Sandberg, oral commun., 1983).

In northeastern Montana, the second Devonian sequence occurs only in the Williston basin (fig. 1) where it contains an evaporite-bearing section over 500 ft thick (Sandberg and Mapel, 1967). Evaporites (anhydrite, salt, and sylvite) in the basinal sequence are fringed by carbonate bioherms or reefs that are excellent reservoirs for petroleum (Sandberg and Hammond, 1958).

The third Devonian sequence (latest Middle and lower Upper Devonian) occurs throughout Montana but thins to an edge at the southeast corner of the State and on the flanks of the Paleozoic Central Montana uplift within the Central Montana province (fig. 1). It attains a thickness exceeding 1,100 ft in parts of western Montana (Sandberg and Mapel, 1967). This sequence comprises the Souris River Formation, equivalent Maywood Formation, and overlying Jefferson Group of the Williston basin (fig. 3*A*), cyclically deposited dolomitized carbonate rocks overlain by anhydritic dolomite and anhydrite. Bioherms (reeflike mounds) occur locally in this sequence in Montana (Sandberg and Poole, 1977, p. 156–157) but are larger north of the International Boundary (Glaze, 1971) and are significant stratigraphic traps for oil in the Williston basin of that area.

The fourth Devonian sequence, late Late Devonian in age (Sandberg and Mapel, 1967) comprises the lower two-thirds of the Three Forks Formation. This sequence is composed of a lower dolomite and evaporite unit representing restricted marine conditions and an upper predominantly shale unit representing open marine conditions. This sequence, absent through much of southeastern Montana, is best developed (over 800 ft thick) in the disturbed belt of northwestern Montana (Sandberg and Mapel, 1967). Good reservoir rocks are commonly absent in this sequence due to generally low porosity and permeability, although sandstone at the top of this sequence is a minor productive reservoir in North Dakota.

The youngest Devonian rocks are the initial part of a depositional sequence that continued into the Mississippian Period (Sandberg and Poole, 1977). The latest Devonian and earliest Mississippian strata are predominantly carbonaceous mudstone, although sandstone or carbonate rocks are locally abundant (Macqueen and Sandberg, 1970). These strata are generally less than 100 ft thick and they are absent in parts of central and southeastern Montana. The youngest Devonian rocks contain kerogen-enriched black shale, excellent source rock, and potential source rock in many parts of Montana (Dow, 1974; Meissner, 1978).

Devonian oil reservoirs are important in the Williston basin of northeastern Montana. Devonian rocks yield natural gas in a limited area on the Sweetgrass Arch. Elsewhere in Montana, Devonian rocks are nonproductive. The Bakken Formation is identified as the principal source rock for Mississippian oil reservoirs in the Williston basin (Dow, 1974). Lateral equivalents of the Bakken in western Montana have been identified as potential source rock, especially for possible Paleozoic reservoirs.

MISSISSIPPIAN

Two depositional sequences comprise Mississippian rocks in Montana (Sando, 1967; Craig, 1972; Peterson, 1978; Roberts, 1979). The lower sequence, which began in latest Devonian with the widespread deposition of kerogen-enriched mud as noted above, culminated in the thick carbonate bank of the Madison Group (Sando, 1967, 1976; Sando and others, 1976; Rose, 1976; Gutschick and others, 1980). The sequence of transgressive and regressive events, which controlled its deposition, has been analyzed and dated by Sandberg and others (1983). The uppermost strata of this sequence include dolomite and evaporite rocks in most areas across the State, although the evaporite rocks, which are assigned to the Charles Formation in the Williston basin, comprise as much as one-third of the total sequence in northeastern Montana where the maximum thickness of the Madison Group is about 2,200 ft. Sandberg (1962) pointed out that episodically renewed uplift of the Cedar Creek anticline, which trends north-northwest along the southwestern margin of the Williston basin in Montana, provided a barrier that caused salt precipitation to the east in the Williston basin whereas only anhydrite precipitation occurred to the west. The Madison Group thins depositionally to a minimum of about 600 ft in the vicinity of the Wyoming border in southeastern and south-central Montana. It has been thinned by erosion on the Milk River uplift in north-central Montana to about 600 ft. The Madison Group in southwestern Montana is about 1,600 ft thick. Equivalent rocks occur in northwestern Montana west of Glacier National Park (Johns, 1970), but the thickness there is not accurately known. The Madison Group contains the most productive Paleozoic reservoir rocks for petroleum in both eastern and western Montana.

