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Description and Genesis of the Western Cold Turkey Creek Field Anomaly, Williston Basin, Bowman County, North Dakota

Karyn A. Alme

Description and Genesis of the Western Cold Turkey Creek Field Anomaly,
Williston Basin, Bowman County, North Dakota

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Karyn A. Alme
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This thesis, submitted by Karyn A. Alme in partial fulfillment of the requirements for the Degree of Masters of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Richard D. [signature]
(Chairperson)

[signature] Forman

Ahmad [signature]

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ABSTRACT

The western Cold Turkey Creek structural anomaly is a subsurface structure in Bowman County, North Dakota, near the southern margin of the Williston Basin. The structure was identified by oil explorationists as a possible impact crater, but its origin remained uncertain. The purpose of this study is to attempt to ascertain if sufficient evidence exists to determine that the anomaly is of impact origin.

The study area was confined to a nine township area surrounding the anomalous structure in Bowman County, North Dakota. One hundred six oil exploration wells were identified in the area, and well logs were examined and interpreted for each. The resulting data were used to generate an isopach map for each of twenty-nine lithologic units identified, and an additional five structure contour maps were generated on the tops of conformable units. Units were correlated and two cross-sections through the structure were generated. One core from a well which penetrated the structure was available for study; it was examined and described. Previously published seismic data were also evaluated and interpreted.

Examination of the isopach maps reveals that significant variations in the thickness of multiple lithologic units occur both within the structural anomaly and in the surrounding study area. Results of this study indicate that all of the lithologic units present within the study area are continuous across the structural anomaly, except one which is discontinuous throughout the study area and doesn't occur in the structure.

Examination of the core revealed nothing suggestive of shock due to explosive impact cratering; only normal sediments were seen. Seismic data and structure contour maps indicate that the shape of the structure is neither circular nor bowl-shaped. Cross sections clearly demonstrate that the anomalous structure developed intermittently from at least the Ordovician until possibly as late as Early Jurassic.

The western Cold Turkey Creek structural anomaly is interpreted to be a complex structure with a long history of development, exhibiting rapid thickness variations over small areas that are suggestive of multiple episodes of up and down motion within the structure. The shape of the structure is inconsistent with that of impact craters, and there is a lack of secondary evidence, such as shatter cones or planar deformation features, to suggest impact as a causal factor. Stratigraphic units appear continuous across the structure and do not show the effects of deformation by hypervelocity impact. The subtle variations in shape, size, and location of the structure suggest that it has developed over a long period of time and therefore, is not the result of an instantaneous event.

INTRODUCTION

General

The western Cold Turkey Creek field anomaly is a subsurface structure located in Bowman County, North Dakota, near the southern margin of the Williston Basin (Fig. 1). The origin of this structure is uncertain however, it exhibits several characteristics similar to other structures in the Williston Basin that have been identified as impact structures.

Purpose

The purpose of this study is to attempt to ascertain whether sufficient evidence exists to determine that the western Cold Turkey Creek field anomaly is of impact origin. Impact events are instantaneous, explosive events. Craters resulting from such events tend to be circular or oval and bowl shaped, with a raised rim, and, depending on size, a central peak. Impact events in the buried rock record are characterized by abrupt lithology changes, including but not limited to missing units, overturned units, and discontinuous, disrupted or brecciated units. Analysis of the data collected in this study will help to determine whether or not the structure is due to an impact event.

Study Area

The area of study for the purpose of this investigation was confined to a nine township portion of Bowman County, North Dakota: Townships 129, 130, 131 North, Ranges 101, 102, and 103 West. There are several oil fields within these townships,

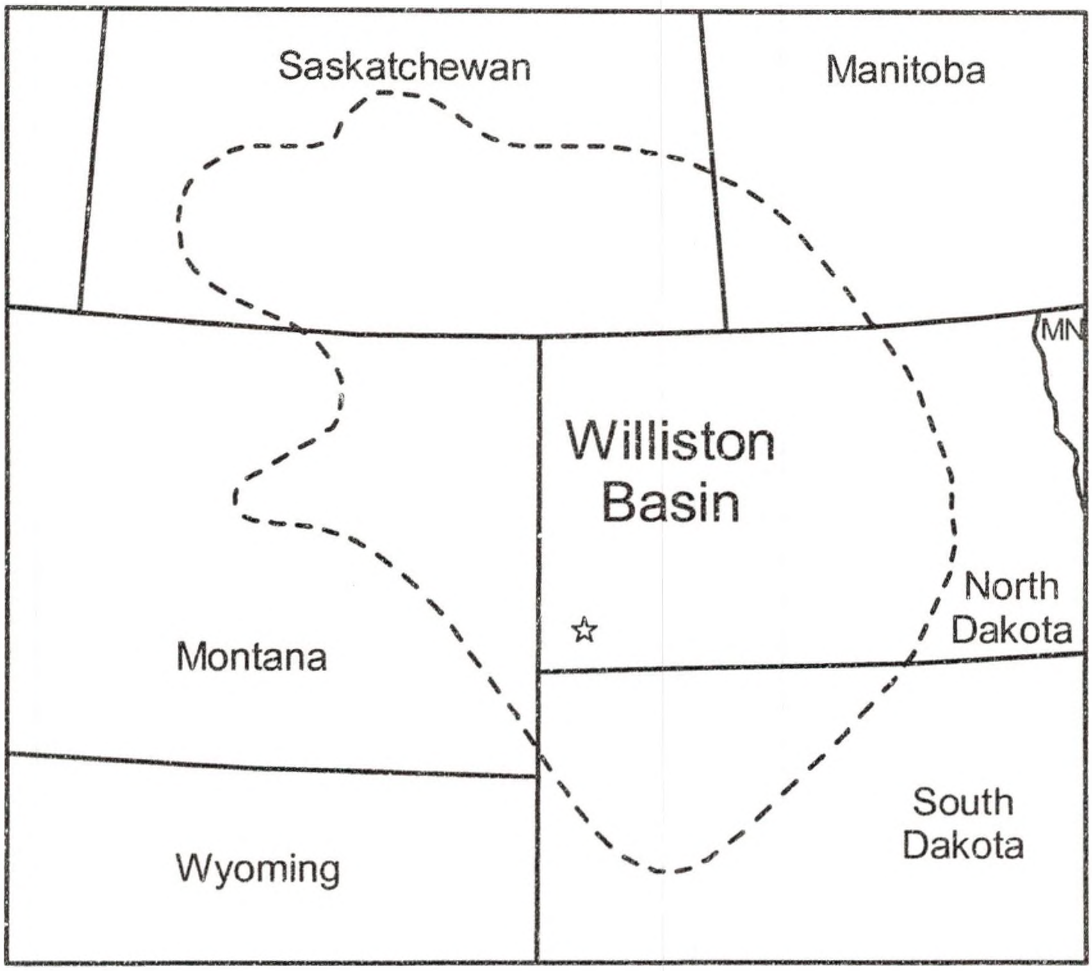


Figure 1. The position and extent of the Williston Basin, relative to the location of the study area. (Modified slightly from Laird, 1956). The star represents the study area location.

either in whole, or in part. Among them is the Cold Turkey Creek field. The western Cold Turkey Creek field anomaly is located in the southwestern corner of Township 130 North, Range 102 West, Bowman County, North Dakota, adjacent to the Cold Turkey Creek oil field (Fig. 2).

Previous Work

From 1969 to 1983, oil explorationists drilled in the anomalous area of the Cold Turkey Creek field due to its seismic patterns bearing a resemblance to those of other impact structures in the Williston Basin (Gerhard et al., 1995). Although there is a lack of published data, explorationists had regarded the Cold Turkey Creek anomaly as a possible impact cratter.

However, Gerhard et al. (1995) demonstrated that small-scale tectonic features could account for the structural anomaly, rather than meteoroid impact or salt dissolution as causal factors. They concluded that the Cold Turkey Creek structure is the result of the interaction between small well-defined basement core blocks moving independently of each other. Gerhard et al. (1995) used orthophotoquad map interpretations of surficial drainage patterns and lineaments, reflection seismic data, and artificial dipmeter reconstruction.

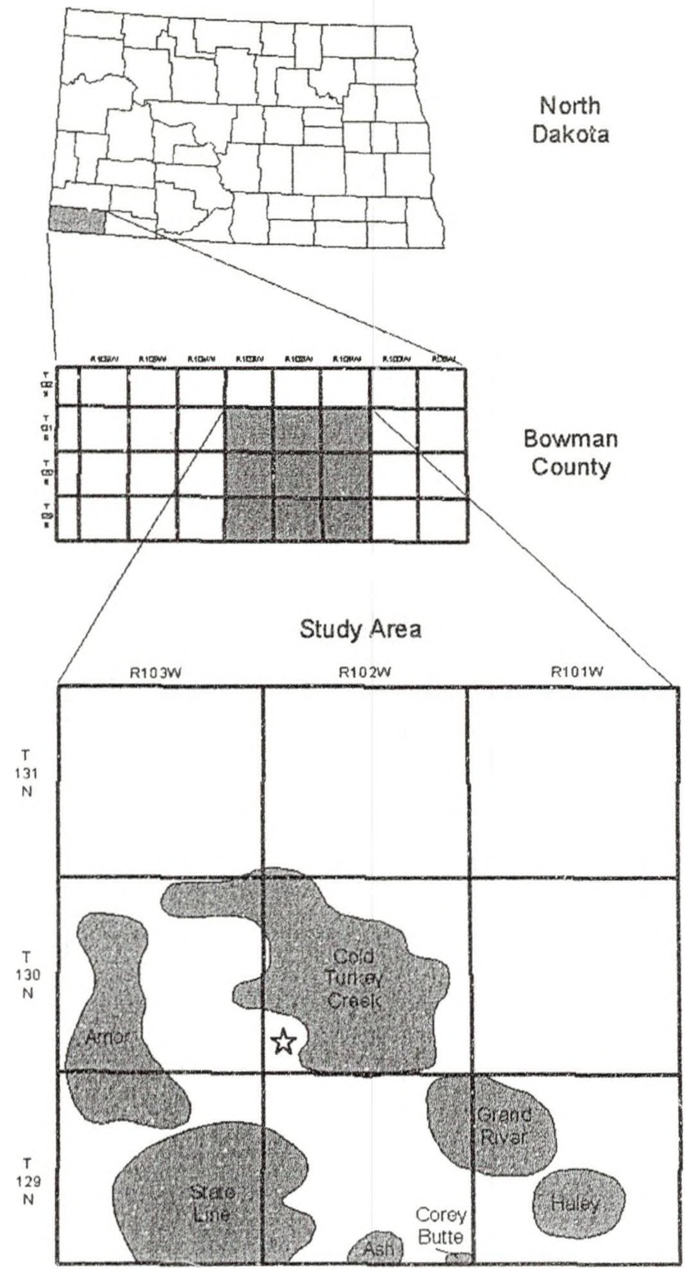


Figure 2. Location of the Study Area, Western Cold Turkey Creek Structural Anomaly, Cold Turkey Creek Field, Bowman County, North Dakota. The star represents the approximate location of the structural anomaly.

REGIONAL SETTING

General

The Williston Basin is a prominent geologic feature in the northern Great Plains. It is a slightly irregular, relatively shallow, intracratonic basin centered in western North Dakota (Carlson and Anderson, 1965). Although the basin includes some 51,000 square miles of North Dakota, it also extends into a significant part of southern Saskatchewan, the southwestern corner of Manitoba, the northwestern portion of South Dakota, and the eastern and north eastern parts of Montana. The outline of the Williston Basin (Fig. 1) is commonly defined by the zero elevation line of the Dakota Sandstone (Laird, 1956) due to its readily identifiable character in wire-line well logs. The Williston Basin is comprised of sedimentary rocks which range in age from late Cambrian to Recent and which reach a maximum thickness of approximately 16,000 feet in western North Dakota (Gerhard et al., 1982). Rocks representing all periods of Phanerozoic time are present within the basin, and occur over a wide area (Gerhard et al., 1982). The relatively quiet tectonic history of the basin and large areal extent of strata facilitate detailed correlation of rock units over large areas (Sawatzky, 1975).

The Williston Basin contains structures of various sizes (Fig. 3). These structures include the large-scale Nesson and Cedar Creek anticlines, other smaller-scale anticlines, faults, and lineaments (Gerhard et al., 1982) as well as impact structures, such as the Red Wing Creek structure (Koeberl and Reimold, 1995) and the Newporte structure (Forsman et al., 1996). The western Cold Turkey Creek Field structural anomaly is also located within the Williston Basin, and is a comparatively small scale structure.

Regional Stratigraphy

The Bighorn Group, of Middle Ordovician to Early Silurian age, contains three formations: the Red River, the Stony Mountain, and the Stonewall (Bluemle et al., 1986). The Red River Formation (Ordovician) is largely composed of limestone and dolomitic limestone. The carbonates of the Red River Formation lie conformably above the terrigenous rocks of the Middle Ordovician Winnipeg Formation (Carroll, 1979). The strata of the Red River Formation are laterally continuous across most of the Williston Basin, and are a source of commercial oil production within the study area (Hvinden, 2001). The Stony Mountain Formation conformably overlies the Red River Formation, and is divided into two members. The lower, or Stoughton member, is mostly interbedded limestone and shale. The upper, or Gunton Member, is composed of dolomite and limestone (Bluemle et al., 1986). The Stonewall Formation lies stratigraphically above the Stony Mountain Formation and is composed of limestone and dolomite with some thin beds of anhydrite (Bluemle et al., 1986), (Fig. 4).

The Interlake Formation (Silurian) is composed of limestone and dolomite, divided into three units: lower, middle, and upper. The lower part is finely crystalline dolomite with thin anhydrite interbedding; the middle portion is fine– to medium-crystalline dolomite; the upper part is dolomite and limestone, silty and sandy near the base (Bluemle et al., 1986). Although sedimentation was continuous from the beginning of Red River deposition through the Silurian, the top of the Interlake Formation is marked by an unconformity, the result of regressing seas (Gerhard et al., 1982).

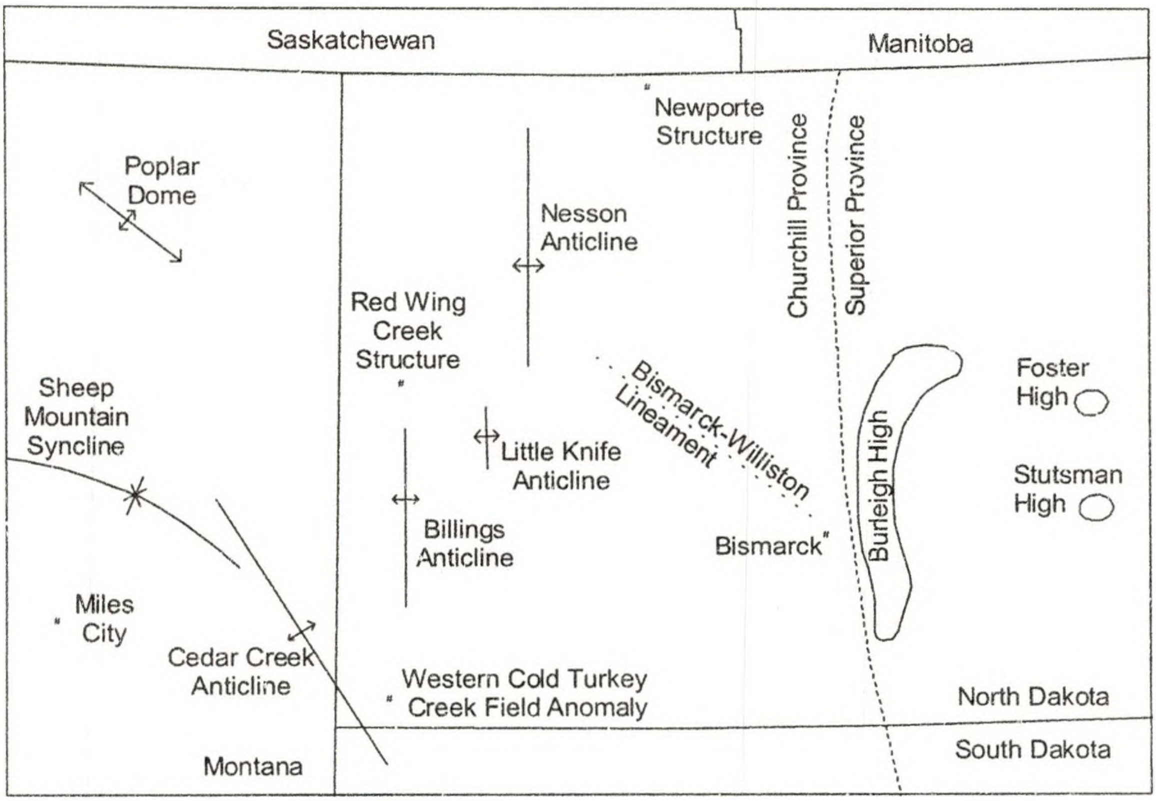


Figure 3. Prominent structural features within the Williston Basin of eastern Montana and western North Dakota (Modified slightly from Gerhard et al., 1982).

Age	Group	Formation	Member
Cretaceous	Montana	Pierre	
	Colorado	Niobrara	
		Carlile	
		Greenhorn	
		Belle Fourche	
	Dakota	Mowry	
		Newcastle	
		Skull Creek	
		Inyan Kara	
Jurassic		Swift	
		Rierdon	
		Piper	
Triassic		Spearfish	Saude
Permian			Pine Salt
			Belfield
		Minnekahta	
		Opeche	
	Minnelusa	Broom Creek	
Pennsylvanian		Amsden	
		Tyler	
Mississippian	Big Snowy	Otter	
		Kibbey	Kibbey sandstone
			Kibbey limestone
			Kibbey shale
	Madison	Charles	
		Mission Canyon	
		Lodgepole	
Devonian		Three Forks	
	Jefferson	Birdbear	
		Duperow	
	Manitoba	Souris River	
		Ashern	
Silurian		Interlake	
Ordovician	Big Horn	Stonewall	
		Stony Mountain	Gunton
			Stroughton
		Red River	
	Winnipeg		
Cambrian		Deadwood	
Precambrian	Wyoming Province		

Figure 4. Generalized stratigraphic column of the study area.

The Ashern Formation (Lower Devonian), is a dark-gray to brick-red dolomite (Bluemle et al., 1986). The study area is located near the southwestern margin of the Ashern Formation's areal extent in the Williston Basin, and as a result, is intermittent to discontinuous within the study area (Carlson and Anderson, 1965).

The Souris River Formation is Middle Devonian. It consists of limestone, dolomite, and thin interbeds of shale, silt and evaporites, representing a cyclic pattern of deposition (Bluemle et al., 1986).

The Late Devonian Jefferson Group is divided into the Duperow and Birdbear Formations. The Duperow Formation lies stratigraphically above the Souris River Formation, and also consists of carbonates, primarily limestone and dolomite. Shale is also present, but in smaller quantities than in the Souris River Formation. The Birdbear Formation is primarily limestone with some dolomite and small amounts of anhydrite (Bluemle et al., 1986).

The Three Forks Formation (Upper Devonian), consists of red and green siltstones and shales, interbedded with dolomite and anhydrite (Carlson, 1967). A thin layer of sandstone occurs at the top of the Three Forks Formation (Bluemle et al., 1986).

The Madison Group ranges in age from Early Mississippian to Late Mississippian, and is divided into three formations: the Lodgepole, the Mission Canyon, and the Charles. The Lodgepole Formation forms the lower portion of the Madison Group. It is a light- to dark-gray, generally dense limestone. The Mission Canyon Formation consists of yellowish-brown to brownish-gray limestone, often fragmental, oölitic, and cherty. It contains intertonguing lenses of anhydrite and shaly dolomitic limestone (Bluemle et al., 1986). The Charles Formation is primarily composed of evaporites, with interbedded halite anhydrite, mudstone, dolomite, and shale. The Lodgepole, Mission Canyon, and Charles Formations are facies that have a complex intertonguing relationship with one another, and cut across log markers (Carlson and Anderson, 1967; Bluemle et al., 1986).

The Big Snowy Group is Late Mississippian and is divided into two formations: the Kibbey and the Otter. The Kibbey Formation conformably overlies the Charles Formation and is divided into three lithologic units. The lowest of these units is the Kibbey shale, which is reddish in color, silty and interbedded with gypsum. The middle unit is the Kibbey limestone. It varies in color from white to brown and is often dense and dolomitic. The "Kibbey lime" is an excellent log marker. The upper unit is the Kibbey sandstone which is reddish to light-gray in color and fine- to medium-grained (Bluemle et al., 1986). The Otter Formation lies stratigraphically above the Kibbey sandstone and occurs predominantly as variegated greenish- and reddish-gray carbonaceous shale. Some thinly bedded fossiliferous limestone occurs within the Otter as well.

The Minnelusa Group lies unconformably on top of the Big Snowy Group. The Pennsylvanian Tyler Formation is the lowermost lithologic unit of the Group. It consists of shale and limestone. The remainder of the Minnelusa Group is early Permian to Late Pennsylvanian and is largely composed of pinkish-gray sandstone and dolomite (Bluemle et al., 1986).

The rocks of the Opeche Formation are Permian, and consist of orange-red, slightly dolomitic shale and siltstone. Streaks of anhydrite and gypsum are also present (Carlson, 1967).

The Minnekahta Formation lies stratigraphically above the Opeche Formation and is Permian. It is composed of a creamy pink and purple mottled limestone (Bluemle et al., 1986).

The Spearfish Formation lies conformably atop the Minnekahta Formation. It has three members; the lowermost stratigraphically is the Belfield Member. The Belfield consists of grey shale and red siltstone. The second member of the Spearfish Formation, which lies above the Belfield Member, is the Pine Salt. The third member is the Saude, which is composed of siltstone, sandstone, and interbeds of shale (Carlson and Anderson, 1965). The Belfield and the Pine Salt are Permian, while the Permian-Triassic boundary occurs somewhere within the Saude (Bluemle et al., 1986).

Jurassic strata lie unconformably above the Spearfish Formation and represent a primarily terrigenous sequence of deposition in the Williston Basin. Jurassic strata in the Williston Basin reach a maximum thickness of 1,200 feet (367 meters) in extreme northwestern North Dakota, and extend over all but the easternmost part of the state. Jurassic rocks generally consist of limestone, shale, gypsum and anhydrites.

The Dakota Group (Lower Cretaceous) is an interbedded sandstone and shale interval. The Inyan Kara Formation is the lowest unit of the group, consisting of light-gray sandstone and shale. The Mowry is the uppermost formation of the Dakota Group. It is a shale unit, medium- to dark-gray in color with traces of light-blue-gray bentonitic clay. The top of the Mowry Formation is marked by a radioactive zone, and thus is a distinctive log marker (Bluemle et al., 1986).

The Colorado Group (Middle Cretaceous) includes the Greenhorn and Niobrara Formations. The Greenhorn Formation is a dark-gray calcareous shale with thin interbeds of shaly limestone. It is also a good log marker, having distinctive electric and radioactive characteristics. The Niobrara Formation is the uppermost unit of the Colorado Group. It is characterized as a medium-light-gray to medium-gray calcareous shale (Bluemle et al., 1986).

The Pierre Formation (Upper Cretaceous) is a thick shale unit. It varies in color from light- to medium- or dark gray, and is generally noncalcareous. The Pierre shale is commonly fissile and may be flaky to blocky. Deposition of the Pierre shale occurred in a marine offshore setting (Bluemle et al., 1986).

METHODS

Introduction

The research for this study involved several steps. A literature search was conducted to obtain reference material about the Cold Turkey Creek field, the Williston Basin, its stratigraphy, structures and tectonic history, as well as impact crater morphology, structure, and occurrence. Depth and thickness data were recorded from well logs from wells in and around the structural anomaly. This data was used to generate isopach and structure contour maps. Core samples from a well which penetrates the structure were observed, and seismic maps of the structural anomaly were also evaluated.

Well Logs

Since the structure in question is a subsurface structure, data were obtained about it remotely. One hundred six wells (Fig. 5) were identified in nine townships around and containing the Cold Turkey Creek oil field, where the structure is located (Appendix A). The North Dakota Geological Survey and the North Dakota Industrial Commission: Oil and Gas Division maintain records of oil exploration wells drilled within the state of North Dakota. These logs are available in paper forms, microfilm, and microfiche. All three formats were utilized to obtain data for this study. At least two types of well logs are normally recorded for each well: dual laterologs and compensated neutron logs. Dual

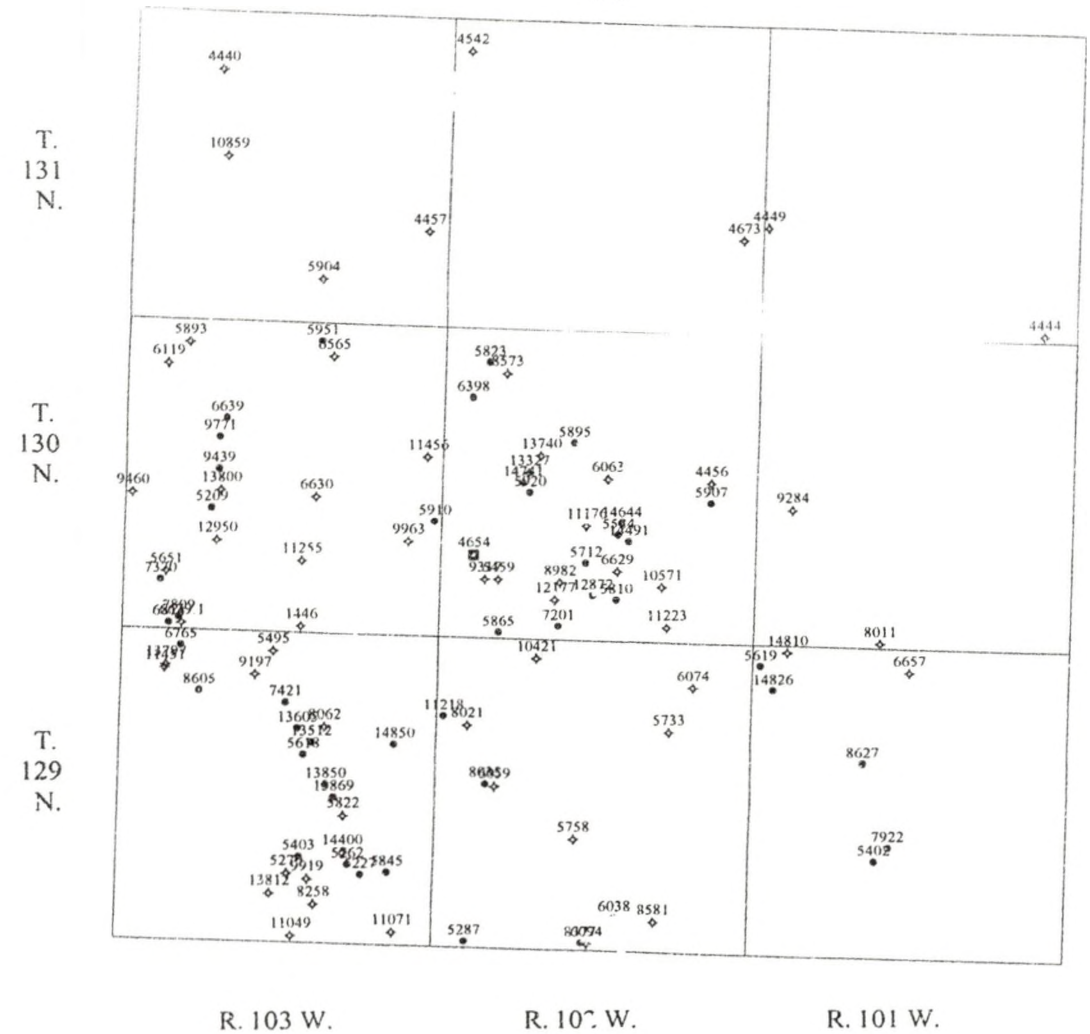


Figure 5. Location of wells from which well logs were examined during this study, and the location of the well from which core was examined. Township boundaries are shown for scale; townships are six miles on each side. Filled circles represent producing wells; open circles represent dry wells; the square represents the well with core samples.

laterologs, which typically record gamma ray, spontaneous potential and resistivity data about the strata, were used for the purpose of this investigation. Compensated neutron logs, which record gamma ray and porosity index data, were not used, as porosity values were unnecessary to the context of this investigation. Wire-line well logs from all one hundred six wells in the area were examined, and interpreted; log signatures were identified and their depths recorded for each of twenty-nine different lithologic units, ranging in age from Ordovician to Cretaceous. These units, from oldest to youngest, are: Red River Formation, Stony Mountain Formation, Stonewall Formation, Interlake Formation, Ashern Formation, Souris River Formation, Duperow Formation, Birdbear Formation, Three Forks Formation, Lodgepole Formation, Mission Canyon Formation, Charles Formation, Kibbey shale, Kibbey limestone, Kibbey sandstone, Otter Formation, Tyler Formation, Minnelusa Group, Opeche Formation, Minnekahta Formation, Spearfish Formation: Belfield Member, Pine Salt Member, Saude Member, Jurassic strata, Inyan Kara Formation, Mowry Formation, Greenhorn Formation, Niobrara Formation, and the Pierre Formation.

The depth and thickness data obtained from the well logs were compiled into a database (Appendix B) using a spreadsheet for ease of analysis. Depths to lithologic unit tops were calculated by subtracting the formation top picks from the kelly bushing to compute the new depth relative to sea level. These data were contoured by SURFER 7 © (Golden Software, 1999) to generate a structural contour map of each lithologic unit surface. Maps are a projection of the state plane onto a flat surface. The thickness of each lithologic unit was calculated by subtracting the depth of the top of the underlying unit from the depth to the top of the unit being measured. These thickness values were then contoured by SURFER 7 © (Golden Software, 1999) to generate isopach maps of each lithologic unit, except the Red River, for which no underlying unit was identified and thus no thickness values were calculated. Contour maps were generated by SURFER 7 © (Golden Software, 1999). The method used for gridding the data were point kriging which used a linear variogram, with slope of one, and anisotropy of zero. A grid of 200 by 200 lines was used, and maximum and minimum values for X and Y were contained within the nine township study area. Contours were smoothed by SURFER 7 ©. The search radius used all data, and the number of points varied for each map generated, ranging from 90 to 98 data points, with the exception of the isopach map of the Pierre Formation, which used 37 data points. Data for lithologic unit tops were also used to construct stratigraphic columns which were then correlated between wells in order to generate two cross-sectional diagrams through the structure.

Seismic Structural Maps

Recent seismic data for the area in question were still proprietary at the time of this writing and were unavailable for study. Therefore, previously published seismic data (Gerhard et al., 1995) were used for interpretation.

Core

One core from the structure was available for study. The core from NDGS well number 4654, International Nuclear Corp. #1 – 61 John M. Susa et al, was examined to determine general lithologic characteristics, and identify any possible definitive evidence of impact. The core is maintained by the North Dakota Geological Survey at the Wilson

M. Laird Core and Sample Library on the University of North Dakota Campus, Grand Forks, North Dakota. The total length of the observed core was 103 feet (31 meters), and was neither complete nor continuous. The core contained sections from the Mission Canyon Formation and the Red River Formation (Appendix C).

DISCUSSION

Impact cratering is a fundamental geologic process, the evidence for which can be seen on the surface of most rocky bodies in the solar system. More than one hundred fifty impact craters have been identified on Earth (Koeberl and Sharpton, 2001), and several have been identified within the Williston Basin (Sawatzky, 1977; Gerlach et al., 1995; Koeberl et al, 1996). An impact crater is the result of the transfer of the kinetic energy of a projectile to the surface of a planet. Crater features are affected by the velocity and mass of the projectile, the nature and composition of the target materials, and the manner in which the target materials respond to the impact-induced shock wave and subsequent excavation of materials (Hamblin and Christiansen, 1990, p. 423). Morphologic characteristics of impact craters are a function of the energy expended during the explosive impact event. A simple crater has a bowl-like depression, with smooth floors and walls and ejected debris surrounding the raised crater rim. Large, complex impact craters, due to higher energy events, are characterized by central peaks or rings, crater rim terraces, and possibly outer rings. An impact is an instantaneous event, and is reflected as such in the rock record.

Most impact craters on Earth have been modified by erosion, subsequent sedimentation, and the dynamic processes of the lithosphere (Hamblin and Christiansen, 1990, p. 199). Nonetheless, certain diagnostic characteristics help to define and identify impact craters in the rock record. Impact craters are typically round or oval. The target material at the site of impact is shocked and excavated by the explosion, causing ejection, ballistic transport, and re-deposition of target material. Therefore, the stratigraphy of the target rocks is highly disturbed; it is marked by missing beds (material excavated during impact), disrupted and overturned beds, and brecciated material. Target rocks are subjected to pressures of many hundreds of GPa and temperatures exceeding several thousand degrees Celsius. As a result, minerals undergo structural and phase changes uniquely characteristic of the extreme high pressures and strain rates of hypervelocity meteorite impact (Koeberl et al., 1996). Several microscopic shock metamorphic effects have been recognized as indicators of impact. Planar deformation features (PDFs) are microscopic features within mineral grains. They consist of narrow planes of glassy material arranged in parallel sets having distinctive orientations with respect to the grain's structure (Koeberl and Sharpton, 2001). High pressure polymorphs of quartz; coesite and stishovite, are also produced by the high pressures associated with impact and have been recognized as indicators of an impact event. Shatter cones are another indicator of impact. They are megascopic cone-shaped structures seen in rocks near impact craters. They have an appearance of regular thin grooves which radiate from an apex. They range in size from less than one centimeter, to more than a meter (Koeberl et al, 1996). Shatter cones form under shock pressures in the range of two to thirty GPa.

