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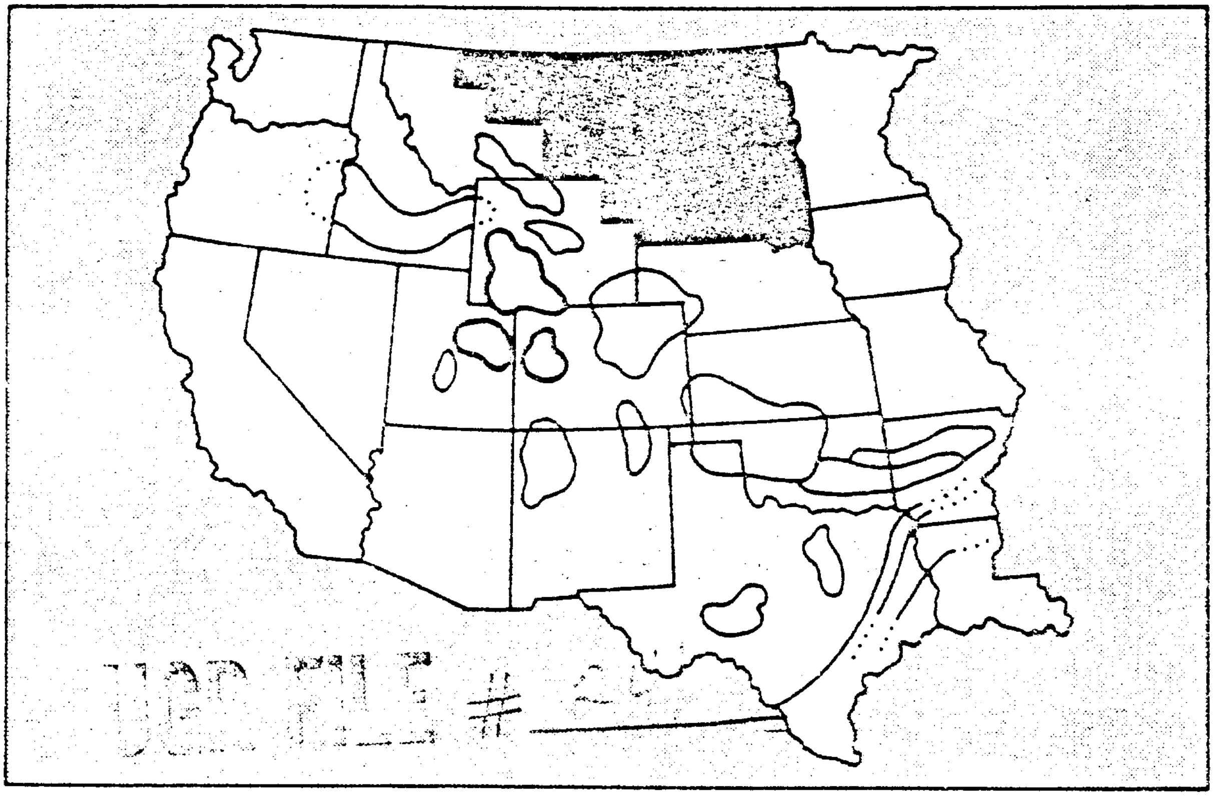
Western Gas Sands Project

NORTHERN GREAT PLAINS PROVINCE REVIEW



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Prepared for
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1. Introduction

This synopsis outlines the Upper Cretaceous low permeability natural (biogenic) gas formations of the Northern Great Plains Province (NGPP) of Montana, Wyoming, North and South Dakota. The main objectives are to present a general picture of the:

- stratigraphy.
- significant structures.
- natural gas potential.

Since the major role of the Western Gas Sands Project (WGSP) Core Program is to evaluate non-commercial areas, which excludes producing fields, no attempt was made to review the major amount of reservoir detail of various gas fields discussed in this report. This information is best supplied by individual operators.

The gas resource potential for the province is significant but the amount can only be surmised at this date. This study will provide a start toward determining a reliable gas in place figure by relating stratigraphic units in producing fields to present non-commercial areas. It will also help determine high potential areas for coring. This synopsis will only be effective if continually updated as more data are gathered.

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2. Location

The Northern Great Plains Province, shown in Figure 1, is located in eastern Montana, northeast Wyoming and all of North and South Dakota. It has an area of approximately 225,000 square miles in the United States, but extends north of the United States—Canadian border, with the boundaries limited by the extent of the included geologic strata. The western border is restricted to outcropping stratigraphic units or where these units develop into conventional commercial natural gas reservoirs. The eastern border is limited by erosion or non-deposition of the stratigraphic units, while the southern border in Wyoming is based on depth of burial (below the range for developing biogenic gas). The southern border of the province continues eastward, following the southern boundary of South Dakota, yet the Niobrara Formation (one of the objective horizons having considerable resource potential) continues into Nebraska (Figure 2 and 3). The province boundaries may be modified at a later date to include additional objectives as more information is obtained.

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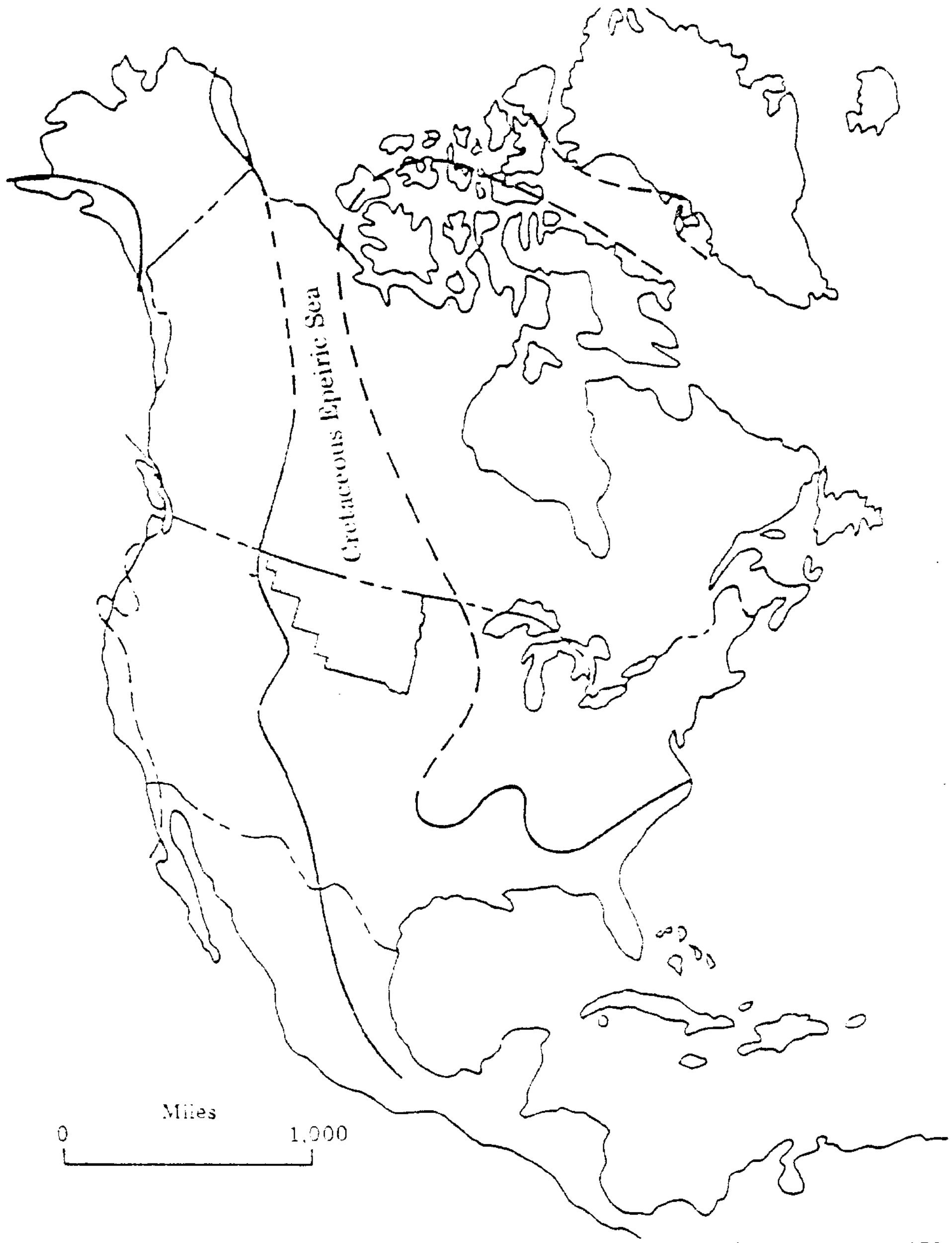

Modified from Gill and Cobban, 1973

Figure 1 The Cretaceous Epeiric Sea with the Northern Great Plains Province Superimposed

