PETROLEUM POTENTIAL OF THE LITTLE MISSOURI NATIONAL GRASSLANDS

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REPORT OF INVESTIGATION 91
NORTH DAKOTA GEOLOGICAL SURVEY

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John P. Bluemle, Acting State Geologist

1991

Sign at the Little Missouri National Grasslands boundary off I-94 at the Fryburg Exit. Photograph courtesy of M. Ray.

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INTRODUCTION

This report condenses an open-file report completed in early 1990 by the North Dakota Geological Survey evaluating the hydrocarbon potential of the Little Missouri National Grasslands (LMNG) for the U. S. Forest Service. The study was completed under two contracts. The first contract, Number 40-0343-9-7031 reviewed the petroleum geology, summarized the exploration history, and identified existing wells, oil fields, and enhanced recovery projects in the study area. It also identified the hydrocarbon occurrence potential and forecast the reasonably foreseeable development in the LMNG. The second contract, Number 40-0343-0-7019 estimated the area and recoverable reserves of existing oil and gas pools and estimated the number of undiscovered pools in the study area. The original report is on file and available to the public at either the North Dakota Geological Survey in Bismarck, North Dakota or at the supervisor's office of the Custer National Forest in Billings, Montana.

1:A OVERVIEW OF THE PETROLEUM GEOLOGY OF THE NORTH DAKOTA PART OF THE WILLISTON BASIN

INTRODUCTION

Deposition occurred during each Phanerozoic period in the Williston Basin (Fig. 1). The Phanerozoic sedimentary record shows major cycles of rapid marine transgression followed by slower marine regression. These cycles are the sequences described by Sloss (1963).

Most of the hydrocarbons produced in the Williston Basin are from Paleozoic rocks. Some Triassic sands produce oil in the northeastern Williston Basin and some Cretaceous sands produce natural gas in the southern Williston Basin. Natural gas was produced from Cretaceous sands in Dickey and LaMoure Counties, and from glacial drift in Bottineau County during the late 1890's to early 1900's.

SEQUENCE STRATIGRAPHY

BASEMENT ROCKS (Precambrian)

Initial Phanerozoic deposition occurred on a weathered surface of Precambrian rocks. Precambrian geology is complex, consisting of many "juxtaposed, fault-bounded lithostructural domains" (Peterman and Goldich, 1982, p. 12). Green et al. (1985, p. 624) suggested that the basement rocks in western North Dakota formed in an orogenic belt, called the Trans-Hudson Orogen, that was either an "island arc and associated fore-arc or back-arc basin", between the Archean Superior and Wyoming Provinces (Fig. 2). One well in Newporte Field produced oil from fractured Precambrian rocks.

SAUK SEQUENCE (Cambrian-Lower Ordovician)

The Deadwood Formation records both the earliest sedimentation in the Williston Basin and the beginning of the Sauk Sequence. Transgression was from the west into an embayment on the edge of the Cordilleran shelf (Carlson, 1960; Lochman-Balk, 1972). Deposition of siliciclastic sediments dominated Cambrian time. By Early Ordovician time deposition of carbonate sediments was occurring in the center of the basin. The Williston Basin had formed and begun to subside by the end of the Sauk Sequence (LeFever et al., 1987). The Deadwood Formation is productive along the Nesson Anticline and in Newporte Field.

TIPPECANOE SEQUENCE (Ordovician-Silurian)

During the Tippecanoe Sequence the Williston Basin was connected to the

STRATIGRAPHIC COLUMN

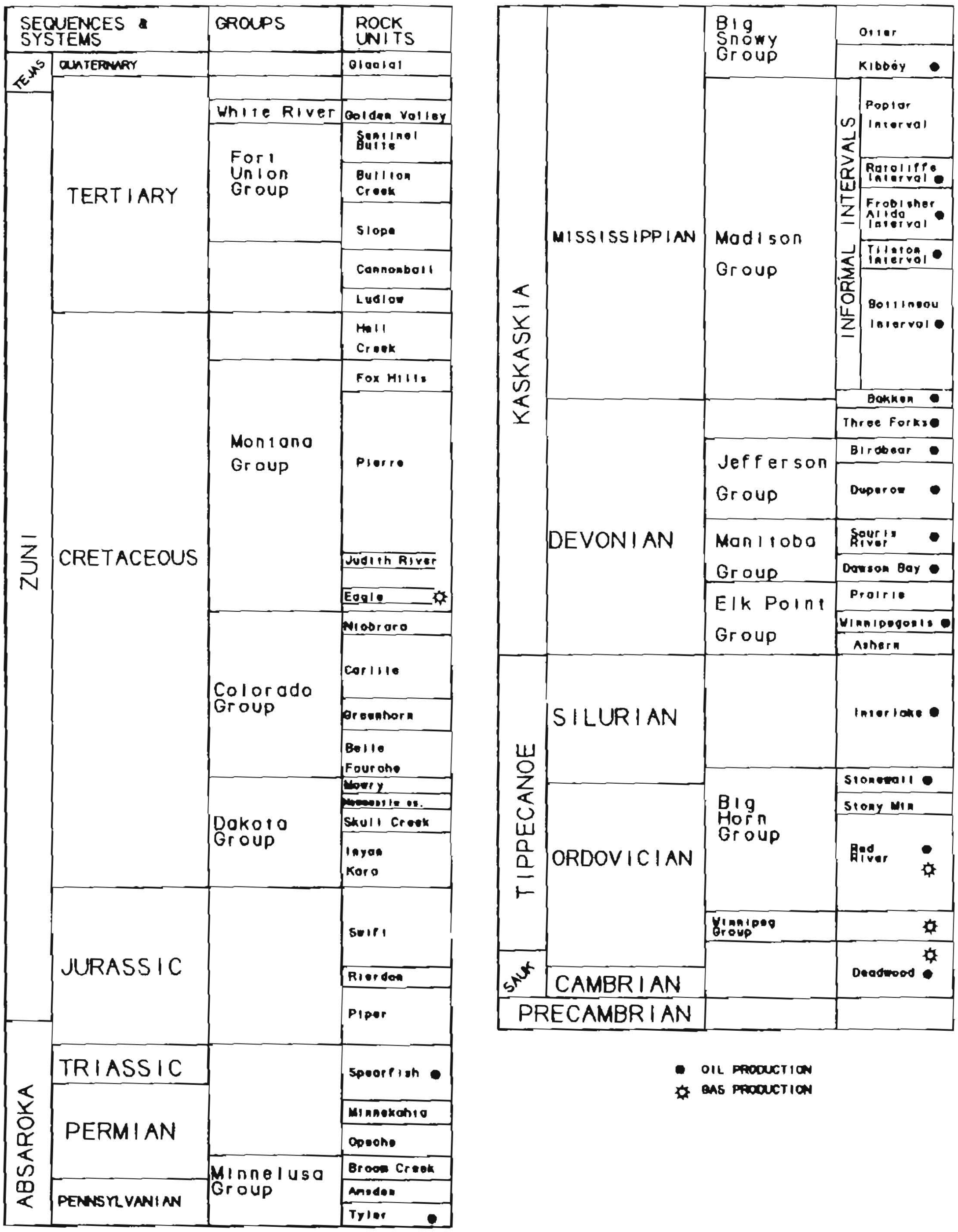

Figure 1. Generalized stratigraphic column of the North Dakota portion of the Williston Basin.

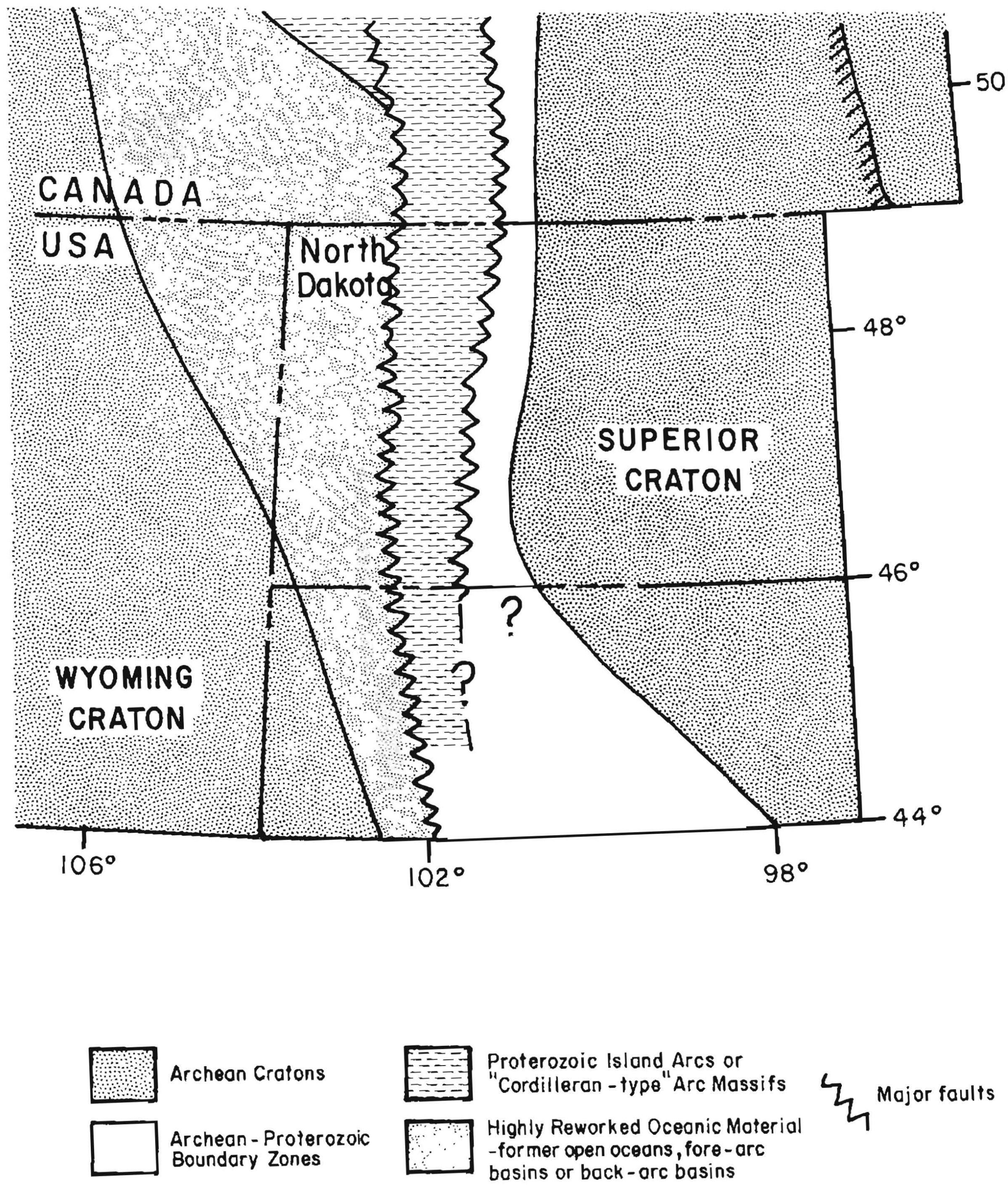

Figure 2. Generalized Precambrian tectonic provinces in North Dakota (modified from Green et al., 1985).

ocean through a southwest seaway and a second, southeast seaway over the Trans-Continental Arch (Fig. 3a). At the base of the Tippecanoe Sequence lies the Winnipeg Group consisting of the Black Island, Icebox, and Roughlock Formations. The Group was deposited in marginal to shallow marine environments. The Black Island Formation has two members (Thompson, 1984): a lower arenite and shale, and an upper quartz arenite. The Icebox Formation is an organic-rich green shale and is thought to be a source rock for Lower Paleozoic reservoirs (Dow, 1974; Williams, 1974). The Roughlock Formation is predominantly a nodular limestone and is transitional with the Red River Formation (LeFever et al., 1987). The Winnipeg Group is productive on the Nesson Anticline and on the Heart River Anticline at Richardton and Taylor Fields in eastern Stark County. Gas production from Black Island sands dominates both occurrences.

The Red River Formation lies at the base of the Big Horn Group and conformably overlies the Roughlock Formation. An informal lower member consisting of a fossiliferous and selectively dolomitized limestone comprises the lower two-thirds of the formation (Carroll, 1979). An informal upper member includes four dolomitized porosity zones, the 'D', 'C', 'B', and 'A' zones. The 'D' zone was deposited in a subtidal to intertidal environment and the three overlying zones in a supratidal environment (Carroll, 1979). Thin argillaceous carbonates or anhydrites generally overlie the porosity zones across most of North Dakota. The Red River Formation is productive in the deeper part of the basin. Most Red River production is associated with structural closures, although the best porosity is not always coincident with the structure's crest (Longman et al., 1983).

The Stony Mountain Formation conformably overlies the Red River Formation and is comprised of interbedded calcareous shales and argillaceous limestones. The Stony Mountain Formation is rarely productive, but where it is productive it is always associated with a Red River structure.

The Stonewall Formation is the uppermost formation in the Big Horn Group and conformably overlies the Stony Mountain Formation. The formation was deposited during Ordovician and Silurian time and consists mainly of dolomites and limestones, with thin anhydrite beds near the basin center. Production from the Stonewall Formation is rare and is usually associated with Red River structures.

The Interlake Formation conformably overlies the Stonewall Formation and records latest Tippecanoe Sequence deposition. Interlake lithologies are dominated by dolomitic mudstones and dolomites. The Interlake Formation was exposed from Late Silurian through Early Devonian and karst topography was formed.

Various interpretations have been made of Interlake stratigraphy. LoBue (1983) informally subdivided the Interlake Formation into three members and interpreted the formation to record a sequence of sublittoral to supralittoral environments. LoBue also recognized paleosols in the Interlake and interpreted them to record periods of prolonged subaerial exposure (LoBue, 1983).

Megathan (1987) assigned group status to the Interlake and defined eight formations within it. Megathan interpreted the Interlake Group as sediments deposited in a succession of hypersaline (lower Interlake) to freshwater (upper Interlake) environments. In contrast, Inden et al. (1988, p. 293) considered the Interlake to be a formation and interpreted it as many "low-energy shallowing-upward, restricted-marine cycles." This report follows the terminology of LoBue (1983).

The upper Interlake Formation is productive along large structures but the controls on production are not well understood. Salt-plugged porosity degrades reservoir performance in some

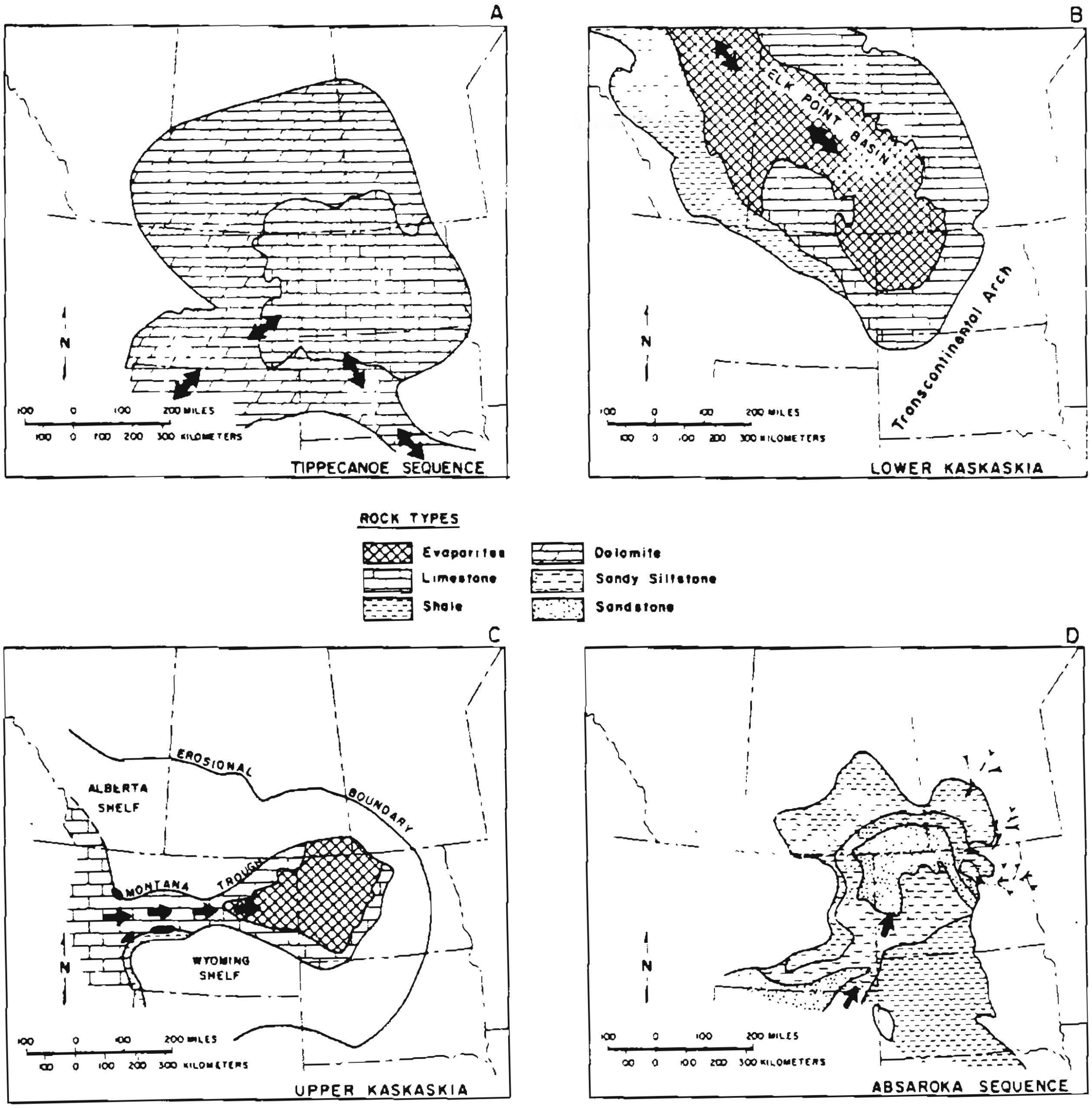

Figure 3. Sequential map series with the Marine Communication directions shown during the Tippecanoe, Lower and Upper Kaskaskia, and Absaroka Sequences (Gerhard et al, 1982) reprinted with permission from AAPG.

places, and fracturing has enhanced performance in others. The middle Interlake Formation is marginally productive in two fields in Stark County. The lower Interlake Formation produces from two porosity zones, informally named the Salsbury and the Putnam. Presently, these two porosity zones produce on major structures in North Dakota.

KASKASKIA SEQUENCE (Devonian-Mississippian)

Deposition of Kaskaskia Sequence rocks in the Williston Basin occurred during two transgressive cycles. Therefore the sequence is divided into two parts. Limestones dominate the Kaskaskia Sequence record, although two major evaporite sections are preserved.

LOWER KASKASKIA SEQUENCE

The initial Kaskaskia Sequence transgression was from the northwest (Fig. 3b) out of the Elk Point Basin. At the base of the sequence is the Ashern Formation. Lobdell (1984) divided the formation into lower red and upper gray dolostone members. The lower member formed in a restricted marine environment, whereas the upper member records a change to a less restricted environment. Both nodular and bedded anhydrite are present throughout the Ashern, but are more common in the lower member. The Ashern Formation is non-productive in North Dakota.

The Winnipegosis Formation conformably overlies the Ashern Formation and is dominantly a limestone. In northwestern North Dakota Winnipegosis deposition occurred in the slowly subsiding Elk Point Basin (Fig. 4). Elsewhere in the state, deposition occurred on a broad stable platform (Ehrets and Kissling, 1987). In the Canadian portion of the Williston Basin, the Winnipegosis Formation produces from pinnacle reefs. Commercial production has been established in North Dakota along the platform margin at Temple and Hamlet Fields and on the platform in Round Prairie Field. Platform margin fields produce from argillaceous carbonates deposited in basin-slope facies; platform fields produce from patch reefs (Ehrets and Kissling, 1978).

