SOUTHWEST MONTANA PROVINCE (029)

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INTRODUCTION

The province, approximately 12,960 sq mi in area, lies north and northwest of Yellowstone National Park and east and southeast of the Cordilleran Thrust Belt in the southwestern part of the State of Montana. It includes that part of the Rocky Mountain Foreland in southwest Montana. Three major Laramide uplifts exist in the province, the Blacktail-Snowcrest, Madison-Gravelly, and Beartooth Uplifts. The entire Phanerozoic stratigraphic sequence varies widely across the province; in the western part, the Laramide Blacktail-Snowcrest Uplift has a profoundly different stratigraphy from areas to the east and south, as this uplift represents the prior upper Paleozoic Snowcrest Trough bounded by thinner upper Paleozoic sequences of the Wyoming Shelf to the east and south. The Devonian Three Forks Formation includes the Bakken-equivalent Sappington Member at the top, and the Permian Phosphoria Formation includes the Shedhorn Sandstone. The eastern part of the province contains more marine Cretaceous rocks than those of the western part of the province. Much of the southern part of the province is floored by Archean igneous and high- grade metamorphic rocks with a thin veneer of Cretaceous to Tertiary igneous rocks. No significant amounts of hydrocarbons have been found in the central and western part of the province. Three Cretaceous gas fields (greater than 6 BCFG) have been discovered near the easternmost corner of the province on the west and south flanks of the Hailstone Dome. One of these produced modest amounts of oil prior to 1970. In the southeastern part of the province, along the Nye-Bowler Wrench Zone, one major field, Dry Creek, has produced more than 4 MMBO and 70 BCFG, and a small gas field with very modest amounts of oil is also present (Golden Dome). Farther west, along the Nye-Bowler trend, three heavy oil accumulations containing 10-13¡ API black oil have produced small quantities of oil by steam injection. Six conventional hydrocarbon plays were individually assessed in the province, Crazy Mountains and Lake Basins Cretaceous Gas (2901), Nye-Bowler Wrench Zone Oil and Gas (2903), Beartooth Frontal Oil and Gas (2904), Snowcrest-Greenhorn Frontal (2906), Tertiary Basins Oil and Gas (2907), and Crazy Mountains and Lake Basins Oil (2910). Two additional plays, Madison Subthrust Oil (2905) and Basement Structure (2908), are discussed but considered to have a play probability of 0.1 or less. Therefore, they were not quantitatively assessed. I particularly acknowledge information provided by David Lopez and Karen Porter of the Montana Bureau of Mines and Geology and Jim Halverson of the Montana Board of Oil and Gas Conservation.

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CONVENTIONAL PLAYS

2901. CRAZY MOUNTAINS AND LAKE BASINS CRETACEOUS GAS PLAY

This confirmed play occupies approximately 4,400 sq mi in the northeastern part of the province. The Crazy Mountains Basin part of the play excludes the area of the early Tertiary Crazy Mountains Laccolith and igneous dike swarm. The Reedpoint Syncline part of the play excludes the Late Cretaceous Sliderock Mountain intrusive-extrusive complex. The play also includes part of the Lake Basin Wrench Fault Zone, and the west and south flanks of the Hailstone Dome. The play is bounded on the northeast by the Hailstone Dome, on the east by the Pryor-Bighorn Uplift, on the south by the Nye-Bowler Wrench Fault Zone, and on the west by the Helena Salient of the Montana Thrust Belt. It is a confirmed structural play characterized by relatively small Cretaceous gas fields in structural and combination structural-stratigraphic traps.

Reservoirs: Numerous Cretaceous sandstones have reservoir potential, primarily the Lower Cretaceous Muddy, Dakota, and Lakota, and the Upper Cretaceous, Frontier, Virgelle, Eagle, and Judith River sandstones. Porosities in the gas-producing fields range from about 12 to 18 percent, and permeabilities range from about 25 to 90 mD (Tonneson, 1985). Reservoir sands appear to be generally less than 100 ft thick and are bounded by marine shales in the eastern part of the play. Abundant volcanoclastic rocks occur in the western part of the play, where the sands are generally of much poorer reservoir quality.

