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A Review of the Geology and Petroleum Resource Potential of North Central Montana

by

T.S. Dyman

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

1 Denver, Colorado 80225

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ABSTRACT

The north central Montana petroleum province includes a 36,000 square mile area bounded by the Montana disturbed belt to the west, the central Montana trough to the south, the Williston basin to the east, and the Canadian border to the north. Approximately 20 percent of the province is composed of federally-owned land. The province has produced more than 340 million barrels of oil and 1175 BCF of gas since 1919 when Cat Creek field was discovered in Petroleum County.

Major structural features of the province include the Sweetgrass arch, Alberta shelf, Bowdoin dome, Scapegoat-Bannatyne trend, Pendroy fault system, Little Belt, Big Snowy, and Little Rocky Mountains uplifts, and the Bearpaw, Sweetgrass Hills, Highwood, and Judith Mountains volcanic and intrusive systems. Many small scale Laramide structures enhance petroleum traps within the province.

Late Precambrian through Tertiary strata occur in outcrop and in the subsurface in the province and can be grouped into four major petroleum plays: Late Proterozoic-Early Paleozoic oil play, Devonian-Mississippian oil and gas play, Jurassic-Lower Cretaceous oil and gas play, and Upper Cretaceous gas play. A fifth play, the Pennsylvanian oil play, is not significant and produces minor oil in the extreme southern part of the province. Even where significant structural closure exists as on the crest of the Sweetgrass arch, most reservoirs are partly controlled by facies changes in reservoir rocks. Source rocks are thermally immature to mature. Most Late Cretaceous gas is biogenic methane from thermally immature source rocks. Paleozoic carbonate reservoirs include evaporite-carbonate cycles, bioclastic carbonate banks, and paleokarst systems enhanced by dolomitization. Clastic reservoirs include marine and nonmarine sandstones with lateral and vertical facies variations.

Since 1915, more than 15,000 wells have been drilled in the province totalling more than 26 million drilled feet of which approximately 11 million drilled feet are from exploratory wells. Total ultimate recoverable oil equals approximately 370 million barrels of which 13 million barrels are found in fields smaller than one million barrels crude oil equivalent. Total ultimate recoverable gas equals approximately 2211 BCF of which 400 BCF are found in fields smaller than one million barrels equivalent. More than 2000 BCF of the total ultimate recoverable gas production occurs in the Jurassic-Lower Cretaceous and Upper Cretaceous plays.

Future new field discoveries may include (1) Devonian and Lower Paleozoic prospects throughout the province where facies and structures are favorable, (2) Cretaceous and Jurassic prospects controlled by permeability barriers especially in the eastern part of the province, and (3) Upper Cretaceous biogenic gas accumulations in the eastern part of the province.

INTRODUCTION

The North Central Montana petroleum province is an area of approximately 36,000 square miles east of the Montana disturbed belt, north of the central Montana trough, and west of the Williston basin (Figure 1). The area is geologically diverse and includes the south Sweetgrass arch, Kevin-Sunburst dome, Bowdoin dome, Bearpaw uplift, and Alberta shelf (Peterson, 1985), and forms part of the Montana plains geomorphic province. Approximately 20 percent of the province is composed of Federaly-owned land of which approximately 20 percent includes Indian tribal land, approximately 55 percent Bureau of Land Management land, and approximately 25 percent National Forest Service and wildlife refuge land (Figure 2).

The region has been actively drilled since 1903 when oil was discovered near Medicine Hat, Alberta (Gussow, 1955). Since then, the province has produced more than 340 million barrels of oil and 1175 BCF of gas from fields greater than 1 million barrels of crude oil (or gas equivalent) field size (Montana Oil and Gas Conservation Commission, 1984; Nehring Field File). Thirty-one fields in the province have an ultimate recoverable production of greater than 1 million barrels of crude oil (or gas equivalent) and produce from an average depth of 2150 feet. Ninety-three fields are smaller than 1 million barrels in size (Petroleum Data System; Montana Oil and Gas Conservation Division, 1984). Petroleum exploration companies continue to maintain an interest in the province. Forty-six percent of the exploratory and production wells drilled in Montana in 1986 lie within the Sweetgrass arch and Sweetgrass Hills regions (Montana Oil Journal, 1986).

The purpose of this report is to define existing production trends and to assess future petroleum potential using a play analysis approach for the north central Montana province emphasizing federally-owned lands. In order to accomplish this task for the region, I will (1) describe the general geology, (2) define significant hydrocarbon plays, (3) analyze reservoir and source rocks for each play, (4) compile a regional exploration history, (5) and present a qualitative statement of future resource potential based on ultimate recoverable reserves.

Data for this report include the published literature, unpublished data, and computerized well and field data files. Petroleum Information Corporation's Well History Control System (WHCS) was used to define exploration and production drilling activity within the province. The Petroleum Data System (PDS) and NRG Associates, Significant Oil and Gas Fields of the United States data base were used to determine cumulative and ultimate recoverable production data by play, and to establish geologic attributes for reservoirs and plays.

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REGIONAL GEOLOGY

Figure 1 illustrates large scale structural elements in Montana and adjacent areas that have recurrently affected sedimentation and facies patterns in the north central Montana petroleum province from Late Precambrian through Mesozoic. Harrison and others (1974) and Cavanaugh and Cavanaugh (1984) described the Precambrian Belt basin as a slowly subsiding reentrant (aulacogen) to the North American craton. The central Montana trough is an eastward extension of the Belt basin and contains a thicker-than-normal sequence of Paleozoic and Mesozoic carbonate and clastic sediments (Roberts, 1979). The Blood Creek syncline is an eastward extension of the central Montana trough and forms an embayment along the western margin of the Williston basin (Thomas, 1974).

The Alberta shelf borders the central Montana trough to the north and occupies much of present day southern Alberta and north central Montana. The shelf was the site of shallow-water carbonate and fine grained clastic shelf sedimentation during the Paleozoic. The Sweetgrass arch, central Montana high, and Milk River uplift were areas of positive relief on the shelf during part of the Paleozoic and Mesozoic. Maughan (1984) introduced the term Milk River uplift to represent a Late Pennsylvanian through Early Jurassic regional source area on the southern part of the Alberta shelf.

The present day Sweetgrass arch marks the approximate position of the Late Precambrian through Early Mesozoic craton-miogeosyncline hinge line establishing the boundary between shallow water shelf sedimentation and deeper water sedimentation farther west (Dickinson, 1976). The absence of Cambrian strata on the present day arch favors a model for at least limited Cambrian uplift of the ancestral arch in the region. Uplift and differential subsidence continued irregularly through the Mesozoic when the region may have acted as an eastern foreland basin "forebulge" associated with flexural loading of the lithosphere from eastward migrating thrust sheets (Lorenz, 1982). The Bow Island arch in southern Alberta is a northeastward trending northern extension of the Sweetgrass arch. The term Sweetgrass arch as used in this report will include the Laramide Sweetgrass arch as well as those earlier ancestral features that lie along the same structural trend.

The Williston basin borders the north central Montana province to the east and contains as much as 8000 feet of Paleozoic strata (Peterson, 1985). This intracratonic basin has affected sedimentation throughout the region since Cambrian.

The region contains many large scale fault systems including the Scapegoat-Bannatyne trend and the Cat Creek, Pendroy, and Havre fault systems (Figure 1). Thomas (1974) defined a series of northeast and northwest oriented basement-controlled fault-bounded blocks that have undergone compressive deformation during the Phanerozoic. These basement blocks and adjacent fault zones were coupled during Laramide compresseve stresses and strongly affected sedimentation patterns in the Cretaceous and Tertiary.

Tertiary intrusive and volcanic rocks include those associated with the Sweetgrass Hills (54-50 Ma), Bearpaw Mountains (54-50 Ma), Little Rocky Mountains (67-60 Ma), Judith and Moccasin Mountains (69-47 Ma), and Highwood Mountains (53-50 Ma) (Lageson, 1985). Laramide uplifts within or near the province include the Little Belt, Big Snowy, Porcupine, and Bowdoin uplifts, and the Sweetgrass arch (Kevin-Sunburst dome and the South arch). Proterozoic through Paleozoic strata are exposed in the cores of the Little Belt and Big Snowy uplifts.

STRATIGRAPHY AND SEDIMENTATION

Late Precambrian clastic and carbonate rocks of the Belt Supergroup are absent throughout most of the province, although Belt-aged metasedimentary rocks may exist in the subsurface along the extreme western and southern boundaries of the province. These Proterozoic metasedimentary rocks reach a maximum thickness of more than 20,000 feet in the central Montana trough to the south and more than 40,000 feet in the Montana disturbed belt to the west (Figures 3 through 5).

Cambrian strata lie unconformably on Archeozoic rocks across the province where Belt strata are absent. The Middle to Late Cambrian eastward transgression in western and northern Montana resulted in deposition of the Flathead Sandstone and overlying marine fossiliferous shales and carbonates (Figure 3). Cambrian strata are approximately 1000 feet thick in most of the province but they thicken to the south in the central Montana trough and to the west in the Paleozoic miogeosyncline where Cambrian rocks are more than 3000 feet thick (Figure 4). Cambrian strata thin to less than 500 feet along the flanks of the Sweetgrass arch and are absent along its crest (Figure 5). Thinning also continues eastward across central Montana into the Williston basin and the Black Hills (Peterson, 1966).

Ordovician and Silurian strata are absent in the western and central part of the province due to pre Late Devonian erosion associated with the central Montana uplift, but are thicker eastward into the Williston basin (Figure 4) where they are more than 2000 feet thick. Along the western margin the the Williston basin, basal quartz-rich sandstone of the Lower Ordovician Winnipeg Formation is overlain by Middle to Upper Ordovician carbonate strata and evaporite cycles of the Red River, Stony Mountain, and Interlake Formations (Figure 3). The paleoequator passed through Montana during the Ordovician resulting in warm water and shallow marine to supratidal depositional environments. The Interlake Formation includes a Late Silurian upper portion composed of stromatolitic, oolitic, and bioclastic dolomite with paleosol and paleokarst horizons.