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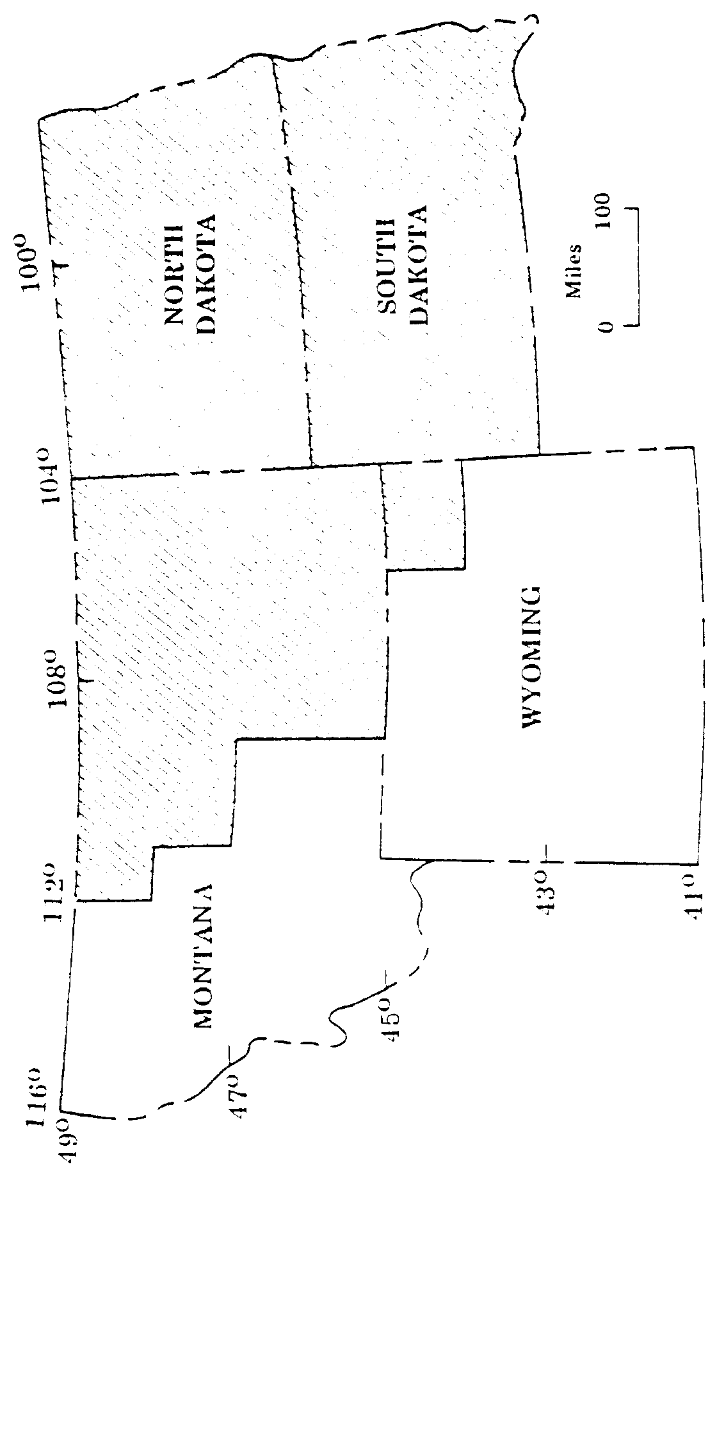

Figure 2 Northern Great Plains Province

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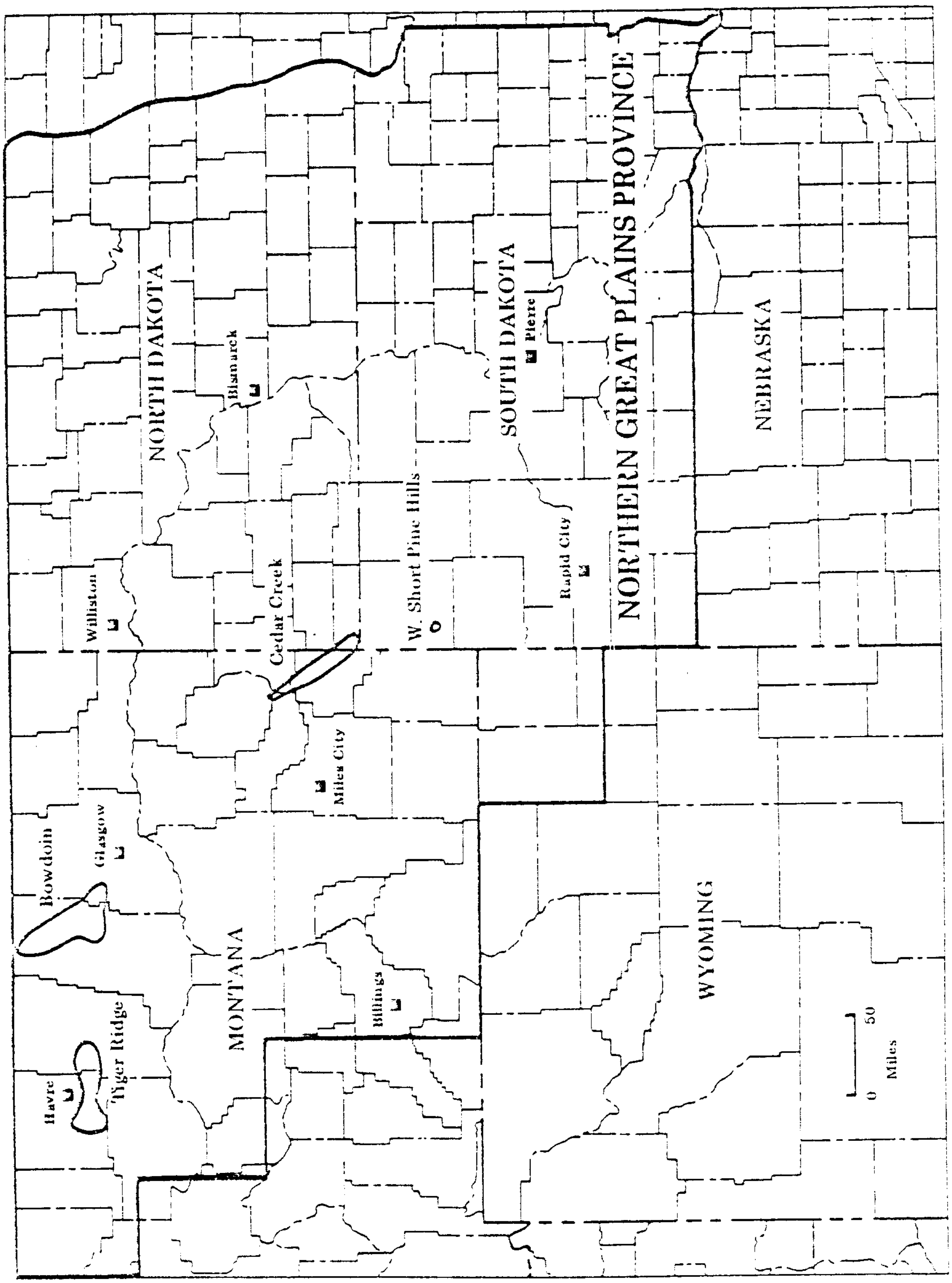

Figure 3 Northern Great Plains Province Showing Major Natural Gas Fields

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3. Stratigraphy

The U.S. Geological Survey (USGS) has designated a major part of the Upper Cretaceous stratigraphic section and a significant part of the Lower Cretaceous stratigraphic section as having low permeability (tight) gas potential in the NGPP. This section comprises all strata from the Lower Cretaceous Mowry Formation up through the Upper Cretaceous Judith River Formation (Figure 4). The older Muddy Formation may also have some "tight gas" potential in the northern part of the province, but will not be discussed in detail, as it primarily does not belong to the "tight gas sands" category of the younger section. Generally, the total Upper and Lower Cretaceous stratigraphic section of Montana represents about 10,000 ft of sediments in the non-marine section of western Montana and Idaho. Eastward, the equivalent, primarily marine section is represented by only 5,500 ft of sediments with 5,000 ft of this being Upper Cretaceous (Alpha, 1958, p. 22). This section, basically near-shore, shoreline, and alluvial sandstone, and marine siltstone and shale is of interest to the Western Gas Sands Project. The source of these clastics was the land area of western Montana and Idaho, although the Sioux Uplift in southeastern South Dakota and the Black Hills Uplift in west-central South Dakota may have been a source for some Muddy and Shannon (Eagle) deposition, respectively.

These sediments were deposited on a shallow marine shelf east of the primary source area, grading from coarse clastics eastward into siltstones, shales, and chalks. After middle Upper Cretaceous time, coarser clastics were deposited more frequently because of the shallower seas and periodic orogenic pulsations.

Generally, geophysical log correlations of these Cretaceous units are very good, although some correlation problems develop due to the predominant massive shale sequence between the Eagle and Muddy Formations. This is not of particular concern locally where changes are less subtle but may present a significant problem regionally. However, the resistivity log "limy kick" at the top of the Greenhorn Formation is a marker between the Eagle and Muddy Formations that can be used regionally. These regional correlations can be occasionally supplemented with time-stratigraphic markers such as bentonite beds (top of Eagle) or ammonites (megafossils) from surface studies.