Source rocks: Cretaceous source rocks include the Skull Creek, Thermopolis, Muddy, Frontier, Cody, and Mowry Shales. Based on data from Burtner and Warner (1984), the Mowry and Skull Creek contain 1 percent or less TOC and predominantly Type III woody to herbaceous gas-prone kerogen. Migration of natural gas from these source rocks into adjacent Cretaceous sandstone reservoirs probably took place during early Tertiary time.

Traps: Traps are on generally north-south trending anticlines, which are fault bounded in part (Tonneson, 1985), and they are the result of Cretaceous to early Tertiary Laramide deformation. Trap size varies from 2,500 to 6,700 acres for the discovered fields (Tonneson, 1985). Seals appear to be the overlying Cretaceous shales. Producing depths range from less than 1,000 ft to 3,925 ft. However, the maximum depth for undiscovered Cretaceous gas accumulations may be as much as 20,000 ft near the western margin of the play west of the Crazy Mountains intrusive complex.

Exploration status and resource potential: Cumulative gas production through 1992 was 29 BCFG for Big Coulee, more than 5 BCFG for Lake Basin (much early gas production not reported--used in manufacture of carbon black), 9.4 BCFG for Lake Basin North field, and 2.9 BCFG for Rapelje (Jacobson and others, 1993). Other fields in this play have produced less than 1 BCFG. The western part of this play has been sparsely drilled, whereas the eastern part has been more intensely explored. I judge that at least three gas fields of at least 6 BCFG remain to be discovered in this play--and that they will be relatively small.

2903. NYE-BOWLER WRENCH ZONE OIL AND GAS PLAY

The Nye-Bowler Lineament was defined by Wilson (1936) as a zone of faults and folds extending west-northwest across the northern part of the Bighorn Basin; it included the Dean Dome near its western limit. The confirmed Nye-Bowler Wrench Zone Oil and Gas Play encompasses a zone of en-echelon faults oblique to the east-southeast trend of the lineament, longitudinal faults parallel with the trend, and oil- and (or) gas-bearing domes and anticlines, which Wilson (1936) interpreted to overlie a left-lateral shear zone in the basement. Mesozoic movements in this zone commenced in middle Campanian (Cretaceous) time as demonstrated by abrupt changes in thicknesses and lithology of stratigraphic units on either side of the zone. Differences in thickness of upper Campanian and Maastrichtian stratigraphic units across the zone, greater by an order of magnitude than differences in middle Campanian thicknesses, indicate more intense lateral and vertical movements during late Campanian and Maastrichtian time; even greater differences indicate a maxima of intensity during Fort Union (early Paleocene) time (Wilson, 1936). Deformation had ceased by Eocene time when the pre-Wasatch erosion surface was developed. The Nye-Bowler Wrench Zone extends westward to include the line of intrusive igneous bodies (Sliderock Mountain intrusive complex) west-northwest of the Dean Dome and farther west to include a zone of en-echelon anticlines (Perry, 1990). The confirmed part of the play lies east of the intrusive complex; the hypothetical part of the play lies west of the complex.

Reservoirs: Reservoirs include numerous Cretaceous sandstones--Eagle, Virgelle, Kootenai (Greybull), Lakota, and Judith River--of variable reservoir quality and thickness (Tonneson, 1985).

Source rocks: Source rocks for the gas and possibly the oil in the eastern part of the play are inferred to be Cretaceous marine shales--the Skull Creek, Thermopolis, Mowry, and Cody. The heavy oil north of the Beartooth Front is considered to be from the Permian Phosphoria Formation (Claypool and others, 1978). If so, then the migration barriers presented by the Late Cretaceous Laramide uplifts of northwestern Wyoming and southwestern Montana could not have been present at the time of hydrocarbon generation and migration, unless unidentified Phosphoria source rocks are present east of these uplifts. Hydrocarbons from Cretaceous source rocks were generated during latest Cretaceous through early Tertiary time.

Traps: Traps are domes and en echelon anticlines along the Nye-Bowler Fault Zone as described above.

