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A REVIEW OF THE GEOLOGY AND PETROLEUM POTENTIAL OF SOUTHWEST MONTANA

BY

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INTRODUCTION

The Southwest Montana province, with an area of approximately 12,960 square miles, extends westward from the Beartooth front in southern Stillwater and Sweetgrass Counties, Montana, to the edge of the Cordilleran thrust belt in Beaverhead County, Montana (Fig. 1). The geologic setting of this region is briefly discussed by Perry and others (1983b). The purpose of the present report is to summarize the geology of hydrocarbon plays of the Southwest Montana province, to provide background for the National Oil and Gas Appraisal. Three principal hydrocarbon plays are defined for this province, based on structural styles: the subthrust play, the basement structure play, and the wrench fault play. Each of these plays has been subdivided into significant subplays based on the geographic distribution of the structural styles.

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. The largest basinal area in the province is the Crazy Mountains basin, bounded on the north by the Lake Basin fault zone (the Lake Basin subplay area of Fig. 1), on the south by the Nye-Bowler fault zone and on the west by the Helena salient of the Cordilleran thrust belt (Fig. 1) (Taylor and others, 1986). Both the Lake Basin and Nye-Bowler fault zones are treated together in this report as a wrench-fault play.

The southwestern part of the Crazy Mountains basin is considered a subplay of the basement structure play. Areas considered prospective for hydrocarbons within the Cretaceous Big Sky and Ruby basins are also included as subplays of the basement structure play (Fig. 1).

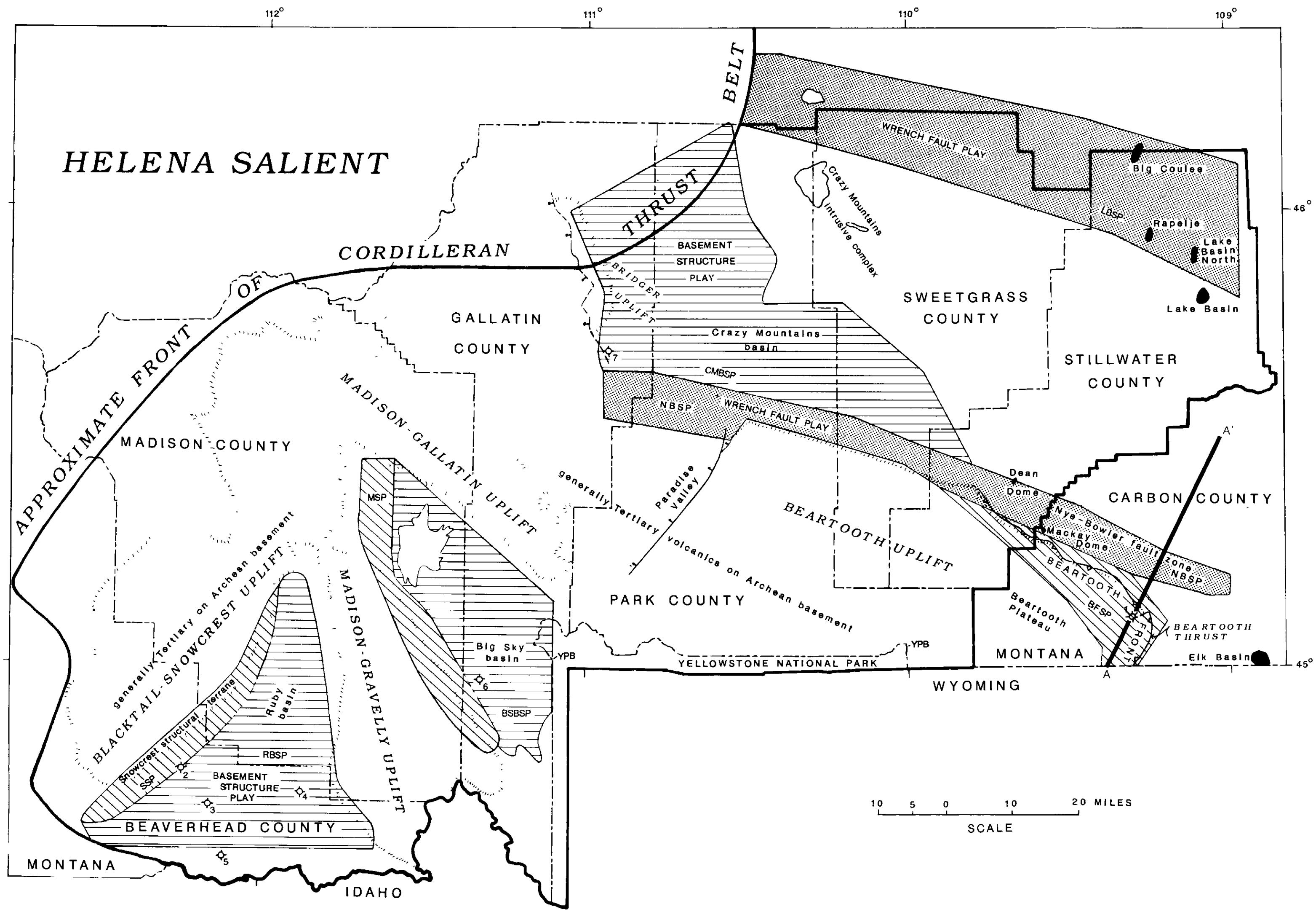
A series of large-scale, thrust-fault bounded, Laramide uplifts occur south and southwest of the Nye-Bowler fault zone. These are, from west to east, the Blacktail-Snowcrest, Madison-Gravelly, and Beartooth uplifts (Fig. 1). The first two were defined by Scholten (1967). The structural geology of the latter was summarized by Foose and others (1961). Basement-involved thrusting affects the northern and eastern margin of the Beartooth uplift (Thom, 1923, 1955; Bonini and Kinard, 1983; Robbins and Erslev, 1986), the eastern margin of the Madison-Gravelly uplift (Swanson, 1950; Hall, 1961; Scholten, 1967; Tysdal, 1986), and the southeastern margin of the Blacktail-Snowcrest uplift (Klepper, 1950; Scholten, 1967; Hadley, 1969; Perry and others, 1983a, 1988). The footwall Paleozoic and Mesozoic sedimentary cover beneath these thrusts comprises the subthrust play.

