WYOMING THRUST BELT PROVINCE (036)

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INTRODUCTION

The province is an arcuate, north-south-trending structural feature covering approximately 15,000 sq mi that extends from the Uinta Mountains on the south to the Teton Range and Snake River Plain on the north, encompassing parts of Wyoming, Utah, and Idaho. It is an easterly bulge, or salient, of the greater Cordilleran Thrust Belt of western North America that stretches over 5,000 mi from Alaska to Mexico. The wide axis of the thrust belt is roughly coincident with the eastern hingeline of a Paleozoic and Mesozoic miogeocline whose depocenter was located in southeastern Idaho, where more than 60,000 ft of predominantly marine sediments of Paleozoic and Mesozoic age were deposited. This sequence was strongly folded and thrust eastward starting in latest Jurassic time in the west and ending possibly as late as Eocene time in the east, followed later by extensional faulting from Eocene to the present. The resulting transition from a thick marine section on the west to a thinner shelf section to the east provides an optimum setting for migration of hydrocarbons from source rocks to updip reservoir rocks in structural traps formed by the thrusting.

Four major thrust systems make up the present structural setting of the province, two of which form its western and eastern boundaries. From west to east these thrust systems are the Willard-Paris, Crawford-Meade, Absaroka, and Prospect-Darby-Hogsback. Thrust faults are low-angle and moderately to highly imbricated, and do not involve crystalline basement, except in the area of the Moxa Arch extension. Productive traps found on three of the major thrust systems are in complexly faulted, upright to nearly recumbent folds. Twenty-nine oil and gas fields, 24 of which are currently productive, have been discovered in the province in traps of this type since the initial discovery at Pineview field in 1975, although exploration dates as far back as the 1890's. Cumulative production from these fields, five of which are giant fields, to the end of 1992 was 253 MMBO and 5.1 TCFG.

Seismic exploration, drilling, and new field discoveries have been heavily concentrated in the southernmost one-fourth of the province area ("Fossil basin" area); this is due mainly to the availability of access on land-grant (Union Pacific Railroad) and other private lands in this area. The northern three-fourths of the province has undergone minimal exploration and drilling, most of which is in small, scattered clusters of activity.

The areal patterns of the six conventional plays individually assessed in the province are constrained mainly by the linear configuration of the major thrust systems; the plays are discussed in the following sequence: Moxa Arch Extension Play (3601), Crawford-Meade Thrusts Play (3602), Northern Thrusts

Play (3603), Absaroka Thrust Play (3604), Hogsback Thrust Play (3606), and Cretaceous Stratigraphic Play (3607). No unconventional plays were defined in this province.

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CONVENTIONAL PLAYS

3601. MOXA ARCH EXTENSION PLAY

The play is characterized by probable CO_2 (carbon dioxide)-rich gas accumulations in Paleozoic carbonate reservoirs in footwall anticlinal traps on the extensional axis of the Moxa Arch. The arch is a north-south-trending regional basement uplift in the western Green River Basin that extends north from the Utah boundary for about 100 mil before swinging northwest at LaBarge where it passes beneath the leading edge of the Hogsback thrust. At this point, within the thrust belt, the axial portion of the arch is part of a large, thrust-faulted northwest-southeast-trending productive structural feature, about 40 mi long and 18 mi wide, locally termed the LaBarge Anticline. From here, the axis of the arch bends again and trends in a northerly direction for about 100 mi, its crestal portion lying below the surface trace of the Darby Thrust. The area of the play follows this extension, its width varying from 6 to 10 mi, from the southeast part of the LaBarge area to an estimated termination south of Jackson, Wyo.

Reservoirs: Recognized and potential reservoirs in the play are in the Ordovician Bighorn Dolomite, Devonian Darby Formation, Mississippian Madison Group, Permian Phosphoria Formation, and possibly the Pennsylvanian Wells Formation (Tensleep Sandstone). Major CO_2-rich gas reservoirs occur mainly in porous dolomite and limestone units of the 850 ft thick Madison, a substantial portion of which is of very good reservoir quality, with porosities greater than 6 percent and as much as 30 percent. The 450 ft thick Bighorn has tested high volumes of CO_2-rich gas in five wells, and core analysis in one of the wells showed an average porosity in one dolomite zone of 11 percent and an average permeability of 77 mD. Reservoirs in the 360 ft thick Darby and 320 ft thick Phosphoria have also yielded significant quantities of gas from generally low porosity, fractured dolomite units. Reservoir development in the Wells is minimal, although substantial initial amounts of gas have been recovered in a few wells. All productive reservoirs contain CO_2, CH_4 (methane), N (nitrogen), H_2S (hydrogen sulfide), and He (helium).