Exploration status and resource potential: The eastern end of the Nye-Bowler Fault Zone includes the oldest and largest field in the zone, the Dry Creek oil field, discovered in 1929, which had produced 4.16 MMBO by 1/10/90. The only significant gas field in the play, nearby Golden Dome, produced only 2

BCFG from Upper Cretaceous sandstones, prior to conversion to gas storage. The eastern part of the Nye-Bowler has been extensively tested, and no fields have been discovered since 1967. To the west, north of the eastern Beartooth Front occur the heavy oil accumulations of the Dean, MacKay, and Roscoe Domes. This viscous black oil with a 10-12¡ API gravity has been produced only in small quantities by steam injection and diesel soaks (Dean Dome--75,945 BO, Mackay Dome--63,472 BO, and Roscoe Dome--14,716 BO, Graumann and others, 1986). These fields are currently shutin. Nonconventional oil resources are abundant in the form of heavy oil, which requires steam injection or other unconventional methods to produce. Conventional undiscovered hydrocarbon resources appear modest. This area has also been extensively explored, yielding no commercial quantities of conventional hydrocarbons. The western part of the play has not been thoroughly explored; undiscovered oil and gas resources are assigned to this, the hypothetical part of the play.

2904. BEARTOOTH FRONTAL OIL AND GAS PLAY (HYPOTHETICAL)

This hypothetical structural play is based on the premise that hydrocarbons may be trapped in subthrust (footwall) Paleozoic and Mesozoic sedimentary rocks beneath thrust "overhangs" associated with the Laramide basement-involved Beartooth Thrust System. A Laramide thrust overhang is anticipated on the eastern and northeastern flank of the Beartooth uplift in the southeastern part of the Southwest Montana Province. The northern flank of the Beartooth Uplift has been thrust obliquely northeastward over the margin of the adjacent Nye- Bowler Wrench Zone, one interpretation of which is shown by Stone (1983). The eastern flank has been thrust northeastward such that the width of overhang is as much as 10 mi along the northeastern corner of the uplift where the vertical component of separation on the bounding fault system is believed to exceed 20,000 ft, and overhang decreases westward and southward from this corner. The inferred area of overhang (233 sq mi) defines the play area. The thrust-uplifted Beartooth block has been erosionally stripped to the Precambrian crystalline rocks. Much of this displacement took place subsequent to Fort Union deposition and may be Eocene in age.

Reservoirs: Potential reservoir rocks include Cretaceous sandstones of variable thickness, porosity, and permeability based on data from fields in the Nye-Bowler Wrench Zone (Tonneson, 1985). Paleozoic potential reservoirs include Permian and Pennsylvanian sandstones and Mississippian limestones of unknown reservoir quality beneath the overhang. Paleozoic source rocks may be absent in this area: the Permian Phosphoria equivalent, the Shedhorn Sandstone, is thin to absent (E.K. Maughan, oral commun., 1985).

Source rocks: Devonian Bakken-equivalents are likewise thin to absent and lacking in source potential. The Cretaceous Thermopolis and Mowry Shales are the principal source rocks in the area. Long-distance migration prior to development of the Laramide Beartooth Uplift is required for the presence of oil derived from Paleozoic rocks to be present in the play area. Inferred structural traps need to be present beneath the Beartooth Thrust. Thick Cretaceous shales likely bound footwall thrust imbricate blocks along the eastern but not the northern margin of the play. The axis of the Bighorn Basin is inferred by Blackstone (1986) to plunge underneath the northeastern part of the Beartooth block.

Exploration status and resource potential: Only two deep wells have been drilled in the play area: (1) the Amoco 1 USA, drilled in the northeastern corner of the Beartooth block to a true vertical depth (TVD) of 7,926 ft below sea level (15,800 ft measured depth) bottoming in Upper Devonian Jefferson Dolomite (Perry and LaRock, 1993), and (2) the Phillips Petroleum Ruby "A" Federal #1-9 which bottomed at 8,200 ft (6,899 ft TVD) in Mississippian Madison Formation (data and reports on file at Montana Board of Oil and Gas Conservation). Both had shows of gas in Cretaceous rocks beneath the overhang. Neither logged shows from the Paleozoic rocks encountered. The Cruse oil seeps area and Dean Dome and MacKay oil fields are just north of the play boundary. However, only one well has been drilled within the play area along the northern Beartooth Front in the vicinity of the Cruse seeps: the Texaco 1 Ostrum, in section 9, T. 6 S., R. 17 E., from which 15 ft of core in the Cretaceous Dakota Sandstone bled oil. Farther west four wells have been drilled along the northern boundary of the play in east-central Park County, one of which, a very shallow (2,728 ft) Pennsylvanian Amsden test, had a show of oil. I consider that there is a 40 percent chance of discovering an accumulation of 1 MMBO or 6 BCFG, or greater.