During latest Winnipegosis deposition, the basin became restricted and eventually halites of the Prairie Formation were deposited. With time, salt deposition spread onto the basin margins and eventually covered the reefs (Kerr, 1988). Dissolution of the Prairie salt is an important local trapping mechanism in the Williston Basin. Beds draped across dissolution edges enhanced closure in many fields such as Glenburn, Sherwood, and Wiley Fields, while two-stage salt dissolution formed the "Nisku Reefs" of northeastern Montana.

When the northern seaway into North Dakota reopened, the Dawson Bay Formation was deposited on a stable, low-relief shelf in a normal to slightly restricted marine environment. In northwestern North Dakota, stromatoporoid-dominated patch reefs formed on an open platform (Dean, 1982). Evaporites in the upper Dawson Bay Formation record renewed restriction of the seaway into the Williston Basin. The Dawson Bay Formation is productive in two fields in North Dakota. At Dolphin and Temple fields, porous carbonates pinch out updip on a structural nose (Dean, 1982; Heck, 1987).

The Souris River Formation conformably overlies the Dawson Bay Formation and is lithologically similar to it. The Souris River Formation produces oil from one well in Dolphin Field. Production from the Souris River Formation along the Nesson Anticline was pooled with production from the Duperow Formation (Pilatzke et al, 1987).

The Duperow Formation conformably overlies the Souris River Formation and consists of repetitive shoaling-upwardsequences (Wilson, 1967; Pilatzke et al, 1987). Each sequence

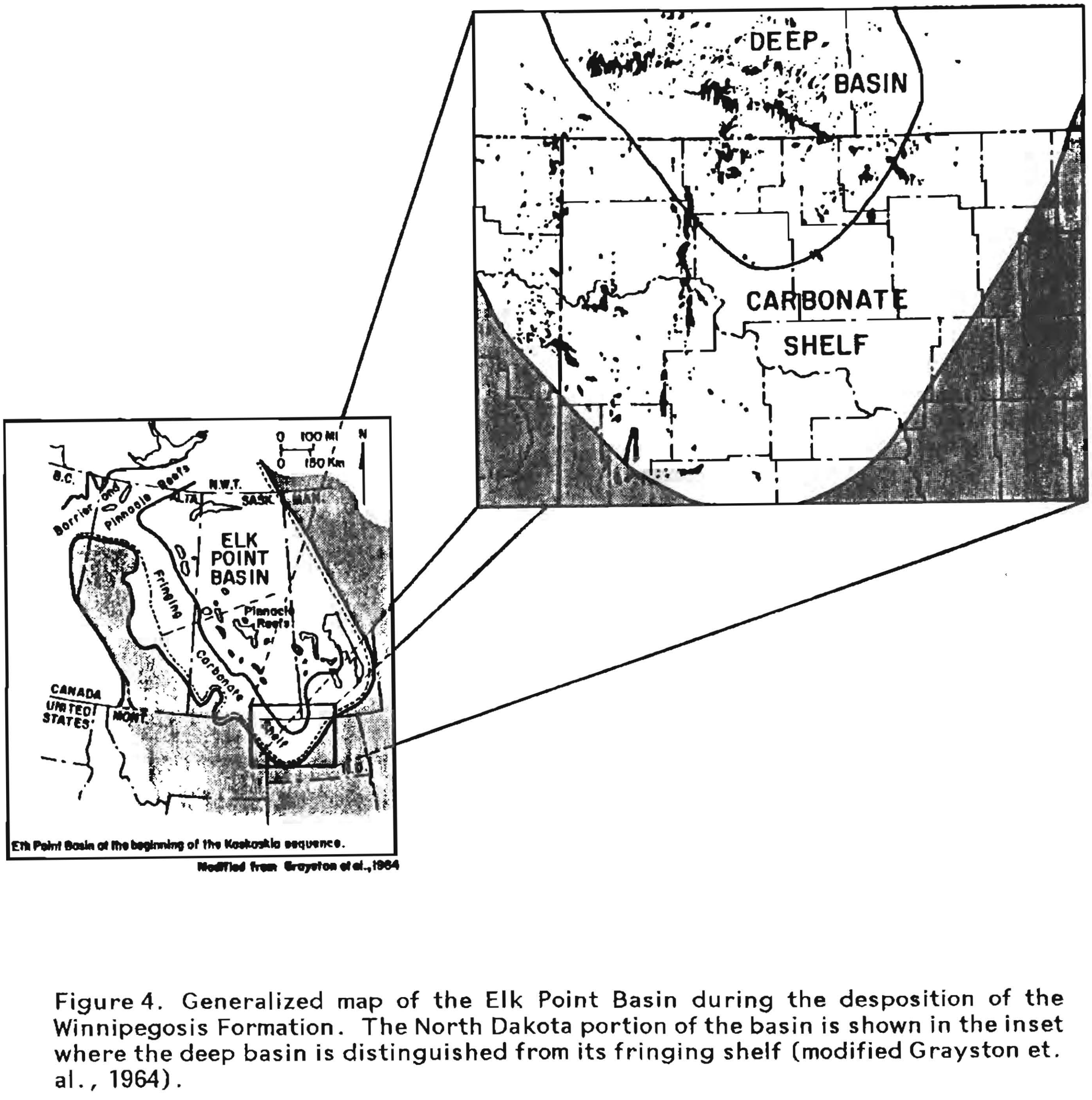

Figure 4. Generalized map of the Elk Point Basin during the desposition of the Winnipegosis Formation. The North Dakota portion of the basin is shown in the inset where the deep basin is distinguished from its fringing shelf (modified Grayston et. al., 1964).

includes rocks deposited in a lower subtidal, middle intertidal, and upper supratidal environment. The Duperow Formation produces from stratigraphic traps in the central Williston Basin, from structural traps along the Nesson Anticline, and from combination traps on the Billings Nose. The Duperow Formation also produces on the eastern flank of the Cedar Creek Anticline, where truncated porous carbonates are capped by Englewood Formation equivalents.

The Birdbear Formation (Nisku Formation of some workers) conformably overlies the Duperow Formation. Loeffler (1982) described the Birdbear Formation as fossiliferous limestones and dolomitic muddy limestones deposited in shallow marine to supralittoral environments. The Birdbear Formation produces from stromatoporoid banks, amphiporid back-bank facies, or locally dolomitized porosities. The Birdbear Formation is productive from small structures along the Nesson Anticline and elsewhere, along the east flank of the Cedar Creek Anticline, and from two-stage salt dissolution structures in northeastern Montana.

The Three Forks Formation conformably overlies the Birdbear Formation. Three Forks sedimentation occurred in shallow marine to supratidal depositional environments in a shallow epeiric sea (Dumonceaux, 1984). The Three Forks Formation is primarily a micrite to dolomicrite interbedded with anhydrite. An informal unit called the Sanish sand is locally developed at the top of the Three Forks Formation and is the primary producing horizon in Antelope Field.

The Bakken Formation conformably overlies the Three Forks Formation in the basin center, and unconformably overlies it elsewhere (Webster, 1984). Gerhard et al. (1982) interpreted the Bakken Formation as a record of the initial phase of upper Kaskaskia Sequence deposition. Recent work by Schmoker and Hester (1982) showed the depositional pattern of the Bakken Formation to be coincident with the Elk Point Basin. Therefore, we include the Bakken Formation in the lower Kaskaskia Sequence.

The Bakken Formation has three informal members, an upper and a lower black, organic-rich shale, and a middle arenaceous limestone to siltstone. Depositional environments interpreted for the Bakken Formation have ranged from deep marine to terrestrial (Webster, 1984).

The Bakken Formation is an excellent source rock and is considered to be the source rock for most reservoirs in Mississippian rocks in the Williston Basin (Dow, 1974; Webster, 1984; Price et al., 1984). Recent work has shown that the Lodgepole Formation was the source of some of that oil (Osadetz and Snowdon, 1986). The Bakken Formation is itself productive on, and next to, the Nesson Anticline, and along its southwestern depositional limit in Golden Valley and Billings Counties. The Bakken Formation has poor matrix permeabilities but produces where overpressured and fractured.

UPPER KASKASKIA SEQUENCE

Deposition of upper Kaskaskia Sequence sediments began sometime during the early Lodgepole. The Williston Basin was by then separated from the Elk Point Basin and transgressions occurred eastward through the Central Montana Trough (Fig. 3c).

The Madison Group comprises three formations, the Lodgepole, Mission Canyon, and Charles. These formations are conformable in the basin center but exhibit complex intertonguing relationships along the basin margins (Fig. 5). Most workers divide the Madison Group into five informal, wireline log-defined, intervals. In ascending order, they are the Bottineau, Tilston, Frobisher-Alida, Ratcliffe, and Poplar intervals (Fig. 5).

The Lodgepole Formation (Bottineau

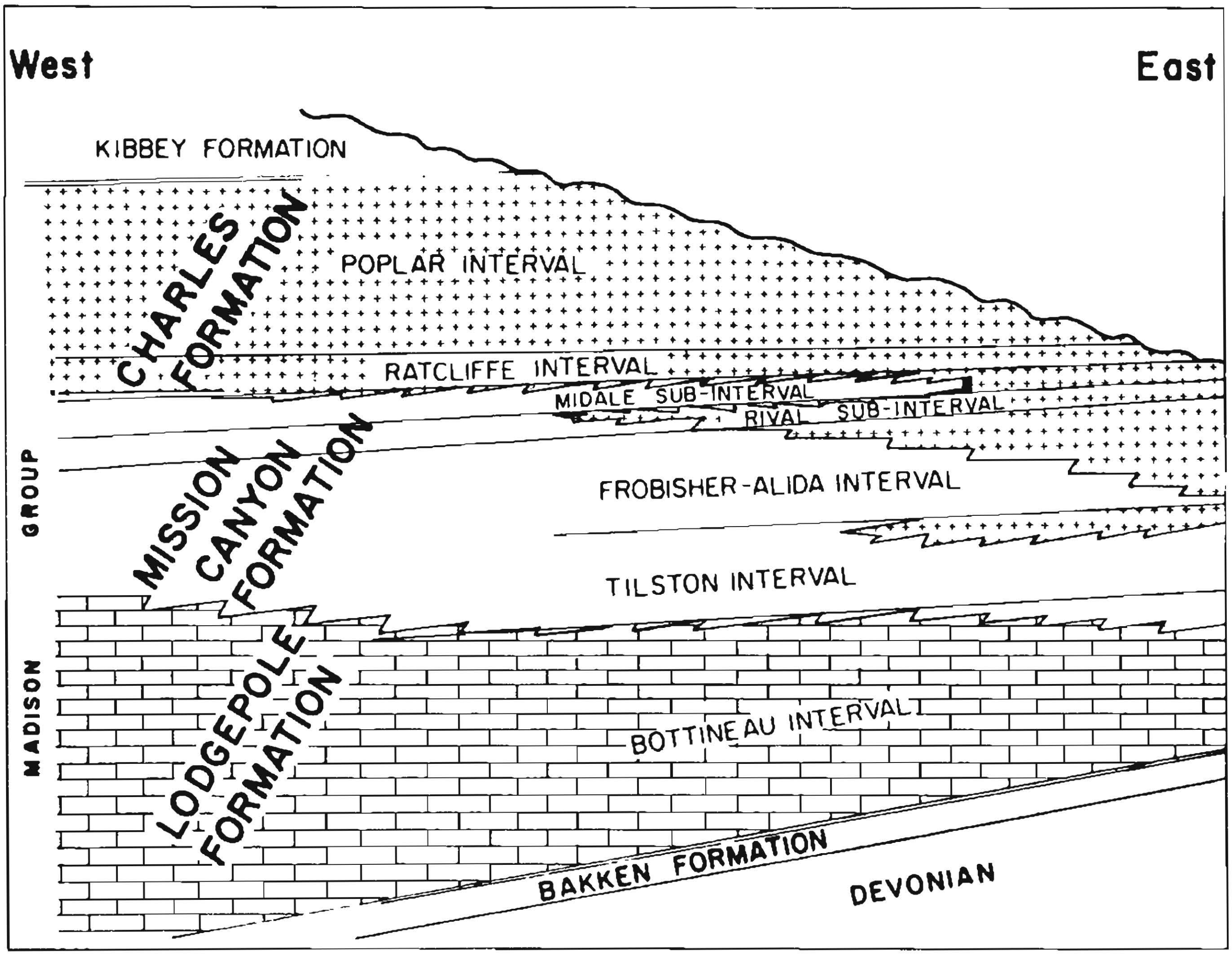

Figure 5. Generalized cross-section of Mississippian strata in the Williston Basin. (Gerhard et al, 1982) Reprinted with permission from A.A.P.G.

interval) conformably overlies the Bakken Formation in the basin center and unconformably onlaps Upper Devonian formations in eastern North Dakota and along the Cedar Creek Anticline. The Lodgepole Formation consists of limestones and dolomites deposited in normal marine to restricted shelf environments (Heck, 1979). Bjorlie and Anderson (1978) identified a system of lower Lodgepole Waulsortian bioherms in eastern North Dakota.

The Lodgepole Formation is a major producing horizon in Manitoba, but no significant production exists in North Dakota. A middle Lodgepole porosity has been productive in four Williams County wells, although production from this zone was uneconomic (LeFever and Anderson, 1984). Shale beds and argillaceous limestones in the lower Lodgepole may be an important petroleum source rock (Osadetz and Snowdon, 1986).

The Mission Canyon Formation (Tilston and Frobisher-Alida intervals) consists primarily of limestones interbedded with anhydrites and dolomites. Deposition occurred in environments that ranged from open marine to coastal sabkha and record a regressive sequence (Lindsay, 1988). The Frobisher-Alida interval encompasses most of the Mission Canyon Formation and has produced more oil than any other stratigraphic unit in the Williston Basin. The Frobisher-Alida interval has been subdivided into eight informal porosity zones. In ascending order they are the Landa, Wayne, Glenburn, Mohall, Sherwood, Bluell, Coteau, and Dale (Fig. 6) (Harris et al., 1966; Voldseth, 1986).

The Charles Formation (Ratcliffe and Poplar intervals) is primarily interbedded evaporites and limestones, and was deposited in a restricted marine environment. The Charles Formation records a major marine regression during deposition of the upper Kaskaskia Sequence.

Lindsay (1988) and Hendricks (1989) identified four main types of Mission Canyon traps:

1) combination structural and stratigraphic traps;
2) porous carbonate (usually an island or shoal) pinching out updip into impermeable (intertidal or inter-island) carbonate;
3) porous carbonate facies changing updip into impermeable anhydrite;
4) truncated porous carbonate capped by impermeable Triassic rocks.

Approximately 65% of the oil produced in North Dakota has come from the Charles and the Mission Canyon Formations.

Latest Kaskaskia Sequence deposition is recorded by the Kibbey and Otter Formations. Both formations consist of interbedded sandstones, shales and limestones. The clastic rocks had an extra-basinal source and "mark the influence of the Ancestral Rocky Mountain orogenic event" (Gerhard et al., 1982, p. 998). The Kibbey Formation is productive along the Weldon Fault in Montana and from one well in Red Wing Creek Field, North Dakota. Shales in the Otter Formation are considered to be the source rocks for lower Absaroka Sequence reservoirs (Dow, 1974). In central North Dakota, the unconformity at the top of the Kaskaskia Sequence truncated only the Otter Formation. Elsewhere, variable amounts of Kaskaskia Sequence strata are missing.

ABSAROKA SEQUENCE

During Absaroka deposition, marine transgressions were from the southwest (Fig. 3d). Deposition was concurrent with tectonic activity west of the Williston Basin. Interbedded marginal marine evaporites, and terrestrial rocks record sedimentation within the basin.

Deposition of the Tyler Formation (Pennsylvanian) occurred in a slowly subsiding basin and marked the beginning of the Absaroka Sequence. Sturm (1982) divided the Tyler Formation into two

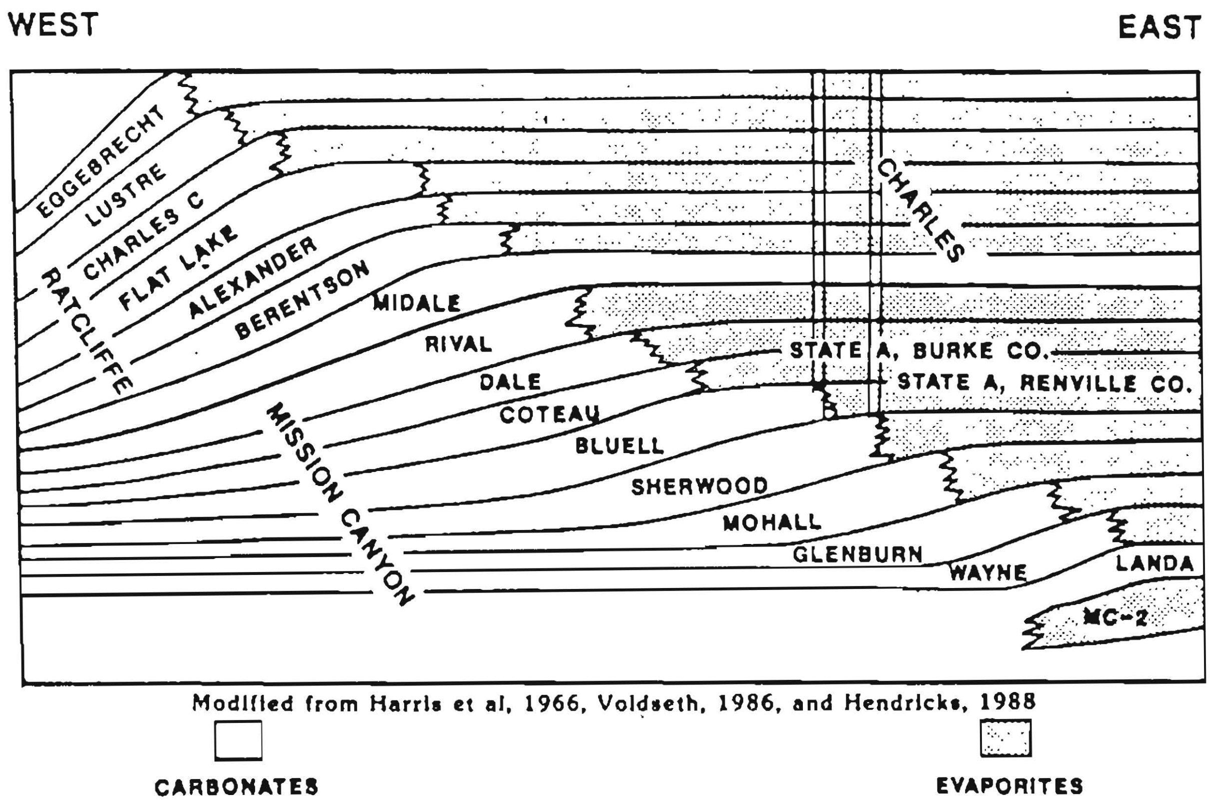

Figure 6. Diagrammatic cross-section of the Mississippian strata in the Williston Basin that illustrates the stratigraphic relationships (modified from Hendricks, 1989).

informal units, a lower unit of interbedded shales, mudstones, and sandstones and an upper unit of interbedded limestones, calcareous mudstones, and anhydrites. Sturm interpreted the lower unit to record the progradation of a delta and the upper unit to record the development of a barrier island. The latter is capped by rocks deposited in lagoonal and estuarine environments. The Tyler Formation produces oil from both the barrier island and from channel-fill sandstones.

The youngest oil-producing formation in North Dakota is the Spearfish Formation (Triassic) that unconformably overlies the Madison Group across much of eastern North Dakota. The Spearfish Formation is productive where oil has migrated into it from the Madison.

1:B HISTORICAL OVERVIEW OF OIL AND GAS EXPLORATION IN NORTH DAKOTA

Oil and gas exploration in North Dakota has been cyclical with three cycles of exploratory drilling since 1951 (Fig. 7). Drilling in North Dakota now appears to be in a phase similar to that at the start of the third cycle.