Source rocks: Dark-gray to black, phosphatic shale of the Phosphoria Formation is the apparent primary source rock for hydrocarbons in the play. Various studies indicate that hydrocarbon generation in the Phosphoria began in Late Jurassic time in the far western part of the thrust belt. Hydrocarbons were expelled, over time, and migrated eastward into the thrust belt area and beyond. Cores from Paleozoic reservoir rocks include fractures filled with dead oil in wells in the LaBarge area. It is postulated that these hydrocarbons were from a Phosphoria source that later accumulated in the Madison and Weber (Tensleep). Subsequent thermal degradation altered the original liquid hydrocarbons into solid bitumen, methane, CO_2, and H_2S. In addition to the CO_2-rich productive wells on the LaBarge anticline, two wells north of the LaBarge area appear to have drilled into the subthrust Paleozoic rocks that constitute the Moxa Arch Extension Play. The wells tested large volumes of CO_2-rich gas in Madison carbonate rocks, similar to the gas mix at LaBarge.

Traps: Traps are speculated to be mostly anticlinal, similar in style to the thrust-faulted footwall trap on the LaBarge Anticline. Seals include anhydrite beds in the upper part of the Madison and in overlying shales of Pennsylvanian age. Drilling depths are estimated to range from 10,000 to 18,000 ft to Madison and Bighorn targets in the footwall section of the arch extension.

Exploration status and resource potential: The first well to penetrate the Paleozoic section and establish the presence of CO_2-rich gas in the area of the play was completed in 1961, and was located on the crestal part of the LaBarge Anticline. More than 50 additional wells have been drilled to Paleozoic targets, clustered mainly on this feature, since the initial test well was drilled. Flow rates in these wells are substantial, ranging from 8 to 18 MMCFPD, with the CO_2 content of total gas increasing with the age or depth of the containing formation. CH_4 content of total gas varies, but an estimated average CH_4 content in the Madison is about 20 percent. Gas from a typical well completed in the Madison analyzed 19 percent CH_4, 70 percent CO_2, 7 percent N , 3 percent H_2S, and 1 percent He.

Production reports list three individual fields within the southern area of the play, Fogarty Creek, Graphite, and Lake Ridge (No. 10, 11, 14, fig. 2), discovered in 1976, 1986, and 1981, respectively; these fields are within the overall LaBarge Anticline complex. Cumulative production from 27 wells to the end of 1992 was 1.2 TCFG and 61,000 barrels of condensate. Future potential for undiscovered methane resources is excellent; however, limiting factors affecting exploration include extremely rugged topography and possible restrictions to access on public lands.

3602. CRAWFORD-MEADE THRUSTS PLAY (HYPOTHETICAL)

This hypothetical play is characterized by (1) probable hydrocarbon accumulations in footwall structural or truncation traps in reservoir rocks interbedded with source rocks, both of Cretaceous age, and (2) gas from Paleozoic shale sources, accumulating in Paleozoic and Mesozoic reservoirs in tightly folded anticlines in hanging wall traps in the Crawford Thrust Plate. The play area lies mainly in Utah and Idaho and is bounded on the west by the Willard-Paris Thrust and on the east by the Crawford-Meade Thrusts. The northwestern boundary is at the edge of the Snake River Plain, and the southern boundary is at a point where the thrust systems swing abruptly westward. The play is approximately 180 mi long and from 8 to 30 mi wide.

Reservoirs: Limited well and seismic data indicate that a moderately thick Cretaceous section is preserved under the leading edge of the Crawford Thrust Plate, where clastic reservoirs of marginal quality and thickness may be present. These include sandstone units of the Frontier and Bear River Formations in which probable reservoir facies are fluvial, deltaic, and barrier bar sandstones. Analogous, known low-productive reservoir facies east of the toe area of the Absaroka thrust are 10-50 ft thick and have porosities that range from 7 to 12 percent, but their permeability is low. Fractured carbonates in the

Triassic Dinwoody and Permian Phosphoria Formations are the productive reservoirs in the abandoned Hogback Ridge field. Other potential reservoirs may exist in younger Triassic and Jurassic units and in older Paleozoic rocks.