System	Series	Group	Formation	West		East
Cretaceous	Upper	Montana Group		Bearpaw Shale	Pierre Shale	Pierre Shale
Cretaceous	Upper	Montana Group		Judith River Formation Parkman Sandstone Member	Pierre Shale	Pierre Shale
Cretaceous	Upper	Montana Group		Claggett Shale	Pierre Shale	Pierre Shale
Cretaceous	Upper	Montana Group		Eagle Sandstone Virgelle-Shannon Sandstone Members	Gammon Shale Member	Pierre Shale
Cretaceous	Upper	Montana Group		Telegraph Creek Formation	Gammon Shale Member	Pierre Shale
Cretaceous	Upper	Colorado Group		Niobrara Formation		Niobrara Formation Smoky Hill Shale Member
Cretaceous	Upper	Colorado Group	Frontier Formation	Carlile Shale Bowdoin Sandstone Member		Carlile Shale Codell Sandstone Member
Cretaceous	Upper	Colorado Group	Frontier Formation	Greenhorn Formation Phillips Sandstone Member		Greenhorn Formation
Cretaceous	Upper	Colorado Group	Frontier Formation	Belle Fourche Shale		Belle Fourche Shale
Cretaceous	Lower	Colorado Group		Mowry Shale		Mowry Shale
Cretaceous	Lower	Colorado Group		Muddy Sandstone		Muddy Sandstone

Figure 4 General Cretaceous Correlation Chart of Northern Great Plains Province Stratigraphy

4. Low Permeability Sandstones, Siltstones, Shales and Chalks

The Cretaceous geology of the NGPP is characterized by lithologic facies deposited in a north-south trending epicontinental sea as depicted in Figure 1. The primary source of clastics for these Cretaceous rocks was from western Montana and Idaho. Predominant continental deposits in the west graded into marine sandstones, siltstones, shales and ultimately chalks toward the eastern part of the province throughout Cretaceous time. An easterly retreating sea allowed the coarse clastics to be deposited further and further eastward during this period.

The oldest unit of current interest to the WGSP is the Mowry Shale, which lies below the Frontier Formation and Belle Fourche Shale. The Mowry Shale covers the entire NGPP as a shelf sandstone or silt and shale facies, except in southeastern South Dakota where its equivalent, the Dakota Formation, is partially represented (McGookey, et al., 1972, p. 201).

There are three lithologic facies in the Mowry Shale and equivalent rocks (Rice, 1978, p. 273). A well developed shelf sandstone facies covers the western part of the NGPP. A less well-developed shelf sandstone facies lies to the east and covers most of the eastern part of Montana and northeast Wyoming. The third facies is a siltstone and shale unit which covers the remainder of Montana and extends into the Dakotas. Currently there is no gas production from the Mowry Shale in the NGPP, although testing in some wells in the northern part of the province indicates potential resources.

The Frontier Formation is a massive continental sandstone in southcentral Montana but extends only a short distance into the southwestern corner of the NGPP. Here it develops, in part, into a shelf sandstone. Although the Frontier Formation or its equivalents also occur in the south-southwestern part of the NGPP, which extends into Wyoming, it is of no immediate interest to the WGSP. The Frontier Formation is possibly equivalent to part of the Niobrara, Carlile, Greenhorn and Belle Fourche Formations in the Powder River Basin (Figure 5). The Frontier Formation, including the Big Elk Sandstone as part of the Frontier, produces natural gas inside the NGPP only in the Hardin Field (Figure 6).

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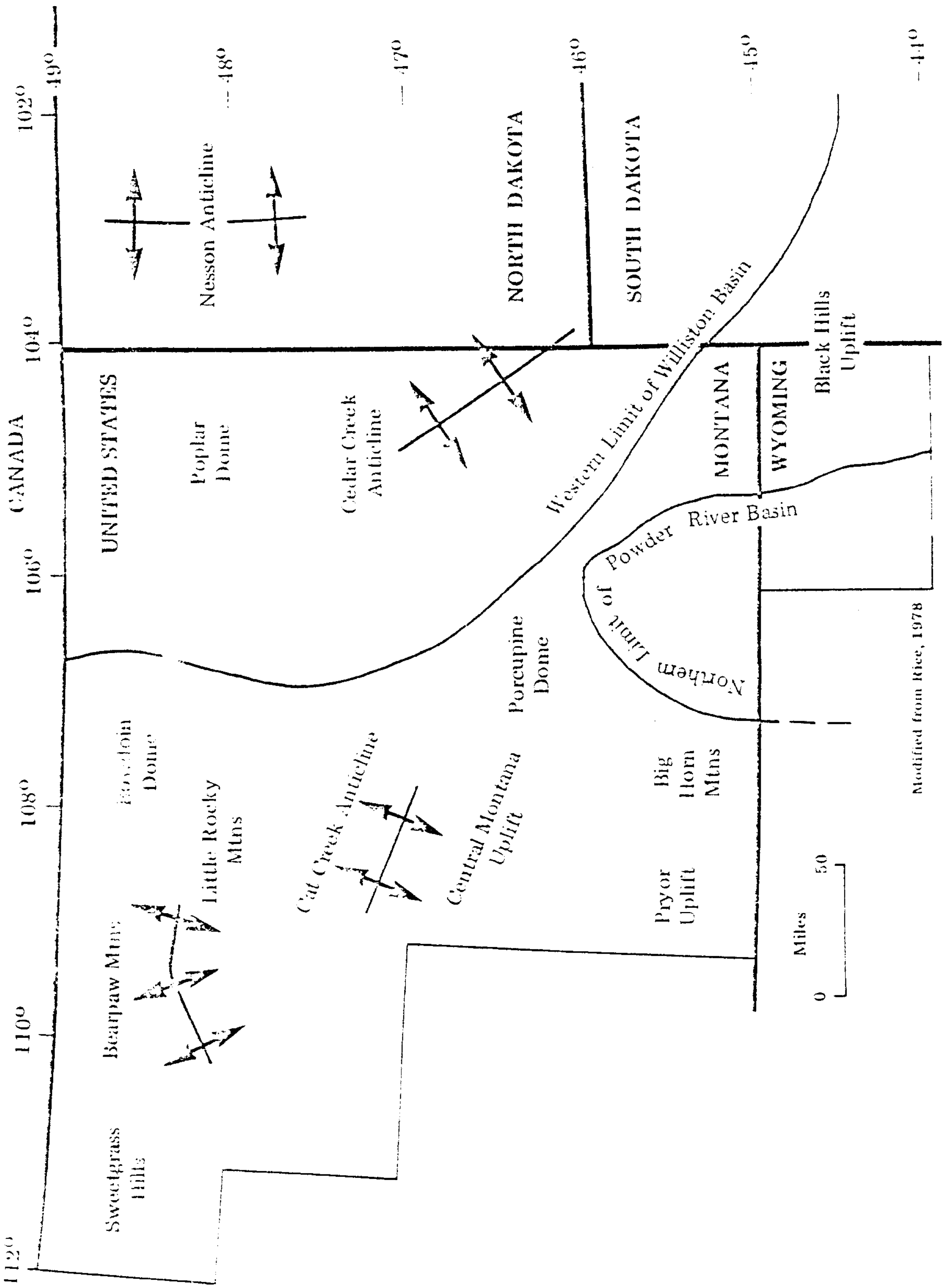

Figure 5 Significant Structures in the Northern Great Plains Province

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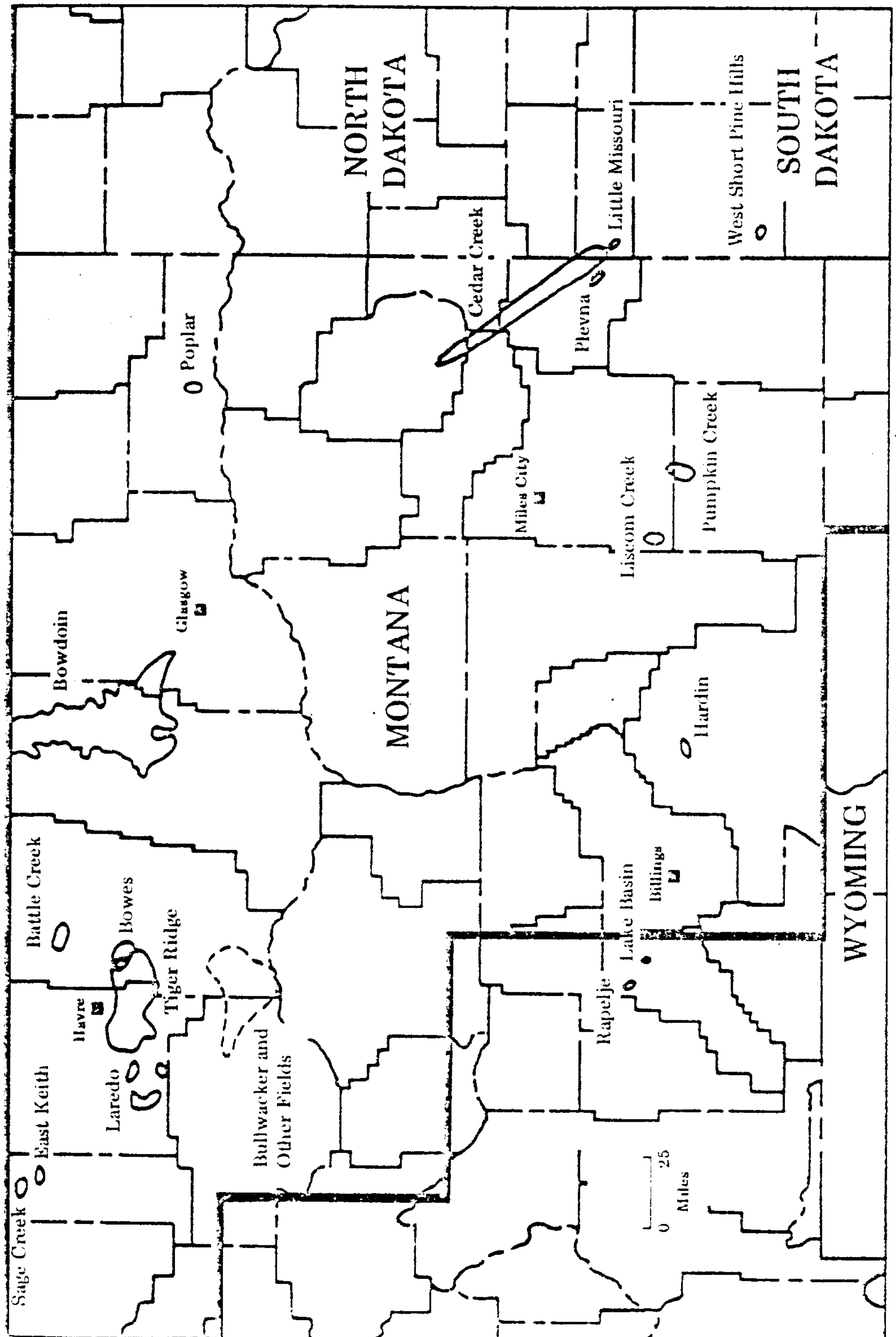

Figure 6 Significant Natural Gas Fields in the Northern Great Plains Province

The Belle Fourche Shale except for southeastern South Dakota covers the entire NGPP. This formation is not productive in the province.