The younger Mississippian sequence that developed throughout Montana succeeding Madison deposition is assigned to the Big Snowy Group. The Big Snowy includes at its base a karst plain-sabkha complex that locally lies unconformably upon the Madison (Roberts, 1979; Sandberg and others, 1983). The sequence is composed of mudstone, sandstone, and evaporite beds, which grade upward into limestone, carbonaceous mudstone, and anhydrite that compose another transgressive-regressive depositional cycle. The Big Snowy Group, originally deposited over all or most of Montana (Maughan and Roberts, 1967), has been preserved from erosion only in the Paleozoic Big Snowy trough in the Central Montana Uplift province, the Williston basin, and in the Paleozoic Snowcrest trough along the southeastern margin of the Blacktail-Snowcrest uplift in southwestern Montana (figs. 1 and 5). Equivalent strata have been identified locally in far northwestern Montana west of the disturbed belt (Johns, 1970), but their extent and thickness are unknown. Thickness of the Big Snowy Group is as much as 1,200 ft in central Montana and it is, at maximum, about half as thick in the Williston basin. Thickness of equivalent rocks in southwestern Montana locally exceeds 1,700 ft within the Paleozoic Snowcrest trough, and these rocks are generally absent on the adjacent Wyoming shelf to the southeast. Oil is produced from reservoir rocks within the Big Snowy Group in the Central Montana Uplift province and Williston Basin province. Black shales in the upper part of the Big Snowy Group are important source rocks in this same province (Kranzler, 1966).

PENNSYLVANIAN

Two depositional sequences comprise the Pennsylvanian rocks in Montana. Initial deposits of the lower sequence are restricted in their distribution to the Paleozoic Snowcrest trough in southwestern Montana, to the Paleozoic Big Snowy trough in central Montana, and to the Williston basin in eastern Montana. These rocks of earliest Pennsylvanian, and possibly youngest Mississippian age, are dominantly dark gray, moderately carbonaceous mudstone; but locally they include sandstone, conglomeratic sandstone, limestone, and very thin coal beds (Harris, 1972; Jenson and Carlson, 1972; Fanshawe, 1978). Fluvially deposited sandstones grade upward into red mudstone beds overlain by limestone at the top of this transgressive sequence. This sequence of rocks, assigned to the Amsden Group in central Montana, is as much as 800 ft thick in the Big Snowy trough. Equivalent rocks are as much as 1,000 ft thick in the Snowcrest trough, but the Amsden is generally less than 200 ft in south-central and northeastern Montana. Equivalent rocks in southeastern Montana are included in the lower member of the Minnelusa Formation, which is no more than about 150 ft thick. Rocks of this sequence are thinned or locally absent at many places in Montana owing to postdepositional erosion (Maughan, 1975), particularly in the area of the Paleozoic Milk River uplift.

The second of the Pennsylvanian sequences comprises mostly sandstone of the Quadrant Sandstone in the western half of the State and mostly sandy dolomite and interbedded sandstone of the Devils Pocket Formation in central Montana and of the middle member of the Minnelusa Formation in eastern Montana. These rocks are 350 ft thick or less, except in the southwest Montana recess where the maximum thickness is about 2,500 ft. Rocks of this age have been removed by erosion from the Milk River uplift in north-central Montana, but probably occur in far northwestern Montana as indicated by outcrops of lithologically similar rocks in the northern Whitefish Range (Johns, 1970, Maughan, 1975). Reservoir rock of Pennsylvanian age yields hydrocarbons locally in central Montana (Kranzler, 1966) and the adjacent Big Horn basin to the south. The Tyler Formation (fig.3*A*) is the principal oil reservoir rock of the Central Montana Uplift province (Maughan, 1983b).

