SOUTHWESTERN WYOMING PROVINCE (037)

By Ben E. Law

INTRODUCTION

The Southwestern Basins Province is located in the Rocky Mountain Foreland. It is an irregularly shaped area encompassing about 40,500 sq mi and is a composite of several basins and adjacent uplifts in Wyoming, Colorado, and Utah: the Laramie, Shirley, Hanna, Carbon, Great Divide, Washakie, Sand Wash, and Green River Basins. The province is bounded on the north and northeast by the Beartooth, Absaroka, and Wind River Uplifts, and the Sweetwater Arch. The eastern boundary is the Laramie Range and the southern boundary passes through the northern part of the Medicine Bow and Park Range Uplifts along the Wyoming-Colorado State line, the Axial Arch, and the Uinta Uplift. The Wyoming-Utah-Idaho Thrust Belt forms the western boundary of the province. Total sedimentary rock thicknesses in the individual basins in the province vary greatly. In the Hanna Basin, one of the deepest in the Rocky Mountain region, the total thickness of sedimentary rocks is more than 42,000 ft. In the northern part of the Green River and Washakie Basins the sections are about 32,000 ft. thick In contrast, the thickness of sedimentary rocks in the Laramie and Shirley Basins is less than 13,000 ft. Stratigraphic nomenclature is also variable through the province area.

Oil and associated gas production, since the 1916 discovery of the large Lost Soldier field, is mainly from fields located in and adjacent to the Laramie Basin, Rawlins Uplift, Axial Arch Uplift and the La Barge Platform-Moxa Arch trend. Productive reservoirs range from Cambrian through Tertiary age and are dominantly sandstone. Carbonate reservoirs are minor. More than 100 fields greater than 1 MMBOE in size have been discovered in the province. Cumulative production from these fields to the end of 1991 is about 849 MMBO and 7.3 TCFG.

STRUCTURE

The Southwestern 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. For the most part, the structural features in the province are the result of compressional deformation during the Laramide orogeny. Some data, however, indicate that some structural features have a pre-Laramide origin. For example, in the Lost Soldier area on the northern part of the Rawlins Uplift, 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 the Paleozoic rocks indicate the presence of major uplifts through most of Paleozoic and Mesozoic time. The Transcontinental Arch and the Pathfinder Uplift 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 Sybille Lineament in the southern end of the Laramie Range (Mullen Creek-Nash Fork Shear Zone of Houston and others, 1968) and the northeast-trending Blackstone Lineament (Wyoming Lineament of Blackstone, 1956) north of the Sierra Madre and Medicine Bow Mountains.

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 more than 42,000 ft thick (Matson, 1984). In the northern part of the Green River Basin and in the Washakie Basin, the depth to Precambrian basement is about 32,000 ft, while the Shirley and Laramie Basins have about 7,000 and 13,000 ft, respectively, of Cambrian through Tertiary rocks.

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 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, a depressed area between the Uncompahgre Uplift to the southwest and Front-Range Uplift 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 more than 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, crossbedded, 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 Wolfcampian age are present in only part of the province. In the Hanna, Laramie, and Shirley Basins, the Wolfcampian Casper Formation and Tensleep Sandstone are present whereas Wolfcampian rocks in the Greater Green River Basin and Jackson Hole 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, oral 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 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 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, two transgressive cycles of marine and nonmarine rocks 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, and Muddy Sandstone. To the west, equivalent units are the Bear River Formation, and Dakota Sandstone. In the western part of the province, these rocks 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.

Conformably overlying Lower Cretaceous rocks are the Upper Cretaceous Mowry Shale and 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 in 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, 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 Southwestern 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, with the result that many sediment sources were local. 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 in general a coal-bearing unit and is lithologically similar to underlying Cretaceous rocks. The Fort Union grades upward into the Eocene Wasatch Formation which in turn intertongues upward 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.

Both conventional and unconventional plays are identified in the Southwestern Wyoming Province. Conventional plays include the following: Rock Springs Uplift (3701), Cherokee Arch (3702), Axial Uplift (3703), Moxa Arch-La Barge (3704), Basin Margin Anticline (3705), Subthrust (3706), Platform (3707), Jackson Hole (3708), Deep Basin Structural (3709), and Sub-Absaroka (3405) described in Big Horn Basin Province (034). Unconventional plays include basin-centered gas plays Greater Green River Basin–Cloverly-Frontier (3740), Greater Green River Basin–Mesaverde (3741), Greater Green River Basin–Lewis (3742), Greater Green River Basin–Fox Hills-Lance (3743), and Greater Green River Basin–Fort Union (3744). Six coalbed gas plays are also included in the unconventional plays: Greater Green River Basin–Rock Springs (3750), Greater Green River Basin–Iles (3751), Greater Green River Basin–Williams Fork (3752), Greater Green River Basin–Almond (3753), Greater Green River Basin–Lance (3754), and Greater

Green River Basin–Fort Union (3755); these plays are further discussed in the chapter on coalbed gas plays by D.D. Rice.

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CONVENTIONAL PLAYS

3701. ROCK SPRINGS UPLIFT PLAY

The Rock Springs Uplift Play includes the Rock Springs Uplift and the western part of the Wamsutter Arch in Wyoming. 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 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. This is primarily a structural play, although there are a few stratigraphic producing fields in the play area.

Reservoirs: The reservoirs in the Rock Springs Uplift Play 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. Porosity generally exceeds 10 percent and permeability exceeds 40 mD.

Source rocks and geochemistry: The most likely source rocks are 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 Almond reservoirs in the Patrick Draw Field indicate a Cretaceous source. Among Cretaceous rocks, the Mowry, Baxter, and Lewis Shales are likely sources. Recent work by the University of Wyoming has identified Almond coal beds as a possible source. All available source rock data indicate that Cretaceous source rocks contain type II and III organic matter.

