U.S. DEPARTMENT OF INTERIOR

U.S. GEOLOGICAL SURVEY

GEOLOGIC FRAMEWORK AND HYDROCARBON PLAYS IN THE SOUTHWESTERN WYOMING BASINS PROVINCE

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Open-File Report 88-450-F

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1988

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GEOLOGIC FRAMEWORK AND HYDROCARBON PLAYS IN THE SOUTHWESTERN WYOMING BASINS PROVINCE

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INTRODUCTION

The Southwestern Wyoming Basins province is located in the Rocky Mountain foreland (fig. 1). It is a composite of several basins and adjacent uplifts in Wyoming, Colorado, and Utah. This irregularly shaped province is bounded on the north and northeast by the Bear Tooth Mountains, Absaroka Mountains, Wind River Mountains, and Sweetwater arch. The eastern boundary is the Laramie Range and the southern boundary passes through the northern part of the Medicine Bow Mountains and Sierra Madre Mountains along the Wyoming State line, the White River uplift, Piceance basin, and the Uinta Mountains. The Wyoming thrust belt forms the western boundary.

The province is one of several provinces in the United States that have recently been assessed for undiscovered recoverable oil and gas resources. The assessments utilized a play analysis approach in which plays were defined on the basis of certain geological characteristics. In this context, the purpose of this report is to provide the geologic framework and hydrocarbon plays for the U.S. Geological Survey's oil and gas assessment of the Southwestern Wyoming Basins province. There are numerous published reports concerning various aspects of the geology of this region and many of those have been utilized in this report.

STRUCTURE

The Southwestern Wyoming Basins province is located in the middle of the Rocky Mountains foreland structural region. Perhaps this area, more than anywhere else in the foreland region, typifies the foreland structural style. The province is composed of basement-involved uplifts and adjacent basins. Figure 2 is a generalized structure contour map of part of the Southwestern Wyoming Basins province showing the major structural features.

For the most part, the structural features in the province are the result of compressional deformation during the Laramide orogeny. There is some information, however, that indicates some of the structural features have a pre-Laramide origin. For example, in the Lost Soldier area on the northern part of the Rawlins uplift (fig. 1), Reynolds (1976) presented structural and stratigraphic evidence of pre-Laramide structural growth. Pre-Laramide structural movement has also been noted by Wach (1977) along the Moxa arch in the Green River basin, by Hansen (1986) in the eastern part of the Uinta Mountains, and by Stone (1986) in the Axial basin uplift of northwest Colorado. In all probability, many of the other structures in the province have experienced pre-Laramide deformation.

Although the style of pre-Laramide deformation is not well known, facies patterns in Paleozoic rocks indicate the presence of major uplifts through most of Paleozoic and Mesozoic time. The Transcontinental arch, ancestral Front Range uplift, Uinta Mountains arch, and the Pathfinder uplift (fig. 3) were structural features that clearly affected sedimentation patterns in pre-Cretaceous rocks (Tonnsen, 1986; Maughan and Perry, 1986). Recurrent movement on some lineaments has probably also occurred through much of Phanerozoic time, such as the northeast-trending

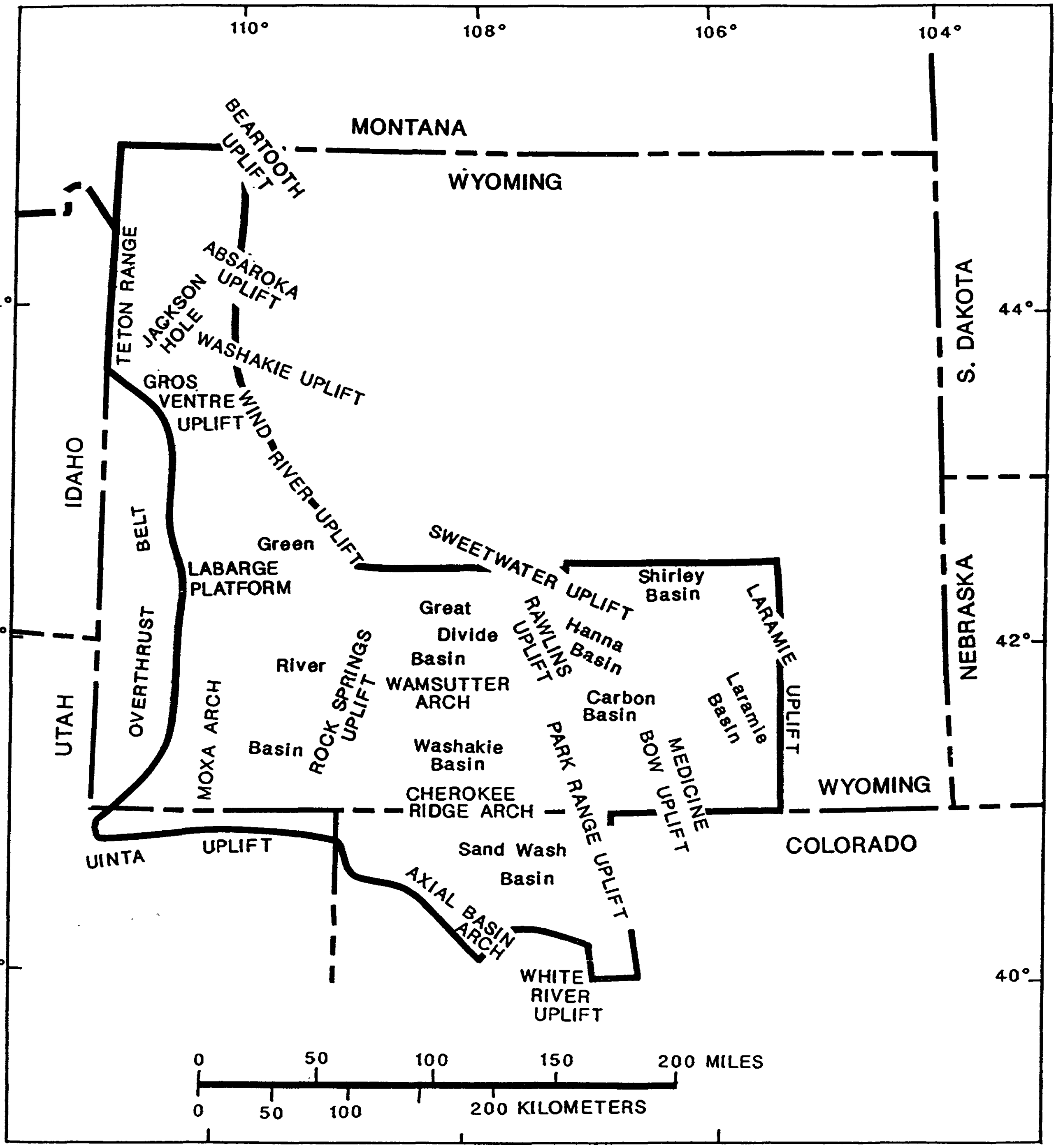

Figure 1.--Index map showing location of the Southwestern Wyoming Basins province and major structural features.