Impact structures have been identified within the Williston Basin (Fig. 3). The Newporte structure (Ordovician) is a petroliferous, subsurface impact crater located just south of the North Dakota border with Saskatchewan. Approximately 2 miles (3.2 km) in diameter, it is a simple crater, having a circular depression surrounded by a raised rim.

PDFs were identified by Gerlach et al, (1995) in thin sections of rocks from wells in the structure's rim. Formations are discontinuous across the structure. The Viewfield crater in Saskatchewan is also a subsurface, bowl-shaped crater with a raised rim. It is considered to be of Jurassic – Triassic age and is identified by seismic data and overturned strata at its rim (Sawatzky, 1975). The Red Wing Creek structure is a larger and more complex impact crater. It too is a petroliferous, subsurface structure, and is located in the center of the Williston Basin, in western North Dakota. Koeberl and Reimold (1996) confirmed the impact origin for the Red Wing Creek structure by identifying PDFs which indicate a shock pressure of at least twelve GPa in samples of well cuttings from the center of the structure. The Red Wing Creek structure has a central uplift, approximately 9.6 miles (15.4 km) in diameter, surrounded by an approximately 3.3 mile (5.3 km) wide ring depression, which is in turn surrounded by a raised rim of deformed rocks. Drilling in the central uplift encountered breccia and shatter cone fragments (Brenan et al., 1975).

RESULTS

Red River Formation

As the base of the Red River Formation was not identified on well logs, no isopach map of the Red River Formation was constructed. However, the structural contour map of the top of the Red River indicates a gradual downward slope toward the northeast portion of the study area. A very slight depression is apparent at the western Cold Turkey Creek structure (Fig. 6).

Stony Mountain Formation

The Stony Mountain Formation, which conformably overlies the Red River Formation, reaches a maximum thickness of 192 feet (59 meters) near the southwestern corner of the study area, where two structures exhibit thickening trends within the State Line oil field (Fig. 7). The Stony Mountain Formation gradually thins toward the northeast corner of the study area to a minimum thickness of 81 feet (25 meters). The unit thickens slightly at the anomalous structure west of the Cold Turkey Creek field.

Stonewall Formation

The Stonewall Formation maintains an almost constant thickness of 110 feet (34 meters) throughout the study area. However, an anomalous area occurs in the southwest corner of the State Line Field, where the Stonewall Formation thickens to 140 feet (43 meters). Another anomalous area coincides with the minimum thickness (65 feet, 20

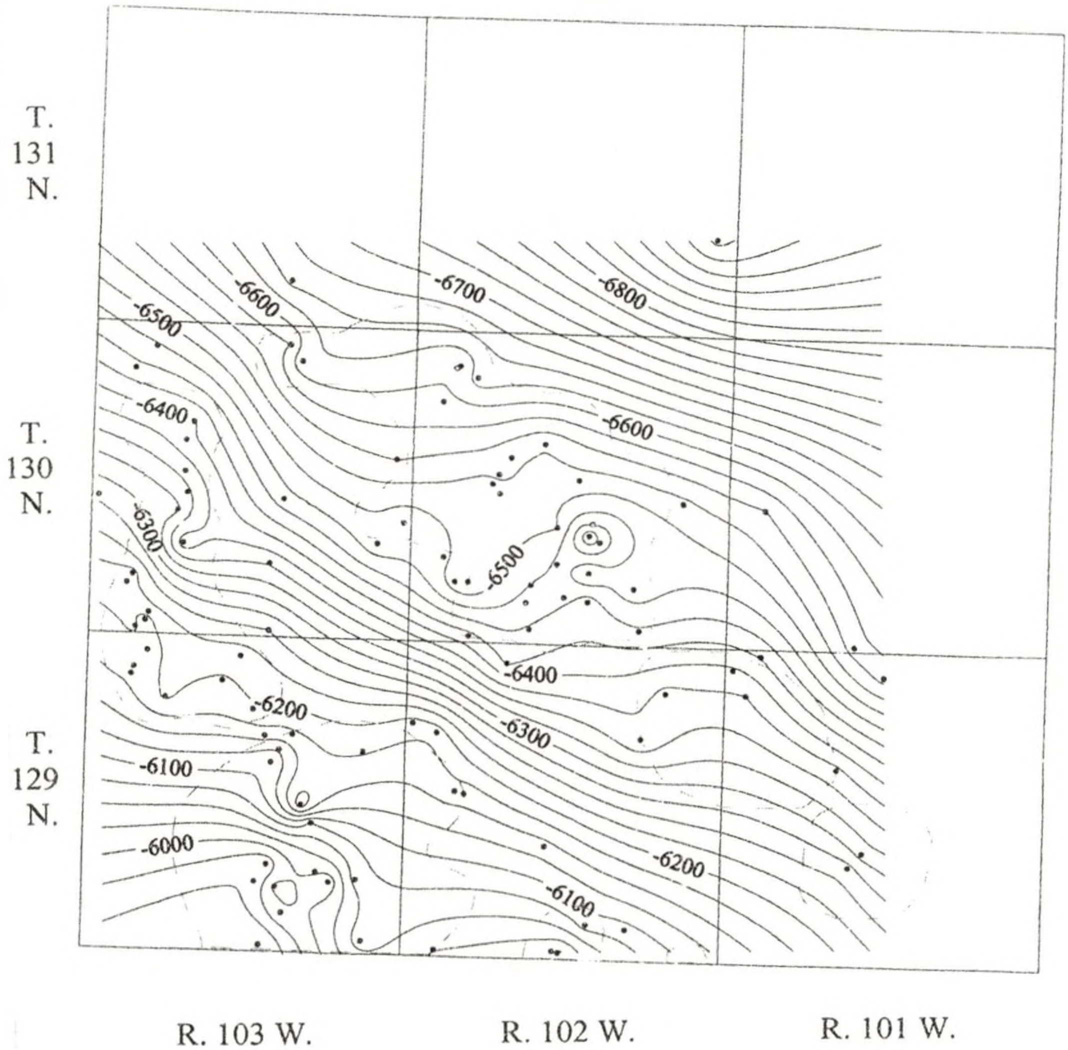


Figure 6. Structure contour map on the Top of the Red River Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey line represents generalized oil field boundaries; refer to Figure 2 for field names. Datum is mean sea level. Contour interval = 25 feet.

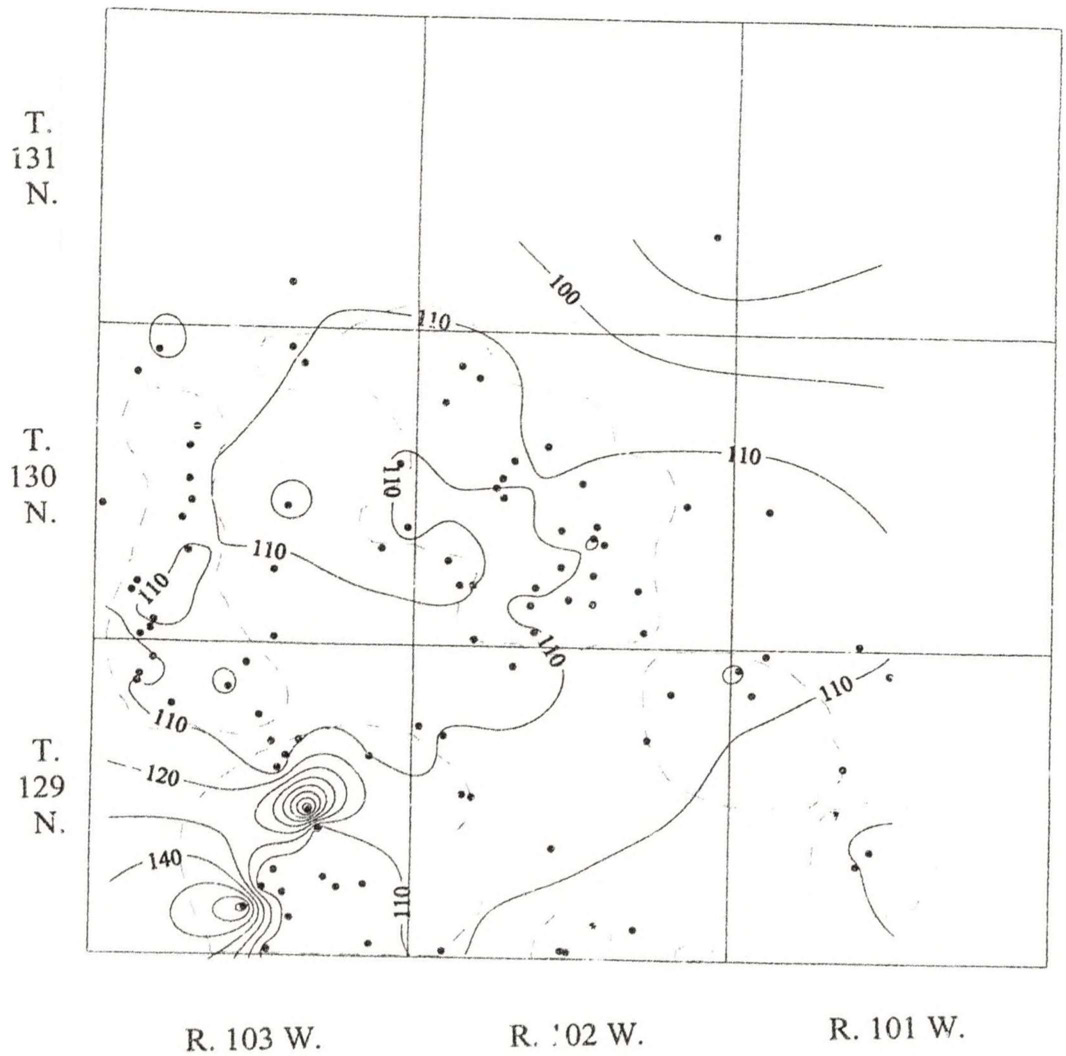


Figure 7. Isopach map of the Stony Mountain Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey line represents generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

meters) of the formation in the northern part of the Amor field in the western part of the study area (Fig. 8).

Interlake Formation

The Interlake Formation (Silurian), which conformably overlies the Stonewall Formation, has a maximum thickness of 410 feet (125 meters) in the eastern part of the study area. The Interlake formation gradually thins westward, reaching a minimum thickness of 217 feet (66 meters) at the extreme western part of the study area, in the southwest portion of the Amor field (Fig. 9). A shallow, irregularly shaped depression occurs in the northeastern portion of the Cold Turkey Creek field. The thickness of the Interlake Formation exhibits very little change at the structural anomaly west of the Cold Turkey Creek field, and the unit is continuous across the structure.

Ashern Formation

Stratigraphically above the Interlake Formation is the Ashern Formation, which forms the base of the Manitoba Group. The Ashern Formation is absent over much of the study area. A few thin lenses occur at the extreme west and southwest edges of the study area, and also in the area north of the Amor field and the northwestern most portion of the Cold Turkey Creek field. The maximum thickness (19 feet, 6 meters) occurs in the southeast quarter of T. 130 N., R. 102 W (Fig. 10). The Ashern Formation is not present within the Cold Turkey Creek structural anomaly.

Souris River Formation

The Souris River Formation is generally greater than 40 feet (12 meters) thick over the study area, with a slight thickening trend on the western-most edge of the study area, near the Amor field. The maximum thickness of 144 feet (44 meters), occurs

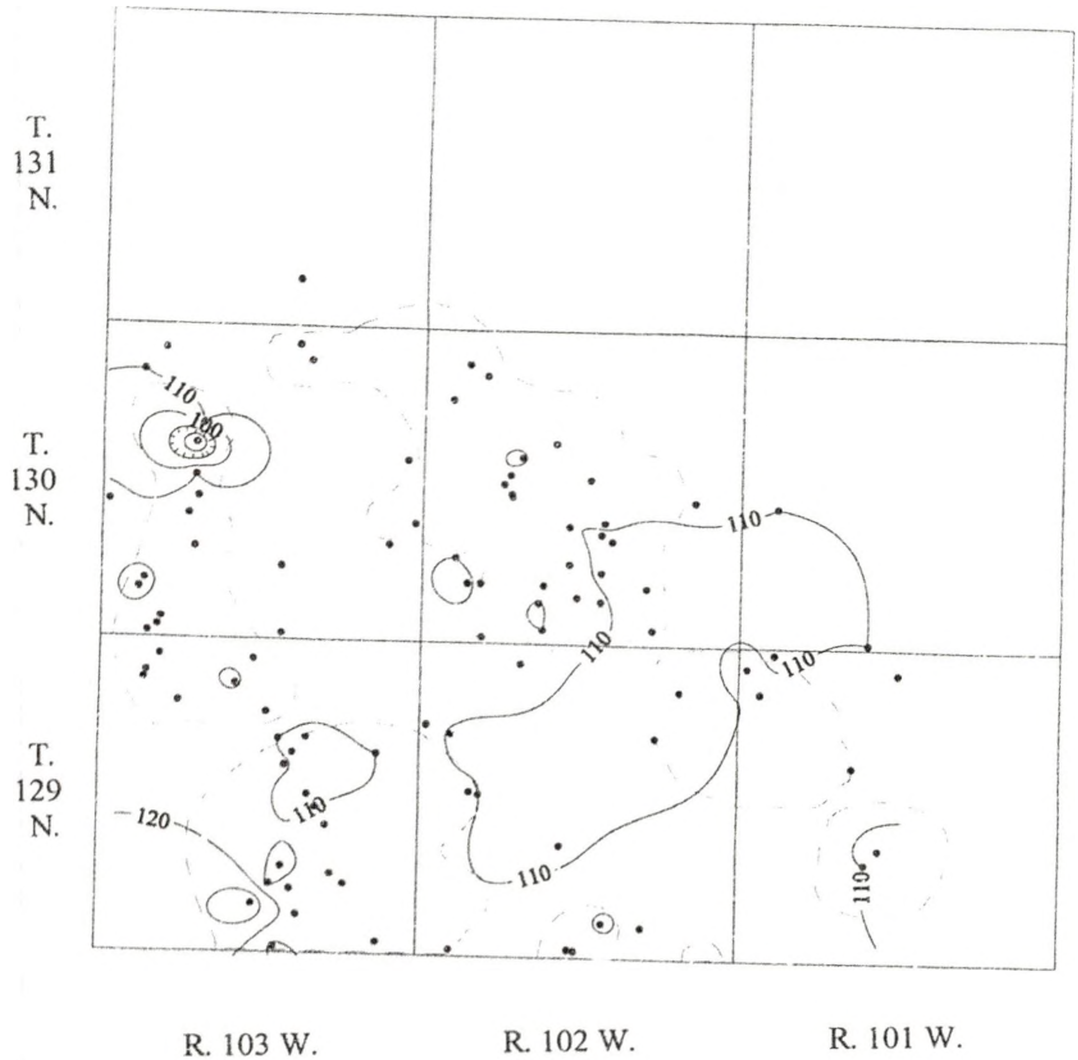


Figure 8. Isopach map of the Stonewall Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

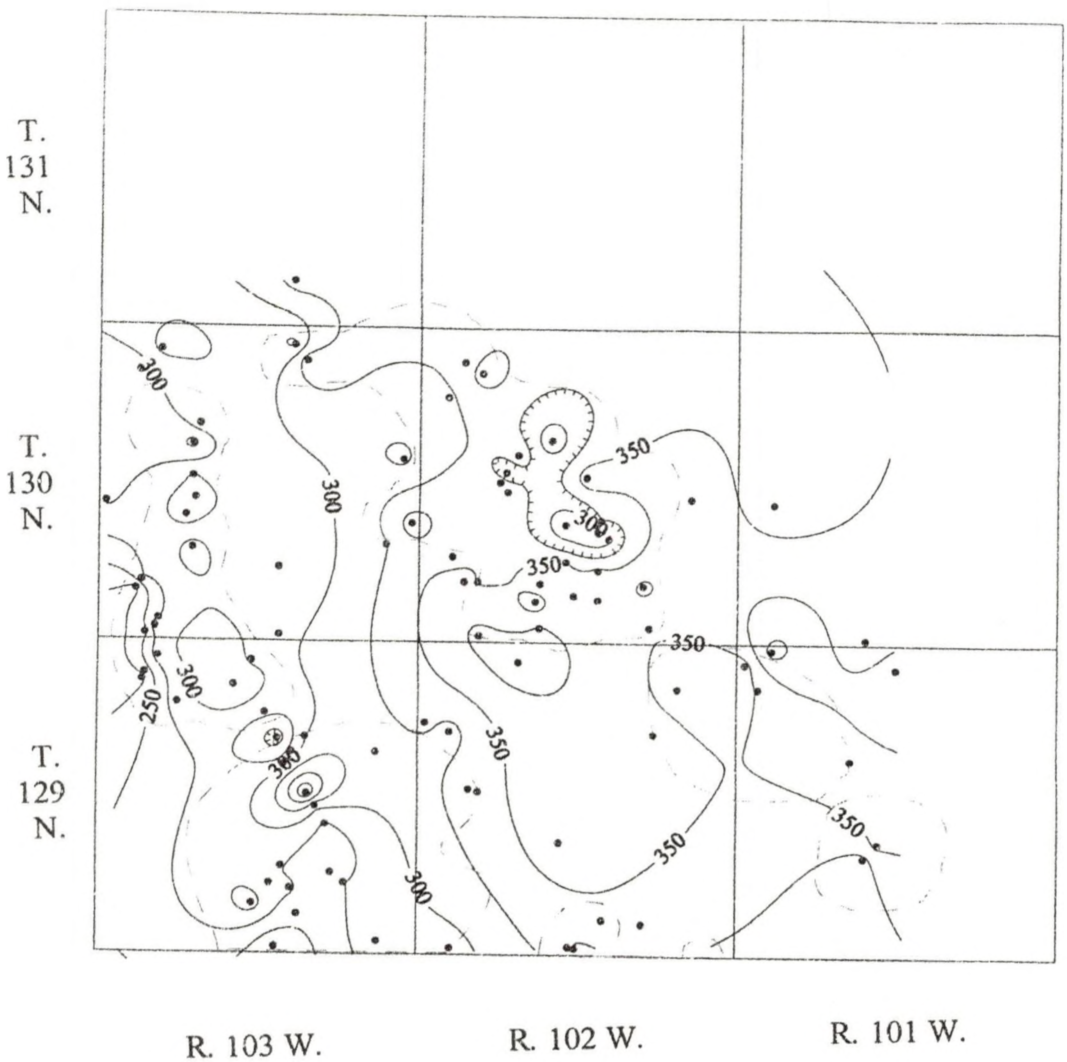


Figure 9. Isopach map of the Interlake Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

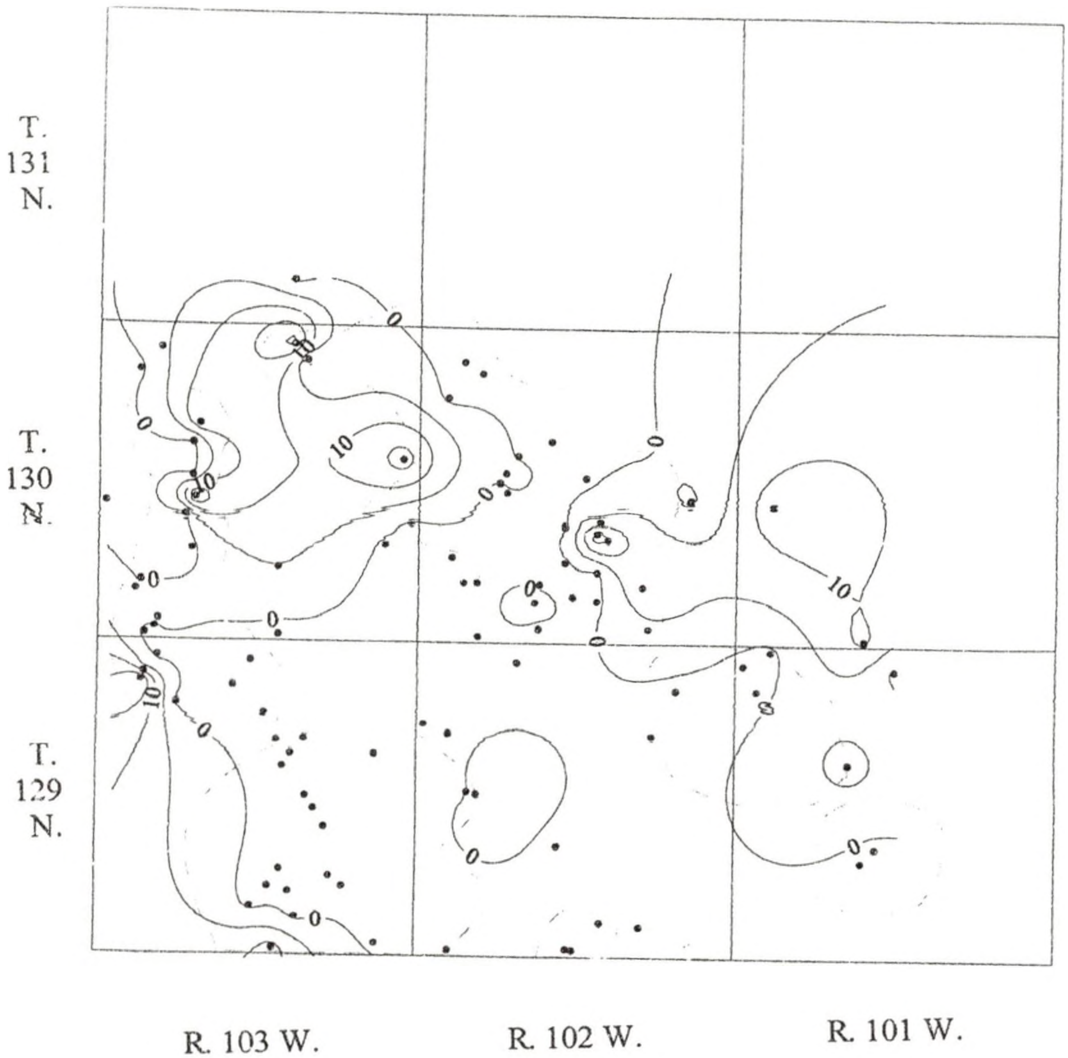


Figure 10. Isopach map of the Ashern Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 5 feet.

within the Cold Turkey Creek oil field in the central portion of T. 130 N., R. 102 W. The minimum thickness of 8 feet (2.4 m) occurs within the southeastern portion of the Amor field (Fig. 11). The thickness of the Souris River Formation is slightly greater on the northern side of the structural anomaly than the southern side, and the unit is continuous across the structure.

Duperow Formation

The Duperow Formation exhibits a slight thickening trend from the southwest to the northeast across the study area, reaching a maximum thickness of 220 feet (67 meters) in the northeast corner of the study area. The minimum thickness of 134 feet (41 meters) occurs as an anomalous area in the center of the study area (Fig. 12), within the Cold Turkey Creek field. From the structure contour map, it is apparent that the Duperow Formation dips downward into the Williston Basin, in a northeasterly direction. A shallow circular depression is present at the structural anomaly west of the Cold Turkey Creek field (Fig. 13).

Birdbear Formation

The isopach map of the Birdbear Formation indicates that the thickness is generally less than 100 feet (30 meters). There is a general thickening trend toward the eastern portion of the study area, with an anomalous area in the Amor field, where rapid thickness changes are evident (Fig. 14). The thickness of the Birdbear Formation is almost constant across the structural anomaly.

Three Forks Formation

The Three Forks Formation generally thickens to 61 feet (19 meters) in the

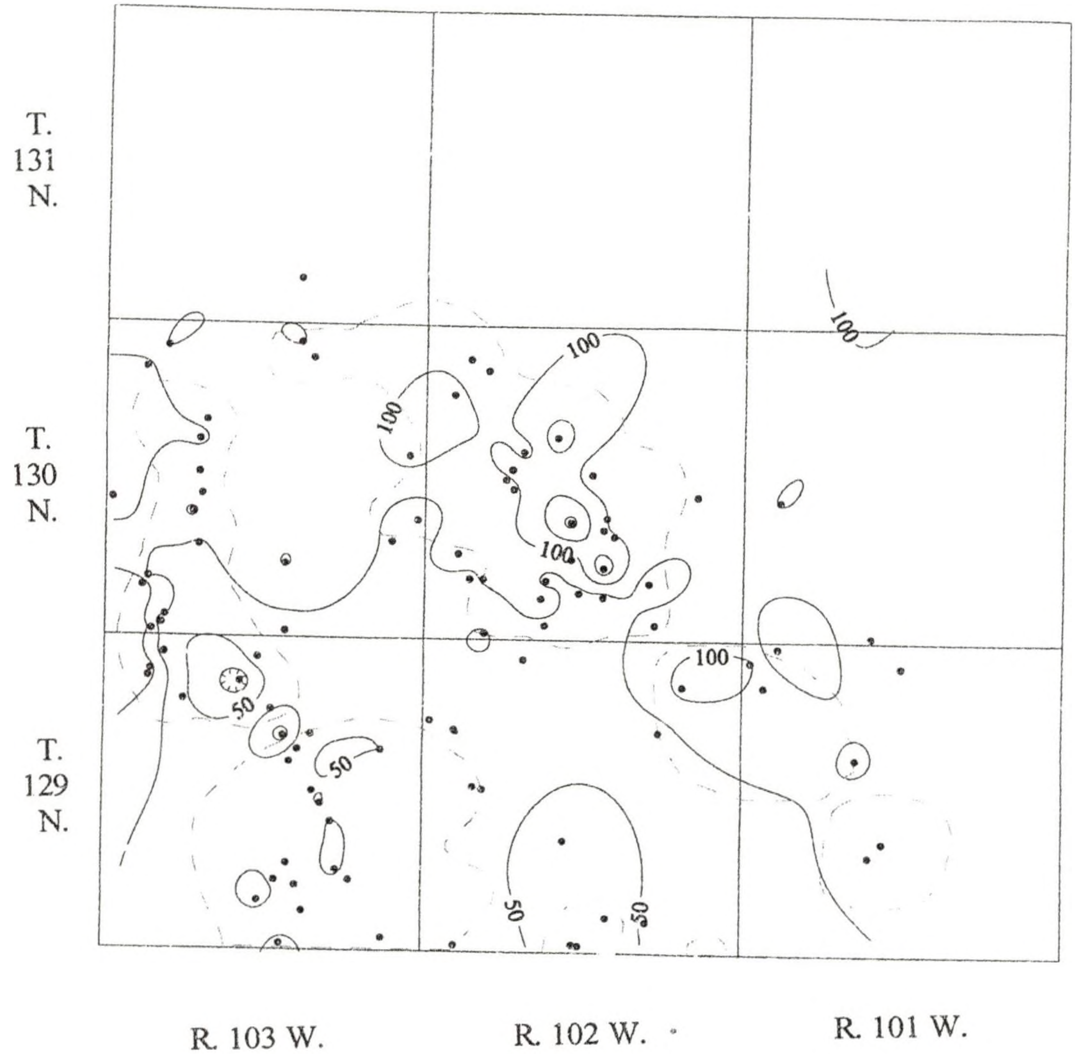


Figure 11. Isopach map of the Souris River Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

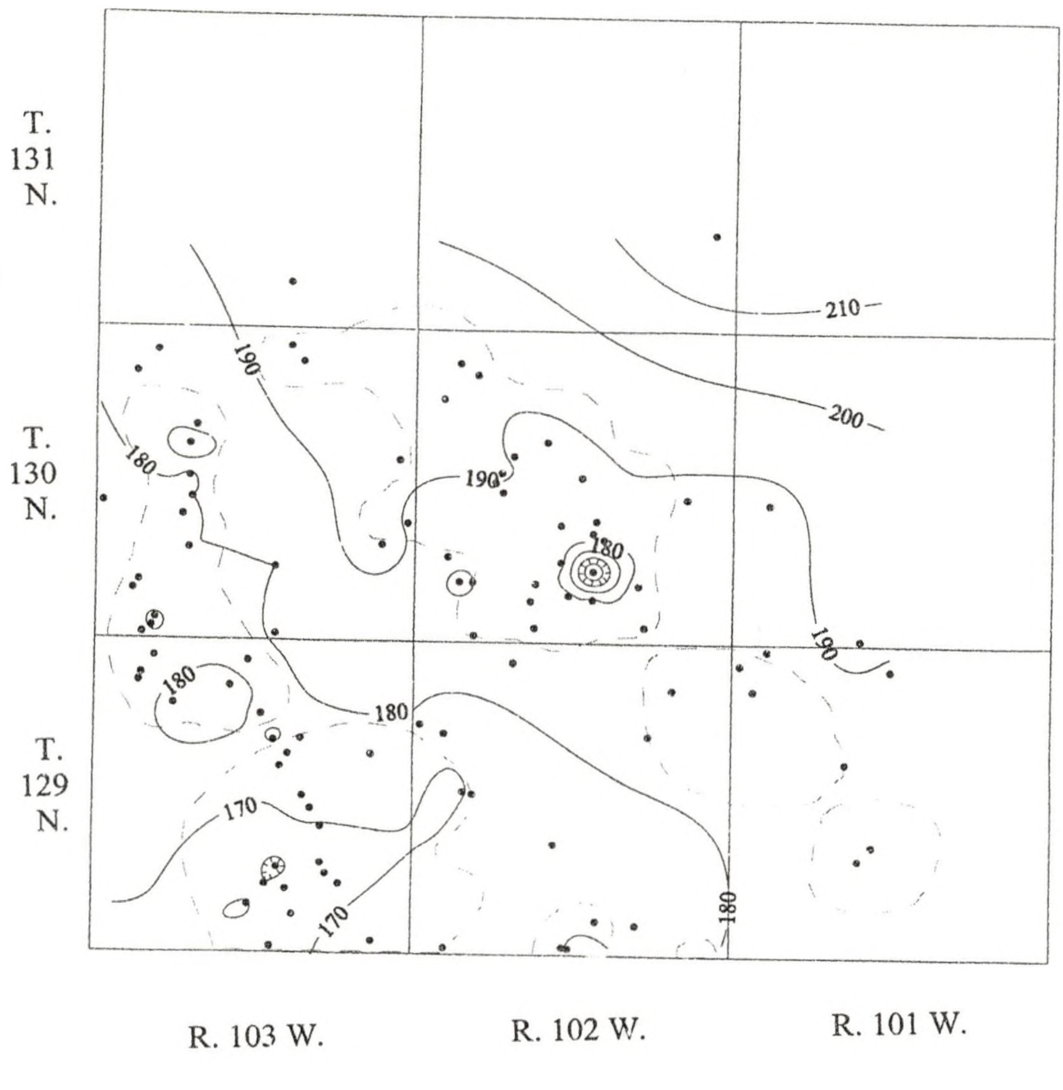


Figure 12. Isopach map of the Duperow Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

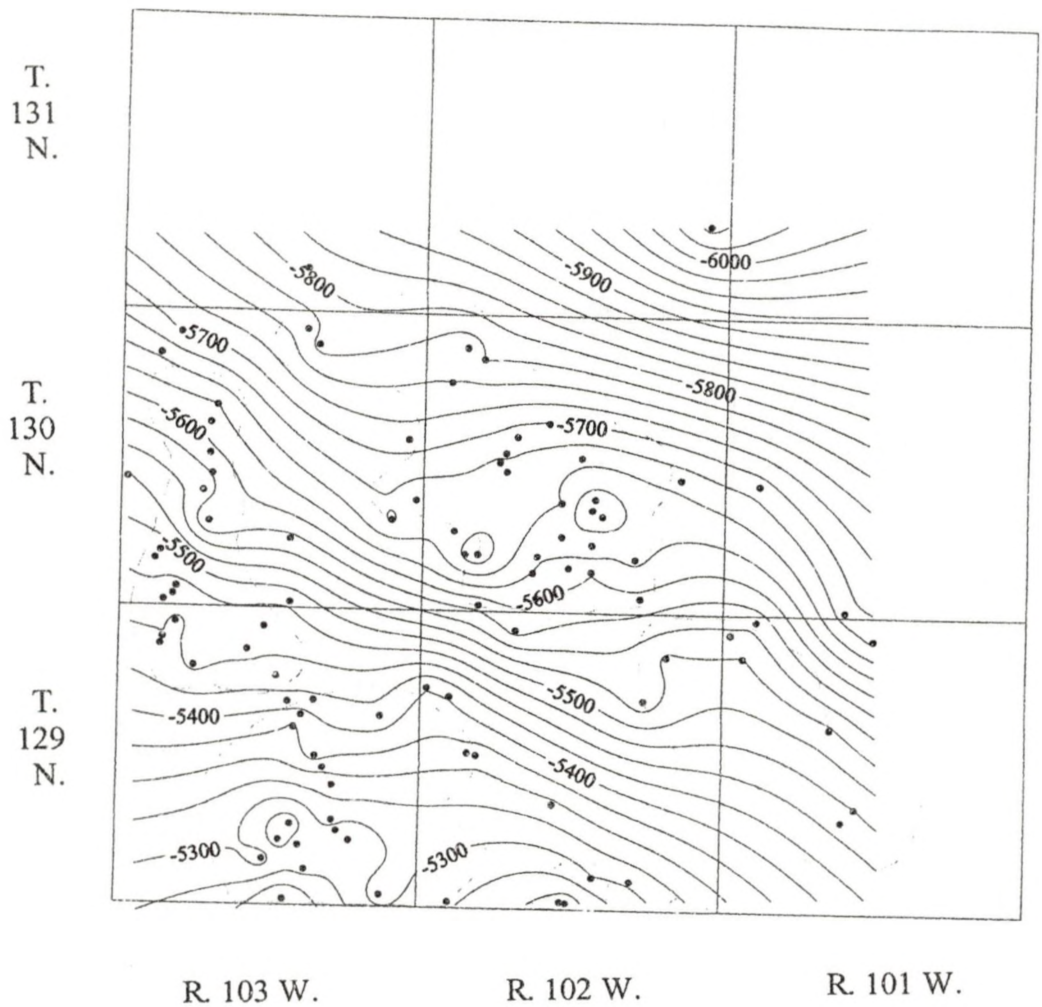


Figure 13. Structure contour map on the Top of the Duperow Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figue 2 for field names. Datum is mean sea level. Contour interval = 25 feet.