PERMIAN

Two Permian depositional sequences are present in Montana. In southeastern Montana and in the Williston basin the lower sequence is included in the upper member of the Minnelusa Formation. The rocks of this lower sequence are dominantly sandstone in the Snowcrest trough of southwest Montana but include interbedded dolomite and sandy dolomite in eastern Montana. A thickness of about 350 ft has been estimated for Permian sandstones of the lower sequence in the Snowcrest trough (Sheldon and others, 1967); the upper member of the Minnelusa is about 300 ft or less in southeastern Montana (Maughan, 1967).

The upper sequence of the Permian is dominantly red mudstone, dolomite, and evaporite beds that include salt deposits in southeastern Montana and the central part of the Williston basin. The sequence is no more than about 300 ft thick in the eastern part of the Central Montana Uplift province, but it thickens eastward. Equivalent rocks in the southwestern part of the Central Montana Uplift province consist of sandstone adjacent to the Milk River uplift and these strata intertongue southwestward into dominantly carbonate rocks of the Park City Formation and into kerogen-enriched mudstone, chert, and phosphorite beds of the Phosphoria Formation (Peterson, 1972a). These rocks are about 600 ft thick adjacent to the Idaho border but thin depositionally northward toward an erosional edge in the vicinity of the Lewis and Clark line and northeastward onto the flank of the Milk River uplift.

Known Permian reservoir rocks for hydrocarbons are rare in Montana. However, kerogen-enriched phosphorite and mudstone of the Phosphoria Formation in southwest Montana provide abundant possible source rock. Similar rocks are considered to be the principal Paleozoic source rocks of the Big Horn basin (Stauffer, 1971) and other parts of Wyoming and southern Montana (Claypool and others, 1978).

TRIASSIC

In south-central and southeastern Montana, Triassic rocks are composed entirely of red mudstone, siltstone, and sandstone. Maximum thickness of these rocks is about 500 ft along the Wyoming border in south-central Montana (McKee and others, 1959, pl. 3). The Triassic strata are bevelled northward by erosion beneath the pre-Middle Jurassic unconformity and extend only into the southern part of the Williston basin (MacLachlan, 1972). Triassic rocks are absent in northern Montana, thin to absent in the Central Montana province, and pinch out northward in the Helena salient of the thrust belt. In southwestern Montana, the Triassic rocks are chiefly mudstone and clayey to silty limestone. Maximum thickness is about 2,000 ft in the vicinity of the Idaho border in southwest Montana (Scholten and others, 1955), but the strata thin northward, probably by erosional bevelling, and are not known to occur north of the Pioneer batholith. Triassic rocks do not contain petroleum reservoir beds or known source rock in Montana.

JURASSIC

Peterson (1972b) recognized four marine transgressive-regressive depositional cycles within the Jurassic sequence in Montana and nearby areas. An earlier Late Triassic or probable Early Jurassic cycle is represented in eastern Montana by red mudstone, siltstone, sandstone, and gypsum (Saude Formation of Zieglar, 1955) which lies unconformably upon northward bevelled strata of the underlying Triassic and Permian Spearfish Formation in southeastern Montana and upon successively older strata farther north in the Williston basin. Jurassic strata in eastern Montana consist mostly of red beds, evaporites, and carbonates in the lower part, overlain by marine mudstone and some sandstone. In western Montana, equivalent marine Jurassic strata consist of dark shales with interstratified thin limestone and sandstone beds of the Sawtooth and Rierdon Formations of the Ellis Group (figs. 3*B*, 4). Local uplifts in southwestern Montana and adjacent areas of the Helena salient (fig. 1) in Late Jurassic time led to the bevelling and removal of the older Jurassic rocks from these proto-Laramide uplifts and the deposition of nearshore sandstone of the Swift Formation. Equivalent strata in central and eastern Montana consist chiefly of shale and sandy shale. The nonmarine Morrison Formation represents the final Jurassic deposits in Montana. The Morrison consists of coastal plain deposits, chiefly sandstone, mudstone, limestone, and coal. Jurassic rocks are as much as 1,400 ft thick in the Williston basin in northeasternmost Montana. The rocks thin to about 750 ft in southeastern Montana and to less than 250 ft adjacent to the Belt arch and the Sweetgrass Arch and are locally absent because of Late Jurassic erosion and (or) nondeposition in some areas of western Montana. Jurassic rocks are thermally mature only in western Montana. The richest Jurassic source rock, that of the Sawtooth Formation (Clayton and others, 1983), is the principal source rock for the Cutbank oil field on the Sweetgrass Arch (D. D. Rice, unpub. data). Jurassic rocks are hydrocarbon reservoirs only locally on the eastern flank of the Sweetgrass Arch and on the Cat Creek anticline in the northeastern part of the Central Montana Uplift province (fig. 1).