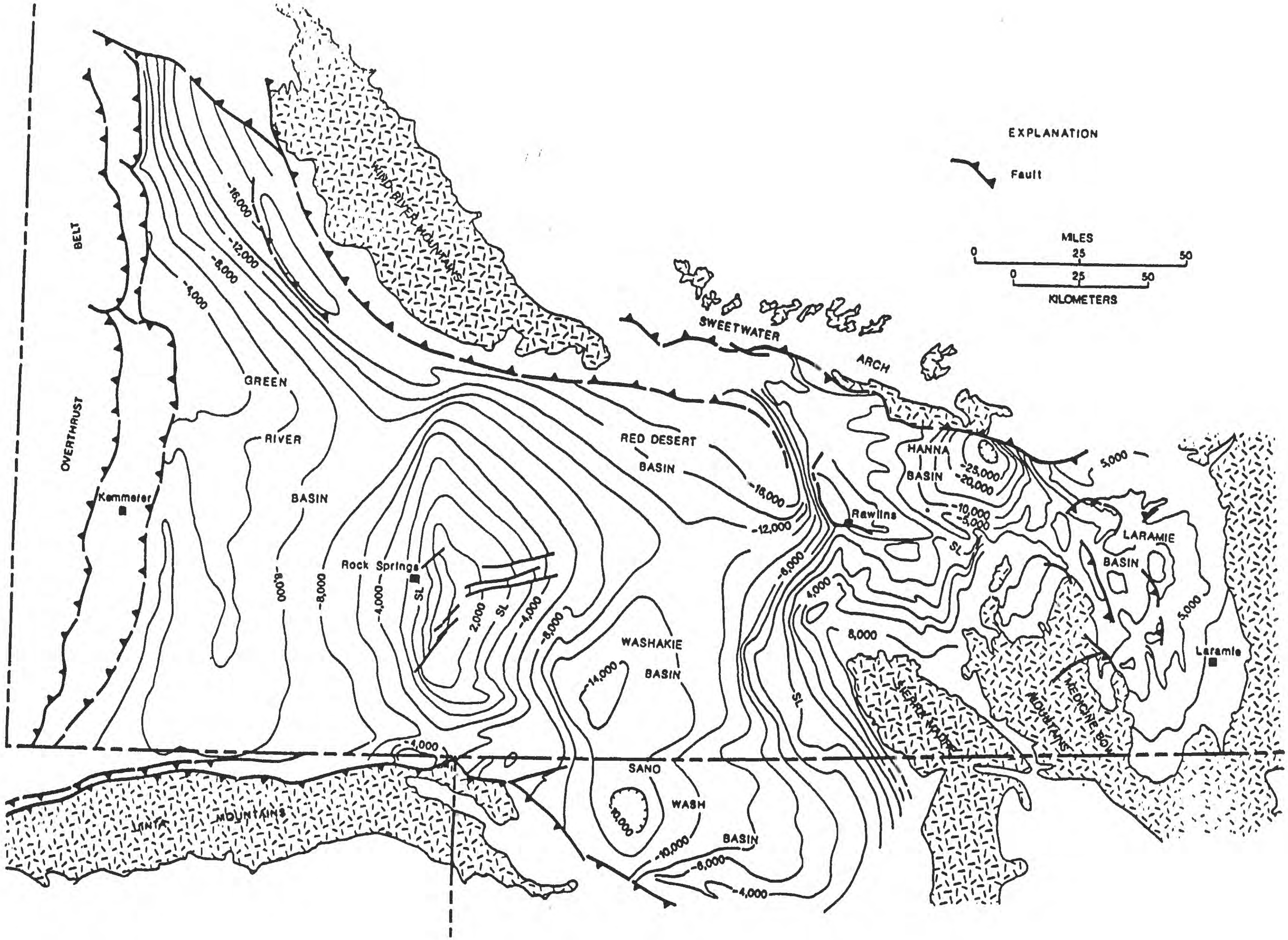

Figure 2.--Structure contour map of part of the Southwestern Wyoming Basins province. Structural datum is the top of the Lower Cretaceous Dakota Sandstone. Contour interval 2,000 and 5,000 ft. Modified from Skeeters and Hale (1972).

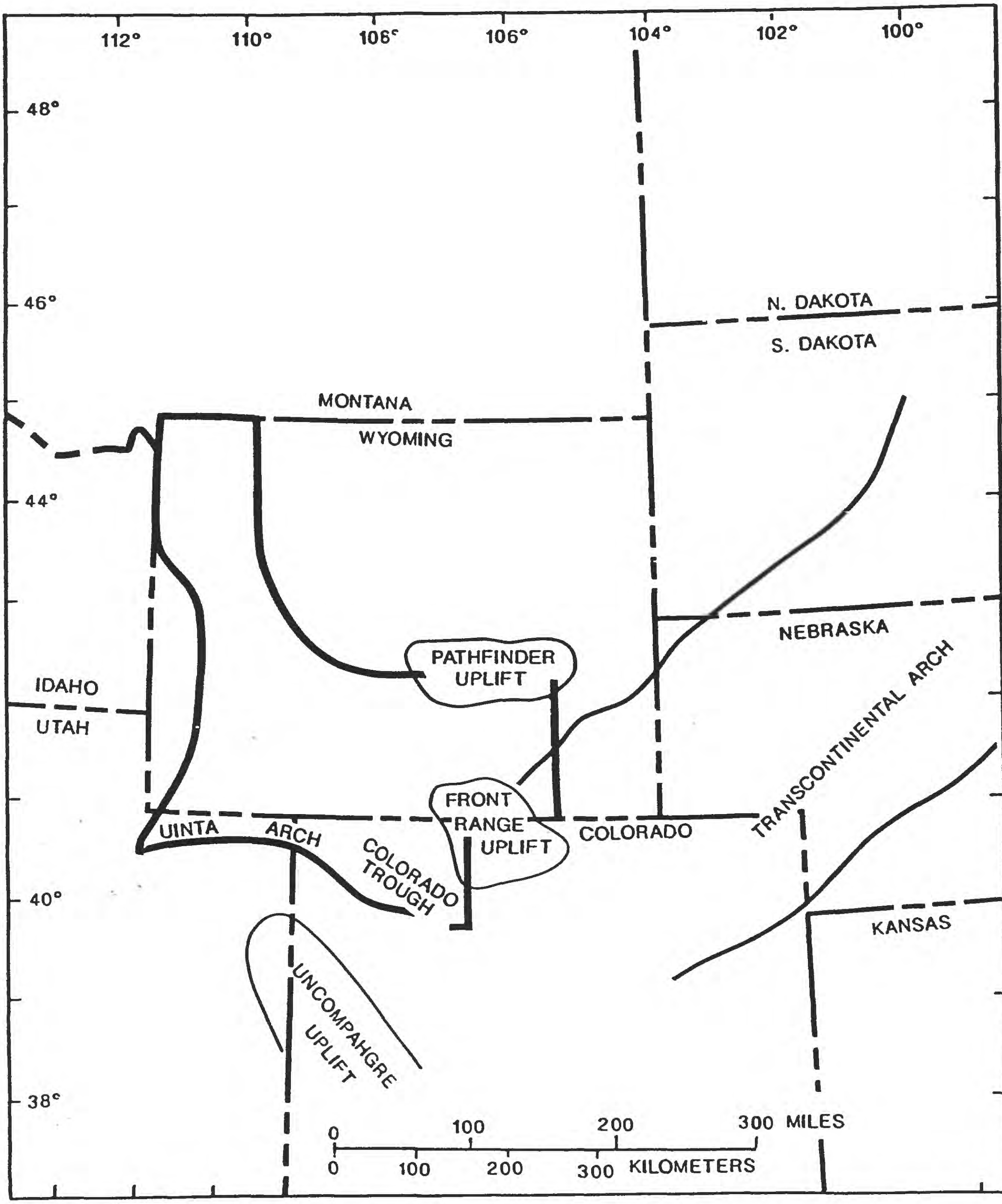

Figure 3.--Map showing major structural features affecting sedimentation patterns in the Southwestern Wyoming Basins province (boldly outlined area) during the Paleozoic and Mesozoic Eras.

Sybille lineament in the southern end of the Laramie Range (Mullen Creek-Nash Fork shear zone of Houston et al., 1968) and the northeast-trending Blackstone Lineament (Wyoming lineament of Blackstone, 1956) north of the Sierra Madre and Medicine Bow Mountains (fig. 4).

STRATIGRAPHY

The thickness of sedimentary rocks in the province is highly variable. In the Hanna basin, one of the deepest basins in the Rocky Mountain region, Phanerozoic sedimentary rocks are over 42,000 ft thick (Matson, 1984). In the northern part of the Green River basin and in the Washakie basin (fig. 1), the depth to Precambrian basement is about 32,000 ft, while the Shirley and Laramie basins (fig. 1) have about 7,000 and 13,000 ft, respectively, of Cambrian through Tertiary rocks. A generalized correlation chart of stratigraphic units within the province is shown in figure 5.

Sedimentation in the province occurred in three stages, referred to as shelf, foreland, and intrabasinal. From Middle Cambrian through Middle Jurassic time, the province was located along the eastern edge of the Cordilleran miogeosyncline (Armstrong and Oriel, 1965) and was part of the Rocky Mountain shelf as defined by Peterson (1977). During this sedimentation stage, the province was periodically inundated from west to east by shallow-water seas. The source of siliciclastic sediments was east of the province. In Late Jurassic time, the long period of shelf sedimentation ended and foreland sedimentation was initiated. Siliciclastic sediments, previously derived from the east, began to be derived from the west. Emerging highlands in eastern Idaho and central Utah became the principal sources of clastic sediments. The intrabasinal sedimentation stage began in middle to late Maestrichtian time and is marked by the development of discrete foreland uplifts and adjacent basins. During this stage, sediments derived from local uplifts were deposited in adjacent basins, which in many areas restricted depositional patterns to specific basins.

CAMBRIAN SYSTEM

In ascending order, Cambrian rocks in the southwestern Wyoming province include the Flathead Sandstone, Gros Ventre Formation, and the Gallatin Limestone. Basal Cambrian rocks are composed of sandstone and conglomeratic sandstones (Flathead Sandstone) deposited unconformably on Precambrian rocks (Lochman-Balk, 1972). Younger Cambrian rocks are predominantly marine carbonates that are about 1,000 ft thick in the western part of the area (Peterson, 1977). These rocks grade eastward into shaly limestones, shales, and sandstones and thin to a zero edge in the vicinity of the Sierra Madre-Park Range and Medicine Bow Mountains, reflecting the presence of the Transcontinental arch.