Because of Late Silurian to Middle Devonian regional emergence, Upper Devonian strata disconformably overlie Cambrian strata in the western and central part of the province, and Ordovician or Silurian strata in the eastern part of the province (Figure 3). More than 2000 feet of Middle to Upper Devonian carbonate-rich strata occur along the western margin of the province and in the central Montana trough to the south. Devonian strata are thin along the axis of the Sweetgrass arch and are absent along the central Montana uplift (Figures 1 and 4). The basal Upper Devonian Souris River Formation (Maywood Formation) is composed of gray shales, dolomites and sandstones representing the initial transgression. Strata of the overlying Jefferson (Duperow), Nisku, and Potlatch Formations are composed predominantly of carbonate-evaporite cycles of bioclastic limestone and dolostone interbedded with anhydrite and shale. Solution breccias are abundant. The overlying Three Forks Formation contains abundant shale reflecting the early development of the Antler orogenic belt to the west in Idaho.

The Late Devonian Three Forks Formation is overlain by organic-rich black shale and thin shallow water sandstone of the Bakken Shale. The Bakken represents an interruption in carbonate deposition associated with Early Mississippian transgression and is regionally equivalent to the Pilot Shale of the Great Basin and the Ekshaw Shale of Alberta. Although it is more than 100 feet thick in the eastern part of the province and in the Williston basin, it is thin or absent on the Sweetgrass arch.

The Bakken Shale is conformably overlain by Mississippian carbonate and clastic rocks of the Madison and Big Snowy Groups (Figure 3). These strata vary in thickness from less than 1500 feet on the Sweetgrass arch to more than 3000 feet in the central Montana trough and Williston basin (Figure 4). The Madison Group is composed of dolomite, limestone, shale, and evaporite beds of the Lodgepole, Mission Canyon, and Charles Formations (Peterson, 1985). Charles carbonate and evaporite rocks are absent in much of the central part of the province east of the Sweetgrass arch because of post Mississippian erosion. Solution breccias and paleokarst features are abundant in the upper part of the Madison Group. The overlying Big Snowy Group is rich in sandstone and shale with minor carbonate and reflects a major change in regional paleogeography associated with very early development of the ancestral Rocky Mountains. The Big Snowy Group is absent in much of north central Montana because of post-Mississippian to pre-Jurassic erosion (Roberts, 1979; Peterson, 1985); but is present in the Little Belt Mountains in the southern part of the province.

Pennsylvanian strata of the Tyler, Alaska Bench, and Devil's Pocket Formations of the Amsden Group and the overlying Quadrant Formation are present in the central Montana trough and extend northward only into the extreme southern part of the province (Maughan, 1975; 1984). They are composed of a mixed clastic and carbonate sequence deposited in both nonmarine and marine depositional environments.

Middle to Late Jurassic strata of the Sawtooth (Piper of the Williston basin), Rierdon, and Swift Formations (Ellis Group), and overlying Morrison Formation (Figure 3) were deposited in three major transgressive-regressive cycles covering most of the Rocky Mountain region (Hayes, 1984; Peterson, 1985). Deposition within the province was affected by uplift of the Sweetgrass arch in the western part of the province and the Belt Island complex in the southern part of the province (Figure 4). Total average thickness of Jurassic strata varies from approximately 250 feet in the northern part of the Sweetgrass arch to approximately 500 feet throughout the rest of the province (Figure 4). Jurassic strata thin to an erosional zero edge in southern Alberta (Hayes, 1984). Thinning of Jurassic strata on the arch is related to penecontemporaneous uplift along the Belt Island system. The sandstone rich Sawtooth Formation is absent in the vicinity of the Belt Island complex. The dominantly carbonate rock facies of the Rierdon Formation laps onto the flanks of the Belt Island complex and is overlain by clastic-rich sediments of the Swift and Morrison Formations. Dark gray shales and coal beds are abundant in the upper part of the Morrison Formation throughout much of the province (Peterson, 1966).

Strata of Cretaceous age are lithologically complex and occur throughout north central Montana. The Lower Cretaceous Kootenai Formation and overlying Lower and Upper Cretaceous Colorado and Montana Groups are approximately 3,000 to 4,000 feet thick in the province, but thicken markedly westward and are more than 18,000 feet thick southwest of the region near Drummond, Montana (Gwinn, 1965). Clastic and carbonate rocks of the basal Kootenai Formation were deposited in widespread fluvial and lacustrine systems in the Early Cretaceous foreland basin (Suttner and others, 1981). Overlying Cretaceous rocks are dominantly sandstone and mudstone deposited in marine and intertonguing fluvial and deltaic settings.

Marine and nonmarine sandstone, shale, and subordinate limestone of the Colorado and Montana Groups were deposited during at least five transgressive-regressive cycles in the Rocky Mountain region (Weimer, 1960; McGookey and others, 1972). Recognition of these cycles is most difficult in the nonmarine fluvial and lacustrine strata of the western part of the province because of rapid facies changes and lack of stratigraphic control. Source areas for Cretaceous strata include the fold-and-thrust belt to the west, the foreland basin, and pyroclastic sources from volcanic centers associated with the Idaho and Boulder batholiths (Schwartz, 1983; Dyman, 1985). Generally, coarse clastic detritus in the west grades into fine clastic and carbonate detritus in the east. Cretaceous rocks have been partly or completely removed from the Sweetgrass arch southeastward to the Little Belt Mountains, but abruptly thicken farther south to more than 7500 feet in the central Montana trough. Thickness variations within the Late Cretaceous Montana Group are locally extreme in the western part of the province due to variation in local sources (Peterson, 1985) (Figure 4). Montana Group strata are absent in the western part of the province.

The Lower Cretaceous Blackleaf Formation was deposited in a transgressive marine depositional environment with a prograding submarine deltaic facies in the middle and upper parts (Bootlegger Member), and a prograding-retrograding volcaniclastic upper deltaic sequence (Vaughn Member). The Upper Cretaceous Marias River Formation unconformably overlies the Blackleaf Formation and was deposited during a later transgression. Overlying Upper Cretaceous strata of the Two Medicine Formation in the west, and the Eagle, Clagget, Judith River, and Bearpaw Formations in the east record a combination of progradation and transgressive-regressive oscillations (E.K. Maughan, written communication, 1987).

PLAY DESCRIPTIONS

Procter, Lee, and Taylor (1982) defined a play as a group of prospects and/or discovered fields (or reservoirs) having common geologic characteristics such as hydrocarbon source rocks, trapping mechanisms, reservoir charcteristics, and stratigraphic and structural geology. Play definition for the north central Montana province is well established because many parts of the province have been extensively drilled and trapping mechanisms are relatively well known. The plays presented in this report are based primarily on the stratigraphic distribution of reservoir and source rocks rather than on the structural style of local areas. Even reservoirs with significant structural closure are controlled partly by facies changes in local reservoir rocks. For each play description in this report, structural complications are discussed for each field where necessary. The following plays are presented in this report: Late Proterozoic-Early Paleozoic oil play, Devonian-Mississippian oil and gas play, Pennsylvanian oil play, Jurassic-Lower Cretaceous oil and gas play, and Upper Cretaceous gas play. Generally speaking, gas is more abundant than oil east of the Sweetgrass arch where source rocks are thermally immature.

Upper Proterozoic-Lower Paleozoic Oil Play

The Upper Proterozoic-Lower Paleozoic oil play includes (1) Precambrian Belt strata along the extreme western and southern margins of the province, (2) Cambrian strata everywhere but the crest of the Sweetgrass arch, and (3) Ordovician strata along the western margin of the Williston basin within the north-central Montana petroleum province. As of December 1984, 61 wells have penetrated Cambrian strata in the province (Ramirez and Helland, 1985), but facies relationships within these strata are not yet well defined. At present, Proterozoic through Ordovician production does not exist in Montana.

Reservoir and source rock lithologies include quartz-rich sandstones of the Flathead and Winnepeg Formations; gray to green shale and carbonate rocks of post Flathead Cambrian formations; and carbonate-evaporite cycles of the Red River, Stony Mountain, and Interlake Formations (Theodosis, 1955; Lochman-Balk, 1972). The best reservoir rocks are carbonate bank and bioclastic dolomite beds associated with anhydrite cap rocks of the carbonate-evaporite cycles.

Dolomitization appears to be a selective process associated with facies changes and brine migration pathways. The best source rocks are dark gray marine shales including the Cambrian Gordon and Switchback Shales and their equivalents, and shale beds within the Red River Formation. Trapping mechanisms include permeability barriers in sandstone, increased porosity associated with selective dolomitization and solution brecciation, and facies changes in carbonate-evaporite cycles. Structural enhancement of existing traps may be common in areas of Laramide faulting and folding. Approximately 250 oil reservoirs produce from dolomite beds of the Red River and Stony Mountain Formations in the Williston basin (Peterson, 1985), the closest being at Putnam field in Richland County, Montana, east of the province. Generally, reservoir rocks include tidal and subtidal bioclastic and laminated dolomite capped by anhydrite (Longman and others, 1983).

The first Winnepeg production in Montana was reported in 1986 by Amerada Hess in Roosevelt County in the western part of the Williston basin. A wildcat well flowed approximately 3 million cubic feet of gas per day at a depth of 11,000 feet (Montana Oil Journal, 1986).

The average depth to the top of the Cambrian where present varies from approximately 3000 to 7000 feet. Nyvatex Exploration reported high gravity oil shows at a depth of 3690 feet in the Cambrian Flathead Formation in their Friedman 26-1XD well in Cascade County (sec. 26, T. 20 N., R. 2 E.) drilled in 1986 (Montana Oil Journal, 1986).

At present, no geochemical data are available to determine thermal maturity, type of organic matter, and timing and migration of hydrocarbons for lower Paleozoic strata in the province. Kohm and Louden (1978), however, evaluated several kerogen samples from the Red River Formation in the Williston basin. Total Organic Carbon values there ranged from 1.8 to 14.0 wt percent and source rocks were considered to be mature.

Devonian-Mississippian Oil Play

The Devonian-Mississippian oil play includes (1) Devonian carbonate strata of the Jefferson Group, and the Nisku, Potlatch, and Three Forks Formations throughout the province; (2) shale and sandstone of the Devonian and Mississippian Bakken Shale especially in the eastern part of the province (Peterson, 1966); and (3) predominantly carbonate rocks of the Mississippian Madison Group throughout the province.

