Montana Bureau of Mines and Geology
Open-file Report

Petroleum Potential of the Greybull Sandstone on the Northern Cheyenne Reservation, South-Central Montana

Contract #: 75-99SW45040

2000

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Petroleum Potential of the Greybull Sandstone on the Northern Cheyenne Reservation, South-Central Montana

by

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Produced in Cooperation with the
U. S. Department of Energy, Office of Petroleum Technology and the Cheyenne Tribe

2000

Contents

Abstract 1
Introduction 1
Research Project Objectives and Procedure 2
Acknowledgements 4
Structural Geology 4
Stratigraphy of the Greybull Interval 4
History of Stratigraphic Nomenclature 4
Stratigraphy in the Northern Cheyenne Reservation Area 5
Regional Sequence Stratigraphic Relationships of the Greybull Sandstone 6
Greybull Channel Occurrences 7
Petroleum Potential in the Greybull Sandstone 8
Summary and Conclusions 9
References 10

Figures

Figure 1. Location of the Cheyenne Reservation area 2
Figure 2. Stratigraphic relationships of the Kootenai Formation and Greybull Sandstone. 3
Figure 3. Kootenai and Fall River Formations; Greybull channel absent 6
Figure 4. Photograph showing tabular cross bedding typical of the Greybull Sandstone 7
Figure 5. Regional stratigraphic nomenclature and correlations. 8
Figure 6. Greybull channels on the Crow and Northern Cheyenne Reservations 9
Figure 7. Subsurface log character of a typical Greybull channel 10

Plates

Plate 1. Structure Contour Map of the Dakota Silt
Plate 2. Gross Thickness Isopach Map of Greybull Valley Fill
Plate 3. Stratigraphic Cross Section A—A’
Plate 4. Potential Oil and Gas Lead in Greybull Valley-Fill Sandstone

Abstract

The focus of this project was to evaluate stratigraphic traps that may be present in valley-fill sandstone of the lower Cretaceous Greybull Sandstone on the Northern Cheyenne Indian Reservation of south central Montana. The area of the reservation is part of the Rocky Mountain Foreland structural province, which is characterized by basement-involved Laramide uplifts and intervening structural basins. The reservation area is on the northwestern flank of the Powder River Basin. Regional dips of rocks underlying the reservation are eastward and southeastward toward the axis of the Powder River Basin. The 480,000-acre reservation is an under-explored area, but has strong potential for the discovery of oil and gas. Oil and gas production is well established in the Powder River Basin of Wyoming to the south and in the areas north and west of the reservation. On the reservation, however, no production has been discovered. Geologic relations and trends indicate that oil and gas accumulations should be present on the reservation, but drilling has not been sufficient for their discovery; only 16 exploration wells have been drilled within the reservation boundaries.

The Greybull Sandstone is part of the transgressive systems tract that includes the overlying Fall River Sandstone and was deposited on a major regional unconformity. The erosional surface at the base of the Greybull is the +100 Ma, late Aptian-early Albian regional unconformity of Weimer (1984). A basin-wide drop in sea level controls this surface; that is, it is a low-stand surface of erosion. In areas where incised Greybull channels are absent, the low-stand erosional unconformity is at the base of the Fall River Sandstone and equivalent formations. During the pre-Greybull low-stand, sediment bypassed this region. During the subsequent marine transgression streams began to aggrade and to deposit sands of the Greybull. With the continued transgression, the Greybull fluvial sands graded upward into marginal marine (probably estuarine) sands, and finally were capped by marine shale. Subsurface mapping incorporated with surface data has resulted in identification of one major Greybull channel crossing the Northern Cheyenne Reservation.

The Greybull Sandstone is a proven petroleum reservoir in the region surrounding the Northern Cheyenne Reservation. Traps in the Greybull are combination traps requiring not only the presence of the channel sandstone but also structural closure. One potential Greybull exploration lead on the reservation was identified where a mapped structural closure coincides with a mapped Greybull channel.

Introduction

The Northern Cheyenne Indian Reservation is situated in south-central Montana, southeast of Billings (fig. 1). The reservation lies at the north end of the Powder River Basin within the foreland structural province. The nearly 480,000-acre reservation has no established oil or gas production, but potential for oil and gas discovery does exist.

Oil and gas production is well established in the Powder River Basin of Wyoming to the south and in the areas north and west of the reservation. On the reservation, however, only limited exploration drilling has been done; there are only 16 wells that have been drilled within the reservation boundaries. Geologic relations and trends indicate that oil and gas accumulations should be present on the reservation, but drilling has not been sufficient for their discovery. The main purpose of this research project was to stimulate exploration and to identify exploration leads that could be presented by the Northern Cheyenne Tribe to potential industry partners.