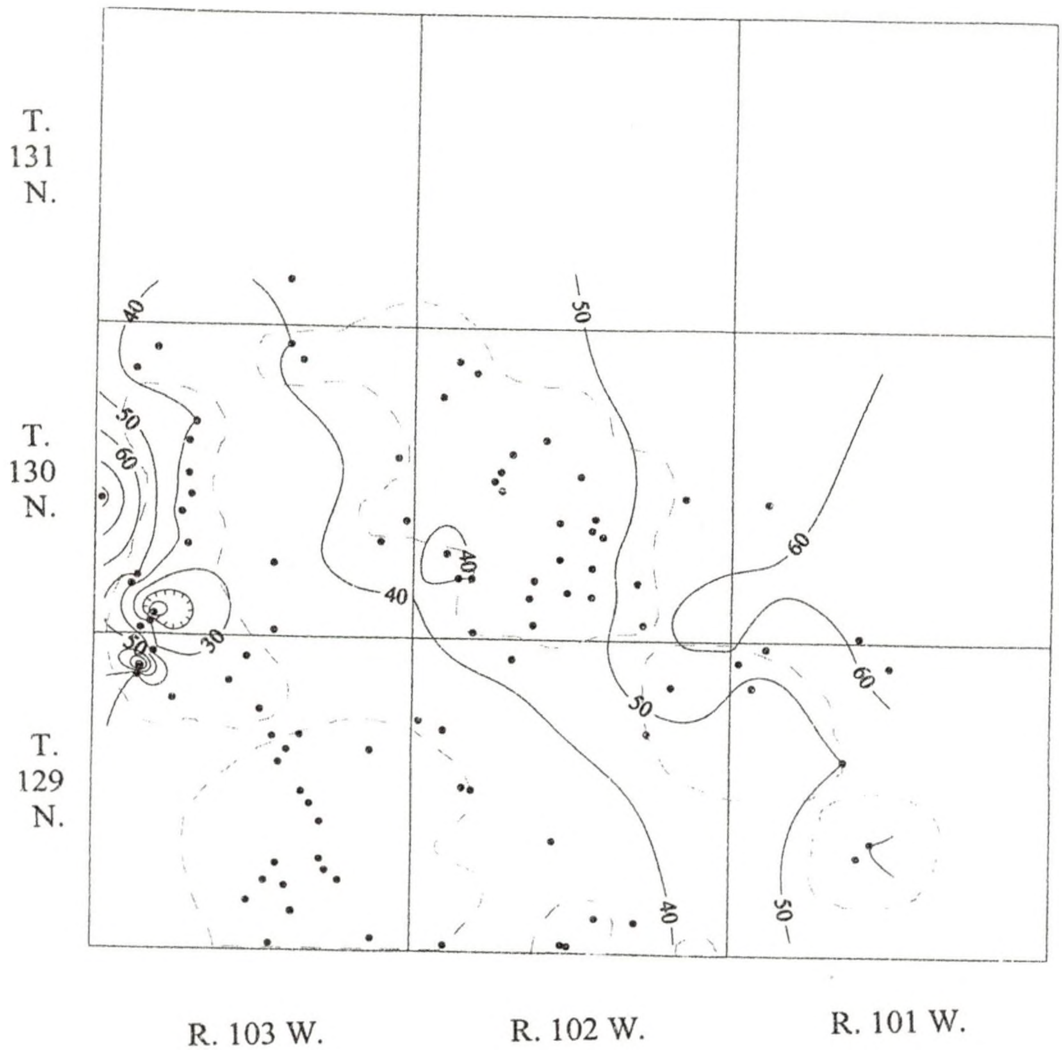


Figure 14. Isopach map of the Birdbear Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field locations; refer to Figure 2 for field names. Contour interval = 10 feet.

eastern portion of the study area and thins to zero feet at the extreme western portion of the study area. The thickness of the Three Forks Formation at the western Cold Turkey Creek structure does not appear anomalous (Fig. 15), and the unit is continuous across the structure.

Lodgepole Formation

The Lodgepole Formation is generally greater than 540 feet (164 meters) thick in the western portion of the study area and generally less than 580 feet (177 meters) in the northern part (Fig. 16). Fairly rapid thickness changes occur where the Lodgepole Formation reaches a maximum thickness of 646 feet (197 meters) in the center of the study area, just to the south of the western Cold Turkey Creek structural anomaly, and the Formation reaches a minimum thickness of 447 feet (136 meters) within the structural anomaly.

Mission Canyon Formation

Rapid thickness changes are again apparent in the Mission Canyon Formation, where maximum thickness (524 feet, 160 meters) and minimum thickness (180 feet, 55 meters) for the study area occur within the western Cold Turkey Creek structural anomaly. The thickness of the area surrounding the structure is fairly constant, with a slight thickening trend toward the east (Fig. 17).

Charles Formation

The Charles Formation maintains a fairly constant thickness across the study area of between 450 and 490 feet (137 and 149 meters, respectively). However, rapid

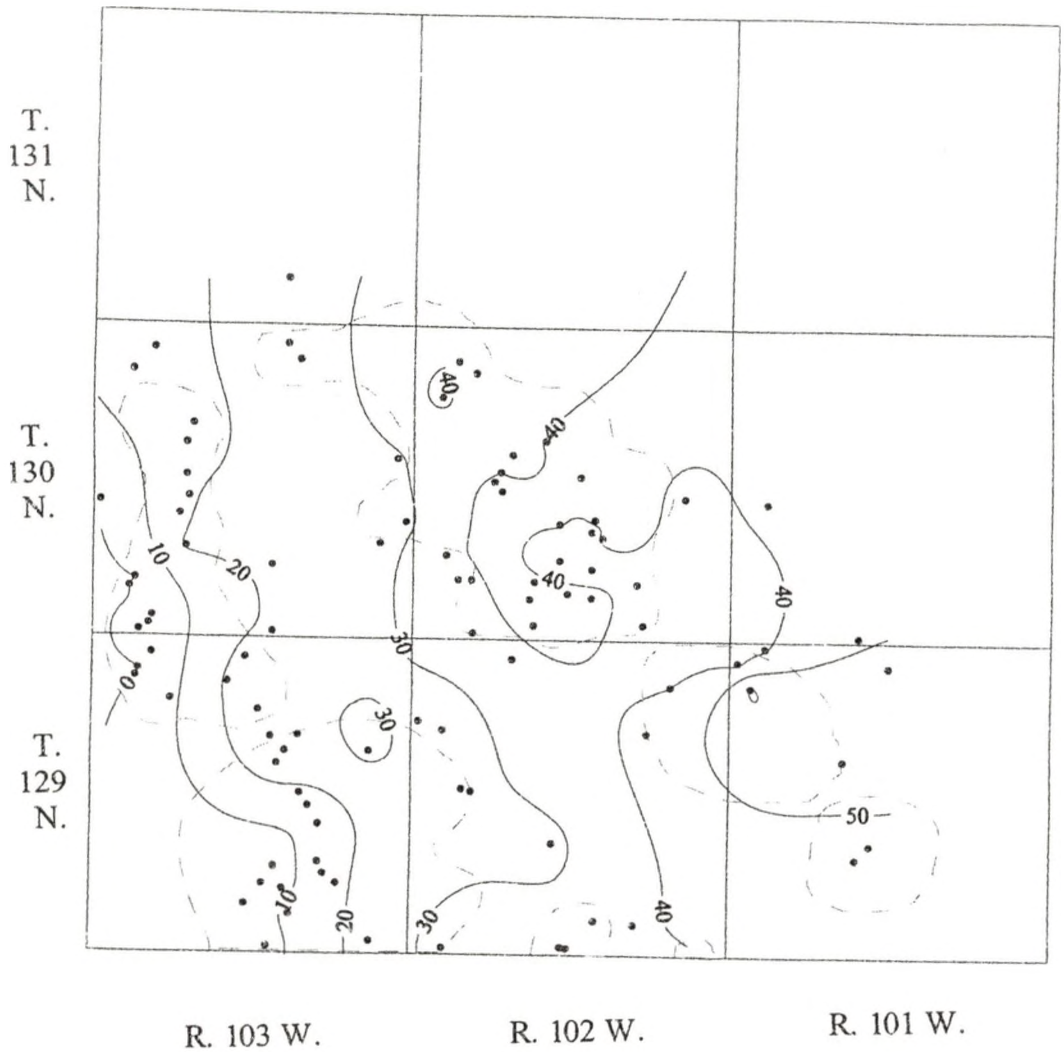


Figure 15. Isopach map of the Three Forks Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

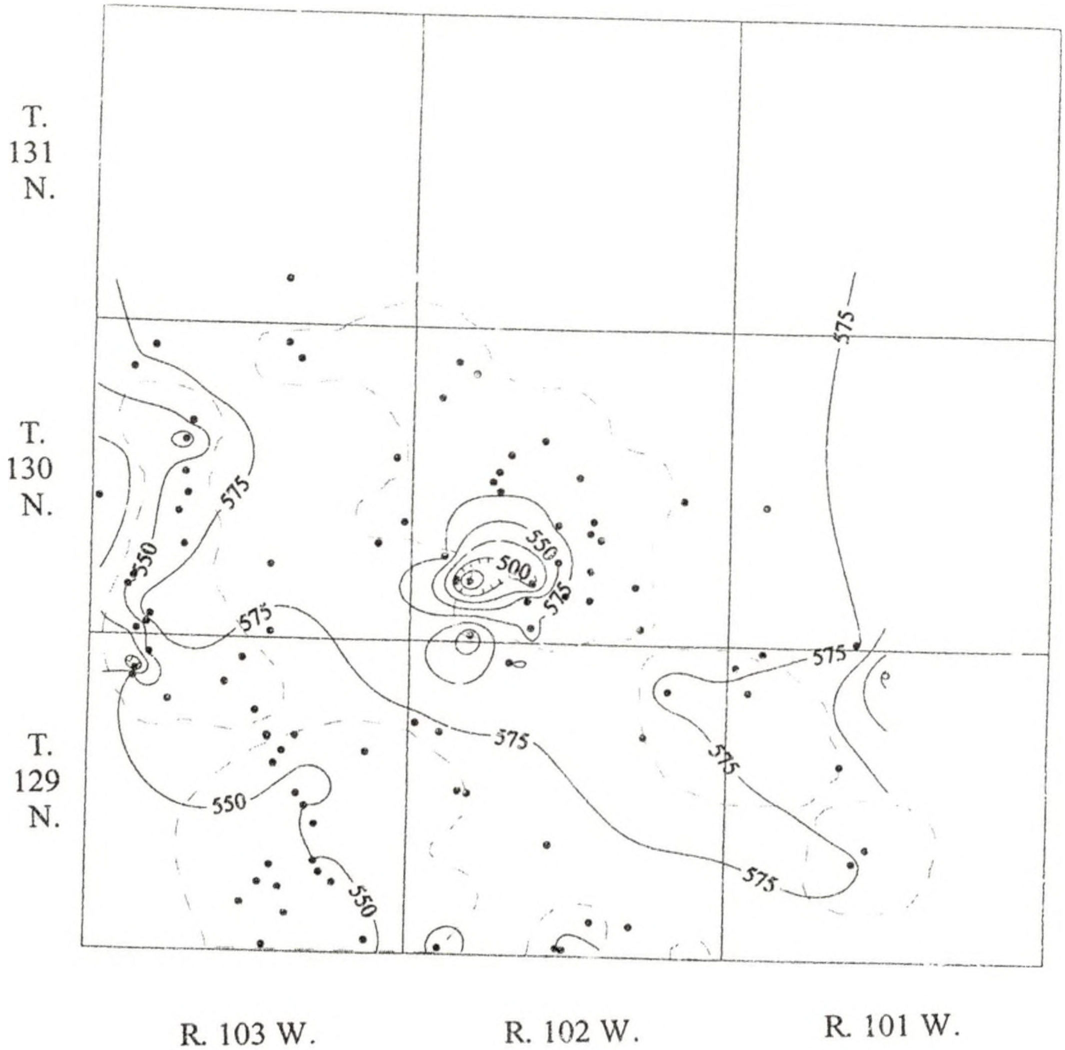


Figure 16. Isopach map of the Lodgepole Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

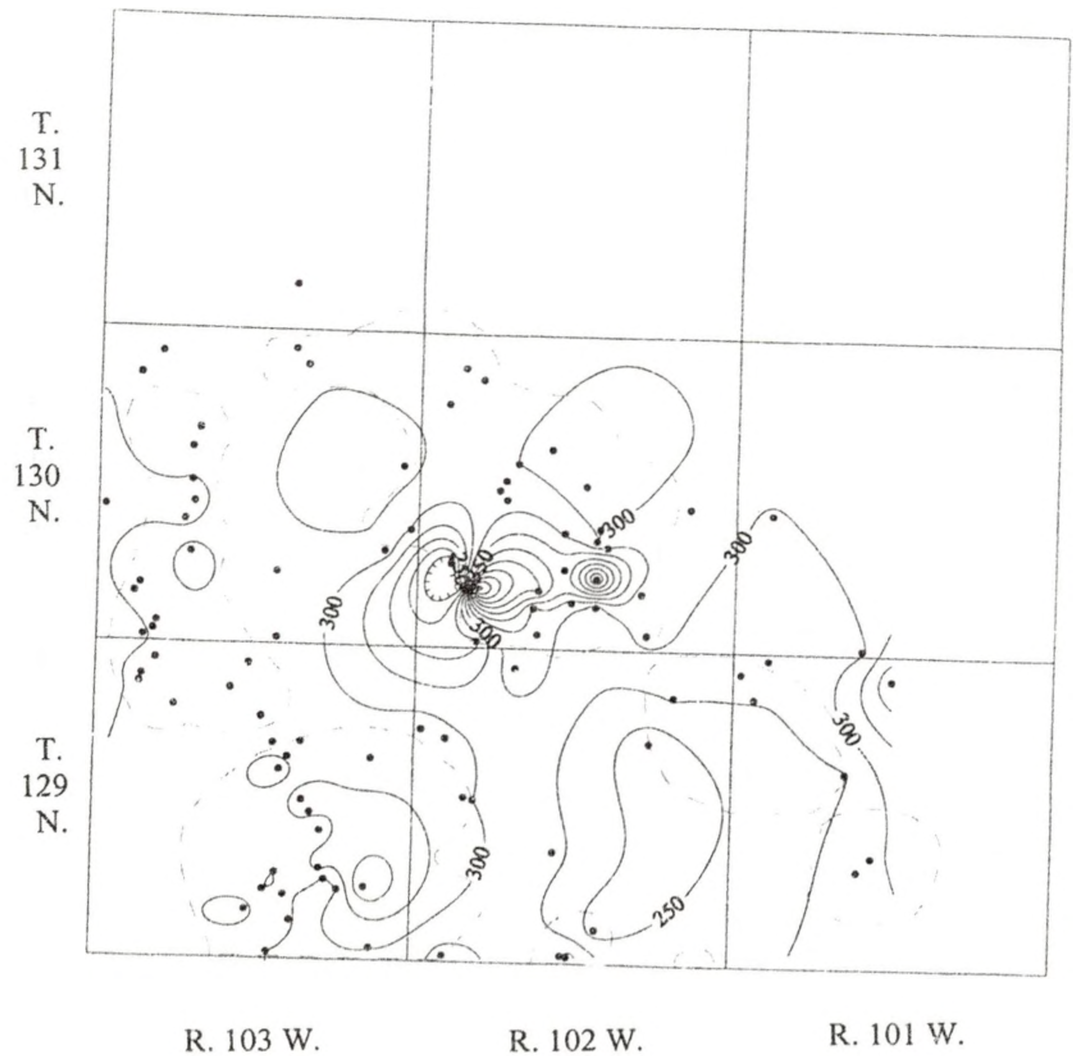


Figure 17. Isopach map of the Mission Canyon Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

thickness changes occur at the western Cold Turkey Creek structural anomaly, where a maximum thickness of 943 feet (287 meters) occurs. East of the structural anomaly, the minimum thickness of 296 feet (90 meters) is also accompanied by rapid thickness changes over a small area (Fig. 18). The area of maximum thickness is evident on the structural contour map as well, where it stands out as a steep slope from a local high to an adjacent local low. The area of minimum thickness is less distinctive on the structural contour map, although it is still apparent as an area of decreased slope. The surrounding study area exhibits a general slope downward to the north-northeast, in the direction of the center of the Williston Basin (Fig. 19).

Kibbey shale

The Kibbey shale, the oldest unit of the Kibbey Formation, generally ranges in thickness from 65 feet (20 meters) to 85 feet (26 meters) across the study area (Fig. 20). Rapid thickness changes are notable in the structural anomaly west of the Cold Turkey Creek field, where the Kibbey shale reaches a maximum thickness of 132 feet (40 meters). The minimum thickness of 37 feet (11 meters) occurs in the center of the southern-most part of the study area.

Kibbey limestone

The Kibbey limestone is the middle unit of the Kibbey Formation, and is the thinnest unit apart from the Ashern (which is absent over much of the study area). The Kibbey limestone generally ranges in thickness across the study area from 11 feet (3.5 meters) to 36 feet (11 meters). The maximum thickness of 83 feet (11 meters) appears as an anomalously thick area in the extreme western portion of the study area, in the

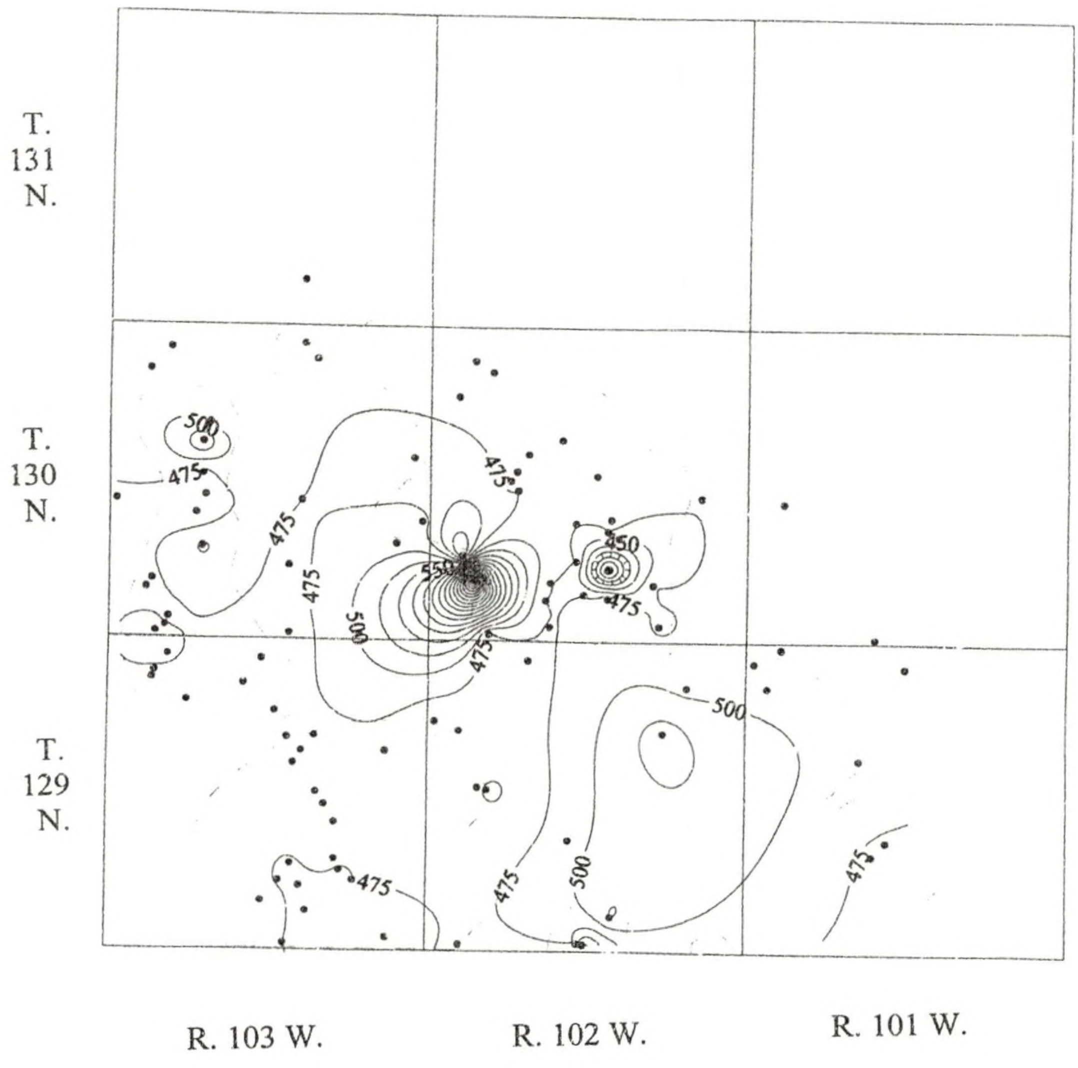


Figure 18. Isopach map of the Charles Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

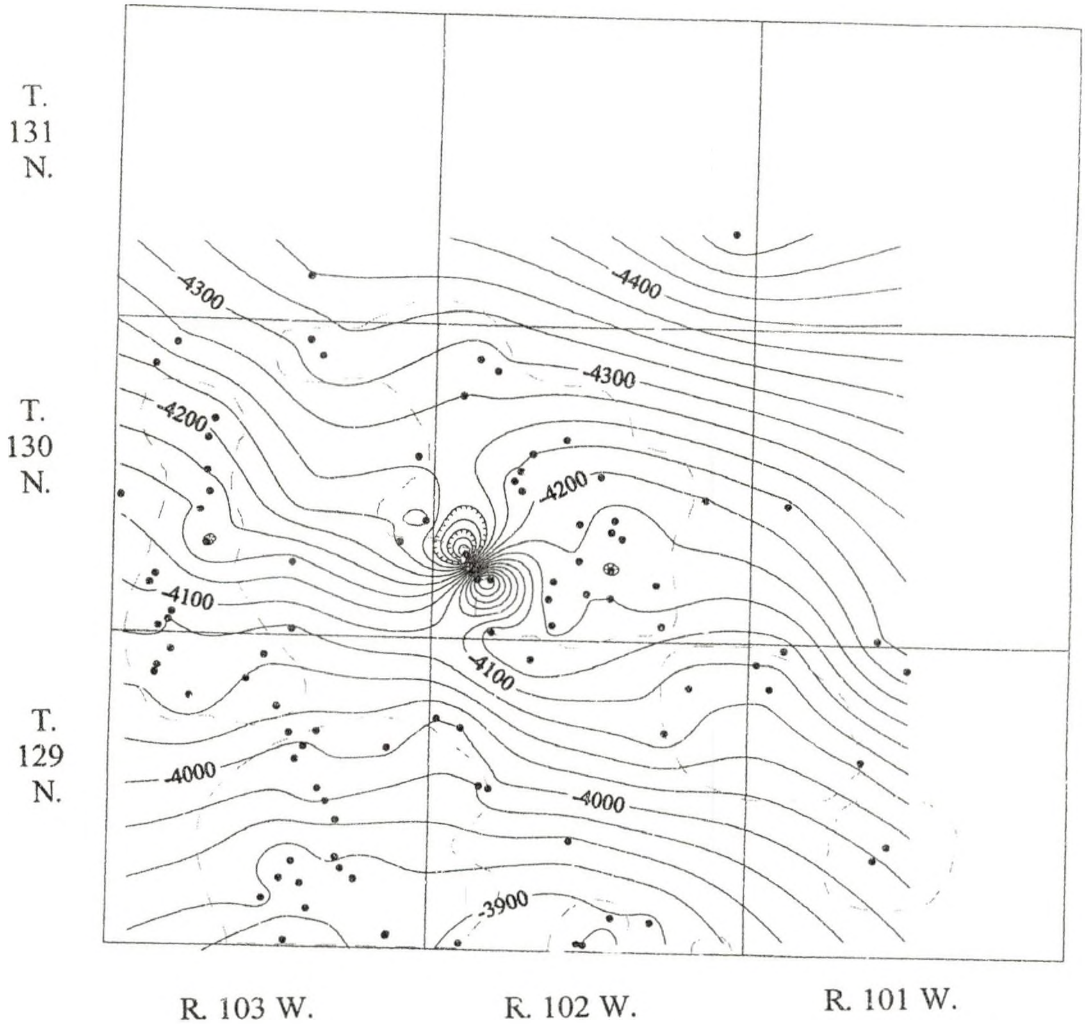


Figure 19. Structure contour map on the top of the Madison Group: the Charles Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Datum is mean sea level. Contour interval = 25 feet.

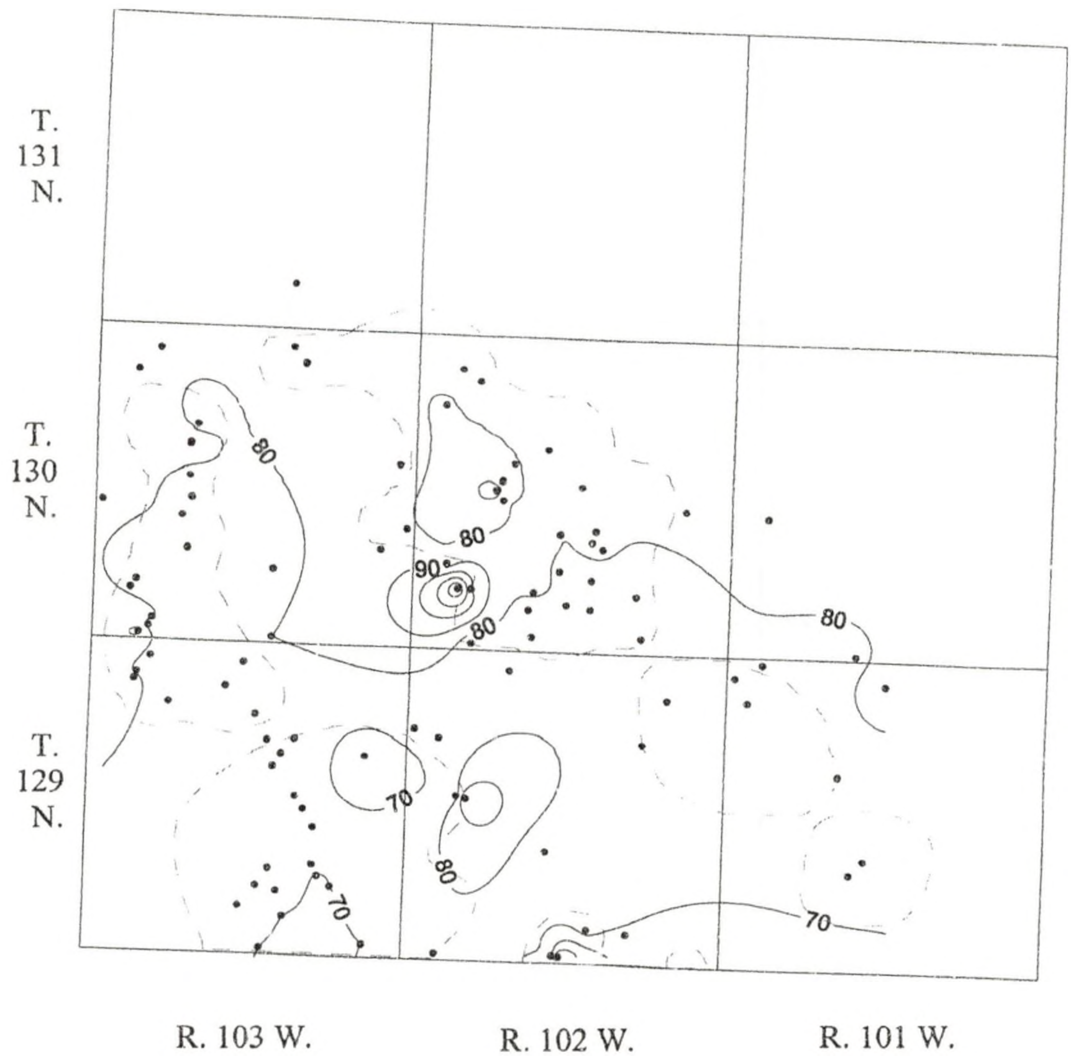


Figure 20. Isopach map of the Kibbey Formation shale. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

northern part of the Amor field (Fig. 21). The unit is continuous across the western Cold Turkey Creek structural anomaly.

Kibbey sandstone

The Kibbey sandstone is the uppermost unit of the Kibbey Formation. It has a variable thickness across the study area, ranging from a minimum of 19 feet (5.8 meters) to a maximum of 178 feet (54 meters). Both the maximum and minimum thicknesses occur in the eastern portion of the Cold Turkey Creek field, in rather close proximity to one another. Several wells in the Amor field at the extreme western side of the study area indicate slightly greater than average thickness changes among them (Fig. 22). Another area of greater than average thickness occurs in T. 129 N., R. 102 W., just north of the Ash field.

Otter Formation

The Otter Formation ranges in thickness from a minimum of 16 feet (5 meters) to a maximum of 227 feet (69 meters) and is variable throughout the study area. Although the thickness of the Otter Formation changes slightly across the western Cold Turkey Creek structural anomaly, the unit is continuous (Fig. 23).