2905. MADISON SUBTHRUST OIL PLAY (HYPOTHETICAL)

This hypothetical structural play is based on the premise that oil may be trapped in the Laramide basement-involved Hilgard Thrust System in the south-central part of the Southwest Montana Province. Here Archean through Paleozoic rocks of the Hilgard Fault System (Tysdal, 1986, 1990) were thrust eastward over Cretaceous rocks of the Big Sky Basin to the east during Maastrichtian (Late Cretaceous) time (Tysdal and others, 1986). The western part of the Hilgard Thrust System was breached and dropped during late Tertiary to Quaternary time by the still active Madison Range Extension Fault System (Tysdal, 1986). The Madison subthrust oil play extends from the lip of the easternmost thrust to the Tertiary Madison Range Normal Fault System on the west, a distance of generally less than 6 mi (Tysdal, 1990).

Reservoirs: Possible reservoir rocks in the area (from map descriptions by Tysdal, 1990) include Pennsylvanian and Permian sandstones that range from about 115 to 315 ft thick and limestones of the Mississippian Madison Group that are as much as 1,450 ft thick. Possible zones of karstic porosity are present in the top of the Madison in this area; the remainder is likely to have very low intergranular porosity. Cretaceous sandstones as much as 400 ft thick may also have reservoir potential.

Source rocks: Pre-Cretaceous source rocks are thin to absent in the area of this play. Cretaceous source rocks are also lean and gas-prone in this area (references given in Perry, 1990). Pre-thrust migration of hydrocarbons from richer Paleozoic source rocks to the west to early formed traps in this play area would provide a possible source.

Traps: Inferred anticlinal and (or) thrust imbricate structural traps blanketed by Cretaceous shales need to be present beneath the overriding Precambrian basement-involved thrusts of the Hilgard System. Overturned footwall rocks as old as the Mississippian Madison Group are exposed (Tysdal, 1990) such that prospective traps are breached. Hydrocarbons originally trapped beneath the Hilgard Thrust System could also have been expelled during extension faulting through steeply dipping to vertical extension fracture networks.

Exploration status: No wells have been drilled in this play. Data from the one nearby drillhole to the east indicated no shows of oil or gas and indicated abundant fresh water in the upper part of the Madison Group. No seeps or other surface indications of hydrocarbons have been reported.

Resource evaluation: Cretaceous intrusive activity has affected the northern part of the play area, and Upper Cretaceous rocks of the Livingston Group contain abundant volcanic ash (Tysdal and others, 1986). In summary, the hydrocarbon potential of this play appears to be low to very low: a play probability of 0.1 was assessed based chiefly on likelihood of breached seals and absence of surface or subsurface indications of hydrocarbons.

2906. SNOWCREST-GREENHORN FRONTAL PLAY (HYPOTHETICAL)

This hypothetical structural play is based on the premise that hydrocarbons may be trapped in subthrust (footwall) Paleozoic and Mesozoic sedimentary rocks beneath thrust "overhangs" associated with the Laramide basement-involved Snowcrest-Greenhorn Thrust System. The play is limited to that part of the Snowcrest-Greenhorn Thrust System having possibly as much as 5 mi of overhang of Paleozoic sedimentary rocks and Archean crystalline rocks in the hanging wall over Paleozoic and Mesozoic rocks of the footwall. Deformed Paleozoic sedimentary rocks and Archean crystalline rocks of the southeastern limb of the Blacktail-Snowcrest Uplift are allochthonous; they have been thrust southeastward over the adjacent Ruby basin (Klepper, 1950; Perry and others, 1983; Guthrie and others, 1989) along the Snowcrest-Greenhorn Thrust System. 90 to 80 MA thrusting represents reverse motion on an earlier down-to-northwest normal fault system (active during Late Paleozoic time), followed by Tertiary normal faulting related to Basin-Range extension (Guthrie and others, 1989).

Reservoirs: Possible reservoir rocks include early and mid-Cretaceous sandstones, Pennsylvanian Quadrant Sandstone, and Mississippian Madison limestones (Guthrie and others, 1989).