North Dakota's first drilling cycle began in 1951 with the discovery of oil in Williams County. Subsequent drilling defined the Nesson Anticline, a 75-mile-long structure with nearly continuous production from multiple pay zones. Two major plays identified in 1953 and 1954 are the Mississippian subcrop play in north-central North Dakota and the Mississippian/Pennsylvanian play in southwestern North Dakota. By 1960, the first cycle had ended. Activity during the early 1960's was primarily development and extension drilling.

The second drilling cycle was in full swing by 1968 following the discovery of shallow Cretaceous oil at Bell Creek Field in the northeastern Powder River Basin. This cycle records the greatest level of drilling for Cretaceous targets in North Dakota, and is an obvious response to an extra-basin stimulus by the oil industry. Oil was discovered in the Red River Formation in Bowman County and the Bakken Formation in Billings County during cycle 2. Both discoveries are important influences on cycle 3 and later drilling. Proven Red River Formation production encouraged operators to drill to the Red River Formation elsewhere thus testing most of the Paleozoic section. The Bakken play is presently one of the most significant plays in the LMNG and was important during cycle 3.

The third exploratory cycle began in the mid-1970's and was the most intensive of the three. Hundreds of new fields and pools were discovered at this time with much of the drilling being concentrated in west-central North Dakota (Fig. 8). The intensity of this cycle was the result of many factors. Two of them were the 1972 discovery of Red Wing Creek Field and the 1973 Arab oil embargo.

Red Wing Creek Field is structurally complex, with a pay section greater than 1000 feet thick. The discovery of this field initiated a major lease play in western North Dakota. Geological and geophysical programs were completed over many of these leases when in 1973, the oil embargo focused industry attention on domestic exploration. During the cycle, no new Red Wing Creek Fields were found, but the rapid escalation of oil prices made almost any discovery economical. Some of the largest fields discovered during this cycle are Mondak Field, Little Knife Field, and the Billings Nose complex. These fields produce primarily from Mississippian reservoirs, though all produce from multiple pays. The collapse of oil prices in 1986 brought a rapid and devastating conclusion to cycle 3.

Cycle 3 saw the first Bakken Formation play. Previously, Bakken completions were primarily for salvage until several Billings County completions

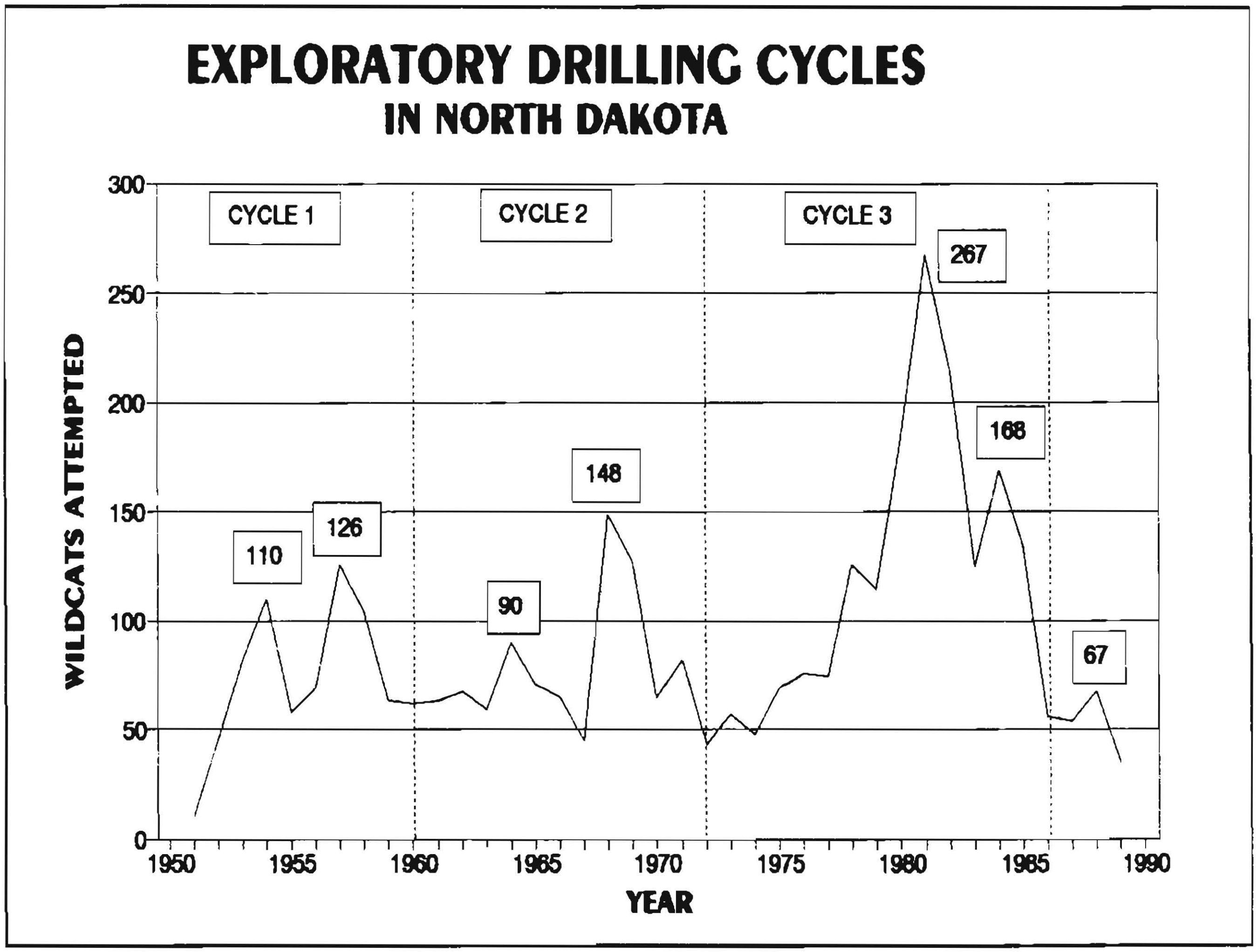

Figure 7. Line graph of the number of wildcat wells drilled per year since 1951 in North Dakota with the three exploratory drilling cycles shown.

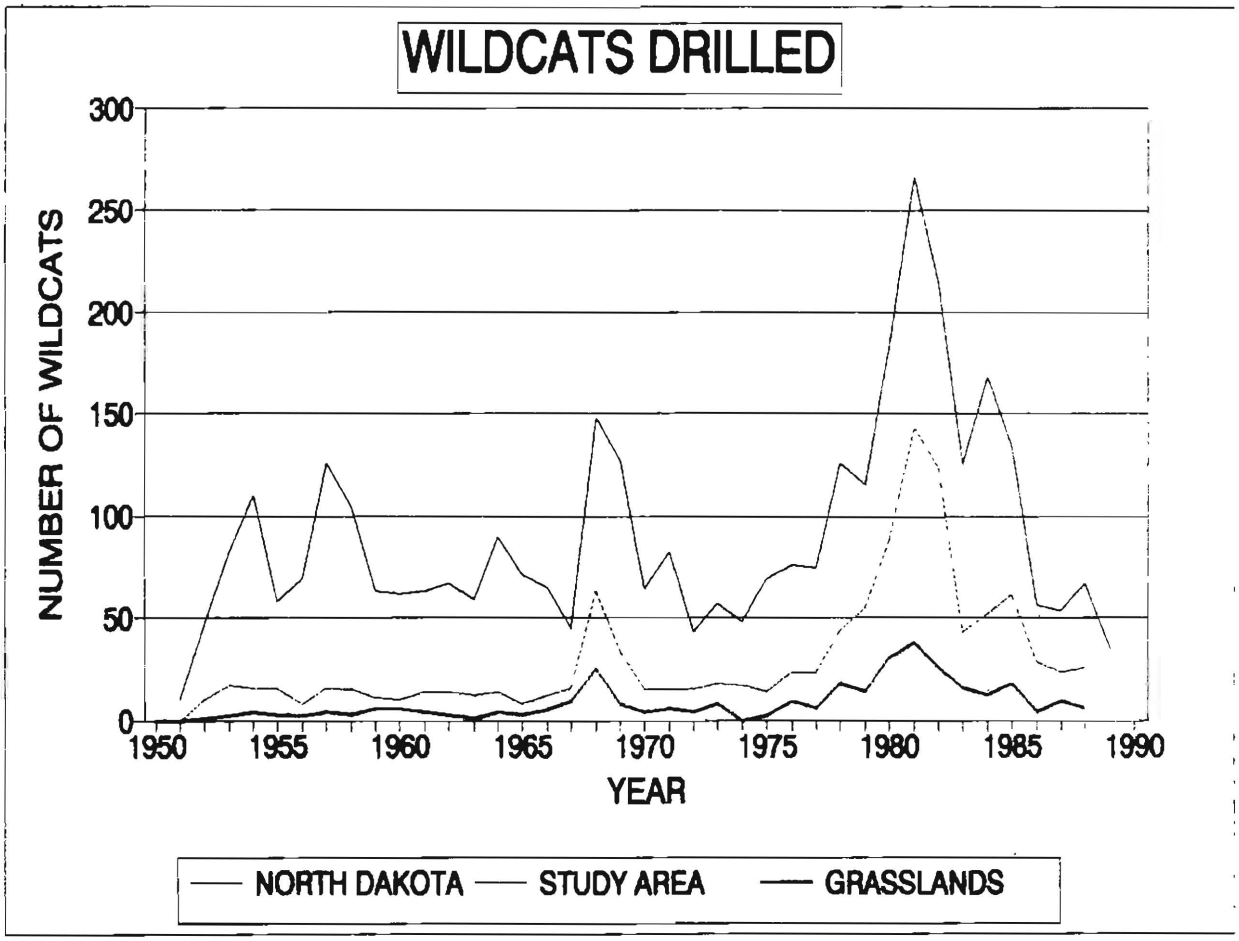

Figure 8. Line graph of the number of wildcat wells drilled per year since 1951 in North Dakota in the study area, and on the LMNG. Graph shows a similar pattern in all three areas.

with high initial potentials focused attention on the formation in the early 1980's. Development of Bakken reservoirs occurred in Elkhorn Ranch, Buckhorn, and Devil's Pass Fields.

North Dakota is presently in a similar situation to that at the start of cycle 3 when a significant new discovery preceded a drilling boom. The discovery of a productive Winnipegosis reef at Tablelands Field in Saskatchewan immediately north of the border, initiated a lease play in Burke, Divide, and Mountrail Counties. Elsewhere, the successful completion of horizontally drilled Bakken wells initiated an intense leasing and drilling program across much of western North Dakota.

Activity in the Winnipegosis play has been sporadic and unsuccessful in North Dakota. In contrast, the Bakken play is active with several companies operating multiple-rig drilling programs. Most of the activity is centered on Billings and McKenzie Counties despite recently drilled wildcats elsewhere.

In summary, Cycle 1 drilling mainly explored for reservoirs along the Nesson Anticline. Cycle 2 activity reflected the northward extension of the Bowman County Red River play and the influence of the discovery of Bell Creek Field. Cycle 3 drilling was concentrated in the central basin for deep multiple-pay targets. The cycle ended when oil prices plummeted during 1986. Two recent discoveries have placed North Dakota in a similar position to that immediately before cycle 3.

CHRONOLOGY OF MAJOR EVENTS IN NORTH DAKOTA

1890's	First reported production of hydrocarbons in North Dakota.
	-Natural gas in artesian wells (Cretaceous) near Edgeley, North Dakota (Dickey, LaMoure, Stutsman Counties).
1910's	Shallow gas produced from glacial till near Mohall.
1929	Cedar Creek Cretaceous gas play extends into Bowman County.
1951	Discovery of oil on the Nesson Anticline.
1953	Definition of the stratigraphic play in Bottineau & Renville Counties.
	-discovery of Madison oil in the Fryburg area, Billings County.
1954	Discovery of Tyler oil in the Fryburg area, Billings County.
1957	Burke County Madison play active.
1958	Oil discovered on the North Dakota portion of the Cedar Creek Anticline.
1961	Elkhorn Ranch Field Bakken pool discovered.
1967	Red River play in Bowman County.
1972	Red Wing Creek Field discovered.

1976	Mondak Field discovered.
1977	Little Knife Field discovered.
1978	Billings "Nose" Anticlinal Complex discovered.
1987	Winnipegosis reef lease play.
1988	Bakken horizontal drilling play.

2:A A HISTORICAL COMPARISON BETWEEN OIL AND GAS EXPLORATION IN THE LITTLE MISSOURI GRASSLANDS AND NORTH DAKOTA

Cyclicity in exploration is evident in the Little Missouri National Grasslands (LMNG). Exploratory activity has mirrored that in the rest of the state (Figs. 7 & 8). In the study area, cycle 1 activity was subdued and centered on the Nesson Anticline. At the peak of cycle 1 in 1957, 126 wildcats[1] were drilled in North Dakota (Fig. 7). Of those, 16 (13.5%) were in the study area[2] and 4 of the 16 (25%) on the LMNG. Activity was greatest in T.139N. and north where 11 of the 16 (69%) wildcats were drilled. The Madison Group was the most popular target in both the state and the study area.

Cycle 2 is unusual because most of the activity occurred in the southern LMNG. In 1968, at the peak of cycle 2, 63 of the 148 (43%) wildcats drilled in the state were located in the study area. Most of the study area wildcats attempted to extend the Cretaceous oil play from Bell Creek Field into North Dakota. Of the 63 study area wildcats, 25 (40%) were located on the LMNG and 43 of the 63 (68%) were south of T.139N. Many of the other wildcats were attempts to extend the Red River play northwards out of Bowman County.

Activity in both the study area and the LMNG peaked during cycle 3. During 1981, 267 wildcats were drilled in North Dakota and 143 (54%) of them were in the project area. Of the 143 wildcats, 38 (27%) were on the LMNG and only 11 (8%) were south of T.139N. The primary target was Madison Group reservoirs, although many tested the Red River Formation.

2:B FUTURE OIL AND GAS EXPLORATION TRENDS IN THE LITTLE MISSOURI NATIONAL GRASSLANDS FOR THE NEXT 5 TO 10 YEARS

For the next three to five years, the Bakken Formation will be the primary target in the study area and most of the tests will be horizontal wells. Drilling and completion technologies will continue to improve. A new fracture technique used by Canadian Hunter Ltd. to stimulate a horizontal well in Canada, probably will

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[1]The North Dakota Industrial Commission's Oil and Gas Division defines a wildcat as any well drilled more than 1 mile from an existing field boundary regardless of depth or formation penetrated, and an extension well as any well within 1 mile of a field boundary.

[2]The study area includes Billings, Dunn, Golden Valley, McKenzie, Slope, Stark, and Williams Counties. The project area covers only the portions of those counties that contain lands in the Little Missouri National Grasslands.

soon be in use in the U. S. Production from the Bakken Formation will be second only to that from the Madison Formation in the project area. This is an optimistic forecast and it is important to realize that production from horizontal Bakken wells is not a panacea for the industry and may create new concerns. Originally, some operators, and many speculators, thought that any horizontally drilled Bakken test would be productive. While this may yet be the case, not all Bakken producers will be economic. Another concern is that reserve additions from pre-Bakken reservoirs will all but cease for the duration of the Bakken play because deeper drilling will be rare. As the Bakken play matures, it will become one of many plays in the study area, not the focus of drilling.

The Madison Group will remain the primary producing horizon in the project area. Additional Madison production will come from recompleted Bakken tests and the occasional wildcat. Within 10 years, significant Madison reserves will be added through EOR techniques, normal infill drilling, or horizontally drilled infill wells. Several companies in Canada have drilled horizontal wells in Madison reservoirs with encouraging results. It is also possible that, with the well control added by Bakken drilling, a significant new Madison trend or structure will be defined.

The Red River Formation will become economically viable only if the price of oil and/or natural gas increases significantly or the exploratory success rate improved. If the play is resumed, the LMNG would be affected because the Red River Formation has a high potential there. A Red River play would also gain impetus from the development of viable exploration models for some pre-Mississippian formations. For example, if a viable Stonewall Formation play existed the incremental cost to test the Red River Formation would be small and many wildcats would be deepened to the Red River Formation.

Deep gas (below 12,000 feet) will become an increasingly sought-after target in the Red River, Winnipeg, and Deadwood Formations. Recent exploration along the Nesson Anticline has shown this play to be viable. Gas is an attractive exploration target because it has a stable base price, unaffected by OPEC. Exploitation of natural gas reserves would require that an infrastructure of pipelines be built.

Some sporadic exploration for the Tyler Formation should be expected. The barrier island complex has been defined and only one- and two-well pools or extensions will be found in it. Any significant Tyler reserves will probably be found in channel sands, south of T139N. Enhanced oil recovery programs scheduled for some of the older Tyler fields should be starting up within the next few years.

Historically, drilling has been concentrated north of T.139N. From 1979-1988, 217 wildcats were drilled north of T.139N. and 41 south of it. Total drilling during the same period is even more lopsided, with 2,356 wells drilled in the north and only 70 wells in the south. This trend is expected to continue because lower occurrence potentials and success rates in the southern portion of the area make it less attractive. Any drilling that occurred in the south would be concentrated on LMNG lands because most of the acreage there is in the LMNG.

2:C ENHANCED OIL RECOVERY

Enhanced oil recovery (EOR) projects in North Dakota have met with varying degrees of success. Some failed to produce any incremental oil while others successfully increased recovery. Most of the unsuccessful EOR projects were attempts to waterflood Madison reservoirs in north-central North Dakota. The failure of these waterfloods is inexplicable because waterfloods in the same strata in Canada have been successful. The failures in North Dakota may have been due to operational reasons or to reservoir properties that differ from those in Canada. Carbonate reservoirs can be extremely inhomogeneous and only a thorough understanding of the reservoir characteristics and careful planning can compensate for these inhomogeneities. The EOR projects attempted in North Dakota are listed in Table 1.

Recently, two EOR projects became operational in the study area. Both the North Elkhorn Ranch and Big Stick Units are waterfloods of the Mission Canyon Formation. Individual wells have responded with increased production, evidence that these waterfloods are successful.

Proposed EOR projects located outside the project area are firefloods at Medicine Pole Hills and Capa Fields. The fireflood at Medicine Pole Hills Field is modelled after a similar, successful project at Buffalo Field in South Dakota. The Capa Madison Unit fireflood was suspended for reasons of economics after a short period of operation. If both firefloods are eventually successful, more may be proposed in the future.

In 1983, Chevron Oil Co. attempted to unitize Little Knife Field for a CO_2 pressure maintenance program. A successful pilot study involving five wells had shown that the program would probably be successful (Desch et al, 1984). The unitization attempt failed because the 80% of the royalty interest owners necessary to ratify a unitization agreement in North Dakota did not agree.

Recent CO_2 enhanced recovery programs in Canada were apparently successful. These, coupled with the apparent success of the Chevron pilot program at Little Knife Field, suggest that there will be a need for CO_2. There are two sources of CO_2 presently available to operators in the Williston Basin. The first source is the Wyoming Thrust Belt, where CO_2 is produced together with other natural gasses. The second source is the Coal Gasification project at Beulah, North Dakota where CO_2 is a byproduct of the gasification process. In either case, pipelines to carry the gas to the reservoir(s) would be necessary. Many fields suitable for CO_2 programs lie within

FIELD	POOL	TYPE
Antelope	Madison	Waterflood
Antelope	Duperow/Birdbear	Waterflood
Big Stick	Madison	Waterflood
Blue Buttes	Madison	Waterflood
Charlson	Madison	Waterflood
Clear Creek	Madison	Waterflood
Dickinson	Tyler	Waterflood
Fryburg	Tyler	Waterflood
Fryburg	Madison	Waterflood
Hawkeye	Madison	Waterflood
Medicine Pole Hills	Red River	Fireflood
Medora	Tyler	Waterflood
Medora	Madison	Waterflood
North Elkhorn Ranch	Madison	Waterflood
Red Wing Creek	Madison	Miscible slug
Rocky Ridge	Tyler	Waterflood
Zenith	Tyler	Waterflood

Table 1 - Enhanced Oil Recovery Projects in North Dakota.