Tyler Formation

The isopach map of the Tyler Formation (Fig. 24), indicates that the thickness of the unit across the study area is slightly variable, with a minimum thickness of 62 feet (19 meters) at the extreme western edge of the study area. The maximum thickness of 400 feet (122 meters) occurs within the western Cold Turkey Creek structural anomaly, and is identified by the tight concentric contours on the isopach map. Although there is a

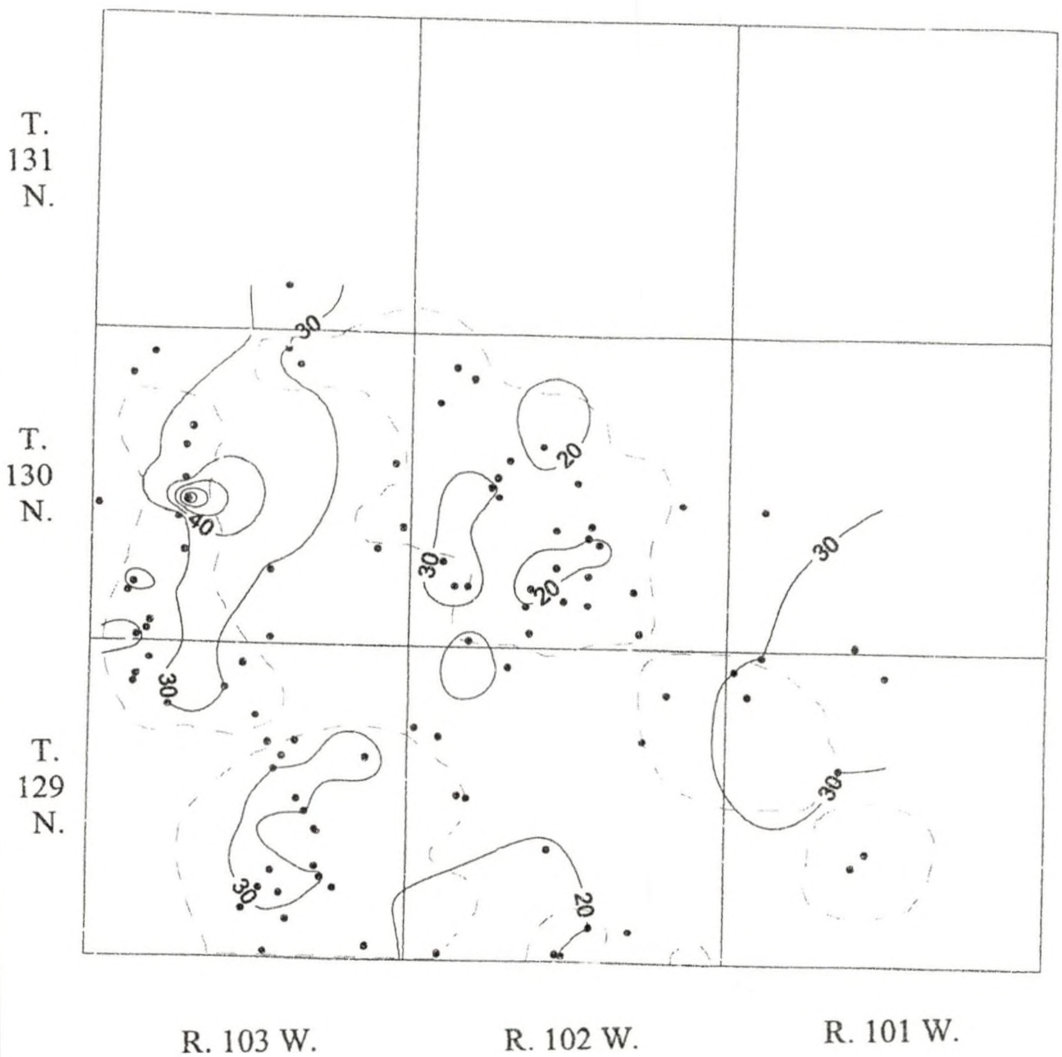


Figure 21. Isopach map of the Kibbey Formation limestone. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

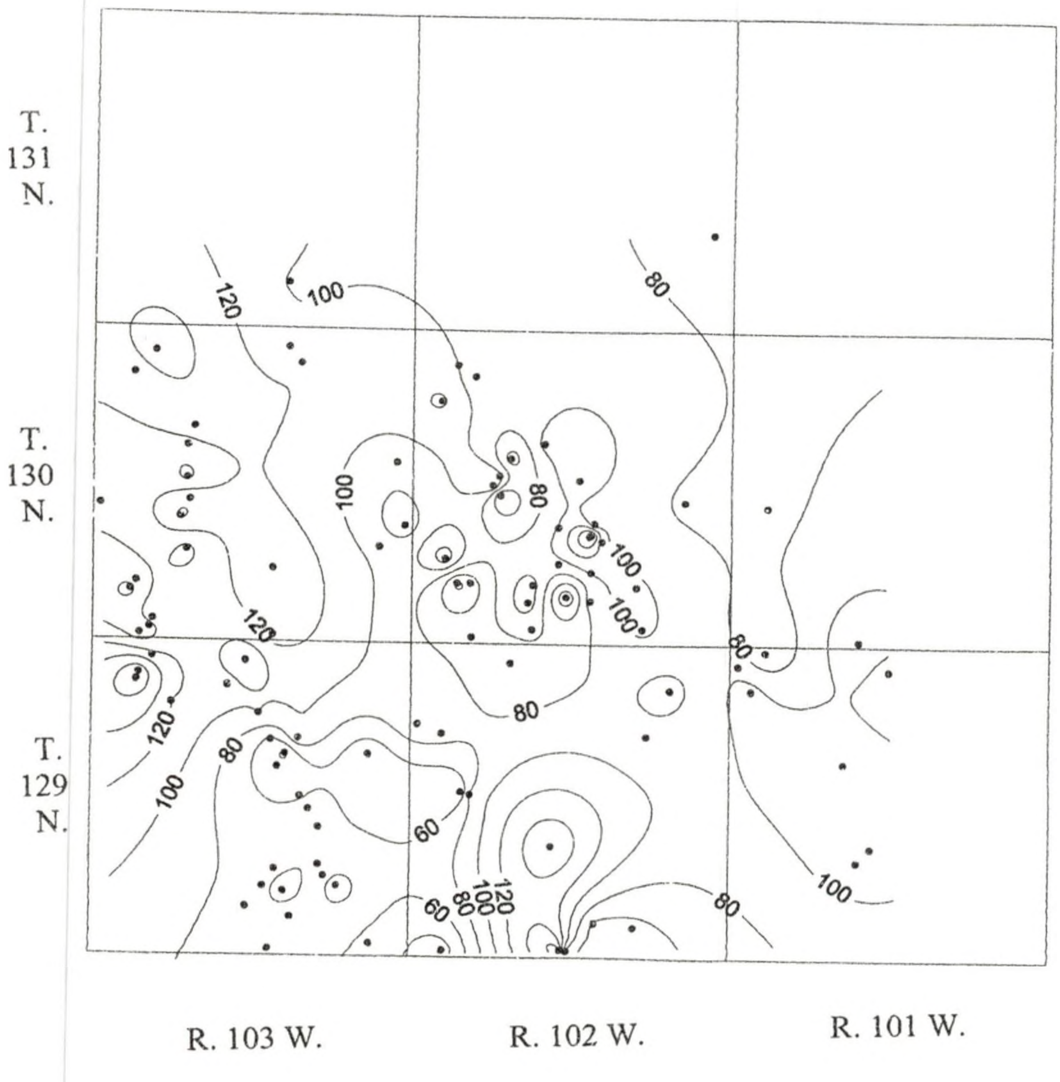


Figure 22. Isopach map of the Kibbey Formation sandstone. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 20 feet.

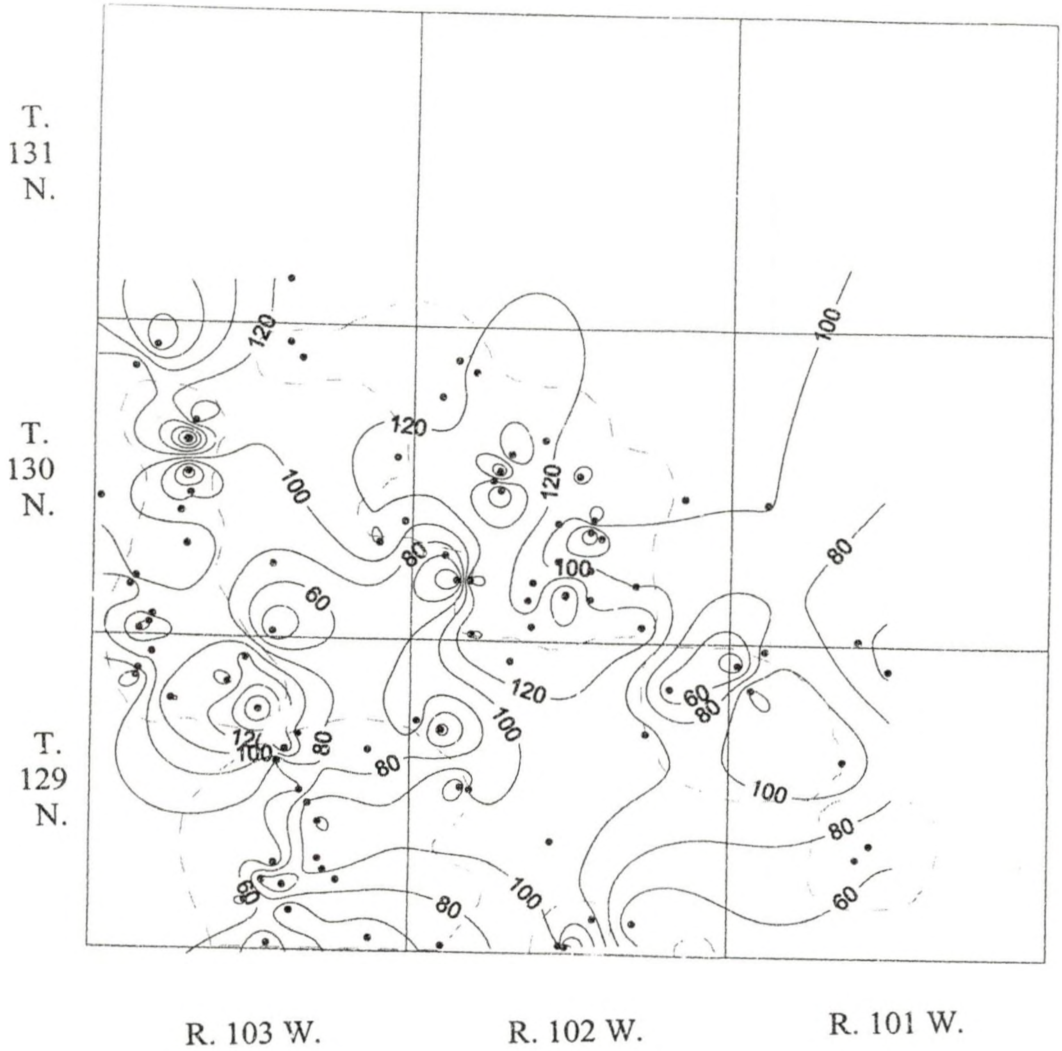


Figure 23. Isopach map of the Otter Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 20 feet.

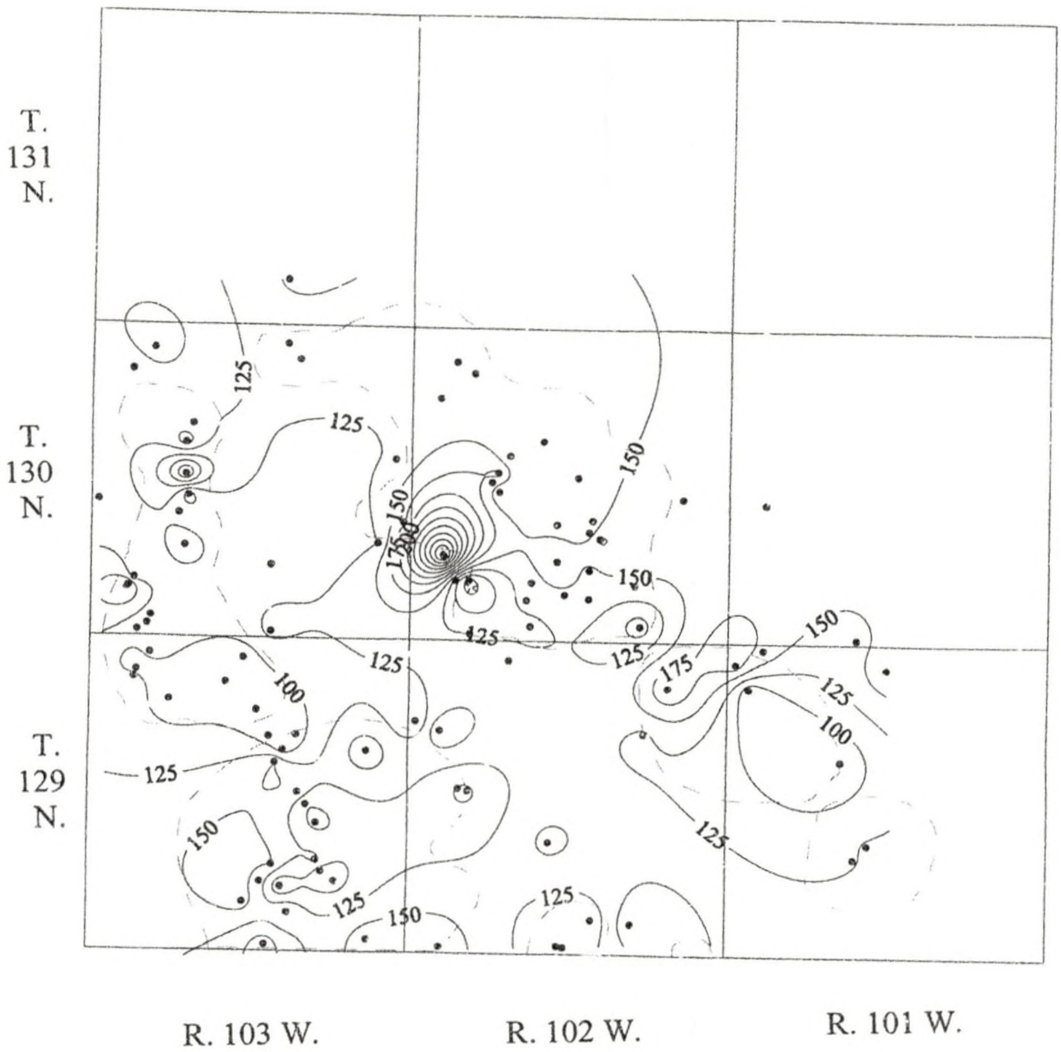


Figure 24. Isopach map of the Tyler Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

substantial thickness change at the western Cold Turkey Creek structural anomaly, the Tyler Formation is continuous across the structural anomaly.

Minnelusa Group: Broom Creek – Amsden Interval

The Minnelusa Group: Broom Creek – Amsden interval reaches a maximum thickness of 322 feet (98 meters) in the extreme eastern part of the study area,while the minimum thickness of 118 feet (36 meters) occurs near the center of the study area, within the Cold Turkey Creek field. The structural anomaly is not marked by rapid thickness changes, and the Minnelusa Group is continuous across the structure (Fig. 25).

Opeche Formation

The Opeche Formation reaches a minimum thickness of 44 feet, (13 meters) in the northwest part of the study area, near the northern portion of the Amor field. The maximum thickness (166 feet, 50 meters) is located in the center of the study area, within the Cold Turkey Creek field. Although the thickness of the Opeche Formation changes slightly across the anomalous structure west of the Cold Turkey Creek field, the unit is continuous across the structure (Fig. 26).

Minnekahta Formation

The thickness of the Minnekahta Formation is relatively constant across the study area, ranging from 39 feet (12 meters) to 59 feet (18 meters). The western Cold Turkey Creek structural anomaly is rather inconspicuous, as the unit's thickness changes very little across the structure (Fig. 27). However, the structure contour map of the Minnekahta Formation depicts a slightly elevated area centered on the western Cold

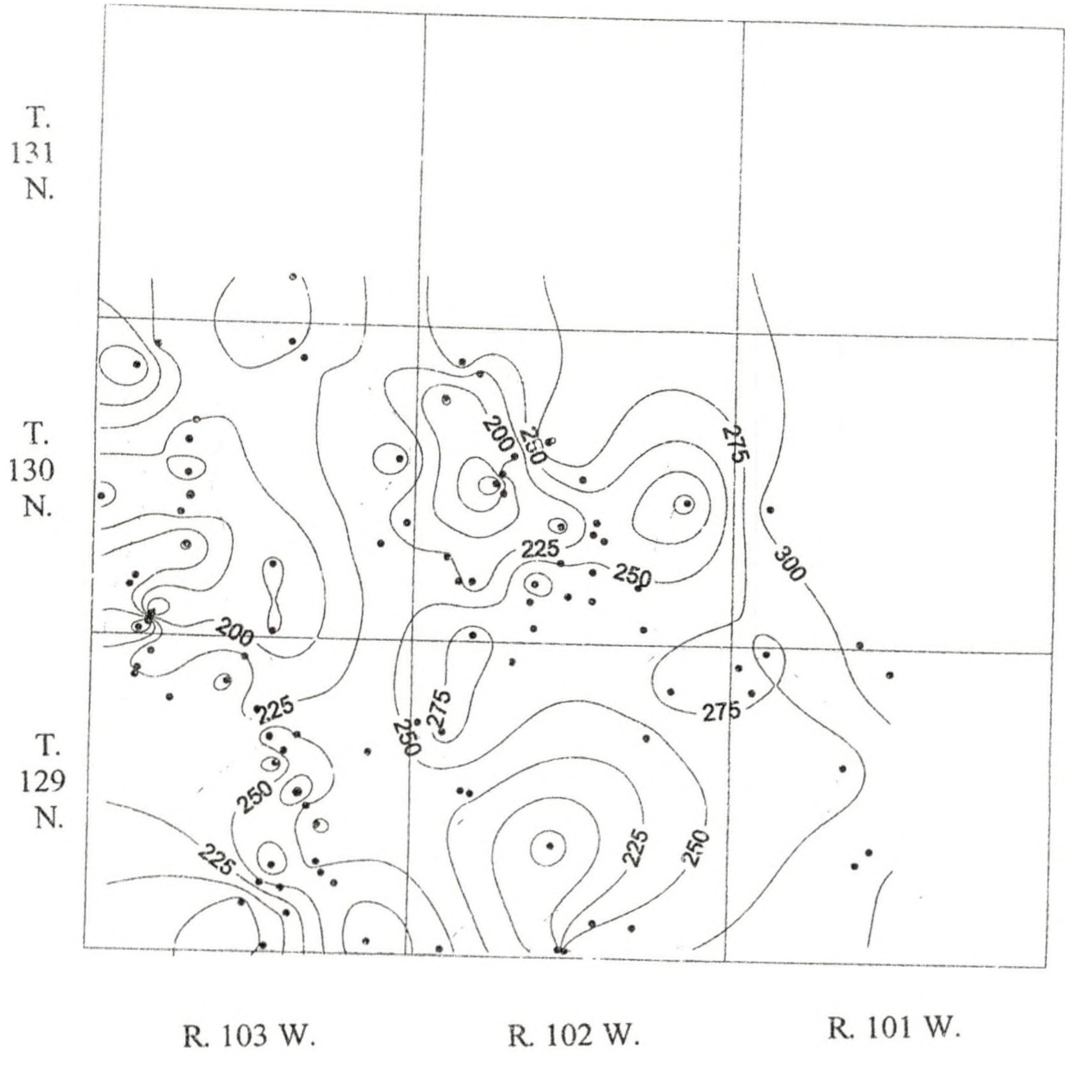


Figure 25. Isopach map of the Minnelusa Group: Broom Creek - Amsden interval. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

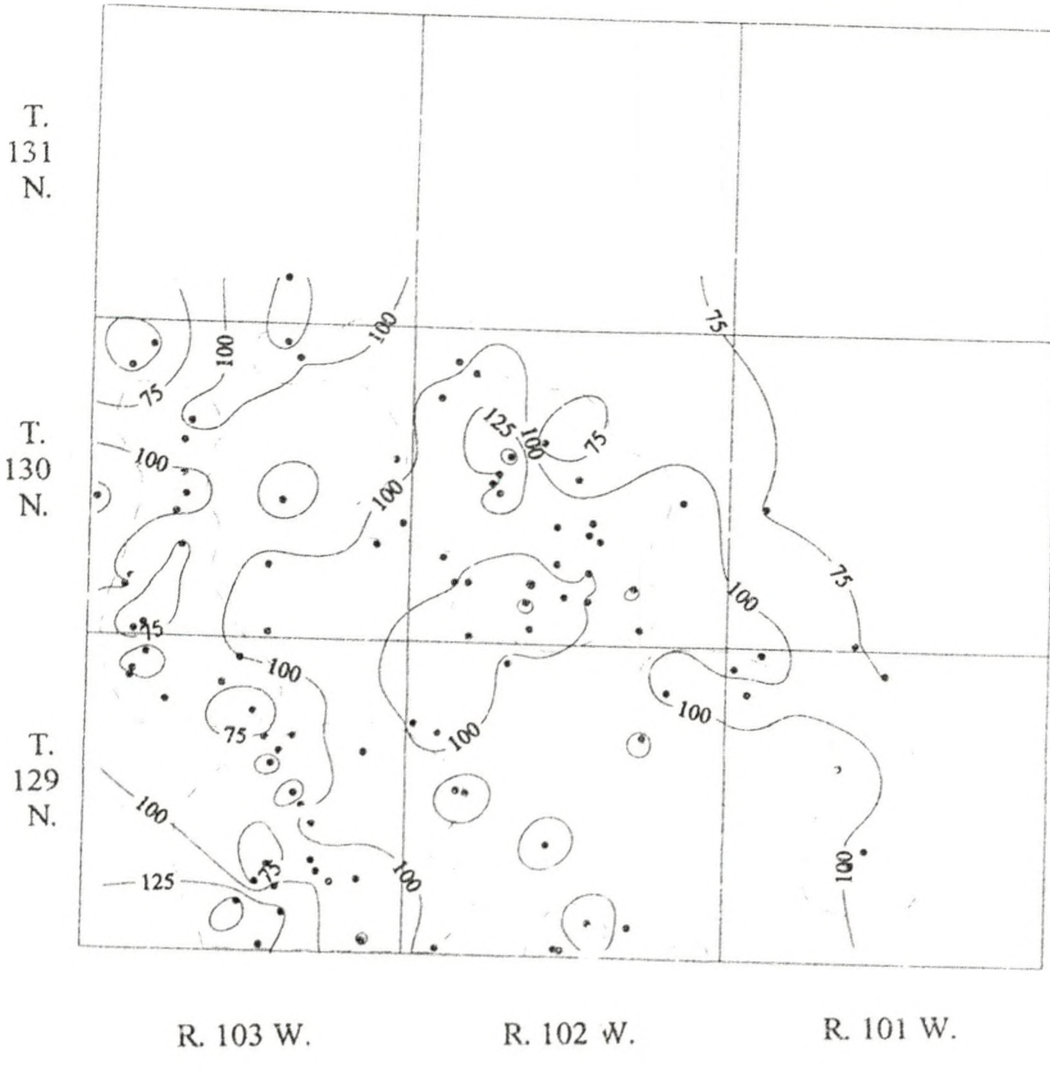


Figure 26. Isopach map of the Opeche Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

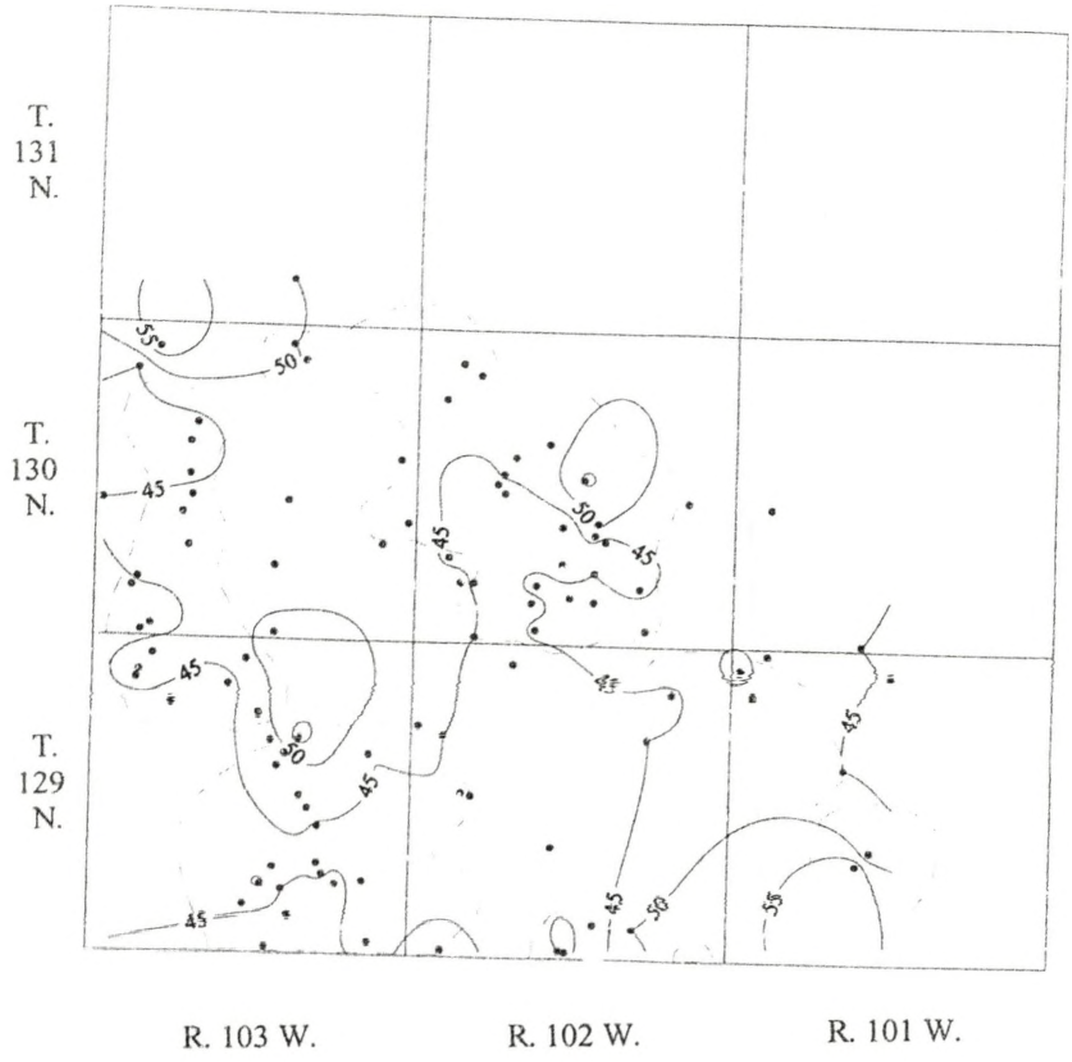


Figure 27. Isopach map of the Minnekahta Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 5 feet.

Turkey Creek structural anomaly. Generally, the Minnekahta Formation trends northward, dipping downslope toward the center of the Williston Basin (Fig. 28).

Belfield Member

The oldest member of the Spearfish Formation is the Belfield Member. The isopach map of the Belfield Member illustrates that there is little variation in the thickness of the Belfield Member across the study area, which ranges from 113 feet (34 meters) to 202 feet (61 meters). There is a slight thinning trend toward the west and northwest and toward the southeast while a slight thickening occurs along a southwest to northeast diagonal through the center of the study area. While there is a slight thickness change across the western Cold Turkey Creek structural anomaly, it does not appear to be significant, and the unit is continuous across the structure (Fig. 29).

Pine Salt Member

The Pine Salt Member is the middle member of the Spearfish Formation, and thickens from east to west-northwest across the study area. The Pine Salt is absent in the southeast corner of the study area, and gradually thickens westward, where a maximum thickness of 278 feet (85 meters) occurs in the northern Amor field (Fig. 30). A slight thickening trend occurs at the structural anomaly. The Pine Salt is continuous across the structural anomaly west of the Cold Turkey Creek field.

Saude Member

The Saude Member is the uppermost and youngest member of the Spearfish Formation, and has a variable thickness across the study area. The Saude Member reaches a minimum thickness of 53 feet (16 meters) in the Ash field at the extreme

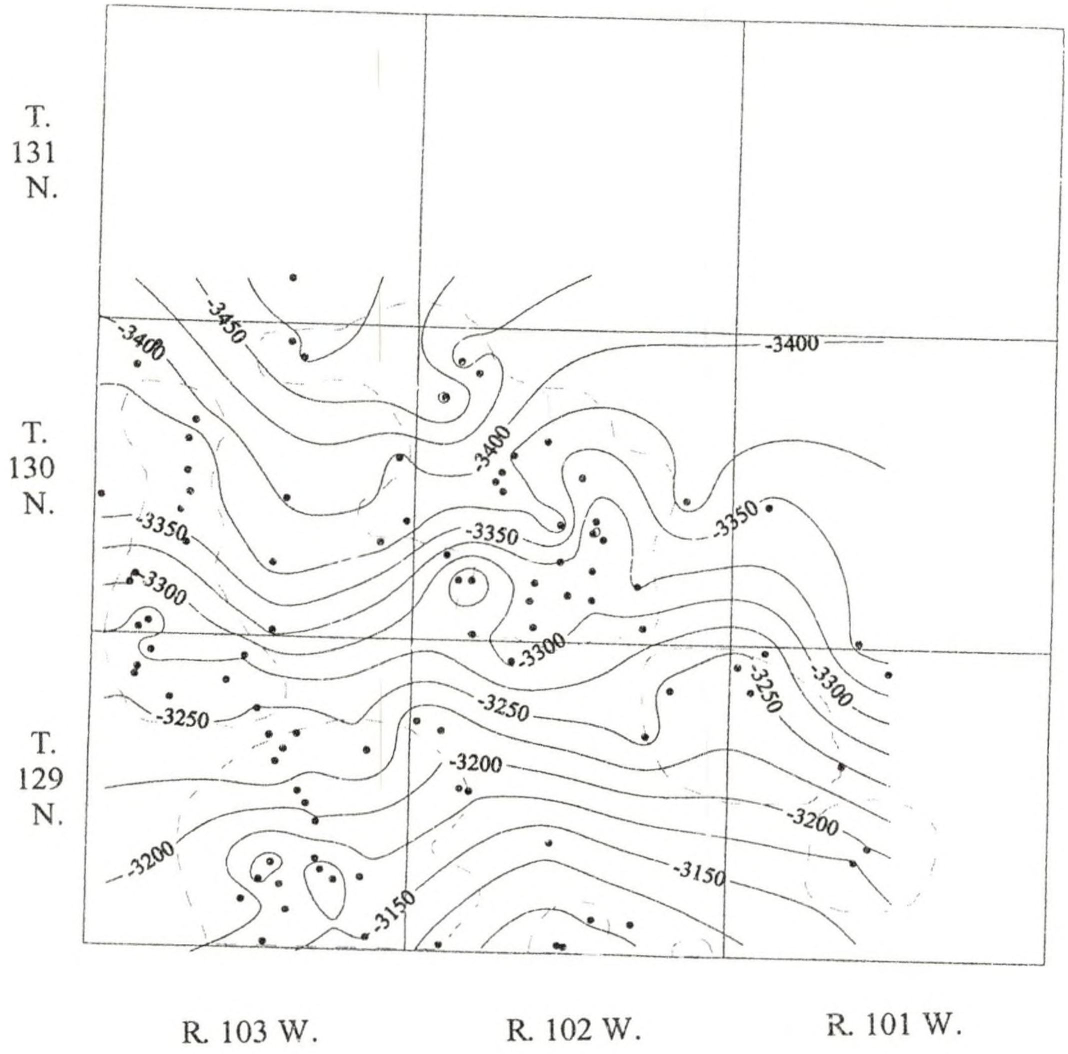


Figure 28. Structure contour map on the Top of the Minnekahta Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Datum is mean sea level. Contour interval = 25 feet.

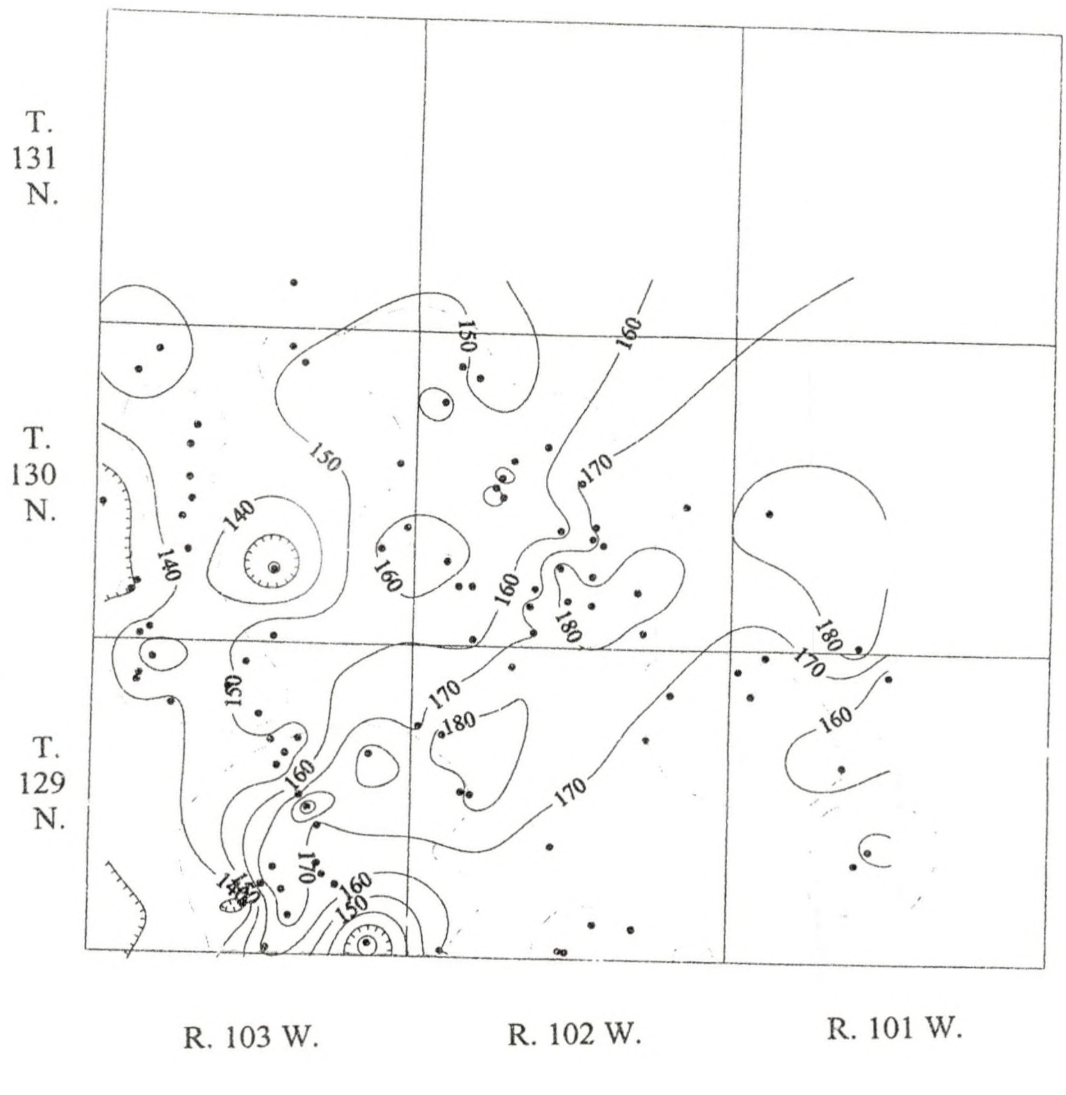


Figure 29. Isopach map of the Belfield Member of the Spearfish Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

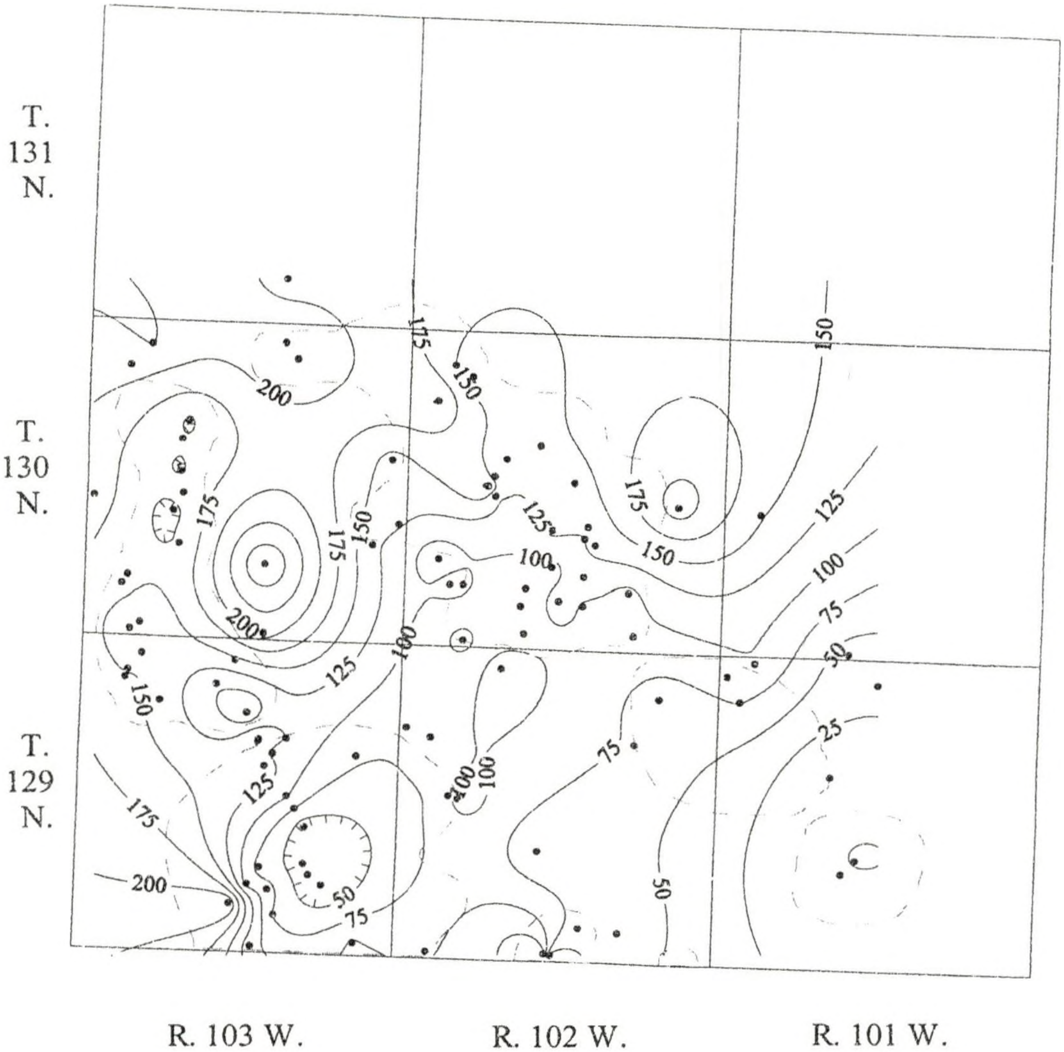


Figure 30. Isopach map of the Pine Salt Member of the Spearfish Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

southern part of the study area, and reaches a maximum thickness of 314 feet (96 meters) in the eastern part of the study area. The thickness of the Saude changes slightly across the western Cold Turkey Creek structural anomaly, nonetheless the unit is continuous (Fig. 31).