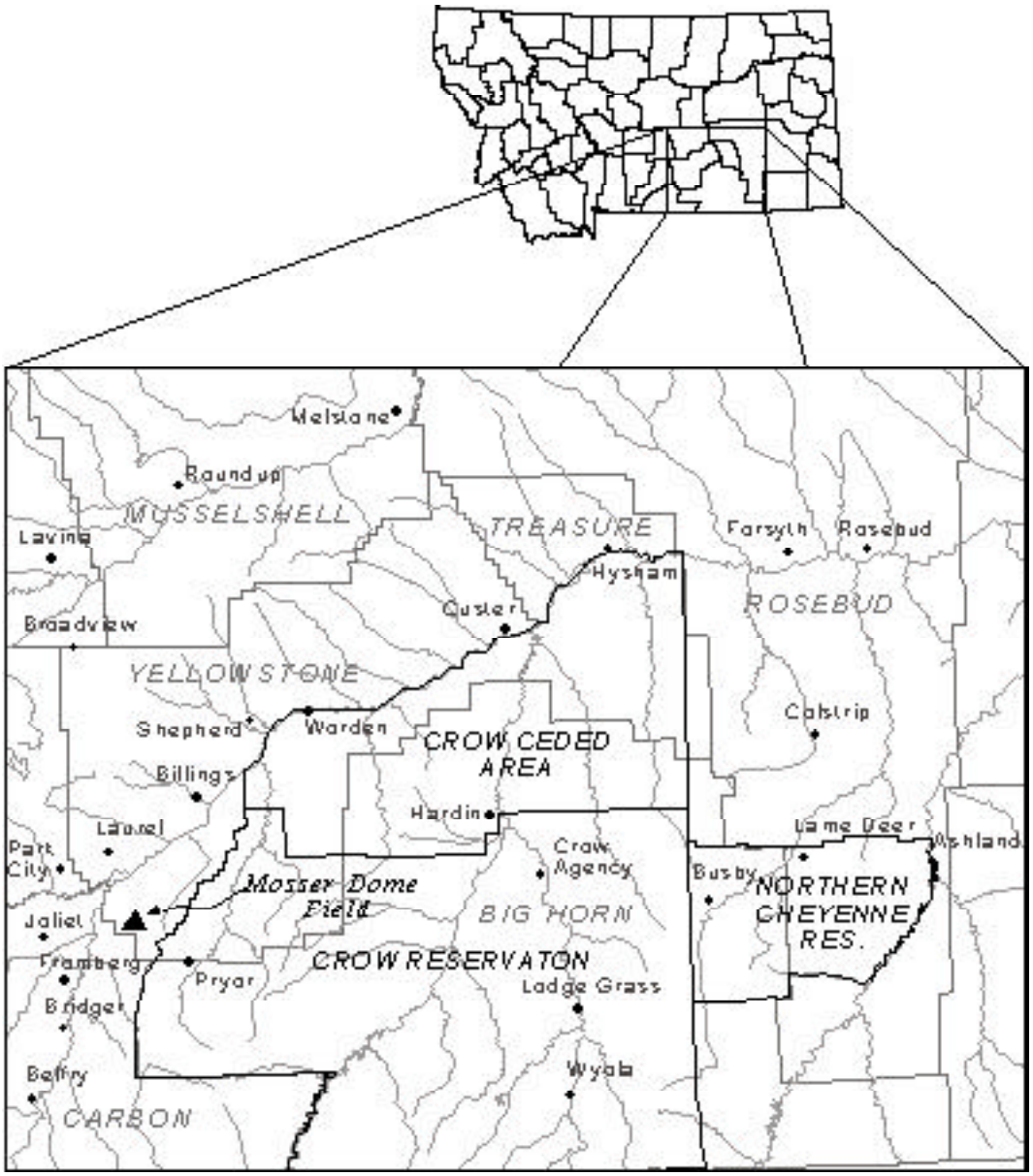

Figure 1. Location of the Cheyenne Reservation Area.

Research Project Objectives and Procedure

The focus of the project was to evaluate stratigraphic traps that may be present in valley-fill sandstone where it is present above the lower Cretaceous Kootenai Formation (fig. 2). This sandstone interval, generally known as the Greybull Sandstone, has been identified at several surface localities to the west on the Crow Reservation (Lopez, 2000 and Shelton, 1972) and is a known oil and gas reservoir in the surrounding region. The Greybull Sandstone produces hydrocarbons in the region of the Northern Cheyenne Reservation, such as at Mosser Dome Field (Hadley, 1954), just a few miles northwest of the Crow Reservation, and in Elk Basin and several other oil and gas fields in the northern part of the Big Horn Basin (Stone, 1986).

In the project area, the research procedure was to first locate exposures of Greybull Sandstone along the margins of the Pryor and Big Horn Mountains. These occurrences were then measured and described in detail; paleocurrent data were also collected. The

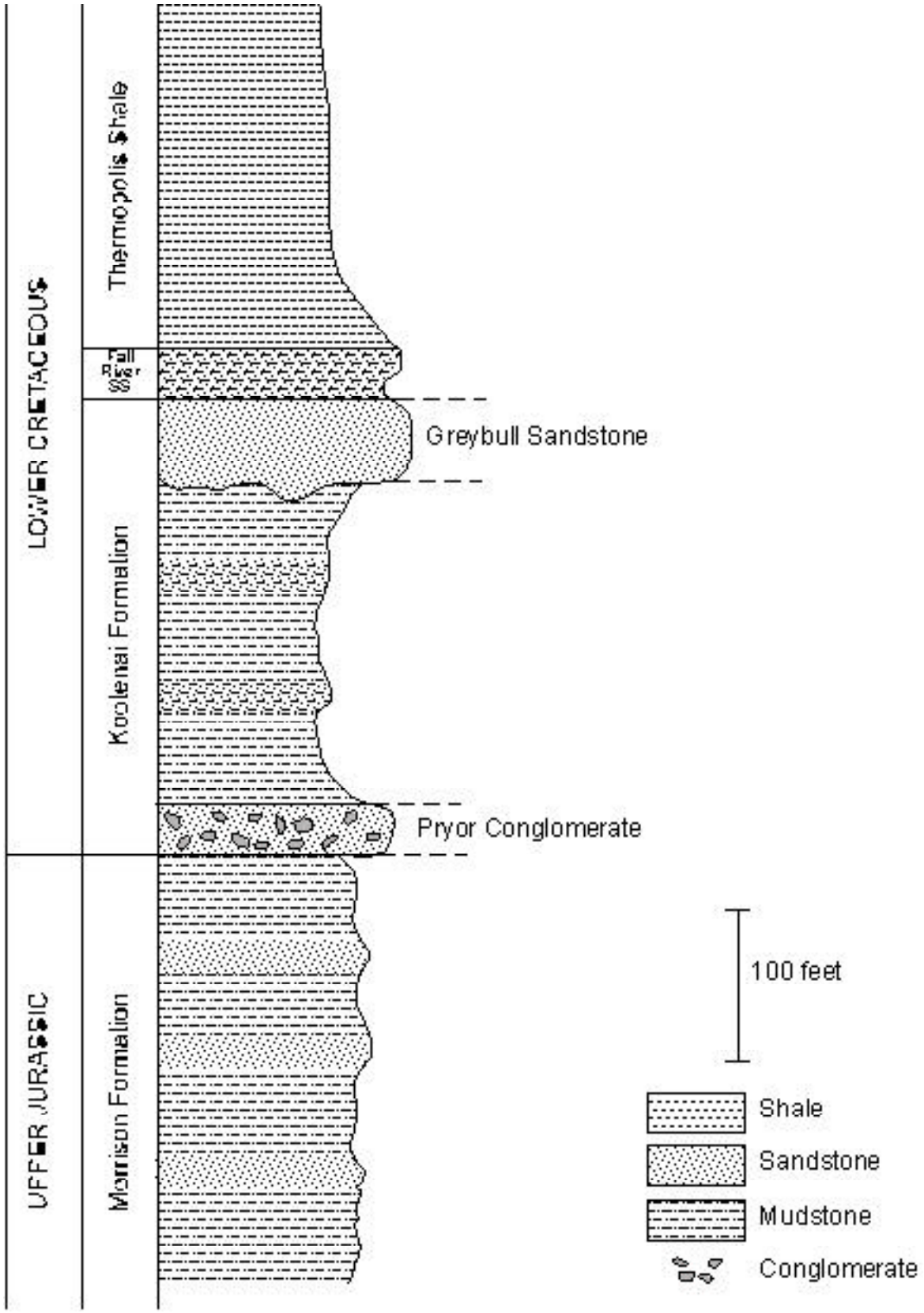

Figure 2. Stratigraphic relationships of the Kootenai Formation and Greybull Sandstone.

surface data were incorporated with sub-surface data collected from oil and gas exploration wells in the project area. Isopach maps were constructed to define the occurrences and trends of Greybull channels. The isopach maps, in conjunction with structure contour maps of the project area, were used to identify potential exploration leads on the Northern Cheyenne Reservation.

Acknowledgements

Research for this project was funded by the United States Department of Energy through the National Petroleum Technology Office (NPTO), Tulsa, Oklahoma, with partial matching funding from the Montana Bureau of Mines and Geology a department of Montana Tech of the University of Montana. The assistance and guidance of program managers, Rhonda Lindsey and Virginia Weyland of the NPTO is acknowledged and appreciated. The support and cooperation of the Northern Cheyenne Tribe, without which this project could not have been undertaken, are also greatly appreciated. The support of tribal members, Jason Whiteman, Ernie Robinson, and Francis (Gus) Harris, is also greatly appreciated.