The Greenhorn Formation lies above the Belle Fourche Shale. The top of the Greenhorn Formation is a limy shale or mudstone and, in places, a fine grained crystalline limestone, which is a good well log correlation point throughout most of the NGPP. This unit generally becomes more calcareous in eastern Montana where calcareous mudstones and clastics give way to deeper water marine sediments. The Cone Member and part of the Floweree Member of the Marias River Shale of northwest Montana are equivalent to the Greenhorn Formation (Energy Resources of Montana, 1975, p. 12-13). In southeastern South Dakota, however, the Greenhorn Formation tends to become less limey and more clastic with an unnamed sandstone member at or near the top of the formation and a smaller sand stringer at its base. The Greenhorn lime unit produces in the northern part of the Bowdoin Field, Montana.

The Phillips (Mosby) Sandstone Member of the Greenhorn Formation, which is below the top limey unit, developed as a shelf sandstone. This member covers a large part of the province extending from the Bowdoin Field westward to the Sweetgrass Arch area of Montana and southeasterly almost to the Wyoming line. East of this the member equivalent is a silt and shale facies which, further eastward, grades into a shaly chalk or chalk (Rice, 1978, p. 274).

The Phillips Sandstone Member produces commercially in the Bowdoin Field. The original field was developed in cleaner sands and the wells proved successful without stimulation. However, later wells drilled northwest of the original field have been stimulated. About 120 miles west of the Bowdoin Field, an equivalent Phillips unit produces in the East Keith and Sage Creek Fields. This interval is called the Second White Specks Sandstone and is approximately the same chronostratigraphic unit as that which produces in Canada.

The Carlile Shale is a marine unit lying between the Greenhorn and Niobrara Formations. This shale sequence covers the entire NGPP, although it can be subdivided into facies (Rice, 1978, p. 274). A shelf sandstone facies, called the Bowdoin Sandstone Member of the Carlile Shale, extends from northcentral Montana southwestward to the western edge of the NGPP. The Bowdoin Member is composed of sandstone and siltstone lenses and laminae interbedded in a massive shale. It was probably deposited in a lower energy environment (deeper waters) than the underlying Phillips unit. This also seems to be reflected in the reservoir properties of the units in the Bowdoin Field, the largest producing area for both members. Generally, the Phillips Member has greater porosity and permeability than the Bowdoin unit. However, this seems also to vary depending on location in the field. Apparently during the deposition of the Carlile and Greenhorn there were periods when more clastics were being deposited and during which water depths fluctuated. This resulted in higher energy deposition of cleaner sandstones interspersed with intervals of lower energy deposition of shales or shaley limes of the Upper Greenhorn.

The Bowdoin Member in the area of the Bowdoin Field is generally not as well developed as an equivalent shelf sandstone in areas west of the Bowdoin Dome. Here in northwestern Montana, the Carlile Shale becomes the Ferdig Member of the Marias River Shale. Approximately equivalent shelf sands (Turner Sandy Member) are also found in southeast Montana, northeast Wyoming, and South Dakota. In southcentral, and possibly as far as eastern, South Dakota, the Codell Sandstone Member may be equivalent to the Turner Sandy Member (Rice, 1977).

The Bowdoin Sandstone Member of the Carlile Shale produces in the Bowdoin Field of Phillips and Valley Counties, Montana. In the original field area, gas was recovered from a cleaner zone that may have been naturally fractured. However, field extensions to the northwest and southeast have required hydraulic fracturing to be commercial. To the west there have been a few productive Bowdoin wells on the southeast flank of the Bearpaw Uplift, although an initial 15 well development program here was reduced after initial wells produced water from clean sands. The Turner Sandy Member produces gas commercially in the Powder River Basin of Wyoming; however the unit is not presently of interest to the WGSP.

The Niobrara Formation represents a transgression of the sea over all of the NGPP. In the deeper marine waters of the eastern part of Montana and throughout North and South Dakota calcareous mudstones and chalks were deposited. Dark marine shales and some coarse clastics were deposited in western Montana (Kevin Shale Member of Marias River Formation and Martin sandy zone). The Niobrara Formation is currently believed to have potential for gas production in five states, including North and South Dakota, and in Canada (Rountree, 1979). The chalks are considered to have high porosities but extremely low permeabilities. The current Niobrara play began in northeast Colorado in 1972: Production was obtained from a chalk section at the top of the Smokey Hill Member of the Niobrara Formation. West of the chalk facies, the Niobrara Formation has had gas shows from wells drilled within and west of the Bowdoin Field in Phillips County, Montana. The Martin sandy zone of the Niobrara Formation tested gas in the discovery well in the Bowdoin Field (Rice, 1978, p. 278).

The Telegraph Creek Formation overlies the Niobrara Formation. This predominantly shale unit is recognized as a formation in western and central Montana but becomes part of the Gammon or Pierre Shale in the eastern part of the state. Locally, well developed sands do occur in the Telegraph Creek Formation, some of which produce gas in the Lake Basin Field, Stillwater County, Montana.

The Eagle Sandstone Formation which includes the Virgelle and Shannon Sandstone Members lies above the Telegraph Creek Formation. Both members are developed at the base of the Eagle Sandstone in various parts of the province. The Eagle Sandstone produces from nearshore (beach) sandstones around the flanks of the Bearpaw Mountains. Production is aided and sometimes hindered (fracturing into the water table) by natural fracturing, although these clean coastal sandstones have good porosity and permeability. The Eagle Sandstone also produces from the same facies to the south in Rapelje Field. Eastward, these beach deposits grade into shelf sandstones. The Eagle Sandstone Formation and equivalent rocks are primarily siltstones and shales in the Bowdoin Field area of north-central Montana. However, shelf sands are developed on the south and southeast sides of the dome and have produced gas in a few wells just southeast of the field. These shelf sandstones are much more extensive from west to east along the southeastern boundary of Montana where the Shannon Member is productive in the Liscom Creek and Pumpkin Creek Fields of Custer and Powder River Counties. Equivalent sands are also productive in the West Short Pine Hills Field, developed recently in Harding County, South Dakota.

Although the Eagle Sandstone Formation was hydraulically fractured in wells drilled southeast of the Bowdoin Field, it has not normally been necessary to fracture the Shannon Member wells in southeast Montana and northwest South Dakota because of the good porosities and permeabilities of the cleaner shelf sands.

Eastward, the Eagle Sandstone Formation and equivalent rocks grade into siltstone and shale of the Gammon Shale. There is no production from this facies except on the Cedar Creek Anticline where the Eagle Formation produces from a sandy-shale sequence. This structure localizes production in the area, aided by natural fracturing. Trapping of hydrocarbons in the Eagle however, is probably due to stratigraphic control more than structural influence. This facies appears also to have resource potential in North and South Dakota because it is in places extremely organic-rich and also naturally fractured.

The marine Claggett Shale overlies the Eagle Formation. The Claggett Shale and equivalent rocks extend throughout the NGPP. Although there is little production from the Claggett in the province, siltstone laminations in the shales are potential "tight gas" reservoirs and could be an economic source of gas in naturally fractured areas. The Claggett Shale produces locally from marine coastal sandstones in the Rapelje Field of Montana, which is just outside the province boundary.

The youngest unit of current interest to the WGSP is the Judith River Formation. This unit produces from continental deposits around the flanks of the Bearpaw Mountains. These deposits, as well as the lower coastal sands of the Parkman Member, may also prove to have significant gas production potential around the flanks of the Bowdoin Field in Phillips and Valley Counties, Montana. While certain reservoirs fit into the realm of "tight gas sands" and are therefore of interest to the WGSP, these continental deposits have limited gas potential due to their restricted areal extent and shallow depths.