Source rocks: Possible source rocks include the Upper Devonian Sappington Member of the Three Forks Formation (Bakken equivalent) and the Permian Phosphoria Formation. Organic carbon values range up to 7.5 percent for the Sappington Member of the Three Forks Formation and to more than 19 percent for the Retort Shale Member of the Permian Phosphoria Formation to the west in the Montana Thrust Belt Province (Claypool and others, 1978; Perry and others, 1983; Perry, 1989), but values are leaner in the play area. Pre-Cretaceous rocks of this subthrust play are considered supermature with respect to oil based on vitrinite studies (Perry and others, 1983). Cretaceous rocks sampled, Thermopolis equivalents, contain less than 1 percent organic carbon; their kerogen is woody to herbaceous (Perry and others, 1983).

Traps: Traps are inferred subthrust four-way structural closures, in the footwall of the sub-Snowcrest Thrust System, in which Cretaceous Frontier sandstones or older rocks may contain hydrocarbons generated in the underlying Paleozoic sequence. The Sage Creek Normal Fault, a down-to-northwest extension fault of Oligocene to Miocene age along the northwest margin of the Snowcrest-Greenhorn Thrust System (Perry and others, 1988; Kulik and Perry, 1988) may have breached subthrust traps. A series of late Tertiary to Quaternary normal faults cut northwestward obliquely across the Snowcrest terrane and locally disrupt the upper plate, and these may have breached subthrust traps also.

Exploration status and resource potential: The Marathon 20-1 Cornell Camp-Federal well, drilled in 1987, penetrated subthrust rocks within the play area (Guthrie and others, 1989). Live oil was recovered from Paleozoic rocks in the hanging wall; no shows of liquid hydrocarbons or natural gas were reported from the subthrust sequence, only dead oil (asphalt). The well was completed as a dry hole.

In summary, the hydrocarbon potential of the Snowcrest-Greenhorn Play appears substantially higher than that of the Madison Subthrust Oil Play, as good source rocks are present and oil has been recovered. Only one test well has been drilled and only one structure tested along this trend.

2907. TERTIARY BASINS OIL AND GAS PLAY (HYPOTHETICAL)

The hypothetical Tertiary Basins Oil and Gas Play is based on the premise that oil and gas from older source rocks have generated hydrocarbons in Tertiary time, which may have been sealed in traps in the deeper parts of several small Tertiary basins in the Southwest Montana Province. From northeast to southwest, Bozeman Valley (Madison-Gallatin Basin, 97 sq mi), Upper Madison Valley (281 sq mi), and Sage Creek-Upper Ruby (202 sq mi) are among the largest and deepest of these basins. These are outlined as part of the Tertiary Basins Oil and Gas Play. These basins are normal fault-bounded on at least one side, contain as much as 9,000 ft of Tertiary sediments, and are the result of Basin-Range extension and associated strike-slip faulting; the deepest is a narrow slot more than 14,700 ft deep within the northern part of Upper Madison Valley (Ruppel, 1993). The southwestern basins are floored by middle Eocene volcanic rocks emplaced between about 49 and 44 MA (Hanneman, 1989). These or the Archean or Paleozoic basement rocks to the northeast are unconformably overlain by late Eocene to early Miocene devitrified volcanoclastic and lacustrine rocks associated with locally derived coarse clastic rocks (Fields and others, 1985).

Reservoirs: Inferred reservoir sands occur in the lower parts of the basin fill; details of reservoir quality are unknown or at least unpublished.

Source rocks: Source rocks may include oil-prone lacustrine rocks or gas-prone coaly rocks in the lower part of the basin fill, but such have not been described in this province. A more likely inferred source is Paleozoic rocks beneath or on the margins of these basins which were not buried deeply enough to become supermature with respect to oil generation until the high heat flow associated with Tertiary extension occurred (based on analogies with the Great Basin).

Traps: Where studied in detail (A.R. Tabrum, Carnegie Museum, written commun., 1985; Hanneman, 1989; Hanneman and Wideman, 1991), these basins are structurally very complex, and are broken by faults into a number of sub-basins. Such faults may provide traps for hydrocarbons sealed by younger fine-grained volcanoclastic rocks. Calcic paleosol zones (Hanneman and Wideman, 1993) may also act as seals to the upward migration of hydrocarbons.