Source rocks: Possible source rocks in the hanging wall of the Crawford Thrust include shale of Mississippian, Permian, and Triassic age. Triassic shales are of limited areal extent and appear to be low in organic carbon, and the Permian Phosphoria is very mature to post-mature, based on thermal-maturity data. It is probable, however, that scattered dry gas shows in the play area and the dry gas produced at Hogback Ridge field are late-stage products of Phosphoria hydrocarbon generation, but Mississippian shales may also have been a very localized source of dry gas in this field. Data from the few wells that penetrated the Crawford Plate in the southern half of the play delineate a narrow corridor of Cretaceous-age potential source rocks beneath the leading edge of the Crawford Plate. Thermal maturation studies of this section indicate that it contains a mixture of kerogen types; however, it does include oil-prone Type II kerogen, and it is tentatively estimated that these oil-prone source rocks are presently at an oil-generative level of thermal maturation. Gas chromatography studies of oil-stained samples in the Jurassic Twin Creek Limestone and Triassic Ankareh and Thaynes Formations from two wells in the hanging wall indicate that the hydrocarbons migrated into the hanging wall in Late Cretaceous time from these footwall Cretaceous source rocks.

Traps: Structural traps normally present along the leading edge of an anticlinal fold trend, typical of the toe area of most thrust sheets, are absent from the Crawford Plate owing to uplift and beveling of the leading edge of the thrust, resulting in the breaching and erosion of possible hanging wall traps. Potential hanging wall traps may exist, however, in the form of low-relief folds above associated splay faults, or in tightly folded anticlines sealed by shale and anhydrite within intraplate imbricate thrusts. Other footwall traps may be present that are related to folding within trailing edge imbricates off the Absaroka Thrust, or splays off the Crawford Thrust into the footwall. Truncation traps, with asphaltic seals, at the updip edge of footwall beds may also be present. Drilling depths are estimated to range from 10,000 to 17,500 ft to Mesozoic and Paleozoic targets.

Exploration status and resource potential: The play is considered to be hypothetical and in a young stage of exploration with only about 50 wildcat wells drilled. The majority of shows reported are limited to dry gas, except for the few wells that had oil staining in Triassic rocks. The only production found in the play was from the one-well Hogback Ridge field, located midway between the edges of the Crawford and Willard-Paris Thrusts. The field was discovered in 1977 and abandoned in 1981 after producing 5.8 BCF of dry gas from fractured carbonates of Permian and Triassic age. A few wells drilled in the northwestern one-third of the play had recorded elevated bottom-hole temperatures, indicating that higher geothermal gradients exist here in proximity to volcanics of the Snake River Plain of Idaho. This

type of setting could be a deterrent to exploration. Any significant potential in the play, particularly for gas, would remain in the footwall Cretaceous section of the Crawford Thrust Plate in the southern half of the play.

3603. NORTHERN THRUSTS PLAY (HYPOTHETICAL)

The area of the hypothetical play includes the northern extensions of three of the major thrust systems, Crawford-Meade, Absaroka, and Prospect-Darby. It is characterized by a range of possible trapping conditions but involves mainly Paleozoic reservoir rocks in hanging wall anticlines juxtaposed against Cretaceous source rocks in the footwall of the thrust systems. The play trends mainly northwest-southeast for a distance of about 105 mi and varies in width from 35 to 55 mi. It is bounded on the west by the Meade Thrust, on the east by the Prospect Thrust, on the northwest by the Snake River Plain and on the south by an east-west projection of the easterly change in strike of the Darby Thrust.

Reservoirs: Potential reservoir rocks are of primarily Ordovician (Bighorn Dolomite), Mississippian (Madison Group), and Pennsylvanian (Wells Formation) age. The best porosity development occurs in the Madison, based on drill-stem test data from the scattered wells that have drilled into dolomitized zones in this 1,400 ft thick unit. The 1,000 ft thick Wells Formation ("Weber Sandstone" of industry usage) is characterized by erratic porosity development, and is relatively tight overall, although fairly strong hydrocarbon shows have been identified in some wells. The Bighorn is 400-500 ft thick and contains zones of intercrystalline and vuggy porosity.

Source rocks: The only source rocks of significance are organic-rich shales in Cretaceous and Permian rocks. Shale beds in the Bear River Formation and Aspen Shale are the richest, and marine shale in the Frontier and Hilliard Formations also contains sufficient organic carbon to be considered potential source rock. The organic-rich shale in the Phosphoria Formation is believed to be in an advanced stage of thermal maturity throughout the play and well into the dry gas stage. Minimal well data available indicate that humic material is common in the organic matter of Cretaceous shale, so that these rocks are slightly more gas prone. Shows of dry gas have been reported in wells in the northwestern area of the play, near the Idaho-Wyoming border, in subthrust Cretaceous rocks. In this same general locality, bleeding oil was reported in fractured Cambrian (Gallatin-equivalent) dolomite beds in one wildcat well. A well that drilled under a blind thrust into Cretaceous shale beneath the Prospect Thrust in the northeastern part of the play flowed subcommercial oil and gas from a thick, porous dolomite zone in the Madison. Probable source of these trapped hydrocarbons is thought to be shale in the Cretaceous Frontier and Hilliard Formations in the footwall of the blind thrust.