East of the continental facies, the Judith River Formation grades into massive, porous coastal sandstones and, continuing further eastward, grades into primarily shelf sandstones varying from cleaner offshore bar deposits to finer grained material deposited in lower energy environments. These shelf sandstones, lying along a north-south band 50 to 100 miles wide in eastern Montana, represent the major "tight gas" potential for this formation. The Judith River Formation produces gas from the cleaner variety of shelf sandstones on the Cedar Creek Anticline (Rice, 1978, p. 275). This unit also has produced gas from shelf sandstones on Poplar Dome in Roosevelt County, Montana. Locally in these facies the Judith River Formation has produced commercially without being hydraulically fractured. This is probably due to cleaner sands on structures (shoaling) or natural fracturing. Further eastward, the Judith River Formation loses much of its gas potential as it grades into stratigraphically equivalent shales (Pierre Shale) of North and South Dakota.

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5. Canadian Low Permeability Sandstones

In southeastern Alberta, Canada, shallow Cretaceous stratigraphic units are equivalent in age, similar in their depositional environments to those rocks described in the United States part of the NGPP, and produce natural gas. The primary low permeability producing formations are the Milk River (Eagle equivalent); Medicine Hat (Niobrara equivalent); and Second White Specks (Phillips equivalent). In 1972 a resource evaluation of the Suffield Block, lying 30 miles north of Medicine Hat, Alberta (Figure 7), was prepared for the province of Alberta by a committee of geological, engineering, land, and economic consultants (Suffield Block Study Committee 1972). In 1974, a report, *The Suffield Evaluation Drilling Program*, was prepared by petroleum consultants for the Study Committee. This program estimated the reserves in the Block to be 2.7 trillion cubic feet (Tcf), including Lower Cretaceous reserves of about 150 billion cubic feet (Bcf). The Milk River Formation, with a reserve figure of almost 2.0 Tcf, has, by far, the greatest potential (Last, Kloepfer 1974).

In the United States, the NGPP, with units of similar depositional environments and reservoir characteristics, and an area 200 times larger than that of the Canadian Suffield Block, should ultimately yield significant natural gas reserves from these Cretaceous formations.

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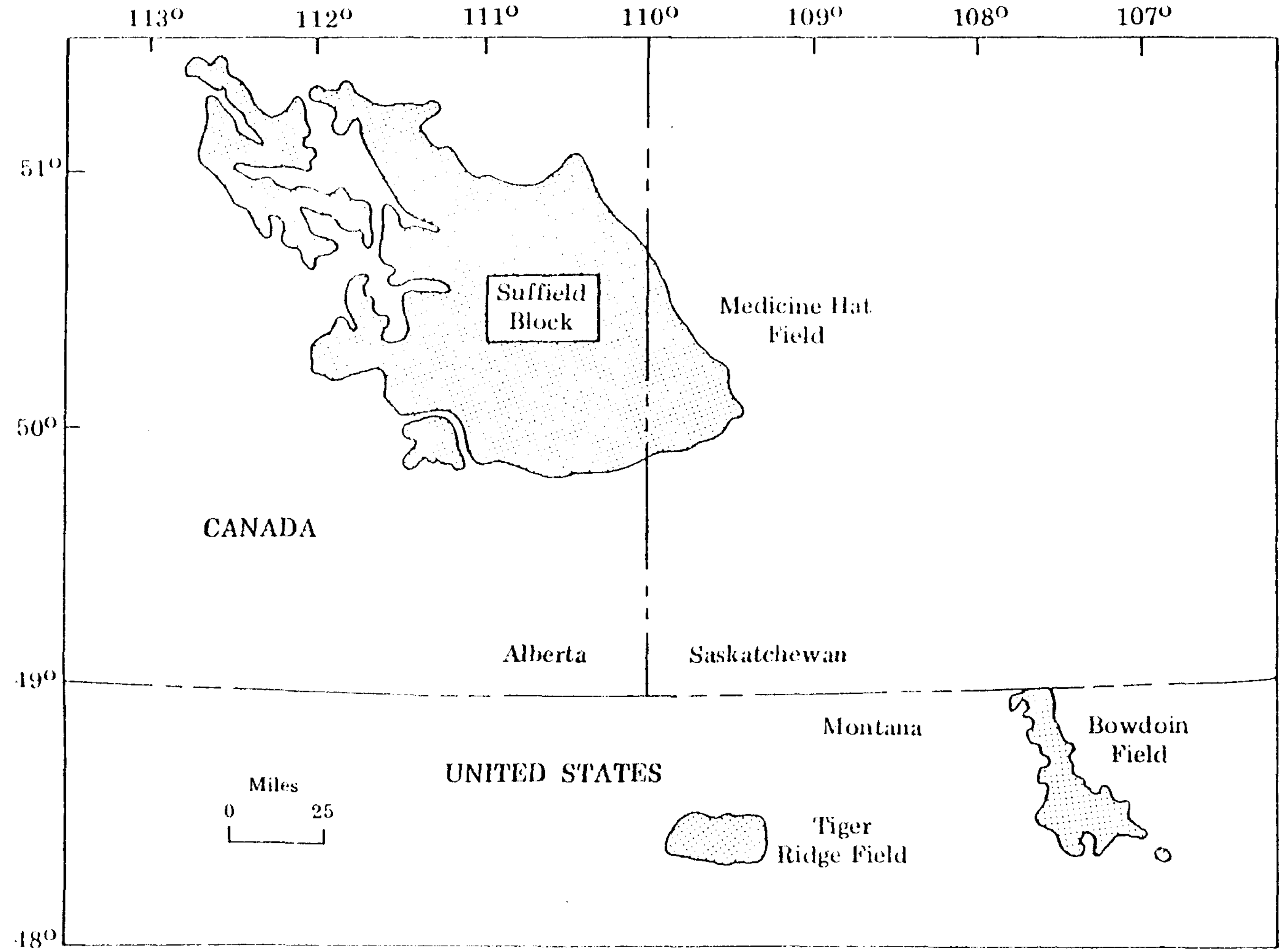

Modified from Rice, 1978

Figure 7 The Suffield Block of Medicine Hat Field, Alberta, Canada

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6. Gas Producing Horizons

This section discusses each of the gas producing formations and how they contribute to the natural gas potential in the NGPP where the entire Upper Cretaceous stratigraphic section is considered to have significant amounts of biogenic gas (Rice, 1975).

The Judith River Formation produces commercially from two main areas in the Northern Great Plains Province. One area is on the flanks of the Bearpaw Mountains, Hill and Blaine Counties, Montana, where production is controlled by naturally fractured or faulted sands with porosities and permeabilities that are sufficient to apparently require little or no stimulation for commercial production. Unfortunately, very few reservoir data are available on the Judith River Formation in this area; however, some of the Judith River Formation parameters are probably similar to those of the deeper Eagle Formation. There should also be reservoirs in these continental deposits that would require stimulation in order to be commercial, due to low porosities and permeabilities. Drilling depths to the Judith River Formation are shallow, about 500 ft. maximum. The total thickness of the unit is about 500 ft.

In southeastern Montana, the Judith River Formation produces from the Cedar Creek and the Plevna Fields. Both fields are structural features (anticlines), although there is also stratigraphic trapping. Drilling depth to the top of the formation is approximately 900 ft. Here the Judith River Formation is a series of interbedded sandstones, siltstones, and shales varying in thickness of reservoir rock from 30 to 100 ft (Figure 8). Reservoir properties range from 10 to 30 percent porosity with an average gas pay thickness of 45 ft. Original field pressure was about 210 psi with a proven productive area of about 115,000 acres (including the Eagle Formation). Gas in place is approximately 340 thousand cubic feet (MCF) per acre foot.

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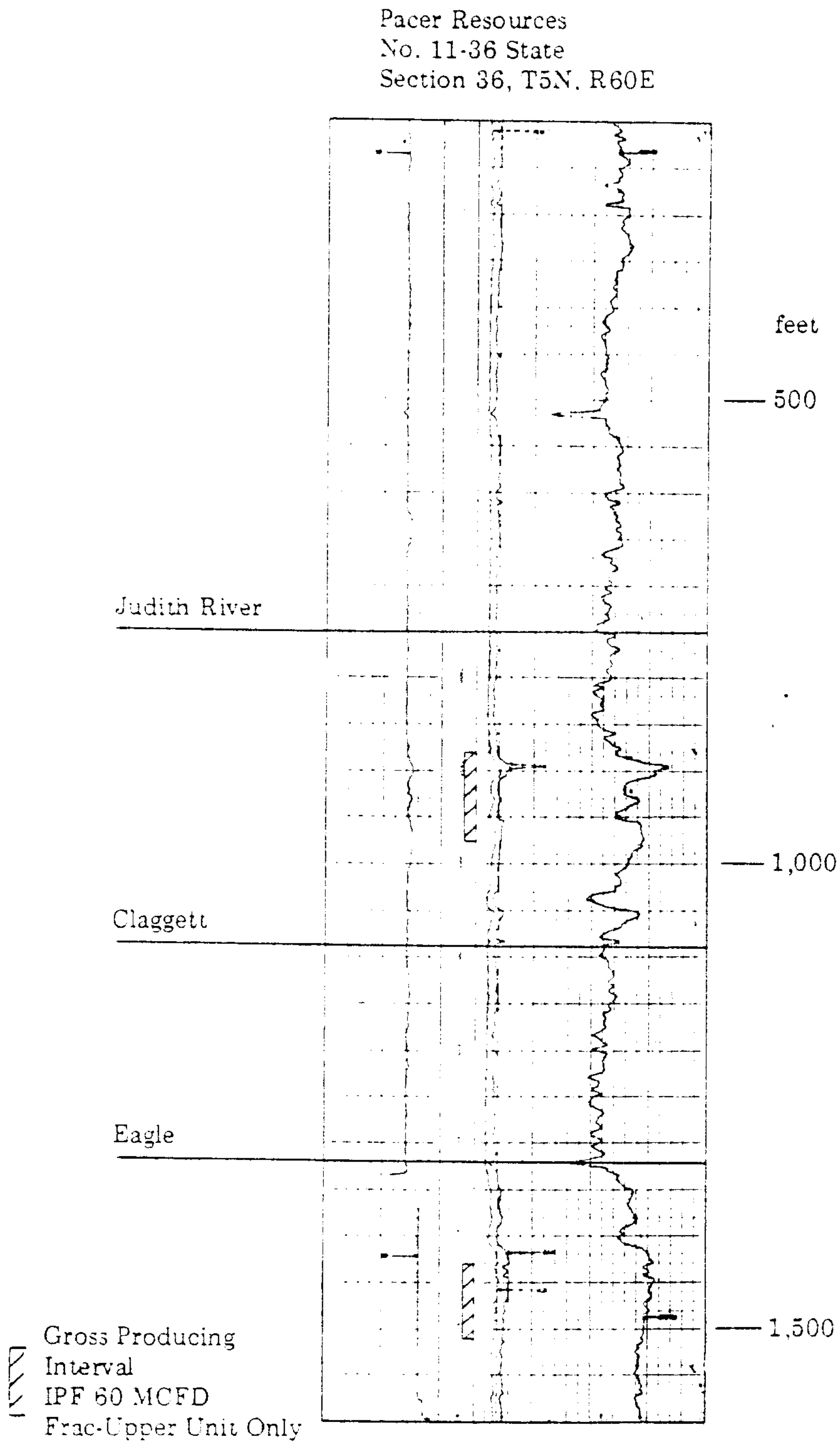