The Mississippian part of the play is moderately explored, especially in Glacier, Toole, Pondera, and Teton Counties where Late Mississippian (Sun River) reservoirs have produced oil and gas since the 1920's (Table 1). Late Devonian strata have been incorporated into this play because of a similarity in reservoir and source rocks and trapping mechanisms.

The best reservoir rocks include (1) dolomite facies in carbonate-evaporite cycles of the Devonian Nisku Formation and its equivalents; (2) thin sandstone beds within the Bakken Formation; and (3) oolitic and bioclastic carbonate banks and karst intervals in the Mississippian Charles (Sun River) and Mission Canyon Formations. Dolomitization within Devonian carbonate sequences is greatest along a northwest trending line parallel to the central Montana uplift in the southern part of the province. Dolomitization may be associated with nearshore salinity variations. Widespread paleokarst intervals in the middle and upper part of the Madison Group are related to post Mississippian erosion in the region. Dolomitized subtidal carbonate banks within the Madison Group are excellent reservoirs where they are interbedded with supratidal anhydrite. Dolomitization is more widespread in Devonian than Mississippian strata.

The best source rocks include black organic shale of the Bakken Shale, the Sappington Member of the Three Forks Formation, and the Lodgepole, and Heath Formations. The Heath Formation occurs only in the central Montana trough at the southern edge of the province. Cole and Daniel (1984) reported vitrinite reflectance values of 0.49 to 0.55 percent for Heath shales in Fergus County, Montana, which indicates that they are thermally immature and are at or immediately below the oil generation window. Higher maturation values are locally indicated inasmuch as the Heath Formation is the source for most (or all) of the oil produced from the Tyler Formation (Maughan, 1984). In the Williston basin, organic matter in the Bakken Shale is primarily sapropelic kerogen from planktonic algae and averages 11 percent total organic carbon (Webster, 1984). These source rocks are generally thermally mature to immature in the central part of the province but are overmature in the disturbed belt to the west. In the western part of the province, Devonian and Mississippian oils migrated eastward from source areas within the disturbed belt.

Trapping mechanisms are similar to those for the Upper Proterozoic-Lower Paleozoic play and are better constrained due to greater information from drilling. Selective dolomitization of limestones, facies barriers in carbonate-evaporite sequences, and paleosol and karst systems provide the best trapping mechanisms. Stratigraphic traps have been enhanced by Laramide folding and faulting. Several Sawtooth (Jurassic) pools may be producing oil from Mississippian source rocks where Jurassic strata unconformably rest on

Sun River dolomite. Many Madison reservoirs (e.g. Pondera) are strongly influenced by Laramide faulting and folding.

The depth to the top of the Devonian varies from approximately 2700 to 6700 feet but the average depth is generally less than 5000 feet. At present, Devonian production is limited to two small Nisku pools in the East Kevin and Kevin-Sunburst fields. Initial production tests indicate less than 20 BOPD for Nisku oil wells. Shows in the Nisku have been reported from several wells in the south Sweetgrass arch area in 1986 (Montana Oil Journal, 1986).

Pondera field in Pondera and Teton Counties, Montana (Figure 6) is a representative example of the Devonian-Mississippian oil play. Pondera field was discovered in 1927 and produces from Sun River paleokarst systems enhanced by Laramide folding. Three hundred and sixty wells were completed by the end of 1984 in an area of more than 7600 acres (Tonnsen, 1985). Production is from an average depth of 1950 feet in a 90 feet thick pay zone with an average porosity of 14 percent. More than 22 million barrels of 32 API gravity oil were produced as of December 1984.

Pennsylvanian Oil Play

The Pennsylvanian oil play is limited to the southern part of the province within the central Montana trough where carbonate rocks and shale of the Amsden Group occur (Figures 3 and 4). At present only Cat Creek Field within this province in Petroleum County produces from the Pennsylvanian Devil's Pocket Formation (Figure 6) although 28 pools occur in the Tyler Formation in the Williston basin immediately southeast of the province (Maughan, 1984, Figure 8 and Table 1). Pennsylvanian reservoir rocks include dolomite and sandstone of the Tyler, Devil's Pocket, and Quadrant Formations. Dark gray shales of the underlying Late Mississippian Heath Formation may have contributed to Pennsylvanian petroleum (Dow, 1974; Williams, 1974; Maughan, 1984), although Cole and Daniel (1984) found immature vitrinite in Heath samples studied in Fergus and Golden Valley Counties just south of the central Montana petroleum province.

Trapping mechanisms within the Pennsylvanian play include facies variations in both sandstones and carbonates and enhanced local porosity variations due to dolomitization. These stratigraphic traps have been enhanced by Laramide folding and faulting.

The Cat Creek field in Garfield and Petroleum Counties, Montana is a representative example of the Pennsylvanian oil play and includes an area approximately 1500 acres in size and produces from dolomites in the Devil's Pocket Formation at an average depth of 2250 feet (Tonnsen, 1985). Trapping mechanisms include increased porosity due to dolomitization and fracture systems associated with localized block faulting.

Jurassic-Lower Cretaceous Oil and Gas Play

The Jurassic-Cretaceous oil and gas play includes predominantly clastic rocks of the Jurassic Sawtooth, Swift, and Morrison Formations, the Lower Cretaceous Kootenai Formation, the Lower and Upper Cretaceous Colorado Group, and the Upper Cretaceous Montana Group (Figures 3 through 5). Jurassic and Cretaceous strata are thin on the Sweetgrass arch, and Cretaceous strata are absent southeastward from the southern part of the Sweetgrass arch to the Little Belt

Mountains (Figure 4).

The play has been moderately explored in part because of initial attention to surface oil seeps and subsequent discoveries at shallow depths (usually less than 2500 feet). The base of the Jurassic varies from 1000 to 5000 feet. The play includes both Jurassic and Lower Cretaceous strata because of the similarity in depositional environments and facies, trapping mechanisms, and source rocks. The best reservoir rocks include fluvial to nearshore marine sandstones of the Swift, Sawtooth, Morrison, and Kootenai (Second and Third Cat Creek, Cutbank, Moulton, and Sunburst sands), Blackleaf (Flood Member, First Cat Creek, and Fall River sands), and Marias River Formations.

The best source rocks include dark gray phosphatic shale beds of Jurassic formations, and dark gray shale beds of the Morrison, Kootenai, Blackleaf, and Marias River Formations and their stratigraphic equivalents. Generally, shales are thermally immature except near the disturbed belt where greater burial depths occur and near Tertiary intrusives and volcanic rocks. Clayton and others (1982) reported total organic carbon values averaging 2.4 wt percent for the Cone Member of the Marias River Shale in the disturbed belt near Glacier National Park. Vitrinite reflectance values average 0.6 along the crest of the Sweetgrass arch. Dyman (1985) reported total average organic carbon values of 0.5 wt percent for Blackleaf equivalents in the Gallatin Range to the south.

Trapping mechanisms are primarily stratigraphic but folding and faulting are locally important. It is often difficult to differentiate between the relative importance of stratigraphic and structural factors in defining traps for Cretaceous strata. Jurassic reservoirs of the Sawtooth and Swift Formations occur in generally lenticular, laterally discontinuous marine sandstones. Permeability barriers associated with deposition and diagenetic alteration of sandstones and Laramide folding and faulting are important reservoir factors. Kootenai (Second and Third Cat Creek) reservoirs developed from facies changes in fluvial and deltaic sandstones where adjacent floodplain and interdistributary mudrocks reduced porosity. Fluvial and deltaic sandstone of the Vaughn Member of the Lower Cretaceous Blackleaf Formation in the western part of the province and to the south in southwestern Montana is rich in volcanic detritus. Complex diagenetic changes have resulted in a significant reduction in porosity (Schwartz, 1983; Dyman, 1985).

Cutbank field in Glacier and Toole Counties, Montana is a representative example of the Jurassic-Lower Cretaceous oil and gas play. The field was discovered in 1926 and has produced more than 40 million barrels of oil and 500 BCF gas. Reservoir rocks include fluvial and deltaic sandstone of the Kootenai Formation (Cutbank, Bow Island, Moulton, and Sunburst sands). One hundred and eighty seven wells produce from an average depth of 3000 feet and cover more than 65,000 acres. The Cutbank sandstone, the most productive gas reservoir, was deposited in a widespread fluvial system that pinches out against Jurassic strata on the east to form a large stratigraphic trap. Sandstone of the Blackleaf Formation and its equivalents generally produces less oil than the Kootenai Formation.

Upper Cretaceous Gas Play

The Upper Cretaceous gas play includes shallow low permeability reservoirs in predominantly clastic rocks of the Montana Group, although Rice and Shurr (1980) have reported similar reservoirs in the Lower Cretaceous Blackleaf Formation and equivalent strata. Late Cretaceous source rocks were generally not buried deep enough for oil generation in northern Montana. Most Late Cretaceous gas is biogenic and methane rich forming from the breakdown of organic matter by anaerobic bacteria at low temperatures.

The play boundary is defined mainly by the distribution of the Late Cretaceous strata. Montana Group rocks are generally absent along the axis of the Sweetgrass arch in the western part of the province due to Tertiary erosion (Figure 1). Reservoirs are generally less than 3000 feet deep and include both marine (shelf) and nonmarine (fluvial to shoreface) depositional environments. The best stratigraphic traps in Upper Cretaceous strata are found in higher permeability shoreface sandstones. An example occurs in the Tiger Ridge field where gas is produced from regressive shoreface sands in the Eagle Sandstone; and another occurs at Bowdoin dome where production is from thin bedded, low permeability sands of the Carlile Shale (Rice and Shurr, 1980). Low permeability marine chalk facies of the Greenhorn Formation, which is approximately equivalent to the Cone Member of the Marias River Formation produce some gas at the north end of the Bowdoin field. Trapping of gas within the chalks may be due to permeability barriers based on facies changes and the distribution of fracture systems. Many Upper Cretaceous traps are in part structurally controlled.