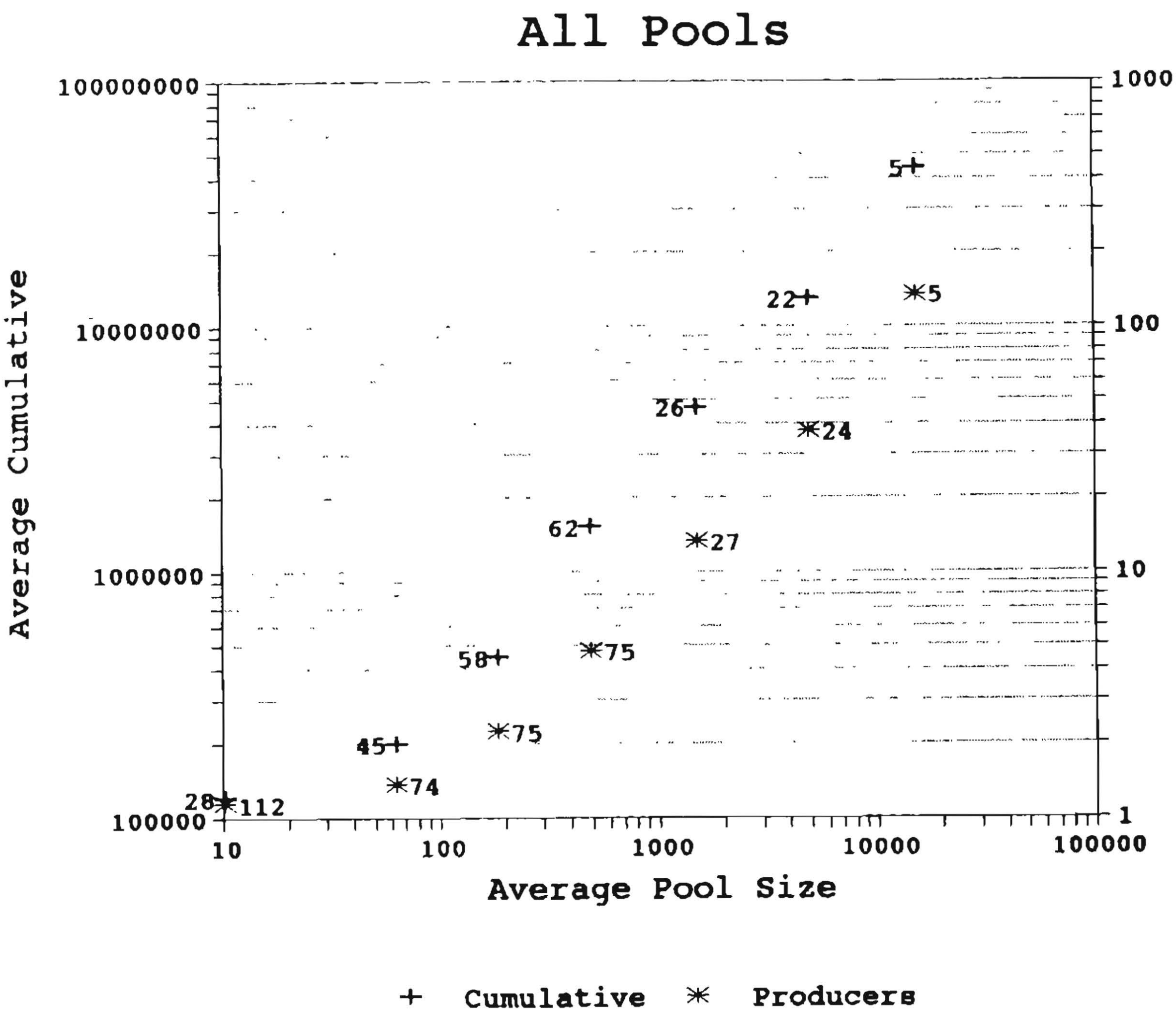

Figure 9. Graph of the average cumulative production and the average number of producing wells in a pool plotted versus the average pool area for six area ranges. These graphs are the average of all pools.

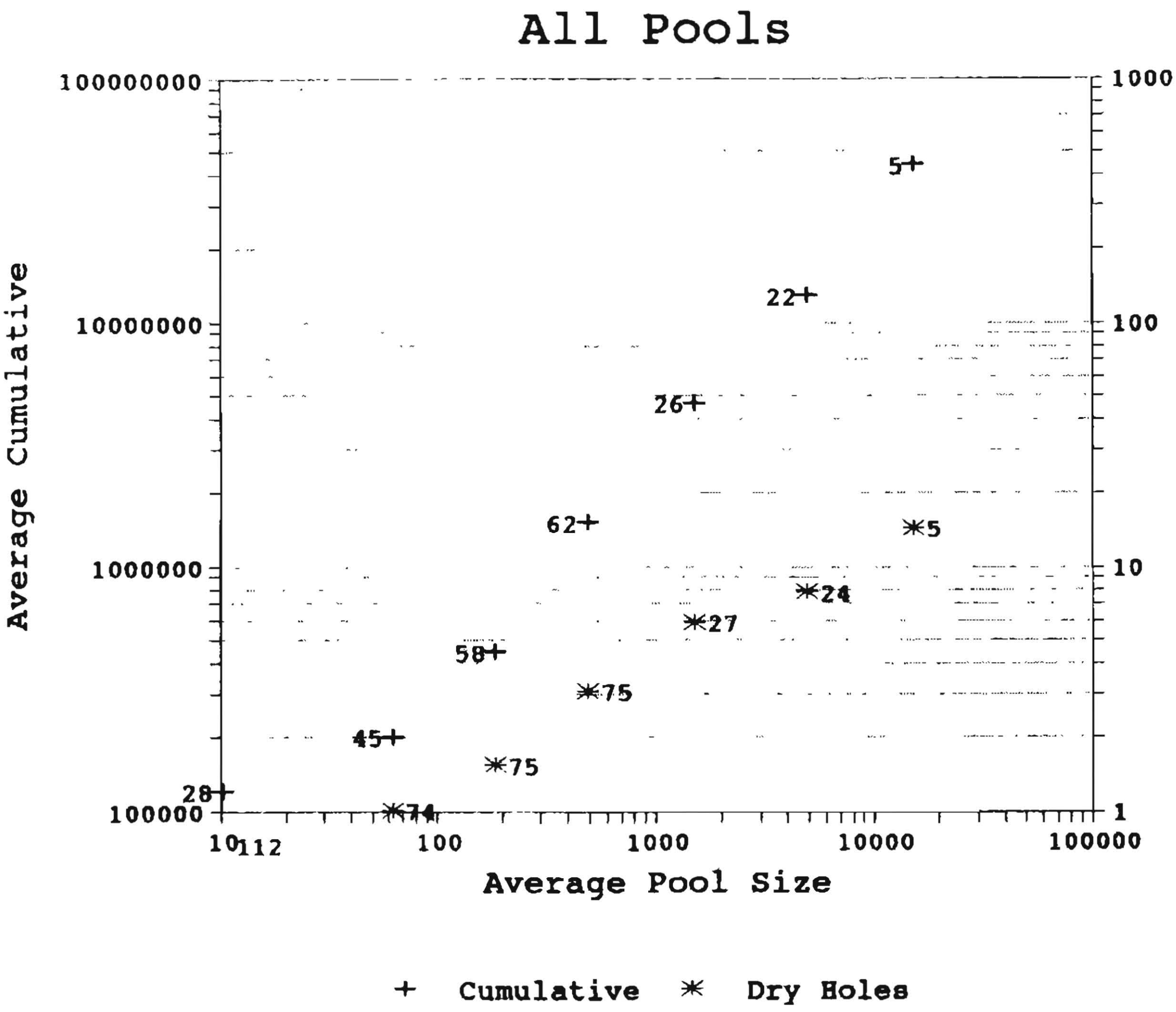

Figure 10. Graph of the average cumulative production and the average number of dry holes in a pool plotted versus the average pool area for six area ranges. These graphs are the average of all pools.

the project area. It is likely that at least one CO_2 program will be attempted at some time.

Following the apparent successes at the North Elkhorn Ranch and Big Stick Units, the probability of additional EOR programs within the study area is very high. The ability of royalty owners to block unitization will focus industry attention on those areas controlled by either a single or a few "friendly" royalty owners. EOR projects are more likely to be approved in areas like the LMNG where public lands are common.

3. FIELD AREAS

The area of each pool in the study area was estimated from field maps and is listed in Appendix A. For those pools with less than 40,000 barrels of recovery, a recovery factor of 1,000 barrels per acre was assumed. Table 2 lists the ranges used.

1. < 33 acres
2. 33-100 acres
3. 100-300 acres
4. 300-900 acres
5. 900-2700 acres
6. 2700-8100 acres
7. >8100 acres.

Table 2. Area ranges.

Two graphs were constructed for each producing formation or pool. The first cross-plots average area against the average ultimate recovery and average number of producing wells for that pool (Fig. 9). The second cross-plots average area against the average ultimate recovery and the average number of dry holes for that pool (Fig. 10). Graphs were made for the following pools, the Birdbear, Bakken, Duperow, Tyler, Madison, Interlake, Stonewall, and Red River. An all-pools graph, where the data from all the formations was averaged, was made. This report contains only the all-pools graph.

4. OCCURRENCE POTENTIAL

Occurrence potential maps of each producing formation in the study area outline the areas of high, moderate, low or unknown potential. Occurrence potentials are based upon the presence or absence of structure, reservoir rocks, source rocks, drilling shows, and upon the quality/quantity of oil produced. An oil field can exist at any level of potential. The occurrence potential is an estimate of the likelihood that an oil field will be found on a given parcel of land and not an absolute measure of whether an oil field is present.

"High Potential": A high potential area must have several fields that produce oil from the subject formation(s) and a high probability exists that the geologic controls, such as structure and source rocks are present and positive. Many of the penetrations must have encountered hydrocarbon shows. In short, most or all the criteria listed in the first paragraph must be satisfied.

"Moderate Potential": A moderate potential area is one where some production exists but where most of the wells penetrating the subject formation are not productive. Traps can be present but either no or uneconomic amounts of oil or gas have been found. It might also be an area that is geologically similar to producing areas elsewhere in the basin, but does not have enough wells to estimate the potential. A good example of this is the Red River Formation across much of Dunn County. A few wells have tested the formation and some have produced oil, but there are not enough wells to fully evaluate the area.

"Low Potential": A low potential area is one where little or no oil has been found. Rare scattered fields may exist but the geologic setting is unfavorable.

"Unknown": The potential of these areas is not well known.

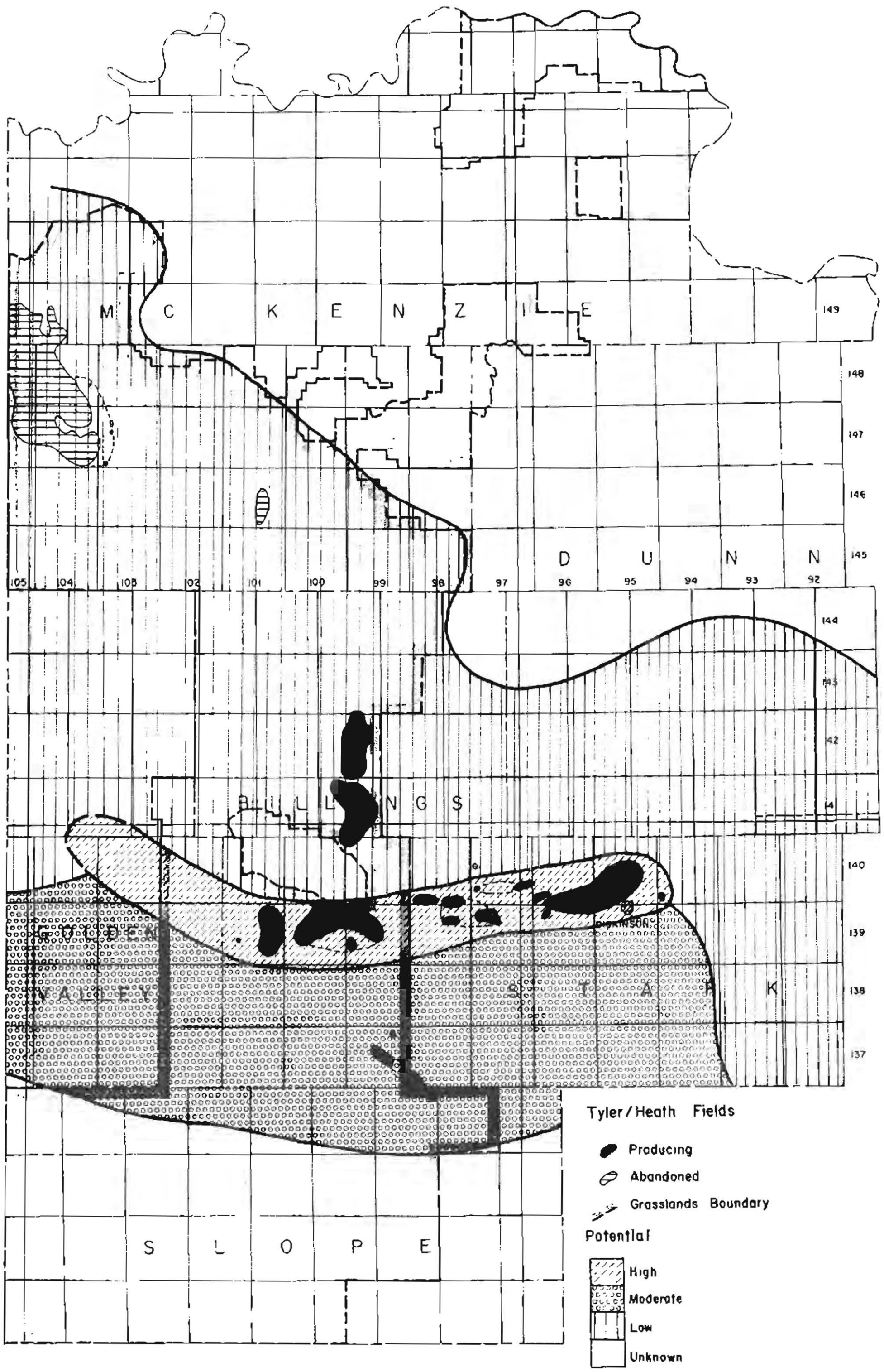

Figure 11. Occurrence potential map of the Tyler/Heath Formations in the study area.

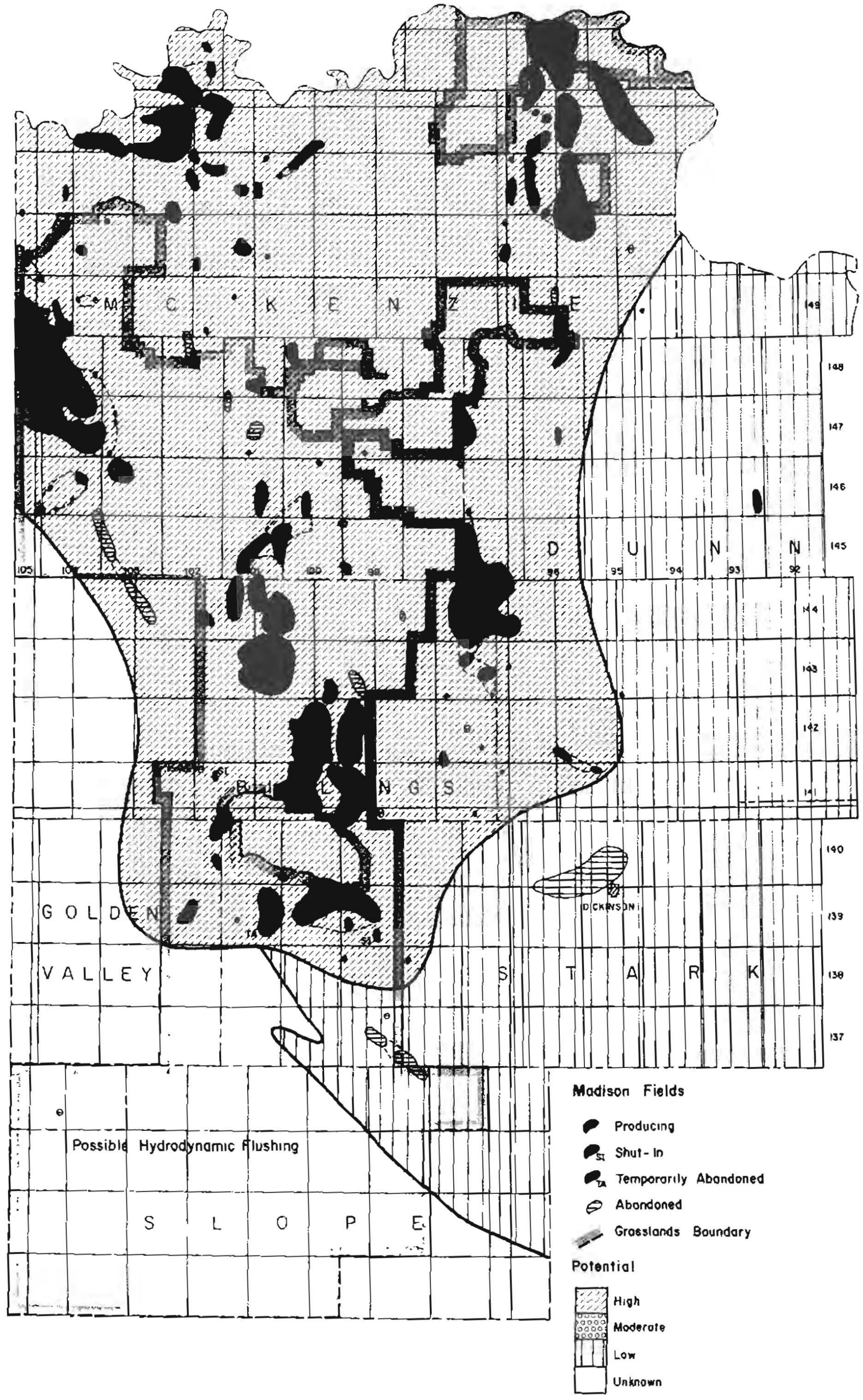

Figure 12. Occurrence potential map of the Madison Formation in the study area.

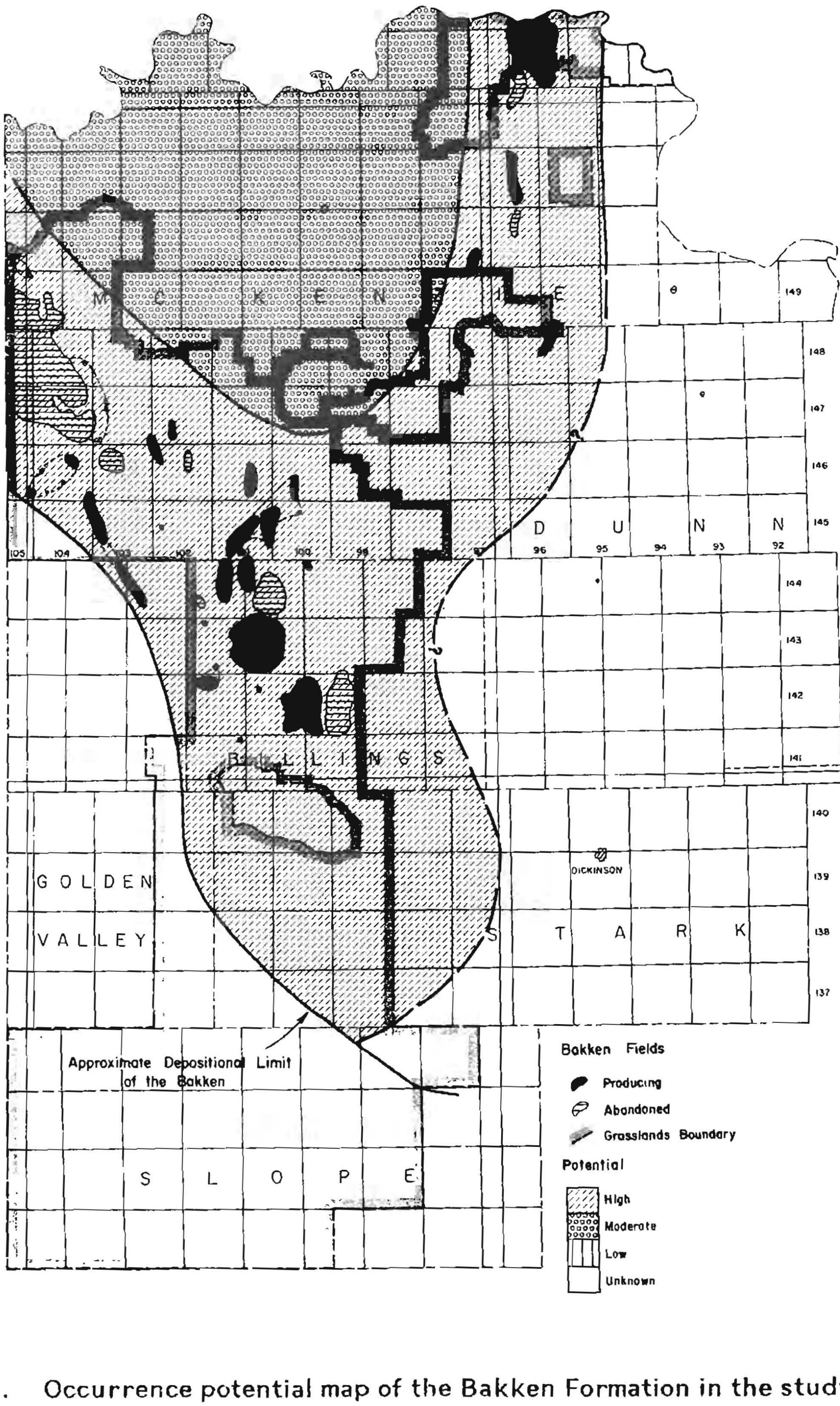

Figure 13. Occurrence potential map of the Bakken Formation in the study area.