Figure 8 Resistivity-Spontaneous Potential Well Log From Cedar Creek Field, Fallon County, Montana

In 1977, four significant wells were drilled in Cedar Creek Field, fractured only in the Judith River Formation and completed in the Judith River and Eagle Formations. Fracture treatments were typical of shallow wells for Montana (30,000 lb sand), however, fracturing has not been a normal procedure in the Cedar Creek Field. The Judith River Formation also has produced in the Poplar Dome Field area of northeast Montana. These are old wells and very few data are available.

The Claggett Formation does not produce in the NGPP; however, it is productive just outside the NGPP boundary in Rapelje Field.

The Eagle Formation produces from several areas in the NGPP. The Virgelle and Shannon Sandstone Members are also productive in the province. The main area of production is around the flanks of the Bearpaw Arch. Here the Eagle Formation (including the Virgelle Member) is a fine grained glauconitic sandstone which produces from faulted (structural) traps (Figure 9). Drilling depths are 1,000 to 1,300 ft. Reservoir parameters include an average gas pay thickness of 35 ft, a porosity of 25 percent, water saturation of 38 percent, and permeabilities of up to 300 md. Initial reservoir pressures were about 380 psia. It should be noted, however, that about one Eagle well in four needs a fracture treatment to be successful. East of the Bearpaw Arch, in Valley County, the Eagle Formation is capable of producing southeast of the Bowdoin Field: two wells were recently drilled and completed in the Eagle Formation. Both were hydraulically fractured and yielded rates of 91 and 265 MCFD, respectively. Porosities in this area are 25 to 30 percent.

Another major Eagle producing area is the Cedar Creek Anticline, southeast Montana. Here the Eagle Formation is a sandy shale sequence with an average gas pay thickness of 60 ft. The average effective porosity is around 8 percent, somewhat less than that of the shallower Judith River Formation. Reservoir pressure is 400 psi at the production depth of 1,300 ft. Trapping is probably both stratigraphically- and structurally-controlled. West and south of this producing area, the Liscom Creek and Pumpkin Creek Fields of Montana and the West Short Pine Hills Field of northwest South Dakota produce from the Shannon Member of the Eagle Formation. Trapping is also probably both structurally- and stratigraphically-controlled. At the Liscom Creek Field, the Shannon Member is a fine-grained to

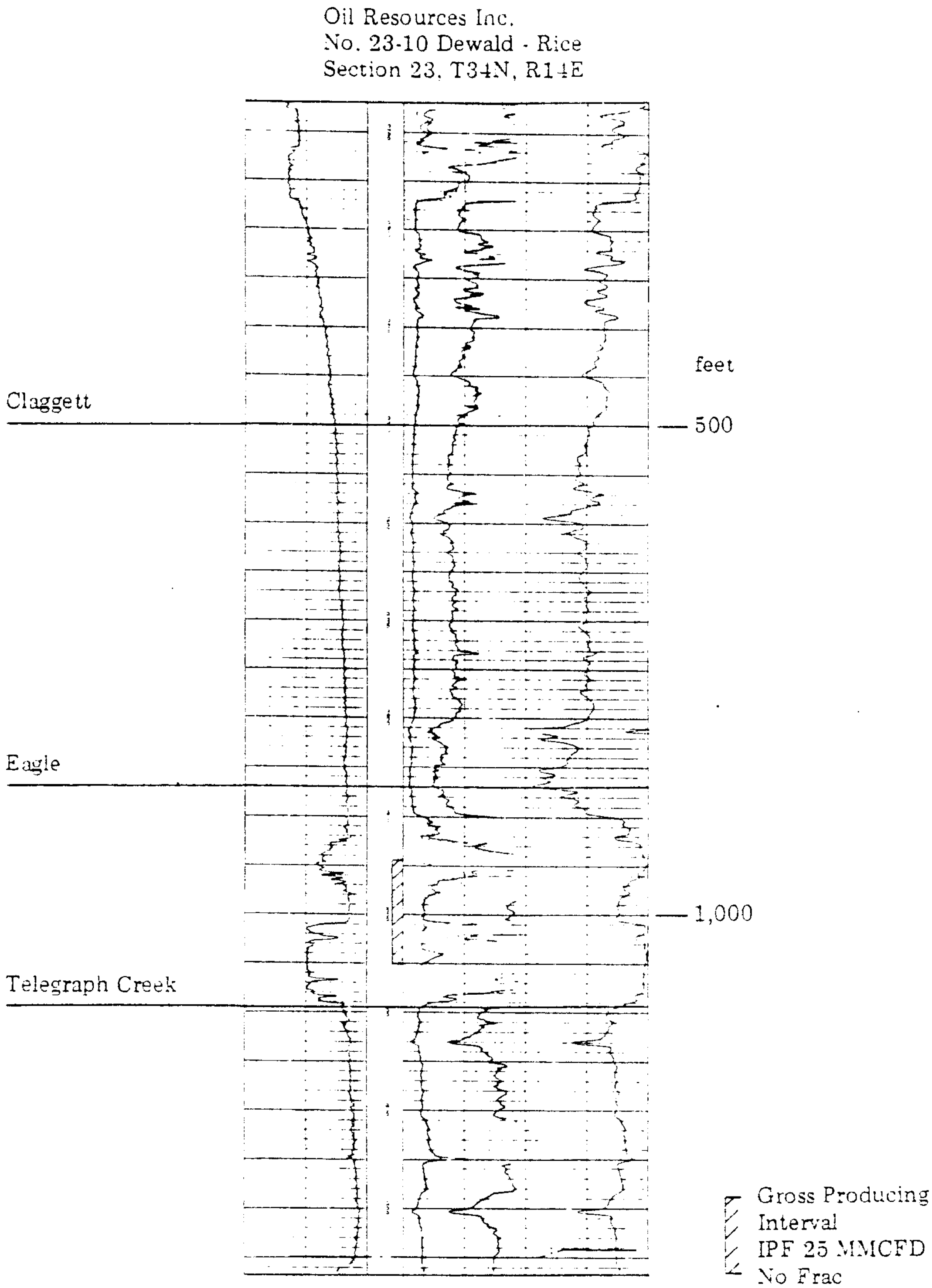

Figure 9 Resistivity-Spontaneous Potential Well Log From Tiger Ridge Field, Hill County, Montana

silty sandstone that produces from an interval about 2,500 ft deep. The gas pay thickness averages about 8 ft, porosity 25 percent and water saturation 45 percent. Initial reservoir pressure was 745 psi. The Shannon Member here produces from a structure-stratigraphic trap. The Shannon Member also produces at the nearby Pumpkin Creek Field. Trapping there appears however, to be primarily stratigraphic. Reservoir properties and drilling depths are similar to those in Liscom Creek Field. Very little Eagle Formation (Shannon) production in southeast Montana has required stimulation. However, some recent attempts have been made to increase production by hydraulic fracturing in the Pumpkin Creek Field.

In South Dakota, the Shannon Member produces from a new field on the Camp Crook Anticline, which lies south of the Cedar Creek Anticline and from which production may be influenced. Porosities and permeabilities from this field are not indicative of "tight gas" sands according to a field operator (McCutchin, 1978).

The Telegraph Creek Formation is not productive in the NGPP although local sands are productive just outside the province boundary.

The Niobrara Formation, while not productive at present in the NGPP, is considered to have significant potential throughout the province. There have been several Niobrara shows in wells drilled in northcentral Montana and recently operators have planned Niobrara tests in the southeastern part of the state. Current interest, however, is primarily in the chalk facies of North and South Dakota which may have significant natural gas resources.