ORDOVICIAN SYSTEM

Ordovician rocks in this province are largely composed of limestone and dolomite of the Bighorn Dolomite. Generally, the Bighorn Dolomite is fossiliferous with local carbonate mounds or reef buildups (Peterson, 1977). In the western part of the province, it is as thick as 500 ft, and in the vicinity of the Sierra Madre uplift, it is truncated. The zero

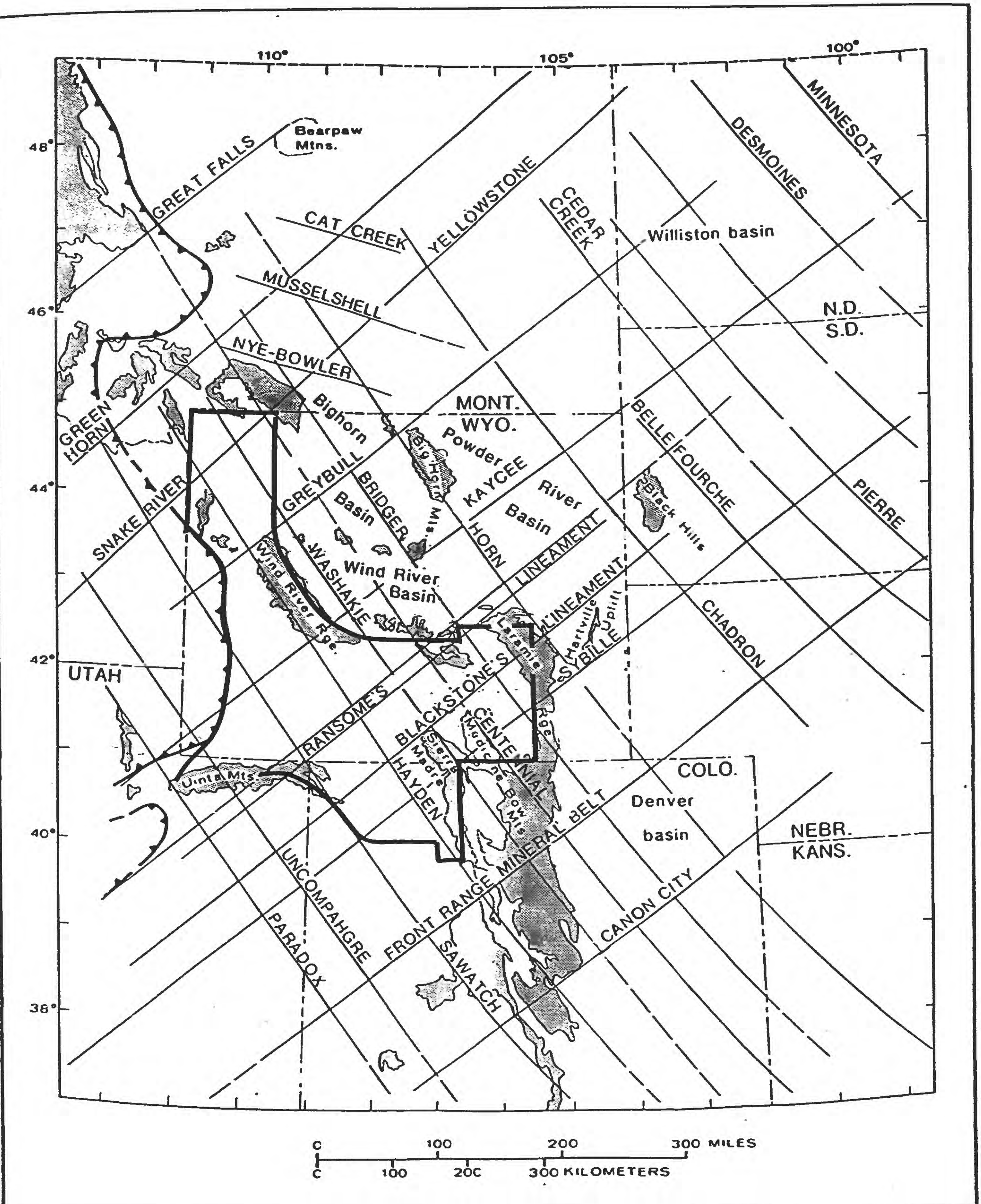

Figure 4.--Map showing principal lineaments in and near Southwestern Wyoming Basins province (boldly outlined area). Modified from Maughan and Perry (1986).

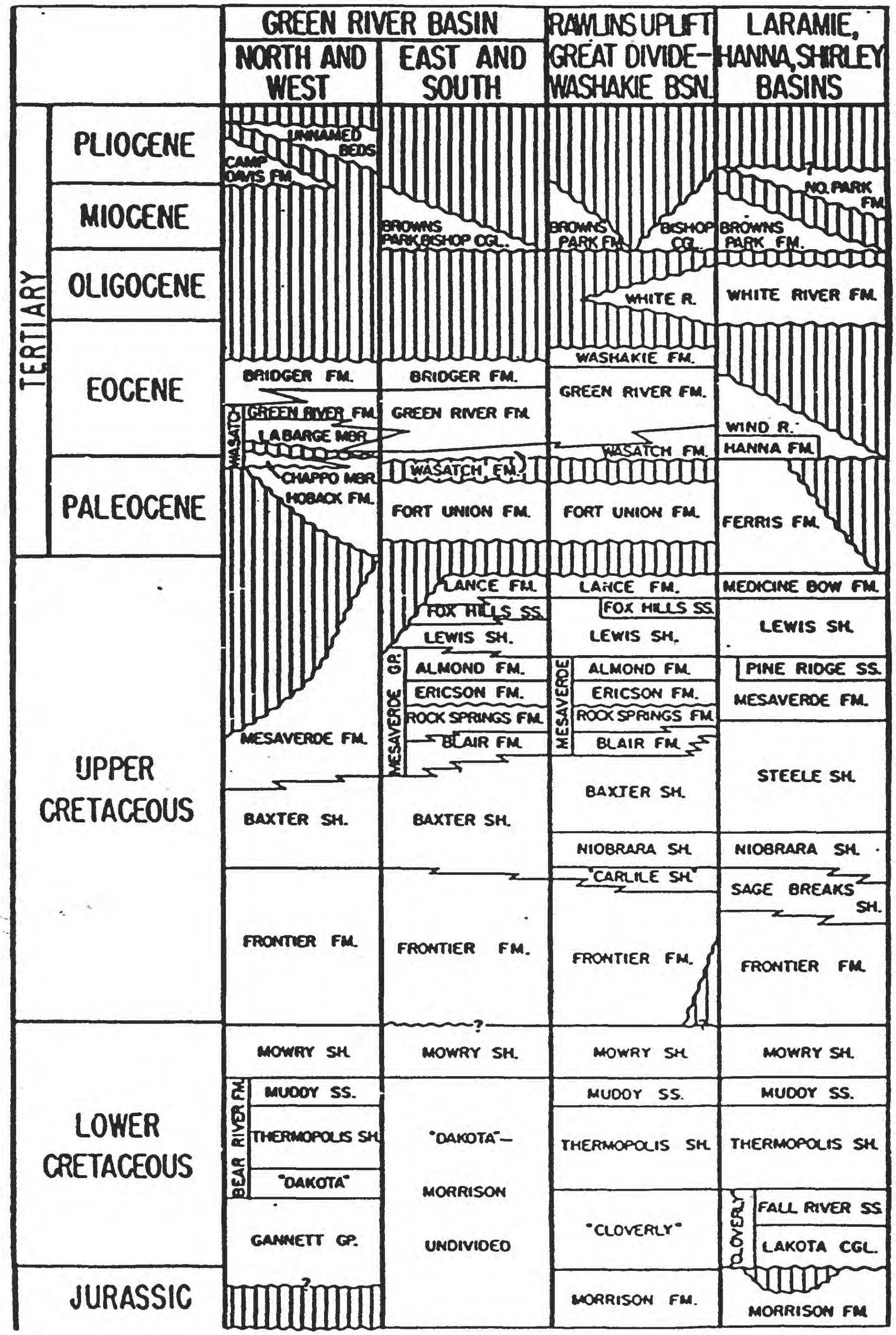

Figure 5.--Generalized stratigraphic correlation chart in the Southwestern Wyoming Basins province.