Although several post-Laramide structural basins are present within the province, none have demonstrated hydrocarbon potential. Therefore no Tertiary basin play is considered.

Significant stratigraphic units

The principal potential reservoir rocks in the Southwest Montana province are the Mississippian Madison Limestone, Pennsylvanian Quadrant Sandstone, and Cretaceous sandstones. Representative stratigraphic columns are shown in Figure 2. A regional karst surface formed on top of the Madison Limestone. Sinkholes and caves have been subsequently filled with porous sand (Sando,

Figure 1. Index map of southwest Montana province (area within heavy closed boundary) showing plays, subplays, selected drillholes, selected physiographic features, and selected tectonic features mentioned in the text. Basement structure play is composed of BSBSP - Big Sky basin subplay, CMBSP - Crazy Mountains basin subplay, and RBSP - Ruby basin subplay, all horizontally ruled. Subthrust play is composed of BFSP - Beartooth subplay, MSP - Madison subplay, and SSP - Snowcrest subplay, all diagonally ruled. Wrench fault play is composed of LBSP - Lake basin subplay and NBSP - Nye-Bowler subplay, both shown with a screen pattern. Numbered well symbols refer to: 1, Amoco 1-USA, TD 15,800 ft (14,205 ft true vertical depth), Carbon County; 2, Marathon 20-1 Cornell Camp-Federal, TD 7711 ft, Beaverhead County; 3, Shell Oil Company 34x-13 Unit, TD 10,244 ft, Beaverhead County; 4, Union Texas Petroleum 1 Metzel-Federal, TD 4,125 ft, Beaverhead County; 5, American Quasar 29-1 Peet Creek-Federal, TD 12,177 ft, Beaverhead County; 6, Phillips Petroleum 1 Carrot Basin, TD 2,140 ft, Gallatin County, and 7, Sohio Petroleum 1-3 Moats, TD 14,041 ft, Gallatin County. Selected structural features shown are modified from Ross and others (1955) and Scholten (1967). Unpatterned areas within play boundaries are significant intrusive bodies.



HELENA SALIENT
APPROXIMATE FRONT OF CORDILLERAN THRUST BELT
WRENCH FAULT PLAY
Big Coulee
LBSP
Rapelje
Lake Basin North
Lake Basin
Crazy Mountains intrusive complex
SWEETGRASS COUNTY
STILLWATER COUNTY
BASEMENT STRUCTURE PLAY
BRIDGER UPLIFT
Crazy Mountains basin
CMBSP
NBSP
WRENCH FAULT PLAY
GALLATIN COUNTY
MADISON COUNTY
MADISON-GALLATIN UPLIFT
MSP
Paradise Valley
generally Tertiary volcanics on Archean basement
BEARTOOTH UPLIFT
Dean Dome
CARBON COUNTY
Nye-Bowler fault zone
NBSP
Mackay Dome
BEARTOOTH FRONT
BFSP
Beartooth Plateau
BEARTOOTH THRUST
Elk Basin
A'
A
PARK COUNTY
YPB
YELLOWSTONE NATIONAL PARK
MONTANA
WYOMING
Big Sky basin
BSBSP
generally Tertiary on Archean basement
BLACKTAIL-SNOWCREST UPLIFT
Snowcrest structural terrane
SSP
Ruby basin
RBSP
BASEMENT STRUCTURE PLAY
MADISON-GRAVELLY UPLIFT
BEAVERHEAD COUNTY
MONTANA
IDAHO
112°
111°
110°
109°
46°
45°
10 5 0 10 20 MILES
SCALE

Figure 1.