CRETACEOUS

Earliest Cretaceous rocks throughout Montana are characterized by nonmarine sandstone, conglomerate, mudstone, and limestone. These rocks are about 100 ft thick in the northern Powder River basin in southeastern Montana, about 200 ft in northeastern Montana, and generally thicken westward to over 1,500 ft in western Montana according to McGookey and others (1972). Oil and gas are produced from the Kootenai Formation on the Sweetgrass Arch, with a source from Jurassic rocks, and in central Montana, with a source from Paleozoic rocks, and with migration of hydrocarbons from source to reservoir along faults. The thick, younger Cretaceous rocks consist of transgressive and regressive cycles of deposition, with eastward thinning deposits of nonmarine rocks and shoreline sandstones (representing regression of the sea) alternating with westward thinning deposits of marine shale (representing transgression of the sea). Volcanism and erosion of uplands in western Montana and adjacent Idaho provided an abundance of clastic debris that was distributed eastward across Montana from these western sediment sources during regressive cycles. Many shale units, particularly those deposited during transgressions, such as the Skull Creek, Mowry, and Marias River Shales, are kerogen-rich but generally are immature except in the western part of the State. Cretaceous rocks have yielded significant amounts of biogenic gas throughout the central and eastern part of the State and are the principal reservoirs of the Bowdoin dome, Bearpaw Mountains area, Sweetgrass Hills, Lake basin, and northern Big Horn basin. Thickness of the Cretaceous sequence ranges from about 3,500 ft of dominantly marine rocks in northeastern Montana to more than 10,000 ft of nonmarine rocks locally in southwestern Montana (Ryder and Scholten, 1973). Lower Cretaceous sandstones are the principal oil reservoirs of the giant Cutbank oil field and smaller fields on the Sweetgrass Arch. Younger Cretaceous sandstones are the principal resevoirs of biogenic gas in central and eastern Montana (fig. 3*B*).

OIL AND GAS POTENTIAL

The principal references for oil and gas potential of western Montana are Rice (1977) for the disturbed belt, Perry and others (1983) for southwestern Montana, and Peterson (1981b) for the Montana thrust belt as a whole. For eastern Montana, we refer to Rice (1979). American Association of Petroleum Geologists Memoir 15 is also useful, particularly articles by Glaze (1971), Kinnison (1971), and Stauffer (1971).

For purposes of this report and its accompanying map (Miscellaneous Investigations Series Map I–1541, in press), Federal Wilderness Lands in Montana with oil and gas potential are grouped or subdivided into 34 clusters of geologically related appraisal areas. Presence or absence of possible source rock, reservoir rock, and structural or stratigraphic traps are the most critical factors used in qualitatively assigning a zero, low, medium, or high oil or gas potential to each of these clusters. The structural and thermal history of each of the clusters was also carefully considered for those areas where such data are available (fig 2).