Traps: Traps may occur as tightly folded anticlines associated with duplex fault zones, or as "pop-up" block structures (triangle zones) formed in areas of backthrusting, and as broad, faulted anticlinal

structures in hanging walls where reservoir beds toe down to blind thrust zones in contact with Cretaceous source rocks in the footwall. Paleozoic rocks contain adequate seals, especially shale in the Devonian Darby Formation and anhydrite beds in the upper part of the Madison. Drilling depths are estimated to range from 4,500 to 15,000 ft.

Exploration status and resource potential: The play is hypothetical because of the extremely low density of drilling (about 60 total wildcats) within the broad area of the play. Although no fields have been discovered and no hydrocarbons produced, the Chevron, USA Cabin Creek wildcat well tested up to 100 BOPD and about 800 MCFGPD from a 200 ft porous dolomite zone in the Madison beneath the Prospect Thrust, and was completed as a noncommercial oil and gas discovery in 1986. No additional confirmation wells were drilled within this prospective area. Future potential for undiscovered oil is fair to good and for gas is excellent. Additional exploration in the play may be hampered by limited access to some public lands and by extremes of topography.

3604. ABSAROKA THRUST PLAY

The play is characterized by gas and oil accumulations in dolomite and sandstone reservoirs in hanging-wall anticlines along three subparallel lines of folding within the Absaroka Thrust Plate. The source is footwall Cretaceous shale. The play contains nearly all the discovered fields in the province. Fields on the eastern line of folds produce mainly oil with associated gas from Mesozoic rocks (mainly Nugget Sandstone); fields on the central line of folds produce primarily sour, wet gas and condensate from Paleozoic rocks (mainly Mission Canyon Limestone); and the western line of low-relief anticlinal folds produces minor wet gas and condensate, also from Paleozoic rocks. The play area trends north-south for approximately 140 mi and ranges from 18 to 35 mi in width in northern Utah and southwestern Wyoming. Play boundaries and fields are shown in figure 5.

Reservoirs: High-quality reservoir rocks of demonstrated productive capacity range from Late Cretaceous to Ordovician in age and comprises 12 different formations. The major producing reservoir on the eastern line of folds is the 1,000 ft thick eolian Jurassic Nugget Sandstone, which has recorded core porosity that ranges from 2 to 23 percent and permeability ranging from 0.1 to 2,000 mD. Net pay thicknesses range as high as 850 ft. The Nugget produces 44¡ API sweet oil and associated gas from 14 fields. Other productive oil and gas reservoirs are found in the Triassic Ankareh and Thaynes Formations and Jurassic Twin Creek Limestone. The primary reservoir on the central line of folding is the 750 ft thick Mission Canyon Limestone of the Mississippian Madison Group. Data from core analysis in this unit shows porosity ranging from 6 to 8 percent and permeability ranging from 0.7 to 1.5 mD. Production of sour gas (15 percent H_2S) and condensate is from an average net pay zone (at Whitney Canyon-Carter Creek) about 260 ft thick in the Mission Canyon. Other sour gas pay zones are in the Lodgepole Limestone, and the Darby and Phosphoria Formations, Weber Sandstone, and Bighorn

Dolomite; minor sweet gas and condensate production occurs in Triassic and Jurassic reservoirs. Sour gas production also occurs in two fields on the western line of folds from Mission Canyon and Bighorn reservoirs.

Source rocks: Organic-rich shale of Cretaceous age preserved in the footwall of the Absaroka Thrust has been well documented by geochemical analysis as the main source of all hydrocarbons trapped in hanging wall structures in the play. The Absaroka Thrust rode on shale in the Cretaceous Bear River Formation, Aspen Shale, and Frontier Formation for about 15 mi in a west-east direction in the play. Hanging-wall reservoir rocks are in direct contact with these subthrust shale source rocks across much of this distance. Hydrocarbons were generated in the shales and migrated along fault pathways into reservoirs in the hanging wall in latest Cretaceous-Tertiary time. Maximum total organic carbon (TOC) recorded from geochemical analysis of the Bear River, Aspen and Frontier is 9.3, 2.7, and 2.0 percent, respectively. Kerogen in these units is mainly mixed Type II and Type III. Preserved organic material is moderately oil-prone and becomes more gas-prone to the west as the percent of humic material increases, and as the maturation level of organic matter advances. This has resulted in hydrocarbons being in the wet gas-condensate stage of maturation in fields along the central and west fold trends and in the oil stage in fields on the eastern trend. Excellent shows and recoveries of both oil and gas from down-hole testing are reported in footwall Cretaceous rocks in a few wells, but no wells have been successfully completed in this footwall section as yet.