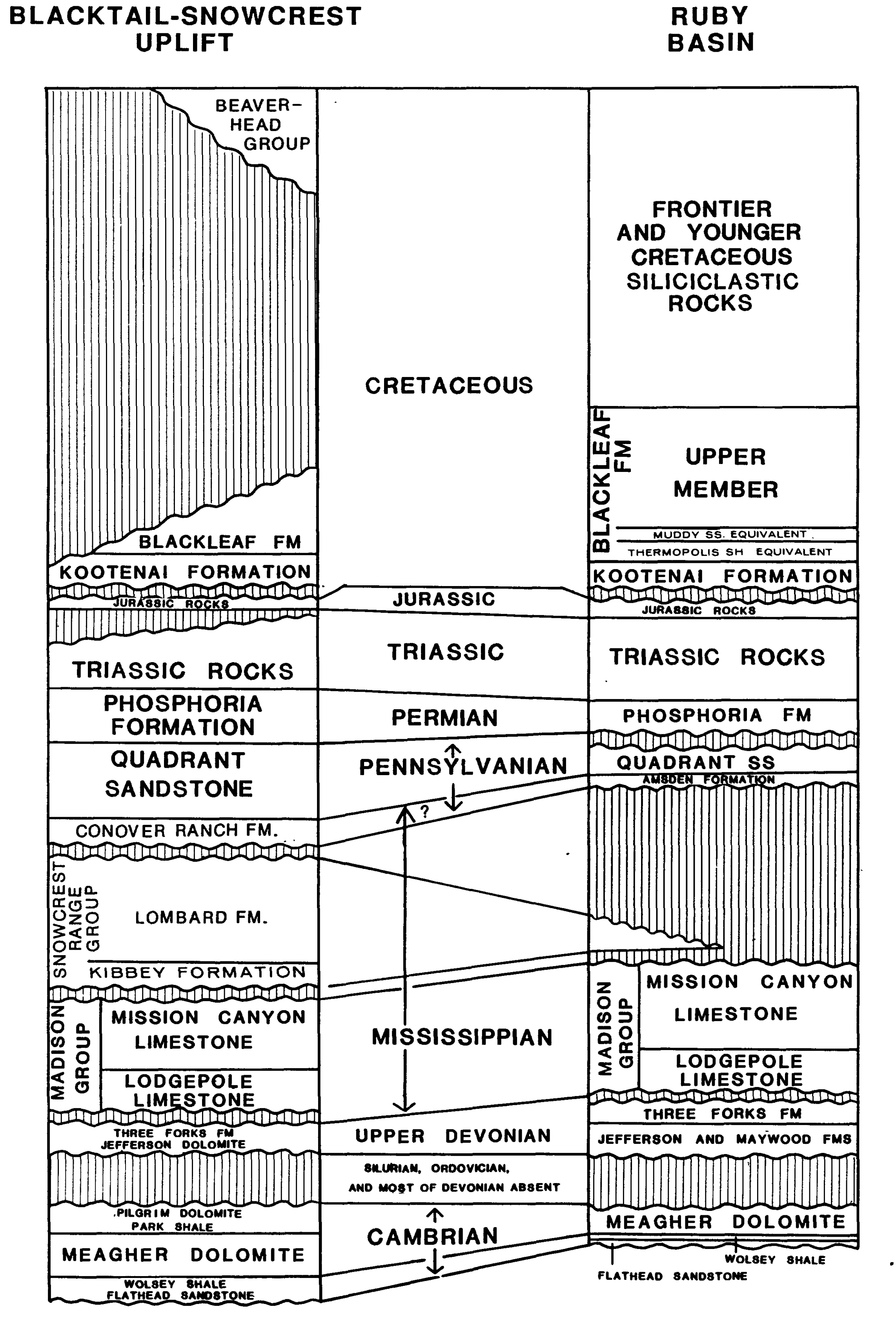


Figure 2. Correlation chart of stratigraphic units in southwest Montana (modified from Perry and others, 1983b).