Cluster 1 tracts lie near the eastern margins of the Pioneer and Phillipsburg batholiths and southern margin of the Boulder batholith within the Helena salient of the Montana thrust belt. These are assigned a low to zero oil potential and low gas potential on the basis of proximity to these major intrusive bodies, absence of hydrocarbon shows in nearby drill holes, and intense thermal alteration of possible source rocks, which probably resulted in thermal destruction of hydrocarbons.

All but one tract in cluster 2 are located north and northwest of the Pioneer batholith, within the vicinity of the Grasshopper and Sapphire thrust plates of Ruppel and others (1981). These areas are assigned a zero oil potential and, optimistically, a low to zero gas potential on the basis of the possibility of thermogenic gas in generally low-grade Precambrian metamorphic rocks of this cluster. The Italian Peaks area, near the southwestern corner of Montana, is also grouped with this cluster. This area contains a stack of thrust sheets, involving chiefly Paleozoic rocks (Skipp and Hait, 1977; Skipp, 1979), with perhaps a somewhat higher oil or gas potential than the remainder of the cluster.

Cluster 3 includes tracts along the Idaho border in and adjacent to the Centennial Mountains. This cluster was assigned a low to zero oil potential and low gas potential in part on the basis of data presented by Perry and others (1983). The cluster lies near the Snake River volcanic plain and is an area that has been subjected to the thermal effects of major igneous activity. The timing of presumed hydrocarbon generation in Cretaceous and older rocks in this cluster predates development of the structural traps within the area. The Centennial fault, mountains, and adjacent topographic basin are late Tertiary to recent geologic features (Witkind, 1975, 1977) coincident with Snake River volcanism.

Cluster 4 lies within the Blacktail-Snowcrest and Madison-Gravelly uplifts of the southern Montana part of the Wyoming Structural province. This cluster was assigned a low oil and gas potential on the basis of the broad distribution of Archean (Precambrian) crystalline and Tertiary volcanic rocks at the surface. Although work in progress suggests that a major Laramide range-front thrust system lies within a part of this cluster, this structure overrides a Laramide basin that contains igneous intrusives and intercalated volcanics and lacks known source beds for hydrocarbons.

Clusters 5 and 6 lie within the Beartooth uplift, north of Yellowstone Park and are assigned a zero oil potential and perhaps optimistically a low to zero gas potential. The entire cluster is associated with Precambrian metamorphic and Tertiary volcanic rocks of the topographically elevated internal part of the Beartooth uplift. However, the northern tract in this cluster lies near the edge of this uplift and has remote possibilities for gas, depending on the untested subsurface structural configuration of this edge of the Beartooth uplift.

Cluster 7 consists of tracts along the northeastern margin of the Madison-Gallatin uplift and southern margin of the Crazy Mountains basin. It is assigned a low oil and gas potential. Drill holes in the region of these tracts have not yielded evidence of hydrocarbons, but sedimentary rocks, including possible reservoirs and source beds for hydrocarbons, are present.

Cluster 8 includes that part of Yellowstone National Park in Montana west of the Wyoming State boundary and adjacent to Idaho. This cluster is assigned an unknown oil and gas potential based on the poorly exposed Paleozoic and Mesozoic stratigraphic sequence and obscured structural relationships, hidden beneath the Tertiary volcanic rocks, and on the lack of any nearby deep drill holes. This cluster lies near the Yellowstone igneous caldera and Snake River volcanic plain, an area of high heat flow and hot springs, with the probable thermal destruction of any generated hydrocarbons (Chadwick and Leonard, 1979; Chadwick, 1981).

Cluster 9 includes a partial tract on the northeast flank of the Beartooth uplift. Like the northern part of cluster 5, it lies near the front of the uplift and is assigned a zero oil and low gas potential on the basis of the remote possibility of deep structural traps associated with possible mountain flank thrust faulting.

Clusters 10 and 11 occupy the crest of the Big Snowy Mountains uplift within the Central Montana Uplift province. This cluster was assigned a low to zero petroleum potential, as most of the possible source and reservoir rocks of this area are exposed on the breached anticline represented by this structure, and generated hydrocarbons would have escaped to the surface.