Timing and migration: The Rock Springs Uplift and associated structural elements are primarily the result of Laramide deformation; thus hydrocarbons that were generated and migrated during this time or later could have accumulated in structural traps. Pre-Cretaceous rocks and most Cretaceous rocks in this area are within the oil generation window. Cretaceous rocks obtained their present levels of thermal maturity by late Eocene or Oligocene time. The temporal relationships among trap formation, hydrocarbon generation, and migration, from Cretaceous and older source rocks were favorable for hydrocarbon accumulation. Thermal maturity patterns in the Patrick Draw field indicate that the migration path of hydrocarbons was through a zone of northeasterly trending faults and fractures. Relatively hot hydrocarbon-bearing fluids migrated vertically through this zone and accumulated in the porous and permeable Almond reservoirs.

Traps and seals: Nearly all production comes 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, where 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 also provide good seals. Depth of occurrence is from 1,700 to 18,300 ft.

Exploration status and resource potential: This is a very maturely explored area. However, there is a high degree of certainty that at least one field greater than 1 MMBOE will be discovered and highly probable of finding a few small fields (<1 MMBO). Most discoveries will probably be gas. The areas of highest potential are located along the west flank, in the vicinity of a buried high-angle reverse or thrust fault and on the highly faulted north plunge of the uplift. Drape folds over faults in Precambrian rocks, like that in the Brady field, are also potential sites of accumulation.

3702. CHEROKEE ARCH PLAY

The Cherokee Arch Play is essentially a structural play that includes the Cherokee Ridge Arch, located along the Wyoming-Colorado State line. 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 echelon 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 Arch 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 percent and permeability ranges from 0.1 to 500 mD (Cardinal and Hovis, 1979; Cronoble, 1969). Reservoir thickness is highly variable, ranging from 10 to 40 ft. Cretaceous reservoirs in the deeper part of the play area are low-permeability reservoirs discussed in the section on unconventional reservoirs.

Source Rocks and Geochemistry: Although there are no oil or gas analyses from fields in the play area, it is likely that the oils are sourced from Cretaceous rocks and the gases are sourced Cretaceous and older rocks. Based on thermal maturity mapping (Pawlewicz and others, 1986; Merewether and others, 1987), Cretaceous and older rocks are thermally mature to overmature with respect to the oil window.

Timing and Migration: When Cretaceous and older rocks entered their oil window (0.6 percent vitrinite reflectance) is not known, 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.

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. Depth of occurrence: 2,000 to 15,000 ft.

Exploration status and resource potential: This area is maturely explored. Deep drilling to the Mississippian Madison Limestone at depths of about 23,000 ft has not encouraged the hope of any pre-Cretaceous reservoirs. Discovery of any fields larger than 1 MMBO is unlikely, however, it is likely that gas fields larger than 6 BCF will be discovered. The gas potential is probably greatest in pre-Cretaceous reservoirs in buried structural traps.

3703. AXIAL UPLIFT PLAY

The Axial Arch Play is located in Colorado and is bounded on the south by the Piceance Basin and on the north by the Sand Wash Basin. It is 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. Most structural features are the result of Laramide orogeny, although there is evidence of recurrent movement on pre-Laramide features.

Reservoirs: The principal reservoirs in the Axial Arch 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 percent and permeability ranges from 0.1 to 300 mD. Reservoir thickness ranges from 8 to 65 ft. Fractured shale reservoirs are also present in a few fields.

Source rocks and geochemistry: Possible hydrocarbon source rocks include the Pennsylvanian Belden (Nuccio and Schenk, 1986; Waechter and Johnson, 1986) the Permian Phosphoria Formation, and various Cretaceous rocks. In part of the play area, the Belden is probably thermally overmature, whereas Cretaceous source rocks are in the oil window.

Timing and migration: The present levels of thermal maturity were probably achieved in the Oligocene. Structural traps were most likely formed as early as Pennsylvanian time and later during the Laramide orogeny. Consequently, the temporal relationships between hydrocarbon generation, migration, and structural development were favorable.

Traps and seals: Most hydrocarbon accumulations are in structural traps although reservoirs such as the Weber, Entrada, Shinarump, Dakota and Frontier have stratigraphic aspects. Seals are provided by shales. Depth of occurrence: 2,000 to 12,000 ft.

Exploration status and resource potential: The area is maturely explored. However, the area is structurally complex and has experienced a long history of structural deformation dating back to Precambrian time. Because recurrent structural deformation occurred on some of the old structures during Late Pennsylvanian and Late Cretaceous to Middle Tertiary time, some older structures have been overlooked. It is unlikely that new discoveries in this area will exceed 1 MMBO.

3704. MOXA ARCH-LA BARGE PLAY

The Moxa Arch - La Barge Play is located in the western part of the Green River Basin of Wyoming, a few miles east of the Wyoming-Idaho Thrust Belt. The area is a large north-south-trending regional structural feature with smaller areas of structural closure along the crest. The arch has a pre-Laramide structural history that has influenced deposition and reservoir quality in Lower and Upper Cretaceous reservoirs.

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 ranges from 5 to 20 percent. Permeability ranges from less than 0.1 mD to several hundred millidarcies. Permeability in the Dakota and Frontier reservoirs appears to be slightly improved along the crest of the arch than on the flanks, possibly due to conditions of deposition and fracturing. For purposes of the resource assessment, reservoirs in the Frontier Formation were assessed as low-permeability, unconventional reservoirs.

Source Rocks and geochemistry: The most likely sources of oil in the play area are from the Phosphoria Formation and Mowry Shale. Based on preliminary oil-to-source rock correlations at the south end of the Moxa Arch, oil and condensate in the Dakota Sandstone is from the Mowry Shale (Law and Clayton, 1987). Gas from Pennsylvanian and Mississippian reservoirs is commonly non-flammable or sour with high proportions of hydrogen sulfide and 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. The arch has also experienced structural inversion; the present, structurally low, south end of the arch was structurally high through early late Cretaceous time and influenced the generation, migration, accumulation, and preservation of hydrocarbons at the south end of the arch (Law and Clayton, 1987).