Swift – Piper Interval

The Jurassic Swift – Piper Interval ranges in thickness from 343 feet (104 meters) in the eastern part of the study area, to 647 feet (197 meters) across the study area in the extreme western part of the Amor field. The Jurassic strata are continuous and the thickness is fairly constant across the western Cold Turkey Creek structural anomaly (Fig. 32).

Inyan Kara Formation

The Inyan Kara Formation reaches its maximum thickness of 662 feet (202 meters) near the center of the study area, in the eastern portion of the Cold Turkey Creek field. The minimum thickness of 454 feet (138 meters) occurs in the northeastern part of the study area. Thickness changes across the western Cold Turkey Creek structural anomaly are minimal and the structure is not distinguishable on the isopach map of the Inyan Kara Formation (Fig. 33).

Mowry – Skull Creek Interval

The Mowry – Skull Creek interval (Cretaceous) has a minimum thickness of 365 feet (111 meters) in the southeast corner of the study area, thickening gradually toward the center of the Cold Turkey Creek field, then thinning slightly northwest of the Cold Turkey Creek field, before thickening again to reach a maximum thickness of 418 feet

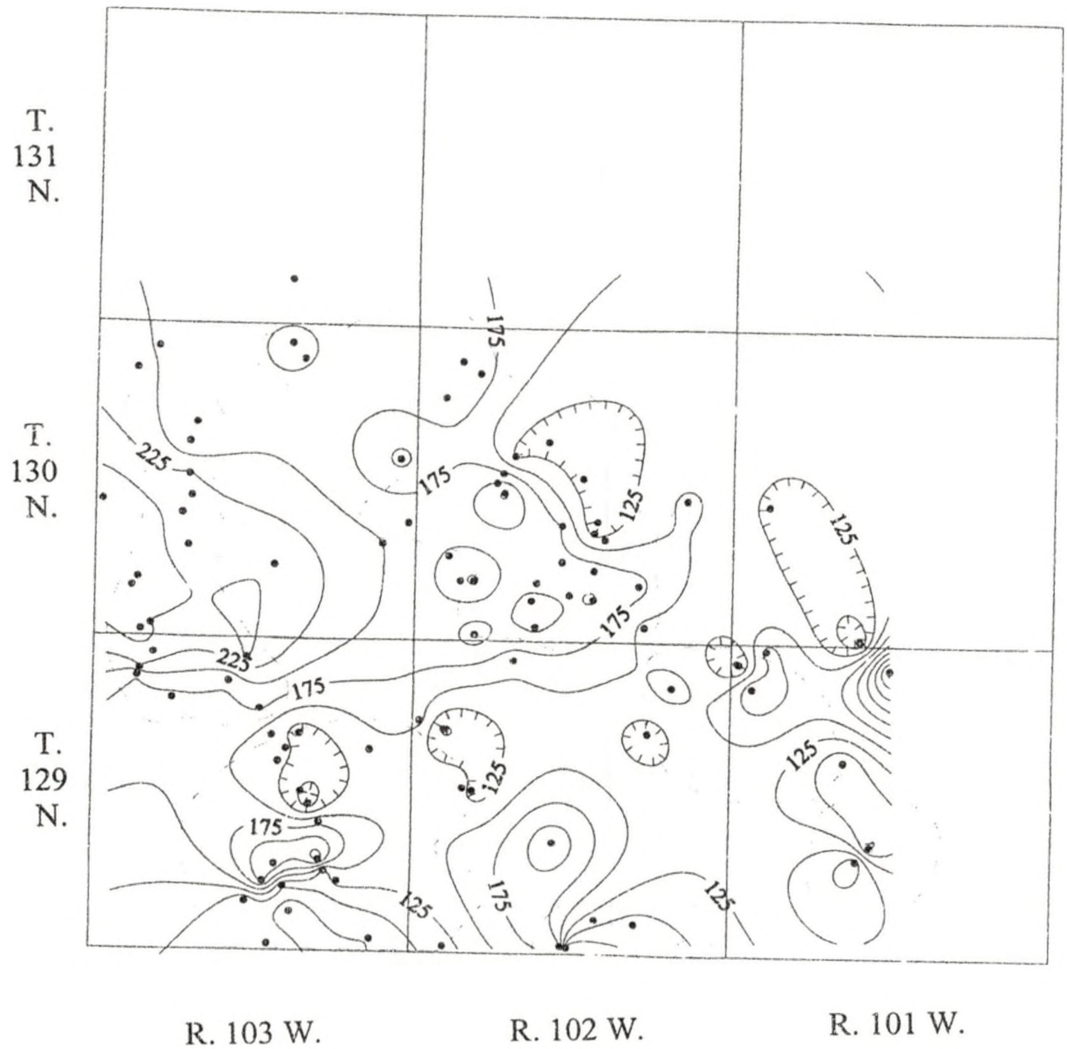


Figure 31. Isopach map of the Saude Member of the Spearfish Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

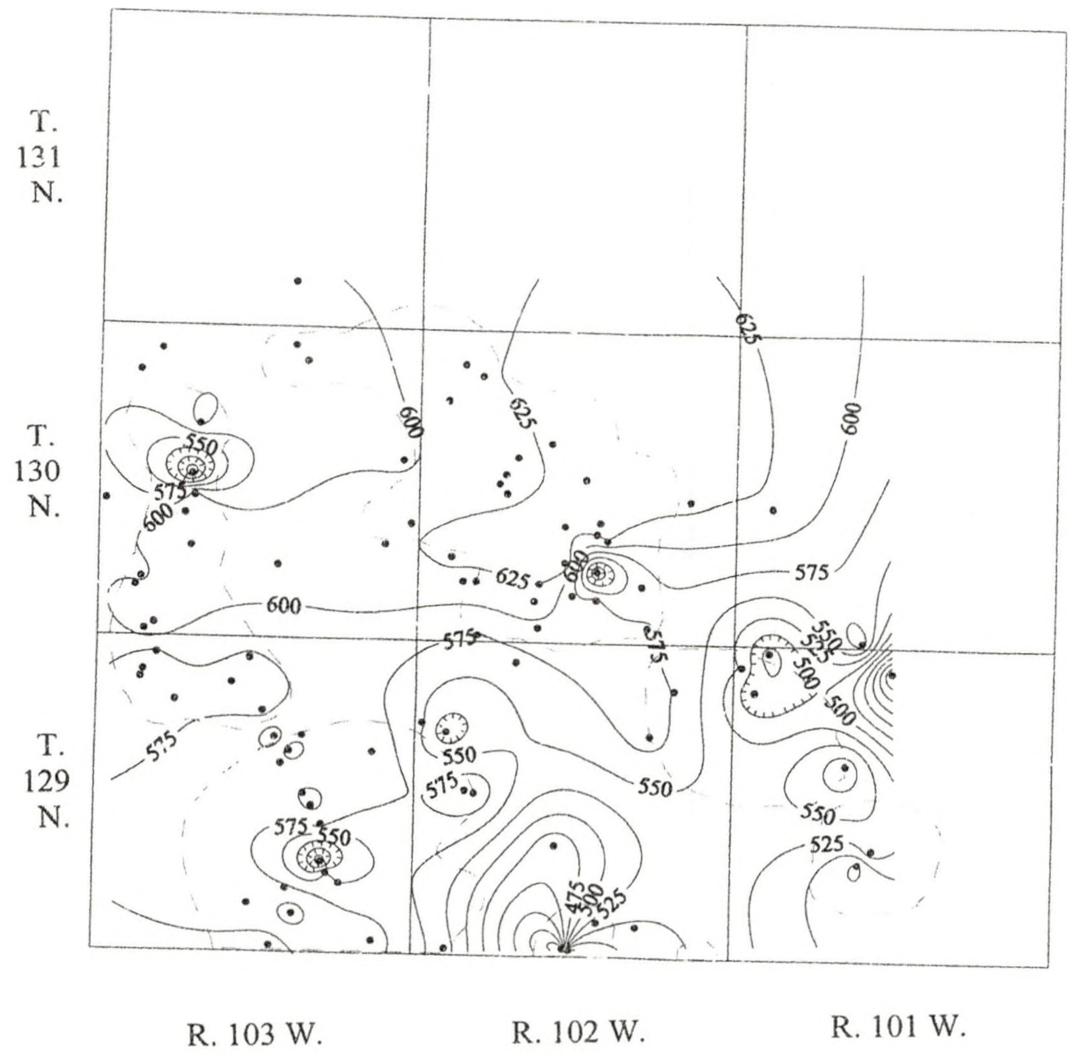


Figure 32. Isopach map of the Jurassic Swift - Piper Interval. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

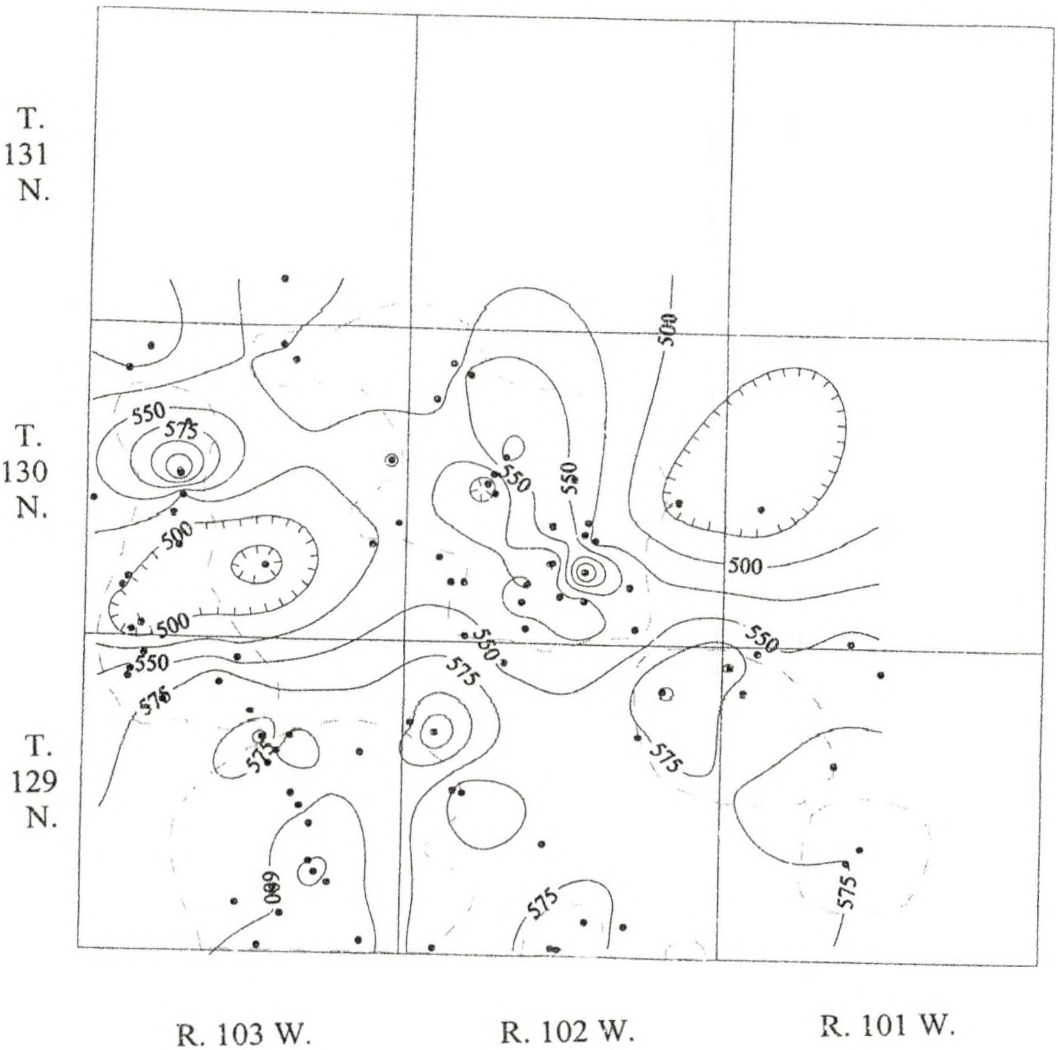


Figure 33. Isopach map of the Inyan Kara Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

(127 meters) in the northwestern most corner of the study area. The Mowry – Skull Creek interval is continuous across the western Cold Turkey Creek structural anomaly, where the thickness is distinguished by a very slight thinning of the surrounding strata (Fig. 34). The structure contour map of the Mowry Formation illustrates a general trend dipping to the east and northeast. Structure contours highlight a slightly elevated area at the western Cold Turkey Creek structural anomaly (Fig. 35).

Greenhorn – Belle Fourche Interval

The Greenhorn - Belle Fourche interval ranges in thickness from a minimum of 428 feet (130 meters) in the southeast central part of the study area to a maximum thickness of 506 feet (154 meters) in the extreme western part of the study area. There is a slight thinning trend eastward across the western Cold Turkey Creek structural anomaly, though the unit is continuous (Fig. 36).

Niobrara – Carlile Interval

The Niobrara – Carlile interval has a fairly constant thickness throughout the study area, with a minimum thickness of 597 feet (182 meters) in the extreme northwestern corner and a maximum thickness of 729 feet (222 meters) in the southwest corner of the study area. The western Cold Turkey Creek structural anomaly is not distinguished by thickness changes; the Niobrara – Carlile interval maintains a fairly constant thickness across the structure (Fig. 37).

Pierre Formation

The Pierre Formation is the most recent unit examined in the study area; it is also the thickest. The Pierre reaches a maximum thickness of 2319 feet (707 meters) in the

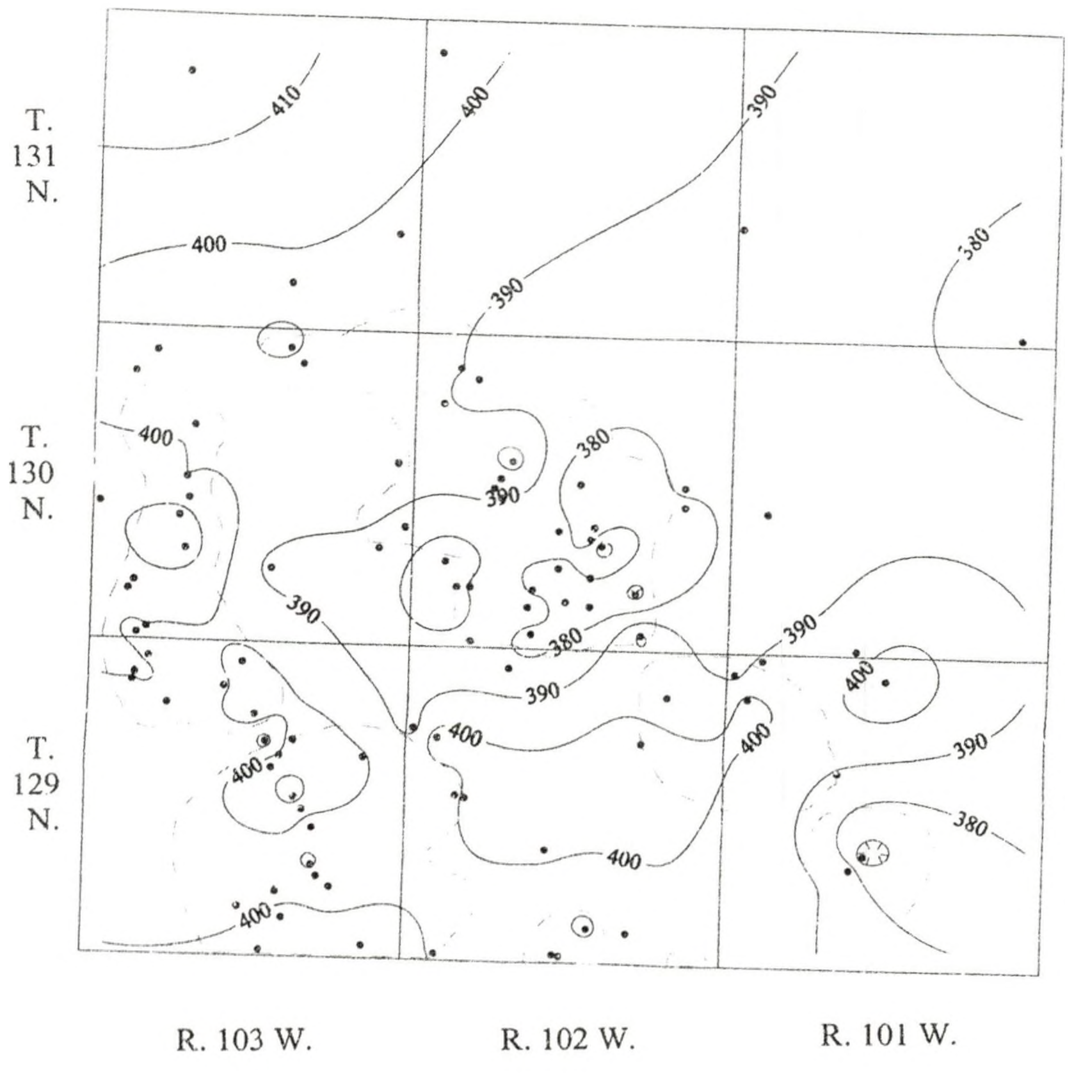


Figure 34. Isopach map of the Mowry - Skull Creek Interval. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

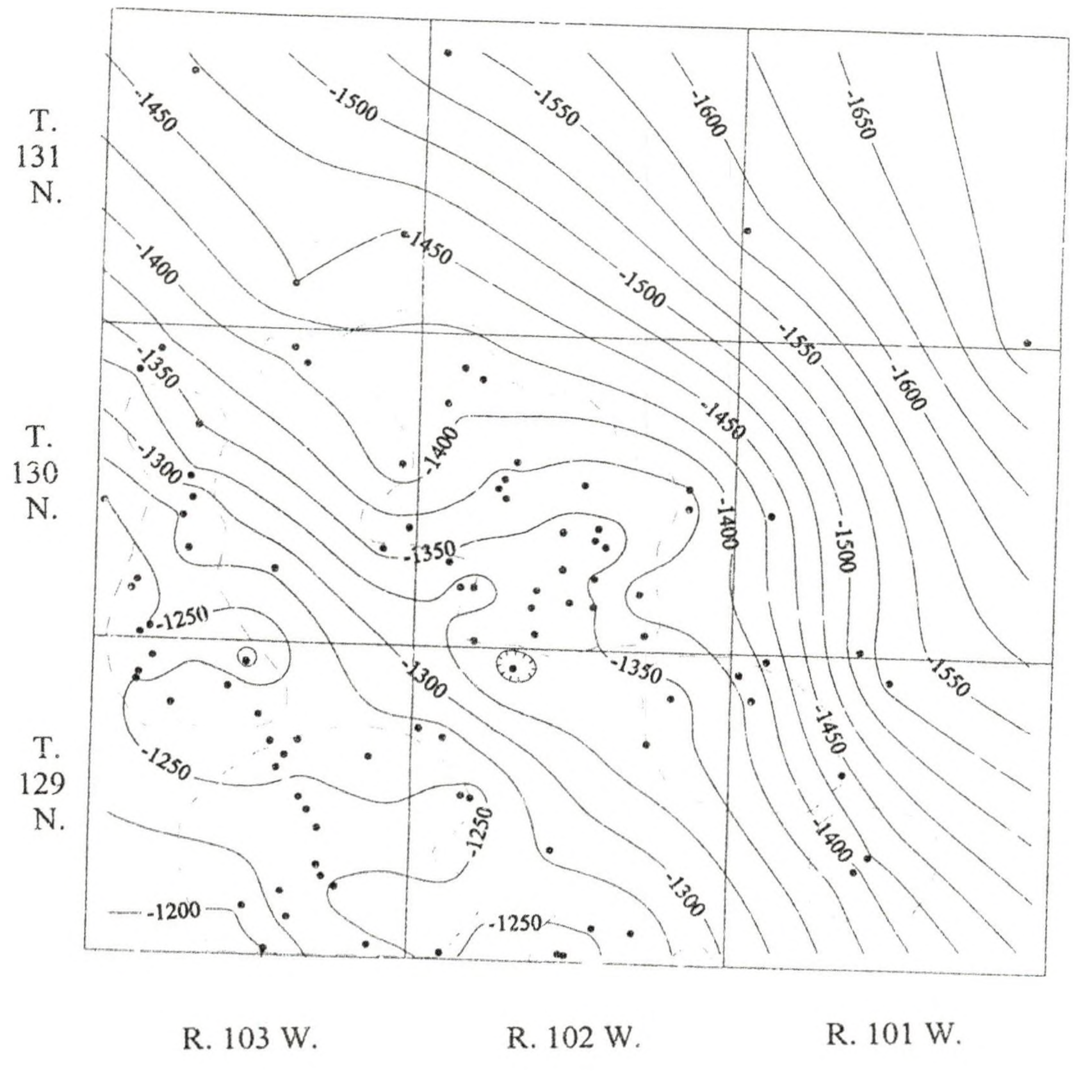
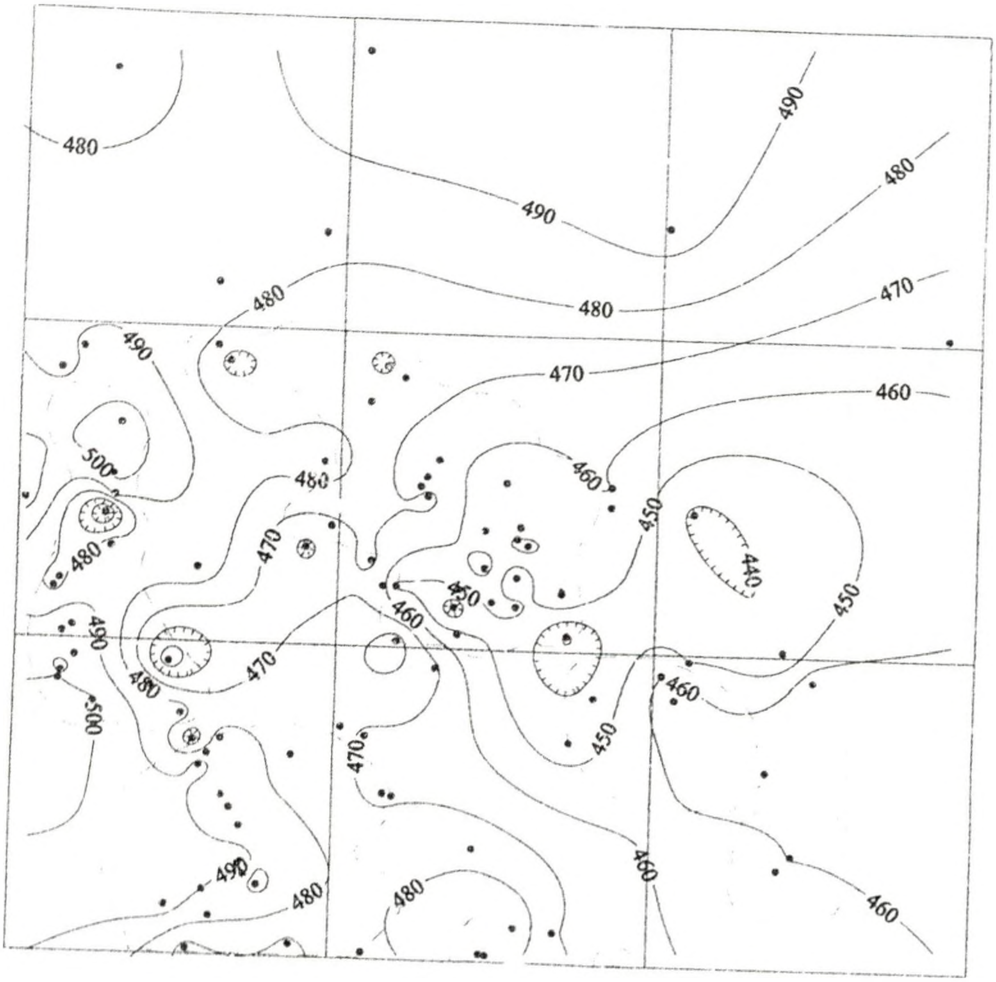


Figure 35. Structure contour map on the Top of the Mowry Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Datum is mean sea level. Contour interval = 25 feet.



R. 103 W.   R. 102 W.   R. 101 W.

Figure 36. Isopach map of the Greenhorn - Belle Fourche Interval. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 10 feet.

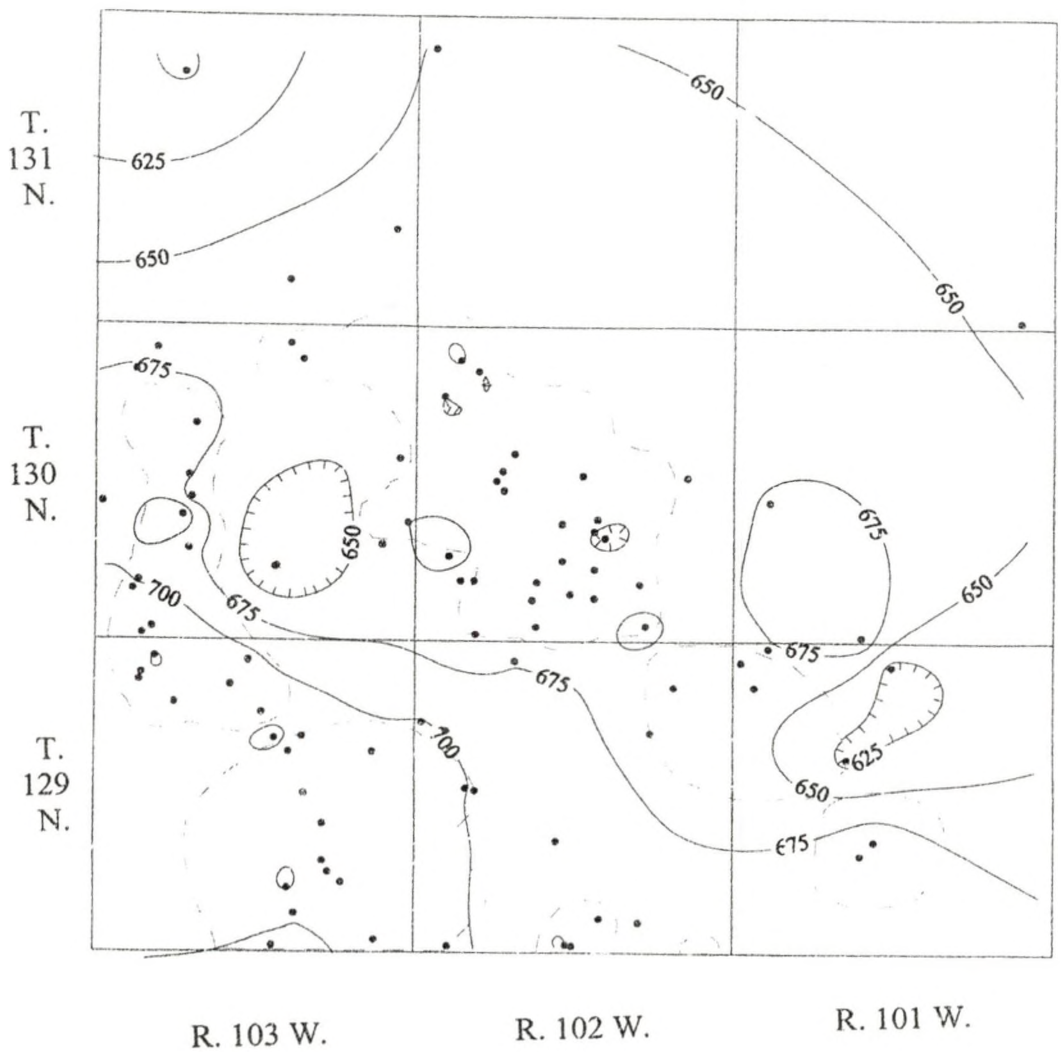


Figure 37. Isopach map of the Niobrara - Carlile Interval. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 25 feet.

northwestern most corner of the study area and a minimum thickness of 1481 feet (451 meters) in the southern portion of the study area. As only 37 of 107 well logs yielded data about the Pierre, the validity of this map is somewhat questionable. Although the western Cold Turkey Creek structural anomaly does not appear distinguishable from its surroundings on this map (Fig. 38), it should be noted that insufficient data has been collected to make a description of Pierre thickness or structure in that location.

Cross Sections

Six wells in and around the structure were used to generate each cross-sectional diagram. These diagrams depict the thicknesses of each unit and the depth to the top of each unit. North Dakota Geological Survey wells numbered 4654, 9317, and 5459 are drilled into the structural anomaly west of the Cold Turkey Creek field. Wells numbered 5823 and 6398 are located north of the structure, and wells 5865 and 8021 are located south of the structure. Wells numbered 11255 and 9963 are located west of the structure, and well number 8982 is located to the east (Fig. 39).