Tiger Ridge field in Hill and Blaine Counties, Montana is a representative example of the Upper-Cretaceous gas play. The field was discovered in 1966 as the result of an offset from a dry Madison test. Eighty-three wells produce methane-rich gas from the Eagle and Judith River Formations in an area approximately 52,000 acres in size. Production occurs at an average depth of 1600 feet in a 45 feet thick pay zone with an average porosity of 26 percent. By December 1984, more than 75 BCF of gas were produced from the field (Tonnsen, 1985).

EXPLORATION SUMMARY

Early drilling in Montana was influenced by the presence of oil seeps. Seeps were identified near Glacier National Park in the 1880's and limited production from oil seeps was reported locally in other parts of the state by 1900 (Darrow, 1955; Fanshawe, 1985). The first field discovered in the region was in sandstone of the Kootenai Formation at Cat Creek in 1919 followed by similar Lower Cretaceous sands at Kevin-Sunburst in 1922 and at Cutbank in 1926. Pondera field was discovered in 1926 and produces from Mississippian carbonates and Bannatyne field was discovered in 1927 and produces from Mississippian and Jurassic traps (Figure 6, Table 1). Since 1915 more than 15,000 wells have been drilled in the province (Petroleum Information Corporation, unpublished data, 1985) totalling more than 26 million drilled feet of which approximately 15 million drilled feet are from development wells, and 11 million drilled feet are from exploratory wells.

Table 1 contains ultimate recovery figures for small and large fields based on computarized data from the Petroleum Data System and NRG Associates field files. Total ultimate recoverable oil equals approximately 370 million barrels of which nearly 13 million barrels are found in fields smaller than 1 million barrels field size. Total ultimate recoverable gas equals approximately 2211 BCF of which 400 BCF are found in gas fields smaller than 1 million barrels equivalent (where 1 MCF of gas equals 6000 barrels of crude oil). More than 94 percent or 2000 BCF of the ultimate recoverable gas production occurs in the Jurassic-Lower Cretaceous play and Upper Cretaceous play. Approximately 75 percent or 275 million barrels of oil occur in Lower Cretaceous strata of the Kootenai Formation and in the Lower Cretaceous portion of the Colorado Group.

Figure 7 illustrates the discovery rate of fields larger than 1 million barrels or equivalent and the relationship between exploratory and production drilling through time. The rate of discovery of these fields increased from 1930 to 1970 during which time the percentage of exploratory wells drilled also increased. From 1960 to 1970 12 significant fields were discovered. During the same period, 53 percent of the wells drilled in the province were exploratory wells. The increased field discovery rate during the 1960's is reflected in the increased production of crude oil illustrated for the same period in Figure 8. In Figure 8 northern Montana is compared to the remainder of the state in terms of average daily production for each year for the period 1943 to 1984. The North Central Montana province includes all of northern Montana and part of central Montana in Figure 8. Even with the discovery of 12 significant fields during the 1960's, average daily production has decreased in north central Montana along with decreasing production in the rest of the state.

Future new field discoveries may include (1) deeper Devonian and Lower Paleozoic prospects throughout the province where facies relationships are favorable, and (2) shallow Cretaceous and Jurassic prospects controlled by permeability barriers in areas of limited drilling. Tribal lands including the Blackfeet and Fort Belknap reservations as well as U.S. Forest Service and BLM lands (Figure 2) may provide future production based on the distribution of play attributes.

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TABLE CAPTIONS

Table 1. Ultimate recoverable oil and gas for fields larger than 1 million barrels or equivalent (where 6000 barrels of crude oil equals 1 MCF of gas). Oil in thousands of barrels; gas in MMCF. DISC= discovery year; ACR/FT= total field acreage and average depth to the producing horizon in feet; TK= average thickness of the producing horizon in feet; TYPE= trapping mechanism where STRUC equals structural trap, STRAT equals stratigraphic trap, and COMB equals combination trap. Ultimate recoverable figures from Nehring file (see text). Plays defined as follows: UC= Upper Cretaceous gas play; JC= Jurassic--Lower Cretaceous oil and gas play; P= Pennsylvanian oil play; and M= Devonian--Mississippian oil and gas play.

Table 2. Ultimate recoverable totals for large and small fields (as defined in Table 1) in the north central Montana petroleum province. Oil in thousands of barrels; gas in MMCF. Data from Petroleum Data System and NRG Associates Significant Oil and Gas Fields of the United States data base Ultimate recoverable figures for small fields computed by multiplying the last available annual production amount (1985 for most fields) by 10 and adding this figure to the cumulative production amount. N= number of fields in each field-size class.

TEXT FIGURE CAPTIONS

Figure 1. (A) Regional paleotectonic features affecting facies distribution of late Precambrian through Mesozoic rocks in Montana and adjacent areas. The central Montana uplift coincides approximately with the central Montana trough. (B) Major paleotectonic features of the north central Montana petroleum province. North central Montana petroleum province outlined with dashed lines. TV= Tertiary volcanic rocks. From Hyndman (1985); Maughan (1984); Peterson (1981, 1985).

Figure 2. Study area location map. Approximate percent of U.S. Bureau of Land Management (BLM) land for each county identified under each county name. BIA= Bureau of Indian Affairs (Indian reservations); NWR= national wildlife refuges; FS= U.S. Forest Service; BLM= Bureau of Land Management.

Figure 3. Generalized stratigraphic correlation chart north central Montana petroleum province and adjacent areas modified from Tonnson (1985).

Figure 4. Late Precambrian through Cretaceous isopach maps modified from Peterson (1966, 1981, 1985). Data in hundreds of feet for late Precambrian through Jurassic maps. Data in thousands of feet for Cretaceous map. North central Montana petroleum province outlined with dashed lines. G= Great Falls; B= Billings.

Figure 5. West-to-east lithofacies cross section western and central

Montana. Modified from Peterson (1985). C= Cambrian; D= Devonian; M= Mississippian; J=Jurassic; K= Cretaceous.

Figure 6. Distribution of significant oil and gas fields in the north central Montana province. Data from NRG Associates Significant Oil and Gas Fields of the United States data base and the Montana Oil Journal.

Figure 7. Drilling and field discovery statistics, north central Montana petroleum province. (A) Number of large field discoveries (greater than 1 million barrels of crude oil or equivalent gas) per 10 year interval. Each reservoir counted separately. (B) Number of exploration wells (wildcats) and total wells drilled during same 10 year interval. Total wells at top of each bar on graph and total exploration wells at top of hatchured bar. Percent exploration wells drilled immediately above exploration well total (e.g. for the period 1970 to 1980, 4145 total wells were drilled, 2058 exploration wells were drilled, and exploration wells made up 50 percent of the total well count during that period).

Figure 8. Crude oil production graph for Montana 1943- 1984. Data in average barrels of oil per day (BOPD). From Montana Oil and Gas Conservation Division 1984 Annual Review.

Table 1.--Ultimate recoverable oil and gas for fields larger than 1 million barrels or equivalent (where 6,000 MCF of gas equals 1 barrel of oil).[1]

[DISC = discovery year; ACR/FT = total field acreage and average depth to producing horizon in feet; TK = average thickness of producing interval in feet; TYPE = trapping mechanism where struc = structural, strat = stratigtaphic, and comb = combination. Ultimate recoverable figures from Nehring field file (see text). Plays defined as follows: UC = Upper Cretaceous gas; JC = Jurassic-Lower Cretaceous oil and gas; P = Pennsylvanian oil; M = Devonian-Mississippian oil and gas.]

	DISC	ACR/FT	TK	TYPE	Gas	Oil	Con	Play
Battle Creek	1977	19,000/	86	struc	39,000			UC
Big Rock	1975	36,000/2,000	11	strat	18,000	7		JC
Blackfoot	1956	600/3,500	15	comb		551		MS
		/3,300	15	comb				JC
Blackjack	1969	1,200/2,000	24	strat	6,300			JC
Border	1929	440/2,400	22	strat		1,390		JC
Bowdoin	1913	350,000/1,500	40	comb	600,000			UC
Bowes	1949	2,500/3,500	30	struc		10,500		JC
Bullwacker	1972	31,000/2,400	40	comb	15,900			UC
Cat Creek	1920	1,500/1,200	70	comb		23,000		JC
		/2,300	20	comb		200		P
Cutbank	1926	64,000/30,000	26	strat	519,000	167,500	11,800	JC
		3,300			27,000			MS
Flat Coulee	1933	3,800/2,900	20	comb		5,700		JC
Fred & George	1963	2,320/2,600	30	strat		13,200		JC
Graben Coulee	1961	3,120/2,900	15	comb		1,900		JC
				comb		200		MS
Grandview	1952	2,480/1,800	16	comb	5,400	20		JC
Gypsy	1955	1,220/3,300	25	comb	4,500	550		JC
Keith	1944	2,900/1,800	50	comb	63,000			JC
Kevin-Sunburst	1922	41,000/1,500	10	strat	108,000			JC
						81,400		MS
Leroy	1968	5,760/1,300	30	struc	13,500			UC

Table 1.--Ultimate recoverable oil and gas for fileds larger than 1 million barrels or equivalent (where 6,000 MCF of gas equals 1 barrel of oil).[1]--continued.