Discussions with Eric Kvale, and Lloyd Furer, John Mitchell, and Ed Mathison gave valuable insight and helped develop the interpretations presented here. Students, Marzha Fritzler, Alicia Little Wolf, and John Yellowmule, assisted in the field and with data compilation; their help was invaluable to this research. Technical reviews of earlier versions of this report by Bob Bergantino, Wayne Van Voast, and Ed Deal were very helpful and are also much appreciated.

Structural Geology

The area of the Northern Cheyenne Reservation is part of the Rocky Mountain Foreland structural province, which is characterized by basement-involved Laramide uplifts and intervening structural basins. The Pryor Mountains and Big Horn Mountains to the west, like other foreland uplifts, are characterized by basement-involved reverse faults and associated asymmetric folds (Lopez, 2000).

The reservation area is on the northwestern flank of the Powder River Basin. Regional dips are eastward and southeastward toward the axis of the Powder River Basin (Plate 1). Structurally, the area can be described as a broad trough plunging to the southeast. In the northeast corner of the reservation an anticlinal ridge interrupts this pattern. Well control in the area is sparse but does allow for the possibility of isolated closures along this anticlinal trend (Plate 1).

Stratigraphy of the Greybull Interval

History of Stratigraphic Nomenclature

The Greybull Sandstone occurs at the top of the Kootenai Formation (fig. 2) and most workers in the past have included it as part of the Kootenai, or Cloverly Formation (Wyoming terminology). The stratigraphic name, Greybull, was first a driller's term applied in the subsurface of the northern Bighorn Basin, Wyoming (Lupton, 1916). It was named in the Greybull Oil Field near the town of Greybull, Wyoming where gas was discovered in the Greybull Sandstone in 1907 (Bartow-Campen, 1986). The name originates from Grey Bull, a chief of the Crow Tribe. In the early days of settlement of the northern Bighorn Basin, Grey Bull's band of Crows spent the winters in the present area of Greybull, Wyoming. The Crows and the early settlers became friends. Because of that friendship, when the population grew large enough for the organization of a town, it was named in honor of Chief Grey Bull.

Hewett and Lupton (1917) formally named the Greybull Sandstone after exposures near the town of Greybull, Wyoming and designated it as the uppermost member of the Cloverly Formation. There still remains some confusion as to whether the name, Greybull, was originally applied to fluvial lenticular sandstone at the top of the Kootenai or to marine sandstone above the Kootenai that correlates with the Fall River Sandstone (Dakota Sandstone, Sykes Mountain Formation).

Moberly (1960) divided the Cloverly into three members: the basal Pryor Conglomerate Member, the Little Sheep Mudstone and the Himes Member. His upper Himes Member is correlative with the Greybull Sandstone. The Little Sheep Mudstone is mainly variegated bentonitic mudstone; colors are mainly medium gray, pale reddish gray, and pale purple gray. The lower Himes is non-bentonitic, volcaniclastic, mainly gray, pale-greenish-gray, and yellowish-brown mudstone interbedded with minor lenticular, salt and pepper, pale-greenish-gray sandstone. The upper Himes (Greybull) is fine- to medium-grained, well-sorted, well-rounded quartz sandstone that is commonly planar cross bedded. Above the Cloverly, Moberly named rocks equivalent to the Fall River Sandstone, the Sykes Mountain Formation. These rocks are thin-bedded, fine-grained argillaceous, quartz sandstone and interbedded medium-gray fissile shale. The sandstone is typically hematitic or limonitic, which led to the early driller's designation as the "rusty beds". Marine fossils and trace fossils are common in the Sykes Mountain Formation.

Kvale (1986) and Kvale and Vondra (1993) referred to the Greybull Sandstone as Upper Himes member of the Cloverly formation, following the terminology of Moberly (1960).

The name, Greybull Sandstone, is in general use in the Northern Cheyenne Reservation region by most area geologists, although Balster (1971) recommended it not be used outside the northern Bighorn Basin (for example, Bartow-Campen, 1986; Shelton, 1972; John Mitchell, personal communication, 1996-2000, and Steve Van de Linder, personal communication 1999).

Stratigraphy In The Northern Cheyenne Reservation Area

The Greybull Sandstone interval is present in the subsurface in the Northern Cheyenne Reservation area, and stratigraphic relationships are like those in the northern Bighorn Basin (Kvale, 1986; Kvale and Vondra, 1993). In this area, the unconformity at the base of the Greybull is incised into the part of the Kootenai Formation that is equivalent to the Little Sheep Mudstone of Moberly (1960). These rocks are bentonitic pale red, pale grayish-purple, and gray mudstones. The Kootenai is 250 to 300 feet thick in areas between channels (see Lopez, 2000 Appendix A). The Lower Himes Member of Moberly (1960) is absent in the area, either by non-deposition or by erosional removal. The generalized sequence of units from the base of the Kootenai is: 1) Pryor Conglomerate, which is brown and brownish-gray, coarse-grained, pebbly sandstone and conglomerate generally about 50 to 100 feet thick, but is very thin near the Wyoming border on the east side of the Big Horn Mountains. 2) Little Sheep Mudstone equivalent, which is bentonitic, pale red, grayish-purple, and gray mudstone with thin interbedded lithic sandstone and cherty nodular limestone; 3) Greybull Sandstone (where present), which typically includes a basal interval of fine- to medium-grained well-sorted, well-rounded, planar cross-bedded quartz sandstone up to 150 feet thick, an interval of brownish gray marine shale about 20 feet thick, and an upper sandstone about 10 to 40 feet thick that is very similar to the lower sandstone; and 4) Fall River Sandstone, which has a basal marine shale interval up to 30 feet thick that grades upward into thin-bedded, fine-grained, argillaceous, brownish-gray, fossiliferous, limonitic to hematitic,