1988), and underlying gypsum beds within the upper Madison have partially dissolved giving rise to collapse breccia (Sando, 1974), thus forming additional porosity. The Pennsylvanian Quadrant Sandstone is thin in the southwestern part of the province (Perry, 1986) and is only 40 ft thick in Paradise Valley (Fig. 1) (Graumann and others, 1986). From Paradise Valley, it thickens eastward and northward but is thin to absent in the northeastern part of the province (Peterson, 1985), where the Quadrant grades into the dominantly dolomitic sandstone beds of the Devils Pocket Formation (E. K. Maughan, written communication, 1989). The stratigraphic relationships of Cretaceous sands and pre-Cretaceous units in the province are shown by Peterson, 1985, Figs. 5 and 6).

Potential hydrocarbon source rocks include organic-carbon-rich Upper Mississippian beds in the western part of the Southwest Montana province and in the Big Snowy trough northeast of the province (Perry and others, 1983a; Maughan, 1984a). Equivalent rocks are absent by unconformity in the central and eastern part of the Southwest Montana province (Harris, 1972). Permian phosphatic shales, present in the western part of the province, are demonstrated oil-prone source rock (Claypool and others, 1978; Perry and others, 1983a; Maughan, 1984b).

Cretaceous marine black shales (Skull Creek, Thermopolis, Mowry, etc.) interfinger westward with strandline and nonmarine sandstones of the Blackleaf and Frontier formations and Livingston Group in the Crazy Mountains, Big Sky, and Ruby basins of southwest Montana. West of the Beartooth uplift, these shales are thin and available TOC values (from Beaverhead County) are less than 0.7% total organic carbon (Perry and others, 1983a). The ratio of amorphous/(woody + herbaceous) kerogen in these shales is believed to decrease rapidly westward from the Beartooth front to the shoreward portions of these shale bodies in the eastern Ruby basin, based on data from the Thermopolis and associated Lower Cretaceous shales (Perry and others, 1983a; T. Dyman, unpublished data, 1987).

DISCUSSION OF PLAYS

SUBTHRUST PLAY

The subthrust play is based on the hypothesis that hydrocarbons may be trapped beneath thrust overhangs along the thrust-faulted margins of Laramide uplifts (Gries, 1981, 1983). The subthrust play consists of three subplays: those beneath major thrust overhangs along the northeastern, eastern, and southeastern margins of respectively the Beartooth, Madison-Gravelly, and Blacktail-Snowcrest uplifts (Fig. 1). The smaller Bridger Range uplift (Fig. 1) is thrust faulted along its eastern margin. This structure is not included in the subthrust play but is included as the western margin of the Crazy Mountains basin subplay of the basement structure play.

Beartooth subplay

A limited Laramide thrust overhang is anticipated on the northeastern flank of the Beartooth uplift in southernmost Stillwater and Sweetgrass Counties (Fig. 1). Hydrocarbons have been trapped adjacent to this overhang in small oil fields in southern Stillwater County, the Dean Dome and Mackay fields along the Nye-Bowler fault zone. Width of the play is up to 4 miles in the southeastern edge of the Southwest Montana province. This overhang becomes larger farther east, along the eastern margin of the Beartooth Plateau

(Bonini and Kinard, 1983) in Carbon County, Montana, at the northwestern edge of the Bighorn Basin.

Geologic characterization: The northeastern flank of the Beartooth uplift has been thrust over the margin of the adjacent Crazy Mountains basin (Stone, 1983, Fig. 6). Along the eastern margin of this subplay, horizontal separation on the bounding Beartooth thrust (along profile AA', Fig. 1) exceeds 6 miles (Bonini and Kinard, 1983) whereas vertical separation exceeds 20,000 ft. The upthrown Beartooth Plateau has been erosionally stripped to the Precambrian crystalline rocks. Studies of synorogenic and post-orogenic sediments adjacent to the Beartooth front, summarized by Dutcher and others, 1986, indicate that most of this stripping took place in late Paleocene to earliest Eocene time but that some additional post-Laramide tilting and uplift of the Beartooth Plateau may have occurred. Structures associated with older displacements along the Nye-Bowler lineament (Wilson, 1936) have been locally overridden by the thrust-bounded Beartooth uplift.

Upper Paleozoic source rocks appear to be absent in this area (Maughan, 1984a and 1984b). Devonian Bakken equivalents are likewise absent (MacQueen and Sandberg, 1970, Fig. 3). The Cretaceous Thermopolis and Mowry Shales are the principal source rocks in the area. Long distance migration (50 to 100 miles) prior to development of the Beartooth uplift is required for the presence of oil derived from Paleozoic rocks to be present in the subplay area.