The Carlile Shale is a major producer in one area in Montana: the Bowdoin Member of the Carlile Shale produces at Bowdoin Field in the north-central part of the state. Drilling depths to the productive interval range from 800 to 1,400 ft. The Bowdoin Member may range from 25 to 100 ft in thickness. This member is actually a shale with thin siltstone and sand lenses intercalated throughout the producing interval (Figure 10). Reservoir parameters include porosities of 15 to 25 percent and permeabilities that may vary from less than one to several millidarcies. Gas pay thickness varies widely across the field from greater than 50 ft (average) to significantly smaller intervals. Although the original Bowdoin Field did not require hydraulic fracturing due to cleaner sands and natural fractures, field extensions to the northwest and southeast require stimulation. West of the Bowdoin Dome on the flanks of the Bearpaw Arch, the Bowdoin equivalent (the Ferdig Member of the Marias River Formation) produces locally.

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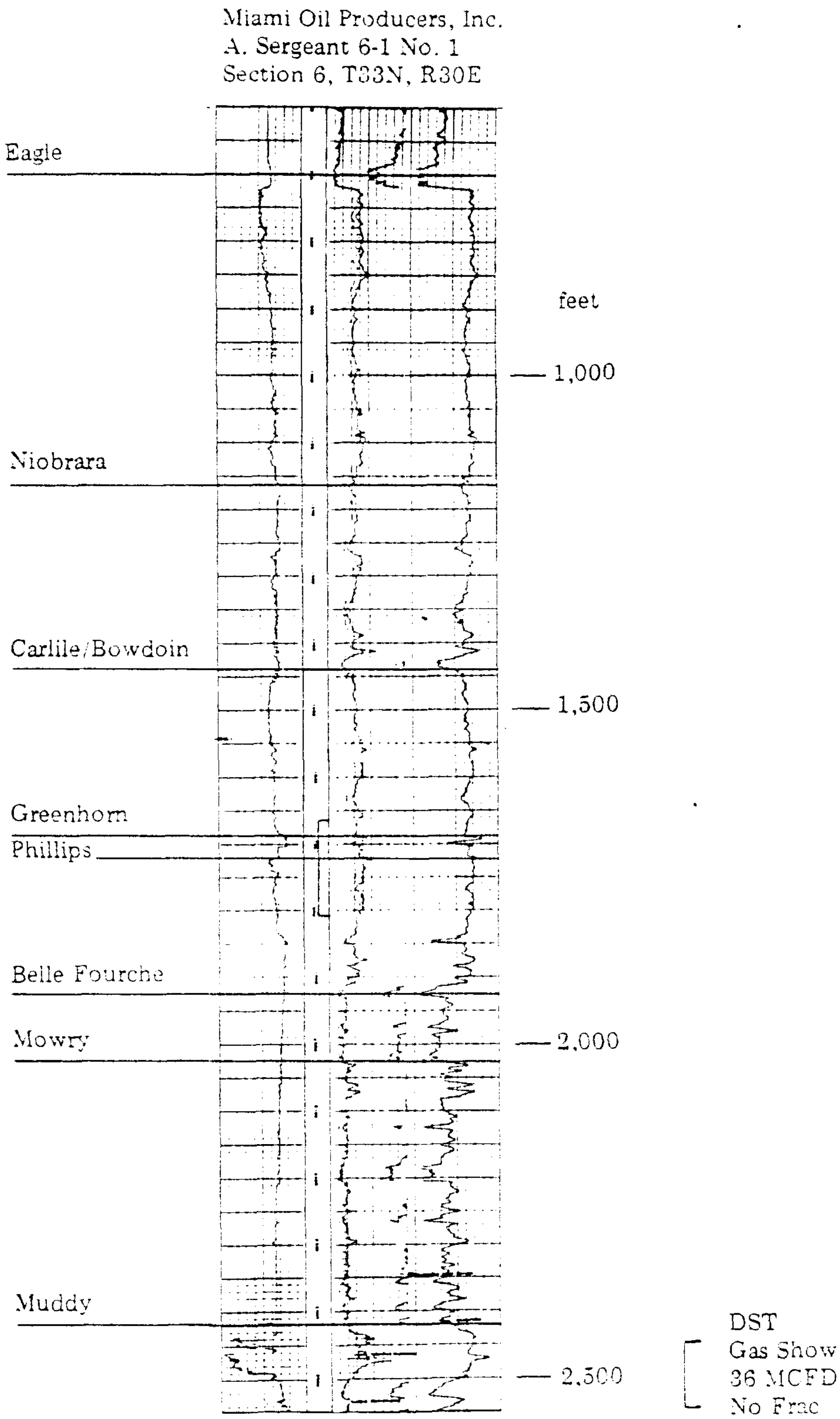

Figure 10 Resistivity-Spontaneous Potential Well Log From Bowdoin Field, Phillips County, Montana

Another major producing zone in the NGPP, the Phillips Member of the Greenhorn Formation lies below the Bowdoin Member. This member produces at the Bowdoin Field and its equivalent (the Second White Specks) also produces northwest of the Tiger Ridge Field. The Second White Specks producing zone has occasionally been correlated incorrectly to the deeper Blackleaf Formation. The upper part of the Greenhorn Formation (lime unit) also produces on the northern edge of the Bowdoin Field. Drilling depths to the Phillips Member in the Bowdoin Field vary from 1,200 to 1,800 ft. Porosities range from 12 to 20 percent, with permeabilities from less than one to probably not more than two millidarcies. The Phillips Sand Member is a sandy, carbonaceous shale that ranges up to 125 ft in thickness with a gas pay thickness of a few tens of feet. As with the Bowdoin Member, the Phillips Member produces without hydraulic fracturing in the initial Bowdoin Field area, but is stimulated beyond this area. The Greenhorn Formation must also be stimulated to produce in the northwest Bowdoin Field. Trapping is probably both stratigraphic and structural, although the massive shale units appear to give more support to stratigraphic trapping.

Production from the Second White Specks zone in the East Keith Field northwest of Tiger Ridge is localized by stratigraphic trapping. This zone also produces at the nearby Sage Creek Field. The reservoir rock is sandstone with a clay and calcareous cement. Both fields have produced naturally, but frequently require stimulation for economic rates.

The Belle Fourche Formation is not productive in the NGPP.

In south-central Montana the Frontier Formation produces in the Hardin Field, a stratigraphic trap. The Frontier Formation is a sandy shale with low porosities and permeabilities that requires stimulation. Drilling depths to the Frontier Formation are less than one thousand feet and gas pay thicknesses range from about 10 to 20 ft.

The Mowry Shale does not produce in the NGPP.

7. Summary of Fracture Treatments

The NGPP has natural gas fields which do not normally require stimulation to produce gas. These fields include those on the flanks of the Bearpaw Arch where the Judith River and Eagle Formations produce from sands with good porosities and permeabilities. Most prominent of these is the large Tiger Ridge Field in Hill and Blaine Counties, Montana. In this field, however, where trapping is primarily fault controlled and where water tables fluctuate widely in different fault blocks, hydraulic fracturing is required in one out of four wells. East of the Tiger Ridge Field, the original Bowdoin Field produced Bowdoin and Phillips gas naturally. However, on extending the field it became necessary to stimulate the zones in order to have commercial wells.

In southeast Montana, hydraulic fracturing is not normally necessary although recently it has been attempted with limited success by operators on some better developed sandstones in order to obtain commercial wells. Fracture treatments are small, averaging about 20,000 to 40,000 lb of 10-20 mesh sand.

8. Production from Low Permeability Gas Sands

The largest area in the NGPP which produces commercially from low permeability gas sandstones is the Bowdoin Field (part of the Bowdoin Dome), north-central Montana. All production in the Bowdoin area comes from four intervals: Eagle Formation, Bowdoin Member of the Carlile Shale, Upper Greenhorn lime unit, and Phillips Member of the Greenhorn Formation. Initially, production was established without having to fracture the wells. However, extension of the field required fracturing the formation to obtain a commercial well (100 MCFD or greater). Initial production figures vary widely around the field. Recent completions in the northwest part of the field have resulted in some of the largest production figures yet from the Bowdoin Dome area. Several wells produced almost 3,000 MCFD each from commingled Bowdoin, Phillips and Greenhorn intervals. Total fracture treatments in these wells ranged up to 100,000 lb of sand. Although the Canadian border limits field extension to the north, recent attempts to extend the field to the southeast have had limited success. A few wells to the southeast have produced close to 1,000 MCFD, while others have been well below 100 MCFD. Fracture treatments have been around 40,000 lb of sand.

A list of key wells in the Bowdoin Field area showing operators, fracture treatments, production figures, and other significant data is presented in Table 1.

West of the Bowdoin Field most of the production is from intervals requiring little or no stimulation. This is especially evident around the Bearpaw Arch with such large fields as Tiger Ridge and Bullwacker. The remaining areas of significant Upper Cretaceous gas production in the NGPP are south and southeast of the Bowdoin Field. The Liscom Creek and Pumpkin Creek Fields of Custer and Powder River Counties, Montana produce naturally from the Shannon Member of the Eagle Formation. Eastward, the Shannon Member also produces naturally from the West Short Pine Hills Field in Harding County, South Dakota. The Judith River and Eagle Formations produce on the Cedar Creek Anticline of Fallon County, Montana, however, there is very little current activity in the Cedar Creek area for shallow gas production. While early production was without stimulation, four recent tests were stimulated in the Judith River Formation: two tests proved marginally productive. These wells are listed in Table 2.