	DISC	ACR/FT	TK	TYPE	Gas	Oil	Con	Play
Miners Coulee	1966	160/2,400	6	strat	5,100	160		JC
Pondera	1927	7,560/2,000	10	comb		27,500		MS
Prarie Dell	1976	18,560/1,000	40	comb	15,000			JC
Rabbit Hills	1972	640/4,100	11	comb		1,240		JC
Reagan	1941	2,480/3,900	20	comb		9,800	560	MS
Red Creek	1958	860/2,600	20	comb		2,688		JC
		/2,800	32	comb		3,712		MS
Rudyard	1955	2,400/760	20	struc	8,400	20		JC
Sawtooth Mtn.	1967	/2,600	40	struc	15,000			UC
Sherard	1923	320/1,500	20	comb	16,500			UC
Tiger Ridge	1966	52,000/1,600	45	comb	285,000			UC
Utopia	1943	3,600/2,200	20	comb	12,000	600		JC
					12,000			MS
West Butte	1968	640/2,200	12	comb	4,500	290		JC
Whitlash	1918	3,280/1,900	20	comb	57,000	5,300		JC

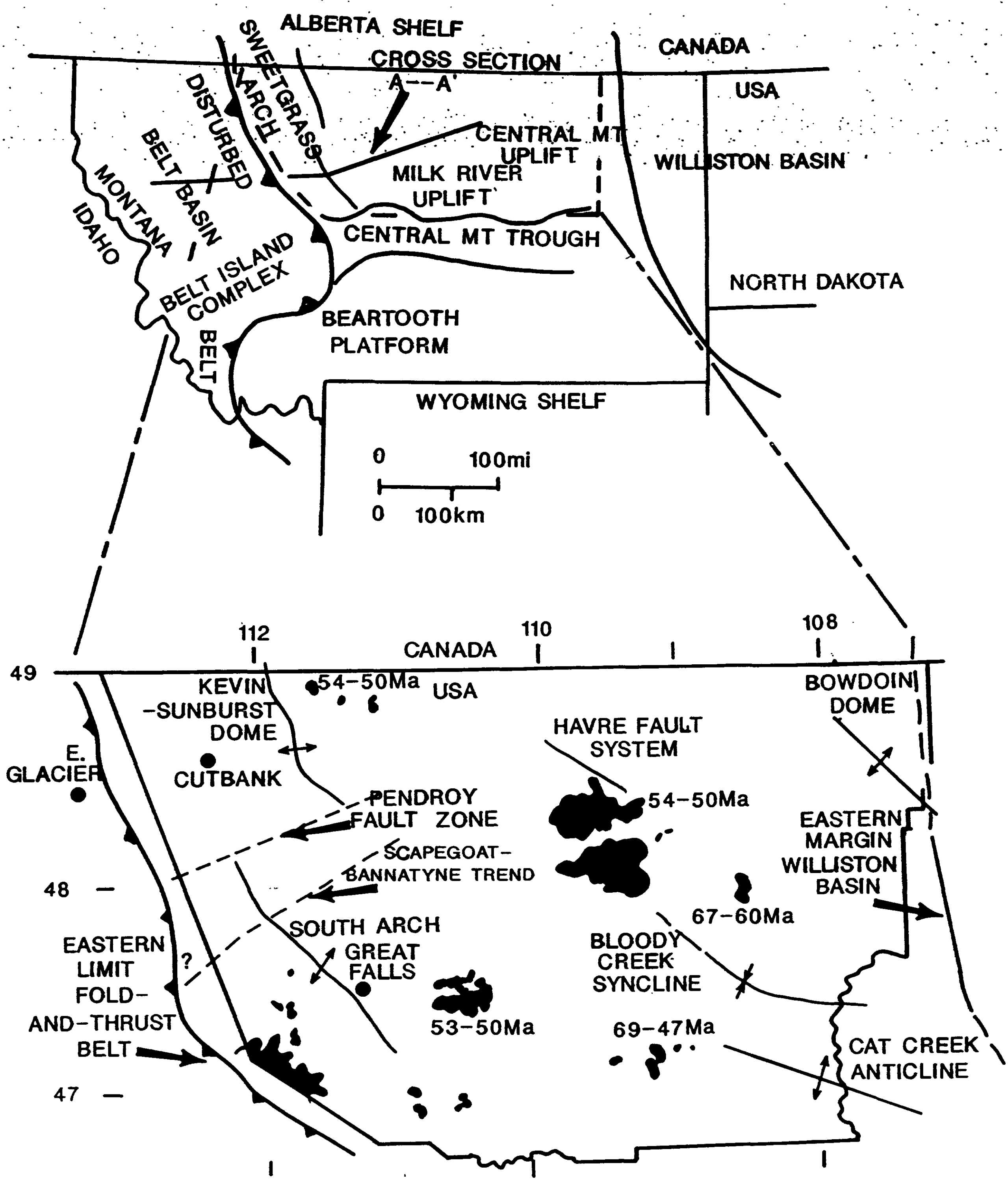
[1]Oil in thousands of barrels; gas in MMCF

Table 2.--Ultimate recoverable totals for large and small fields in the north central Montana province. Data from Petroleum Data System and Nehring field files.

[N = number of fields in each field-size class.]

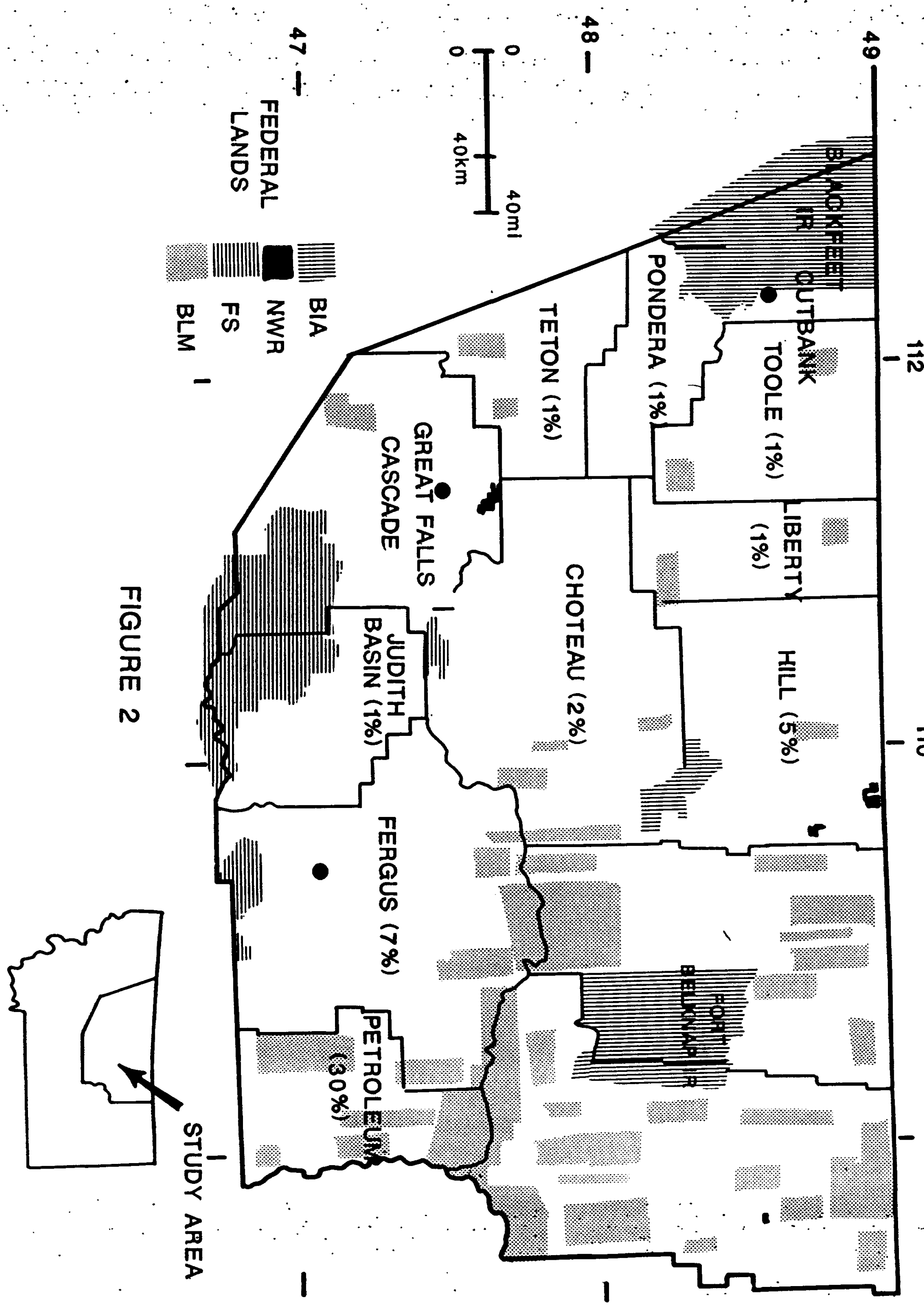
Plays	Large fields N = 31		Small field N = 93		Totals N = 124	
	Oil	Gas	Gas	Oil	Gas	Oil
Upper Cretaceous gas	984,900	--	74,500	53	1.020,400	53
Jurassic-Cretaceous oil and gas	826,200	234,065	245,500	3,929	1,071,700	237,994
Pennsylvanian oil	--	200	--	--		200
Late Devonian-Mississippian oil and gas	39,000	123,163	80,000	8,760	119,000	131,923
Lower Paleozoic-Proterozoic oil	--	--	--	--	--	--
Totals	1,850,100	357,428	400,000	12,742	2,211,100	370,170

[1]Ultimate recoverable figures for small fields computed by multiplying the last available annual production figure (1985 for this table) by 10 and adding this to the cumulative production figure.