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 whereas the fields south of the

La Barge Platform along the arch have significant stratigraphic aspects. Depth of occurrence: 2,500 to 18,000 ft.

Exploration status and resource potential: The play area is maturely explored. Although a large amount of industry activity is taking place in the area, most of the activity is development drilling. It is likely that deeper, pre-Cretaceous reservoirs will be found, although the quality of gas in pre-Cretaceous reservoirs may have a large non-flammable component. Within the play area, the Frontier Formation is locally designated as a tight gas reservoir.

3705. BASIN MARGIN ANTICLINE PLAY

The play area is a narrow tract 5 – 20 mi wide paralleling the thrust margins of the Greater Green River Basin in Wyoming, Utah, and Colorado. This is essentially a structural play that, in part, overlaps with the tight gas play.

Reservoirs: Reservoirs include all oil- and gas-producing reservoirs in the geologic column.

Source rocks and geochemistry: Source rocks include the Mowry Shale, Phosphoria Formation, and coals and carbonaceous shale within Cretaceous and Tertiary rocks.. Along the north flank of the Uinta Mountains, thermal maturity levels in the play area are unusually low, 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.

Traps and seals: The trapping mechanism in this play is structural. The analogs are the anticlines associated with the Clay Basin, Pinedale, and Mickelson Creek fields. These anticlines appear to be 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. Depth of Occurrence is as much as 30,000 ft.

Exploration status and source potential: Immature to moderately mature 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. A discovery in excess of 1 MMBOE is not unlikely.

3706. SUBTHRUST PLAY (HYPOTHETICAL)

The Subthrust Play is highly speculative. The play area is located along the overridden thrust margins of basins in Wyoming, Utah, and Colorado and has been thoroughly discussed by Gries (1983).

Reservoirs: Reservoirs include any of those previously discussed in the province.

Source rocks and geochemistry:. Source rocks include Tertiary and Cretaceous shales, the Phosphoria Formation , and possibly the Belden Shale equivalent rocks.

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.

Traps and seals: The following kinds of traps may be present 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, such as the Moxa Arch. Seals include low-permeability Cretaceous and older shales and faults. Depths 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 and resource potential: The Southwestern Wyoming Province probably contains more wells drilled in subthrust plays than anywhere else in the U.S., and most certainly, in the Rocky Mountain region. However, the play is immature to moderately maturely explored. Large areas appear to be unevaluated. No fields have been established in the play area but the attributes of the play and the relatively unexplored nature of the play are intriguing.

3707. PLATFORM PLAY

The Platform Play is primarily a structural play and encompasses nearly all of the eastern half of the Southwestern Wyoming Province. It extends from the eastern edge of the Great Divide and Washakie Basins east to the Laramie Range. Without exception, existing fields are in structural traps. Some of the oldest fields in Wyoming are located within this play area.

Reservoirs: Cambrian through Tertiary sandstones and carbonates.

Source rocks, geochemistry, timing, and migration: Based on unpublished oil analyses from nine fields within this area, the source of oil in Cretaceous and Jurassic reservoirs is Cretaceous rocks and the source of oil in the Casper Formation and older reservoirs is Paleozoic rocks, probably the Phosphoria and (or) some Pennsylvanian source rock. Although undocumented, structural traps probably have been present through most of the Phanerozoic history of the area. When generation and migration of oil from the various source rocks took place is not known, but structural traps likely were available for the accumulation of hydrocarbons during most of the Phanerozoic.

Traps and seals: Existing accumulations are all in 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. However, this has not been demonstrated. Depth of occurrence: 1,200 to 9,200 ft and most commonly 3,000 to 6,000 ft.

Exploration status and resource potential: 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. Although any new discoveries in excess of 1 MMBO are unlikely, structures associated with basement-involved deformation may be identified with the application of modern geophysical techniques.

3708. JACKSON HOLE PLAY (HYPOTHETICAL)

The hypothetical Jackson Hole Play includes the part of the northwest corner of Wyoming north of the Gros Ventre Uplift and west of the large volcanic-covered area of the Absaroka Volcanics. It is a structurally complex area containing several large faulted anticlines. The play has no production although hydrocarbon seeps and numerous shows of oil and gas have been reported during drilling.

Reservoirs: Reservoirs in the Jackson Hole Play 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 ranges from less than 20 ft to a few hundred feet. No data are available concerning porosity and permeability.

Source rocks and geochemistry: The most likely hydrocarbon source rocks are black shales in the Amsden, Phosphoria, Thermopolis, Mowry, and Cody. Oil seeps in volcanic rocks of the Absaroka Range and Yellowstone Plateau have been reported and numerous gas seeps have been reported from several areas. Thermal maturity data are not available but Antweiler and others (1983) report that black shales from several units of different age in and near the Teton Wilderness are mature but not overmature with respect to hydrocarbon generation. However, excessive levels of thermal maturity are a major concern, especially in the northwest part of the play area where geothermal activity is common.

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.

Traps and seals: The Jackson Hole Play is primarily a structural play. Several large untested northwest-trending anticlines lie in the play are (Love and others, 1975; Antweiler and others, 1983). Fractured reservoirs may also be present. Shale in Cretaceous and older rocks provide adequate seals. Depth of occurrence: 1,000 to 13,000 ft.

Exploration status and resource potential: The area is poorly explored. Exploration has been limited largely because most acreage in the play is within the National Parks or Wilderness system. At least one undiscovered accumulation larger than 1 MMBOE seems likely.

3709. DEEP BASIN STRUCTURAL PLAY (HYPOTHETICAL)

This play is speculative and includes only the Madison Limestone in the deeper part of the Greater Green and Hanna Basins where it is not considered in other plays. The depth of the play exceed 15,000 ft. Accumulations are expected to be low-quality gas with no possibility of oil. Because of the high porosity and permeability of the Madison, hydrocarbon accumulations will most likely be in structural traps.