Exploration status and resource potential: Very few (probably less than six) significant wells have been drilled in Tertiary basins in the Southwest Montana Province. Considering the structural complexity of these basins, they are essentially untested. However, these basins have no demonstrated source-rock potential, and the largest, the Upper Madison Valley, rests primarily on high-grade Archean metamorphic rocks. Therefore a relatively low probability (0.24) of occurrence of a hydrocarbon accumulation of minimum size (1 MMBO or 6 BCFG) was assessed.

2908. BASEMENT STRUCTURE PLAY (HYPOTHETICAL)

This hypothetical play includes two areas: the southern Big Sky Basin (394 sq mi) and Ruby Basin (805 sq mi). This play is based on the hypothesis that hydrocarbons may have been trapped by early-formed basement-involved structures with closures of less than 1,000 ft, many of which may not be represented by the structural attitudes at the surface of unconformably overlying younger rocks. Northwest-trending structures may have been actively growing during Late Paleozoic time (Maughan, 1983). Small north-northwest-trending anticlines are present in the northern part of the Ruby Basin area (Mann, 1960). Other such structures appear to be present farther southwest in the basin as indicated by gravity modelling (Kulik and Perry, 1988) and by seismic profiles. The Ruby Basin forms the northwestern margin of the Late Paleozoic Wyoming Shelf (Perry, 1986). Deep drillholes in the Ruby Basin and uplift south of the play area indicate a gradually northward thickening of the Upper Paleozoic sequence across the area from the Monida paleohigh, where Upper Paleozoic rocks are locally only 310 ft thick (Perry, 1986). The Big Sky Basin is a small Cretaceous basin containing several northwest-trending structures. At least one of these structures is demonstrated by Tysdal (1986) to predate the Late Cretaceous Hilgard Thrust System along the western margin of the basin. The Big Sky Basin contains a thin sequence of Upper

Paleozoic rocks comparable to those of the Ruby Basin (Perry, 1990). The "Christmas-tree laccolith" dated by Tysdal and others (1986) as latest Cretaceous, occupies much of the northern part of the Big Sky Basin. The presence of this laccolith provides not only a minimum age for Hilgard thrusting but also severely reduces the oil potential of this basin. The two basins were part of the much larger intracratonic foreland basin (which included the present northern Bighorn Basin) along the western margin of the Western Interior Cretaceous seaway until latest Cretaceous time. K-Ar and $^{40}Ar/^{39}Ar$ dating of hornblende from laccolithic rocks that intruded the Hilgard Thrust System by Tysdal and others (1986) indicate that thrusting along the western margin of the Big Sky Basin occurred prior to 68 MA.

Reservoirs: Possible reservoir rocks in both basins include Early and Middle Cretaceous sandstones (generally less than 300 ft thick), thin Permian sandstone, Pennsylvanian Quadrant Sandstone (50 to 200 ft thick), and Mississippian Madison limestones with possible karstic porosity at the top.

Source rocks: Paleozoic rocks within the Ruby Basin are postmature with respect to oil generation (Perry and others, 1983); no values are available for the Big Sky Basin. Lower Cretaceous rocks are considered gas-prone and are expected to be relatively impoverished in organic carbon (Perry and others, 1983, and unpublished data).

Exploration status: Two deep drillholes in the southern third of the Ruby Basin area contained no shows of oil or gas. The American Quasar no. 29-1 Peet Creek-Federal well (Perry, 1986, fig. 1), drilled along the southern margin of the play area, also yielded no hydrocarbons. This drillhole yielded brackish water from Devonian rocks below 11,000 ft, suggesting deep circulation of ground water along the nearby Centennial Extension (normal) Fault. The Phillips Petroleum no. 1 Carrot Basin drillhole in the southern part of the Big Sky Basin (Perry, 1990, fig. 1) was dry. The structure on which it was drilled appears to contain brackish water within the Madison Limestone, suggesting deep ground water circulation and absence of a seal for hydrocarbons (Perry, 1990).

Resource potential: These findings suggest that the Big Sky and Ruby Basins have low to very low hydrocarbon potential. The play probability was rated very low (0.08) for the occurrence of an undiscovered hydrocarbon accumulation of the minimum size, based in large part on the occurrence of fresh to brackish water and no hydrocarbons, as well as thin, impoverished source rocks in wells drilled to 1993.