ALBERTA SHELF
SWEETGRASS ARCH
CROSS SECTION A--A'
CANADA
USA
DISTURBED BELT
BELT BASIN
CENTRAL MT UPLIFT
MILK RIVER UPLIFT
WILLISTON BASIN
MONTANA
IDAHO
CENTRAL MT TROUGH
BELT ISLAND COMPLEX
NORTH DAKOTA
BEARTOOTH PLATFORM
BELT
WYOMING SHELF
0 100mi
0 100km
112
110
108
49
CANADA
USA
KEVIN -SUNBURST DOME
54-50Ma
BOWDOIN DOME
HAVRE FAULT SYSTEM
E. GLACIER
CUTBANK
PENDROY FAULT ZONE
54-50Ma
EASTERN MARGIN WILLISTON BASIN
SCAPEGOAT-BANNATYNE TREND
48
67-60Ma
SOUTH ARCH
EASTERN LIMIT FOLD-AND-THRUST BELT
GREAT FALLS
BLOODY CREEK SYNCLINE
53-50Ma
69-47Ma
CAT CREEK ANTICLINE
47

FIGURE 1



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0 40km
FEDERAL LANDS
BIA
NWR
FS
BLM
BLACKFEET IR
CUTBANK
TOOLE (1%)
PONDERA (1%)
TETON (1%)
LIBERTY (1%)
HILL (5%)
CHOTEAU (2%)
GREAT FALLS
CASCADE
JUDITH BASIN (1%)
FERGUS (7%)
PETROLEUM (30%)
FORT BELKNAP IR
STUDY AREA

FIGURE 2

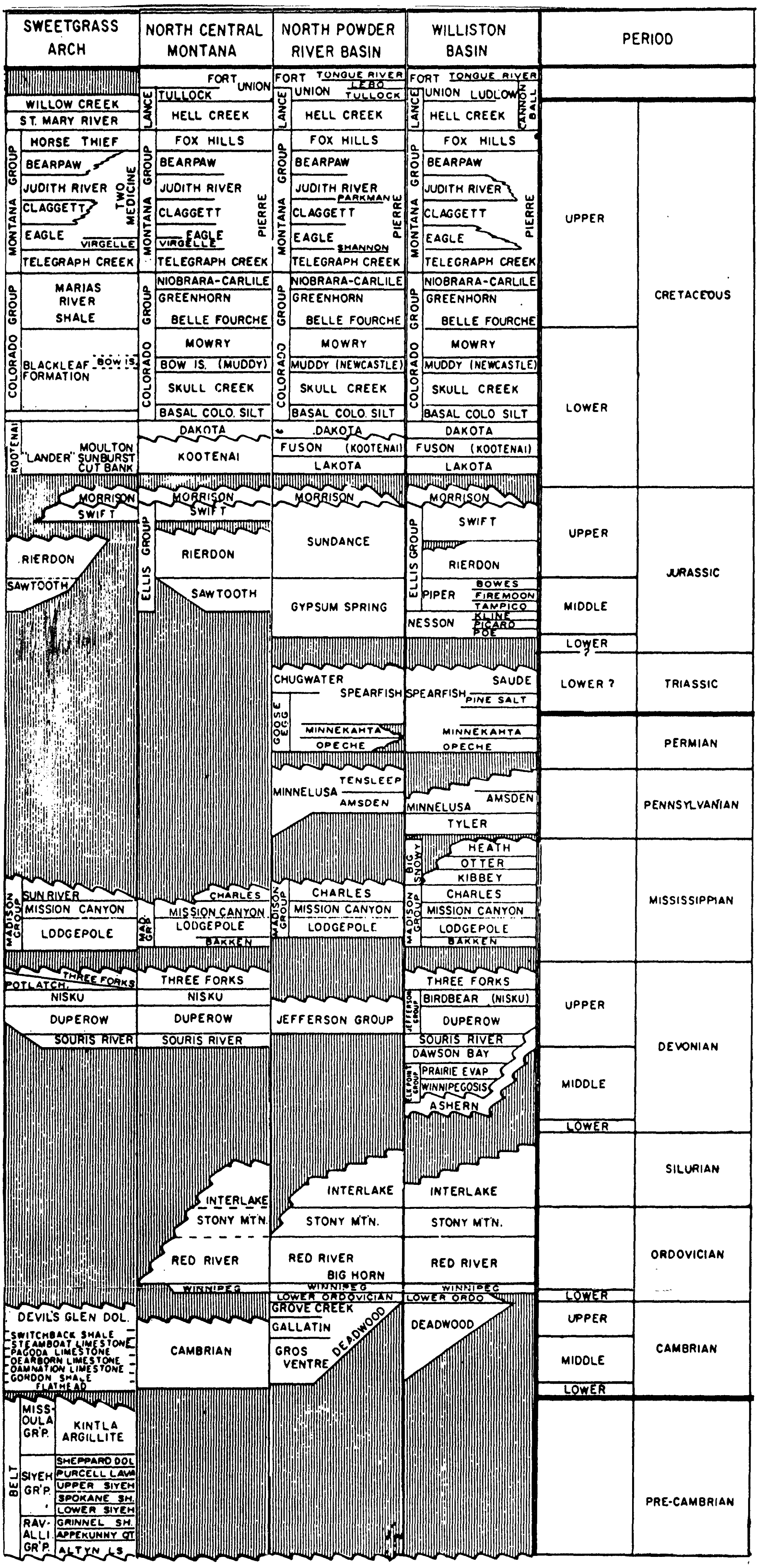
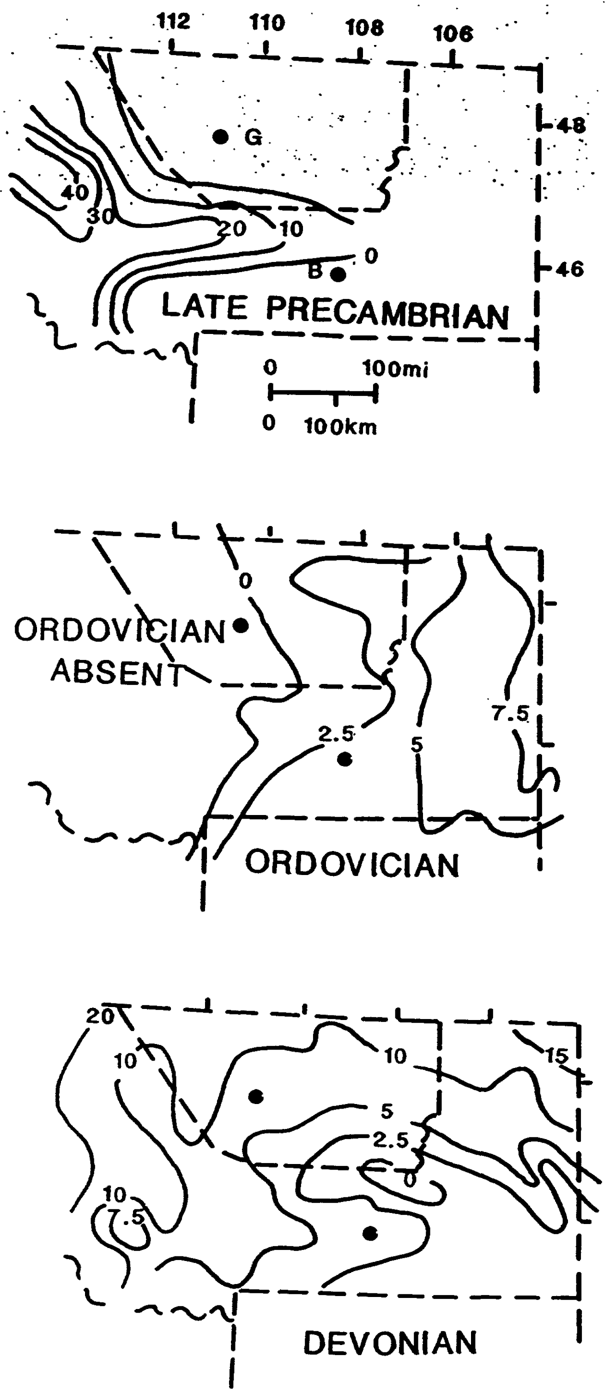

SWEETGRASS ARCH
NORTH CENTRAL MONTANA
NORTH POWDER RIVER BASIN
WILLISTON BASIN
PERIOD
WILLOW CREEK
ST. MARY RIVER
HORSE THIEF
BEARPAW
JUDITH RIVER
CLAGGETT
EAGLE
VIRGELLE
TELEGRAPH CREEK
TWO MEDICINE
MONTANA GROUP
MARIAS RIVER SHALE
BLACKLEAF FORMATION
BOW IS.
COLORADO GROUP
KOOTENAI
"LANDER"
MOULTON
SUNBURST
CUT BANK
MORRISON
SWIFT
RIERDON
SAWTOOTH
SUN RIVER
MISSION CANYON
LODGEPOLE
MADISON GROUP
THREE FORKS
POTLATCH
NISKU
DUPEROW
SOURIS RIVER
DEVIL'S GLEN DOL.
SWITCHBACK SHALE
STEAMBOAT LIMESTONE
PAGODA LIMESTONE
DEARBORN LIMESTONE
DAMNATION LIMESTONE
GORDON SHALE
FLATHEAD
MISSOULA GR'P.
KINTLA ARGILLITE
SIYEH GR'P.
SHEPPARD DOL.
PURCELL LAVA
UPPER SIYEH
SPOKANE SH.
LOWER SIYEH
RAVALLI GR'P.
GRINNEL SH.
APPEKUNNY QT.
ALTYN LS.
BELT
FORT UNION
LANCE
TULLOCK
HELL CREEK
FOX HILLS
PIERRE
NIOBRARA-CARLILE
GREENHORN
BELLE FOURCHE
MOWRY
BOW IS. (MUDDY)
SKULL CREEK
BASAL COLO. SILT
DAKOTA
KOOTENAI
ELLIS GROUP
MAD. GRP.
CHARLES
BAKKEN
INTERLAKE
STONY MT'N.
RED RIVER
WINNIPEG
CAMBRIAN
TONGUE RIVER
LEBO
PARKMAN
SHANNON
MUDDY (NEWCASTLE)
FUSON (KOOTENAI)
LAKOTA
SUNDANCE
GYPSUM SPRING
CHUGWATER
SPEARFISH
GOOSE EGG
MINNEKAHTA
OPECHE
TENSLEEP
MINNELUSA
AMSDEN
JEFFERSON GROUP
BIG HORN
LOWER ORDOVICIAN
GROVE CREEK
GALLATIN
GROS VENTRE
DEADWOOD
LUDLOW
CANNON BALL
PIPER
BOWES
FIREMOON
TAMPICO
KLINE
NESSON
PICARD
POE
SAUDE
PINE SALT
TYLER
HEATH
OTTER
KIBBEY
BIG SNOWY
BIRDBEAR (NISKU)
DAWSON BAY
PRAIRIE EVAP
WINNIPEGOSIS
ASHERN
ELK POINT GROUP
LOWER ORDO.
UPPER
LOWER
CRETACEOUS
MIDDLE
JURASSIC
LOWER ?
TRIASSIC
PERMIAN
PENNSYLVANIAN
MISSISSIPPIAN
DEVONIAN
SILURIAN
ORDOVICIAN
CAMBRIAN
PRE-CAMBRIAN