UNCONVENTIONAL PLAYS

Basin-Centered Gas Plays

Basin-centered plays include reservoirs from Cambrian through Paleocene rocks although the more important reservoirs are in Cretaceous and lower Tertiary rocks. These gas accumulations occur in large parts of the Green River, Great Divide, Washakie, Sand Wash, and Hanna Basins. Basin-centered gas accumulations are a type of unconventional gas accumulations that differ significantly from conventional gas accumulations. They have the following attributes : (1) generally, very large accumulations occupying the more central, deeper parts of basins, (2) absence of down-dip water contacts, (3) abnormally over- or underpressured, (4) gas is the pressuring phase, (5) produce little or no water, (6) permeability less than 0.1 mD, (7) overlain by a normally pressured transition zone containing gas and water, (8) contain thermogenic gas, 9) source of gas is local--either from interbedded or adjacent lithologies, (10) gas is thermogenic, (11) top of accumulations occur at 0.75 to 0.9 percent vitrinite reflectance, (12) structural and stratigraphic trapping aspects are of secondary importance, (13) the "seal" for these gas accumulations is due to the presence of multiple fluid phases in low-permeability reservoirs; it is a relative permeability barrier. In the Greater Green River Basin, relevant literature concerning the geologic characteristics and resource assessment include Law and others (1980), McPeek (1980), Law (1984), Law and Spencer (1989), Law and others (1989), and The Scotia Group (1993).

The basin-centered gas plays in the Greater Green River Basin were subdivided into five stratigraphic plays: Greater Green River Basin–Cloverly-Frontier (3740), Greater Green River Basin–Mesaverde, Greater Green River Basin–Lewis (3742), Greater Green River Basin–Fox Hills-Lance (3743), and Greater Green River Basin–Fort Union (3744). Because of the difficulty in accurately locating the areas of conventional reservoirs within the tight reservoir area, some conventional reservoirs will almost certainly be included in the tight gas reservoir play. For example, within the Mesaverde and Cloverly-Frontier Play areas, some conventional reservoirs are included.

3740. GREATER GREEN RIVER BASIN–CLOVERLY-FRONTIER PLAY (HYPOTHETICAL)

The play area encompasses an area of about 12,500 sq mi. The play area includes all of the overpressured, deeper parts of the Greater Green River Basin in Wyoming and Colorado. Along the Moxa Arch, in the western part of the Green River Basin, the Dakota and equivalent rocks are excluded; these rocks have been assessed as conventional reservoirs in the Moxa Arch-LaBarge Play.

Reservoirs: The Cloverly-Frontier Play includes the strata in the interval from the base of the Cloverly and equivalents to the top of the Frontier Formation with the exception of the Dakota and equivalent rocks in the area of the Moxa Arch. Individual sandstone reservoirs in the play range in thickness from 10 to 70 ft

Source rocks, geochemistry, timing and migration: Sources of gas are from coal and carbonaceous shale in the Cloverly and Frontier and shale in the Mowry. Because gas in gas accumulations is generated within, or in close proximity to reservoirs in basin-centered gas accumulations, the temporal relationships between the generation, migration, and development of a trap is not nearly as important as in conventional gas accumulations. When the reservoirs in the Cloverly-Frontier Play were charged with gas and became saturated and overpressured is uncertain. Burial and thermal reconstructions suggest that gas, generated from this interval may have begun during late Eocene time.

Traps and seals:. See introduction to basin-centered gas plays. The depth of reservoirs within the play area is highly variable, ranging from 10,000 to 20,000 ft. Throughout most of the play area, the depth to the top of the Frontier is about 17,000 ft.

Exploration status: Along the Moxa Arch, the play is mature and is currently experiencing a large amount of drilling. Elsewhere in the play area where drilling depths exceed 16,000 ft there are uncertainties concerning the quality of matrix and fracture permeability. However, with the advent and application of new drilling and completion techniques, reservoirs in the deeper parts of the play area may prove to be economically productive.

3741. GREATER GREEN RIVER BASIN–MESAVERDE PLAY (HYPOTHETICAL)

The play encompasses an area of about 8,200 sq mi in Wyoming and Colorado. The play area extends through the deeper parts of the Great Divide, Washakie, Sand Wash Basins and the northern part of the Green River Basin.

Reservoirs: The Mesaverde Play includes the stratigraphic interval from the base of the Rock Springs Formation and equivalent rocks to the top of the Almond Formation in the Great Divide, Washakie, and Sand Wash Basins. West of the Rock Springs Uplift, in the Green River Basin, the play includes the stratigraphic interval from the base of the Rock Springs Formation and equivalent rocks to the top of the Ericson Sandstone. The thickness of the stratigraphic interval ranges up to 5,000 ft, and the cumulative thickness of individual reservoirs ranges from less than 750 to 2,000 ft. Individual reservoirs range in thickness from 10 to 75 ft.

Source rocks, geochemistry, timing, and migration: The most likely source rocks are coal and carbonaceous shale within the play interval (Law, 1984). As previously discussed, the temporal relationships between gas generation, migration, and trap formation in basin-centered gas accumulations are not as important as they are in conventional gas accumulations. Gas began to be generated from the Mesaverde interval in late Eocene or Oligocene time. The charging and development of gas saturated, overpressured reservoirs is not known.

Traps and seals: Like all basin-centered gas accumulations, traps and seals as visualized in conventional hydrocarbon accumulations, are of secondary importance and are not of fundamental importance   For a detailed discussion of the boundaries of basin-centered gas accumulations see Masters (1979), Meissner (1984), Law (1984), and Spencer (1989). Depth of occurrence**:** The depth to the top of reservoirs in the Mesaverde Play ranges from 8,000 to 18,000 ft.

Exploration status: The play is immaturely explored with the exception of the Almond Formation reservoirs in the Washakie Basin, where several fields produce gas from the uppermost part of the Almond. The Almond production represents "sweet spots" where the reservoir quality is much better than the rest of the Mesaverde reservoirs. Most of the Mesaverde Play remains unevaluated and it is likely that at least one accumulation larger than 1 MMBOE will be discovered.