At the base of each well, is the top of the Red River Formation (Figs. 40 and 41). There is some variation in the depth to the top of the Red River Formation. The thickness of the Stony Mountain Formation is fairly consistent, although the slope is slightly variable. The same observations can be made for the Stonewall, and Interlake Formations. The thickness of the Souris River Formation is slightly more variable than that of the underlying units, and it is notable that the Ashern Formation is present only in NDGS well number 11255, the western-most well of the west – east cross-section (Fig. 41). The Ashern Formation is a discontinuous unit across the study area, and is not

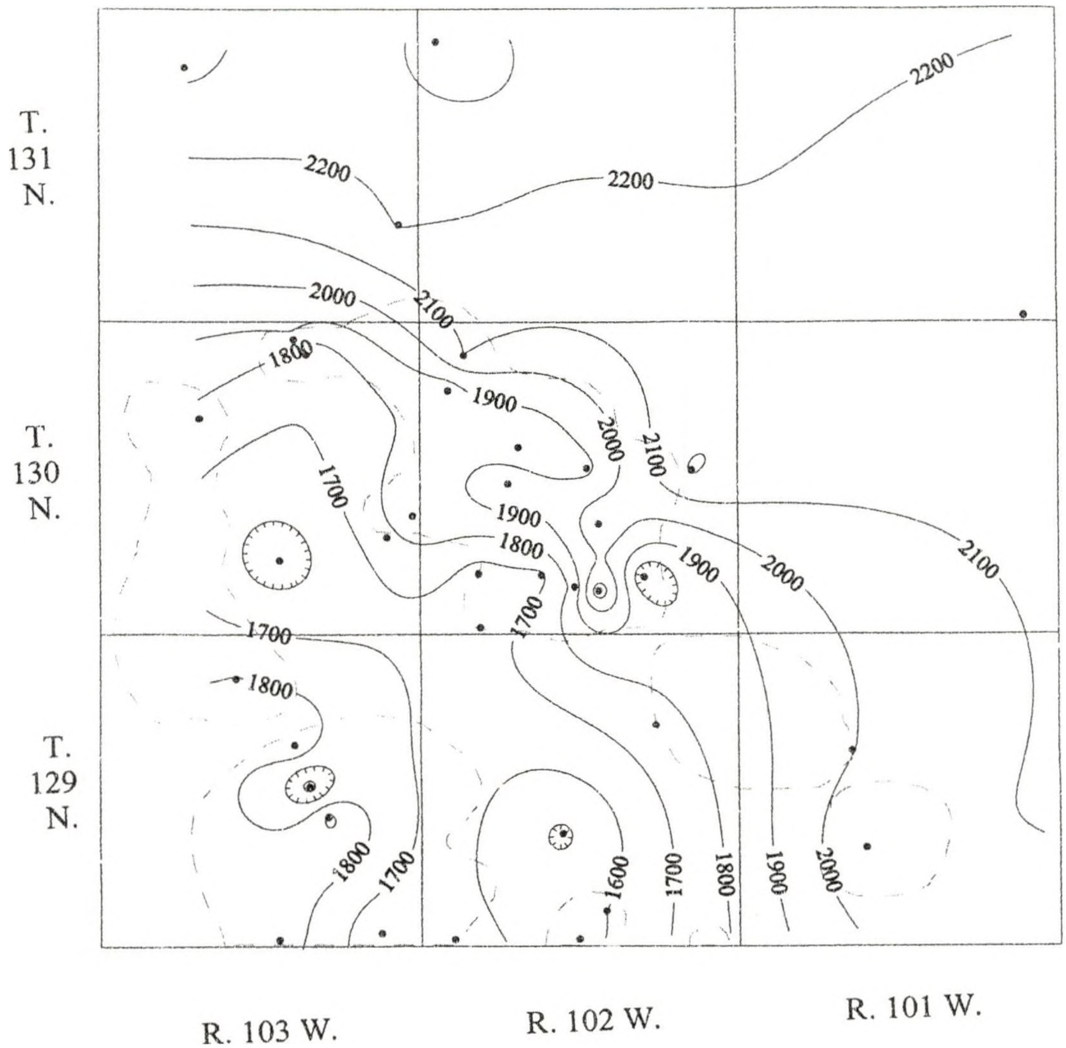


Figure 38. Isopach map of the Pierre Formation. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed grey lines represent generalized oil field boundaries; refer to Figure 2 for field names. Contour interval = 100 feet.

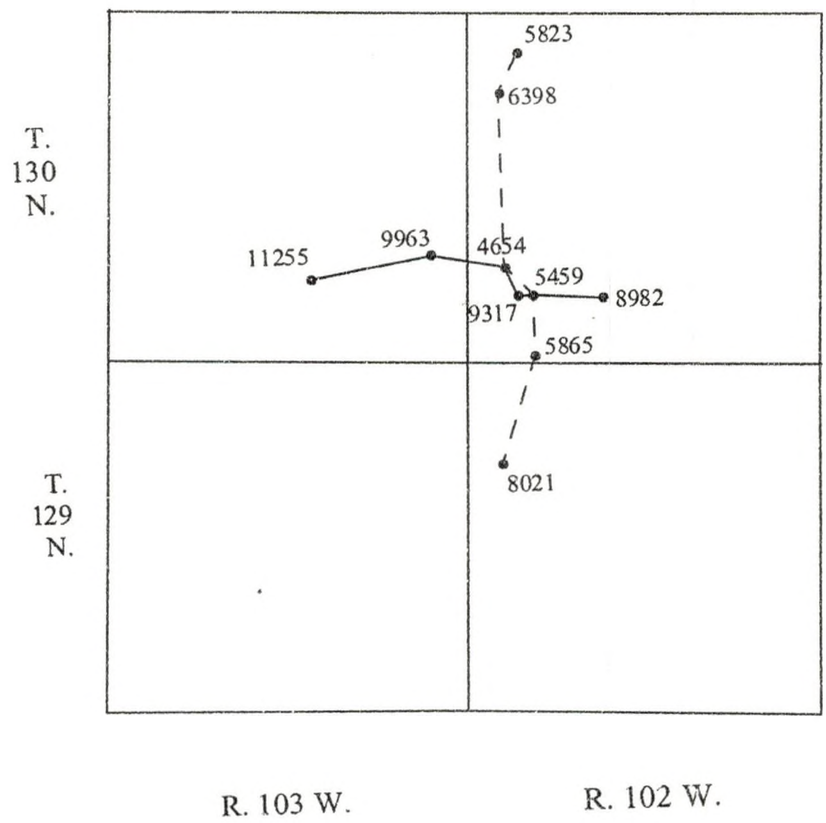


Figure 39. Location of cross-sections. Township boundaries are shown for scale; townships are six miles on each side. Points represent well locations. Dashed line represents north - south cross-section. Solid line represents west - east cross-section.

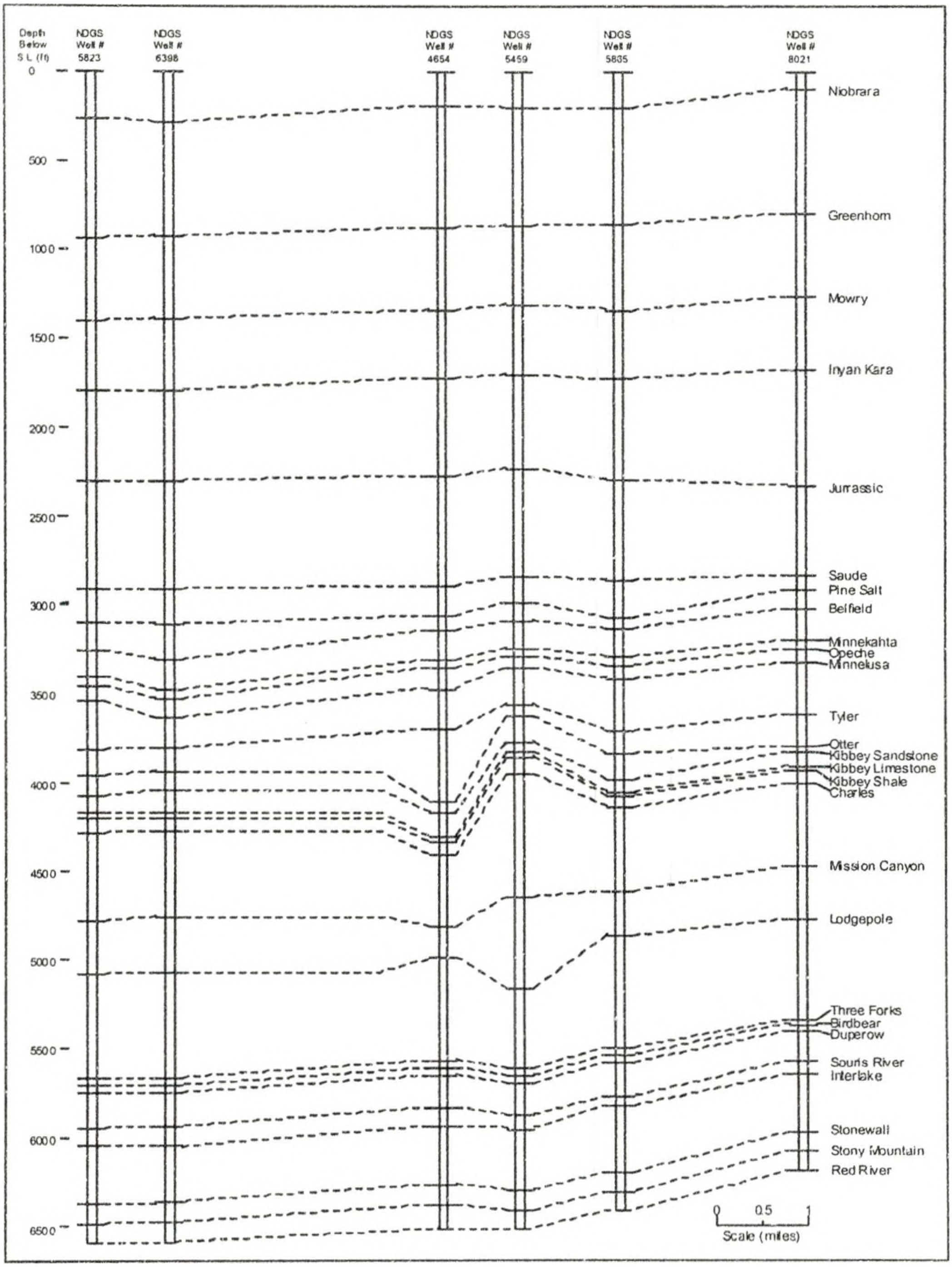


Figure 40. A north to south cross-section through the western Cold Turkey Creek field anomaly, illustrating thickness variations of lithologic units. Vertical exaggeration = 10x.

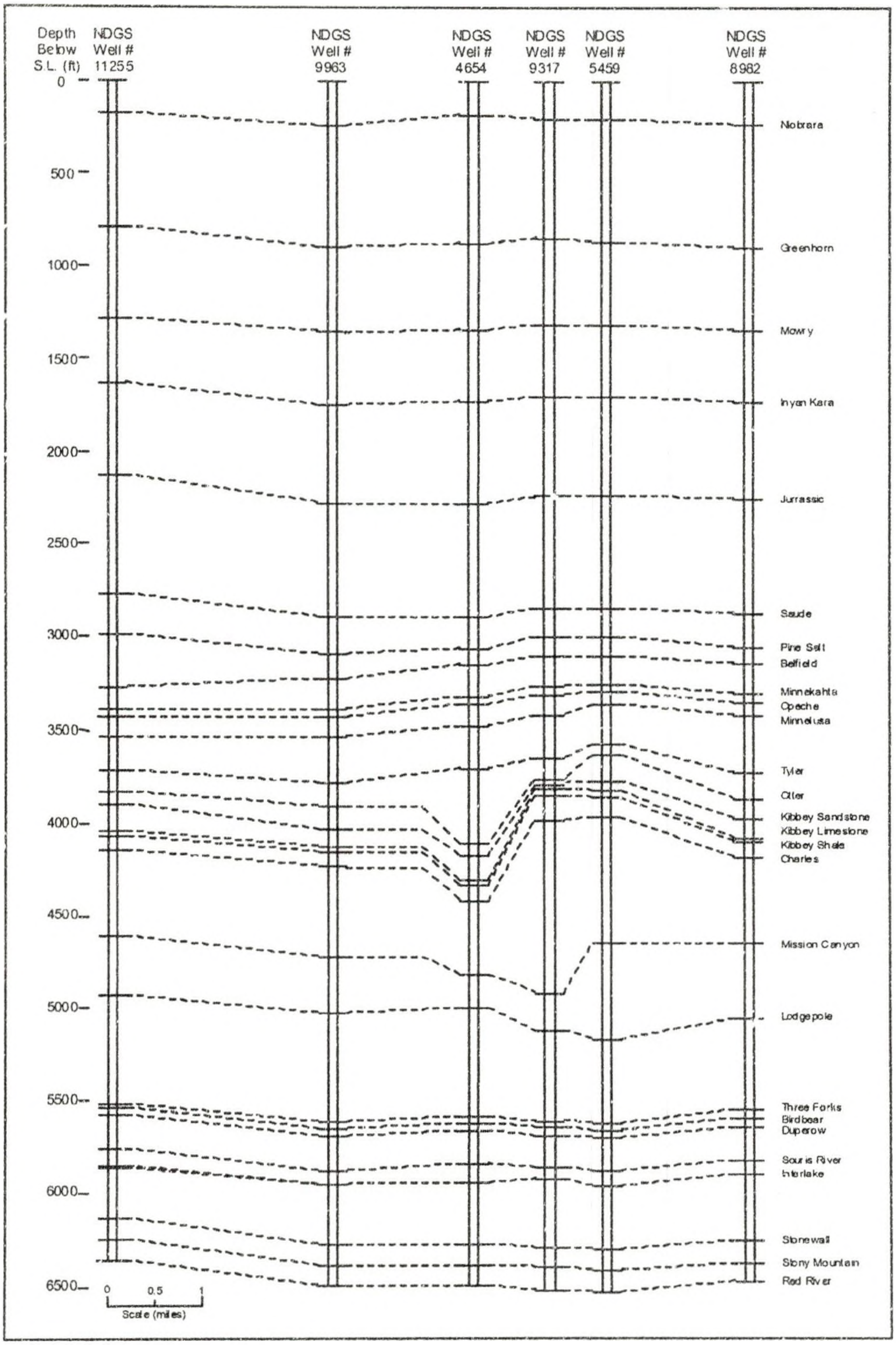


Figure 41. A west to east cross-section through the western Cold Turkey Creek field anomaly, illustrating thickness variations of lithologic units. Vertical exaggeration = 10x.

present within the western Cold Turkey Creek structural anomaly or in the wells immediately nearby. The thicknesses of the Duperow, Birdbear, and Three Forks Formations are also fairly consistent across the structure in both the north – south and west – east cross-sectional views. These formations are continuous across the structure and are nearly horizontal, lacking in any dramatic thickness changes. A very slight depression in these formations is evident in well 5459.

The Lodgepole Formation is continuous across the structure, despite thickness changes. The Lodgepole Formation thins across the structure, notably in wells 9317 and 5459, which are located near the approximate center of the structure and just east of center, respectively (Fig. 16)

The Mission Canyon, middle formation of the Madison Group, appears thinner in wells 4654 and 9317, within the structural anomaly, than in wells surrounding the structure and is also anomalously thicker than nearby wells in well 5459. The unit can be correlated between wells across the structure, and is considered continuous, despite thickness changes. The relative depths to the surface of the Mission Canyon and subsequent decreased slope from the north and west toward NDGS well 4654, suggest the presence of a depression to the northwest of well 4654 on the northwest side of the structure. This indicates a shift in the location of the depression on the Mission Canyon top, relative to the location of the depressed area on the top of the underlying Lodgepole Formation.

The Charles Formation is the uppermost unit of the Madison Group, and is continuous across the western Cold Turkey Creek structure. The unit thins at NDGS well number 4654 on the northwest side of the structure, and then thickens at NDGS well number 9317. While the Charles Formation is only slightly thicker at well number 5459 than it is east and west of the area surrounding the structure, it is noticeably thicker than in wells north and south of the structure. The elevation at which the top of the Charles Formation occurs in NDGS well number 4654 is lower than its elevation in surrounding wells, suggesting the presence of a depression on the northwest side of the structure. The top of the Charles Formation occurs at a higher elevation in wells 9317 and 5459, indicating the presence of a local high on the center and south side of the structure.

The Kibbey shale overlies the Charles Formation, and is a substantially thinner unit. The Kibbey shale is continuous across the structure, though it too varies in thickness; the unit thickens at well 9317. The thickness is fairly constant in the other wells. The relative depths to the top of the Kibbey shale indicate that it occurs at a higher level in wells 9317 and 5459 than it does in neighboring wells, and it occurs as a local low in well number 4654.

The Kibbey limestone, middle unit of the Kibbey Formation, is also continuous across the structure. The unit gradually thickens south and eastward to well 5459, before thinning slightly in well number 8982 which is adjacent to and due east of the structure. The relative depths to the top of the Kibbey limestone indicate that in wells 9317 and 5459, the elevation of the Kibbey lime is higher than the surrounding area, and that it occurs at a lower elevation in well 4654 than either the surrounding area or the structure itself.

The Kibbey sandstone is continuous across the structure and gradually thickens north and westward, with a slightly greater thickness occurring in NDGS well number 4654. The top of the Kibbey sandstone appears elevated and horizontal in an east – west direction between wells 9317 and 5459 within the structure. To the north and west, the surface of the Kibbey sandstone slopes downward to a local low elevation at well 4654, on the northwest side of the western Cold Turkey Creek structural anomaly.

The Otter Formation is continuous across the structure, although the thickness is variable, both within the structure and in surrounding areas. The top of the Otter Formation mimics the surface of the underlying Kibbey Formation, with the surface of the Otter Formation occurring at a higher elevation in well 5459 than in surrounding wells. The surface is also elevated above the surrounding terrain in well 9317, but less so than in well 5459. There is a thickening trend in well 5459 and a thinning trend in well 9317, while the thickness of the Otter Formation is only slightly greater in well 4654 than it is in wells surrounding the structure.

The Tyler Formation unconformably overlies the Otter Formation, and is continuous across the structure, although its thickness is not constant. North Dakota Geological Survey well number 4654 indicates a pronounced increase in thickness, more than double the thickness present in adjacent wells. The relative depths to the top of the Tyler Formation indicate that the elevation of the surface of the Tyler is elevated at well 5459 above the rest of the structure. The surface of the Tyler Fomation dips to the northwest and is accompanied by a raised area at well 5459.

The top of the Minnelusa Group exhibits a slight depression to the northwest of the structure, with a slightly raised area occurring at well 5459. The unit generally dips very slightly to the northwest. The thickness of the Minnelusa Group is less variable than underlying units, with a slight thickening trend to the south and east apparent in both cross-sections (Figs. 40 and 41). The unit is continuous across the structure.

The Opeche Formation exhibits a slight thinning trend to the south and the east, though the unit is continuous across the structure. Although the Opeche Formation unconformably overlies the Minnelusa Group, the topography of the top of the Opeche Formation is very similar to that of the underlying unit. There is a slight depression to the north and west of the structure, accompanied by a slightly raised area at well 5459.

The Minnekahta Formation lies stratigraphically above the Opeche Formation, and is continuous across the western Cold Turkey Creek structure. The thickness of the Minnekahta Formation exhibits very little variation in the cross-sections. The top of the Minnekahta Formation exhibits a nearly horizontal slope, dipping slightly westward in the west – east cross-section (Fig. 41). Again, a slightly raised area occurs in well 5459 and also in well 9317.

Overlying the Minnekahta Formation is the Belfield Member, the lowermost member of the Spearfish Formation. The thickness of the Belfield Member shows little variation in the cross-sections, and is continuous across the structure. The west – east cross-section illustrates that the unit dips slightly to the northwest. However, the surface of the unit appears to be more variable in the north – south cross-sectional view, where the Belfield Member occurs at a slightly higher elevation in well 5459 than in surrounding areas.

The Pine Salt Member of the Spearfish Formation is continuous across the western Cold Turkey Creek structural anomaly. Although its thickness is slightly variable within the structure, the Pine Salt thins in well 4654, and then thickens in wells to the north and west. Other wells to the south and east exhibit little variation in thickness. The top of the Pine Salt Member, although nearly horizontal, exhibits a very slightly raised area at wells 5459 and 9317.

The uppermost member of the Spearfish Formation is the Saude Member, which is continuous across the structure, even though its thickness is only slightly variable. The top of the Saude Member is nearly horizontal, with only the westernmost well having a higher elevation than the others in the cross-section.

The Jurassic and Cretaceous strata above the Triassic Saude Member are all continuous units across the western Cold Turkey Creek structural anomaly. All of these units have a nearly horizontal orientation, with a slight northeast dip direction. None of these units exhibit significant thickness changes at or near the structure. The thicknesses of the Jurassic and Cretaceous strata show little variation anywhere in either of the cross-sections (Figs. 40 and 41).

Seismic Structural Maps

Two seismic structural maps of the western Cold Turkey Creek structural anomaly were available in a previously published work (Gerhard et al, 1995).

The seismic structural contour map of the top of the Ordovician Winnipeg horizon utilizes a contour interval of 3 msec, which is similar to, but not the same as measurements of feet. The contour interval of msec represents the amount of time taken for the signal to travel down to the surface before it is reflected back to the seismograph. Since the time traveled is proportional to the velocity, it yields an approximation for distance to the reflecting unit. The Winnipeg Formation lies stratigraphically below the Red River Formation, and thus is representative of data not available in the well log data base collected for this study. Figure 42 illustrates the western Cold Turkey Creek structural anomaly as a rhombic antiformal structure located in the southwestern corner of Township 130 North, Range 102 West, in sections 29, 30, 31, and 32. North Dakota Geological Survey well numbered 4654 is located on the northwest flank of the structure, while the well numbered 9317 is positioned near the highest area of the structure in section 30, just south of the approximate center. North Dakota Geological Survey well numbered 5459 is due east of well number 9317, and is located in the downward sloping area adjacent to the flat, elevated top, in section 29. The eastern side of the structure is marked by a very steep slope, while the western side slopes much more gradually to the surrounding terrain. In the northeast corner of section 29 is a depression. Elsewhere on the map, the structure contours indicate that the depth increases in the north and northwest portions of the map, indicating a gradual slope dipping to the north and northeast toward the center of the Williston Basin.

The seismic structural contour map on the top of the approximate Mississippian Mission Canyon Formation illustrates a more complicated structure (Fig. 43). The

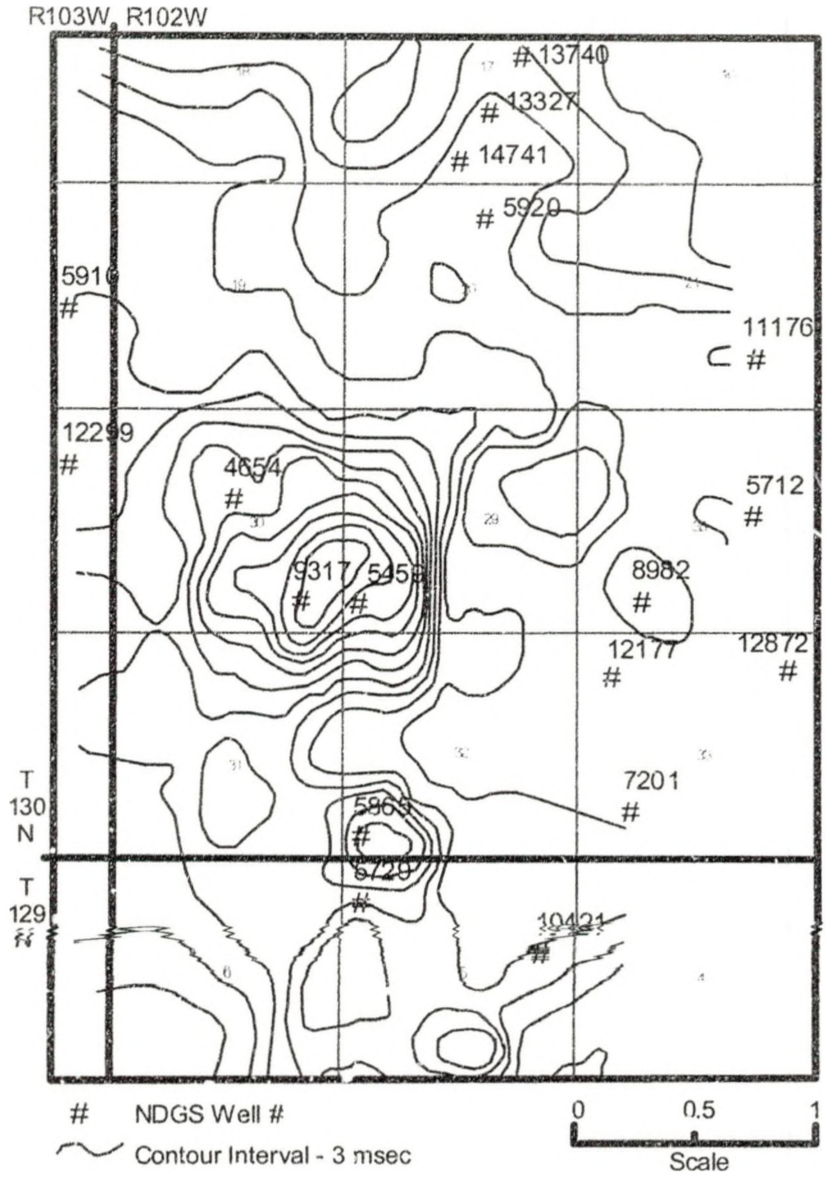


Figure 42. Seismic structural contour map on the top of the Ordovician Winnipeg horizon (Modified slightly from Gerhard et al., 1995).

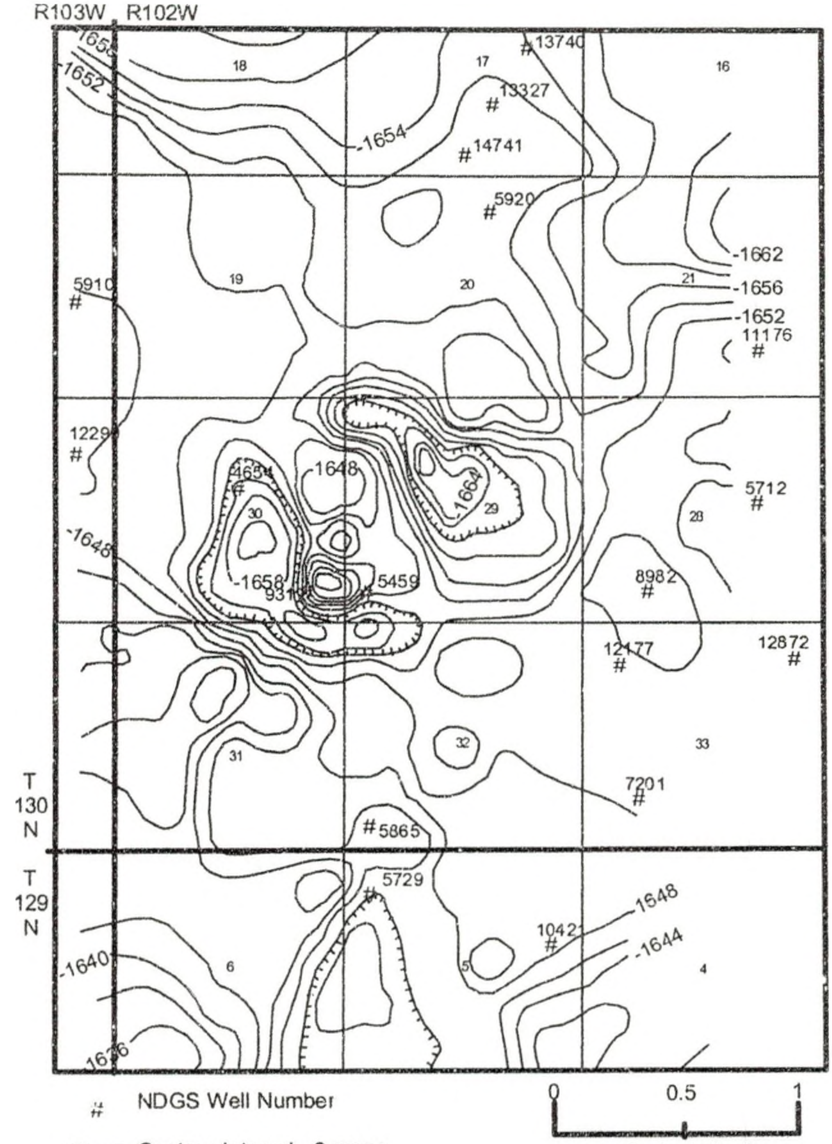


Figure 43. Seismic structural map on the surface of the approximate Mississippian Mission Canyon horizon (Modified slightly from Gerhard et al., 1995).

the depth indicated. Generally, greater depths are indicated by structure contours in the north and northeastern portions of the seismic structural contour map of the Mission Canyon, suggesting a general north-northeast dip direction for the Mission Canyon Formation (Fig. 43) surrounding the anomalous structure. The southwest side of the structure has a steep slope, which ends in an irregularly-shaped shallow depression, which trends northwest to southeast, extending approximately from well 4654 to south of well 9317 and eastward to south of 5459. Adjacent to and sharply contrasting the depression is an elevated knob, just northeast of well 9317, in the southeast corner of section 30. Section 29 is dominated by the presence of a second elongated, irregular depression trending northwest to southeast. Between the two depressions is a northwest to southeast trending antiform.

Core

The core from North Dakota Geological Survey well number 4654 located on the northwestern part of the western Cold Turkey Creek structural anomaly in Township 130 North, Range 102 West, Section 30, SWNE, was examined and described (Appendix C). 103 feet of discontinuous core from well 4654 contained sections from the Mission Canyon Formation and the Red River Formation. Core intervals are in feet below the surface.

The core interval from 7568 feet to 7642 feet, although discontinuous, contained 71 feet (21 meters) from the Mississippian Mission Canyon Formation. This predominantly consisted of limestone, massive to finely laminated, with carbonate mud and anhydrite nodules throughout (Appendix C). This description is consistent with published descriptions of typical Mission Canyon characteristics common throughout the Williston Basin. Nothing atypical was observed: no unusual structures, textures, or unexpected lithologies.

The core interval from 9440 feet to 9567 feet was also discontinuous, and represented only a portion (33 feet, 10 meters) of the Red River Formation from well 4654. The core in this interval was composed of limestone, mottled gray, finely laminated to massive, with occasional fossils and occasional stylolites (Appendix C). This description is consistent with other published descriptions of typical Red River Formation rocks elsewhere in the Williston Basin.

INTERPRETATION

In general, several characteristics are used to identify an impact crater in the rock record, namely: shape, structure, stratigraphic signature, and secondary indicators, such as PDF's, high pressure polymorphs of quartz, and shatter cones. Additionally, an impact crater is the result of an instantaneous event. In order to evaluate the origin of the western Cold Turkey Creek structural anomaly as a possible result of impact, the anomaly's structure and stratigraphy were examined and described to determine if the structure represented an instantaneous geologic event, later simply buried by additional sedimentation. If the structure could be determined to be the result of impact, data collected by this study should be able to determine the geologic time for that impact.

The results of this study indicate that the structure does not represent an instantaneous geologic event. The earliest development of the structure is at least as old as the Winnipeg Group (Ordovician), if not older. The seismic data indicates the presence of the structure within the Winnipeg, and lacking any information about strata older than this, the possibility exists that the structure may have developed earlier. Analysis of the data obtained from this study suggests that the western Cold Turkey Creek structural anomaly may have begun, in part, as a rhombic, antiformal structure on the surface of the Ordovician Winnipeg Group.

On the surface of the Red River Formation, the structure appears as an anomalous elevated area on an otherwise smooth slope into the center of the Williston Basin. Well log data for the Red River, Stony Mountain, and Stonewall Formations above the Winnipeg, indicate that the strata are nearly horizontal in the area of the structure, and that there is little variation in the thickness of these units. Very slight thickness changes are apparent in wells 4654 and 9317 in the Interlake and Souris River Formations, suggesting that there was some localized and subtle relative motion up and down during the deposition of these units. The Duperow, Birdbear, and Three Forks Formations above the Souris River maintain almost constant thicknesses within the three wells which penetrate the structure. The surface and slope of these units reflect the thickness changes in the underlying Interlake and Souris River Formations, and otherwise appear relatively unaffected by the structural anomaly.

The entire Madison Group, however, is marked by changes in the area of the structural anomaly. Rapid thickness changes over short distances again indicate relative up and down motion within each unit and between wells. The surface of the Lodgepole Formation is irregular, and the thickness of the unit changes dramatically between wells 4654, 9317, and 5459 (Figs. 16 and 41). In the Mission Canyon Formation, the surface is also irregular, but it does not mimic that of the underlying Lodgepole Formation. The seismic structural contour map of the approximate Mississippian Mission Canyon Formation indicates how complex the structure has become since deposition of the Ordovician Winnipeg Group. The rhombic antiformal structure has become a northwest- to southeast- trending antiform, accompanied by depressions on its northeast and southwest flanks (Fig. 43). The depression to the northeast occurs in the same location as a depression northeast of the rhombic antiformal structure in the Winnipeg (Fig. 42). The structure is not circular. The thickness of the Mission Canyon Formation is highly variable across the structure, with a dramatic increase in thickness at well 5459 (Figs. 17 and 41). Further, the structure continues to change through the deposition of the Charles Formation, as indicated by additional dramatic thickness changes between wells within the structure.

Superimposed on top of the Madison Group, the Kibbey and Otter Formations reflect the complicated underlying structure. The Kibbey shale exhibits dramatic thickness changes over a small area, especially between wells 5654 and 9317, where the difference is nearly 50 feet (Fig. 20). This is a substantial change for a relatively thin unit, and indicates that the structure continued to develop during deposition of the Kibbey shale. The Kibbey limestone, by contrast, maintains an almost constant thickness between the three wells in the structure (Fig. 21), suggesting a hiatus in structural development. Although the surface of the Kibbey limestone reflects the underlying structure, it remains unaltered by the process that caused the thickness changes in the Kibbey sandstone, stratigraphically above. The Kibbey sandstone like the Kibbey shale, exhibits significant thickness changes between the three wells which penetrate the structure. This indicates renewed development of the structural anomaly.

The Otter Formation also reflects the underlying structure, but is further complicated by a substantial increase in thickness at well 5459. At this location, the unit has a greater thickness than elsewhere in the structure, as well as the surrounding area. This suggests relative up and down motion between wells 9317 and 5459, though more pronounced than such motion in the Kibbey sandstone.

Stratigraphically above the Otter Formation, the top of the Tyler Formation exhibits a decrease in slope across the structure, becoming somewhat more horizontal.