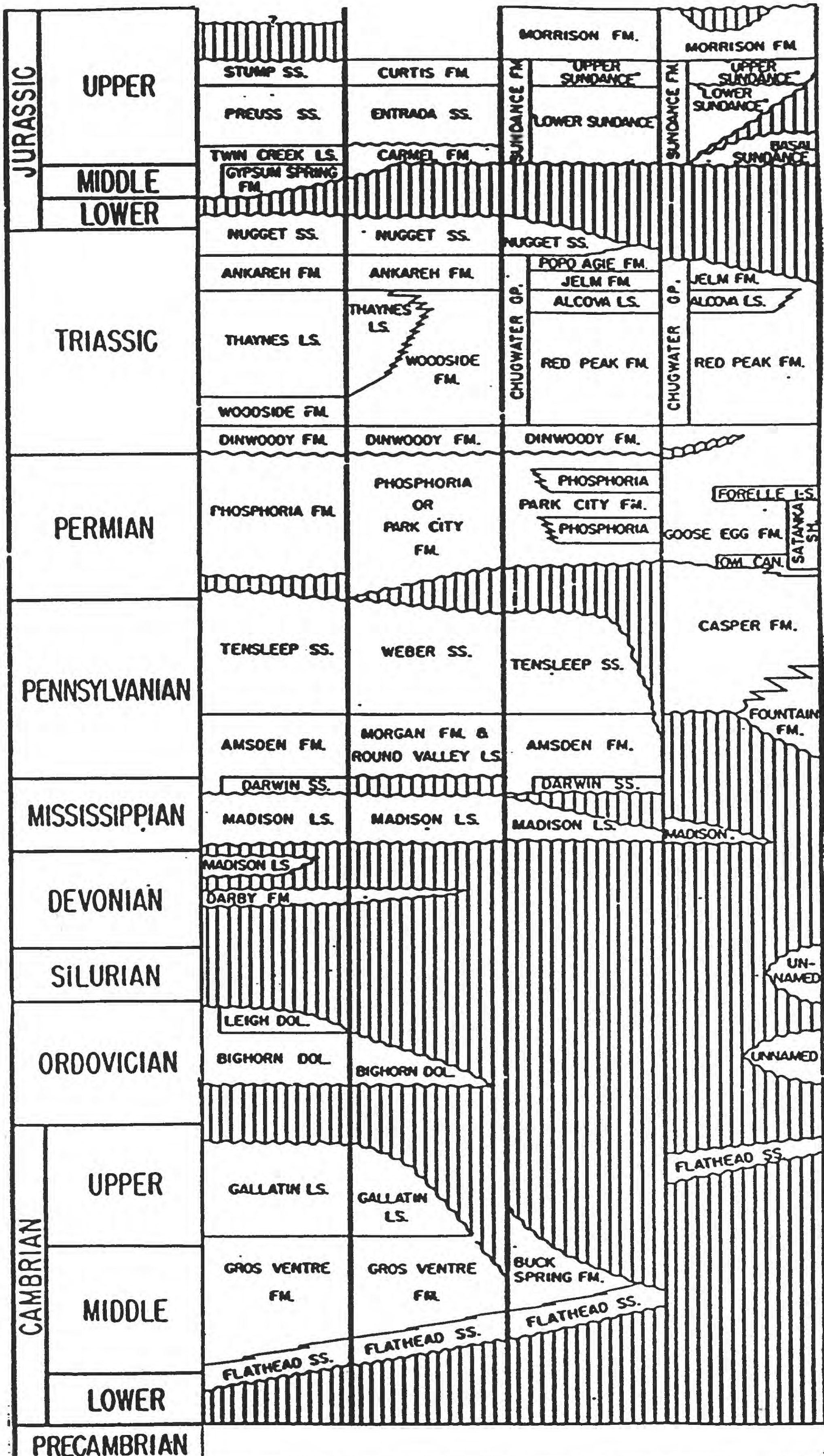

Figure 5.--Continued.

edge of the Bighorn Dolomite is nearly coincident with the northwest flank of the Transcontinental arch (Peterson, 1977; Peterson and Smith, 1986).

SILURIAN SYSTEM

There are no known Silurian rocks present in the province. It is likely that Silurian rocks were deposited in the western part of the province but were subsequently eroded (Peterson, 1977), perhaps in response to uplift and erosion during the Devonian Antler orogeny.

DEVONIAN SYSTEM

Devonian rocks unconformably overlie older Paleozoic rocks in the province. The Upper Devonian Darby Formation, in part, equivalent to the Chaffee Group in northwestern Colorado, consists of fine-grained sandstone, fossiliferous carbonate, and anhydrite. The Darby is about 200 ft thick in the western part of the province and thins to an erosional edge in the vicinity of the Rawlins uplift. In the Colorado trough (fig. 3), a depressed area between the Uncompahgre uplift (fig. 3) to the southwest and Front-Range uplift (fig. 3) to the northeast, approximately 250-300 ft of the Upper Devonian Chaffee Group is present. The Chaffee Group consists of the Parting Sandstone and overlying Dyer Formation. Facies relationships in the Parting Formation indicate that the Front-Range uplift may have been the source of the clastic sediments (Baars and Campbell, 1968; Baars, 1972).

MISSISSIPPIAN SYSTEM

Mississippian rocks in the province include the Madison Limestone and the Darwin Sandstone Member of the Mississippian-Pennsylvanian Amsden Formation. The Madison unconformably overlies older Paleozoic rocks and is unconformably overlain by younger Paleozoic rocks. The Madison was deposited in shallow-water shelf environments and consists of limestone and dolomite (Craig, 1972; Rose, 1977). The thickness varies from an erosional edge along the flanks of the Sierra Madre uplift and Medicine Bow Mountains (northwest edge of the Transcontinental arch) to over 1,000 ft along the northern flank of the Uinta Mountains (Craig, 1972).

Unconformably overlying the Madison Limestone is the Darwin Sandstone of Chester age. In western and central Wyoming, the Darwin has been interpreted as an estuarine deposit covering the karst topography of the Madison Limestone (Craig, 1972). The Darwin is as thick as 1,500 ft in the west-central and north-central part of the province.

PENNSYLVANIAN SYSTEM

Pennsylvanian strata in the province include a large number of stratigraphic units such as the Morgan Formation, Fountain Formation, Amsden Formation, Tensleep Sandstone, Quadrant Sandstone, Casper Formation, Maroon Formation, and Weber Sandstone. In contrast to the underlying Paleozoic rocks which were deposited under relatively uniform conditions, Pennsylvanian rocks are characterized by abrupt facies changes and great variations in thickness (Mallory, 1972). Pennsylvanian rocks range in thickness from an erosional edge around the periphery of the

Sierra Madre uplift, Medicine Bow Mountains, and Laramie Range (Front-Range uplift) to about 1,300 ft in the Greater Green River basin (Sweetwater trough of Mallory, 1972) and the Axial arch uplift (Colorado trough).

In general, the facies patterns of Pennsylvanian rocks reflect the ancestral Front-Range uplift and Pathfinder uplift of central Wyoming. Marginal to these uplifts are coarse arkosic sandstones and conglomerates that grade basinward into sandstones and carbonates. Sandstones of the Tensleep are well sorted, cross bedded, and locally contain beds of sandy carbonate rock and calcareous sandstone. The environment of deposition in the well-sorted quartzose sandstone of the Tensleep and equivalent rocks is eolian. Sadlick (1955, 1957) suggested a shallow-water marine environment for the Morgan Formation. Driese and Dott (1984) have proposed alternating marine and eolian environments of deposition for the upper member of the Morgan in the Uinta Mountains area.

PERMIAN SYSTEM

Permian rocks in the province range in thickness from 0 to about 500 ft and consist of shale, siltstone, sandstone, and carbonate. Several stratigraphic units are recognized, including the Tensleep Sandstone, Weber Sandstone, Casper Formation, Phosphoria Formation, Park City Formation, Goose Egg Formation, and Chugwater Formation. Throughout the area, Permian rocks unconformably overlie Pennsylvanian rocks. During Early Permian time, depositional events were similar to those during Pennsylvanian time. In Late Permian time, the province and adjacent areas were inundated by a shallow-water sea, represented by the Phosphoria Formation.

Rocks of Wolfcamp age are present in only part of the province. In the Hanna, Laramie, and Shirley basins, the Wolfcamp Casper Formation and Tensleep Sandstone are present whereas Wolfcamp rocks in the Greater Green River basin and Jackson Hole (fig. 1) area were removed by pre-upper Leonard erosion (Rascoe and Baars, 1972). Upper Leonard and Guadalupe rocks occur in most of the area. In the western part of the area, they consist of interbedded carbonate rocks, calcareous sandstone, calcareous siltstone, and phosphatic shale in the Phosphoria Formation. In the eastern part of the area, these rocks grade into red silty sandstone and shale of the Chugwater Formation.

TRIASSIC SYSTEM

Triassic rocks in the province are chiefly redbed sequences of shale, siltstone, and sandstone, with minor amounts of limestone. Along the western edge of the province, Lower to Upper Triassic rocks are characterized by intertonguing relationships between marine limestone and shale of the Dinwoody Formation and Thaynes Limestone and nonmarine shale, siltstone, and sandstone of the Woodside and Ankareh Formations. Overlying these units is the Upper Triassic(?)-Lower Jurassic Nugget Sandstone. The maximum thickness of Triassic rocks is about 3,000 ft, along the western edge of the province. In the central and eastern parts of the province Triassic rocks thin to less than 1,000 ft and are composed of sandstone, siltstone, shale, and minor amounts of limestone in the Goose Egg and Red Peak Formations, Alcova Limestone, Jelm Formation, and Nugget Sandstone (MacLaughlin, 1972).

JURASSIC SYSTEM

The Jurassic System in the province is dominated by deposition of marine shale, sandstone, and limestone to the west and intertonguing continental to marine sandstone, siltstone, and varicolored shales to the east. A major change of facies patterns, however, in Upper Jurassic rocks marks a shift in the location of source terranes for the remainder of the Mesozoic Era.

In the western part of the province, Jurassic stratigraphic units, in ascending order, include the Nugget Sandstone, Twin Creek Limestone, Preuss Formation, Stump Formation, and Morrison Formation. The maximum thickness is about 2,500 ft (Peterson, 1972). To the east, Jurassic rocks thin to less than 500 ft and include the Gypsum Spring, Sundance, and Morrison Formations.

Lower Jurassic rocks are represented by the widespread occurrence of the eolian Nugget Sandstone. The age of the Nugget Sandstone has been considered to be Triassic and Jurassic but more recent work indicates that the age of the Nugget may be restricted to Early Jurassic (Fred A. Peterson, pers. commun., 1988). During deposition of Middle to Upper Jurassic rocks, an eastward transgression occurred in which the marine Twin Creek Limestone and nonmarine Gypsum Spring Formation and lower part of the Sundance Formation were deposited. Overlying these rocks in the western part of the province is the nonmarine Upper Jurassic Stump Formation and in the eastern part of the province, the marginal marine upper part of the Sundance Formation. The source of clastic sediments in these rocks, as indicated by facies patterns, is from western highlands. The youngest Jurassic rocks in the province are nonmarine deposits of conglomerate, sandstone, siltstone, and shale in the Morrison Formation. The Morrison was deposited mainly in a fluvial-dominated environment.

CRETACEOUS SYSTEM

In the Southwestern Wyoming Basins province and throughout the Rocky Mountain region, deposition of Cretaceous rocks is notable because of the development of the Western Interior Seaway that extended from the Gulf of Mexico to the Arctic Ocean. Throughout most of Cretaceous time, sedimentation is marked by several well-documented cycles of marine transgressions and regressions.