Status of exploration: Southern Stillwater County has been extensively drilled. The Dean Dome and Mackay oil fields are just north of the subplay boundary. One deep well has been drilled along the southeastern extension of the subthrust area, west of the Beartooth front, the Amoco 1-A USA drillhole completed in 1988 (no. 1, Fig. 1), for which little public information is available. This drillhole apparently penetrated the Beartooth thrust at approximately the depth predicted by Bonini and Kinard's (1983) thrust model. Oil and gas shows are rumored to have been encountered in the Cretaceous footwall sequence beneath the Precambrian rocks of the hanging wall of the Beartooth thrust. The oil and gas potential of this subplay appears to be moderate to high.

Madison subplay

A Laramide thrust overhang has long been recognized (Swanson, 1950; Tysdal, 1986) in the area immediately west of Yellowstone Park in eastern Madison and southwestern Gallatin Counties, Montana. Drilling in this area has been sparse. The Madison subplay extends from the lip of the thrust on the east to the Tertiary Madison Range normal fault system on the west, a distance of generally less than 6 miles (Fig. 1).

Geologic characterization: Archean through Paleozoic rocks of the Hilgard fault system (Tysdal, 1986) were thrust eastward over Cretaceous rocks of the Big Sky basin in eastern Madison County, Montana, during Maestrichtian (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). It is possible that hydrocarbons originally trapped beneath the Hilgard thrust system would have been released during extension faulting if steeply dipping fractures associated with this extension faulting breached pre-existing reservoirs.

Pre-Cretaceous source rocks are thin to absent in the area of this play (see Peterson, 1985). Cretaceous source rocks are also lean in this area. Pre-thrust migration of hydrocarbons from richer Paleozoic source rocks of the Snowcrest trough (Perry, 1986) to early formed traps in this subplay area would provide a possible source. Cretaceous rocks of the Ruby basin to the west appear to be gas-prone and relatively low in organic carbon (Perry and others, 1983a).

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 subplay appears to be low to very low.

Snowcrest subplay

The Snowcrest overhang subplay (Fig. 1) is in that part of the Snowcrest-Greenhorn Laramide (thick-skinned) thrust system with possibly as much as 5 miles of overhang of Paleozoic sedimentary rocks and Archean crystalline rocks in the hanging wall over Mesozoic rocks of the adjacent Ruby syncline. This subplay is based on the possibility of 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.

Geologic characterization: The southeastern limb of the Blacktail-Snowcrest uplift appears to be allochthonous; it has been thrust southeastward over the adjacent Ruby basin (Klepper, 1950; Kulik and Perry, 1982; Perry and others, 1983a) along the Snowcrest-Greenhorn thrust system. As deformed Paleozoic sedimentary rocks and Archean crystalline rocks of the hanging wall of the inferred sub-Snowcrest thrust are at the surface, this subplay is essentially a Rocky Mountain foreland subthrust play such as described by Gries (1983). Possible reservoir rocks include early and mid-Cretaceous sandstones, Pennsylvanian Quadrant Sandstone, and Mississippian Madison limestones. 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% for the Sappington Member of the Three Forks Formation and to over 19% for the Retort Shale Member of the Permian Phosphoria Formation to the west and northwest in the Montana thrust belt province (Claypool and others, 1978; Perry and others, 1983a; Perry, 1989) but are leaner in the area of this subplay. Pre-Cretaceous rocks of this subthrust play are considered supermature with respect to oil based on vitrinite studies (Perry and others, 1983a). Cretaceous rocks sampled, Thermopolis equivalents, contain less than 1% organic carbon; their kerogen is woody to herbaceous (Perry and others, 1983a).

The Sage Creek normal fault (Perry and others, 1988; Kulik and Perry, 1988), a down-to-northwest extension fault of Oligocene to Miocene age along the northwest margin of the Snowcrest structural terrane 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.

Status of exploration: The recently drilled (1987) Marathon 20-1 Cornell Camp-Federal well (no. 2, Fig. 1) is believed to have penetrated a subthrust closure within the area of this subplay. 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 subplay appears minimal. However, only one test well has been drilled and only one structure tested along this trend.

BASEMENT STRUCTURE PLAY

The Basement structure play includes three subplays: the southwestern Crazy Mountains basin, southern Big Sky basin, and Ruby basin subplays. This play is based on the hypothesis that hydrocarbons may have been trapped by early-formed basement-involved structures with closures of less than 1000 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). Wise (1983) has shown that such structures in the northern Bighorn Basin preceded development of the major Beartooth uplift. If we consider the possibility of long-distance updip migration of hydrocarbons from the west, it appears reasonable that hydrocarbon accumulations in northwest-trending structural closures in the northern Bighorn Basin were implaced prior to the rise of the Beartooth uplift. Similar paleostructures in the area of the Crazy Mountains basin have long been surmised (Thom, 1923, 1957; Peterson, 1985).