Traps: Traps in productive structures on the fold trends are basically truncation anticlines complicated by faulting (Mesozoic or Paleozoic hanging-wall rocks truncate against the subjacent Absaroka Thrust). Structural geometry of traps varies from asymmetric, overturned folds (Ryckman Creek), to leading-edge fold pair (Anschutz Ranch East west and east lobes), and upright fold (Whitney Canyon-Carter Creek). Trap size ranges from 1 sq mi low-relief anticlines (Bessie Bottom), to giant accumulations such as Whitney Canyon-Carter Creek field, which has 1,470-2,500 ft of structural closure and a hydrocarbon column of 2,400 ft, and Anschutz Ranch East which has 2,000 ft of structural closure in the west lobe and 1,000 ft in the east lobe. Maximum hydrocarbon column in the Anschutz Ranch East trap is 2,100 ft. Major seals include anhydrite in the Twin Creek Limestone and salt in the Preuss Sandstone, where present, overlying Nugget oil reservoirs in the eastern fold trend, and anhydrite at the top of the Madison Group, along with thick shale in the Triassic section capping wet gas Paleozoic reservoirs in the two western lines of folds. Drilling depths range from about 5,000 to more than 17,000 ft to footwall Cretaceous rocks beneath the Absaroka Thrust.

Exploration status and resource potential: Between 1975, when Pineview field was discovered, and 1992, a total of 24 new fields (actively producing) had been found in both plays, 14 on the oil and associated gas productive eastern trend of folds and 10 on the wet gas and condensate productive central

and western lines of folds. Most recently (late 1993), substantial new oil production was found by horizontal drilling in the Elkhorn Ridge field in fractured Jurassic Twin Creek Limestone; this is the first horizontally drilled production in the play and in the province. Cumulative production to the end of 1992 on the eastern trend is approximately 235 MMBO and 2.8 TCFG. Four giant fields, Anschutz Ranch East, Painter Reservoir, Painter Reservoir East, and Pineview, have produced the bulk of the oil and gas in the play. Cumulative production on the western fold trend from four fields reported is 18 MMB of oil and condensate and 1.1 TCFG; the giant Whitney Canyon-Carter Creek field accounted for more than 90 percent of this total. The largest field in the play is Anschutz Ranch East with an estimated 1 BBOE ultimate recovery; Whitney Canyon-Carter Creek has an estimated ultimate recovery of 500 MMBOE (includes gas, condensate, sulfur, and NGL).

Seismic coverage in the northern half of the play is less than 10 percent of the dense coverage in the southern productive half, with only about 25 total wildcat wells drilled in the northern portion (north of Bighorn production at Collett Creek field). Although the richly productive easterly trend of folds involving the Nugget Sandstone is essentially cut off by overriding of Paleozoic rocks some 10 mi north of Ryckman Creek field, the productive central and western fold trends persist into the sparsely explored northern half of the play. The most northerly production (Bighorn Dolomite) in the play was established in the late 1980's on the central fold trend at the Bridger Fork and Collett Creek fields; these oil and associated gas discoveries are located 3 and 5 mi, respectively, north of Bighorn gas and condensate production at the Road Hollow field. Bear River and Frontier sandstone reservoirs in the Absaroka footwall have tested excellent flows of sweet gas and some liquids from intervals in the few wells that have penetrated this Cretaceous section in the play. Future potential of the play ranges from good to excellent.

3606. HOGSBACK THRUST PLAY

The play is defined by probable hydrocarbon accumulations in highly imbricated fault traps related to the hanging wall of the Hogsback Thrust in both carbonate and clastic reservoirs of Paleozoic and Mesozoic age. The play extends for 120 mi from the north flank of the Uinta Mountains northward to the west-east strike line of the Darby Thrust west of LaBarge, Wyo. The width ranges from 12 to 15 mi from the toe of the Absaroka Thrust on the west, to the toe of the Hogsback Thrust, the eastern boundary of the province.

Reservoirs: Data from the few discovered fields in the play indicate that reservoirs are mainly carbonate and sandstone rocks in the Devonian Darby Formation, Mississippian Madison Group, and the Pennsylvanian Amsden, Permian Phosphoria, and Triassic Thaynes Formations. General estimated thicknesses of reservoir units vary widely from 130 ft in the Darby, to 8 to 10 ft zones in the Madison, 70 ft in the Amsden, 90 ft in the Phosphoria, and about 30 ft in the Thaynes. Reservoir quality is estimated to

be generally fair. Cretaceous reservoirs (Frontier and Bear River Formations in the footwall) are mainly thinner sandstones interbedded with shale and are of fair quality.