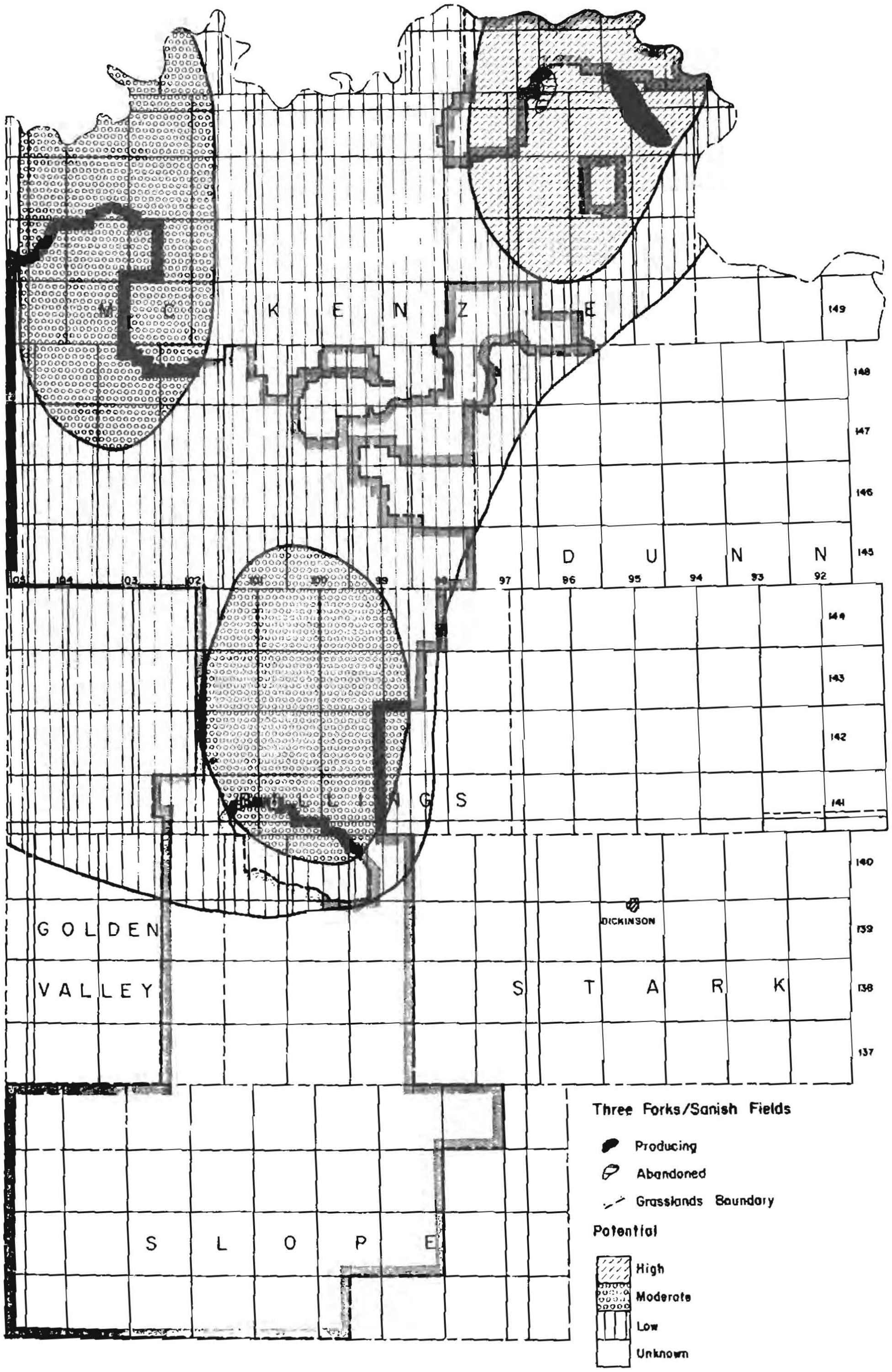

Figure 14. Occurrence potential map of the Three Forks/Sanish Formations in the study area.

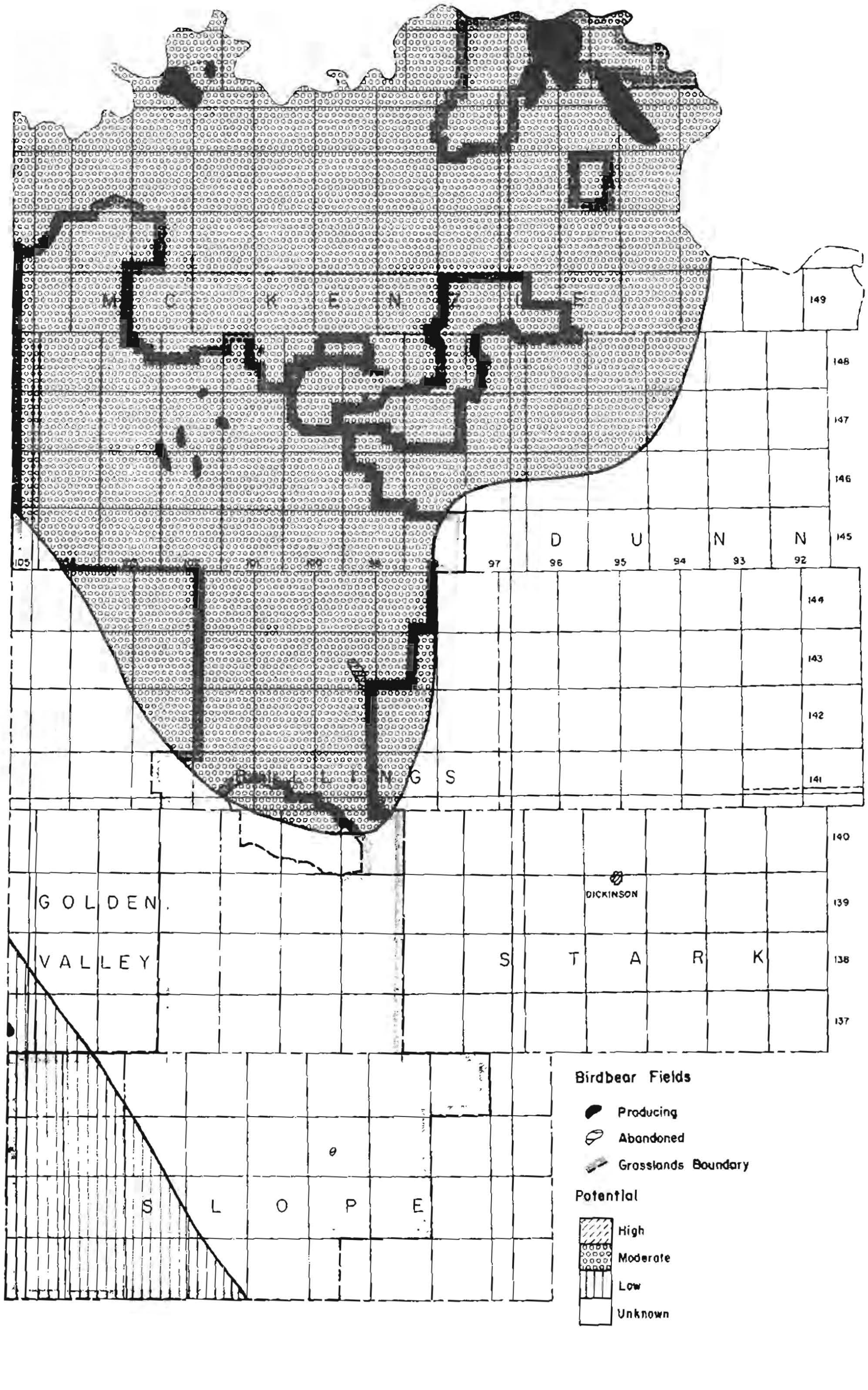

Figure 15. Occurrence potential map of the Birdbear Formation in the study area.

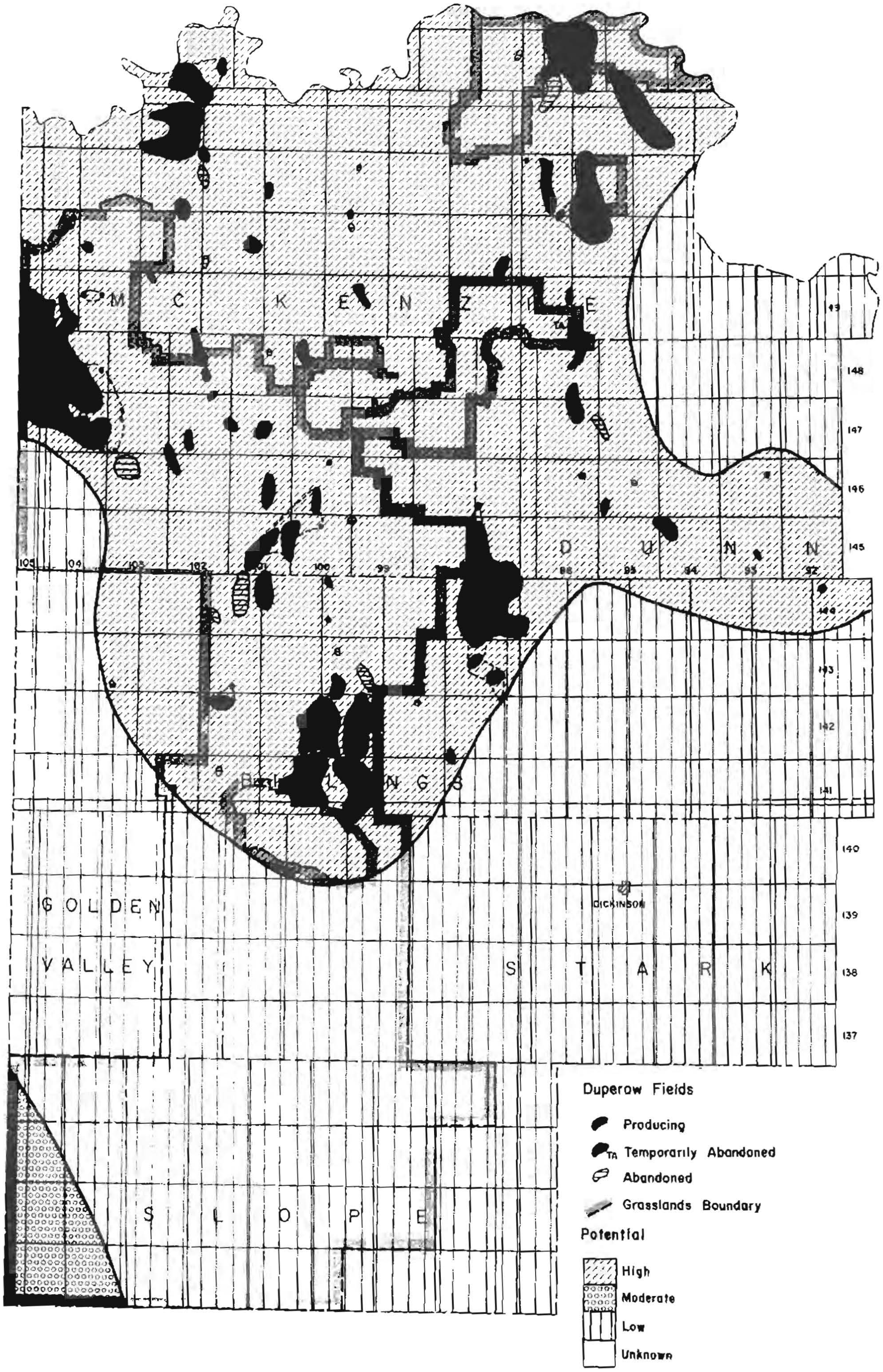

Figure 16. Occurrence potential map of the Duperow Formation in the study area.

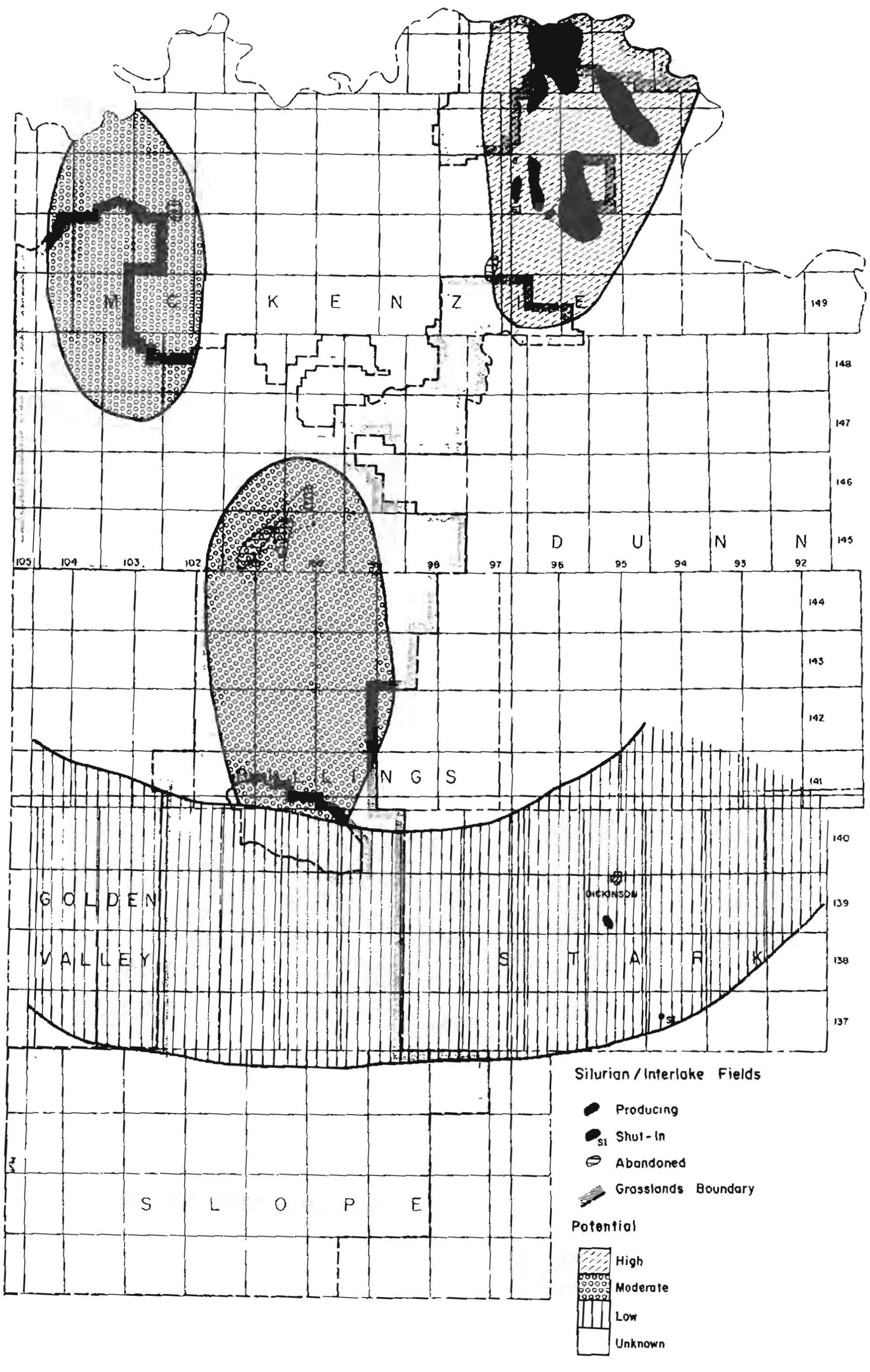

Figure 17. Occurrence potential map of the Silurian/Interlake Formations in the study area.

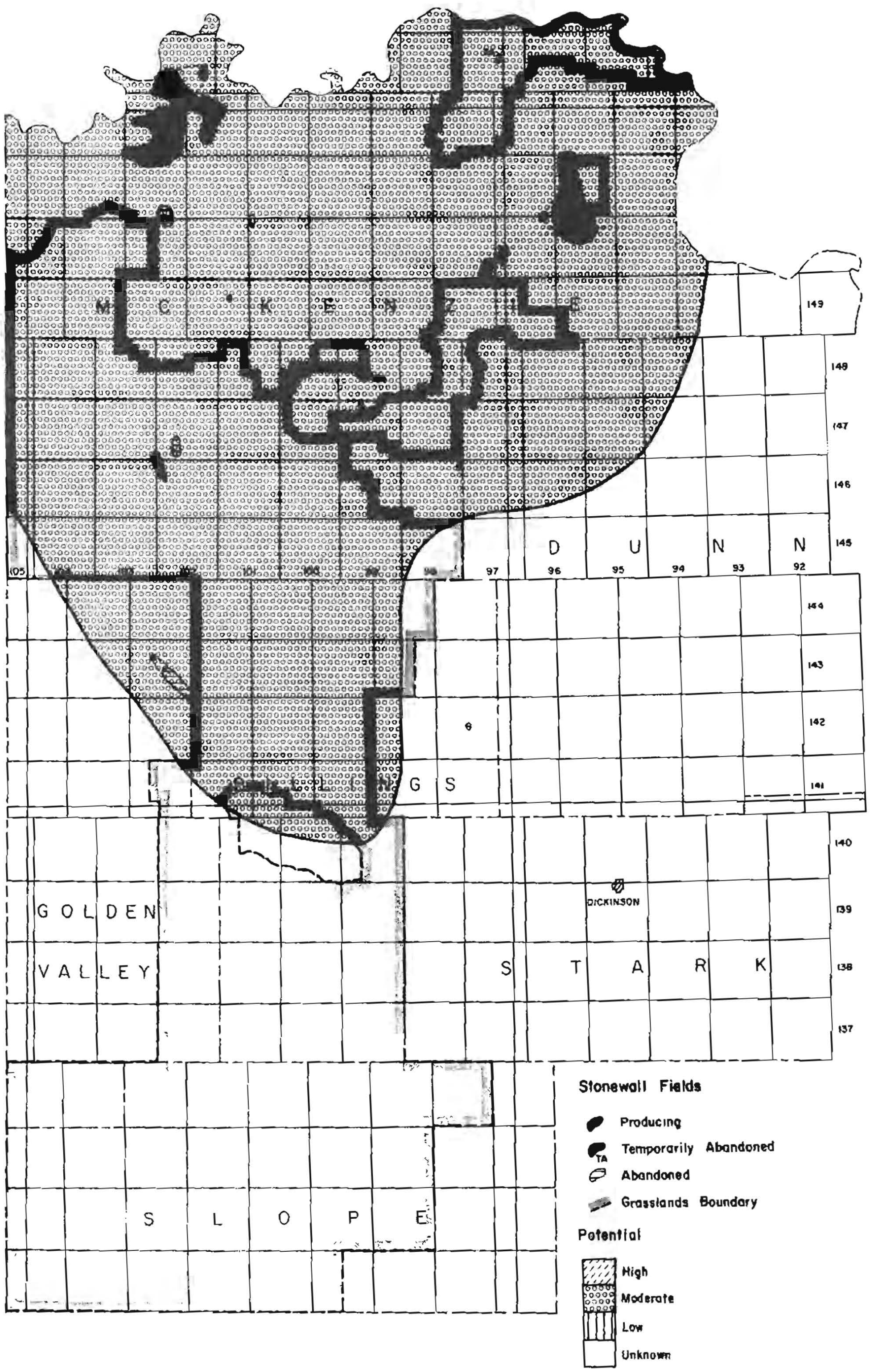

Figure 18. Occurrence potential map of the Stonewall Formation in the study area.