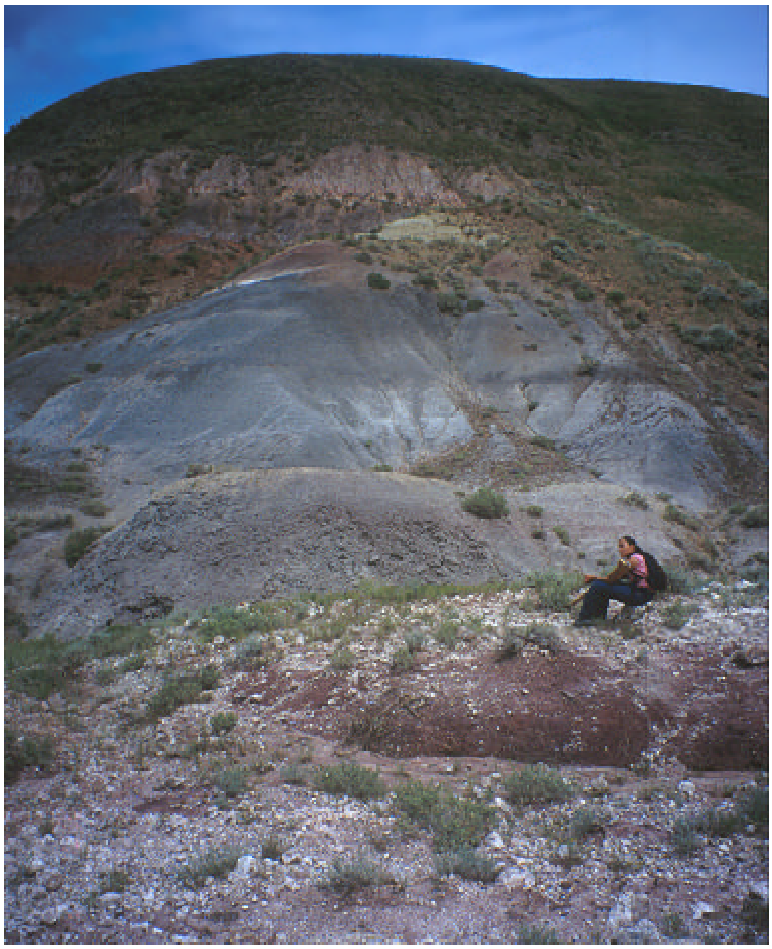

Figure 3. Kootenai (Kk) and Fall River (Kpr) section outside Greybull channel area. The regional unconformity is at the base of the Fall River Sandstone. (North Rotten Grass measured section, Crow Reservation, see *Lopez 2000)*

quartz sandstone interbedded with thin dark-gray shale (total thickness 75-100 feet). Outside Greybull channel areas, the erosional unconformity occurs at the base of the Fall River Sandstone, where it rests directly on mudstone of the Kootenai Formation (fig. 3). Where the unconformity at the base of the Greybull is exposed it is marked by a bleached interval up to 6 feet thick in the Kootenai mudstone.

The Greybull channels are sand filled on the Crow Reservation and in the subsurface on the Northern Cheyenne Reservation. The lower sandstone is as much as 150 feet thick. The maximum documented total thickness of channel fill is in a well in section 3, T. 8 S., R. 34 E. (on the Crow Reservation), where the thickness, including the lower and upper sandstones, is 215 feet. The base of the Greybull Sandstone contains rip-up clasts, wood fragments, and locally a small amount of pebbles. The sandstones are fine to medium grained, well sorted, clean quartz sandstones with large-scale tabular planar crossbed sets 1 to 5 feet thick (fig. 4). Generally the sandstone is light brownish gray because of speckled limonite stain. The cross beds are strongly unidirectional and are locally over-steepened to over-turned in the down-flow direction. Commonly the variation of cross-bed dip directions from the mean is 30(or less (see appendix B). The geometry and character of these fluvial sandstones indicate they were deposited in nearly linear fluvial-dominated channel systems (Kvale and Vondra, 1993). Gray mudstone, parallel lamination, and local bioturbation present at the top of the upper Greybull Sandstone indicate the beginning of marginal marine deposition in the upper Greybull.

Regional Sequence Stratigraphic Relationships of the Greybull Sandstone

Recent work in the Cretaceous of the western interior basin, including the results of the research reported here, leads to the conclusion that the Greybull Sandstone is part of the transgressive systems tract (terminology of Van Wagoner and others, 1990) that includes the Fall River Sandstone and that it overlies a major regional unconformity (Haun and Barlow, 1962; Weimer, 1984; Kvale and Vondra, 1993; Way, and others, 1994; and Mathison and White, 1999). This erosional surface is the +100 Ma, late Aptian-early

Albian regional unconformity of Weimer (1984) and Sequence Boundary 1 (SB1) of Porter and others, 1993). A basin-wide drop in sea level controlled this surface; that is, it is a low-stand surface of erosion. In areas where incised Greybull channels are absent, the low-stand erosional unconformity is at the base of the Fall River Sandstone and equivalent formations. During the pre-Greybull low-stand, sediment bypassed this region. During the subsequent transgression, streams began to deposit sands of the Greybull. With the continued transgression, the lower Greybull fluvial sands graded upward to marginal marine sands (probably estuarine) in the upper Greybull, and finally were capped by marine shale. The occurrence of these shales at the base of the Fall River Sandstone represents the initial marine flooding surface. A transgressive surface of erosion may be present at the base of the Fall River Sandstone. Similar relationships for the Greybull interval and equivalent rocks are now known in the Powder River Basin, Bighorn Basin, across Montana, and in Saskatchewan (Kvale and Vondra, 1993, Way and others, 1994, Mathison and White, 1999, Mathison, 1999). Regional stratigraphic relationships in Wyoming and Montana are shown in Figure 5. Analysis of sparse microflora in samples from within the Greybull interval yields ages of Middle to early Late Albian (Lloyd Furer, personal communication, 1999; Mathison and White, 1999, Mathison, 1999). Samples from surface exposures to the west, on the Crow Reservation, were barren of microfossils.

*Figure 4. Photograph looking north at Little Mountain section of Greybull Sandstone (on Crow reservation) showing typical tabular cross-bedding (*see *Lopez 2000).*

Greybull Channel Occurrences

Surface exposures of four separate Greybull channels were identified in the Kootenai-Fall River outcrop belt around the margins of the Pryor and Big Horn Mountains on the Crow Reservations (fig. 6) (Lopez, 2000). Paleocurrent analysis established that the channels have west or west-southwest current directions (Lopez, 2000), indicating that the channels should project eastward under the Northern Cheyenne Reservation. Subsequent subsurface mapping incorporated with surface data showed that one of these channels exposed at the surface extends across the Northern Cheyenne Reservation (fig. 6, Plate 2). Descriptions of all nearby surface exposures of Greybull channels on the Crow Reservation are available in Lopez, 2000. The typical subsurface

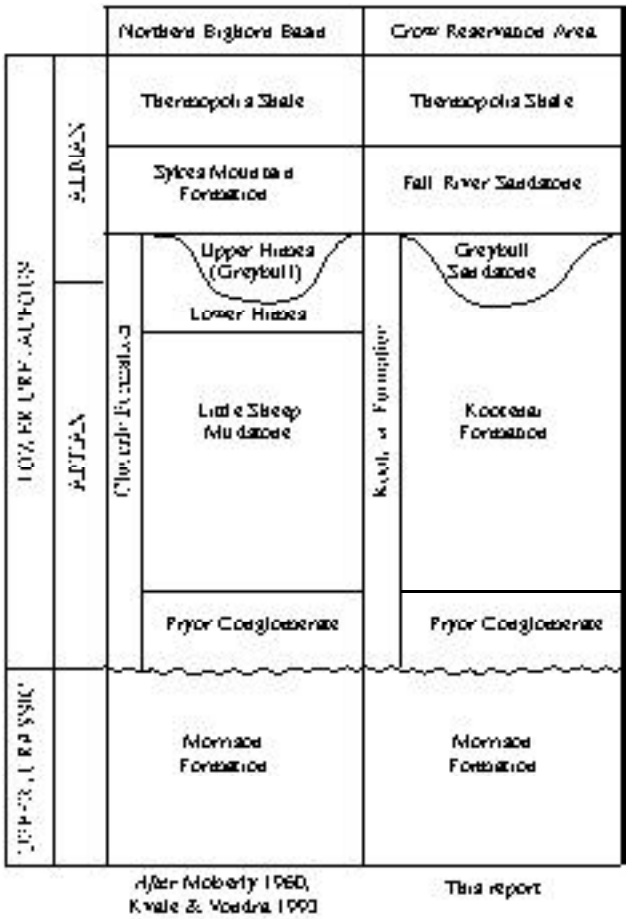

Figure 5. Regional stratigraphic nomenclature and correlations.

log signature of Greybull channels and non-channel areas is shown in Figure 7 and Plate 3.