However, evidence for the continued development of the structure is indicated by the substantial gain in thickness at well 4654, and also by the thin nature of the unit at well 5459 (Figs. 24 and 41). Strata above the Tyler Formation exhibit very little expression of the structure below, though the structure is still faintly apparent as a slight rise above the surrounding Tyler terrain.

In both the Minnelusa and Opeche Formations, thickness changes are apparent between wells within the structure, and those outside the structure. Stratigraphically above, the thicknesses of the Minnekahta Formation and Belfield Member of the Spearfish Formation are nearly constant across the structure. However, the overlying Pine Salt has a slightly more variable thickness across the structure. It should be noted that the Pine Salt has a variable thickness across the entire study area, and therefore it is difficult to determine whether thickness variations within the structure are due to structural development.

The Saude Member of the Spearfish Formation exhibits some differences in thickness between wells 4654, 9317, and 5459, although they are not as dramatic as those of underlying units. Jurassic and Cretaceous strata above the Saude maintain almost constant thicknesses across the structure, indicating that further development of the structure had ceased sometime during or after the deposition of the Saude, perhaps during the Jurassic.

An impact crater, if present, should be marked by: highly disturbed beds, missing beds, and overturned beds near the crater rim. Examination of isopach maps and cross-sectional diagrams indicate that although thickness changes occur through time at the western Cold Turkey Creek structural anomaly, all units are present and continuous across the structure. The only exception is the Ashern Formation, which is absent at the structural anomaly and discontinuous across the study area, as the study area is located at the erosional edge of the Ashern's extent in the Williston Basin. There is no evidence to suggest overturned or otherwise disrupted strata.

The core from North Dakota Geological Survey well number 4654 was found to contain predominantly limestones, typical of Mission Canyon and Red River rocks. The core description corresponds to descriptions of type sections of Mission Canyon and Red River rocks elsewhere in the Williston Basin. There was no apparent quartz or feldspar which would suggest the presence of coesite, stishovite or planar deformation features (PDFs). Shatter cones were not observed in either interval, nor were any other extraordinary deformation features observed.

CONCLUSIONS

1) All of the lithologic units examined in this study are continuous across the western Cold Turkey Creek structural anomaly, with the exception of the Ashern Formation, which is discontinuous throughout the surrounding area because the study area is located on the erosional margin of the unit. The Ashern does not appear to pinch out at the structural anomaly. Further, the lithologic units do not appear to have been overturned or disturbed by compressive and expansive pressures associated with a hypervelocity impact.

2) The seismic data indicates that the shape of the structure changes through time. The structure appears as a rhomic antiform in the Winnipeg (Ordovician), and as an elongated antiform accompanied by irregularly shaped depressions in the Mississippian Mission Canyon. The structure contour maps, although lacking somewhat in well control, do not suggest the presence of a single circular crater, but rather a structure which changes shape through time. The structure does not exhibit a circular or oval shape, with a smooth floor and sides, or a raised rim.

3.) There are no secondary indicators of impact. The core examined for this study does not suggest the presence of any shock features in the Mission Canyon or Red River intervals. Rather, the rocks from the core section are typical of representative rock sections elsewhere in the basin.

4.) Examination of the isopach maps of each stratigraphic unit and analysis of the cross-sections indicate that there is not a single episode of excavation followed by infilling. Rather, there are multiple, complex episodes of both gradational and rapid thickening and thinning of units, not in a single location, but in several locations both within the structure, and throughout the study area. The structure is not the result of an instantaneous event, but rather developed through a succession of multiple events over time.

The Western Cold Turkey Creek structural anomaly is a complex structure. A lack of seismic data and minimal well control prohibit the interpretation of a detailed structural reconstruction. However, data obtained and analyzed during the course of this study clearly indicate that the structure has developed over time. The structure is not the result of an instantaneous event, and thus, by definition, is not an impact crater. Further, the shape of the structure is inconsistent with that of impact craters, there is a lack of evidence for secondary indicators of an impact, and the units in the study area appear to be continuous across the structure; there are no missing, discontinuous, or highly disturbed beds that would suggest the presence of an impact crater.

Through the course of this study, several other anomalous structures in addition to the western Cold Turkey Creek field anomaly were observed within the study area. Data obtained from this study could be used to generate cross-sections of these other anomalous structures in an attempt to better understand the structural history of both the western Cold Turkey Creek field anomaly and the study area at large. Interpretation of the western Cold Turkey Creek field anomaly and other anomalous structures in the study area associated with oil fields may help to clarify our understanding of other small-scale features within the Williston Basin.

APPENDICES

APPENDIX A

Names and Location of Wells. All wells from which well logs were studied are located in Bowman County, North Dakota, and are listed according to their North Dakota Geological Survey well number. The locations of these wells are described as follows: Townships and ranges are north and west respectively. (T = township, R = range, S = section, Q = quarter of the quarter section description, and KB = kelly bushing: elevation above sea level). The operator and well name are from records of the North Dakota Geological Survey.

WELL	T	R	S	Q	KB	OPERATOR	NAME
1446	130	103	34	SESW	3028	JAMES H. SNOWDEN, ET AL	M. A. MORRISON #1
4440	131	103	8	NWNE	3102	INTERNATIONAL NUCLEAR CORP.	LUTZ ETAL #1-6
4444	131	101	36	SESW	2934	INTERNATIONAL NUCLEAR CORP.	STATE NORTH DAKOTA #1-4-5
4449	131	101	19	SWSW	2932	INTERNATIONAL NUCLEAR CORP.	LEWTON #1-5-8
4456	130	102	13	SWSW	2916	INTERNATIONAL NUCLEAR CORP.	PAULSON #1-26-4
4457	131	103	25	NWNE	3046	INTERNATIONAL NUCLEAR CORP.	WERRE #1-27-18
4542	131	102	6	NESW	3001	INTERNATIONAL NUCLEAR CORP.	WAHL #1-53
4654	130	102	30	SWNE	2935	INTERNATIONAL NUCLEAR CORP.	JOHN M. SUSA ET AL #1-61
4673	131	102	25	NWNE	2922	INTERNATIONAL NUCLEAR CORP.	STEWART #1-63
5209	130	103	20	NWSE	3029	DEPCO INC.	DRONEN #33-20
5227	129	103	26	NWSE	2938	DEPCO INC.	GRENI #33-26
5262	129	103	26	SENW	2934	DEPCO, INC.	GRENI #22-26
5270	129	103	27	NWSW	2967	DEPCO INC.	HUGHES #13-27
5287	129	102	31	SWSE	2965	DEPCO INC.	OTTERNESS #34-31
5402	129	101	28	NENW	2889	KENNETH LUFF, INC. & HANOVER PLANNING	JETT #1-28
5403	129	103	27	SENW	2967	KENNETH LUFF, INC. & HANOVER PLANNING	HUGHES #1-27
5459	130	102	29	SWSW	2916	DEPCO INC.	PETERS #14-29
5495	129	103	4	SENE	3015	PATRICK PETR. CORP.	MANN-GRENI #1
5584	130	102	22	SESW	2888	KENNETH LUFF, INC. & HANOVER PET.	FARIS ET AL #1-22
5618	129	103	15	SENW	2954	KENNETH LUFF, INC.	G. HUGHES #1-15
5619	129	101	6	SWNW	2915	KENNETH LUFF, INC.	E. HANSEN #1-6
5651	130	103	30	SESE	3045	DEPCO INC.	NYGAARD #44-30
5712	130	102	28	SENE	2915	KENNETH LUFF, INC.	RICHARDS #1-28
5733	129	102	11	E2SW	2832	PENNZOIL COMPANY	BAGLEY # 1
5758	129	102	21	SWSE	2859	OIL DEV. CO. OF TEXAS	FANDRICK #1
5810	130	102	34	N2NW	2919	KENNETH LUFF, INC. & HANOVER PET.	FARIS #1-34
5822	129	103	23	NESW	2976	KENNETH LUFF, INC. & HANOVER PET.	G. HUGHES #1-23

WELL	T	R	S	Q	KB	OPERATOR	NAME
5823	130	102	6	NESE	2961	KENNETH LUFF, INC. & HANOVER PET.	MOSBRUCKER #1-6
5845	129	103	25	NWSW	2935	KENNETH LUFF, INC. & HANOVER PET.	GRENI #1-25
5865	130	102	32	SWSW	2918	DEPCO INC.	FLEMING #14-32
5893	130	103	5	SWNW	3068	DEPCO INC.	NJOS #12-5
5895	130	102	16	NENW	2919	KENNETH LUFF, INC.	RAINBOW-STATE #1-16
5904	131	103	34	NWNE	3043	PETROLEUM, INC.	HILTON #1
5907	130	102	24	NWNW	2921	KENNETH LUFF, INC., & PENNZOIL	F. PAULSON #1-24
5910	130	103	24	E2SE	2960	DEPCO INC.	PLADSEN COM. #43-24
5920	130	102	20	NWNE	2960	KENNETH LUFF, INC.	M. L. PETERS #1-20
5951	130	103	3	SWNE	3030	KENNETH LUFF, INC.	WESLEY ANDERSON #1-3
6038	129	102	34	SENW	2870	KENNETH D. LUFF	BOCK-WHITE #1-34
6059	129	102	17	SWSW	2882	FARMLAND INT'L. ENERGY	HALM #1-17
6063	130	102	15	SWSW	2915	KENNETH LUFF INC.	MRNAK-F.L.B. #1
6074	129	102	2	SESE	2857	FARMLAND INT'L. ET AL	RICHARDS & SOUTHLAND ROYALTY #1-2
6094	129	102	33	SESE	2903	KENNETH D. LUFF	J. FANDRICK #1-33
6119	130	103	6	S2SE	3109	PENNZOIL CO.	MILTON G. ANDERSON #1
6398	130	102	7	SWNE	2951	KENNETH D. LUFF	MRNAK #1-7
6565	130	103	3	NESE	3005	TEXAS OIL & GAS CORP.	ANDERSON-STATE #1
6629	130	102	27	NESW	2928	WULF OIL CORP.	HERMAN BAGLEY ET AL #1
6630	130	103	22	SWNE	2978	KENNETH D. LUFF	V. DOMAGALA #1-22
6639	130	103	8	SESE	3051	FLORIDA GAS EXPL. CO.	GROSS #1-8
6657	129	101	4	SENE	2813	CONSOLIDATED OIL & GAS	LEWISON DR. U. #1
6679.1	130	103	32	NWSW	3048	KENNETH LUFF, INC.	OSCAR NYGAARD 1-32
6765	129	103	5	SWNW	3017	TERRA RESOURCES, INC.	NYGAARD # 1-5
6814	130	103	31	SESE	3015	TERRA RESOURCES INC.	T. NYGAARD #1-31
7201	130	102	33	NESW	2871	KENNETH LUFF	RICHARDS #1-33
7370	130	103	31	NWNE	3080	TERRA RESOURCES, INC.	T. NYGAARD #2-31

WELL	T	R	S	Q	KB	OPERATOR	NAME
7421	129	103	10	SWNW	2972	KENNETH LUFF, INC.	OLSEN #1-10
7809	130	103	32	W2SW	3038	KENNETH LUFF, INC.	NYGAARD #2-32
7922	129	101	21	SWSE	2836	KENNETH LUFF, INC.	HANSEN #1-21
8011	130	101	33	SESW	2830	CONSOLIDATED OIL & GAS, INC.	SOLHEIN #1
8021	129	102	7	NWSE	2953	INEXCO OIL CO.	STINCHFIELD #1-7
8035	129	102	18	SESE	2885	INEXCO OIL CO.	STATE HALM #1-18
8062	129	103	10	SESE	2923	KENNETH LUFF	STATE-OLSEN #2-10
8258	129	103	34	C NE	3001	FLORIDA EXPLORATION COMPANY	CRAIG #1-34
8377	129	102	33	SESE	2926	HUSKY OIL COMPANY	FANDRICK #16-33
8573	130	102	5	SWSW	2952	HUSKY OIL COMPANY	MOSBRUCKER #13-5
8581	129	102	35	SWNW	2874	LUFF EXPLORATION COMPANY	BOCK-WHITE #1-35
8605	129	103	8	NENW	3006	TERRA RESOURCES, INC.	PFEIFER #1-8
8627	129	101	16	W2NW	2800	ENERGY MINERALS CORPORATION	LUTES STATE #1
8982	130	102	28	SESW	2892	LUFF EXPLORATION CO.	RICHARDS #2-28
9197	129	103	4	SWSE	2954	LUFF EXPLORATION CO.	MANN #0-4
9284	130	101	19	SWNE	2869	KENAI OIL & GAS, INC.	AASEN #1
9317	130	102	30	SESE	2934	TERRA RESOURCES, INC.	RICHARD #1-30
9439	130	103	17	S2SE	3030	HUSKY OIL CO.	HUSKY-STRIKER #15-17
9460	130	103	19	SWNW	3121	MOSBACHER-PRUETT OIL CO.	FOSSUM #19-1
9771	130	103	17	C NE	3037	STRIKER PETROLEUM CORP.	FOSSUM-STATE #8-17
9919	129	103	27	SWSE	2934	LUFF EXPLORATION CO.	HINKLEY J-27
9963	130	103	25	NENW	2944	NATIONAL OIL CO.	G. EHRMANTROUT #21-25
10421	129	102	5	SENE	2897	ABRAXAS PETROLEUM CORPORATION	LEWTON #1
10571	130	102	26	SWSW	2941	STRIKER PETROLEUM CORPORATION	RUPPERT #1
10859	131	103	17	SESE	3160	TEMPLETON ENERGY, INC.	JAMES 1
11049	129	103	34	SESW	3058	SOUTHLAND ROYALTY COMPANY	STATE LINE WEST 1-34
11071	129	103	36	CSW	2992	AMOCO PRODUCTION CO.	BROCK STATE 1-36

WELL	T	R	S	Q	KB	OPERATOR	NAME
11176	130	102	21	SESE	2927	AMOCO PRODUCTION COMPANY	BAGLEY 1-21
11218	129	102	7	NWSW	2989	WESSELY ENERGY CORP.	STINCHFIELD 1-7
11223	130	102	35	NESW	2975	WESSELY ENFRGY CO.	HILTON 1-35
11255	130	103	27	NESW	2999	SOUTHLAND ROYALTY CO.	MORRISON 1-27
11451	129	103	6	SESE	3059	TENNECO OIL CO.	SCHAAF 1-6
11456	130	103	13	NWSE	3019	LUFF EXPLORATION CO.	BARTEL J-13
12177	130	102	33	NWNW	2874	BROSCHAT ENGR. AND MGMNT. SERVICES	WEISENBERGER #1
12872	130	102	33	NENE	2913	WYOMING RESOURCES CORP.	FARIS USA # 1
12950	130	103	29	NWNE	3028	DEKALB ENERGY CO.	DRONEN # 31-29
13327	130	102	17	SWSE	2945	DISCOVERY GEOSERVICES CORP.	PETERS #1-17
13512	129	103	15	NWNE	2952	WYOMING RESOURCES CORP.	FLB HUGHES #1
13605	129	103	10	SESW	2927	WYOMING RESOURCES CORP.	BOWMAN #1
13740	130	102	17	SENE	2923	SAGE ENERGY COMPANY	PETERS #1
13797	129	103	6	NESE	3050	WYOMING RESOURCES,INC.	#1 SCHAAF
13800	130	103	20	SENE	3011	NORTH AMERICAN RESOURCES CO.	42-20 DRONEN
13812	129	103	33	NENE	2984	CONTINENTAL RESOURCES, INC.	1-33 HANSEN
13850	129	103	15	SESE	2966	WYOMING RESOURCES	FLB HUGHES 2H
13869	129	103	23	NWNW	2964	CONTINENTAL RESOURCES INC.	1-23 DOWNING
14400	129	103	26	NENW	2921	UMC PETROLEUM CORP.	GRENI #1-26 H
14491	130	102	27	NWNE	2908	LUFF EXPLORATION CO.	STATE MUSLOW #B-27
14644	130	102	22	NESW	2881	LUFF EXPLORATION CO.	PANG FARIS #K-22
14741	130	102	17	SWSE	2952.5	THE EXPLORATION COMPANY	MARTY #1-17
14810	129	101	6	NWNE	2913.7	LUFF EXPLORATION	#B6 HILTON
14826	129	101	6	SESW	2840	LUFF EXPLORATION	ABRAHAMSON N-6
14850	129	103	13	NWNW	2912	CONTINENTAL RESOURCES	#1-13 ROBERTSON

APPENDIX B

Group, Formation and Member Tops. Wells are listed according to their North Dakota Geological Survey well number. All wells are located in Bowman County, North Dakota. Depths are indicated in feet from Kelly Bushing; Pierre Formation, Niobrara Formation, Greenhorn Formation, Mowry Formation, Inyan Kara Formation, Spearfish Formation / Saude Member, Pine Salt Member, Belfield Member, Minnekahta Formation, Opeche Formation, Minnelusa Group, Tyler Formation, Otter Formation, Kibbey Formation / Kibbey sandstone, Kibbey limestone, Kibbey shale, Charles Formation, Mission Canyon Formation, Lodgepole Formation, Three Forks Formation, Birdbear Formation, Duperow Formation, Souris River Formation, Ashern Formation, Interlake Formation, Stonewall Formation, Stony Mountain Formation, Red River Formation. (no data = missing data; not picked = insufficient information to determine elevation; not here = lithology is absent in well log).

	NDGS Well No. 1446	NDGS Well No. 4440	NDGS Well No. 4444	NDGS Well No. 4449
Pierre Formation	no data	1186	1394	1254
Niobrara Formation	no data	3505	3515	not picked
Greenhorn Formation	3790	4102	4161	4025
Mowry Formation	not picked	4575	4624	4520
Inyan Kara Formation	not picked	4993	5000	4908
Jurassic	not picked	no data	no data	no data
Saude Member	not picked	no data	no data	no data
Pine Salt Member	5990	no data	no data	no data
Belfield Member	6200	no data	no data	no data
Minnekahta Formation	6360	no data	no data	no data
Opeche Formation	6412	no data	no data	no data
Minnelusa Group	6538	no data	no data	no data
Tyler Formation	6710	no data	no data	no data
Otter Formation	6843	no data	no data	no data
Kibbey sandstone	6860	no data	no data	no data
Kibbey limestone	6991	no data	no data	no data
Kibbey shale	7020	no data	no data	no data
Charles Formation	7100	no data	no data	no data
Mission Canyon Formation	7563	no data	no data	no data
Lodgepole Formation	7880	no data	no data	no data
Three Forks Formation	8450	no data	no data	no data
Birdbear Formation	8471	no data	no data	no data
Duperow Formation	8508	no data	no data	no data
Souris River Formation	8690	no data	no data	no data
Ashern Formation	not here	no data	no data	no data
Interlake Formation	8756	no data	no data	no data
Stonewall Formation	9053	no data	no data	no data
Stony Mountain Formation	9170	no data	no data	no data
Red River Formation	9278	no data	no data	no data

	NDGS Well No. 4456	NDGS Well No. 4457	NDGS Well No. 4542	NDGS Well No. 4654
Pierre Formation	969	1146	1214	not picked
Niobrara Formation	3180	3350	3393	3118
Greenhorn Formation	3830	4010	4045	3808
Mowry Formation	4290	4493	4545	4280
Inyan Kara Formation	4672	4891	4948	4652
Jurassic	no data	no data	no data	5199
Saude Member	no data	no data	no data	5830
Pine Salt Member	no data	no data	no data	6001
Belfield Member	no data	no data	no data	6082
Minnekahta Formation	no data	no data	no data	6251
Opeche Formation	no data	no data	no data	6295
Minnelusa Group	no data	no data	no data	6412
Tyler Formation	no data	no data	no data	6640
Otter F[illegible]ation	no data	no data	no data	7040
[illegible] andstone	no data	no data	no data	7101
[illegible]ey limestone	no data	no data	no data	7236
Kibbey shale	no data	no data	no data	7267
Charles Formation	no data	no data	no data	7350
Mission Canyon Formation	no data	no data	no data	7750
Lodgepole Formation	no data	no data	no data	7930
Three Forks Formation	no data	no data	no data	8511
Birdbear Formation	no data	no data	no data	8550
Duperow Formation	no data	no data	no data	8589
Souris River Formation	no data	no data	no data	8773
Ashern Formation	no data	no data	no data	not here
Interlake Formation	no data	no data	no data	8872
Stonewall Formation	no data	no data	no data	9203
Stony Mountain Formation	no data	no data	no data	9313
Red River Formation	no data	no data	no data	9428

	NDGS Well No. 4673	NDGS Well No. 5209	NDGS Well No. 5227	NDGS Well No. 5262
Pierre Formation	no data	6103	5880	5872
Niobrara Formation	no data	6246	5904	5912
Greenhorn Formation	no data	6394	6072	6075
Mowry Formation	no data	6441	6120	6119
Inyan Kara Formation	6657	6544	6215	6217
Jurassic	no data	6730	6482	6482
Saude Member	no data	6851	6569	6570
Pine Salt Member	7227	6936	6660	6673
Belfield Member	7300	7080	6750	6744
Minnekahta Formation	no data	7100	6771	6777
Opeche Formation	7420	7180	6841	6845
Minnelusa Group	no data	7630	7316	7328
Tyler Formation	no data	7966	7615	7625
Otter Formation	no data	8532	8162	8168
Kibbey sandstone	no data	8550	8180	8184
Kibbey limestone	8980	8586	8212	8218
Kibbey shale	9200	8764	8378	8383
Charles Formation	no data	not here	not here	not here
Mission Canyon Formation	no data	8870	8428	8467
Lodgepole Formation	no data	9131	8702	8720
Three Forks Formation	9799	9246	8812	8832
Birdbear Formation	9880	9349	8913	8938
Duperow Formation	8980	8586	8212	8218
Souris River Formation	9200	8764	8378	8383
Ashern Formation	no data	not here	not here	not here
Interlake Formation	no data	8870	8428	8457
Stonewall Formation	no data	9131	8702	8720
Stony Mountain Formation	9799	9246	8812	8832
Red River Formation	9880	9349	8913	8938

	NDGS Well No. 5270	NDGS Well No. 5287	NDGS Well No. 5402	NDGS Well No. 5403
Pierre Formation	no data	1380	1041	no data
Niobrara Formation	no data	3033	3136	no data
Greenhorn Formation	no data	3740	3829	no data
Mowry Formation	no data	4218	4280	no data
Inyan Kara Formation	no data	4617	4667	no data
Jurassic	no data	5172	5240	no data
Saude Member	5640	5710	5708	5640
Pine Salt Member	5850	5824	not here	5858
Belfield Member	5940	5920	5899	5927
Minnekahta Formation	6107	6080	6061	6107
Opeche Formation	6146	6128	6120	6150
Minnelusa Group	6208	6240	6219	6208
Tyler Formation	6452	6501	6515	6508
Otter Formation	6590	6668	6638	6660
Kibbey sandstone	6698	6732	6702	6698
Kibbey limestone	6769	6760	6810	6768
Kibbey shale	6800	6777	6839	6800
Charles Formation	6872	6857	6912	6872
Mission Canyon Formation	7350	7330	7383	7350
Lodgepole Formation	7650	7596	7672	7650
Three Forks Formation	8187	8177	8250	8188
Birdbear Formation	8193	8210	8291	8192
Duperow Formation	8225	8245	8350	8225
Souris River Formation	8385	8417	8536	8383
Ashern Formation	not here	not here	not here	not here
Interlake Formation	8437	8481	8617	8436
Stonewall Formation	8712	8770	8934	8712
Stony Mountain Formation	8820	8880	9044	8820
Red River Formation	8922	8991	9153	8922

	NDGS Well No. 5459	NDGS Well No. 5495	NDGS Well No. 5584	NDGS Well No. 5618
Pierre Formation	1465	not picked	1039	no data
Niobrara Formation	3120	3080	3120	no data
Greenhorn Formation	3782	3788	3770	3719
Mowry Formation	4230	4230	4232	4212
Inyan Kara Formation	4612	4632	4607	4619
Jurassic	5150	5170	5150	5202
Saude Member	5768	5742	5775	5786
Pine Salt Member	5912	5994	5894	5920
Belfield Member	6017	6140	6018	6065
Minnekahta Formation	6168	6292	6183	6206
Opeche Formation	6212	6341	6230	6254
Minnelusa Group	6275	6441	6350	6372
Tyler Formation	6480	6668	6583	6576
Otter Formation	6542	6753	6719	6726
Kibbey sandstone	6688	6883	6759	6786
Kibbey limestone	6737	6961	6937	6832
Kibbey shale	6772	6990	6957	6862
Charles Formation	6872	7069	7038	6939
Mission Canyon Formation	7560	7533	7512	7407
Lodgepole Formation	8084	7843	7812	7686
Three Forks Formation	8531	8410	8408	8262
Birdbear Formation	8570	8432	8438	8288
Duperow Formation	8610	8470	8482	8326
Souris River Formation	8790	8644	8669	8497
Ashern Formation	not here	not here	8772	not here
Interlake Formation	8870	8711	8792	8556
Stonewall Formation	9217	9007	9071	8842
Stony Mountain Formation	9330	9119	9180	8954
Red River Formation	9440	9228	9289	9055

	NDGS Well No. 5619	NDGS Well No. 5651	NDGS Well No. 5712	NDGS Well No. 5733
Pierre Formation	not picked	not picked	not picked	1300
Niobrara Formation	3175	3106	3144	3068
Greenhorn Formation	3835	3803	3796	3734
Mowry Formation	4295	4282	4260	4178
Inyan Kara Formation	4683	4689	4638	4584
Jurassic	5288	5191	5130	5154
Saude Member	5811	5786	5777	5740
Pine Salt Member	5903	6052	5962	5850
Belfield Member	5988	6210	6054	5923
Minnekahta Formation	6152	6341	6239	6090
Opeche Formation	6204	6388	6282	6135
Minnelusa Group	6307	6470	6396	6264
Tyler Formation	6596	6722	6644	6504
Otter Formation	6786	6830	6815	6624
Kibbey sandstone	6810	6944	6901	6734
Kibbey limestone	6907	7040	6993	6820
Kibbey shale	6937	7072	7010	6847
Charles Formation	7016	7146	7089	6923
Mission Canyon Formation	7500	7618	7563	7461
Lodgepole Formation	7784	7932	7920	7696
Three Forks Formation	8363	not here	8470	8284
Birdbear Formation	8401	8472	8501	8327
Duperow Formation	8460	8523	8548	8372
Souris River Formation	8647	8698	8731	8556
Ashern Formation	not here	not here	not here	not here
Interlake Formation	8751	8770	8816	8620
Stonewall Formation	9090	9042	9167	8984
Stony Mountain Formation	9202	9151	9281	9090
Red River Formation	9311	9260	9387	9203

	NDGS Well No. 5758	NDGS Well No. 5810	NDGS Well No. 5822	NDGS Well No. 5823
Pierre Formation	1486	969	1090	1121
Niobrara Formation	2967	3146	3015	3221
Greenhorn Formation	3663	3815	3720	3900
Mowry Formation	4140	4267	4206	4368
Inyan Kara Formation	4542	4641	4601	4759
Jurassic	5099	5152	5217	5266
Saude Member	5554	5735	5802	5880
Pine Salt Member	5777	5937	5970	6070
Belfield Member	5831	6035	6008	6220
Minnekahta Formation	5992	6221	6174	6373
Opeche Formation	6032	6267	6218	6421
Minnelusa Group	6118	6368	6338	6504
Tyler Formation	6280	6622	6558	6772
Otter Formation	6438	6764	6650	6918
Kibbey sandstone	6551	6876	6773	7031
Kibbey limestone	6713	6966	6837	7131
Kibbey shale	6732	6990	6856	7160
Charles Formation	6804	7068	6930	7242
Mission Canyon Formation	7291	7565	7397	7741
Lodgepole Formation	7575	7849	7713	8045
Three Forks Formation	8140	8432	8267	8631
Birdbear Formation	8168	8478	8279	8671
Duperow Formation	8202	8520	8313	8716
Souris River Formation	8375	8703	8482	8906
Ashern Formation	not here	not here	not here	not here
Interlake Formation	8413	8768	8559	9000
Stonewall Formation	8777	9132	8832	9333
Stony Mountain Formation	8884	9243	8947	9445
Red River Formation	8999	9355	9050	9558

	NDGS Well No. 5845	NDGS Well No. 5865	NDGS Well No. 5893	NDGS Well No. 5895
Pierre Formation	no data	1428	no data	no data
Niobrara Formation	no data	3118	3278	no data
Greenhorn Formation	no data	3775	3944	no data
Mowry Formation	no data	4260	4435	no data
Inyan Kara Formation	no data	4642	4827	no data
Jurassic	no data	5206	5310	5223
Saude Member	no data	5779	5894	5864
Pine Salt Member	no data	5993	6092	5980
Belfield Member	no data	6059	6318	6124
Minnekahta Formation	6107	6216	6473	6281
Opeche Formation	6148	6261	6532	6328
Minnelusa Group	6229	6338	6576	6385
Tyler Formation	no data	6625	6792	6688
Otter Formation	no data	6753	6876	6820
Kibbey sandstone	no data	6895	7075	6946
Kibbey limestone	no data	6970	7228	7053
Kibbey shale	no data	6987	7255	7065
Charles Formation	no data	7060	7336	7150
Mission Canyon Formation	7299	7531	7835	7649
Lodgepole Formation	7675	7776	8138	7940
Three Forks Formation	no data	8422	8717	8528
Birdbear Formation	no data	8456	8733	8569
Duperow Formation	no data	8500	8770	8617
Souris River Formation	no data	8687	8951	8805
Ashern Formation	no data	not here	9052	not here
Interlake Formation	no data	8735	9056	8946
Stonewall Formation	no data	9115	9323	9225
Stony Mountain Formation	8886	9227	9442	9342
Red River Formation	8995	9333	9540	9447

	NDGS Well No. 5904	NDGS Well No. 5907	NDGS Well No. 5910	NDGS Well No. 5920
Pierre Formation	no data	no data	1285	1207
Niobrara Formation	3339	no data	3183	3205
Greenhorn Formation	4004	3830	3858	3856
Mowry Formation	4493	4289	4326	4330
Inyan Kara Formation	4891	4666	4713	4719
Jurassic	5432	5129	5242	5222
Saude Member	6030	5760	5863	5842
Pine Salt Member	6210	5916	6060	6073
Belfield Member	6400	6130	6188	6202
Minnekahta Formation	6540	6306	6350	6352
Opeche Formation	6590	6352	6398	6395
Minnelusa Group	6718	6472	6520	6532
Tyler Formation	6915	6661	6728	6717
Otter Formation	7068	6827	6897	6844
Kibbey sandstone	7180	6930	7002	7022
Kibbey limestone	7279	7007	7068	7060
Kibbey shale	7310	7037	7096	7086
Charles Formation	7392	7119	7177	7165
Mission Canyon Formation	7872	7595	7662	7640
Lodgepole Formation	8192	7903	7961	7956
Three Forks Formation	8788	8486	8545	8534
Birdbear Formation	8812	8524	8573	8578
Duperow Formation	8853	8580	8614	8620
Souris River Formation	9050	8768	8803	8806
Ashern Formation	not here	not here	not here	not here
Interlake Formation	9140	8847	8858	8898
Stonewall Formation	9475	9212	9220	9244
Stony Mountain Formation	9591	9323	9333	9365
Red River Formation	9700	9438	9441	9470

	NDGS Well No. 5951	NDGS Well No. 6038	NDGS Well No. 6059	NDGS Well No. 6063
Pierre Formation	1411	1355	no data	1286
Niobrara Formation	3290	2955	2957	3160
Greenhorn Formation	3957	3632	3651	3822
Mowry Formation	4435	4121	4120	4275
Inyan Kara Formation	4820	4508	4525	4646
Jurassic	5351	5101	5055	5191
Saude Member	5934	5635	5656	5822
Pine Salt Member	6141	5747	5763	5937
Belfield Member	6360	5813	5876	6074
Minnekahta Formation	6500	5974	6062	6246
Opeche Formation	6550	6015	6105	6302
Minnelusa Group	6685	6160	6245	6388
Tyler Formation	6871	6405	6475	6654
Otter Formation	7010	6510	6570	6792
Kibbey sandstone	7120	6617	6665	6886
Kibbey limestone	7220	6674	6751	7002
Kibbey shale	7250	6694	6777	7030
Charles Formation	7334	6768	6878	7110
Mission Canyon Formation	7820	7295	7320	7608
Lodgepole Formation	8130	7534	7620	7898
Three Forks Formation	8721	8101	8180	8485
Birdbear Formation	8748	8132	8209	8528
Duperow Formation	8788	8168	8240	8572
Souris River Formation	8984	8344	8414	8760
Ashern Formation	9087	not here	8478	not here
Interlake Formation	9110	8390	8482	8842
Stonewall Formation	9380	8732	8822	9206
Stony Mountain Formation	9496	8854	8932	9318
Red River Formation	9605	8955	9042	9431