Source rocks: Limited geochemical analyses suggest that hydrocarbon source rocks may be shale in the Amsden and Phosphoria in the hanging wall of the Hogsback Thrust in the central and northern area of the play, and footwall Cretaceous shale, especially in the southern portion of the play. Analysis of samples in footwall Cretaceous shale, mainly in the Frontier, in a few deep wells indicates that catagenesis has advanced at least to the peak oil-generation stage in these rocks and has reached the dry gas phase in a number of places. Analysis of footwall Frontier shale in the deepest and most southerly well in the play, at 18,400 ft, showed the kerogen in these rocks to be in the oil stage of catagenesis. Based on the presence of noncommercial oil accumulations in two abandoned fields, Mill Creek and Christmas Creek, hydrocarbons were generated in these footwall Cretaceous shales and migrated along faults into Thaynes, Phosphoria, and Darby reservoirs in the hanging wall in Late Cretaceous-early Tertiary time. Fair shows of gas and moderate gas recoveries from drill-stem tests (DST) are reported in the Triassic Thaynes and Phosphoria Formations, Weber Sandstone, and Madison Group (where oil was also swabbed) in wells drilled in the central and northern areas of the play.

Traps: Traps are in highly faulted, narrow anticlines and within sharply bounded splay faults in the hanging wall near the eastern edge of the Hogsback Thrust. Scant information is available on trap geometry or amount of closure in discovered fields. Seismic and well information indicates that the leading edge of the Hogsback Thrust is characterized by numerous imbricate faults that appear to limit traps to distinct zones within the imbricate faults. This is typified by holes drilled in the vicinity of the one-well Horse Trap field (Amsden gas), where one of the drill holes cut 12 separate faults within a 4,800 ft interval in Paleozoic rocks. Shale and anhydrite seals are present in both Paleozoic and Mesozoic rocks, although the effectiveness of the seals may be lessened in places by excessive faulting. Drilling depths will range from less than 6,000 to about 17,000 ft.

Exploration status and resource potential: Exploration is minimal; about 30 scattered wells have been drilled in the play since the middle 1960's and only a very limited amount of seismic exploration took place in the northern half, although seismic coverage in the southern half of the play is nearly as dense as in the area of the Absaroka Thrust Play (3604). Exploration to 1993 resulted in the discovery in the early 1980's of three one-well fields in four different-age reservoirs (all abandoned or shut-in as subcommercial)--Mill Creek, Horse Trap, and Christmas Creek. Projected sizes of undiscovered accumulations are estimated to be in the small to medium size range; future potential for oil is moderate and for gas fair to good.

3607. CRETACEOUS STRATIGRAPHIC PLAY

The play is characterized by probable oil accumulations resulting from pinchout of reservoir sandstone facies updip and eastward into shale source-rock facies of Cretaceous age on the west-dipping trailing edge of the Hogsback Thrust. The play extends from the Wyoming-Utah line northward for 115 mi to a point west of the LaBarge complex. The western boundary of the play is at the toe of the Absaroka Thrust, and the play extends 3-8 mi to the east on the western part of the hanging wall of the Hogsback Thrust. Within this trend lies the axial trace of the narrow, sharply folded Lazeart Syncline, whose gently inclined eastern limb forms the trailing edge (hanging wall) of the Hogsback Thrust. The western limb of the syncline is vertical, overturned in places as much as 35¡ past vertical, and truncated by the Absaroka Thrust.

Reservoirs: Nearly the entire 15,000 ft Cretaceous section is present in the play, including the Adaville, Hilliard, and Frontier Formations, Aspen Shale and Bear River Formation. Potential reservoirs are limited, however, to sandstone beds of fluvial, deltaic, barrier bar, and offshore bar origin within the 3,000 ft thick Frontier and 800 ft thick Bear River. Reservoir sandstones interbedded with coals in the lower Frontier range from 10 to 40 ft thick and have porosities of 7 to 12 percent, but their permeability is generally low, averaging 0.1 mD or less. Thin, fossiliferous brown sandstones of the Bear River are interbedded with black shale and thin stringers of impure coal. Reservoir quality of the sandstones is fair to good, with porosity ranging up to 16 percent and permeability commonly exceeding 0.1 mD. Reservoirs in both formations, or equivalent units, are productive in a number of fields on the Moxa Arch in the Green River Basin.