Ruby basin subplay

Small north-northwest-trending anticlines are present in the northern part of the Ruby basin subplay area (Mann, 1960, Fig. 5). 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 subplay is based on the hypothesis that one or more of these small structures may contain hydrocarbons.

Geologic considerations: The area of the Ruby basin subplay forms the northwestern margin of the Late Paleozoic Wyoming shelf (Perry, 1986). Deep drillholes in the Ruby basin and uplift south of the play are discussed by Perry (1986). These indicate a gradually northward thickening of Upper Paleozoic sequence across the area of this subplay from the Monida paleohigh, where Upper Paleozoic rocks are locally only 310 ft thick. Paleozoic rocks within the Ruby basin subplay are postmature with respect to oil generation (Perry and others, 1983a). Lower Cretaceous rocks are considered gas-prone and are expected to be relatively impoverished in organic carbon (Perry and others, 1983a).

Status of exploration: The Shell Oil Company 34x-13 Unit and Union Texas Petroleum no. 1 Metzel-Federal drillholes, in the southern third of the subplay area (respectively, no. 3 and no. 4, Fig. 1), contained no shows of oil or gas. The American Quasar no. 29-1 Peet Creek-Federal well (no. 5, 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 groundwater along the nearby Centennial (extension) fault. These findings suggest that the Ruby basin subplay has low to very low hydrocarbon potential.

Big Sky basin subplay

The Big Sky basin (Fig. 1) 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 subplay is based on the hypothesis that early Laramide basement-involved structures exist within the basin which may have trapped hydrocarbons prior to Hilgard thrusting. The Oregon Basin and Elk Basin anticlines in the northern Bighorn Basin appear to bear similar temporal relations to the Beartooth thrust (Wise, 1983; Blackstone, 1986).

Geological considerations: The Big Sky basin contains a thin sequence of Upper Paleozoic rocks comparable to those of the Ruby basin (compare Tutten, (1960) and Perry (1986)). Tysdal and others (1986) show that much of the Late Cretaceous depositional history of the basin is closely similar to that of the Crazy Mountains basin to the north. The two basins were part of the 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. Although the constraints are not as tight as one would like, it appears possible that hydrocarbons may have migrated updip into early Laramide basement-involved closures within the Big Sky basin prior to development of the Hilgard thrust system. Maughan (1984b) has suggested that Phosphoria oil may have reached early Laramide closures within the northern Bighorn Basin by the same scenario, prior to development of the Madison-Gravelly and Beartooth uplifts.

The 'Christmas-tree laccolith' of Swanson (1950), 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 severely reduces the oil potential of this subplay.

Status of exploration: The Phillips Petroleum no. 1 Carrot Basin drillhole in the southern part of the Big Sky basin (no. 6, Fig. 1) was dry. The structure on which it was drilled appears to contain brackish water within the Madison Limestone, suggesting deep groundwater circulation and absence of a seal for hydrocarbons (Tutten, 1960). In summary, the hydrocarbon potential of this subplay appears limited. However, only one very shallow test well has been drilled (TD 2140 ft) and only one structure partially tested.

Crazy Mountains basin subplay

The Crazy Mountains basin subplay is based on the hypothesis that early Laramide basement-involved closures are present within the subplay area. Garrett (1972) indicates that intrabasin structures are present. The relatively narrow Bridger uplift forms the western edge of this subplay. It is bounded on the east by a west-dipping Laramide-style thrust. The eastern margin of this narrow uplift has recently been drilled (Sohio 1-3 Moats, TD 14,041 ft, no. 7, Fig. 1), and no hydrocarbons were encountered in the subthrust block. Numerous other test wells have been drilled within the subplay area (Graumann and others, 1986), none of which contained commercial quantities of hydrocarbons.

Geological considerations: The Crazy Mountains basin is developed on the southern flank of the late Proterozoic Belt embayment, a major paleotectonic feature, termed an aulacogen by Fanshawe (1986). The region has been unstable through much of Phanerozoic time (Peterson, 1985). The basin lies southeast of the Big Snowy trough and contains a relatively thin Upper Paleozoic sequence (Peterson, 1985). Devonian (Bakken equivalent) and Permian (Phosphoria) hydrocarbon source rocks are thin to absent (MacQueen and Sandberg, 1970; Maughan, 1984b). Permian rocks are low in organic matter where they occur in areas immediately west of the Crazy Mountains basin (Maughan, 1984b). Lower Cretaceous source rocks are also low in organic matter, based on data from Burtner and Warner, 1984). No other source rocks have been identified in the subplay area. Long distance migration (more than 50 miles) of hydrocarbons from Permian source rocks to the west has been suggested by Maughan (1984b).