In the Southwestern Wyoming Basins province, Lower Cretaceous rocks unconformably overlie the Jurassic Morrison Formation and consist of conglomeratic sandstone, sandstone, siltstone, and shale. Placement of the basal contact is uncertain in some areas because of the paucity of biostratigraphic data and the lithologic similarity to underlying Jurassic rocks. Within Lower Cretaceous rocks, there are two transgressive cycles of marine and nonmarine rocks that mark the beginning of several transgressions and regressions through most of the Cretaceous. These Lower Cretaceous transgressive cycles are recorded in the eastern part of the area by deposition of the Fall River Sandstone, Thermopolis Shale, Muddy Sandstone, and Mowry Shale. To the west, equivalent units are the Bear River Formation, Dakota Sandstone, and Mowry Shale. In the western part of the province, sandstones in these cycles were deposited in fluvial-dominated environments that grade eastward into marginal marine sandstones. Lower Cretaceous rocks range in thickness from about 1,500 ft in the Green River basin to about 300 ft in the Sand Wash and Laramie basins.

Unconformably overlying Lower Cretaceous rocks is the Upper Cretaceous Frontier Formation. The Frontier is composed of a marine to nonmarine sequence of sandstone and shale that represent a transgressive and regressive cycle of deposition. In western Wyoming, nonmarine and nearshore marine siliciclastic rocks grade eastward into offshore marine siliciclastic and carbonate units (Merewether and Cobban, 1986). Unconformities within the Frontier are indicative of transgressions and regressions as well as structural deformation. The Frontier is thickest in the western part of the Green River basin (~1,100 ft) and thins to the east to about 550 ft in the Laramie basin.

Conformably overlying the Frontier is the marine Upper Cretaceous Steele Shale and equivalent rocks, the Mancos, Cody, Baxter, and Hilliard Shales. The Steele Shale and equivalent rocks are thickest in the Laramie and Shirley basins, and thin to the west. Within the Steele Shale, there are a few sandstones and siltstones, such as the Airport Sandstone Member in the vicinity of the Rock Springs uplift that were deposited as shelf deposits. In the Laramie basin, a marine limestone and limy shale, the Niobrara Formation, overlies the Frontier Formation. The Niobrara grades westward into marine shales that are indistinguishable from adjacent shales.

Overlying the Steele Shale and equivalent rocks is a thick sequence of nonmarine and marginal marine siliciclastic rocks. In the Green River basin, this sequence of rocks is up to 10,000 ft thick and is composed of sandstone, siltstone, shale, and coal. With the exception of the lower few hundred feet of rocks, which were deposited in nearshore marine environments, the entire sequence was deposited in nonmarine fluvial and upper deltaic environments. East of the Green River basin, these rocks thin and grade into and intertongue with nonmarine and nearshore marine shales, siltstones, and sandstones of the Steele Shale, Mesaverde Group, Lewis Shale, Fox Hills Sandstone, Lance Formation, and Medicine Bow Formation. The last marine transgression in the Wyoming province is represented by the Lewis Shale which extended as far west as the west flank of the Rock Springs uplift.

TERTIARY SYSTEM

Beginning in Late Cretaceous time and continuing into the Tertiary, many of the present-day structural features became more prominent, providing local sources for sediments. As a consequence, the stratigraphic units are less continuous and more variable than older rocks in terms of lithology and facies relationships. Tertiary rocks in the province consist of conglomerates, sandstones, siltstones, shales, limestones, and coals that were deposited in fluvial to lacustrine environments. The thickest sequence of Tertiary rocks is in the Hanna basin, where they may be as great as 16,000 ft (Hansen, 1986). In the Washakie basin, Tertiary rocks are about 13,000 ft thick. The contact between Tertiary and Cretaceous rocks is unconformable. Throughout most of the province, lower Tertiary rocks include the Paleocene Fort Union Formation. The Fort Union is generally coal-bearing and is lithologically similar to underlying Cretaceous rocks. The Fort Union grades upward into the Eocene Wasatch Formation which in turn passes upward and intertongues with the Eocene Green River Formation. Unconformably overlying these lower Tertiary rocks are Oligocene and Miocene rocks such as the White River Formation in the Laramie and Shirley basins and the Browns Park and Bishop Conglomerate in the Sand Wash basin.

HYDROCARBON OCCURRENCE

The Southwestern Wyoming Basins province is, in general, a maturely explored province. The producing trends in the province are shown in figure 6, and the principal oil and gas fields are listed in table 1. Most hydrocarbon production is from anticlinal accumulations around the margins of basins such as the Lost Soldier, Wertz, Wilson Creek, Table Rock, and Brady fields. There are very few purely stratigraphic accumulations. The most notable stratigraphic accumulation occurs in the Patrick Draw field, located on the east side of the Rock Springs uplift (fig. 6, table 1). In the Patrick Draw field, oil is trapped in updip pinchouts of the Upper Cretaceous Almond Formation (Weimer, 1965, 1966). The production of oil and associated gas is primarily from fields located in and adjacent to the Laramie basin, the Rawlins uplift, the Axial arch uplift, and the La Barge platform in the west-central part of the Green River basin. With few exceptions, hydrocarbon production in the Greater Green River basin is nonassociated gas. Producing reservoirs range from Cambrian through Tertiary rocks and are composed dominantly of sandstone with minor carbonate reservoirs.

PETROLEUM SOURCE ROCKS

There is a paucity of information concerning petroleum source rocks in the region. The evaluation of source rocks in the province is largely inferred from studies conducted in adjacent areas (Claypool et al., 1978; Clayton and Swetland, 1977; Clayton and Ryder, 1984; Nuccio and Schenk, 1986) and a consideration of the lithologic composition. Specific petroleum source-rock studies conducted in the province include a report on the Lower Cretaceous Mowry Shale by Burtner and Warner (1984) and an investigation of Upper Cretaceous and lower Tertiary rocks in the Greater Green River basin by Law (1984).

Based on studies conducted in areas adjacent to the Southwestern Wyoming Basins province, the Permian Phosphoria Formation and the Mowry Shale are the principal sources of oil and gas. Other stratigraphic units that may have some potential for oil generation include some of the Mississippian and older carbonate rocks, the Pennsylvanian Amsden Formation, the Triassic Thaynes Limestone, the Jurassic Twin Creek Limestone, the Lower Cretaceous Thermopolis Shale, the Upper Cretaceous Niobrara Formation, and the Upper Cretaceous Lewis Shale.

The organic-rich shales and phosphorite in the Phosphoria Formation are considered to be a good petroleum source rock in the western part of the province (Claypool et al., 1978; Powell et al., 1975; Maughan, 1984). Maughan (1984) suggested that in northwestern Colorado oil in the Pennsylvanian Tensleep was probably derived from the Phosphoria. Sheldon (1967) speculated that oil in upper Paleozoic rocks in central and eastern Wyoming was generated from Phosphoria shales in western Wyoming and eastern Idaho and migrated eastward into favorable reservoirs.

An alternative source of oil in upper Paleozoic reservoirs may be from the Powder River and Denver basins, in black shales in the middle member of the Permian-Pennsylvanian Minnelusa Formation. Clayton and Ryder (1984) have documented the occurrence of excellent source-rocks (average total organic coal content of 5.4%) in the Powder River and Denver basins. Oil sourced from these rocks would not require long-distance migration.