Petroleum Potential in the Greybull Sandstone

The Greybull Sandstone is a proven petroleum reservoir in the Northern Cheyenne Reservation region. It produces oil and gas at Mosser Dome Oil Field, at Elk Basin, Golden Dome and several other fields in the northern Bighorn Basin. Regionally, the Greybull Sandstone, is known to possess excellent reservoir qualities: up to 30% porosity and up to 1 darcy of permeability (Bartow-Campen, 1986). Mosser Dome Field has produced about 400,000 barrels of oil (Montana Board of Oil and Gas Conservation data) from Greybull channel sandstone about 50 feet thick in a domal structural closure of about 60 acres (Hadley, 1954). At Elk Basin a volume of 51.4 billion cubic feet of gas was produced from the Greybull between 1922 and 1949, after which the reservoir was converted to gas storage (Stone, 1986). Production is from about 30 feet of upper Greybull Sandstone in a structural closure of about 2000 acres (Stone, 1986). The total Greybull channel fill is up to 150 feet thick in the Elk Basin Field area (Stone, 1986).

As can be seen in the Elk Basin and Mosser Dome examples, as well as other fields in the Bighorn Basin that produce from the Greybull, the traps are combination traps, requiring not only the presence of the channel sandstone but also structural closure. In the crest of the dome at Soap Creek Oil Field on the Crow Reservation, the Greybull Sandstone is oil stained and was apparently oil saturated, but has been breached by erosion along Soap Creek. This occurrence of oil saturation is very significant in evaluating the potential of the Greybull on the Northern Cheyenne Reservation because it establishes that: 1) oil was generated and migrated into the Greybull Sandstone; and 2) an accumulation of oil is possible in a favorable structural trapping configuration.

Therefore, potential Greybull exploration leads on the Northern Cheyenne Reservation were identified where mapped structural closures are coincident with mapped Greybull channels. Structure was mapped on the Dakota Silt marker, a regional marker about 200 feet above the Greybull interval (plate 1). The interpretation shown on the isopach map of Greybull channel fill, shows that one major channel should cross the reservation (plate 2). Another channel crosses just the northwest corner of the reservation.

On the Northern Cheyenne Reservation a potential exploration lead occurs where the Greybull channel crosses an anticlinal ridge in the northeast part of the reservation; T3S, R42E (Plate 4). Well control is limited, but the available structural data allows the

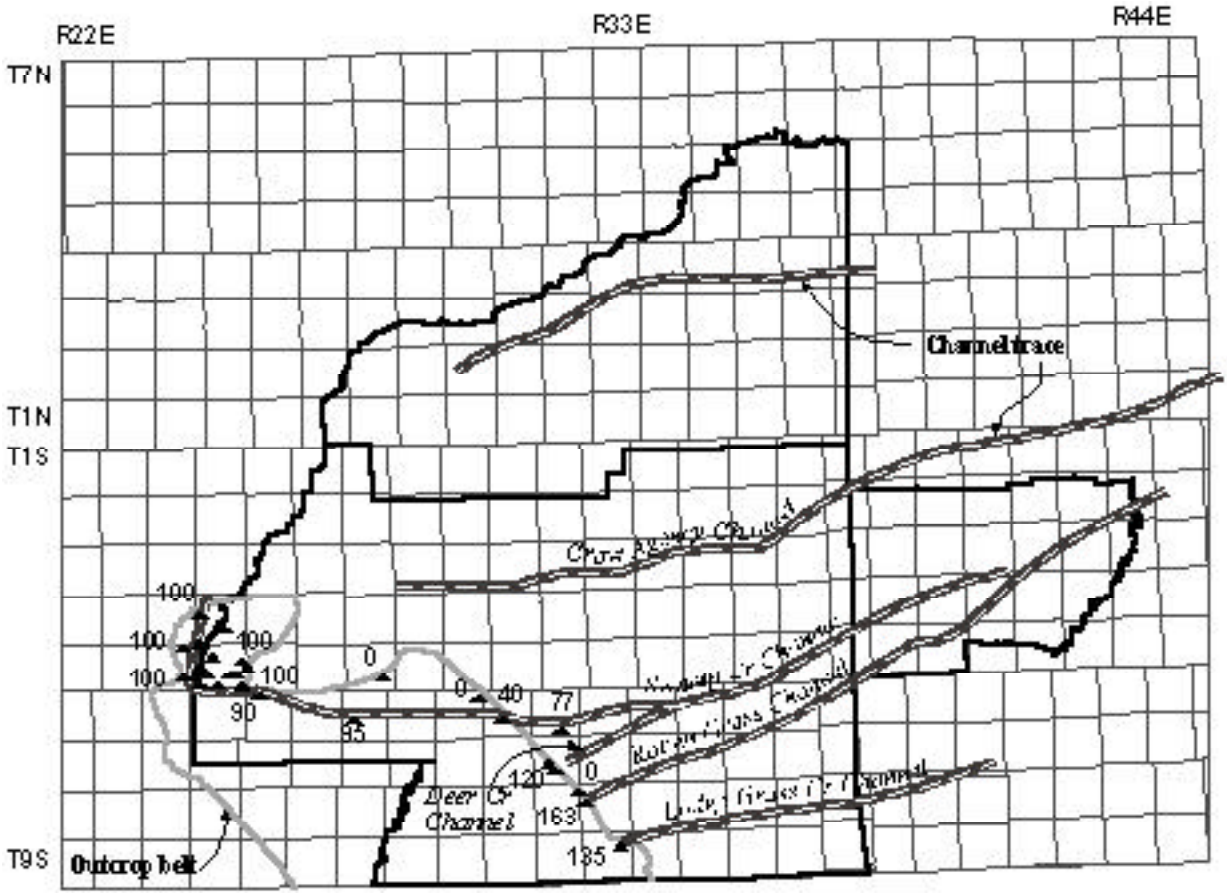

Figure 6. Greybull channel occurrences on the Crow and Northern Cheyenne reservations; triangles along the outcrop margin indicate locations of surface exposures examined and give the thickness of corresponding Greybull channel fill.

interpretation of a closure along this ridge that could form a structural trap for hydrocarbons. Assuming a conservative productive area of 640 acres and a reservoir pay thickness of about 50 feet, potential reserves for this lead could be 6.4 million barrels of oil (MMBO). This number is based on a recovery factor of 200 BO/acre-ft derived from Mosser Dome, which produced 400,000 BO from 60 acres and 30 feet of pay; which yields a recovery factor of 222 BO/acre-ft. Because of the limited well control this lead probably will require confirmation by some other technique such as soil-gas geochemistry or seismic exploration.