2910. CRAZY MOUNTAINS AND LAKE BASINS OIL PLAY (HYPOTHETICAL)

The Crazy Mountains and Lake Basins Oil Play occupies approximately 4,400 sq mi in the northeastern part of the province: the Crazy Mountains Basin exclusive of the early Tertiary Crazy Mountains laccolith and igneous dike swarm, and Reed Point Syncline exclusive of the Cretaceous Sliderock Mountain intrusive-extrusive complex. The play also includes part of the Lake Basin Wrench Fault Zone, and the west and south flanks of the Hailstone Dome. The play is bounded on the northeast by the Hailstone Dome, on the east by the Pryor-Bighorn Uplift, on the south by the Nye-Bowler Wrench Fault Zone, and on the west by the Helena Salient of the Montana Thrust Belt. It is a hypothetical stratigraphic play characterized by relatively small carbonate (Waulsortian) mud mounds.

Reservoirs and traps: Waulsortian mud mounds as much as 300 ft thick occur in the Paine Member of the Lodgepole Formation, Mississippian Madison Group, east, west and north of the play area. These are composed of lime mudstone, sparry calcite, and skeletal debris. They are commonly dolomitized, resulting in good secondary porosity. Sinkholes and zones of karstic porosity in the upper part of the Madison Group are part of the major Madison aquifer system and are likely flushed within the play area.

Source rocks: Paleozoic source rocks are poorly known in the play area; the Bakken-equivalent Upper Devonian to Lower Mississippian oil-prone mudstone is very thin to absent, and Permian Phosphoria source rocks are absent (Peterson, 1985). Southward migration of hydrocarbons from the Central Montana Trough could have occurred prior to Late Cretaceous and early Tertiary subsidence of much of the play area. The Madison Group in the western part of the area has been exposed to relatively high geothermal gradients: the Madison there is generally deeply buried and may have been subjected to temperatures beyond the range of liquid hydrocarbon stability.

Exploration status and resource potential: Only a handful of wells have penetrated the Madison Group within the play area. Most appear to have encountered fresh to brackish water. In order for hydrocarbons to be present in Waulsortian mounds in the lower part of the Madison Group, the generally tight thin-bedded Lodgepole must be reservoir-separated from the top of the Madison. Traps may be very subtle: locally the Lodgepole is very shaly. Such shale intervals may provide bottom seals for fresh- to brackish-water circulation. The presence of throughgoing open vertical fractures would destroy such seals. Because of hydrocarbon source and possible seal problems, the play likely has a low to very low probability of success. The probability of occurrence of an undiscovered accumulation of at least minimum size (1 MMBO or 6 BCFG) is considered to be 0.2.

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.