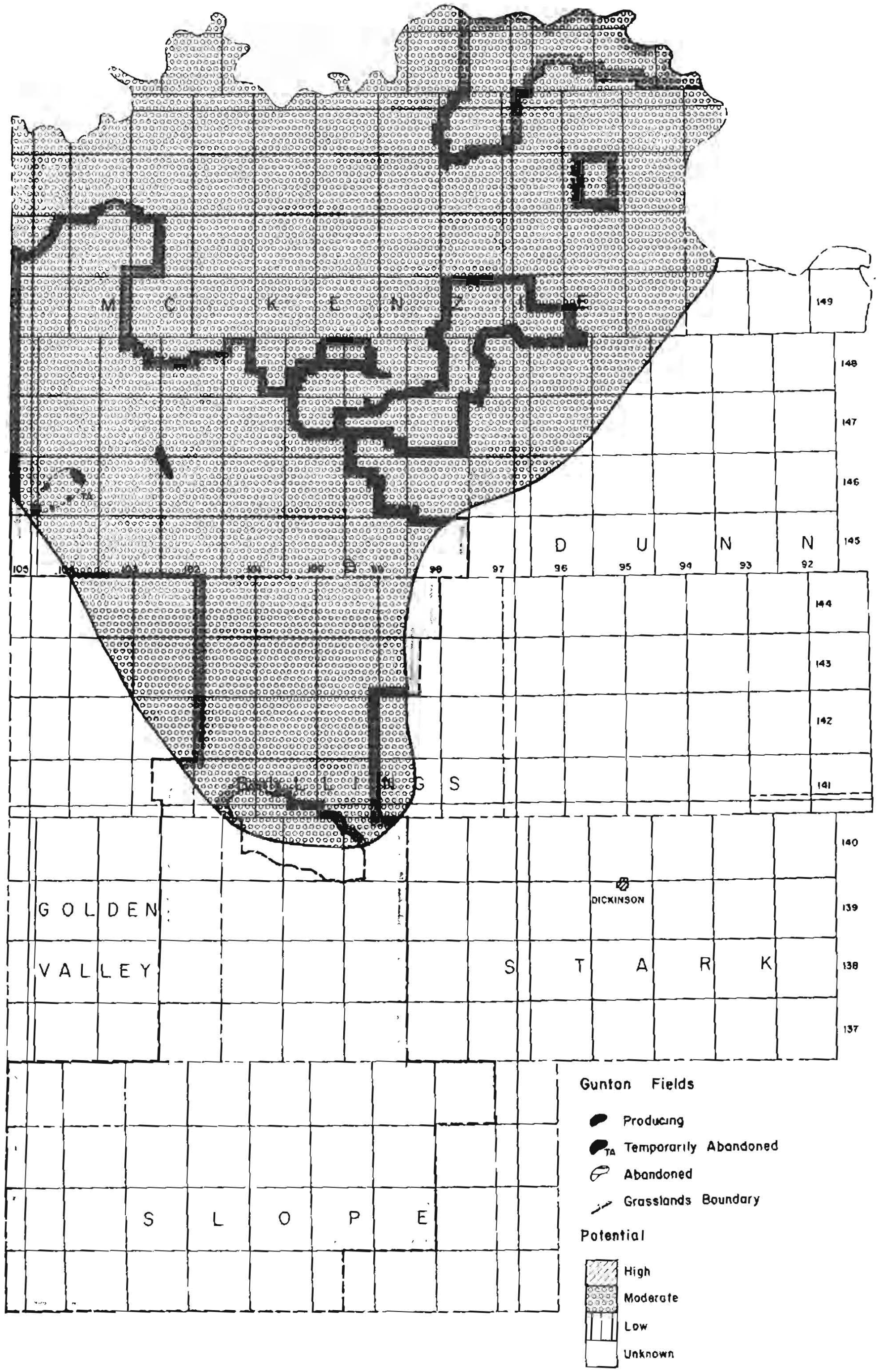

Figure 19. Occurrence potential map of the Gunton Formation in the study area.

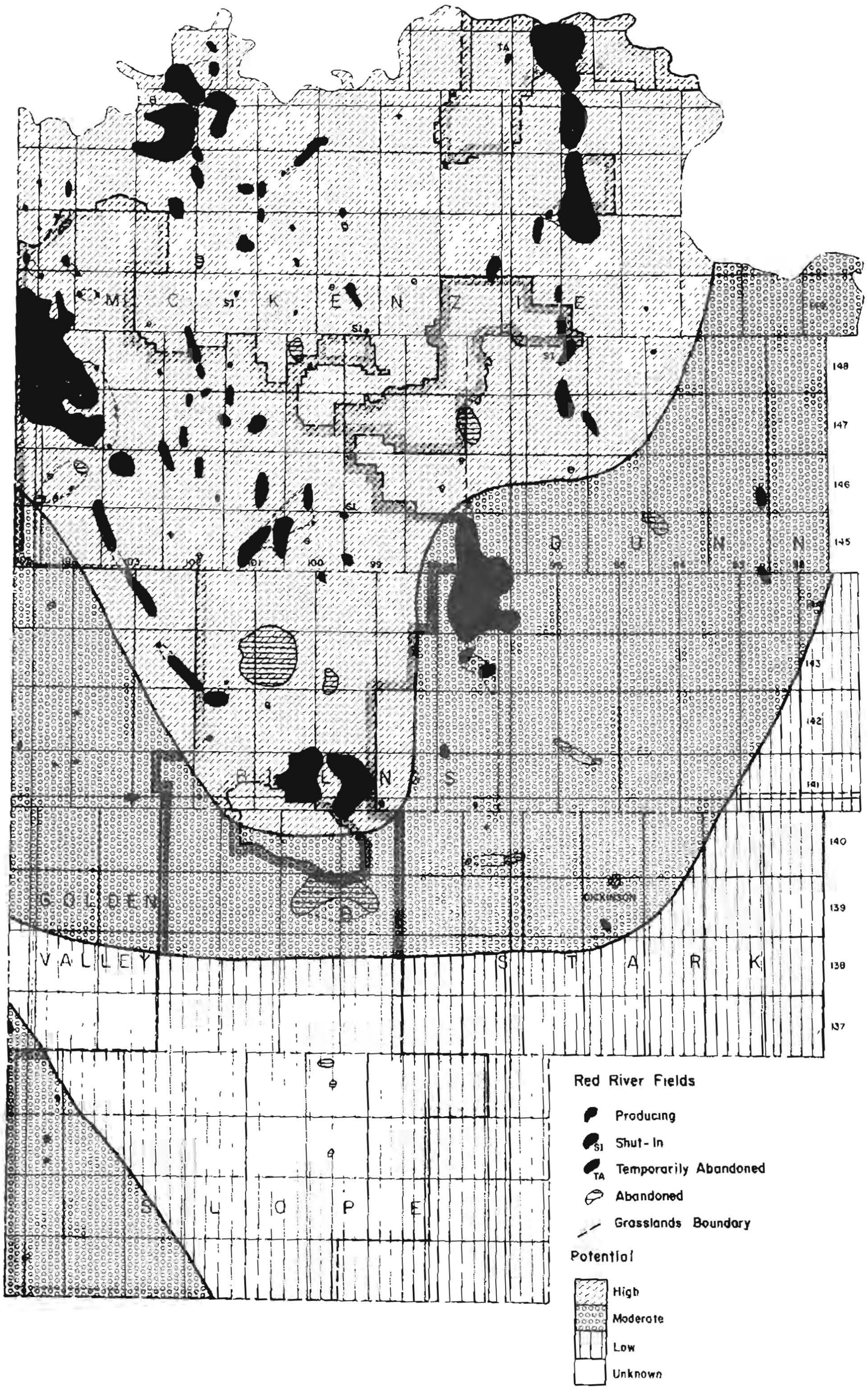

Figure 20. Occurrence potential map of the Red River Formation in the study area.

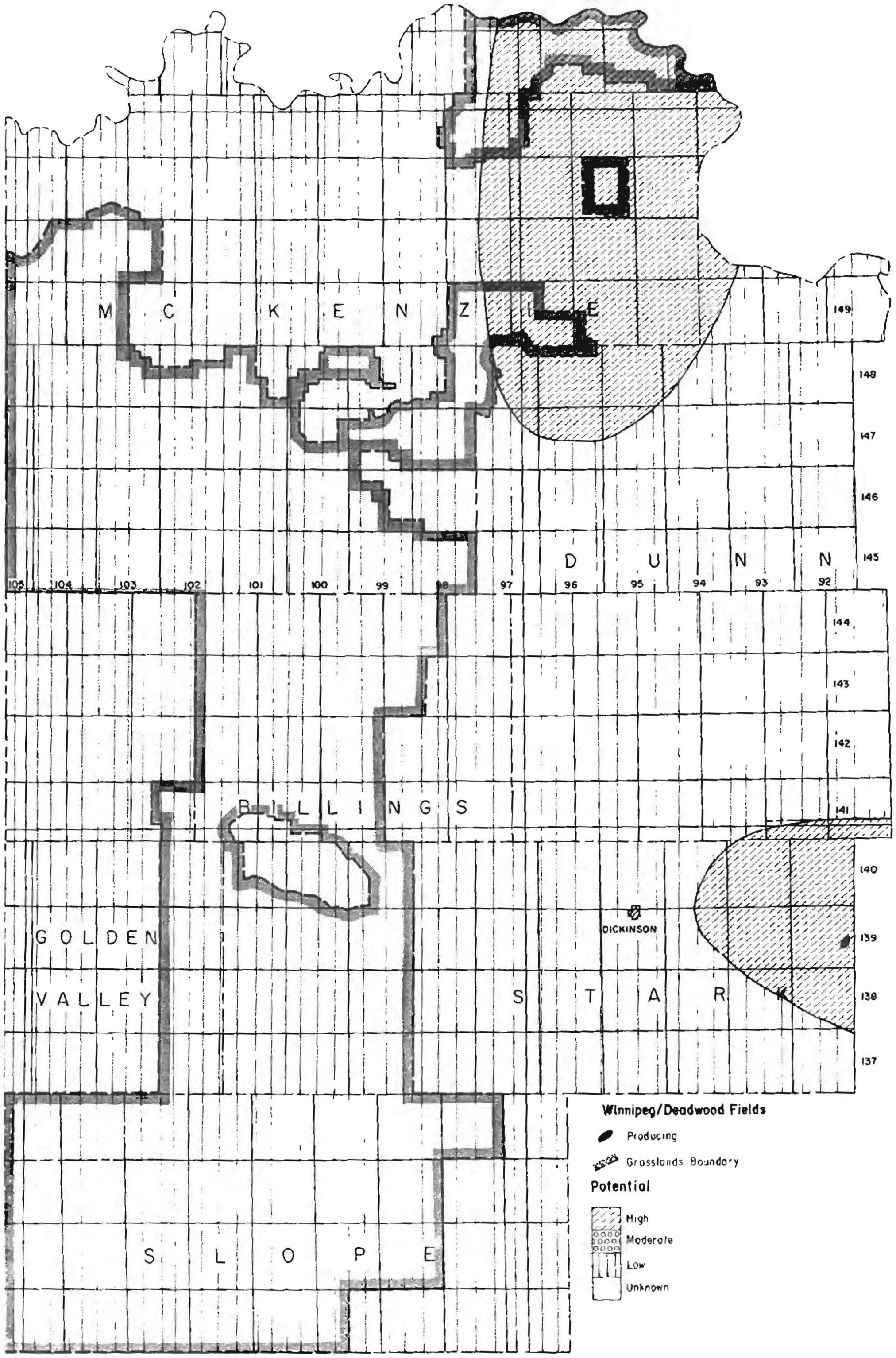

Figure 21. Occurrence potential map of the Winnipeg/Deadwood Formations in the study area.

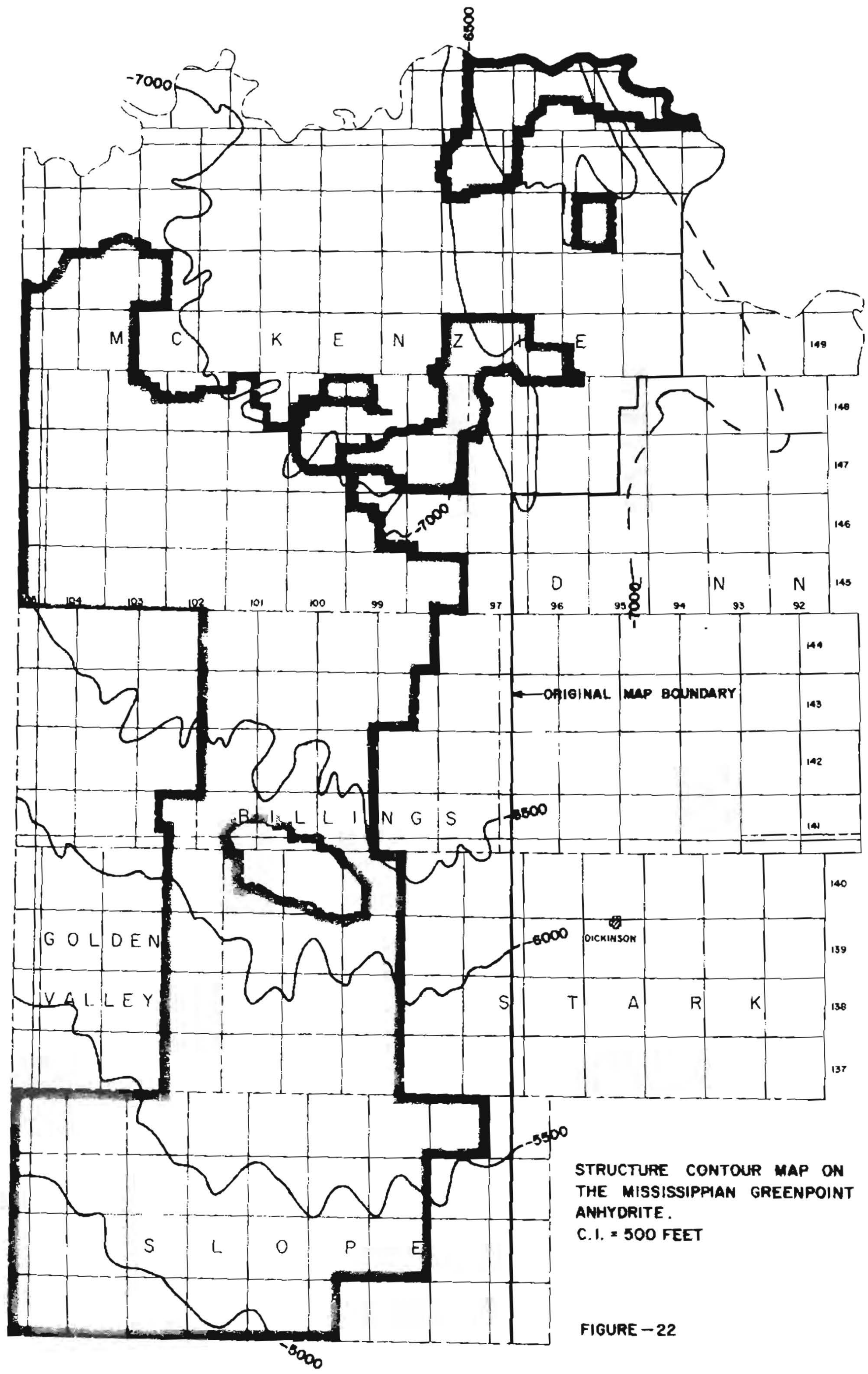

Figure 22. Structure contour map on the Mississippian Greenpoint Anhydrite in the study area.

Individual potential maps for the most productive formations in the study area are shown in figures 11-21. In general, the highest potentials lie on and around the Billings and Nesson Anticlines. Potentials are higher north of T.139N. than to the south.

A structure contour map on the Mississippian Greenpoint Anhydrite, a regional marker bed, outlines the major structures in the study area (Fig. 22). In the Williston Basin, hydrocarbon accumulations are structurally controlled. Those areas where future drilling is most likely to occur can be seen by combining the individual occurrence potential maps with the structure map. Where the occurrence potentials and structure are high, future drilling is likely.

5. UNDISCOVERED FIELDS

Two methods were used to estimate the number of undiscovered fields within the study area. The first method is based on historical drilling data while the second method extrapolates from U.S.G.S. estimates for the entire Williston Basin. To compare the two methods it was necessary to use the field size classification scheme of the U.S.G.S. (Fig. 23).

In the first method, cumulative wildcats drilled are plotted versus cumulative fields discovered for each field class. By fitting a curve to the resulting plot, an estimate of the total number of fields can be made for each class. The difference between the number of fields found to date and the estimated total is the number of undiscovered fields. Estimates for classes 1-3 were not made because of inadequate data. A high and a low value were estimated and averaged for the classes 4-10. Using this method, twenty-five fields in size classes 6-10 remain in the study area (Fig. 24). If each of the twenty-five fields recovered the average of its class range, then approximately 100,000,000 barrels of oil remain to be found in the study area.

The second method is based upon the U.S.G.S. estimates for the entire Williston Basin. The percentage of the Williston Basin's fields found in the study area was multiplied by the U. S. G. S. estimate for the entire basin (E. Attanasi, personal communication, 1990). Using this method, 893 fields remain in the study area (Fig.25). Most of these fields will be small, contain less than 62,500 barrels of oil, and fall into classes 1-3. These classes had no estimates using the first method, so the two methods cannot be compared in these classes. However, estimates for the larger classes can be compared. In classes 6-10, 38 fields remain to be found in the study area. If these 38 fields contain the average of their class range, then they contain 138,-000,000 barrels of oil. Method two resulted in a slightly higher estimate of the number of remaining fields for classes 6-8. Both methods indicate that there are several undiscovered fields between 5 MMBO (MMBO = million barrels of oil) and 10 MMBO remaining in the study area.