3742. GREATER GREEN RIVER BASIN–LEWIS PLAY (HYPOTHETICAL)

This play includes the stratigraphic interval of the Lewis Shale. The play area encompasses an area of about 3.900 sq mi and is restricted to the deeper parts of the Great Divide, Washakie, and Sand Wash Basins in Wyoming and Colorado. The western boundary of the play coincides with the western edge of the Lewis Shale transgression.

Reservoirs: Reservoirs in the Lewis occur as isolated sandstones bounded above and below by shale. The cumulative thickness of reservoirs in the play ranges from less than 200 ft to more than 600 ft and the median thickness is 400 ft. Individual sandstone reservoirs range in thickness from 10 to 100 ft.

Source rocks, geochemistry, timing, and migration: Sources of gas are from the marine shales of the Lewis Shale. As previously discussed, the temporal relationships between gas generation, migration, and trap formation in basin-centered gas accumulations are not so important as they are in conventional accumulations. Gas began to be generated from shales in the Lewis Shale in Oligocene time. The charging and development of gas saturated, overpressured reservoirs is not known.

Traps and seals: See discussion in introduction of basin-centered gas accumulations. The depth to the top of reservoirs in the Lewis Play ranges from 8,000 to 14,000 ft.

Exploration status and resource potential: The play is moderately explored. Several fields produce from low-permeability reservoirs within the play area. However, a large area is undrilled and untested. It is likely that at least one accumulation larger than 1 MMBOE will be discovered.

3743. GREATER GREEN RIVER BASIN–FOX HILLS-LANCE PLAY (HYPOTHETICAL)

The play includes the stratigraphic interval from the base of the Fox Hills Sandstone to the top of the Lance Formation. In the Green River Basin, the play includes the interval from the top of the Ericson Sandstone to the top of the Lance Formation. The play area encompasses an area of about 4,100 sq mi in the northern part of the Green River Basin and in the deeper parts of the Great Divide, Washakie, and Sand Wash Basins of Wyoming and Colorado.

Reservoirs: The reservoirs in the Fox Hills part of the play are represented by deltaic sandstones. In contrast, reservoirs in the Lance part of the play were deposited in fluvial dominated systems and are more lenticular than those in the Fox Hills. The cumulative thickness of reservoirs in the play ranges from less than 250 ft to greater than 1,500 ft, with a median thickness of 675 ft. Individual reservoirs range in thickness from 10 to 100 ft.

Source rocks, geochemistry, timing, and migration: Sources of gas are from coal and carbonaceous shale in the Fox Hills Sandstone and Lance Formation. See discussion of timing and migration in introduction of basin-centered gas accumulations

Traps and seals: See discussion in introduction of basin-centered gas accumulations. Depth of Occurrence: The depth to the top of reservoirs within the play area ranges from 8,000 to 12,000 ft. Through most of the area the depth is about 11,000 ft.

Exploration status and resource potential: The play is immaturely explored. Through nearly all of the play area, the reservoirs in the play interval have been very sparsely tested. It is likely that at least one accumulation larger than 1 MMBOE will be discovered.

3744. GREATER GREEN RIVER BASIN–FORT UNION PLAY (HYPOTHETICAL)

The play interval extends from the base of the Paleocene Fort Union Formation to the top of the Fort Union. However, basin-centered gas accumulations in the Fort Union are restricted to approximately the lower half of the formation. The play encompasses an area of about 520 sq mi and is restricted to the deepest part of the Washakie Basin, Wyoming.

Reservoirs: Reservoirs in the play are composed of sandstone that was deposited in fluvial-dominated systems. Consequently, they are lenticular. The cumulative thickness of reservoirs range from less than 500 ft to more than 1,500 ft and the median thickness is 600 ft. Individual reservoirs range in thickness from 10 to 80 ft.

Source rocks, geochemistry, timing, and migration: Sources of gas are from coal and carbonaceous shale in the Fort Union Formation. See discussion of timing and migration in introduction of basin-centered gas accumulations.

Traps and seals: See discussion in introduction of basin-centered gas accumulations. Depth of Occurrence: The depth to the top of basin-centered gas accumulations ranges from 9,000 to 9,500 ft.

Exploration status and resource potential: The play is immaturely explored. The objective of most wells drilled in the Washakie Basin has been the Almond or Lewis, consequently the gas accumulations in the

Fort Union have been bypassed, perhaps because of the more laterally continuous nature of reservoirs in the Almond as well as the historical success of production from the Almond and Lewis. It is likely that at least one accumulation larger than 1 MMBOE will be discovered.

Coalbed Gas Plays

The Southwestern Wyoming Province contains major coal resources. Kaiser (1993) has estimated the coal resources in Cretaceous and Tertiary rocks at 1,276 billion tons. The estimate of gas contained in these coal beds is 314 TCF (Kaiser, 1993). For purposes of the assessment of coalbed gas, the six coal-bearing intervals are treated as plays, from oldest to youngest: the Greater Green River–Rock Springs Play (3750), Greater Green River–Iles Play (3751), Greater Green River–Williams Fork Play (3752), Greater Green River–Almond Play (3753), Greater Green River–Lance Play (3754), and Greater Green River–Fort Union Play (3755).

The Southwestern Wyoming Province, also known as the Greater Green River Basin of Wyoming, Colorado, and Utah, is located in the Rocky Mountain foreland and encompasses an area of about 20,000 sq mi. It is a composite of five smaller basins in Wyoming, Colorado, and Utah that includes the Hoback, Green River, Great Divide, Washakie, and Sand Wash Basins. The structural and stratigraphic framework of the region are summarized by Ryder (1988). Notable studies concerning the coalbed methane resources of the region include those by Boreck and others (1981), McCord (1984), Kelso and others (1991), Kaiser and others (1993), Hamilton, (1993), and Kaiser (1993). Other relevant studies include those by Law (1984), Pawlewicz and others (1986), Merewether and others (1987), MacGowan and others (1992), and Garcia-Gonzalez and others (1993).