	NDGS Well No. 6074	NDGS Well No. 6094	NDGS Well No. 6119	NDGS Well No. 6398
Pierre Formation	no data	1414	not picked	1389
Niobrara Formation	3094	2975	3274	3228
Greenhorn Formation	3755	3668	3951	3878
Mowry Formation	4198	4150	4438	4352
Inyan Kara Formation	4590	4550	4830	4743
Jurassic	5194	5123	5330	5261
Saude Member	5768	5730	5912	5872
Pine Salt Member	5870	5783	6119	6067
Belfield Member	5930	5820	6331	6270
Minnekahta Formation	6099	5983	6489	6433
Opeche Formation	6143	6022	6534	6480
Minnelusa Group	6237	6136	6578	6590
Tyler Formation	6524	6413	6882	6760
Otter Formation	6725	6516	7000	6891
Kibbey sandstone	6770	6688	7100	6996
Kibbey limestone	6842	6756	7228	7120
Kibbey shale	6863	6780	7256	7147
Charles Formation	6940	6817	7338	7226
Mission Canyon Formation	7433	7229	7818	7710
Lodgepole Formation	7710	7542	8141	8028
Three Forks Formation	8280	8070	8713	8616
Birdbear Formation	8320	8103	8729	8658
Duperow Formation	8378	8134	8765	8701
Souris River Formation	8560	8321	8948	8894
Ashern Formation	not here	not here	not here	not here
Interlake Formation	8667	8361	9018	9000
Stonewall Formation	9005	8679	9335	9320
Stony Mountain Formation	9112	8790	9445	9433
Red River Formation	9224	8895	9553	9546

	NDGS Well No. 6565	NDGS Well No. 6629	NDGS Well No. 6630	NDGS Well No. 6639
Pierre Formation	1575	not picked	no data	1435
Niobrara Formation	3286	3170	no data	3210
Greenhorn Formation	3946	3840	no data	3895
Mowry Formation	4412	4280	no data	4400
Inyan Kara Formation	4812	4660	no data	4800
Jurassic	5312	5302	no data	5363
Saude Member	5900	5770	no data	5970
Pine Salt Member	6102	5960	6015	6153
Belfield Member	6324	6072	no data	6300
Minnekahta Formation	6483	6248	6380	6441
Opeche Formation	653[illegible]	6293	6430	6485
Minnelusa Group	6635	6392	6490	6599
Tyler Formation	6857	6655	no data	6800
Otter Formation	6992	6800	no data	6925
Kibbey sandstone	7094	6907	no data	7010
Kibbey limestone	7214	7008	7110	7148
Kibbey shale	7243	7030	no data	7180
Charles Formation	7326	7108	7220	7258
Mission Canyon Formation	7806	7404	7695	7734
Lodgepole Formation	8128	7892	no data	8055
Three Forks Formation	8724	8492	no data	8618
Birdbear Formation	8748	8523	no data	8635
Duperow Formation	8790	8570	no data	8675
Souris River Formation	8984	8704	no data	8858
Ashern Formation	not here	not here	no data	8940
Interlake Formation	9058	8848	8900	8955
Stonewall Formation	9399	9204	no data	9235
Stony Mountain Formation	9516	9312	9318	9345
Red River Formation	9627	9426	9442	9448

	NDGS Well No. 6657	NDGS Well No. 6679.1	NDGS Well No. 6765	NDGS Well No. 6814
Pierre Formation	not picked	no data	no data	not picked
Niobrara Formation	3263	no data	3027	3050
Greenhorn Formation	3878	no data	3753	3755
Mowry Formation	4345	no data	4250	4250
Inyan Kara Formation	4755	no data	4644	4648
Jurassic	5312	no data	5177	5134
Saude Member	5655	no data	5750	5747
Pine Salt Member	5969	no data	5990	6010
Belfield Member	6003	no data	6140	6142
Minnekahta Formation	6157	no data	6299	6287
Opeche Formation	6202	no data	6348	6329
Minnelusa Group	6276	6562	6462	6382
Tyler Formation	6598	6701	6660	6670
Otter Formation	6769	6813	6772	6778
Kibbey sandstone	6825	6900	6854	6903
Kibbey limestone	6915	7022	6978	6989
Kibbey shale	6946	7049	7006	7003
Charles Formation	7028	7130	7083	7095
Mission Canyon Formation	7512	7601	7560	7578
Lodgepole Formation	7886	7914	7868	7915
Three Forks Formation	8377	not here	8428	8447
Birdbear Formation	8429	not here	8431	8452
Duperow Formation	8493	8514	8463	8486
Souris River Formation	8680	8683	8636	8660
Ashern Formation	not here	8761	not here	not here
Interlake Formation	8760	8766	8699	8757
Stonewall Formation	9148	9038	8987	8999
Stony Mountain Formation	9263	9150	9098	9110
Red River Formation	9372	9262	9208	9219

	NDGS Well No. 7201	NDGS Well No. 7370	NDGS Well No. 7421	NDGS Well No. 7809
Pierre Formation	not picked	not picked	not picked	no data
Niobrara Formation	3090	3134	3048	3070
Greenhorn Formation	3755	3840	3757	3789
Mowry Formation	4207	4317	4243	4290
Inyan Kara Formation	4582	4719	4649	4690
Jurassic	5123	5222	5246	5163
Saude Member	5717	5825	5811	5786
Pine Salt Member	5922	6089	5990	6035
Belfield Member	6013	6253	6063	6158
Minnekahta Formation	6182	6382	6221	6300
Opeche Formation	6228	6424	6269	6341
Minnelusa Group	6317	6529	6321	6390
Tyler Formation	6585	6764	6526	6688
Otter Formation	6700	6948	6612	6798
Kibbey sandstone	6830	7008	6800	6921
Kibbey limestone	6919	7081	6900	7007
Kibbey shale	6947	7110	6929	7035
Charles Formation	7024	7188	7005	7112
Mission Canyon Formation	7497	7658	7476	7588
Lodgepole Formation	7813	7977	7795	7899
Three Forks Formation	8385	not here	8352	8458
Birdbear Formation	8428	8528	8378	8461
Duperow Formation	8471	8569	8413	8493
Souris River Formation	8654	8743	8591	8661
Ashern Formation	not here	8861	not here	not here
Interlake Formation	8721	8864	8663	8720
Stonewall Formation	9099	9082	8947	9008
Stony Mountain Formation	9209	9191	9064	9118
Red River Formation	9318	9300	9169	9225

	NDGS Well No. 7922	NDGS Well No. 8011	NDGS Well No. 8021	NDGS Well No. 8035
Pierre Formation	not picked	not picked	not picked	not picked
Niobrara Formation	3103	3208	3050	2962
Greenhorn Formation	3797	3904	3749	3665
Mowry Formation	4258	4344	4217	4132
Inyan Kara Formation	4623	4738	4622	4525
Jurassic	5215	5296	5278	5079
Saude Member	5757	5886	5782	5673
Pine Salt Member	5828	5962	5876	5821
Belfield Member	5860	6000	5971	5903
Minnekahta Formation	6034	6187	6155	6078
Opeche Formation	6080	6232	6200	6123
Minnelusa Group	6174	6308	6282	6258
Tyler Formation	6468	6616	6568	6487
Otter Formation	6596	6755	6742	6585
Kibbey sandstone	6660	6818	6770	6722
Kibbey limestone	6766	6938	6858	6760
Kibbey shale	6795	6972	6880	6787
Charles Formation	6867	7051	6952	6860
Mission Canyon Formation	7339	7533	7419	7326
Lodgepole Formation	7635	7828	7725	7632
Three Forks Formation	8204	8409	8296	8192
Birdbear Formation	8250	8458	8322	8220
Duperow Formation	8310	8519	8356	8252
Souris River Formation	8491	8716	8527	8420
Ashern Formation	not here	8802	not here	not here
Interlake Formation	8570	8813	8603	8493
Stonewall Formation	8926	9170	8918	8831
Stony Mountain Formation	9032	9280	9026	8942
Red River Formation	9146	9392	9138	9053

	NDGS Well No. 8062	NDGS Well No. 8[illegible]58	NDGS Well No. 8377	NDGS Well No. 8573
Pierre Formation	not picked	not picked	not picked	not picked
Niobrara Formation	2983	3030	3010	3239
Greenhorn Formation	3701	3753	3681	3889
Mowry Formation	4185	4236	4166	4365
Inyan Kara Formation	4589	4646	4559	4747
Jurassic	5194	5248	5146	5310
Saude Member	5772	5862	5500	5933
Pine Salt Member	5883	5920	5688	6118
Belfield Member	6008	5992	5838	6251
Minnekahta Formation	6152	6169	6003	6393
Opeche Formation	6209	6216	6043	6440
Minnelusa Group	6303	6344	6154	6566
Tyler Formation	6551	6550	6340	6784
Otter Formation	6640	6703	6441	6922
Kibbey sandstone	6730	6740	6533	7052
Kibbey limestone	6830	6818	6706	7138
Kibbey shale	6858	6843	6717	7162
Charles Formation	6935	6913	6784	7248
Mission Canyon Formation	7306	7397	7258	7729
Lodgepole Formation	7718	7698	7545	8053
Three Forks Formation	8278	8240	8101	8650
Birdbear Formation	8306	8252	8136	8682
Duperow Formation	8342	8285	8166	8728
Souris River Formation	8520	8451	8338	8918
Ashern Formation	not here	not here	not here	not here
Interlake Formation	8576	8515	8381	8997
Stonewall Formation	8875	8774	8717	9360
Stony Mountain Formation	8983	8892	8830	9475
Red River Formation	9092	8997	8935	9590

	NDGS Well No. 8581	NDGS Well No. 8605	NDGS Well No. 8627	NDGS Well No. 8982
Pierre Formation	not picked	not picked	1160	1436
Niobrara Formation	2974	3052	3156	3119
Greenhorn Formation	3659	3773	3775	3782
Mowry Formation	4130	4274	4240	4233
Inyan Kara Formation	4530	4672	4629	4610
Jurassic	5097	5249	5218	5140
Saude Member	5652	5821	5814	5764
Pine Salt Member	5742	5990	not here	5952
Belfield Member	5811	6130	5890	6034
Minnekahta Formation	5980	6268	6047	6198
Opeche Formation	6030	6311	6092	6245
Minnelusa Group	6147	6396	6207	6313
Tyler Formation	6408	6643	6469	6614
Otter Formation	6578	6728	6548	6753
Kibbey sandstone	6618	6850	6665	6860
Kibbey limestone	6672	6970	6772	6967
Kibbey shale	6700	7000	6802	6982
Charles Formation	6768	7076	6880	7064
Mission Canyon Formation	no data	7546	7374	7540
Lodgepole Formation	7540	7861	7647	7943
Three Forks Formation	8102	8420	8212	8431
Birdbear Formation	8141	8428	8269	8473
Duperow Formation	8178	8462	8319	8520
Souris River Formation	8353	8547	8500	8704
Ashern Formation	not here	not here	8574	not here
Interlake Formation	8404	8701	8581	8772
Stonewall Formation	8740	8990	8948	9143
Stony Mountain Formation	8857	9103	9067	9260
Red River Formation	8963	9210	9168	9366

	NDGS Well No. 9197	NDGS Well No. 9284	NDGS Well No. 9317	NDGS Well No. 9439
Pierre Formation	1224	not picked	not picked	not picked
Niobrara Formation	3028	3182	3132	3170
Greenhorn Formation	3745	3861	3789	3848
Mowry Formation	4223	4299	4253	4350
Inyan Kara Formation	4622	4683	4624	4750
Jurassic	5220	5137	5162	5412
Saude Member	5788	5757	5778	5863
Pine Salt Member	5968	5877	5934	6090
Belfield Member	6072	6029	6044	6238
Minnekahta Formation	6220	6212	6198	6387
Opeche Formation	6263	6257	6245	6430
Minnelusa Group	6343	6330	6348	6533
Tyler Formation	6600	6645	6580	6751
Otter Formation	6696	6801	6692	6987
Kibbey sandstone	6788	6902	6708	7006
Kibbey limestone	6897	6978	6742	7100
Kibbey shale	6927	7006	6778	7130
Charles Formation	7003	7088	6910	7208
Mission Canyon Formation	7474	7575	7853	7673
Lodgepole Formation	7786	7874	8050	8000
Three Forks Formation	8352	8455	8538	8570
Birdbear Formation	8373	8497	8575	8588
Duperow Formation	8411	8555	8615	8624
Souris River Formation	8596	8742	8792	8802
Ashern Formation	not here	8843	not here	not here
Interlake Formation	8604	8856	8853	8900
Stonewall Formation	8931	9192	9228	9173
Stony Mountain Formation	9040	9302	9336	9283
Red River Formation	9151	9418	9448	9390

	NDGS Well No. 9460	NDGS Well No. 9771	NDGS Well No. 9919	NDGS Well No. 9963
Pierre Formation	not picked	no data	not picked	1426
Niobrara Formation	3176	no data	2986	3185
Greenhorn Formation	3864	no data	3683	3844
Mowry Formation	4370	no data	4173	4301
Inyan Kara Formation	4778	no data	4562	4689
Jurassic	5318	no data	5160	5212
Saude Member	5911	5924	5740	5837
Pine Salt Member	6181	6100	5844	6037
Belfield Member	6371	6251	5933	6167
Minnekahta Formation	6490	6396	6107	6329
Opeche Formation	6535	6438	6152	6377
Minnelusa Group	6668	6511	6261	6482
Tyler Formation	6831	6691	6508	6725
Otter Formation	6932	6774	6582	6850
Kibbey sandstone	7039	7001	6708	6973
Kibbey limestone	7143	7113	6751	7066
Kibbey shale	7170	7147	6787	7090
Charles Formation	7253	7232	6860	7173
Mission Canyon Formation	7725	7787	7341	7658
Lodgepole Formation	8057	8087	7643	7973
Three Forks Formation	not here	8596	8185	8554
Birdbear Formation	8560	86[illegible]	8192	8581
Duperow Formation	8644	8650	8226	8623
Souris River Formation	8814	8852	8390	8818
Ashern Formation	not here	not here	not here	not here
Interlake Formation	8878	8921	8442	8890
Stonewall Formation	9182	9256	8721	9213
Stony Mountain Formation	9295	9321	8835	9325
Red River Formation	9402	9431	8941	9438

	NDGS Well No. 10421	NDGS Well No. 10571	NDGS Well No. 10859	NDGS Well No. 11049
Pierre Formation	no data	1505	1318	1212
Niobrara Formation	3113	3205	no data	3062
Greenhorn Formation	3787	3870	no data	3791
Mowry Formation	4259	4331	no data	4258
Inyan Kara Formation	4642	4697	no data	4663
Jurassic	5185	5240	no data	5282
Saude Member	5750	5806	no data	5840
Pine Salt Member	5908	5990	no data	5940
Belfield Member	6023	6082	no data	6050
Minnekahta Formation	6202	6268	no data	6213
Opeche Formation	6243	6312	no data	6262
Minnelusa Group	6348	6411	no data	6392
Tyler Formation	6610	6667	no data	6569
Otter Formation	6750	6812	no data	6652
Kibbey sandstone	6886	6911	no data	6752
Kibbey limestone	6945	7014	no data	6820
Kibbey shale	6966	7039	no data	6850
Charles Formation	7042	7115	no data	6920
Mission Canyon Formation	7511	7589	no data	7395
Lodgepole Formation	7828	7900	no data	7695
Three Forks Formation	8403	8479	no data	8236
Birdbear Formation	8439	8516	no data	8242
Duperow Formation	8481	8572	no data	8276
Souris River Formation	8666	8759	no data	8442
Ashern Formation	not here	8821	no data	8522
Interlake Formation	8719	8830	no data	8534
Stonewall Formation	9106	9210	no data	8760
Stony Mountain Formation	9219	9317	no data	8868
Red River Formation	9325	9431	no data	8973

	NDGS Well No. 11071	NDGS Well No. 11176	NDGS Well No. 11218	NDGS Well No. 11223
Pierre Formation	1442	not picked	no data	not picked
Niobrara Formation	3052	3161	3083	3232
Greenhorn Formation	3772	3816	3784	3912
Mowry Formation	4240	4270	4259	4340
Inyan Kara Formation	4650	4656	4646	4742
Jurassic	5264	5228	5238	5270
Saude Member	5851	5856	5793	5847
Pine Salt Member	5927	6030	5952	5989
Belfield Member	6030	6161	6030	6086
Minnekahta Formation	6143	6317	6198	6263
Opeche Formation	6186	6357	6246	6312
Minnelusa Group	6258	6471	6344	6416
Tyler Formation	6559	6660	6604	6677
Otter Formation	6724	6802	6700	6761
Kibbey sandstone	6772	6905	6794	6904
Kibbey limestone	6826	7006	6894	7008
Kibbey shale	6849	7030	6916	7031
Charles Formation	6919	7110	6990	7110
Mission Canyon Formation	7402	7586	7448	7581
Lodgepole Formation	7703	7908	7763	7890
Three Forks Formation	8245	8489	8332	8478
Birdbear Formation	8269	8530	8360	8510
Duperow Formation	8304	8577	8391	8568
Souris River Formation	8482	8767	8570	8757
Ashern Formation	not here	not here	not here	8844
Interlake Formation	8538	8928	8628	8848
Stonewall Formation	8832	9203	8960	9200
Stony Mountain Formation	8946	9313	9080	9309
Red River Formation	9055	9428	9180	9421

	NDGS Well No. 11255	NDGS Well No. 11451	NDGS Well No. 11456	NDGS Well No. 12177
Pierre Formation	1631	not picked	no data	no data
Niobrara Formation	3167	3090	3296	3095
Greenhorn Formation	3790	3807	3948	3769
Mowry Formation	4278	4310	4435	4201
Inyan Kara Formation	4665	4705	4830	4593
Jurassic	5126	5267	5384	5100
Saude Member	5740	5830	5979	5716
Pine Salt Member	5988	6007	6121	5927
Belfield Member	6266	6169	6262	6013
Minnekahta Formation	6383	6313	6414	6187
Opeche Formation	6428	6359	6460	6230
Minnelusa Group	6538	6453	6547	6338
Tyler Formation	6708	6690	6812	6591
Otter Formation	6820	6805	6941	6729
Kibbey sandstone	6894	6831	7078	6833
Kibbey limestone	7032	7008	7162	6944
Kibbey shale	7061	7030	7188	6965
Charles Formation	7139	7113	7273	7038
Mission Canyon Formation	7609	7586	7737	7513
Lodgepole Formation	7928	7908	8070	7834
Three Forks Formation	8507	not here	8662	8407
Birdbear Formation	8528	8463	8691	8452
Duperow Formation	8567	8500	8732	8498
Souris River Formation	8747	8671	8923	8682
Ashern Formation	8849	8780	9032	8780
Interlake Formation	8854	8802	9050	8783
Stonewall Formation	9128	9019	9345	9117
Stony Mountain Formation	9248	9131	9461	9226
Red River Formation	9352	9240	9570	9340

	NDGS Well No. 12872	NDGS Well No. 12950	NDGS Well No. 13327	NDGS Well No. 13512
Pierre Formation	1310	not picked	not picked	1130
Niobrara Formation	3140	3147	3197	3020
Greenhorn Formation	3806	3828	3850	3726
Mowry Formation	4258	4315	4311	4211
Inyan Kara Formation	4634	4730	4705	4612
Jurassic	5152	5222	5224	5215
Saude Member	5733	5839	5847	5780
Pine Salt Member	5930	6075	6027	5912
Belfield Member	6041	6227	6163	6030
Minnekahta Formation	6224	6372	6330	6178
Opeche Formation	6270	6420	6376	6225
Minnelusa Group	6364	6492	6500	6308
Tyler Formation	6625	6750	6710	6578
Otter Formation	6771	6885	6890	6663
Kibbey sandstone	6939	7006	6959	6806
Kibbey limestone	6958	7100	7067	6842
Kibbey shale	6985	7129	7090	6871
Charles Formation	7064	7208	7167	6948
Mission Canyon Formation	7538	7713	7647	7414
Lodgepole Formation	7852	8002	7957	7722
Three Forks Formation	8437	8572	8544	8279
Birdbear Formation	8482	8593	8584	8306
Duperow Formation	8530	8631	8628	8343
Souris River Formation	8713	8811	8820	8520
Ashern Formation	not here	not here	8954	not here
Interlake Formation	8781	8883	8960	8580
Stonewall Formation	9140	9192	9257	8865
Stony Mountain Formation	9255	9306	9368	8972
Red River Formation	9370	9417	9482	9080

	NDGS Well No. 13605	NDGS Well No. 13740	NDGS Well No. 13797	NDGS Well No. 13800
Pierre Formation	not picked	1384	not picked	no data
Niobrara Formation	2995	3184	3078	3135
Greenhorn Formation	3732	3842	3802	3796
Mowry Formation	4193	4305	4286	4291
Inyan Kara Formation	4578	4710	4700	4697
Jurassic	5112	5292	5256	5218
Saude Member	5730	5892	5811	5828
Pine Salt Member	5867	6013	6035	6063
Belfield Member	6023	6141	6175	6227
Minnekahta Formation	6172	6294	6317	6375
Opeche Formation	6220	6340	6365	6422
Minnelusa Group	6297	6506	6478	6542
Tyler Formation	6564	6703	6690	6712
Otter Formation	6650	6829	6758	6797
Kibbey sandstone	6780	6993	6830	6875
Kibbey limestone	6837	7041	7007	7011
Kibbey shale	6863	7069	7038	7094
Charles Formation	6940	7148	7116	7170
Mission Canyon Formation	7411	7638	7590	7640
Lodgepole Formation	7728	7938	7904	7968
Three Forks Formation	8276	8535	not here	8533
Birdbear Formation	8304	8566	8405	8552
Duperow Formation	8342	8609	8500	8588
Souris River Formation	8523	8798	8670	8768
Ashern Formation	not here	not here	8777	8845
Interlake Formation	8637	8886	8783	8867
Stonewall Formation	8870	9232	9019	9136
Stony Mountain Formation	8980	9341	9132	9248
Red River Formation	9089	9454	9249	9356

	NDGS Well No. 13812	NDGS Well No. 13850	NDGS Well No. 13869	NDGS Well No. 14400
Pierre Formation	no data	1467	1406	no data
Niobrara Formation	not picked	3017	not picked	2959
Greenhorn Formation	3690	3724	3728	3664
Mowry Formation	4186	4205	4209	4157
Inyan Kara Formation	4582	4619	4613	4560
Jurassic	5157	5209	5202	5182
Saude Member	5748	5811	5807	5634
Pine Salt Member	5826	5910	5890	5874
Belfield Member	6054	6013	5966	5910
Minnekahta Formation	6180	6180	6168	6076
Opeche Formation	6224	6227	6218	6121
Minnelusa Group	6384	6283	6306	6204
Tyler Formation	6548	6598	6551	6438
Otter Formation	6710	6746	6653	6569
Kibbey sandstone	6745	6803	6756	6685
Kibbey limestone	6818	6857	6834	6745
Kibbey shale	6847	6888	6865	6772
Charles Formation	6921	6962	6938	6853
Mission Canyon Formation	7375	7432	7394	7305
Lodgepole Formation	7708	7774	7722	7637
Three Forks Formation	8256	8297	8273	8187
Birdbear Formation	8263	8315	8288	8203
Duperow Formation	8297	8353	8321	8236
Souris River Formation	8468	8528	8496	8400
Ashern Formation	not here	not here	not here	no data
Interlake Formation	8512	8580	8544	no data
Stonewall Formation	8826	8983	8853	no data
Stony Mountain Formation	8966	9086	8964	no data
Red River Formation	no data	no data	9156	no data

	NDGS Well No. 14491	NDGS Well No. 14644	NDGS Well No. 14741	NDGS Well No. 14810
Pierre Formation	not picked	no data	not picked	not picked
Niobrara Formation	3140	3120	3202	3197
Greenhorn Formation	3780	3778	3857	3870
Mowry Formation	4243	4228	4322	4320
Inyan Kara Formation	4640	4600	4716	4711
Jurassic	5150	5130	5198	5267
Saude Member	5773	5775	5818	5729
Pine Salt Member	5906	5880	6019	5913
Belfield Member	6040	6011	6203	6011
Minnekahta Formation	6215	6184	6350	6172
Opeche Formation	6258	6235	6392	6220
Minnelusa Group	6383	6350	6512	6332
Tyler Formation	6608	6584	6630	6600
Otter Formation	6788	6721	6798	6768
Kibbey sandstone	6858	6851	6943	6858
Kibbey limestone	6965	6934	7065	6916
Kibbey shale	6982	6963	7100	6946
Charles Formation	7063	7043	7164	7025
Mission Canyon Formation	7523	7523	7647	7518
Lodgepole Formation	7848	7823	7956	7795
Three Forks Formation	8430	8403	8540	8374
Birdbear Formation	8473	8447	8581	8413
Duperow Formation	8520	8492	8622	8470
Souris River Formation	8708	8680	8812	8651
Ashern Formation	8810	8780	not here	not here
Interlake Formation	8825	8786	8892	8705
Stonewall Formation	9121	9110	9239	9115
Stony Mountain Formation	9230	9221	9352	9224
Red River Formation	9341	9336	9462	9340

	NDGS Well No. 14826	NDGS Well No. 14850
Pierre Formation	not picked	not picked
Niobrara Formation	3092	2997
Greenhorn Formation	3754	3702
Mowry Formation	4220	4179
Inyan Kara Formation	4622	4580
Jurassic	5172	5168
Saude Member	5647	5758
Pine Salt Member	5844	5900
Belfield Member	5920	5979
Minnekahta Formation	6083	6163
Opeche Formation	6130	6208
Minnelusa Group	6221	6321
Tyler Formation	6498	6548
Otter Formation	6580	6718
Kibbey sandstone	6703	6778
Kibbey limestone	6810	6821
Kibbey shale	6846	6854
Charles Formation	6921	6918
Mission Canyon Formation	7414	7389
Lodgepole Formation	7690	7702
Three Forks Formation	8258	8262
Birdbear Formation	8319	8294
Duperow Formation	8364	8330
Souris River Formation	8549	8507
Ashern Formation	not here	not here
Interlake Formation	8641	8557
Stonewall Formation	8993	8870
Stony Mountain Formation	9103	8980
Red River Formation	9215	9090

APPENDIX C

Core Descriptions. Core samples are from North Dakota Geological Survey well number 4654, Operator: International Nuclear, Name: John M. Susa et al #1-61. Depths are from the Kelly Bushing as given on the core boxes. Core descriptions were made using a hand lens and were classified according to Folk (1959, carbonates), Picard (1971, mudrocks), and Maiklem et al. (1969, evaporites). Rock colors were based on the Goddard et al. (1963) Rock Color Chart.

NDGS Well No. 4654
International Nuclear, J. M. Susa #1-61
SWNE, Sec. 30, T. 130 N., R. 102 W.
Bowman County

Depth (feet)	Description
Mission Canyon Formation	
7568 – 7571	Limestone, light brown to tan, finely laminated with occasional stylolites, effervescent, occasional fossils occur throughout, calcareous. At 7568.5 large stylolitic boundary is present.
7571 – 7571.5	Limestone, light brown to tan, finely laminated with occasional stylolites, becoming more stylolitic downward than above, effervescent, occasional fossils occur throughout, calcareous.
7571.5 - 7572	Limestone, medium grey, stylolitic, calcareous.
7572 – 7573.5	Limestone, light brown to tan, finely bedded, interbedded with fossiliferous limestone.
7573.5 – 7574	Limestone, grey, massive with occasional laminations.
7574 – 7575.5	Limestone, grey, forms matrix with anhydrite nodules.
7575.5 – 7576	Limestone, fragmented, grey matrix with angular tan limestone particles scattered throughout, particle sizes range from 1 mm to 2 cm.
7576 – 7678	Limestone, grey brown, massive to finely laminated, calcareous, occasional stylolites.
7578 – 7579.5	Limestone, light brown and grey interbedded limestone, laminated and stylolitic.
7579.5 – 7581.5	Limestone, light brown and grey, finely laminated, grading downward to massive limestone with fine grey laminations.
7581.5 – 7583	Limestone, dark grey, alternating layers with medium grey limestone, finely laminated, occasional fossiliferous layers occur, having a thickness not greater than 1 cm.
7583 – 7586	Limestone, grey, very finely laminated, interbedded with carbonate mud, occasional stylolites occur near the bottom.

Depth (feet)	Description
7586 – 7587	Limestone, micritic matrix bearing anhydrite nodules.
7587 – 7587.5	Limestone, grey, very well laminated, interbedded with carbonate mud.
7587.5 – 7592.5	Limestone, petroleum stained light brown, petroliferous, finely laminated, 1.2 – 2.6 cm anhydrite layers commonly occur with anhydrite layers near the bottom. Anhydrite appears fractured.
7592.5 – 7593	Limestone, petroleum stained light brown, petroliferous, fragmented limestone with anhydrite nodules.
7593 – 7594	Limestone, petroleum stained light brown, petroliferous, finely laminated, 1.2 – 2.6 cm anhydrite layers commonly occur with anhydrite layers near the bottom. Anhydrite appears fractured.
7594 – 7596	Limestone, grey, with carbonate mud, occasional anhydrite veins occur.
7596 – 7597	Limestone, grey, grading from carbonate mud to finely laminated limestone.
7597 – 7597.3	Limestone, dark grey matrix with tan to light brown limestone mixed in, appears bioturbated.
7597.3 – 7598	Limestone, medium to dark grey, massive calcareous, effervesces, occasional stylolites.
7598 – 7598.5	Limestone with anhydrite nodules. Transition from limestone to chicken-wire anhydrite.
7598.5 – 7606	Chicken-wire anhydrite, white anhydrite with grey and brown veins of limestone, with occasional grey laminated limestone layers, 2mm – 2cm thick.
7606 – 7606.5	Mudstone, light brown, finely laminated, calcareous, effervesces.
7606.5 – 7607	Chicken-wire anhydrite, anhydrite with grey and dark grey veins of limestone, and calcareous mudstone veins throughout, highly fractured, fractures occurring every 2 mm to 10 mm.

Depth (feet)	Description
7607 – 7609.3	Chicken-wire anhydrite, moderately fractured, 2 cm to 4 cm, calcareous mudstone and limestone veins throughout. Anhydrite appears darker (less white) than before.
7609.3 – 7609.8	Mudstone to muddy limestone, medium grey, massive, calcareous, with occasional laminations, small anhydrite nodules occur near the top, gradational to above.
7609.8 – 7612	Interbedded limestones and mudstones, finely laminated, alternating light grey, dark grey, light brown layers of muddy limestone.
7612 – 7612.7	Limestone, light to medium grey, massive, with anhydrite veins (white), rare laminations.
7612.7 – 7613.3	Transition from limestone above to mudstone below, fractured with anhydrite lenses and layers, 2 cm thick shale / clay layer, dark grey color occurs at base.
7613.3 – 7614.5	Mudstone, light grey, massive, calcareous, becoming more consolidated downward, changing color to light brown to tan downward.
7614.5 – 7614.8	Shale, black, with thinly laminated dark brown layers, well consolidated, well indurated, calcareous.
7614.8 – 7615	Limestone, dark grey, fragmented with clasts 1 mm to 1 cm of angular mudstone, limestone, and anhydrite.
7615 – 7618.5	Limestone, dark grey with carbonate mud, having occasional anhydrite veins.
7618.5 – 7621	Limestone, dark grey, fragmented with clasts 1 mm to 1cm of angular mudstone, limestone, and anhydrite.
7621 – 7624	Limestone, medium grey to dark grey, interlayered with carbonate mud, occasional fossils occur, massive.
Red River Formation	
7627 – 7633	Limestone, medium to dark grey, massive with laminations at top and bottom. Anhydrite nodules and veins scattered throughout. Anhydrite lenses occur near base.

Depth (feet)	Description
7633 – 7638.7	Limestone, medium grey, fragmented, with clasts ranging from 1 mm to greater than 15 cm. Large angular clasts are calcareous carbonate mudstone. Crystaline anhydrite appears to have 'grown' in place or into an open space, having needle-like crystals, readily visible to the naked eye. Carbonate mud is 6 cm thick at base, with increasing carbonate mud downward. Increased fragmentation upward.
7638.7 – 7640.5	Limestone, medium grey to grey brown, massive, with occasional veins of dark material, occasional stylolites, and occasional thin anhydrite veins occur within carbonate mud.
7640.5 – 7640.9	Limestone, buff to light tan, fine laminations, bounded by stylolites above and below.
7640.9 – 7642	Limestone, medium grey to grey brown, carbonate mud throughout, occasional fossil.
7642 – 9440	No Core.
9440 – 9446	Limestone, mottled appearance, light grey, medium grey and dark grey layers throughout, stylolites common, fossils scattered throughout, calcareous.
9446 – 9448.3	Limestone, alternating light grey, medium grey, and dark grey layers, finely laminated, occasional stylolites near top, calcareous.
9448.3 – 9454	Limestone, light grey to brownish grey, massive with occasional thin layers and lenses of darker carbonate material, occasional stylolites, occasional fossils.
9454 – 9457.5	Limestone, medium to dark grey, gradation from massive limestone with mottled appearance, down to poorly laminated, medium grey limestone with occasional pseudo-oolitic structures.
9457.5 – 9461	Limestone, light to medium grey, mottled in appearance, grading downward to massive, occasional fossil.
9461 – 9556	No Core.

Depth (feet)	Description
9556 - 9561.5	Limestone, light grey, medium grey and dark grey with a mottled appearance, exhibiting more laminar structures downward, occasional stylolites, few pseudo-oolitic structures near base, calcareous.
9561.5 – 9562.3	Siltstone, light tan to buff, finely laminated, moderately consolidated, calcareous.
9562.3 – 9567	Limestone, medium grey, alternating massive and finely laminated, slightly fractured in some areas, calcareous.

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