6. ESTIMATED ULTIMATE RECOVERIES

Estimates of the ultimate recovery and abandonment date for most of the pools in the study area can be found in Appendix A. Performance curves were generated from monthly production data for each pool and extrapolated to an economic limit. Estimates could not be made for some pools because of increasing production rates or erratic production histories with month or year-long gaps. The economic limit was expressed in barrels per day rather than in a complicated formula where oil prices, operating costs, taxes, and royalties are calculated. The economic limits established were depth dependent and set at 10 barrels of oil per day (BOPD) for completions above 10,000 feet and 15 BOPD for wells completed below 10,000 feet. It was assumed that multi-well pools would be plugged on an individual well

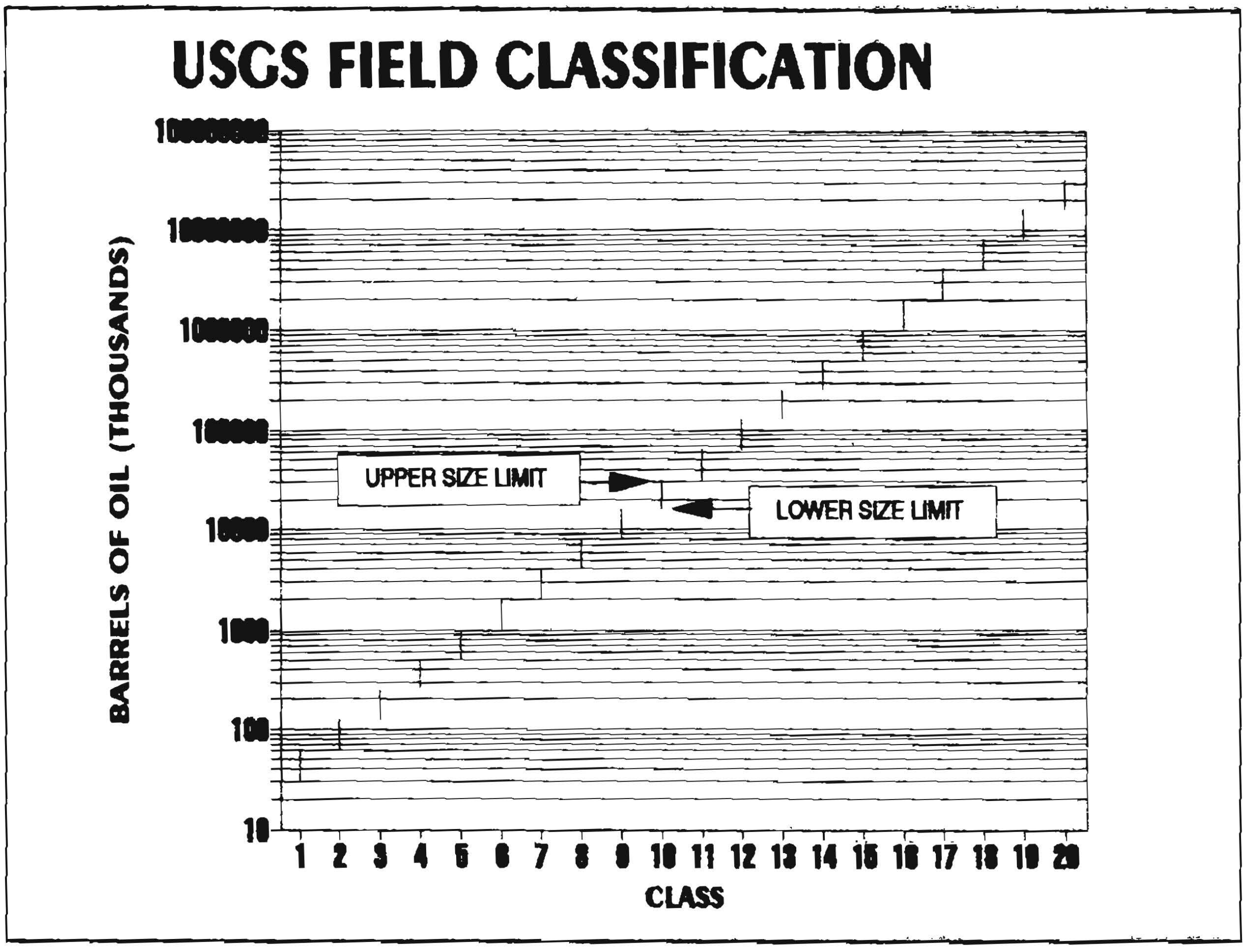

Figure 23. Graphical display of the field size classification system of the U.S. Geological Survey.

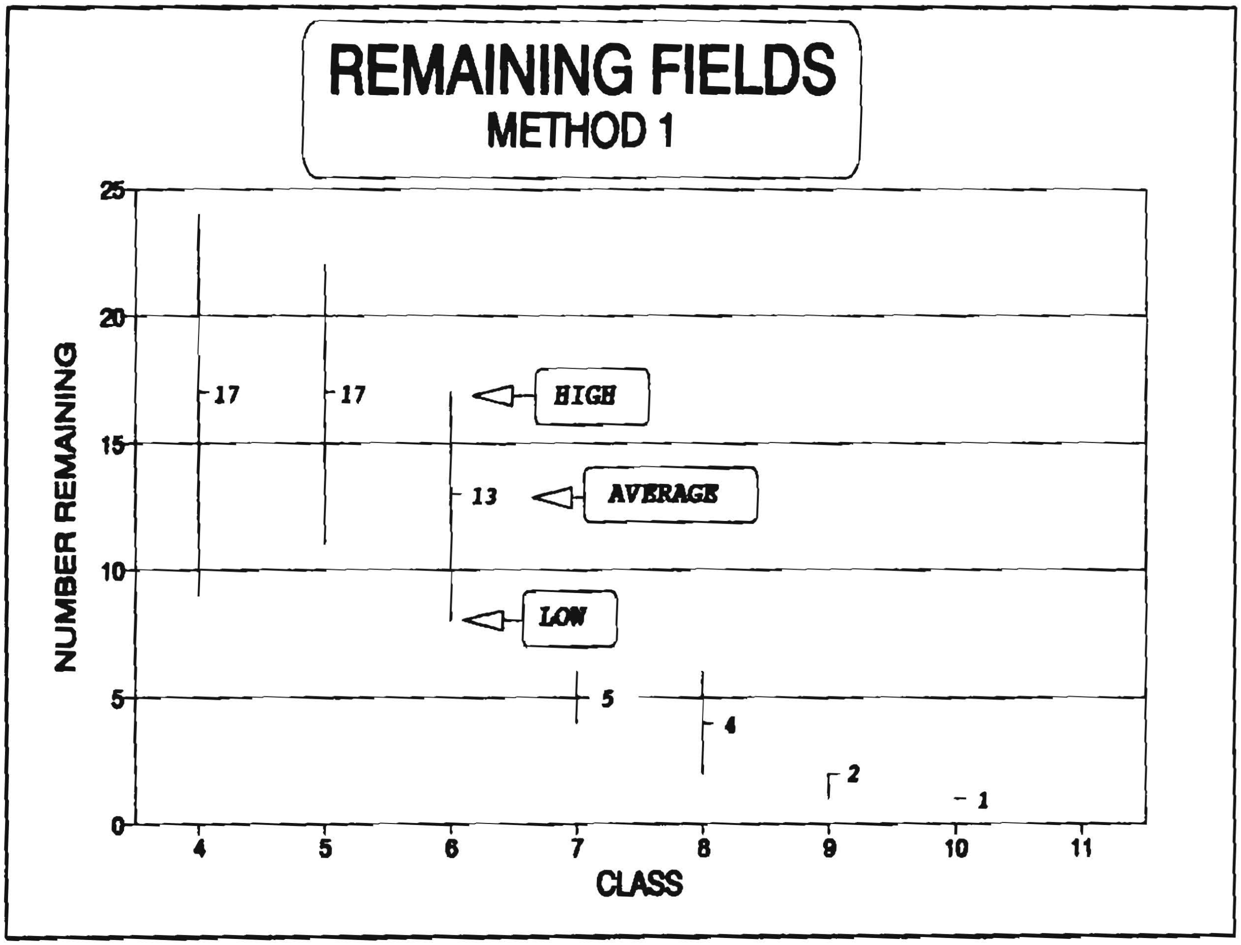

Figure 24. Graph of the estimated number of remaining fields in the study area for U.S.G.S. field-size classes 4-11 using a curve-fitting method.

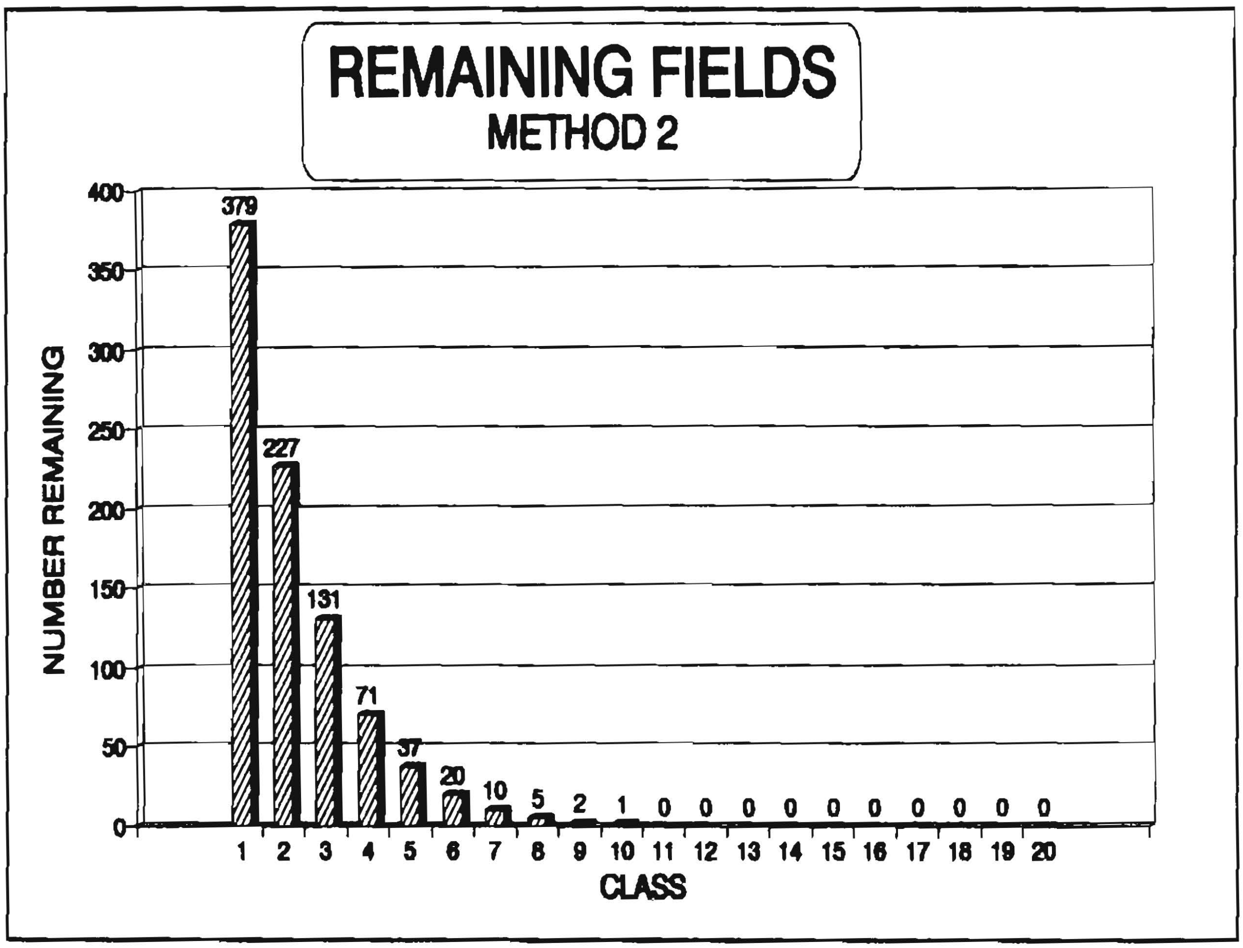

Figure 25. Bar graph of the estimated number of remaining fields in the study area for U.S.G.S. field-size classes 1-20. Estimated numbers are the fields in the study area to the Williston Basin percentage of the U.S.G.S. estimate on undiscovered fields for the entire Williston Basin (E. Attanasi, 1990, personal communication).

and not on a pool-wide basis. For example, a 10-well pool producing from 9,000 feet would not be abandoned when the pool total reached 100 BOPD (3,000 barrels per month). Instead, each well would be plugged as it reached its own economic limit so the pool would be abandoned when the last well reached 10 BOPD (300 barrels per month). These estimates are optimistic but will not significantly increase the reserve estimates for most pools because the majority of the oil recovered from a field is recovered during the first years of production. Pools with only a few wells would be overestimated because this method extrapolates production too far into the future.

Performance curves were also made for the gas pools in the study area. Most of these pools also have separate oil performance curves. A more accurate estimate of the pool's ultimate recovery could be derived by converting the gas to barrels of oil equivalents (BOE's) and adding the BOE's to the oil estimate. To make the conversion, divide the thousands of cubic feet of gas (MCFG) produced by 6 (1 BOE=6,000 cubic feet). This was not done in this study because the future value of gas might be significant and production estimates for natural gas beneficial.

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Appendix A

Estimated Pool Ultimate Recoveries

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Alexander	Madison	21-Sep-82	453,150	Sep 2001
Alexander	Red River	09-Oct-69	84,545	Apr 1994
Amidon	Birdbear	27-Aug-77	4,611	*
Amidon	Red River	17-Dec-74	15,064	*
Anderson Coulee	Madison	20-Jun-81		
Antelope	Devonian	16-Feb-60	6,252,579	Jan 2007
Antelope	Madison	12-May-56	16,067,319	Feb 1997
Antelope	Sanish	06-Dec-53	12,386,929	Apr 2010
Antelope	Silurian	16-Feb-60	4,982,606	Jul 2011
Antelope Creek	Madison	20-Dec-87	5,282	*
Antelope Creek	Red River	07-Oct-84		NA
Antelope Creek	Stonewall	17-Jan-87		NA
Arnegard	Madison	16-Jul-80	228,572	Sep 2011
Ash Coulee	Bakken	29-Jul-81	73,309	Apr 1998
Ash Coulee	Red River	16-May-82		NA
Assiniboine	Madison	11-Nov-86	295,935	Mar 1999
Assiniboine	Red River	10-Apr-82	669,791	Aug 1996
Baker	Madison	30-Apr-82	344,145	Aug 1996
Baker	Red River	21-Sep-85	979,625	May 2002
Banks	Red River	12-Dec-81		
Barta	Madison	16-Aug-85	129,508	Aug 1998
Beach	Red River	16-Nov-80	382,108	Feb 2001
Bear Butte	Birdbear	09-Jul-82	228,210	Jan 1998
Bear Butte	Duperow	03-Oct-81		NA
Bear Creek	Duperow	14-Sep-83	4,096,817	Oct 2001
Bear Creek	Red River	01-Sep-81	736,775	Mar 1993
Bear Den	Duperow	02-Jan-60	89,193	*
Bear Den	Madison	04-Sep-57	2,263,257	Oct 2057
Bear Den	Red River	20-Mar-86		NA
Beaver Creek	Red River	18-Apr-79	7,678,087	Jun 2053
Beaver Creek	Stonewall	24-Jul-80		NA
Beicegal Creek	Duperow	15-May-81		NA
Beicegal Creek	Madison	12-Jan-83		NA
Beicegal Creek	Red River	11-Feb-83		NA
Belfield	Heath	19-Sep-54	6,528	*
Bell	Tyler	27-Aug-82	2,600,520	Feb 2006
Bennett Creek	Madison	24-Mar-80	104,265	Oct 1992
Berg	Madison	29-Oct-80	692,442	Aug 2019
Bicentennial	Bakken	18-Aug-80		NA

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Bicentennial	Madison	13-Dec-78		NA
Bicentennial	Red River	01-Sep-76	5,918,754	Aug 2021
Big Stick	Bakken	28-May-80	58,664	Dec 1992
Big Stick	Duperow	03-Apr-79	613,564	Jan 1992
Big Stick	Madison	10-Sep-79	48,842,422	Apr 2038
Blacktail	Madison	31-Jul-60	15,664	*
Blue Buttes	Duperow	14-Jan-81	1,025,212	Sep 2013
Blue Buttes	Madison	22-Aug-55	48,509,792	May 2059
Blue Buttes	Red River	17-Sep-80	746,041	Sep 2000
Blue Buttes	Silurian	13-Feb-80	15,423,370	Jun 2025
Blue Buttes	Stonewall	05-May-85	2,164,074	May 2002
Bonnie View	Red River	13-Aug-82	180,458	Jun 1993
Bowline	Madison	17-Jul-81		NA
Bowline	Red River	26-May-83	421,141	Feb 1996
Boxcar Butte	Duperow	16-Jan-83	119,893	Aug 1993
Boxcar Butte	Madison	01-Jul-81		NA
Boxcar Butte	Red River	02-Jun-75	3,756,395	Sep 2008
Buckhorn	Bakken	20-Sep-81		NA
Buckhorn	Duperow	24-Nov-81		NA
Buckhorn	Madison	06-Oct-80	6,395,235	Oct 2023
Buffalo Wallow	Duperow	13-Oct-82	390,102	Aug 1994
Buffalo Wallow	Madison	08-Feb-83	2,558,989	Feb 2020
Buffalo Wallow	Red River	11-Jun-82		NA
Buford	Madison	14-Jul-87	5,655,229	Jul 2045
Buford	Red River	14-Nov-86	583,402	Jun 1997
Bull Moose	Duperow	14-Nov-85	704,537	Dec 1994
Bull Moose	Madison	07-Oct-78	526,199	Jun 1990
Bull Moose	Red River	27-Feb-81	2,736,862	Jun 2004
Bull Run	Madison	16-Mar-80		NA
Bull Run	Red River	09-Dec-80	882,379	Jul 2000
Bull Snake	Duperow	24-Mar-82		NA
Bull Snake	Madison	16-Dec-83	454,986	Mar 1991
Bull Snake	Red River	29-Oct-81	261,371	*
Bully	Red River	08-Nov-84		NA
Burning Mine	Red River	01-Apr-82	293,720	Jan 1994
Butte	Madison	27-Jul-83		NA
Camel Butte	Bakken	04-Nov-83	17,452	*
Camel Butte	Devonian	07-Sep-64	1,040,248	Jul 1995
Camel Butte	Madison	27-May-58	2,000,204	May 2013
Camel Butte	Silurian	01-Jun-81	727,449	Jan 2001
Camel Hump	Red River	08-Sep-80	1,085,079	Aug 2005
Camp	Madison	20-Oct-82	2,997,316	Jun 2014
Camp	Red River	13-Sep-82	203,621	Jul 1993
Camp	Stonewall	12-Aug-82	114,527	Dec 1991

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Cannonball	Red River	22-Apr-83	129,818	Jun 1992
Cartwright	Duperow	26-Nov-87		NA
Cartwright	Interlake	03-Mar-87		NA
Cartwright	Madison	21-Sep-80	696,920	Jun 1997
Cartwright	Red River	10-Aug-79		NA
Cash	Red River	14-Mar-82	241,917	Apr 1994
Charbonneau	Duperow	15-Oct-79	276,375	Sep 1992
Charlie Bob	Duperow	23-May-81		NA
Charlson	Bakken	21-Mar-79	91,272	Nov 1992
Charlson	Devonian	26-Dec-60	6,741,888	Feb 2009
Charlson	Madison	03-Aug-52	34,263,984	May 2055
Charlson	Red River	27-Nov-79	1,096,632	Mar 1998
Charlson	Silurian	29-Mar-77	16,716,799	Feb 2001
Chateau	Duperow	24-Jun-80		NA
Chateau	Madison	02-Jan-86		NA
Cherry Creek	Duperow	03-Sep-79	939,528	Aug 2002
Cherry Creek	Red River	06-Sep-78		NA
Cinnamon Creek	Bakken	22-Dec-88	75,265	Feb 1994
Cinnamon Creek	Red River	06-Nov-80	220,669	Mar 1991
Clear Creek	Madison	04-Oct-58	12,268,523	Apr 2046
Corral Creek	Duperow	01-Jul-78		NA
Corral Creek	Red River	10-Oct-79	245,392	*
Covered Bridge	Bakken	29-Jul-85		NA
Covered Bridge	Birdbear	09-Mar-83	484,052	Feb 1997
Covered Bridge	Red River	13-May-81	451,643	Dec 2000
Croff	Devonian	03-Sep-61	1,263,579	Jan 2000
Croff	Madison	19-May-52		NA
Croff	Red River	07-Jul-82	364,926	Oct 1993
Crooked Creek	Madison	18-Jul-88	164,911	Jan 1999
Dance Creek	Madison	29-Dec-83		NA
Dance Creek	Tyler	20-Feb-84	36,782	Jan 1992
Davis Creek	Madison	10-Sep-87	472,418	Aug 2004
DeMores	Bakken	13-Jun-82		NA
Delhi	Red River	30-Dec-80		NA
Devils Pass	Bakken	18-Mar-78	989,967	Jul 1997
Devils Pass	Duperow	13-Mar-81	331,901	Dec 1993
Devils Pass	Madison	23-Aug-81	2,255,737	Jul 2018
Dimmick Lake	Madison	17-Dec-57	2,216,568	Oct 2007
Dimmick Lake	Silurian	05-Jan-85		NA
Divide	Red River	22-Mar-83		
Divide	Three Forks	18-Feb-83		
Dobson Butte	Interlake	31-Jul-82	651,666	Jul 1994
Dobson Butte	Red River	28-Jun-87	52,487	Jan 1991
Dore	Red River	22-Feb-83	78,702	*