Coal has been mined for many years in the Southwestern Wyoming Province (037). In the vicinity of the Rock Springs Uplift, coal has been mined from the Upper Cretaceous Rock Springs and Almond Formations, and the Paleocene Fort Union Formation. Currently, coal is mined from the Almond and Fort Union Formations in surface mines on the southeast and northeast flank of the Rock Springs Uplift, respectively, and from the Rock Springs Formation in subsurface mines on the west flank of the uplift. In the Sand Wash Basin, coal has been mined from the Upper Cretaceous Williams Fork and Almond Formations, and from the Paleocene Fort Union Formation at several surface and subsurface mines. Currently, most coal is mined from the Williams Fork Formation in surface mines in the Craig and Meeker areas of Colorado.

Coal beds in these Cretaceous and Tertiary rocks were deposited in environments that include fluvial, delta-plain, and back-barrier depositional systems. The thicker and more continuous coal beds occur in intervals or zones 100–1,200 ft thick. As many as 30 coal beds occur in any single coal zone, but more commonly there are 4 to 8 coal beds. Individual coal beds are generally discontinuous, although coal zones can be traced along outcrops and in the subsurface for many miles. Individual coal beds are as thick as 50 feet. The present-day, maximum depth of burial of the coal zones is about 18,000 ft. For purposes of estimating recoverable gas from coal beds, however, only coal beds buried less than 6,000 ft are considered.

Within the depth constraints of this assessment, the rank of coal beds in the various coal zones ranges from sub-bituminous B to high volatile bituminous B (0.45 - 0.75 percent R_o). The coal is composed of a humic-type organic matter; vitrinite is the main coal maceral. Cleat development is good and is considered normal for sub-bituminous and bituminous coal. The gas content of the coal ranges from less than 100 Scf/t to 541 Scf/t, and the gas typically has large amounts of methane with lesser amounts of ethane and heavier hydrocarbons. Carbon dioxide is present in amounts up to 25 percent.

Exploration activity for coalbed methane in the Southwestern Wyoming Province (037) has been low to moderate. Most drilling activity has focused on the Rock Springs Formation around the northern flanks of the Rock Springs Uplift and the Williams Fork and Almond Formations in the southeast part of the Sand Wash Basin. The presence of large amounts of water in the coal has been the largest obstacle to economic production of gas. Attempts to dewater the coals to levels at which economic rates of gas production may occur have been unsuccessful. Environmental problems related to water disposal have also been obstacles to gas production. The generally low gas content associated with the low rank coals in the play areas, coupled with high water content, indicates that the occurrence of producible coalbed methane in this region is different from that in the San Juan and Black Warrior Basins.

Despite these problems, there remains a good potential for gas production in the province. The areas that have the highest potential for gas production are those areas where coalbed water can be effectively drawn down to levels at which economic rates of gas can be produced. Prospective areas might include the crests of folds where gas has accumulated by buoyancy, sites where the flow of water through coal beds is impeded by the presence of faults, or near mining operations that have lowered the water table in coal. It seems clear, that to be successful in this region, an exploration strategy must be developed that recognizes the need to locate those areas where coal beds may be successfully dewatered.

3750. GREATER GREEN RIVER BASIN–ROCK SPRINGS PLAY

Coal beds in the Upper Cretaceous Rock Springs Formation of the Mesaverde Group are the objective of this play. The play encompasses an area of about 400 sq mi on the northeast, north, and west flanks of the Rock Springs Uplift, near the center of the Greater Green River Basin. The coal beds in the Rock Springs Formation were deposited in deltaic environments along a northeast-trending shoreline; the southeast edge of the play boundary marks the edge of this shoreline. The coal-bearing interval is as thick as 400 ft and contains from 1 to 12 coal beds. Cumulative thickness of coal beds within the Rock Springs is commonly 25–00 ft. Individual coal beds range in thickness from 2 to 15 ft and have been mined at several localities on the northern end of the uplift.

Coal rank ranges from sub-bituminous B to high volatile bituminous B (0.45 - 0.74 percent R_o). The coals are of a humic type, composed mostly of vitrinite. Ash content ranges from 5 to 25 percent. Face and butt cleats are well developed and face cleats strike in east-northeast to northeast directions.

Gas content from core and drill cutting samples of coal as measured by the direct method, are as high as 541 standard cubic feet per ton (scf/T). Most samples are less than 150 scf/ton. Gas content in samples collected from coal beds in the Rock Springs decrease with depth, unlike the relationship between gas content and depth in most basins. The reasons for this anomalous condition are not known.

The potential for reserves from this play is low to moderate. Six (6) wells have evaluated the coalbed methane potential of the Rock Springs Formation in the play area and were abandoned due to water disposal problems.

3751. GREATER GREEN RIVER BASIN–ILES PLAY

This play includes coals within the Upper Cretaceous Iles Formation. The play encompasses an area of about 1,050 sq mi located in the southeastern part of the Sand Wash Basin of Colorado and along the eastern edge of the Washakie Basin in Wyoming. The Iles coal zone contains up to 7 coal beds with an aggregate thickness of as much as 50 ft. Individual coal beds are as thick as 15 ft.

Coal beds in the Iles were deposited in a deltaic environment. On the basis of depositional environments similar to that of coals in the Rock Springs and Williams Fork Formations, the coal beds in the Iles are most likely a humic type and composed mainly of vitrinite. Thermal maturity ranges from 0.45 to 0.7 percent R_o.

This play is immaturely explored and has not been tested.

3752. GREATER GREEN RIVER BASIN–WILLIAMS FORK PLAY

The play area encompasses an area of about 650 sq mi in the southeastern part of the Sand Wash Basin in Colorado. There are two coal zones within the Williams Fork Formation; an upper zone containing as many as 12 coal beds and a lower coal zone containing as many as 18 coal beds. The aggregate thickness of coals in both zones is as much as 220 ft. Individual coal beds are as thick as 45 ft. Coal beds within the Williams Fork Formation are the principal coalbed gas objectives in the Greater Green River Basin.