Clusters 12 and 13 lie on the northeast flank of the Little Belt Mountains. Cluster 12 was assigned a low oil potential and low to zero gas potential, as some potential reservoir rocks are present in the subsurface farther down on the flanks of this uplift and possible, though unlikely, structural traps and seals may be present. Cluster 13 was assigned a low to zero petroleum potential, as Precambrian rocks are exposed in the area. Surrounding Paleozoic rocks, otherwise containing potential source rock and reservoir rocks, are also exposed at the surface.

Cluster 14, in the northwestern part of the Big Belt Mountains, was assigned a zero oil potential and low to zero gas potential. This cluster is at the southern edge of the Adel Mountain Volcanics area and the northern edge of extensive exposures of Precambrian Belt sedimentary rocks. Important parts of the sedimentary section, including possible source rock and reservoir rocks, are absent by erosion or exposed along the margins of this area. Structural traps are either absent or obscure.

Cluster 15 lies in the frontal part of the Montana thrust belt within the southwest Montana recess. It is assigned a medium oil potential and medium to high gas potential on the basis of the possibility of structural traps in thermally mature strata expected to contain both source and reservoir rocks, beneath the thermally immature strata of the Tendoy thrust sheet (Perry and others, 1983). Possible source beds include kerogen-rich mudrock of the Permian Phosphoria Formation and kerogen-rich Upper Mississippian shale. Possible reservoir rocks include the Mississippian Madison Group and Pennsylvanian Quadrant Sandstone.

Cluster 16 lies in the western part of the Wyoming Structural province adjacent to the southwest Montana recess, on or associated with the Blacktail-Snowcrest uplift. This cluster was assigned a medium oil and medium to high gas potential on the basis of the presence of source rocks, possible reservoir rock, and structural traps associated with thrust faulting within this uplift and along the southeast margin of the uplift. The petroleum potential is discussed in more detail by Perry and others (1983).

Cluster 17 includes the eastern part of the Bob Marshall Wilderness and associated Wilderness Study Areas evaluated by Rice (1977). It is assigned a medium oil and high gas potential on the basis of the presence of kerogen-rich source rock, reservoir rocks, and numerous structural traps. The area is assigned a higher gas than oil potential as a result of organic geochemical studies by Clayton and others (1983) and because of the nature of nearby discovered hydrocarbon accumulations.

Cluster 18, just west of cluster 17, is assigned a low to zero oil potential and medium gas potential. In cluster 18, source rock and potential reservoirs are, or were, more deeply buried than in cluster 17, reducing porosity, permeability, and causing possible thermal destruction of heavier hydrocarbons to methane. Structural traps are similar to those of cluster 18 and are discussed by Rice (1977).

Cluster 19 occupies the western part of the Bob Marshall Wilderness and associated Wilderness Study Areas. This cluster is assigned a zero oil potential and low gas potential. This evaluation is based on the predominance of Precambrian sedimentary rock, which lacks any documented hydrocarbon potential, and the presence of large extension faults, along which hydrocarbons have likely escaped from inferred deeply buried Paleozoic rocks (beneath the Lewis and associated thrusts).

Cluster 20 includes the eastern part of Glacier National Park. This area is assigned a low oil potential and medium to high gas potential. It is the site of the first producing oil field in Montana. Oil possibilities appear restricted to fracture production from the Cone Member of the Cretaceous Marias River Shale (fig. 4). Limited fracture porosity and extremely low intragranular porosity within the Marias River in the adjacent Blackfeet Indian Reservation indicate a low potential for oil farther west. The giant Waterton gas field, north of the International Boundary, may project under the northern edge of cluster 20. Analogous structures are most likely present in this area beneath the Lewis thrust plate (Kulik, 1983).