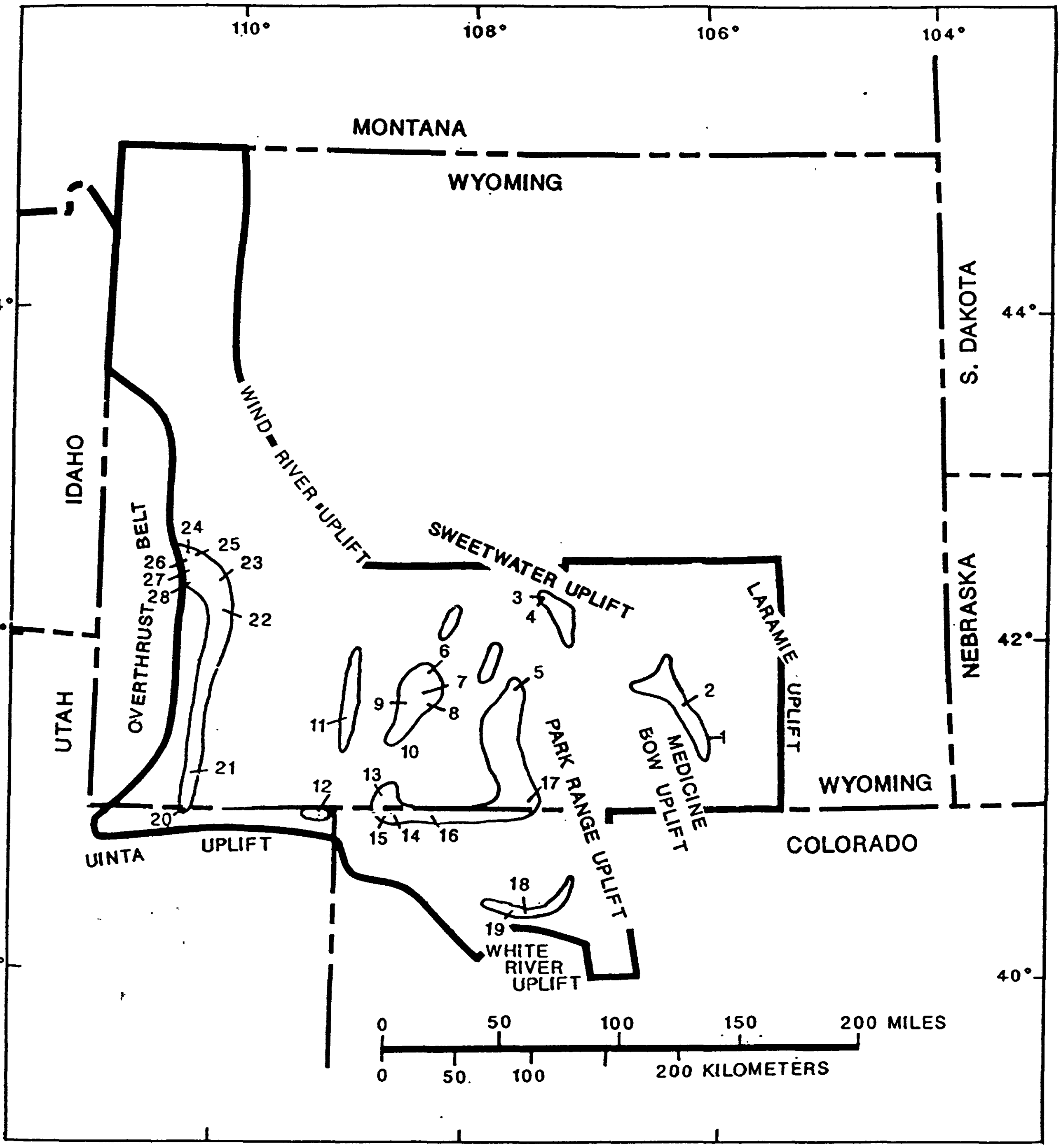

Figure 6.--Map showing oil and gas producing trends and principal fields in the Southwestern Wyoming Basins province. Numbers refer to oil and gas fields listed in table 1.

Table 1.--Cumulative oil and gas production for selected fields in the Southwestern Wyoming Basins province. Field numbers refer to approximate locations as indicated in figure 6.

Field No.	Field Name	Oil (BBLS)	Gas (MCF)
3	Lost Soldier	205,395,877	76,799,987
9	Patrick Draw	78,392,677	255,816,348
10	Brady	50,257,368	240,587,093
12	Clay Basin	515,704	151,887,046
4	Wertz	92,671,038	26,457,573
20	Bridger Lake	10,882,721	47,793,636
27	La Barge	23,477,197	217,681,475
23	Birch Creek	10,386,196	159,330,629
25	Big Piney	6,587,875	162,266,056
21	Church Buttes	182,234	343,439,492
24	Tip Top	5,063,891	321,728,920
28	Hogsback	8,394,811	301,323,312
2	Rock River	38,295,425	9,000,443
8	Table Rock	3,836,240	400,273,741
11	Baxter Basin South	5,934	131,250,909
13	Canyon Creek	1,203,477	237,050,840
6	Desert Springs	1,975,733	243,638,800
5	Echo Springs	2,851,455	113,622,347
22	Green River Bend	9,728,127	173,500,876
1	Queely	12,381,361	0
17	West Side Canal	2,728	122,974,952
14	Hiawatha	3,860,796	131,499,039
19	Wilson Creek	82,945,381	61,705,185
7	Arch	18,208,705	82,059,200
26	Dry River	13,942,762	69,346,374
15	Hiawatha West	224,623	139,208,472
18	Iles	18,718,588	2,044,696
16	Powder Wash	6,994,288	214,844,003

The Mowry and Skull Creek Shales have been recognized for many years as one of the more important hydrocarbon source rocks in the Rocky Mountain region (Rubey, 1928; Schrayer and Zarella, 1963, 1966; Clayton and Swetland, 1980; Warner, 1982; Burtner and Warner, 1984). The Mowry Shale through most of the Southwestern Wyoming Basins province contains 1-2% organic carbon (Burtner and Warner, 1984) and is a likely source of oil and gas for many Cretaceous and younger reservoirs. The Mowry and equivalent rocks may also have been the source of hydrocarbons in older reservoirs as suggested by Clayton and Swetland (1980), Momper and William (1979), and Warner (1982).

Gas is likely sourced from several stratigraphic units. In the Greater Green River basin, carbonaceous shales and coal beds in Upper Cretaceous and lower Tertiary rocks are the primary sources of gas in Upper Cretaceous and lower Tertiary reservoirs (Law, 1984).

PLAY IDENTIFICATION

The following plays were identified in the Southwestern Wyoming Basins province: 1) Rock Springs, 2) Cherokee, 3) Axial, 4) Moxa, 5) Platform, 6) Jackson Hole, 7) Basin Margin, 8) Subthrust, 9) Basin Center, and 10) Tight gas reservoirs. The plays were selected on the basis of regional structural and stratigraphic considerations, evaluation of the exploration and development history, and the likelihood of undiscovered, recoverable oil or gas accumulations in excess of 1 MMBO or 6 BCFG. Plays discussed range from proven, long-established plays to untested highly speculative plays. Play outlines are shown in figure 7.

Rock Springs Play

The Rock Springs play includes the Rock Springs uplift and the western part of the Wamsutter arch (fig. 7). The western boundary is coincident with the surface trace of a buried high-angle thrust fault (Garing and Tainter, 1985). The area has numerous northeast- and east-northeast-trending normal faults. Along the crest of the uplift are several small faulted anticlinal closures. On the east flank of the uplift are two notably significant anticlinal folds (Table Rock and Brady structures) bounded on their west flanks by high-angle reverse or thrust faults. The Rock Springs uplift is believed to be primarily due to Laramide deformation.

Reservoirs

The principle reservoirs include the Mississippian Madison Limestone, Pennsylvanian Weber Sandstone, Permian Phosphoria Formation, Jurassic Nugget and Entrada Sandstones, Lower Cretaceous Dakota Sandstone, Upper Cretaceous Frontier Formation, Blair Formation, Almond Formation, Lewis Shale sandstones, and Eocene Wasatch Formation (Colburn, 1979; Nicolaysen, 1979). In general, reservoir porosity exceeds 10% and permeability exceeds 40 md.

Traps and Seals

Nearly all production in this play is from structural traps along the crest of the uplift and from faulted anticlines on the east side of the uplift. A notable exception is the Patrick Draw field located on the crest of the Wamsutter arch, on the east flank of the uplift (fig. 6,

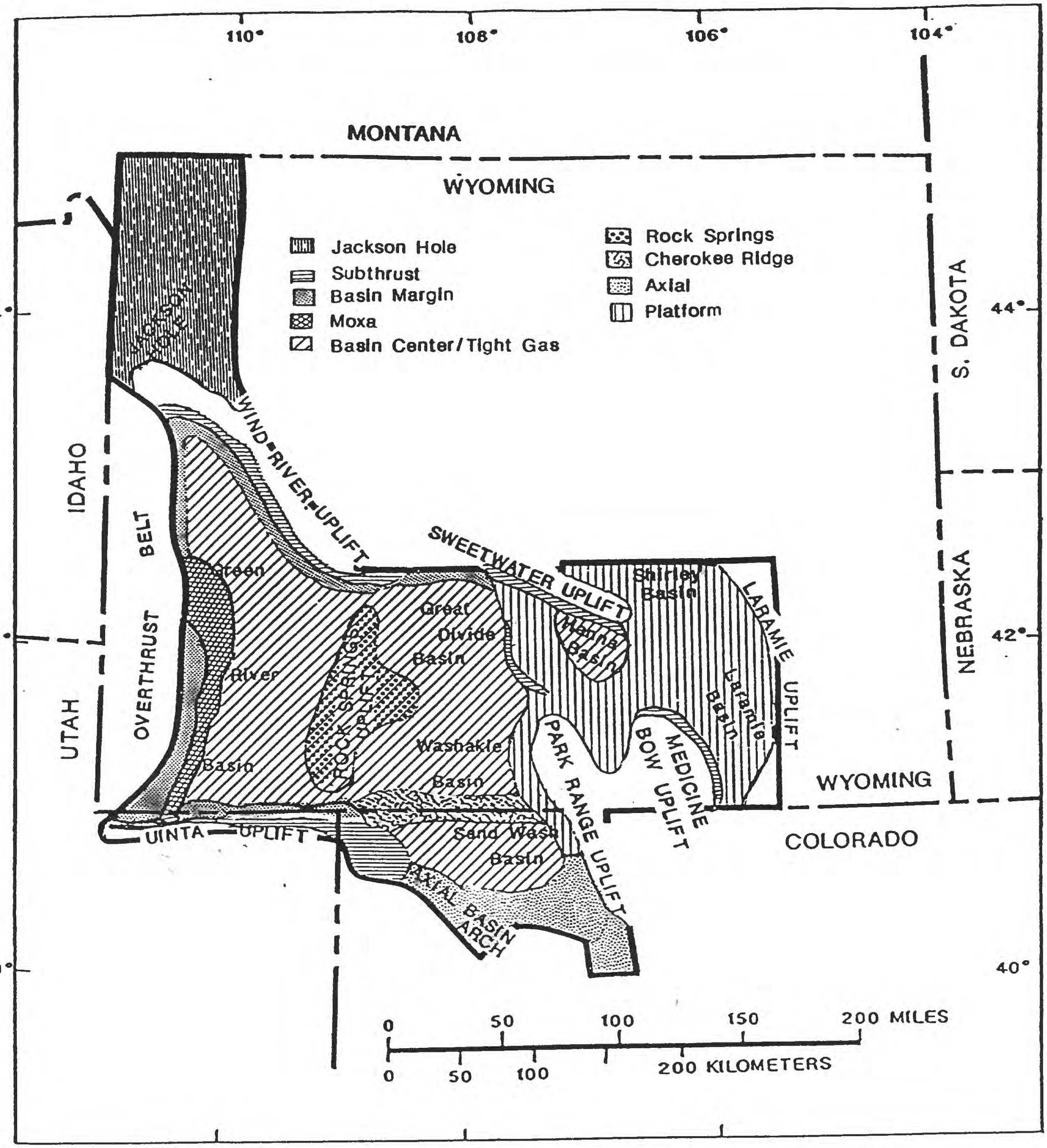

Figure 7.--Map showing approximate locations of plays in the Southwestern Wyoming Basins province.

table 1). In this field, oil is trapped in updip pinchouts of sandstone in the Almond Formation (Weimer, 1965, 1966). Cretaceous shales and/or juxtaposition of relatively impermeable lithologies along faults provide good seals.