Although there are no maceral analyses available for Williams Fork coals, they are most likely similar to other Cretaceous coals in the Rocky Mountain region; they are probably vitrinite-rich coal beds. Ash content ranges from 1 to 28 percent. Gas content ranges from less than 1 to more than 540 scf/ton and averages 147 scf/ton. Thermal maturity of Williams Fork coal beds ranges from 0.4 to 0.7 percent R_o. At this level of thermal maturity, the gases generated from the coal beds might be expected to be both thermogenic and biogenic. Gases desorbed from coal are dry with a gas dryness index (the ratio of methane to methane through pentane-C_1/C_{1-5}) ranging from 0.79 to 1.0. Carbon dioxide content ranges from 1 to 25 percent. Coal beds in the Williams Fork attained their level of thermal maturity during Oligocene time, during maximum burial.

The play area is lightly to moderately explored. About 5 wells have been drilled and tested the production potential of Williams Fork coal beds. To date, there is no commercial production. Potentially good areas for reserves may occur along the crests of folds where gas can accumulate by buoyancy or in areas where the flow of water in the coals is impeded by a permeability discontinuity, such as a fault. Other potentially good areas for gas production include areas where the water table has been lowered, such as wells located in close proximity to surface mining. In these areas, gas begins to desorb from the coal matrix because of the reduction in pressure caused by the dewatering process and gas then flows to the well bore along the cleat system.

3753. GREATER GREEN RIVER BASIN–ALMOND PLAY

The Greater Green River Basin–Almond Play encompasses an area of about 2,200 sq mi and occurs in two, widely separated areas. The first area is located in the southeast part of the Washakie Basin and the southeastern part of the Sand Wash Basin. The second area is located around the flanks of the Rock Spring Uplift, and extends southward into Colorado, on the west side of the Sand Wash Basin. The Almond coal zone contains 1 to 5 coal beds that range in thickness from 2 to 12 ft . Cumulative thickness of coal in the zone ranges from 15 to 37 ft. The coal beds were deposited in back-barrier depositional environments.

Almond coals are composed primarily of vitrinite macerals, but a large amount of the vitrinite is of a high-hydrogen type, and therefore the coals are both gas and liquid prone. On the basis of a few analyses of Almond coals, the ash content ranges from 3 to 15 percent. Thermal maturity ranges from 0.4 to 0.7 percent R_O and gas content is less than 100 scf/ton.

The Greater Green River Basin–Almond Play is immaturely explored. The few wells that have been drilled and evaluated in the Sand Wash basin have encountered large amounts of water. Attempts to dewater the coals have been unsuccessful. Like the other coalbed methane plays in the Greater Green River Basin, potentially good areas for reserves are those areas where the coals can be effectively dewatered.

3754. GREATER GREEN RIVER BASIN–LANCE PLAY

Like the Greater Green River Basin–Almond Play (3753), the Greater Green River Basin–Lance Play has two play areas. The first is located on the east side of the Washakie Basin and extends southward into Colorado into the southeast part of the Sand Wash Basin. The second area is located around the Rock Springs Uplift, extending southward into Colorado on the west side of the Sand Wash basin. The combined areas encompass about 2,700 sq mi. The more laterally persistent coal zone occurs in the lower part of the Lance Formation. Stray coals occur mainly in the middle part of the Lance. The main coal zone ranges in thickness from 100 to 400 ft. There are 1 to 8 coal beds in the Lance that have a cumulative thickness of as much as 85 ft. Individual coal beds are as thick as 13 ft. Coal beds in the Lance Formation were deposited in fluvial dominated systems.

Thermal maturity of coal beds in the Greater Green River Basin–Lance Play ranges from 0.4 to 0.65 percent R_O. Organic thermal maturation was achieved in Oligocene time, during maximum burial. The coals are inferred to be vitrinite-rich coals with ash contents of 3-20 percent. Gas content of these coals is unknown, but they are assumed to be comparable to coals of similar rank and quality elsewhere. The level of thermal maturity of Lance coal beds indicates that the sorbed gas may be a mixture of thermogenic and biogenic gas.

The Greater Green River Basin–Lance Play is immaturely explored, and there have not been any tests of the coalbed methane potential. The low levels of thermal maturity are indicative of low levels of gas content. The low gas content in conjunction with probable high water content, indicate the necessity of locating wells in areas that are at or slightly above the regional water table, such as along the crests of folds, lenticular coals that are not exposed to water recharge areas, or areas where faults have impeded the flow of water.

3755. GREATER GREEN RIVER BASIN–FORT UNION PLAY

The Greater Green River Basin–Fort Union Play encompasses an area of about 6,500 sq mi and occurs in two areas. The first is in the Moxa Arch-LaBarge Platform area in the western part of the Green River Basin. The second area covers nearly all of the Eastern part of the Greater Green River Basin, exclusive of the deeper parts of the Great Divide, Washakie, and Sand Wash Basins. Coal occurs in several parts of the Fort Union. However, the most important and laterally persistent coal zone is in the lower part of the Fort Union Formation. The coal zone ranges in thickness from 150 to 350 ft and contains from 1 to 9 coal beds. The cumulative thickness of coals within the zone ranges from 10 to 100 ft. Individual coal beds are as thick as 50 ft. Coal beds in the Fort Union were deposited in fluvial environments.

The level of thermal maturity ranges from 0.4 to 0.65 percent R_o. The coals are inferred to be vitrinite-rich with ash contents ranging from 1 to 25 percent. Gas contents from Fort Union coals in the Sand Wash Basin range from 9 to 301 scf/ton and more commonly are less than 100 scf/ton. Adsorption isotherms of Fort Union coals in the Sand Wash basin indicate that the gas storage capacity is generally less than 300 to 400 scf/ton. These data indicate that Fort Union coals may be regionally undersaturated and will require significant reductions of pressure in order to initiate gas flow. On the basis of the low level of thermal maturity, coal-derived gas is probably a mixture of thermogenic and biogenic gas.