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Earl	Madison	21-Oct-77		
Edge	Duperow	18-Oct-85		NA
Edge	Madison	18-Jun-85	179,321	Feb 2006
Edge	Silurian	30-Jan-85		NA
Eleven Bar	Red River	26-Jul-66		NA
Elidah	Gunton	12-Mar-88		NA
Elidah	Red River	14-May-82		
Elk	Duperow	18-Aug-82	437,143	Aug 1994
Elk	Madison	18-May-80	5,299,110	Jun 2013
Elk	Red River	13-Aug-81	1,812,950	Nov 2002
Elk	Stonewall	28-Jan-82	748,763	May 2000
Elkhorn Ranch	Bakken	27-Jun-61		NA
Elkhorn Ranch	Madison	11-Oct-74	21,484,993	Sep 2058
Elkhorn Ranch	Red River	16-May-82		NA
Ellsworth	Red River	02-Nov-80	244,820	Jan 1997
Elm Tree	Bakken	29-Mar-86	22,376	Sep 1991
Estes	Bakken	30-Nov-82		NA
Estes	Madison	15-Mar-82	519,161	Aug 2006
Estes	Red River	03-Jan-81	256,488	Jan 1996
Fairfield	Duperow	09-Jul-80		NA
Fancy Buttes	Madison	18-Jun-57	96,802	*
Flat Top Butte	Bakken	01-Jun-83	331,237	Feb 1998
Flat Top Butte	Duperow	13-Jun-80	292,607	Jan 1997
Flat Top Butte	Heath	29-Sep-60		*
Flat Top Butte	Madison	12-Jul-79	3,068,115	Aug 2036
Flat Top Butte	Red River	06-Apr-81	400,938	Mar 1991
Four Eyes	Duperow	26-Jun-78	1,177,432	Jul 1998
Four Eyes	Madison	17-Jan-79	6,123,315	May 2019
Four Eyes	Red River	18-May-79		NA
Franks Creek	Heath	19-Feb-76	16,261	*
Fryburg	Heath	13-Mar-54	17,691,106	Oct 2011
Fryburg	Madison	22-Sep-53	28,641,053	Jan 2114
Fryburg	Red River	30-Apr-63	48,406	*
Glass Bluff	Madison	29-Aug-82	5,722,469	Sep 2009
Gorham	Duperow	07-Oct-82		NA
Grassy Butte	Duperow	30-May-81	487,815	Dec 1997
Grassy Butte	Madison	02-May-78	1,620,624	Jan 2017
Green River	Heath	24-Apr-74	1,726,562	Sep 2015
Green River	Ordovician	30-Oct-81		NA
Harding	Madison	09-Dec-85	698,988	Dec 2013
Harding	Red River	19-Dec-85	291,406	Nov 1996
Hardscrabble	Birdbear	05-Aug-85	104,674	May 1992
Hardscrabble	Duperow	25-Jun-85	2,220,836	Feb 2016
Hardscrabble	Madison	17-Jul-84	719,237	Sep 2000

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Hardscrabble	Red River	08-Jul-82	1,091,891	Jun 2013
Hardscrabble	Stonewall	11-Mar-85		NA
Hawkeye	Madison	23-Nov-55	9,859,972	Aug 2018
Hawkeye	Red River	12-Jan-85	312,843	Sep 1999
Hay Creek	Red River	24-Jan-88	247,018	Mar 1992
Hay Draw	Bakken	21-Nov-88	34,871	Sep 1992
Hay Draw	Birdbear	02-Mar-86	622,356	Jul 1999
Hay Draw	Duperow	12-Aug-87	283,645	Aug 1996
Hay Draw	Red River	11-Nov-84	625,242	Mar 2009
Hay Draw	Stonewall	22-Apr-87		NA
Haystack Butte	Madison	09-Feb-78	16,692	*
Heart River	Heath	23-Aug-78	120,169	Sep 2001
Hoot Owl	Red River	07-Jun-81	143,581	Jan 1992
Hungry Man Butte	Madison	26-Aug-87	249,647	Jul 2012
Ice Caves	Bakken	06-Feb-86		NA
Ice Caves	Duperow	17-Feb-82	1,600,346	Nov 2002
Ice Caves	Red River	30-Jan-82		NA
Indian Hill	Birdbear	05-Jan-84	1,073,959	Jan 2018
Indian Hill	Duperow	15-Jun-84	1,942,332	Nov 2002
Indian Hill	Madison	24-Sep-82	11,365,304	Nov 2016
Indian Hill	Red River	22-Nov-78	2,399,968	Mar 1998
Indian Hill	Stonewall	02-Sep-82	3,552,755	May 2020
Johnson Corner	Bakken	09-Nov-82		NA
Johnson Corner	Red River	31-Jan-81	308,382	Mar 1994
Johnson Corner	Stony Mountain	26-Oct-84		NA
Juniper	Red River	19-Oct-82		NA
Keene	Bakken	01-Aug-80		*
Keene	Bakken	24-May-62		NA
Keene	Birdbear	24-May-62	2,359	*
Keene	Duperow	26-Oct-61		NA
Keene	Madison	08-Mar-56	4,349,763	Mar 2024
Keene	Silurian	18-Jun-82	5,707,349	Aug 2005
Knutson	Madison	09-Oct-83	5,951,739	Nov 2007
Little Knife	Bakken	09-Aug-85	3,106	*
Little Knife	Duperow	27-Jun-78	567,258	Jan 2005
Little Knife	Madison	07-Feb-77	72,937,860	Oct 2018
Little Knife	Red River	19-Jan-83	43,171	*
Little Tank	Red River	21-Jun-82	422,677	Jun 2001
Lone Butte	Madison	24-Apr-81	7,883,761	Feb 2009
Lone Butte	Red River	15-Jun-81		NA
Lonesome	Duperow	28-Jun-83		NA
Lonesome	Madison	28-Jul-83	166,964	Aug 1997
Lonesome	Red River	28-Apr-81	1,184,601	Jan 1996
Lost Bridge	Bakken	03-Mar-82	9,690	*

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Lost Bridge	Devonian	23-Oct-59	365,204	*
Lost Bridge	Duperow	25-Mar-81	422,445	Jun 1999
Lost Bridge	Madison	01-Apr-75		NA
Lost Bridge	Red River	22-Jun-79		NA
Magpie	Duperow	19-Mar-80	910,176	Aug 2007
Marley	Red River	02-Jun-81		NA
Marmarth	Red River	12-Jul-80		NA
Marquis	Duperow	02-Mar-85	377,110	Feb 1999
Marquis	Madison	09-Jul-85		NA
Mary	Madison	17-Jun-83		NA
Mary	Red River	08-Oct-82		NA
Mary	Stonewall	24-Oct-83		NA
Medora	Heath	17-Aug-64	8,092,627	Nov 2034
Medora	Madison	29-Jun-64	9,275,138	Sep 2061
Middle Creek	Madison	15-Jul-80	1,401	*
Mikkelson	Bakken	26-Jul-81		NA
Moline	Red River	18-Aug-81		NA
Mondak	Bakken	17-Jun-82		NA
Mondak	Duperow	14-Mar-81		NA
Mondak	Madison	01-Oct-76	15,774,196	Nov 2013
Mondak	Red River	17-Jun-76	737,108	Jul 1998
Mondak	Tyler	31-Jul-81		NA
Morgan Draw	Bakken	05-Oct-82	306,085	May 2004
Morgan Draw	Duperow	05-Oct-82		NA
Morgan Draw	Madison	30-Mar-82	426,802	Jul 1999
Murphy Creek	Bakken	03-Oct-82	70,423	Feb 1994
Nameless	Duperow	21-Sep-86		NA
Nameless	Madison	14-Nov-81	1,249,933	Jul 2065
Nameless	Red River	29-Jun-81	564,388	Aug 1999
Nameless	Silurian	21-Mar-82		NA
Nameless	Stonewall	21-Dec-82		*
Nelson Bridge	Red River	24-Mar-83	695,663	Jun 2006
New Hradec	Red River	22-Jul-82		NA
North Branch	Birdbear	24-Jan-86		NA
North Branch	Duperow	06-Feb-85	1,050,555	Mar 1995
North Branch	Red River	06-May-82	566,157	Feb 1999
North Creek	Tyler	22-Jun-84		NA
N. Elkhorn Ranch	Bakken	26-Aug-84		NA
N. Elkhorn Ranch	Madison	20-Jun-81	15,736,126	Jun 2043
North Fork	Bakken	18-Sep-80	5,583	*
North Fork	Devonian	28-Nov-65	936,691	Jun 1997
North Fork	Red River	17-Sep-81	534,037	Jun 1995
North Fork	Silurian	01-Mar-58		*

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
North Fork	Stonewall	13-Mar-82	135,547	Dec 1992
N. Tobacco Garden	Duperow	19-May-81		NA
Norwegian Creek	Madison	14-May-76		NA
Oakdale	Madison	01-May-76	488,477	Feb 2004
Park	Birdbear	23-Jul-88		NA
Park	Madison	22-Nov-82		NA
Park	Red River	08-Jun-82		NA
Patent Gate	Duperow	21-Nov-82	355,052	Mar 1996
Patent Gate	Madison	22-Mar-85		NA
Patent Gate	Red River	17-Nov-81	137,018	*
Pearl	Duperow	11-Feb-82		NA
Pembroke	Red River	19-Mar-82		NA
Pershing	Devonian	14-Jul-65	6,595	*
Pershing	Madison	02-Apr-58	1,881,183	Mar 2011
Pershing	Stonewall	08-Mar-86		NA
Phelps Bay	Bakken	19-Dec-85	214,855	Jul 2003
Pierre Creek	Bakken	27-Nov-84	4,007,906	Nov 2035
Pierre Creek	Birdbear	13-Dec-85		NA
Pierre Creek	Duperow	22-Jan-88	507,438	Jun 1992
Pierre Creek	Gunton	14-Jan-81		
Pierre Creek	Red River	14-Jan-81	1,261,490	Dec 1994
Pierre Creek	Stonewall	16-Jul-88		NA
Pleasant Hill	Red River	02-Mar-82		NA
Poe	Madison	16-Dec-82		NA
Poe	Red River	22-Dec-81	545,590	May 1992
Poker Jim	Bakken	03-Apr-82		NA
Poker Jim	Duperow	21-Sep-79		NA
Poker Jim	Madison	23-Jun-78	1,084,759	Oct 1999
Poker Jim	Ordovician	12-Jun-82		NA
Poker Jim	Red River	10-Mar-71	200,525	*
Pronghorn	Duperow	28-Dec-82		NA
Pronghorn	Madison	05-Aug-81	889,368	Apr 2012
Pronghorn	Red River	11-Jul-81		NA
Ragged Butte	Madison	27-Sep-82	2,534,173	Apr 2027
Ranch Coulee	Red River	26-Feb-82		NA
Randolph	Duperow	06-Nov-83	1,315,409	May 2008
Randolph	Madison	22-Mar-80		NA
Rattlesnake Point	Duperow	26-Oct-77	1,408,211	Aug 2002
Rattlesnake Point	Red River	29-Aug-84		NA
Rawson	Duperow	30-Apr-81	213,133	Aug 1991
Rawson	Madison	06-Jul-81	839,617	Nov 2001
Rawson	Red River	09-Nov-81	50,879	*
Red Wing Creek	Madison	25-Oct-72	22,506,108	Jul 2061
Rhoades	Red River	19-Jan-82		NA

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Rider	Madison	18-Dec-71	781,834	Nov 2037
Riverside	Red River	08-May-82	133,694	Feb 1991
Rocky Hill	Madison	17-Jun-87	114,852	Sep 2000
Rocky Ridge	Heath	07-Jan-57	5,329,705	Nov 2005
Rocky Ridge	Madison	03-Mar-72	45,982	*
Roosevelt	Bakken	03-Feb-81	5,268,167	Mar 2026
Roosevelt	Duperow	12-Feb-82	1,155,765	Apr 2000
Roosevelt	Red River	20-Aug-80	167,653	May 1992
Rough Rider	Bakken	29-Jul-81		NA
Rough Rider	Duperow	21-Dec-85	1,587,650	May 1996
Rough Rider	Interlake	09-Oct-86		NA
Rough Rider	Madison	08-Dec-59	19,498,482	Sep 2020
Rough Rider	Red River	06-Feb-82	498,334	Dec 1999
Russian Creek	Madison	11-Apr-78	398,961	Sep 2001
Russian Creek	Red River	12-Jan-82	35,887	*
Saddle Butte	Madison	20-Oct-79		NA
Saddle Butte	Stonewall	04-Sep-79	453	*
Sakakawea	Madison	19-Mar-84	724,431	Nov 2033
Sand Creek	Devonian	13-Apr-58	27,428	*
Sand Creek	Red River	11-Apr-86		NA
Sand Creek	Stonewall	22-Apr-86		NA
Sandrocks	Red River	19-May-82		NA
Sather Lake	Madison	19-May-82	201,087	Apr 2000
Scairt Woman	Gunton	14-Feb-81		NA
Scairt Woman	Madison	05-Dec-79		NA
Scairt Woman	Red River	17-Jul-81	221,600	Jun 1993
Scoria	Heath	27-Dec-57		
Scoria	Madison	24-Dec-57		
Second Creek	Red River	06-Mar-77	9,099	*
Sheep Butte	Red River	03-Dec-80	152,393	Jan 1992
Sioux	Duperow	18-Nov-86	286,531	May 1996
Sioux	Madison	22-Sep-82	105,336	Jan 1993
Sioux	Red River	08-Feb-80	2,819,314	Jun 2008
Six Creek	Red River	14-May-82		NA
Snow	Madison	20-May-82	404,984	Mar 1995
Snowcover	Birdbear	18-Dec-86	250,971	Nov 1998
Snowcover	Duperow	02-May-84	222,110	Oct 1993
Snowcover	Red River	22-Apr-83	477,832	Dec 1996
South Boxcar	Duperow	16-Jan-83	137,632	Mar 1990
South Boxcar	Red River	25-Jul-83		NA
South Bull Moose	Madison	04-Nov-81		NA
South Heart	Heath	02-Nov-73	1,458,221	Jun 2007
S. Red Wing Creek	Madison	15-Aug-83		NA
S. Tobacco Garden	Duperow	01-Oct-86		NA

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
S. Tobacco Garden	Red River	03-Jan-81		NA
Spotted Horn	Madison	19-Jul-81		NA
Spring Creek	Red River	22-Nov-83		
Spring Creek	Stonewall	31-May-82	12,599	*
Square Butte	Madison	10-May-69	4,199,809	Jul 2050
Squaw Creek	Madison	09-Sep-88		NA
Squaw Creek	Red River	04-Feb-82		NA
Squaw Gap	Bakken	21-Sep-80		NA
Squaw Gap	Gunton	02-May-88		NA
Squaw Gap	Madison	01-Feb-80	853,474	Dec 2001
Squaw Gap	Red River	27-Feb-80		NA
St. Jacobs	Birdbear	28-Oct-81		NA
St. Jacobs	Duperow	02-Mar-82		NA
St. Jacobs	Madison	27-Oct-81		NA
T. R.	Duperow	12-Jul-79	1,846,101	Jun 1997
T. R.	Madison	10-Aug-78	18,545,808	Oct 2026
T. R.	Red River	14-Sep-79		NA
Timber Creek	Red River	27-Aug-81	54,515	*
Tobacco Garden	Bakken	22-Jul-81		NA
Tobacco Garden	Duperow	01-Dec-80	825,826	Jul 2024
Tobacco Garden	Red River	17-May-82	370,518	Mar 2006
Trailside	Duperow	19-Jun-82		NA
Trailside	Madison	17-May-85	407,920	Sep 2006
Tree Top	Bakken	18-Sep-84		NA
Tree Top	Duperow	13-Oct-79	1,513,048	Apr 2018
Tree Top	Madison	19-Jul-79	34,774	*
Tree Top	Tyler	18-Sep-84	13,899,333	Feb 2020
Trotters	Red River	22-Dec-81		NA
Twin Valley	Red River	07-Apr-83		
Ukraina	Madison	02-Jan-86		NA
Ukraina	Red River	22-Apr-80		NA
Union Center	Madison	16-Apr-76	1,319,187	Sep 2011
Wannagan	Red River	19-Jun-81	872,378	Jun 2008
West Butte	Madison	12-Jul-85		NA
West Butte	Red River	16-May-85		
Westberg	Bakken	13-Dec-82	16,675	*
Westberg	Birdbear	10-May-82		NA
Whiskey Joe	Duperow	24-Apr-80	1,166,297	Apr 2001
Whiskey Joe	Madison	03-Sep-79	20,683,741	Apr 2083
Whiskey Joe	Red River	08-Jun-82		
Whitetail	Duperow	12-May-88		NA
Whitetail	Red River	28-Mar-79		NA
Williams Creek	Birdbear	10-Dec-87	131,643	Jul 1992
Williams Creek	Red River	14-Jan-79	408,583	May 2001

* Ultimate recovery already reached
NA - Ultimate recovery could not be calculated

Field	Pool	Discovery Date	Estimated Ultimate Recovery	Estimated Date of Ultimate Recovery
Willmen	Madison	18-Jul-88	103,794	Dec 1997
Winter Butte	Duperow	13-May-82	227,739	Nov 1991
Winter Butte	Madison	28-Dec-84		NA
Winter Butte	Red River	29-Mar-82	305,847	Oct 1994
Yellowstone	Ordovician	12-Jan-76	1,884,528	Dec 2026
Zenith	Heath	12-Oct-68	6,443,881	Oct 2002

Gas Pools

Field	Pool	Discovery Date	Estimated Ultimate Recovery (MCF)	Estimated Date of Ultimate Recovery
Bear Creek	Red River	01-Sep-81	5201517	May 1994
Beicegal Creek	Red River	11-Feb-83	463174	*
Blue Buttes	Red River	17-Sep-80	2332972	Feb 1998
Buffalo Wallow	Red River	11-Jun-82		NA
Bully	Red River	08-Nov-84	255192	*
Charlson	Red River	27-Nov-79	39783972	Feb 2004
Cherry Creek	Red River	06-Sep-78	2174893	*
Croff	Red River	07-Jul-82	8004313	Jan 2005
Ellsworth	Red River	02-Nov-80	2920344	May 2001
Hawkeye	Red River	12-Jan-85	2092248	Oct 1997
Ice Caves	Red River	30-Jan-82	1892996	Jan 1997
Johnson Corner	Red River	31-Jan-81	1546394	Nov 1994
Juniper	Red River	19-Oct-82	1091356	*
North Fork	Red River	17-Sep-81	9925588	Nov 2001
Park	Red River	08-Jun-82	163295	*
Patent Gate	Red River	17-Nov-81	731796	Jan 1990
Pleasant Hill	Red River	02-Mar-82	610460	*
Poe	Red River	22-Dec-81	7457795	Oct 1996
Rough Rider	Red River	06-Feb-82	3988009	Sep 1996
Scairt Woman	Red River	17-Jul-81	13680775	Jan 2007
Timber Creek	Red River	27-Aug-81	1088352	Apr 1993
Tobacco Garden	Red River	17-May-82	20121239	Aug 2005

* Ultimate Recovery already reached
NA - Ultimate Recovery could not be calculated