Figure 3


112
110
108
106
48
46
G
B
40
30
20
10
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LATE PRECAMBRIAN
0 100mi
0 100km
CAMBRIAN
ORDOVICIAN ABSENT
ORDOVICIAN
SILURIAN ABSENT
SILURIAN
DEVONIAN
MISSISSIPPIAN

FIGURE 4

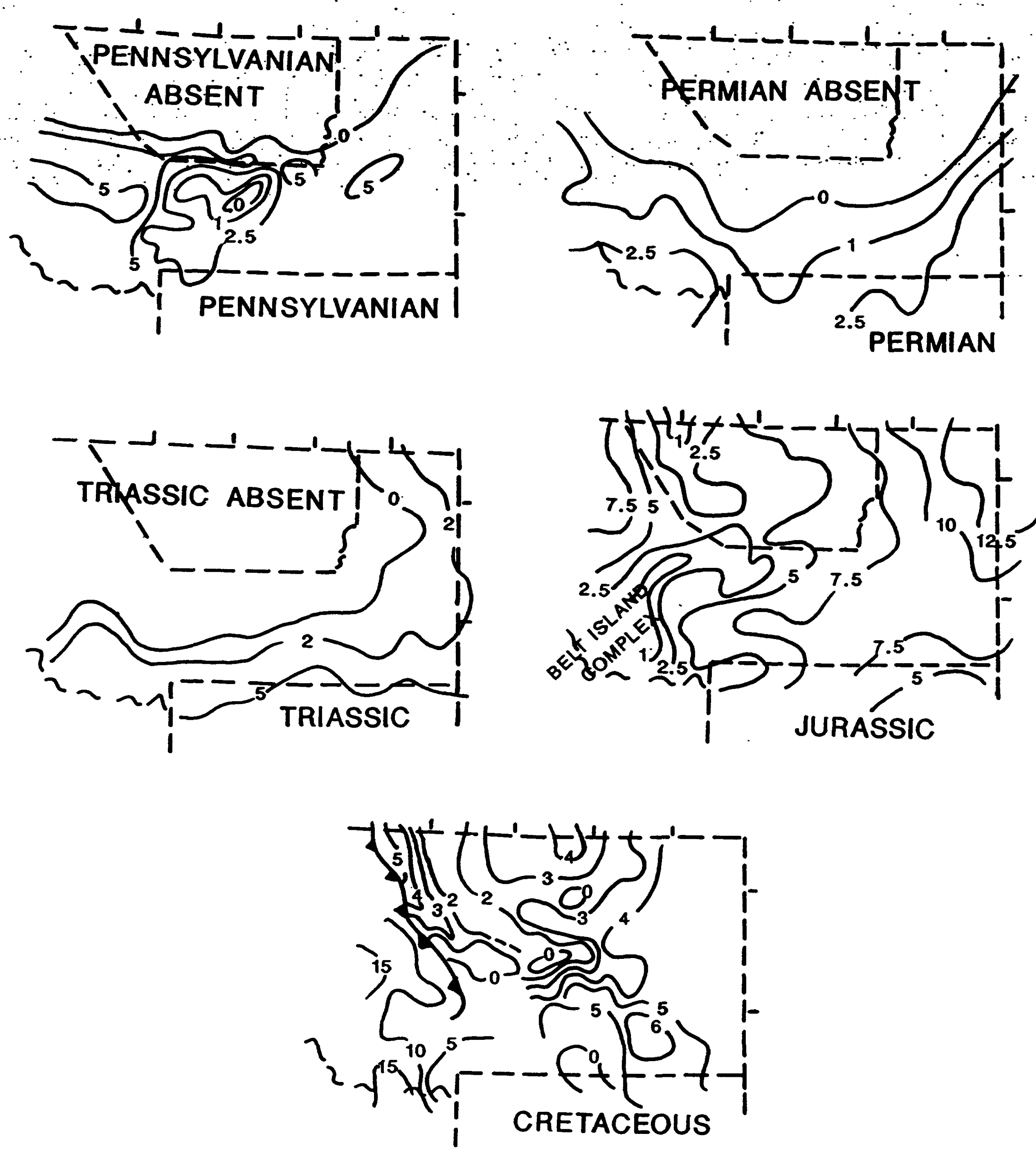


Figure 4 continued

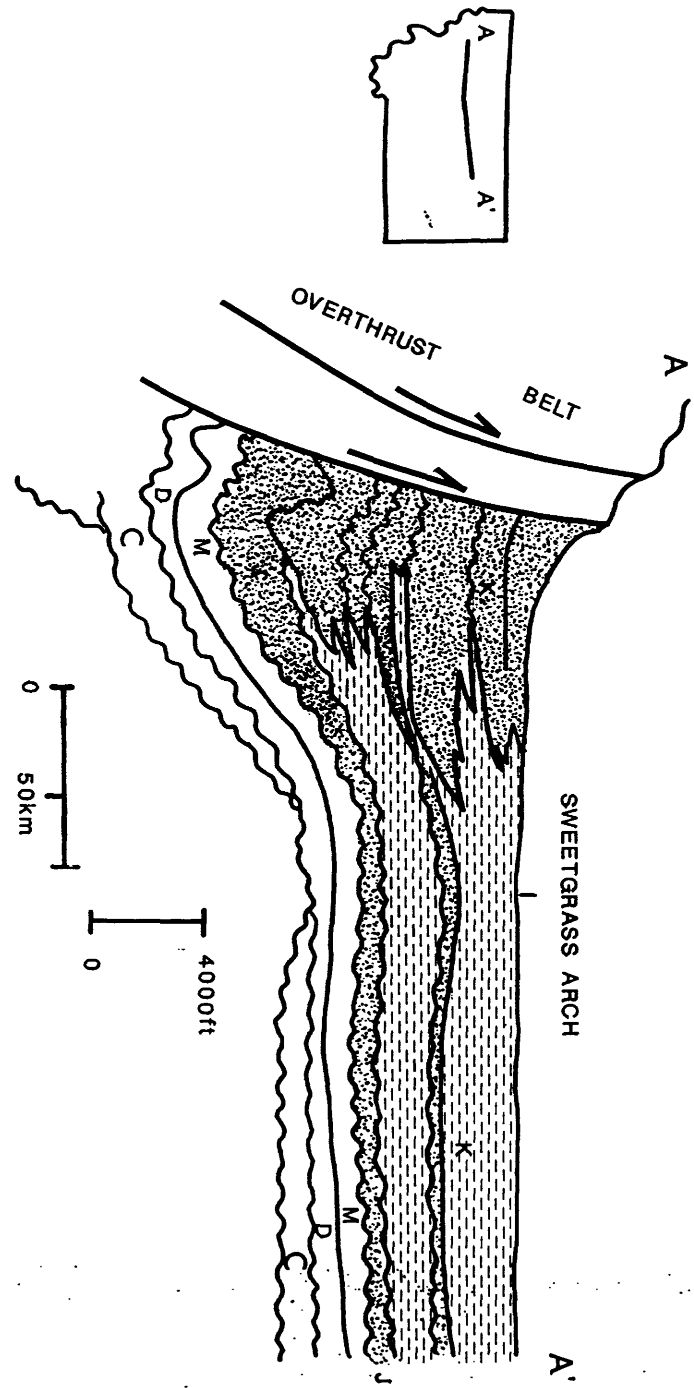
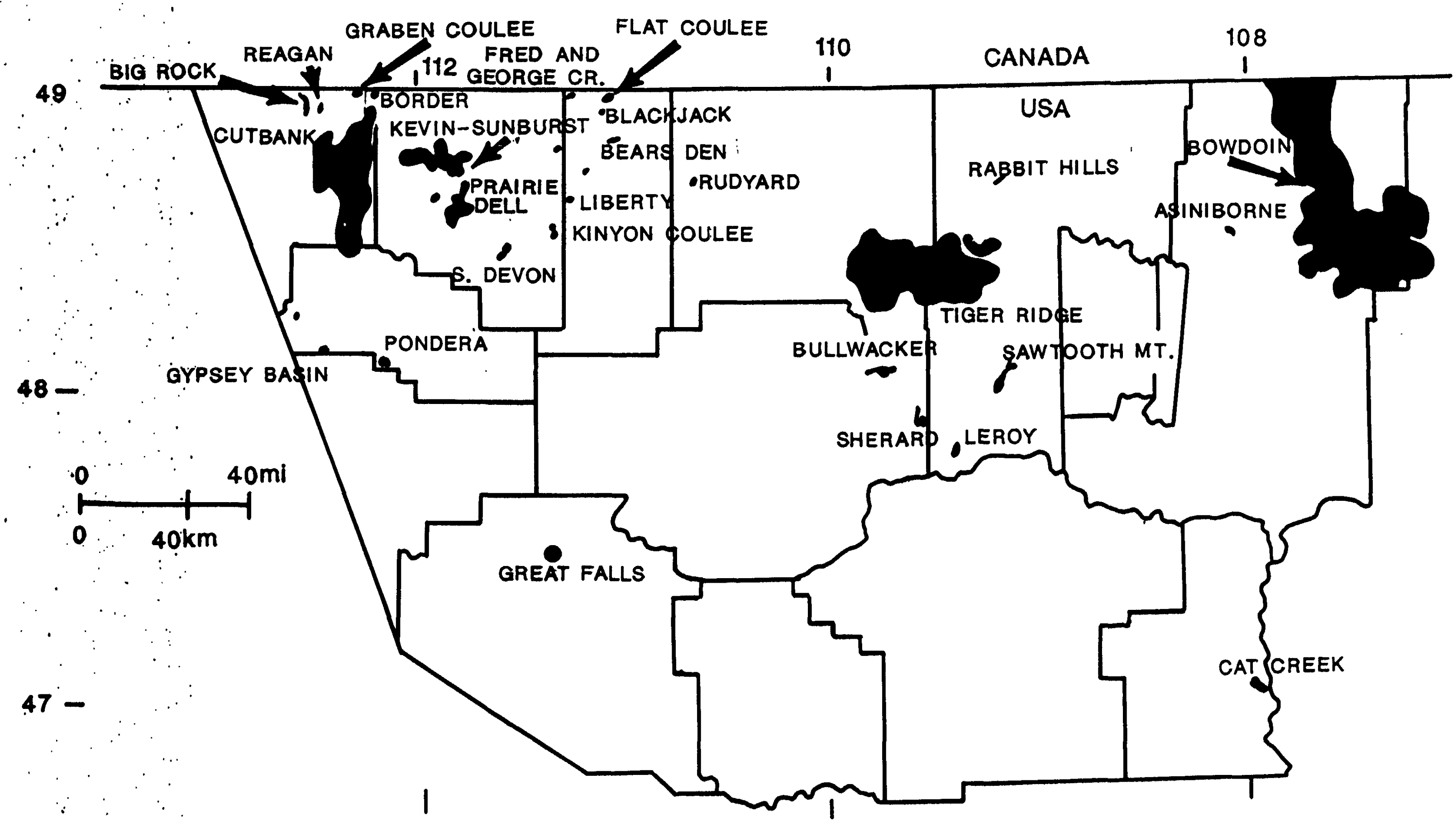
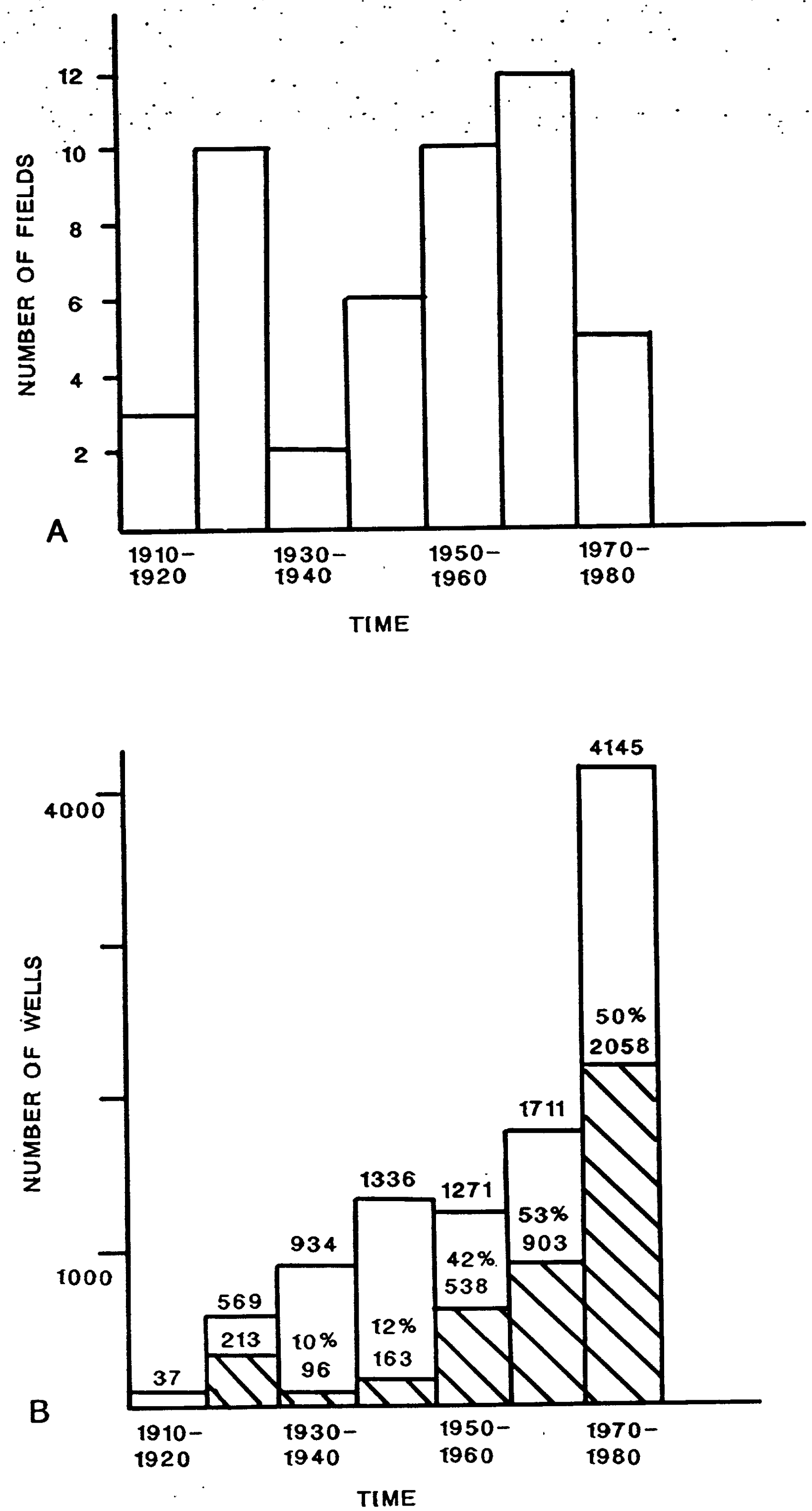