Source rocks: Within the total Cretaceous section deposited in the province, the thickness of dark shales containing organic carbon alone exceeds 5,000 ft. TOC of shale in the Adaville and Hilliard is about 1 weight percent, but the most organic rich shale in the play, and the main oil source rock, is interbedded with sandstone in the Frontier and Bear River and intervening Aspen Shale. Maximum TOC measured in these units is 2 weight percent, 9.3 weight percent, and 2.7 weight percent, respectively. These interbedded shale beds contain mixed Type II and Type III kerogen which is at the stage of peak oil generation mainly in the vicinity of the trailing edge of the Hogsback Thrust hanging wall. Produced oil from two recent Frontier discoveries is 40¡ API gravity, waxy, and has a pour-point of 70¡ F. Active oil seeps are present in outcrops of the Cretaceous section along and in front of the toe of the Absaroka Thrust in the southern part of the play, where a sizable number of older, shallow wells have produced small amounts of oil. Generation and migration of oil occurred in Late Cretaceous to early Tertiary time from indigenous source to reservoirs in the Frontier and Bear River. It has been suggested that the Cretaceous shale section is still generating hydrocarbons.

Traps: Stratigraphic trap potential exists where porous and permeable sandstone beds grade updip (east) and pinch out into tighter, nonpermeable sandstone or shale on the trailing edge of the Hogsback Thrust.

Top and bottom seals are source shale encompassing the reservoir sandstone. Several fields on the Moxa Arch, productive from both Frontier and Bear River, are at least partly controlled by this same type of stratigraphic pinchout. The projected depth range for future drilling is estimated to be from 4,000 to 17,000 ft. Seismic data in the vicinity of the two recent discoveries show that they are located on uniform westward-dipping (±30¡) beds on the Hogsback hanging wall with no indication of structural reversal or faults to account for hydrocarbon accumulations in the two discoveries, except by stratigraphic control.

Exploration status and resource potential: The earliest exploration and drilling in the play were concentrated near oil seeps in the vicinity of the present-day Aspen field in 1884. The first wells completed, however, were in the nearby Spring Valley field in 1900, followed by the discovery of the Sulphur Creek field in 1942. Depth to production in the Aspen, Frontier, and Bear River in these field ranges from 100 to 2,000 ft, and oil gravity ranges from 22¡ to 48¡ API. Two recent discoveries in 1984 and 1985, the Lazeart (87 BOPD) and Elkol (6 BOPD) fields (currently shut-in), were drilled to test the validity of a Frontier-Bear River stratigraphic play. Without additional offset drilling, the size of these accumulations cannot be determined; however, some 20 separate sandstone zones with oil saturation were logged between 6,300 and 7,000 ft in the lower Frontier in the Lazeart discovery.

Cumulative production from all fields in the play to the end of 1992 was 276,909 BO and 30,525 MCFG. Future potential for oil and associated gas is low to moderate, and field sizes are anticipated to be in the small to medium category. The amount of oil-in-place in Cretaceous rocks in the play, based on present data, appears to be quite significant, but improvement in extraction practices will be necessary in order to realize commercially recoverable amounts of oil in undiscovered accumulations. Advances in the technology of reservoir stimulation, possibly the use of inclined or horizontal drilling techniques, and different completion methods may be required to accomplish this.

UNCONVENTIONAL PLAYS

There are no unconventional plays described in this province report. However, unconventional plays listed in the surrounding provinces may include parts of this province. Individual unconventional plays are usually discussed under the province in which the play is principally located.