During Late Cretaceous time, the southwestern part of the basin received about 8,900 ft of volcanoclastic sediments of the Livingston Group, derived primarily from the Boulder batholith to the west (Skipp and McGrew, 1972). The Livingston Group thins rapidly to the north and east (Roberts, 1963).

Igneous dikes and plugs associated with the Eocene Crazy Mountains intrusive complex occur throughout the western part of the Crazy Mountains basin. Gravity modelling by Bonini and others (1972) indicate that the Crazy Mountains intrusive complex probably merges into a single large laccolithic body at depth, thus limiting the size of the Crazy Mountains subplay area. However, such igneous activity would have provided local heat sources to generate thermogenic gas if source rocks were present. The near absence of good organic-rich source rock is a strongly negative factor. In summary this subplay has low to very low hydrocarbon potential.

WRENCH FAULT PLAY

Two fault zones within the Southwest Montana province have long been interpreted to exhibit Late Cretaceous to Tertiary left-lateral shear within the basement, the Lake Basin fault zone to the north and Nye-Bowler zone to the south (Thom, 1923; Garrett, 1972). En echelon folds and faults occur in the sedimentary cover along both fault zones which include known hydrocarbon traps. Both are considered subplays of a wrench-fault play (Fig. 1). The wrench-fault play is based on the hypothesis that more such traps remain to be discovered.

Lake basin subplay

The Lake basin fault zone extends more than eighty miles east-southeast from the edge of the Helena salient of the Cordilleran thrust belt to beyond the east edge of the southwest Montana province. Four small gas fields are associated with this fault zone in the northeastern part of the province (Table 1). These gas fields occur on north to north-northeast-trending anticlines in a nearly east-west zone of en echelon right-separation faults which also trend north-northeast. These faults appear analogous to R′ riedel shear fractures of a left-lateral fault zone (Tchalenko, 1970, Fig. 1), although strike-slip motion has not been adequately documented in the Lake Basin subplay area. If this is a zone of left-lateral wrench faulting as first suggested by Thom (1923), such faulting must be deep seated, and the

Table 1

Cretaceous Gas Fields		Estimated Gas in Place
Big Coulee	Methane/dry gas	33.6 x 10^9 cu ft
Lake Basin	Sweet/dry gas	7.8 x 10^9 cu ft
North Lake Basin	Sweet/dry gas	12 x 10^9 cu ft
Rapelji	Sweet/dry gas	69 x 10^9 cu ft

Reservoir Rocks	
Big Coulee	Lakota (Lower Cretaceous) and Morrison (Jurassic)
Lake Basin	Claggett, Dakota, Eagle, Frontier, and Telegraph Creek (Cretaceous)
North Lake Basin	Dakota, Eagle, Basal Frontier/Big Elk, Telegraph Creek, Virgelle (Cretaceous)
Rapelji	Claggett, Eagle, Virgelle (Upper Cretaceous)

Data modified from Doroshenko and others (1975), based on PI data.