FIGURE 5



49
48 —
47 —
112
110
108
CANADA
USA
BIG ROCK
REAGAN
GRABEN COULEE
FRED AND GEORGE CR.
FLAT COULEE
BORDER
CUTBANK
KEVIN-SUNBURST
BLACKJACK
BEARS DEN
RUDYARD
PRAIRIE DELL
LIBERTY
KINYON COULEE
S. DEVON
PONDERA
GYPSEY BASIN
RABBIT HILLS
BOWDOIN
ASINIBORNE
TIGER RIDGE
BULLWACKER
SAWTOOTH MT.
SHERARD
LEROY
GREAT FALLS
CAT CREEK
0 40mi
0 40km

FIGURE 6


12
10
8
6
4
2
NUMBER OF FIELDS
A
1910–1920
1930–1940
1950–1960
1970–1980
TIME
4145
4000
NUMBER OF WELLS
50%
2058
1711
1336
1271
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42%
538
1000
569
213
10%
96
12%
163
37
B
1910–1920
1930–1940
1950–1960
1970–1980
TIME

FIGURE 7

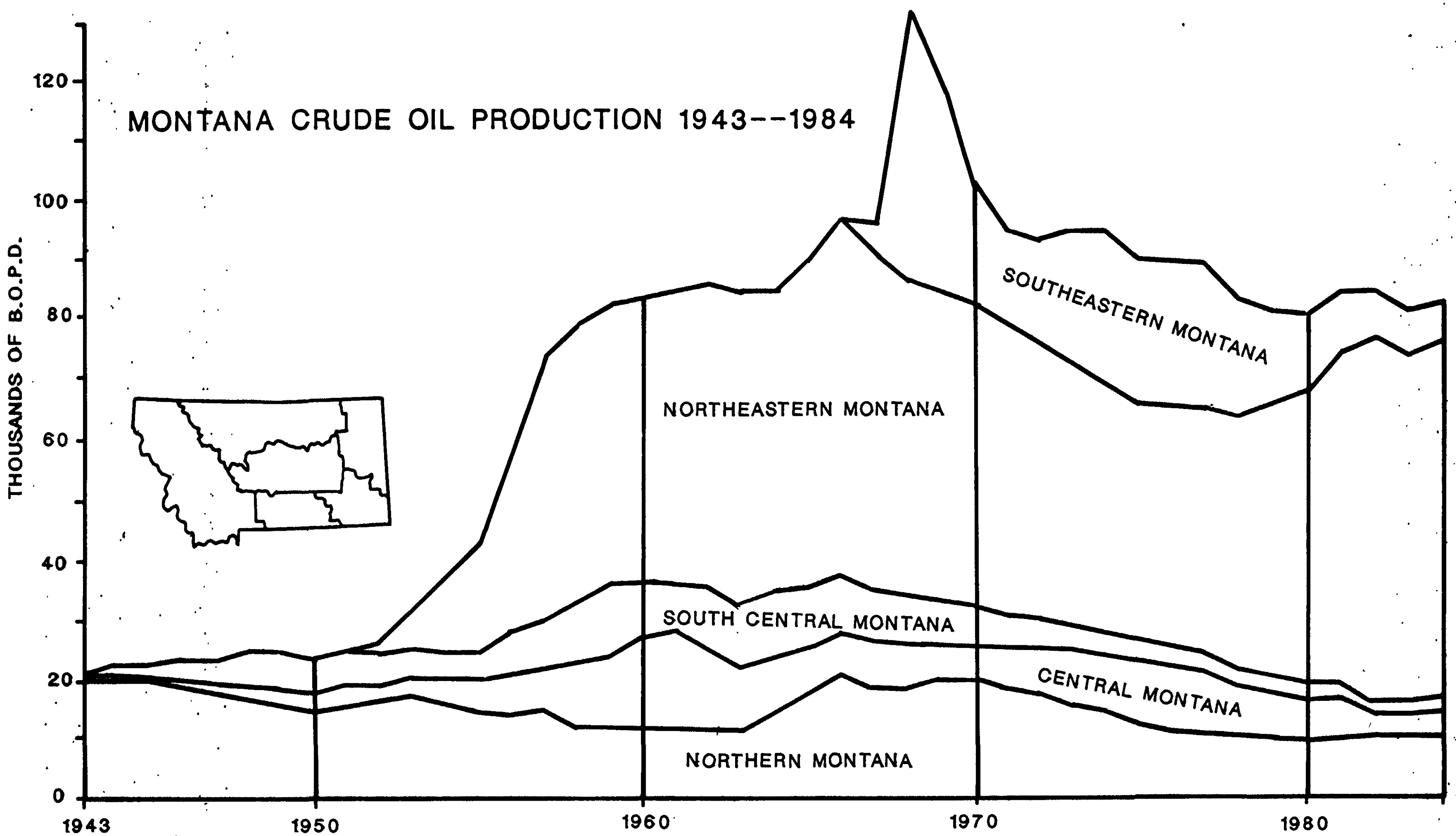
MONTANA CRUDE OIL PRODUCTION 1943--1984
THOUSANDS OF B.O.P.D.
120
100
80
60
40
20
0
1943
1950
1960
1970
1980
SOUTHEASTERN MONTANA
NORTHEASTERN MONTANA
SOUTH CENTRAL MONTANA
CENTRAL MONTANA
NORTHERN MONTANA

FIGURE 8