Summary and Conclusions

The focus of the project was to evaluate stratigraphic traps that may be present in valley-fill sandstone of the lower Cretaceous Greybull Sandstone. The Greybull Sandstone is part of the transgressive systems tract that includes the overlying Fall River Sandstone and was deposited on a major regional unconformity. The erosional surface at the base of the Greybull is the +100 Ma, late Aptian-early Albian regional unconformity of Weimer (1984). A basin-wide drop in sea level controlled this surface; that is, it was a low-stand surface of erosion. In areas where incised Greybull channels are absent, the low-stand erosional unconformity is at the base of the Fall River Sandstone and equivalent formations. During the pre-Greybull low-stand, sediment bypassed this region. During the subsequent transgression, streams began to aggrade and to deposit

sands of the Greybull. With the continued transgression, the Greybull fluvial sands graded upward into marginal marine (probably estuarine) sands, and finally were capped by marine shale. Interpretations based on subsurface mapping and surface data indicate that one major Greybull channel crosses the Northern Cheyenne Reservation (fig. 7).

The Greybull Sandstone is a proven petroleum reservoir in the Northern Cheyenne Reservation region. As can be seen from the Elk Basin and Mosser Dome examples, as well as from other fields in the Bighorn Basin that produce from the Greybull, the traps are combination traps, requiring not only the presence of the channel sandstone but also structural closure. Therefore, potential Greybull exploration leads on the Northern Cheyenne Reservation were identified where mapped structural closures are coincident with mapped Greybull channels. One exploration lead has been identified in the northeast corner of the reservation.

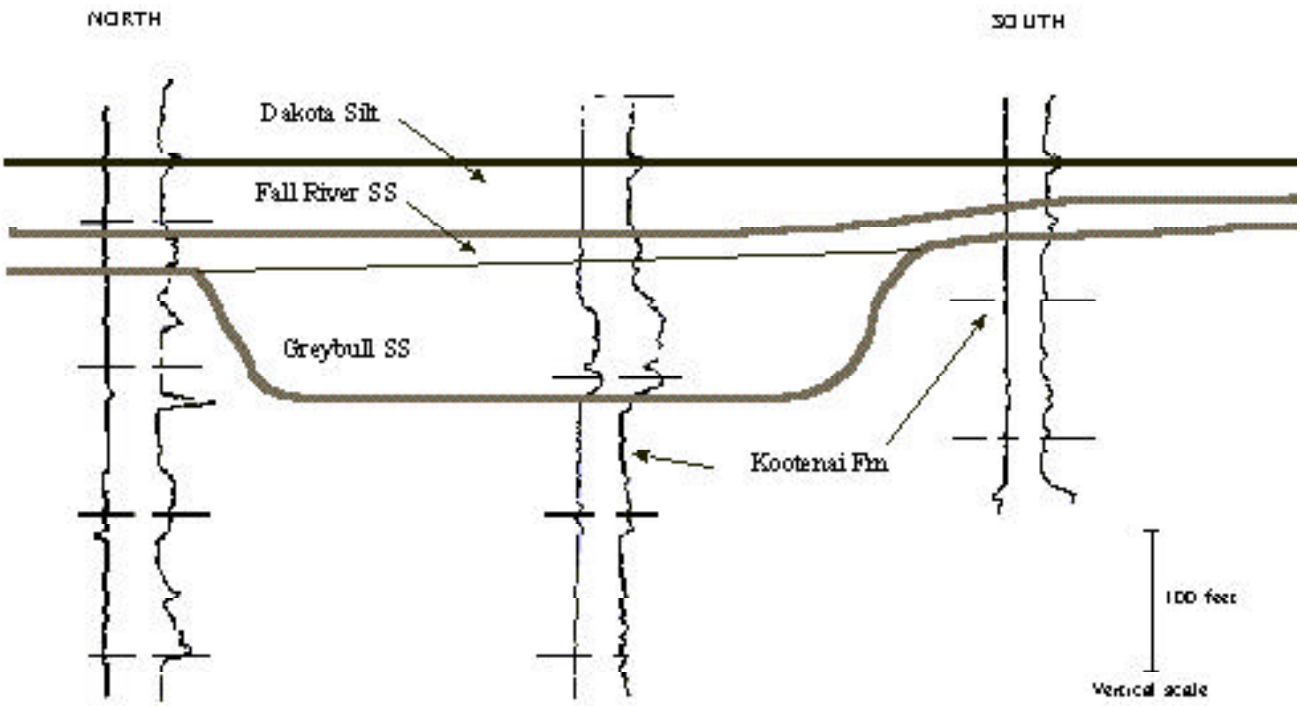

Figure 7. Subsurface SP and resistivity log characters of a Greybull channel at Lodge Grass Field, Crow Reservation, Montana; stratigraphic cross section hung on the Dakota Silt marker.

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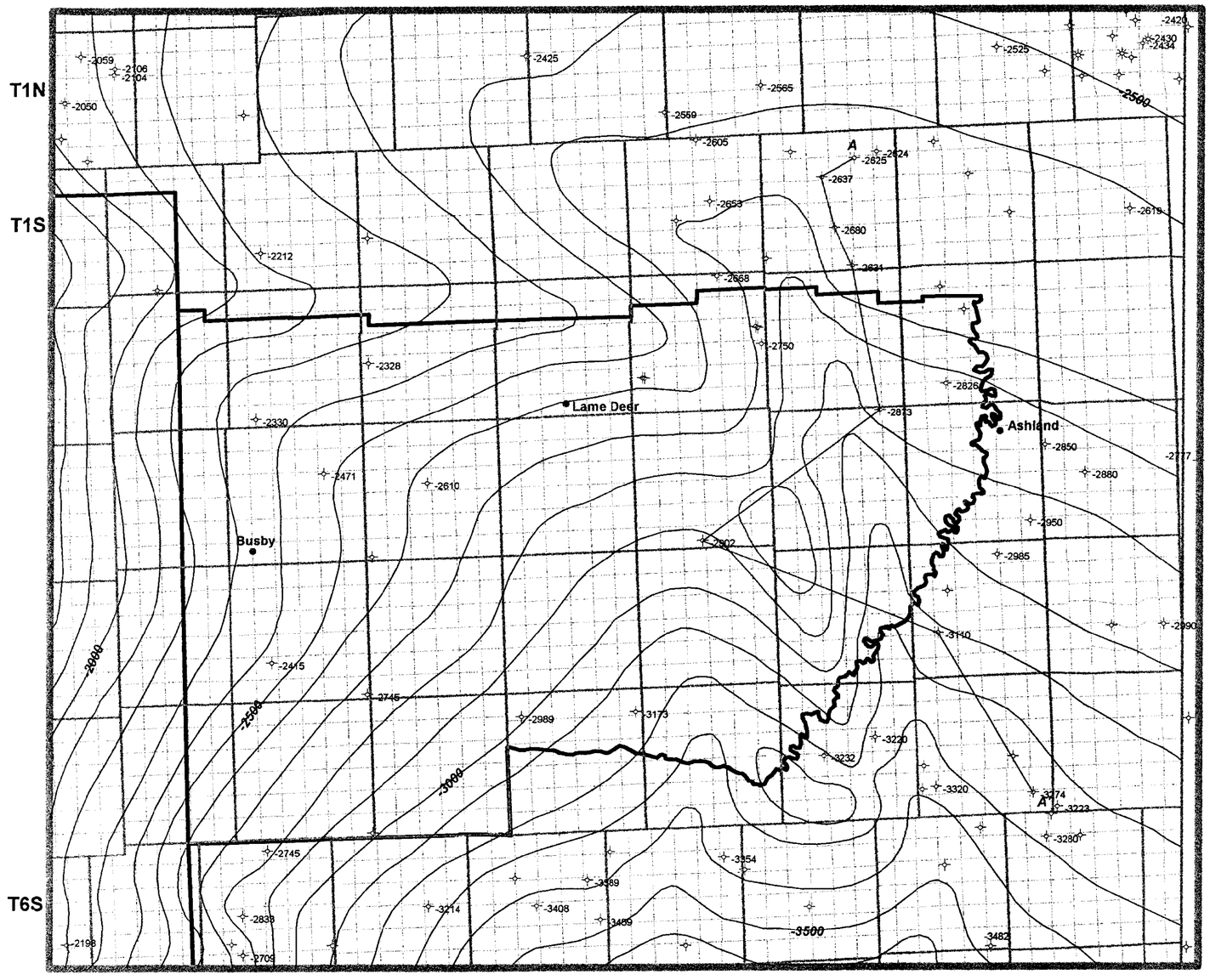
PLATE 1