Source Rocks and Geochemistry

The most likely source rocks of oil and gas include the Phosphoria Formation and Mowry Shale. Nonassociated gas in Cretaceous reservoirs could be from any part of the Cretaceous sequence. Unpublished analyses of oil from the Almond Formation in the Patrick Draw field suggest a Cretaceous source.

Timing and Migration

The Rock Springs uplift and associated structural elements are primarily the result of Laramide deformation. Hydrocarbons that may have been generated and migrated during this time or later could have accumulated in structural traps. Pre-Cretaceous and most of the Cretaceous sequence in this area are within the oil generation window (Pawlewicz et al., 1986; Merewether et al., 1987). Cretaceous rocks obtained their present levels of thermal maturity by late Eocene or Oligocene time. Thus, the temporal relationships between trap formation and hydrocarbon generation and migration from Cretaceous and older source rocks were favorable for hydrocarbon accumulation.

Depth of Occurrence

Reservoirs occur at depths ranging from 1,700 to 18,300 ft.

Exploration Status

This is a very maturely explored area, although the west flank of the Rock Springs uplift remains relatively unexplored. Along the west flank, there is some potential for the occurrence of structural traps in association with a buried high-angle reverse or thrust fault. It seems unlikely that new discoveries will exceed 1 MMBO. There remains, however, a good possibility of finding a few small fields (<1 MMBO). Most discoveries will probably be gas.

Cherokee Play

The Cherokee Play is essentially a structural play that includes the Cherokee Ridge arch, located along the Wyoming-Colorado State line (fig. 7). The Cherokee Ridge arch separates the Washakie basin in Wyoming from the Sand Wash basin in Colorado. The area is characterized by an east-west-trending zone of en échelon faults and folds that are believed to be due to wrenching (Stone, 1969; Bader, 1987). Structural deformation occurred during the Laramide orogeny.

Reservoirs

Reservoirs in the Cherokee Play include the Jurassic Nugget Sandstone, Lower Cretaceous Dakota Sandstone, Upper Cretaceous Williams Fork Formation, Almond Formation, Lewis Shale sandstones, Lance Formation, Paleocene Fort Union Formation, and Eocene Wasatch Formation. Porosity ranges from 10 to 30% and permeability ranges from 0.1 to 500 md (Cardinal, 1979; Cronoble, 1969). Reservoir thickness is highly variable, ranging from 10 to 40 ft.

Traps and Seals

The trapping mechanism for nearly all accumulations is structural. Existing fields are anticlinal folds that are commonly faulted. Impermeable shales and/or faults provide the seals.

Source Rocks and Geochemistry

Although there are are no oil or gas analyses from this play area, it is likely that the oils are sourced from Cretaceous rocks and the gases are sourced by Cretaceous and older rocks. Based on thermal maturity mapping by Pawlewicz et al. (1986) and Merewether et al. (1987), Cretaceous and older rocks are thermally mature to over mature.

Timing and Migration

It is not known when Cretaceous and older rocks entered the oil window (0.6 percent vitrinite reflectance) but it is likely that structural traps were in existence when Cretaceous source rocks entered the oil window. Older source rocks such as the Permian Phosphoria Formation may have passed through the oil window (1.3 percent vitrinite reflectance) prior to the formation of structural traps.

Depth of Occurrence

The depth of reservoirs ranges from 2,000 to 15,000 ft.

Exploration Status

The area is maturely explored. Because the structures are Laramide features and that may have affected subsequent depositional patterns, the remaining potential in the area is mainly stratigraphic. Deep drilling to the Mississippian Madison Limestone at depths of about 23,000 ft has not been encouraging for pre-Cretaceous reservoirs. It is unlikely that any fields larger than 1 MMBO will be discovered.

Axial Play

The Axial play area is located between the Piceance and the Sand Wash basins (fig. 7). It appears to be a southeast extension of the eastern end of the Uinta Mountains uplift. During much of Paleozoic time, the Axial arch area was a structurally depressed area referred to as the Colorado trough.

Reservoirs

The principal reservoirs in the Axial play area include the Pennsylvanian Minturn Formation and Weber Sandstone; Triassic Shinarump Sandstone, and Moenkopi Formation; Jurassic Entrada Sandstone and Morrison Formation; Lower Cretaceous Dakota Sandstone; and Upper Cretaceous Frontier Formation, Niobrara Formation, and Marapos Sandstone Member of the Mancos Shale. Porosity ranges from 12 to 20% and permeability ranges from 0.1 to 300 md. Reservoir thickness ranges from 8 to 65 ft.

Traps and Seals

Most hydrocarbon accumulations are in structural traps although reservoirs such as the Weber, Entrada, Shinarump, Dakota and Frontier have stratigraphic aspects. Fractured reservoirs in the Upper Cretaceous Mancos Shale are also important (Harnett, 1988; Cummings, 1959; Mallory, 1977).

Source Rocks and Geochemistry

Possible hydrocarbon source rocks include the Pennsylvanian Belden Shale, Permian Phosphoria Formation, and various Cretaceous rocks. Recent work south of the Axial arch by Nuccio and Schenk (1986) has identified the Lower and Middle Pennsylvanian Belden Formation as a potential source rock. Waechter and Johnson (1986) have suggested that the Belden and Phosphoria Formations may have been the source of oil in the Weber Sandstone.

Timing and Migration

There are no published references concerning the burial and thermal history of rocks in this area. However, because the area has experienced recurrent structural deformation (DeVoto et al., 1986; Stone, 1986), structural traps were most likely formed as early as Pennsylvanian time. Thus, the temporal relationships between hydrocarbon generation and migration, and structural trap development were favorable.

Depth of Occurrence

The depth of reservoirs ranges from 2,000 to 12,000 ft.

Exploration Status

The area is maturely explored. However, because the area is structurally complex and has experienced a long history of structural deformation dating back to Precambrian time, with recurrent movement occurring on some of these old structures during Late Pennsylvanian and Late Cretaceous to Middle Tertiary time, there is a possibility that some older structures have been overlooked. It seems unlikely that new discoveries in this area will exceed 1 MMBO.

Moxa Arch - La Barge Play

The Moxa arch - La Barge play area is located in the western part of the Green River basin, a few miles east of the Wyoming-Idaho thrust belt (fig. 7). The area is a large north-south-trending regional structural feature with smaller areas of structural closure along the crest.

Reservoirs

Reservoirs include the Madison Limestone, Morgan Formation, Nugget Sandstone, Bear River Formation, Dakota Sandstone, Frontier Formation, Mesaverde Group, and Almy Formation. South of the La Barge platform, the principal reservoirs are the Dakota Sandstone and Frontier Formation. Porosity and permeability in the Dakota and Frontier reservoirs appear to be slightly improved along the crest of the arch than on the flanks.

Traps and Seals

The trapping mechanisms in the play area vary from structural to stratigraphic. Most of the fields in the vicinity of the La Barge platform are primarily structural while the fields south of the La Barge platform along the arch have significant stratigraphic aspects.

Source Rocks and Geochemistry

The most likely sources of oil in the play area are the Phosphoria Formation and Mowry Shale. Based on preliminary oil-to-source rock correlations at the south end of the Moxa arch, Law and Clayton (1987) suggested that the oil and condensate in the Dakota Sandstone is from the Mowry Shale. Gas from Pennsylvanian and Mississippian reservoirs is commonly non-flammable or sour with high proportions of carbon dioxide.

Timing and Migration

The Moxa arch has experienced pre-Laramide deformation (Wach, 1977) possibly as old as late Paleozoic. Therefore, source rocks that may have generated hydrocarbons during or subsequent to that deformation could have migrated to favorable structural and/or stratigraphic traps along the crest of the structure. At the south end of the arch, Law and Clayton (1987) presented some evidence that oil migrated into Dakota reservoirs prior to or near the start of the Laramide orogeny.

Depth of Occurrence

The depth of reservoirs ranges from 2,500 to 18,000 ft.

Exploration Status

The play area is maturely explored. Although there is a large amount of activity in the area, most of the activity is development drilling. It is likely that deeper reservoirs will be found. Within the play area, the Frontier Formation is locally designated as a tight gas reservoir. In the assessment, however, the Frontier was not considered as a tight gas reservoir. At the south end of the Moxa arch, there is considerable activity following the discovery of oil and condensate fields, which produces from the Dakota Sandstone. There is also a lot of drilling activity in the northern part of the play area where high initial production rates of gas and condensate from the Dakota occur.