The Greater Green River Basin–Fort Union Play is immaturely explored. Excessive water production is the main obstacle to economic gas production. The low levels of gas contained in the coal in conjunction with high levels of water saturation require areas where dewatering can be achieved. Areas where the water table has been drawn down, such as near active surface mines, may be potentially good sites for coalbed methane wells. Other areas of some potential include areas where the flow of water through coal has been impeded or along the crests of folds where gas can accumulate by buoyancy.

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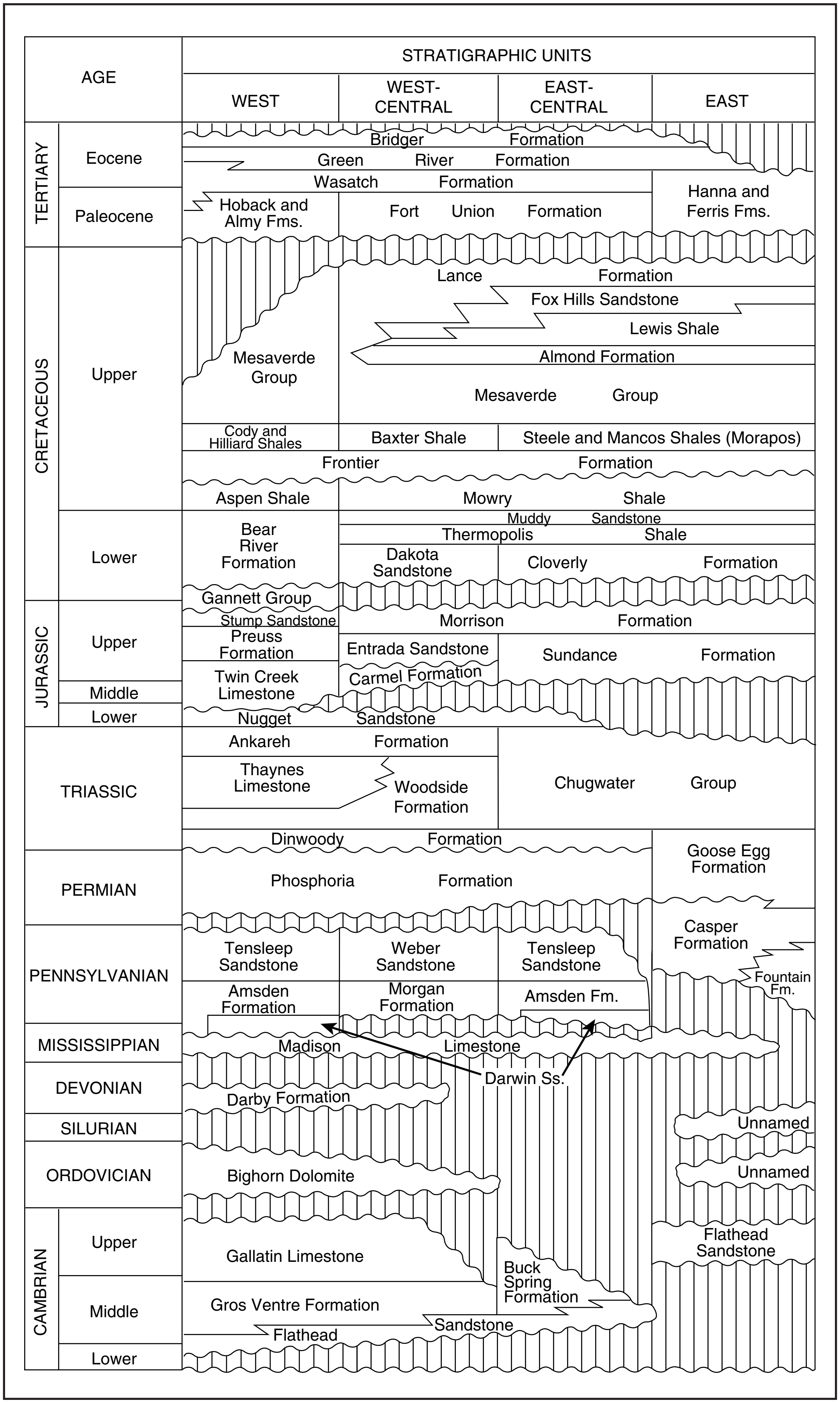
AGE
STRATIGRAPHIC UNITS
WEST
WEST-CENTRAL
EAST-CENTRAL
EAST
TERTIARY
Eocene
Paleocene
Bridger Formation
Green River Formation
Wasatch Formation
Hoback and Almy Fms.
Fort Union Formation
Hanna and Ferris Fms.
CRETACEOUS
Upper
Lance Formation
Fox Hills Sandstone
Lewis Shale
Almond Formation
Mesaverde Group
Mesaverde Group
Cody and Hilliard Shales
Baxter Shale
Steele and Mancos Shales (Morapos)
Frontier Formation
Aspen Shale
Mowry Shale
Lower
Bear River Formation
Muddy Sandstone
Thermopolis Shale
Dakota Sandstone
Cloverly Formation
Gannett Group
JURASSIC
Upper
Middle
Lower
Stump Sandstone
Morrison Formation
Preuss Formation
Entrada Sandstone
Sundance Formation
Twin Creek Limestone
Carmel Formation
Nugget Sandstone
TRIASSIC
Ankareh Formation
Thaynes Limestone
Woodside Formation
Chugwater Group
Dinwoody Formation
PERMIAN
Goose Egg Formation
Phosphoria Formation
PENNSYLVANIAN
Casper Formation
Tensleep Sandstone
Weber Sandstone
Tensleep Sandstone
Fountain Fm.
Amsden Formation
Morgan Formation
Amsden Fm.
MISSISSIPPIAN
Madison Limestone
Darwin Ss.
DEVONIAN
Darby Formation
SILURIAN
Unnamed
ORDOVICIAN
Bighorn Dolomite
Unnamed
CAMBRIAN
Upper
Gallatin Limestone
Flathead Sandstone
Middle
Buck Spring Formation
Gros Ventre Formation
Flathead Sandstone
Lower