Cluster 21 occupies the western part of Glacier National Park and adjacent northern extension of the Bob Marshall Wilderness. This cluster was assigned a low to zero oil potential and medium to low gas potential. Structurally this cluster is similar to cluster 19. However the presence of a deep Tertiary basin and associated hydrocarbon seepages along the western margin of Glacier National Park leads us to assign a slightly higher qualitative assessment than that assigned to cluster 19.

Cluster 22 occupies the eastern part of the northern Whitefish Range. We have assigned it a zero oil potential and low gas potential on the basis of the abundance of Precambrian Belt sedimentary rocks at the surface. Possible Mississippian and Pennsylvanian source and reservoir rocks occur east of this area beneath the eastern part of the major thrust system that underlies cluster 22. The assignment of potential is based on available surface geologic data and reasonable extrapolations of these data collected by J. W. Whipple and W. J. Perry, Jr.

Cluster 23, west and southwest of cluster 22, lies within the Proterozoic Belt basin of northwestern Montana, as does cluster 22 (Harrison and others, 1974). Major thrust sheets in this area are composed almost entirely of Precambrian rocks, although Paleozoic rocks could be present beneath some of these thrust sheets. The possibility of oil or gas production from such Paleozoic rocks and geophysical interpretations of subsurface structure have generated exploration interest in the region of clusters 22 and 23. On the basis of reasonable extrapolations of the surface structure, such rocks appear unlikely to be present in structural traps within the area of cluster 23. Cluster 23 is assigned a zero oil potential and low to zero gas potential, as rocks with demonstrated oil and gas potential are not yet known to occupy structural traps in this area.

Clusters 24 and 25 lie respectively south and southeast of the Bearpaw Mountains laccolith in a shallow gas-producing region of north-central Montana. Cluster 24 is within an area of natural gas production. It is assigned a medium to low oil potential and a high gas potential. Cluster 25 is within and adjacent to the Little Rocky Mountains igneous intrusives complex, an unfavorable area for hydrocarbons. It is assigned a zero oil and low to zero gas potential.

Clusters 26 and 27 lie within and adjacent to the Charles M. Russell Wildlife Refuge, an area of which the petroleum geology was intensively studied by Rice (1979). The Refuge is assigned a medium oil and gas potential. Because the area is situated on the northwest flank of the Blood Creek syncline, traps for Paleozoic oil will be chiefly stratigraphic in nature with local structural enhancement (Rice, 1979). Significant biogenic gas resources may be present in Upper Cretaceous reservoirs, stratigraphically controlled accumulations similar to those in adjacent areas (Rice, 1979).

Cluster 28 lies within the southwestern part of the Williston basin, an area of active hydrocarbon exploration and extensive production. This cluster is assigned a high oil and medium gas potential. The principal Paleozoic oil reservoirs in this province in Montana lie in the Upper Devonian Birdbear and Upper Mississippian Charles and Kibbey Formations (Rice, 1979). Recent oil discoveries have been made in limestones of the Mississippian Madison Group. Most of the oil fields are structurally controlled hydrocarbon accumulations with stratigraphic enhancement (Rice, 1979). The most recently discovered petroleum accumulations tend to lie in stratigraphic traps with structural enhancement.

Cluster 29 lies within the northern part of the Powder River basin in the area of the Tongue River syncline. It is assigned a low oil and medium gas potential. The cluster lies in a structural low near the margin of a basin that has not yielded abundant hydrocarbons in Montana. Although a significant number of possible reservoir rocks are present and possible stratigraphic traps may be present, possible source beds for hydrocarbons are generally immature.

Cluster 30 lies near the southeastern margin of the Montana portion of the Powder River basin. It is assigned a moderate oil and high gas potential on the basis of nearby hydrocarbon production in Wyoming and also on the basis of a more favorable structural location than cluster 29.

Cluster 31 lies near the northeastern margin of the Big Horn basin and is assigned a low to medium oil potential and a medium gas potential. The Montana portion of the Big Horn basin has historically yielded smaller amounts of hydrocarbons than that portion in Wyoming. Possible reservoir rocks are present in this area and stratigraphic traps may be present, but possible post-Paleozoic source rocks are generally immature.