Basin Margin Anticline

The Basin Margin anticline play is located in the Greater Green River basin (fig. 7). The play area is a narrow tract 5 to 20 miles wide paralleling the thrust margins of the Greater Green River basin. This is essentially a structural play.

Reservoirs

Potential reservoirs in this play include all oil- and gas-producing reservoirs in the geologic column.

Traps and Seals

The trapping mechanism in this play is structural. The analogues are the anticlines associated with the Clay basin, Pinedale, and Mickelson Creek fields. These anticlines appear to genetically related to the structural deformation associated with thrusting along the north flank of the Uinta Mountains, the southwest flank of the Wind River Mountains, and the Overthrust belt, respectively. Relatively impermeable lithologies such as the Upper Cretaceous Baxter or Hilliard Shales provide good seals.

Source Rocks and Geochemistry

Source rocks are envisioned to include any of the previously mentioned source rocks in the province. Along the north flank of the Uinta Mountains, unusually low levels of thermal maturity occur in the play area, thereby effectively lowering the top of the oil window to depths greater than 15,000 ft (Law and Clayton, 1987).

Timing and Migration

Basin margin anticlines are most likely Laramide features, associated with adjacent thrusting events. Therefore, hydrocarbons that were generated and migrated during and after Late Cretaceous time could have been trapped in Laramide structural features.

Depth of Occurrence

The depth of reservoirs may range up to 30,000 ft.

Exploration Status

This is an immature to moderately mature explored play. However, large areas along the north flank of the Uinta Mountains and along the southwest flanks of the Wind River Mountains and Gros Ventre Range are virtually unexplored. Although it is unlikely that there will be a discovery in excess of 1 MMBO, these large, relatively unexplored areas could contain structures large enough to have 35 MBO.

Subthrust Play

The subthrust play is highly speculative. The play area is located along the overridden thrust margins of basins (fig. 7) and has been thoroughly discussed by Gries (1983).

Reservoirs

Possible reservoirs include any of the reservoirs previously discussed in the province.

Traps and Seals

The following kinds of traps may occur in the subthrust play: 1) conventional anticline, 2) stratigraphic, 3) fault truncation of upturned strata, and 4) fracturing. Anticlinal traps may be of two types, those formed as a result of the thrusting and those pre-thrusting anticlines that were overridden at the time of thrusting.

Source Rocks and Geochemistry

Proposed source rocks in the subthrust play are the same as those for the province as a whole.

Timing and Migration

In general, thrusting in the province was a Laramide event. Therefore, structural traps originating as a consequence of thrusting would constrain the timing of accumulation to no older than Late Cretaceous. However, in the case of pre-thrusting traps, hydrocarbons may have accumulated much earlier. For example, in the subthrust area along the north flank of the Uinta Mountains, Law and Clayton (1987) proposed that Lower Cretaceous Dakota Sandstone reservoirs were charged with oil prior to thrusting, when the reservoirs were structurally higher than areas to the north--a structural configuration opposite to that of present-day structures. They further demonstrated that in the subthrust projection of the Moxa arch, the top of the oil generation window occurs in pre-Cretaceous rocks at depths greater than 16,000 ft. Law and Clayton (1987) suggested that during Late Cretaceous time, oil originating from a northern source in the Lower Cretaceous Mowry Shale migrated southward to structurally higher areas where it accumulated in the Dakota. Following the structural depression and thrusting in this area, preservation of the oil was facilitated by the circulation of cold meteoric water along faults and fractures into the deep basin. Thus, temperatures at depth were depressed, effectively lowering the top of the oil generation window to unusually great depths and preserving the oil. Whether this condition exists in other subthrust areas within the province is not known, but the observation along the north flank of the Uintas is intriguing and makes this aspect of the subthrust play more attractive.

Depth of Occurrence

The depth of occurrence is unknown but is related to depths of sedimentary rocks beneath the hanging wall of the thrust margin.

Exploration Status

The southwestern Wyoming province probably contains more wells drilled for this objective than anywhere else in the U.S., and most certainly, in the Rocky Mountain region. However, the play is immature to moderately maturely explored. There are large areas that appear to be unevaluated. There are no fields in the play area but the attributes of the play and the relatively unexplored nature of the play are intriguing.

Platform Play

The platform play encompasses nearly all of the eastern half of the Southwestern Wyoming Basins province (fig. 7). It extends from the eastern edge of the Great Divide and Washakie basins east to the Laramie Range.

Reservoirs

Hydrocarbon reservoirs in this province include Cambrian through Tertiary sandstones and carbonates.

Traps and Seals

Trapping mechanisms in this play area include structural and stratigraphic traps although existing accumulations are all structural traps. Seals are provided by very low permeability shales. The potential for stratigraphic traps exists in several of the reservoirs such as the Casper Formation, Sundance Formation, Dakota Formation, and Muddy Sandstone, where they may undergo facies changes into finer grained, relatively impermeable lithologies.

Source Rocks and Geochemistry

Based on unpublished oil analyses from nine fields within this area, oil in Cretaceous and Jurassic reservoirs is sourced from Cretaceous rocks and oil in the Casper Formation is sourced from Paleozoic rocks (Jerry Clayton, pers. commun., 1988).

Timing and Migration

Although undocumented, it is probable that structural traps have been present through most of the Phanerozoic history of the area. It is not known when generation and migration of oil from the various source rocks occurred but it is likely that structural traps were available for the accumulation of hydrocarbons during most of the Phanerozoic.

Depth of Occurrence

The depth of reservoirs ranges from 1,200 to 9,200 ft and most commonly are 3,000 to 6,000 ft.

Exploration Status

The area is maturely explored. Some of the oldest fields in the Rocky Mountain region occur in the play area (Lost Soldier - 1916, Rock River - 1918, Wertz - 1921). There have been only a few discoveries since 1960. Cumulative production in these fields are listed in table 1. It seems highly unlikely that any new discoveries in excess of 1 MMBO will be made.

Jackson Hole Play

The Jackson Hole play area includes the northwest corner of Wyoming, north of the Gros Ventre uplift (fig. 7). It is a structurally complex area containing several large faulted anticlines. There are also large areas covered by volcanic flows that preclude surface evaluation. There is no production in the play area, although numerous shows of oil and gas have been reported during drilling.

Reservoirs

Reservoirs include the Madison Limestone, Darwin Sandstone Member of the Amsden Formation, Tensleep Sandstone, Phosphoria Formation, Crow Mountain Sandstone Member of the Chugwater Formation, Cloverly Formation, Muddy Sandstone, Frontier Formation, Bacon Ridge Sandstone, and Mesaverde Formation. The thickness of these reservoirs is highly variable, ranging from less than 20 ft to a few hundred feet. No data are available concerning porosity and permeability.

Traps and Seals

The Jackson Hole play is primarily a structural play. There are several large untested northwest-trending anticlines in the play area (Love et al., 1975; Antweiler et al., 1983). A seismic section through the Sohare anticline is an example of the structure in the area (Albertus, 1985). Fractured reservoirs may also be present.

Source Rocks and Geochemistry

The most likely hydrocarbon source rocks are black shales in the Amsden, Phosphoria, Thermopolis, Mowry, and Cody. According to Antweiler et al. (1983), a 50-ft-thick petroliferous black shale in Mississippian rocks may also be a potential source of oil and gas. Oil seeps in volcanic rocks of the Absaroka Range and Yellowstone Plateau have been reported by Love and Good (1970) and numerous gas seeps have been reported from several areas (Antweiler et al., 1983). Thermal maturity data are not available but Antweiler et al. (1983) report that black shales from several units of different age in and near the Teton Wilderness are mature with respect to hydrocarbon generation but are not overmature.

Timing and Migration

Most of the structural deformation in the play area occurred during the Laramide orogeny. No information is available concerning the temporal relationships between structural trap formation and the generation of hydrocarbons from the various source rocks.

Depth of Occurrence

Reservoirs occur at depths ranging from 1,000 to 13,000 ft.

Exploration Status

The area is poorly to moderately explored. Exploration has been limited largely because most acreage in the play is within the National Parks or Wilderness system and the large volcanic-covered areas require geophysical exploration. It seems unlikely that new discoveries will exceed 1 MMBO. The play has some potential, however, because of the relatively unexplored status of the play and the structural complexity of the area.

Basin Center Play

This play includes the areas not considered in the other plays. It includes reservoirs that are stratigraphically equivalent to other assessed Cretaceous and Tertiary tight gas reservoirs as well as reservoirs stratigraphically above and below the tight reservoirs.

Tight Gas Play

The tight gas play includes Cretaceous and lower Tertiary reservoirs in large parts of the Green River, Great Divide, Washakie, Sand Wash, and Hanna basins. With the exception of the Hanna basin, the tight gas reservoir play was assessed. The results of that assessment are presented in a report by Spencer and Law (1988), and a detailed report of that assessment is in preparation.

The tight gas play was subdivided into five stratigraphic intervals which include: 1) the Lower Cretaceous Dakota Sandstone and Upper Cretaceous Frontier Formation, 2) the Upper Cretaceous Mesaverde Group, 3) the Upper Cretaceous Lewis Shale, 4) the Upper Cretaceous Lance Formation, and 5) the lower Tertiary Fort Union Formation.

Because of the difficulty in accurately locating the areas of conventional reservoirs within the tight reservoir area, some conventional reservoirs were probably included in the tight gas reservoir play.

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