Structure contour lines are drawn on basis of limited well control and are therefore, speculative and approximate.

Scale = 1:250,000

Structure contour lines
Contour interval = 100 ft

Reservation Boundary

Trace of Cross Section A-A' of Plate 3

Well Symbols
posted values are elevation of Dakota Silt
wells with no data did not penetrate deep enough

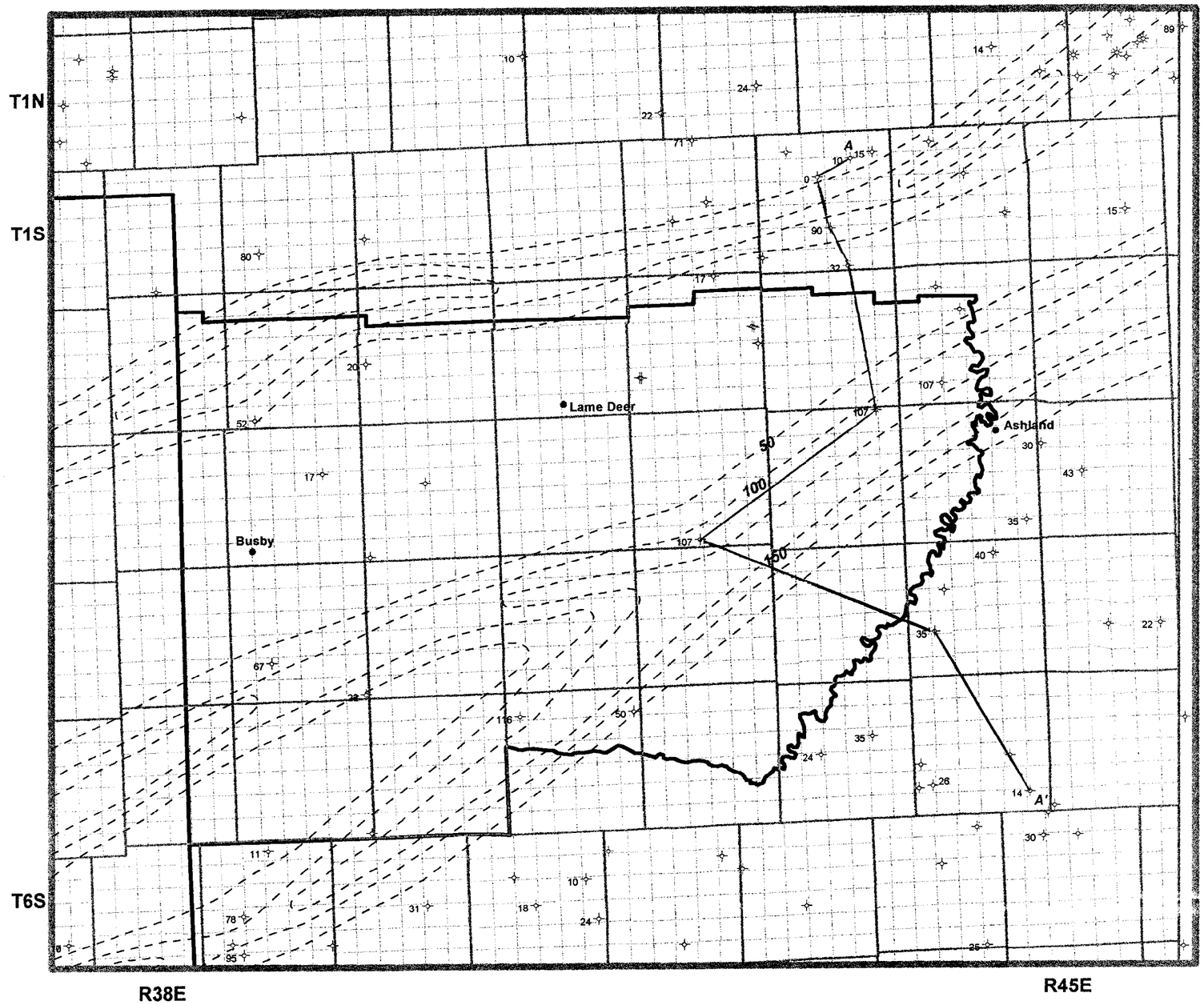
D&A

GAS

PLATE 1 - STRUCTURE CONTOUR MAP ON THE DAKOTA SILT NORTHERN CHEYENNE RESERVATION AREA

David A. Lopez, 2000

PLATE 2



N

Greybull valley fill isopach contour lines
Contour interval = 50 ft

Reservation Boundary

Trace of Cross Section A-A' of Plate 3

Well Symbols
values posted are thickness of Greybull valley fill
wells with no data did not penetrate deep enough

D&A

GAS

Isopach linesare drawn on basis of limited well control. Surface paleocurrent information from the Crow Reservation to the west (see Lopez, 2000) is also incorporated. Interpretation of channel ditstribution is, therefore, speculative and approximate.