REFERENCES

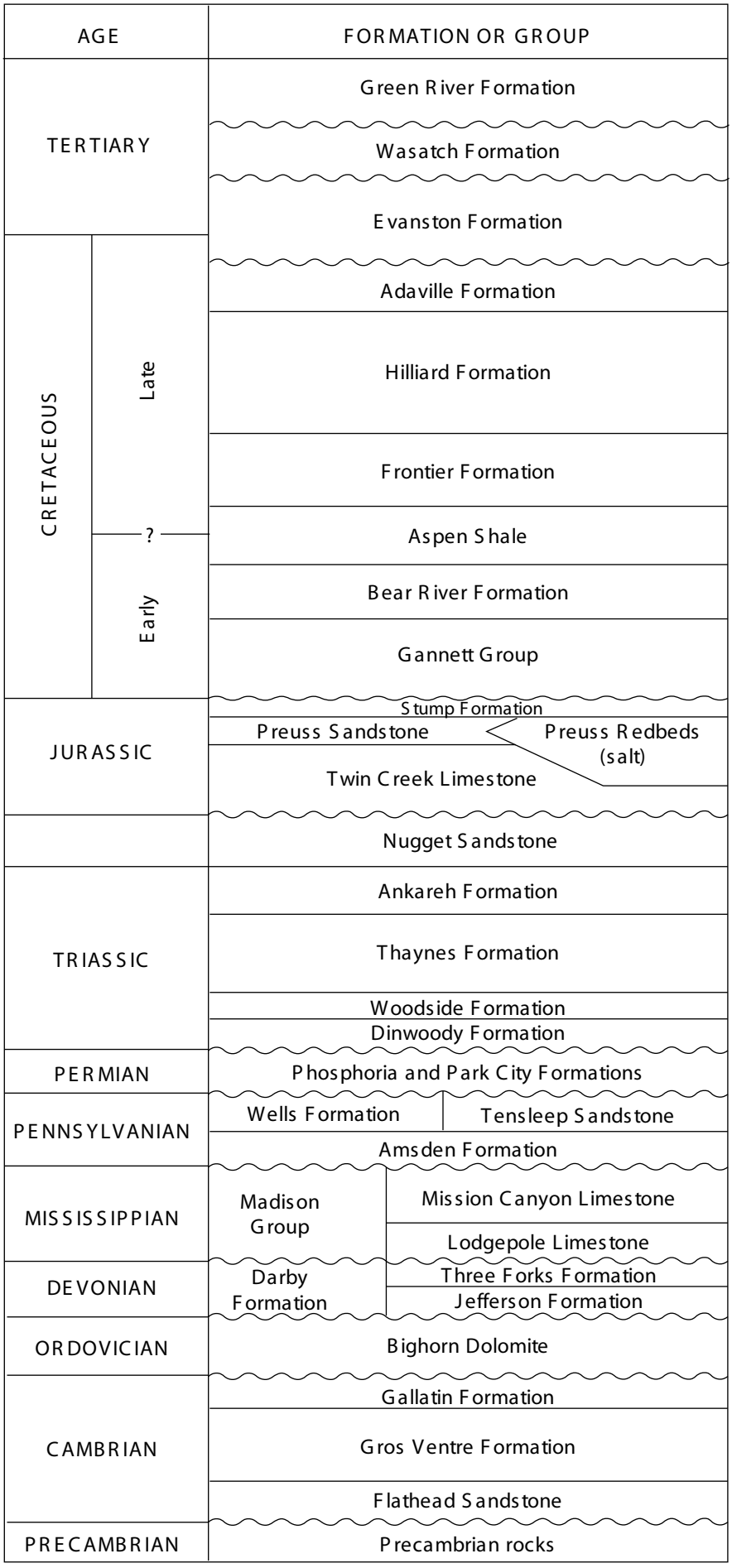
Powers, R.B., 1993, Wyoming-Utah-Idaho Thrust Belt province (090), *in* Powers, R.B., ed., Petroleum exploration plays and resource estimates, 1989, onshore United States--Region 3, Colorado Plateau and basin and range: U.S. Geological Survey Open-File Report 93-248, p. 74-92.

Powers, R.B., ed., 1982, Geologic studies of the Cordilleran Thrust Belt: Rocky Mountain Association of Geologists, 2 vols., 976 p.

Powers, R.B., (in press), Geologic summary and hydrocarbon assessment of the Wyoming-Utah-Idaho thrust belt province: U.S. Geological Survey Open-File Report 88-450Q.

State of Utah, Department of Natural Resources, 1992, Oil and gas production report, Salt Lake City, Utah, 219 p.

State of Wyoming, Oil and Gas Conservation Commission, 1992, Statistical summaries, Casper, Wyoming, 267 p.


AGE
FORMATION OR GROUP
TERTIARY
Green River Formation
Wasatch Formation
Evanston Formation
CRETACEOUS
Late
Adaville Formation
Hilliard Formation
Frontier Formation
?
Aspen Shale
Early
Bear River Formation
Gannett Group
JURASSIC
Stump Formation
Preuss Sandstone
Preuss Redbeds (salt)
Twin Creek Limestone
Nugget Sandstone
TRIASSIC
Ankareh Formation
Thaynes Formation
Woodside Formation
Dinwoody Formation
PERMIAN
Phosphoria and Park City Formations
PENNSYLVANIAN
Wells Formation
Tensleep Sandstone
Amsden Formation
MISSISSIPPIAN
Madison Group
Mission Canyon Limestone
Lodgepole Limestone
DEVONIAN
Darby Formation
Three Forks Formation
Jefferson Formation
ORDOVICIAN
Bighorn Dolomite
CAMBRIAN
Gallatin Formation
Gros Ventre Formation
Flathead Sandstone
PRECAMBRIAN
Precambrian rocks