Cluster 32 lies in the southern part of the Madison-Gravelly uplift adjacent to the Idaho-Montana State boundary and Snake River volcanic plain. It is assigned a low to zero oil and gas potential. The thermal effects of both Snake River volcanism and that of nearby Yellowstone Park decrease the hydrocarbon potential of this area with respect to cluster 4 to the north, an area structurally similar to cluster 32.

Cluster 33 lies within a small basin developed by Tertiary to recent extension faulting within the core of the Laramide Madison-Gravelly uplift. This cluster is assigned a medium oil potential and medium to high gas potential. Although other Tertiary basins in western Montana contain oil shale, a potential source rock, and possible reservoir beds, none of these Tertiary basins have yet yielded commercial quantities of hydrocarbons. If such kerogen-rich deposits are present in this basin, the thermal effects of nearby Tertiary volcanism and high heat flow may have led to thermal generation of hydrocarbons.

Cluster 34 lies east of the Bowdoin dome on the western margin of the Williston basin in northeastern Montana. It is assigned a low to medium oil potential and medium to high gas potential. This cluster lies near shallow gas accumulations in stratigraphic traps on the Bowdoin Dome. These biogenic gas accumulations are in Upper Cretaceous mudstones. Stratigraphic traps in Paleozoic and Cretaceous rocks may localize hydrocarbon accumulations within the area of cluster 34.

SUMMARY

Of the 6,930,433 acres of Wilderness Lands in Montana the potential acreage can be summarized as follows: high potential, 1,374.2 thousand acres; medium potential, 1,154.8 thousand acres; low potential, 1,325.9 thousand acres; low to zero potential, 1,212.1 thousand acres; zero potential, 1,825.4 thousand acres; and 38.2 thousand acres classified as having unknown potential. The petroleum potential by acreage of all Wilderness Land categories in the Western United States is shown in this circular by B. M. Miller in table 1, chapter P.

GLOSSARY

aulacogen A tectonic trough developed in the continental crust, bounded by extension faults. Aulacogens are nearly perpendicular to continental margins and open outward toward the adjacent continental margin (from Bates and Jackson, 1980).

biogenic gas Methane-rich gas formed by living organisms, particularly microorganisms.

contraction fault A fault in sedimentary rocks across which there has been bed-parallel shortening, giving rise to tectonic thickening (from Bates and Jackson, 1980); now in international use to mean a fault that shortens an arbitrary datum plane (McClay, 1981); thrust fault is a partial synonym.

extension fault A fault in sedimentary rocks across which there has been bed-parallel extension, giving rise to tectonic thinning (from Bates and Jackson, 1980); now in international use to mean a fault which extends an arbitrary datum plane (McClay, 1981); normal fault is a partial synonym.

foreland A stable area marginal to an orogenic belt (thrust belt), toward which the rocks of the belt were thrust (from Bates and Jackson, 1980).

graben An elongate, relatively depressed crustal unit or block that is bounded by faults on its long sides (Bates and Jackson, 1980).

karst A type of topography that is formed in limestone, gypsum, and other rocks by dissolution, and that is characterized by sinkholes, caves, and underground drainage (Bates and Jackson, 1980).

kerogen The disseminated organic material in sedimentary rocks that is insoluble in nonoxidizing acids, bases, and organic solvents (Hunt, 1979).

miogeocline A prograding wedge of shallow-water sediment at the continental margin (from Bates and Jackson, 1980).

sabkha An environment of sedimentation of evaporite-salt, tidal-flood, and wind-sorted deposits just above normal high tide level, occurring under arid to semiarid very hot climatic conditions on restricted coastal plains (from Bates and Jackson, 1980).

shelf A stable area that was periodically flooded by shallow marine waters and received a relatively thin cover of sediments (from Bates and Jackson, 1980).

thermally mature That attribute of source rock which pertains to its thermal history; geothermally heated such that oil generation has occurred.

thermogenic Generated by thermal cracking processes that result from increased temperature and geologic time.

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