Scale = 1:250,000

PLATE 2 - GROSS THICKNESS ISOPACH MAP OF GREYBULL VALLEY FILL NORTHERN CHEYENNE RESERVATION AREA

David A. Lopez, 2000

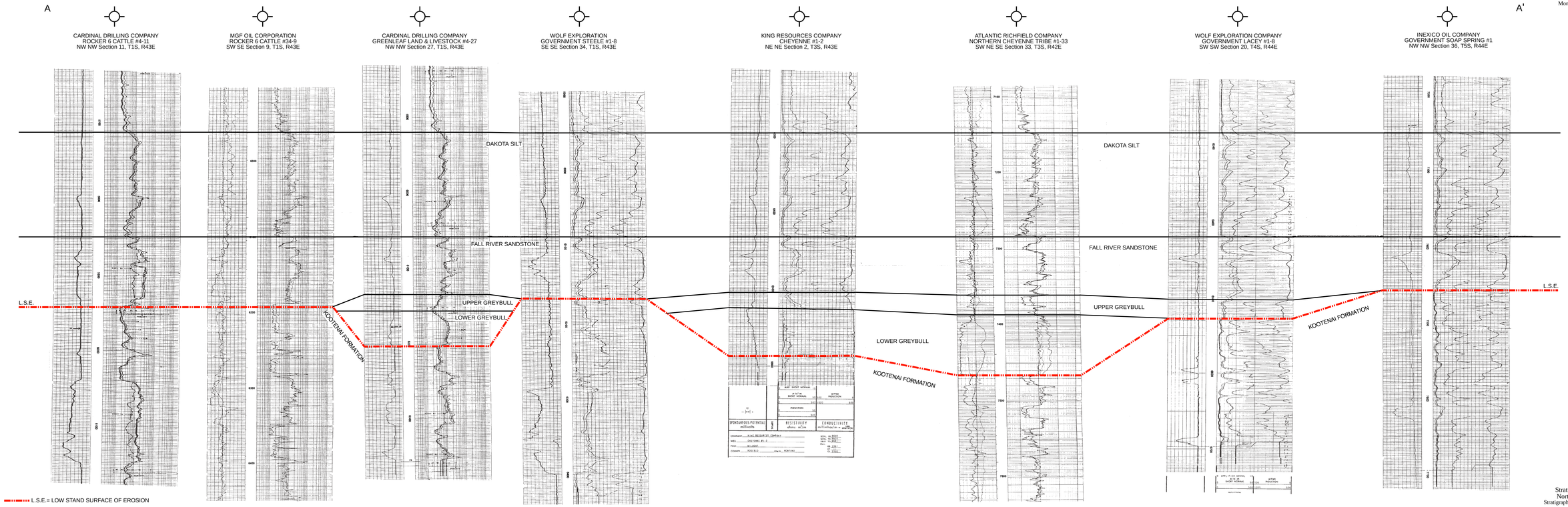
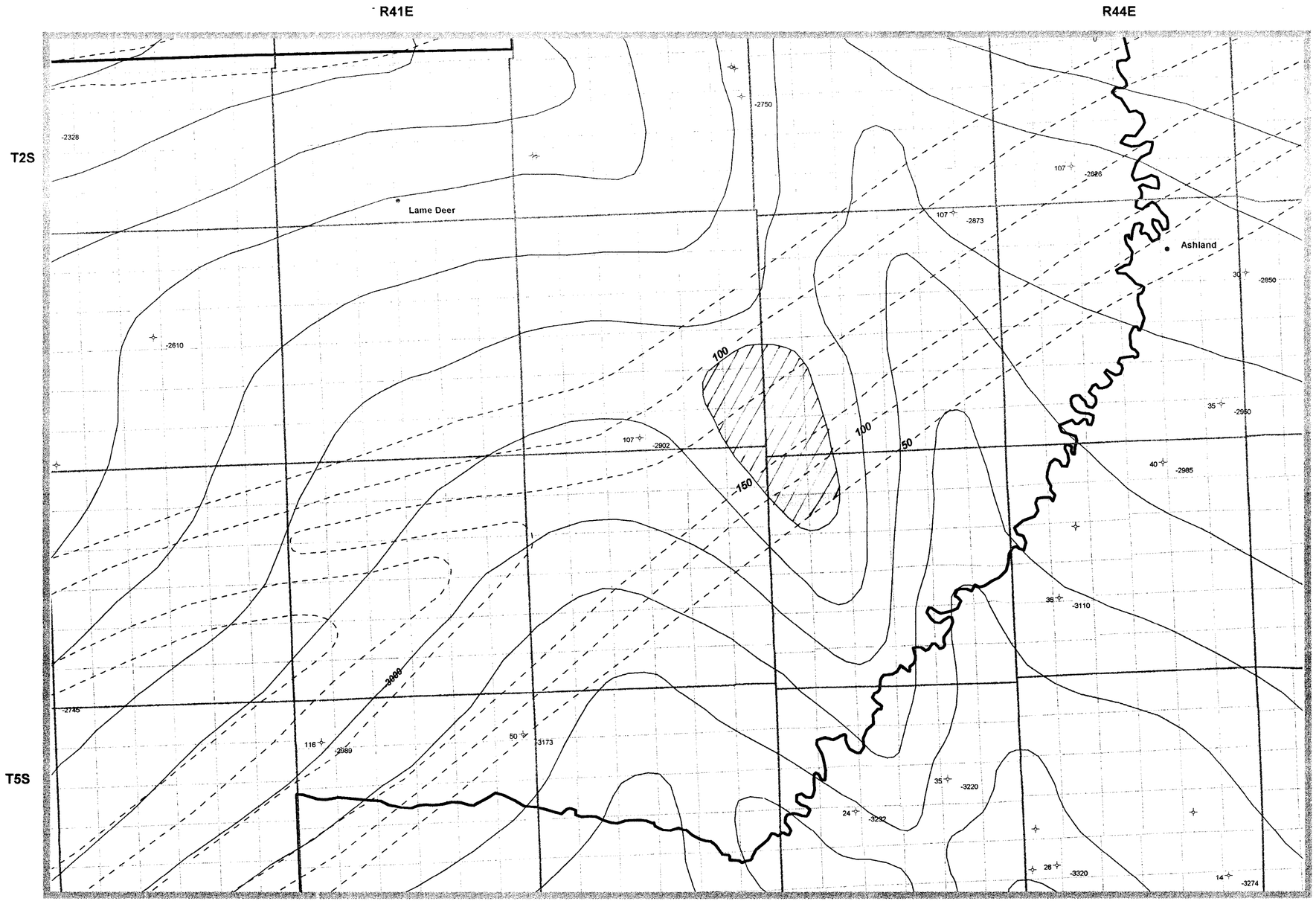


Plate 3
Stratigraphic Cross Section A--A'
Northern Cheyenne Reservation
Stratigraphic datum is of of Fall River Sandstone

Location of cross section show on Plate 2

PLATE 4



N

Greybull valley fill isopach lines,
Contour interval = 50 ft

Structure Contour lines, drawn on Dakota Silt
Contour Interval = 100 ft

Reservation Boundary

Well Symbols
Greybull valley fill thickness posted to left
Dakota Silt elevation posted to right

D&A

GAS

SCALE = 1:100,000

PLATE 4 - POTENTIAL OIL AND GAS LEAD IN GREYBULL VALLEY-FILL SANDSTONE NORTHERN CHEYENNE RESERVATION

David A. Lopez, 2000

Openfile MBMG 416