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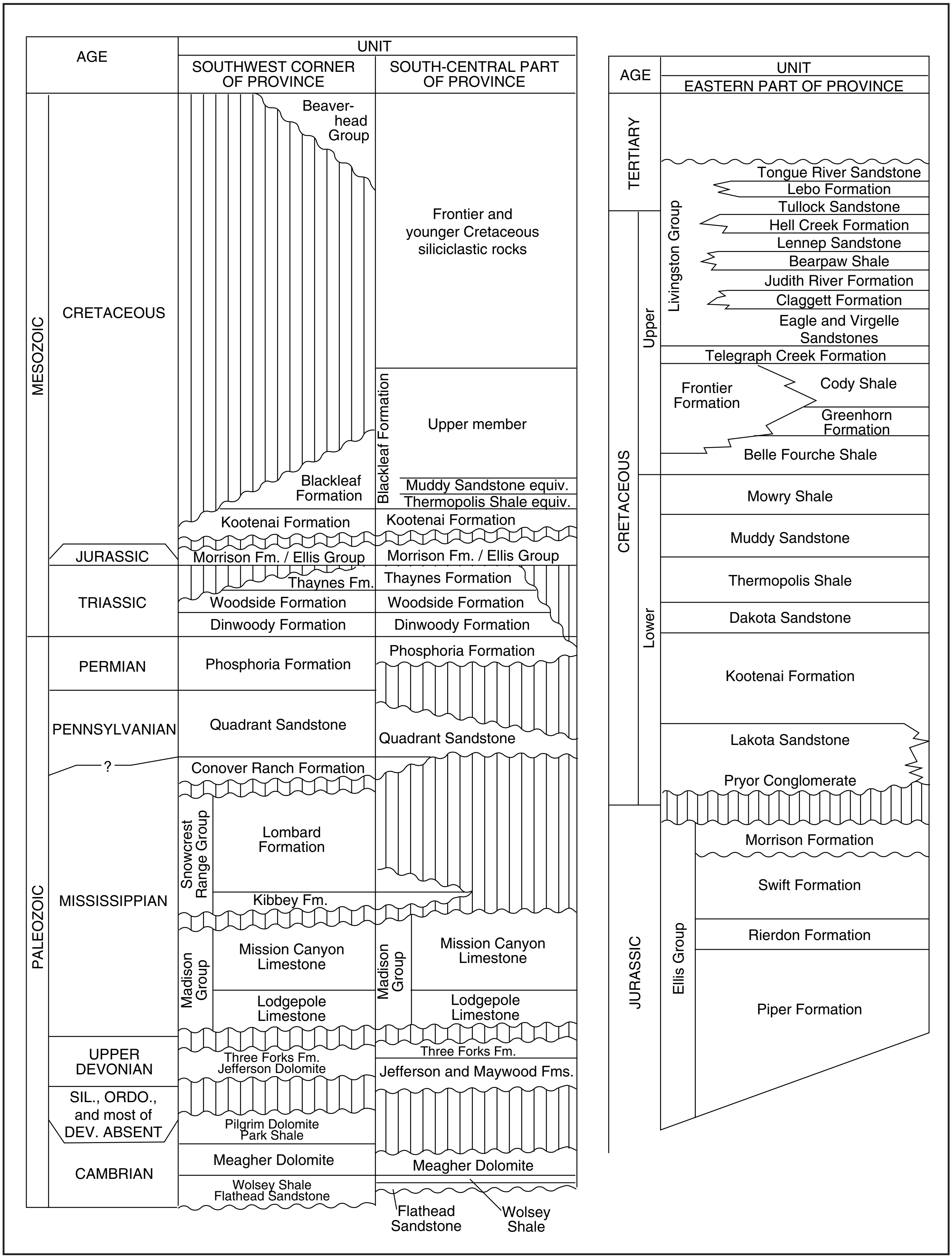

AGE
UNIT
SOUTHWEST CORNER OF PROVINCE
SOUTH-CENTRAL PART OF PROVINCE
MESOZOIC
CRETACEOUS
Beaver-head Group
Frontier and younger Cretaceous siliciclastic rocks
Blackleaf Formation
Upper member
Muddy Sandstone equiv.
Thermopolis Shale equiv.
Blackleaf Formation
Kootenai Formation
Kootenai Formation
JURASSIC
Morrison Fm. / Ellis Group
Morrison Fm. / Ellis Group
TRIASSIC
Thaynes Fm.
Thaynes Formation
Woodside Formation
Woodside Formation
Dinwoody Formation
Dinwoody Formation
PALEOZOIC
PERMIAN
Phosphoria Formation
Phosphoria Formation
PENNSYLVANIAN
Quadrant Sandstone
Quadrant Sandstone
?
Conover Ranch Formation
MISSISSIPPIAN
Snowcrest Range Group
Lombard Formation
Kibbey Fm.
Madison Group
Mission Canyon Limestone
Lodgepole Limestone
Madison Group
Mission Canyon Limestone
Lodgepole Limestone
UPPER DEVONIAN
Three Forks Fm.
Jefferson Dolomite
Three Forks Fm.
Jefferson and Maywood Fms.
SIL., ORDO., and most of DEV. ABSENT
Pilgrim Dolomite
Park Shale
CAMBRIAN
Meagher Dolomite
Meagher Dolomite
Wolsey Shale
Flathead Sandstone
Flathead Sandstone
Wolsey Shale
AGE
UNIT
EASTERN PART OF PROVINCE
TERTIARY
Tongue River Sandstone
Lebo Formation
Tullock Sandstone
Hell Creek Formation
Lennep Sandstone
Bearpaw Shale
Judith River Formation
Claggett Formation
Eagle and Virgelle Sandstones
Livingston Group
CRETACEOUS
Upper
Telegraph Creek Formation
Frontier Formation
Cody Shale
Greenhorn Formation
Belle Fourche Shale
Lower
Mowry Shale
Muddy Sandstone
Thermopolis Shale
Dakota Sandstone
Kootenai Formation
Lakota Sandstone
Pryor Conglomerate
JURASSIC
Ellis Group
Morrison Formation
Swift Formation
Rierdon Formation
Piper Formation