Table 1 Key Wells, Bowdoin Field, Phillips and Valley Counties, Montana

JOSEPH J. C. PAINE & ASSOCIATES/MONTANA UTILITIES GAS COMPANY No. 1

NW SE 3/36N/31E, 1,750 FSL 2,310 FEL. 1,700 Phillips test. Contr: Elenburg. Pl Base Map MB-5A. API 25-071-21502. FR 9/1/76. Spud 11/11/76. 7 @ 164 w/65, 4-1/2 @ 1,697 w/190. El: 2,621 KB. 1,721 TD. Perf 1,416-17, 1,423-24, 1,430-31, 1,435-36, 1,441-42, 1,447-48, 1,450-51, 1,456-57, 1,461-62, 1,472-73, 1,475-77, 1,479-80, 1,483-84, 1,491-94, 1,501-04, 1,510-11 w/1 pf. Fractured w/499 BW, 60,000 sd. Perf 1,609-15, 1,617-18, 1,641-46, 1,650-51, 1,656-61 w/1 pf. Fractured w/355 BW, 40,000 sd. Completed 4/23/77. IPF 2,585 MCFD. Producing Zones: Bowdoin 1,416-1,511 (gross), Greenhorn 1,609-1,618 (gross), Phillips 1,641-1,661 (Commingled).

SOUTHLAND ROYALTY 1-28-33NE FEDERAL

NW SW 28/33N/33E, 1,939 FSL 1,141 FWL. 1,350 Phillips. Contr: Elenburg. Pl Base Map MB-5A. API 25-071-21672. FR 11/22/78. Spud 12/1/78. 7 @ 158 w/65, 4-1/2 @ 1,269 w/130. El: 2,330 KB. Log Tops: Bowdoin 767, Greenhorn 1,100, Phillips 1,106. No cores or tests. 1,276 TD. Perf 1,106-17 w/1 pf. Acidized w/250 gal. Fractured w/14,658 gal wtr, 40,000 sd. Completed 12/3/78. IPF 564 MCFD, 32/64 ck. Producing Zone: Phillips 1,106-1,117.

MIDLANDS GAS 1 FEDERAL-2313

NE SW 23/31N/33E, 1,837 FSL 1,486 FWL. 1,700 Phillips test. Contr: Elenburg. Pl Base Map MB-5A. API 25-071-21623. FR 6/14/77. Spud 7/26/78. 7 @ 163 w/65, 4-1/2 @ 1,373 w/150. El: 2,432 KB. 1,397 TD. PB 1,120. Perf 976-994, 1,002-08 w/1 pf. Fractured w/12,936 gal emul, 40,000 sd. Perf 1,187-92, 1,198-1,202, 1,233-38, 1,242-44 w/1 pf. Completed 8/18/78. IPF 178 MCFD, 24/64 ck. Producing Zone: Bowdoin 976-1,008 (gross).

JOSEPH J. C. PAINE & ASSOCIATES 1-2406 KUKI

SE NW 24/30N/36E, 1,980 FNL 1,767FWL. 1,750 Phillips. Contr: KB. Pl Base Map MB-5A. API 25-105-21145. FR 6/27/78. Spud 10/23/78. 7 @ 199 w/80, 4-1/2 @ 1,600 w/165. El: 2,488 KB. No cores or tests. 1,770 TD. PB 1,590. Perf 1,461-62, 1,466-80, 1,485-86, 1,488-89, 1,492-93, 1,501-03 w/1 pf. Fractured w/357 BW, 40,000 sd. Completed 11/1/78. IPF 905 MCFD. Producing Zone: Bowdoin 1,461-1,503 (gross).

JOSEPH J. C. PAINE & ASSOCIATES 1-0296 FEDERAL

Lot 6, 2/29N/36E, 1,725 FNL 2,094 FWL, irregular section. 1,900 Phillips. Contr: KB. Pl Base Map MB-5A. API 25-105-21142 (well number changed from 1-0269). FR 6/26/78. Spud 6/3/78. 7 @ 157 w/75, 4-1/2 @ 1,738 w/185. El: 2,390 KB. Cored 550-575, recovered 17 (no description available). Cored 575-605, recovered 4 (no description available). Cored 835-854, recovered 16 (no description available). Cored 854-877, recovered 23 (no description available). Cored 877-881, recovered 14 (no description available). Cored 1,350-80, recovered 30 (no description available). Cored 1,380-1,410, recovered 30 (no description available). Cored 1,410-40, recovered 30 (no description available). Cored 1,440-70, recovered 12 (no description available). Cored 1,605-34, recovered 29 (no description available). Cored 1,636-64, recovered 30 (no description available). Cored 1,664-92, recovered 28 (no description available). Cored 1,692-1,722, recovered 30 (no description available). No tests. 1,779 TD. PB 1,423. Perf 536, 538, 541, 549, 551, 555, 557, 559 w/1 pf. Perf 823, 829, 831, 833, 835, 837, 839, 841, 847, 853, 855, 857 w/1 pf. Fractured w/279 BW, 40,000 sd. Perf 1,364-66, 1,368-70, 1,372-75, 1,377-89, 1,394-1,410 w/1 pf. Perf 1,589-96, 1,603, 1,608-20 w/1 pf. Perf 1,657-61, 1,664-75, 1,680-88, 1,690-94, 1,696-98, 1,702 w/1 pf. Fractured w/333 BW, 40,000 sd. Completed 11/2/78. IPF 85 MCFD. Producing Zones: Eagle 536-857 (gross), Bowdoin 1,364-1,410 (gross). Commingled.

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Table 2 Key Wells, Cedar Creek Field, Fallon County, Montana

PACER RESOURCES 11-36 STATE

C SW 36/5N/60E, 1,320 FSL 1,320 FWL. 1,600 Eagle test. Contr: Elenburg. Pl Base Map MB-21A. API 25-025-21114. FR 1/4/77. Spud 3/27/77. 7 @ 167 w/65, 3-1/2 @ 1,600 w/300. El: 3,021 KB. Log Tops: Judith River 885, Claggett 1,084, Eagle 1,322. No cores or tests. 1,600 TD. Perf 888-906, 956-960, 970-976 w/1 pf. Sand Fractured w/31,000 sd. Perf 1,434-37, 1,444-47, 1,478-82, 1,487-91, 1,500-03, 1,506-10 w/1 pf. Completed 4/12/77. IPF 60 MCFD. Producing Zones: Judith River 88-976 (gross), Eagle 1,434-1,510 (gross). Commingled.

PACER RESOURCES 11-7 BN

SW SW 7/6N/61E, 1,280 FSL 1,130 FWL. 2,000 Eagle test. Contr: Elenburg. Pl Base Map MB-21A. API 25-025-21120. (Spot changed from C SW, ftg changed from 1,320 FSL 1,320 FWL). FR 3/29/77. Spud 4/18/77. 7 @ 155 w/65, 3-1/2 @ 1,750 w/300. El: 2,994 KB. Log Tops: Judith River 970, Eagle 1,374. No cores or tests. 1,750 TD. Perf 1,025-31, 1,036-42 w/2 pf. Sand Fractured w/31,000 sd. Completed 5/5/77. IPF 40 MCFD. Producing Zone: Judith River 1,025-1,042 (gross).

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9. Western Gas Sands Project Core Area

The NGPP includes 225,000 square miles in Montana, North Dakota, South Dakota and Wyoming, all of which contain sections of interest to the WGSP Core Program. Drilling depths to the objective core sections vary somewhat throughout the province, but are relatively shallow (less than 5,000 ft) compared to the much greater depths in the sedimentary basins of Wyoming, Colorado, and Utah. Drilling depths to reach objective sections (Carlile and Greenhorn) north and west of the Tiger Ridge Field are less than 2,500 ft. East of the Tiger Ridge area around the Bowdoin Dome the objective section extends into the Mowry Shale and possibly the Muddy Sandstone. Drilling depths to reach the Muddy Sandstone range from 2,500 to 3,000 ft. In southeast Montana, the objective sections include the Niobrara and Greenhorn Formations. Drilling depths to reach the deeper Greenhorn Formation are around 4,000 ft, diminishing significantly toward the Black Hills Uplift. On the Cedar Creek Anticline, depths to the Eagle Formation are less than 1,500 ft, but deepen significantly off structure.

In North and South Dakota, the Niobrara section is of primary interest. Depths to the Niobrara Formation in the center of the Williston Basin are near 4,000 ft, although shallower depths can be expected further eastward out of the basin.

10. Completed Coring Jobs

One well has been cored in the NGPP for the WGSP prior to the completion of this report. This well is located in section 2, T29N, R36E, Valley County, Montana, southeast of the Bowdoin Field and is listed in Table 1. Two hundred ninety-three feet (293 ft) of 2-1/2 in. core was recovered during July, 1978. Cored intervals include the Eagle, Carlile (Bowdoin) and Greenhorn (Phillips) Formations. A comprehensive suite of geophysical well logs (dual induction-laterolog, proximity-microlog, neutron, density and sonic) was run on this well. Final results of this operation are still pending; the data will be released upon completion of analyses by the USGS, Los Alamos Scientific Laboratories, and the Bartlesville Energy Technology Center of the DOE. Core Laboratories, Inc., however, has provided data on porosities, permeabilities, saturations and grain densities.

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