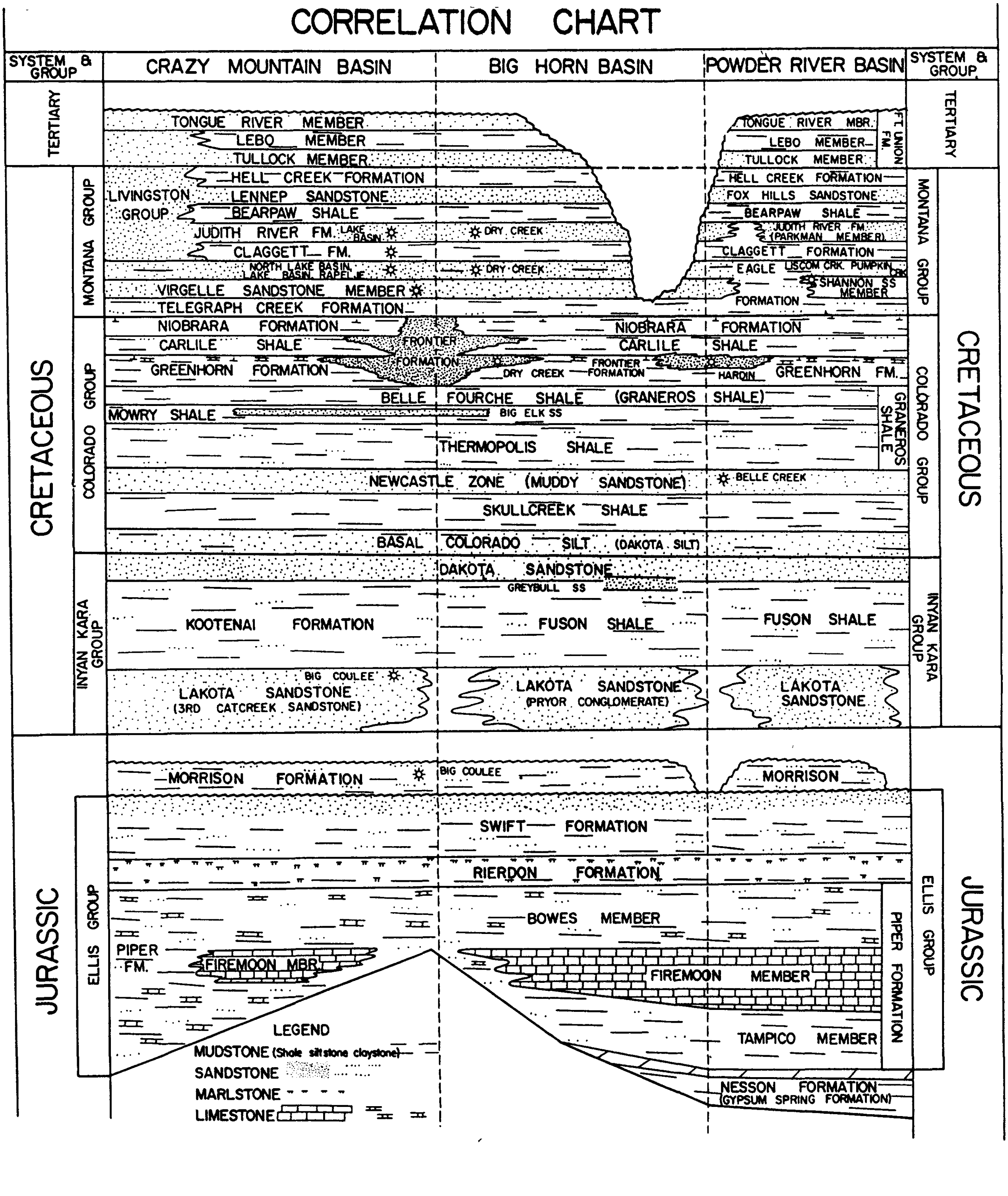


Figure 3. Correlation chart for Jurassic and Cretaceous rocks in Crazy Mountains basin and other basins in southern Montana (from Doroshenko and others, 1975), showing primary reservoir rocks in Lake basin subplay (those under heading "Crazy Mountain basin").

sedimentary rocks at the surface exhibit only what appear to be the antithetic R′ second-order faults.

Geological characterization: Cretaceous sands from the the Lower Cretaceous Dakota up through Upper Cretaceous Judith River Formations are the primary reservoir rocks in this play (Figure 3). Source rocks are believed to be the Cretaceous Mowry and Skull Creek marine black shales. Burtner and Warner (1984, Table 3, locality 66) present geochemical data from the Skull Creek and Mowry from one drillhole in the eastern part of the subplay area where total organic carbon (TOC) is 0.9 wt % for the Mowry and 1.0 wt % for the Skull Creek. Their data indicates that both shales are gas-prone. Their contour map of TOC in the Mowry (Burtner and Warner, 1984, Fig. 15) indicates that the Mowry contains less than 1.0 wt % TOC throughout all but the easternmost part of the subplay area.

Status of exploration: Numerous wells have been drilled within the area of the Lake Basin subplay, resulting in the discovery of several small gas fields (Fig. 1) that are nearly depleted. The discovery of one or more such fields in the subplay area may be expected. Oil potential of this subplay appears to be low to very low.

Nye-Bowler subplay

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 and included the Dean dome (Fig. 1) near its western limit. This name is extended westward in this report to include the line of intrusives west-northwest of the Dean dome and the zone of en echelon anticlines near Livingston. The eastern end of this subplay includes the heavy oil accumulations of the Dean and Mackay domes. This viscous black oil with a 10^{o} API gravity has been produced only in small quantities by steam injection and diesel soaks (Dean dome - 75,945 bbl, Mackay dome - 63,472 bbl, Graumann and others, 1986). Both fields are currently shut in.

Geological Characterization: The Nye-Bowler subplay consists of a zone of en echelon faults oblique to the ESE trend of the lineament, longitudinal faults parallel with the trend, and 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 Maestrichtian 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 Maestrichtian time; even greater differences indicate a maxima of intensity during Ft. Union (early Paleocene) time (Wilson, 1936). Deformation had ceased by Eocene time when the pre-Wasatch erosion surface was developed.

Status of exploration: The eastern part of this subplay has been extensively tested (Graumann, 1986). Nonconventional oil resources are abundant in the form of heavy oil which requires steam injection or other nonconventional methods to produce. Conventional hydrocarbon resources appear modest. The western part of the play has also been explored, yielding no commercial quantities of hydrocarbons.

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