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The Stratigraphy And Depositional History Of The Deadwood Formation, With A Focus On Early Paleozoic Subsidence In The Williston Basin

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THE STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE DEADWOOD FORMATION, WITH A FOCUS ON EARLY PALEOZOIC SUBSIDENCE IN THE WILLISTON BASIN

by

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This thesis, submitted by Anthony H. Sarnoski, Jr in partial fulfillment of the requirements for the Degree of Master 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.

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Anthony H. Sarnoski, Jr.

December 20, 2015

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ABSTRACT

The Deadwood Formation is an assemblage of siliciclastic, carbonate, and evaporite sedimentary rocks in North Dakota, South Dakota, Montana, Wyoming, Manitoba, and Saskatchewan. The majority of the lateral extent of the Deadwood Formation is in the subsurface of the Williston Basin, where it is the basal lithostratigraphic unit. Deposition began roughly 501 million years ago, as the Sauk sequence reached the exposed Precambrian igneous and metamorphic rock of the North American Craton.

Six identifiable and widespread gamma ray markers occur in the well logs, dividing the formation into six informal units, label members A through F in ascending order. The initial deposits on the craton were conglomerates and sandstones of the Cambrian Member A. These sediments were overlain by glauconite rich, siltstones and fine-grained sandstones of the Cambrian and Ordovician Member B. After the deposition of Member B, three regressive-transgressive sequences took place, depositing a succession of sandstones, limestones, dolomudstones, siliciclastic mudstones, and calcareous siltstones. These deposits represent the Ordovician members, C, D, E and F.

Using the thickness, depositional environments, age of each member, and other well information, tectonic subsidence values were determined using backstripping analysis. This analysis was completed by inputting all of the information into Novva®, a 1D geological modeling software released by Sirius Exploration Geochemistry Inc. Data

collected from well logs and core, other data researched by the author, and information from previous works was combined with information and calculations supplied by Novva®. The results produce an accurate computation of the depositional history for the seven wells that penetrated all six members of the Deadwood Formation and the Precambrian basement.

Prior to and at the start of Deadwood deposition the Williston Basin did not exist. Evidence from isopach maps created for each member of the Deadwood Formation and the results from Novva® concluded that subsidence in the area, now known as the Williston Basin, did not begin until Member C was being deposited. This places the initiation of the Williston Basin to be roughly 485 to 482 million years ago.

CHAPTER I

INTRODUCTION

Study Area

The Deadwood Formation and its chronostratigraphic equivalents occur throughout much of the Midwest of the United States. Due to hydrocarbon production in the area, wells are abundant in areas with oil plays and lacking in areas without oil. This has limited the study area to most of North Dakota, a large majority of South Dakota, eastern Montana, southeastern Saskatchewan, and the extreme southwestern corner of Manitoba (Figure 1). Members A and B of the Deadwood Formation occur outside of the study area, especially to the west and north in Canada and in the northwestern corner of Wyoming. The study area covers most of the Williston Basin.

The overall area of the study area is quite large but the area of data is very small (Figure 1). The densest cluster of wells is near the Nesson Anticline in western North Dakota, the northern border of Montana and North Dakota, and right above the border in Saskatchewan. The Deadwood Formation is the basal lithostratigraphic unit where it occurs, with only the Precambrian basement rock below it. The Precambrian consists of igneous and metamorphic rocks which are much more difficult to drill through than sedimentary rock. Along with currently low interest in oil and gas production from the Deadwood Formation and increased costs of deep wells, most wells have only drilled the upper portion of the Deadwood Formation, especially towards the center of the basin.

This area in western North Dakota is the most important to the study; the thickest and most complete sections of the Deadwood Formation are preserved here.

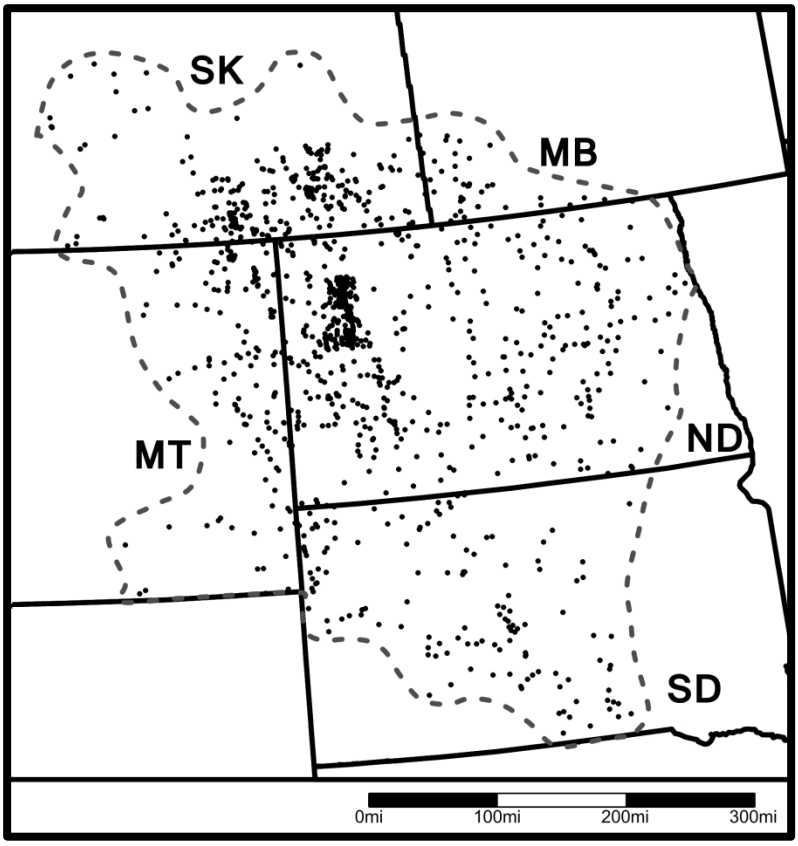

Figure 1. Map displaying the study area. The boundary is represented by the hashed line, the points represent wells used in this study.

Geological Setting

The Deadwood Formation occurs almost entirely in the subsurface. The only outcrop exposures occur in limited areas of the Black Hills of South Dakota and Wyoming. It is a heterogeneous combination of numerous different lithologies, including varying amounts and combinations of sandstones, siltstones, shales, limestones, and evaporites. The division of the formation into six members (Figure 3) is determined by distinctive and widely traceable gamma ray signatures (Figure 2). These markers relate to changes in lithology but similar lithologies are found in multiple members.

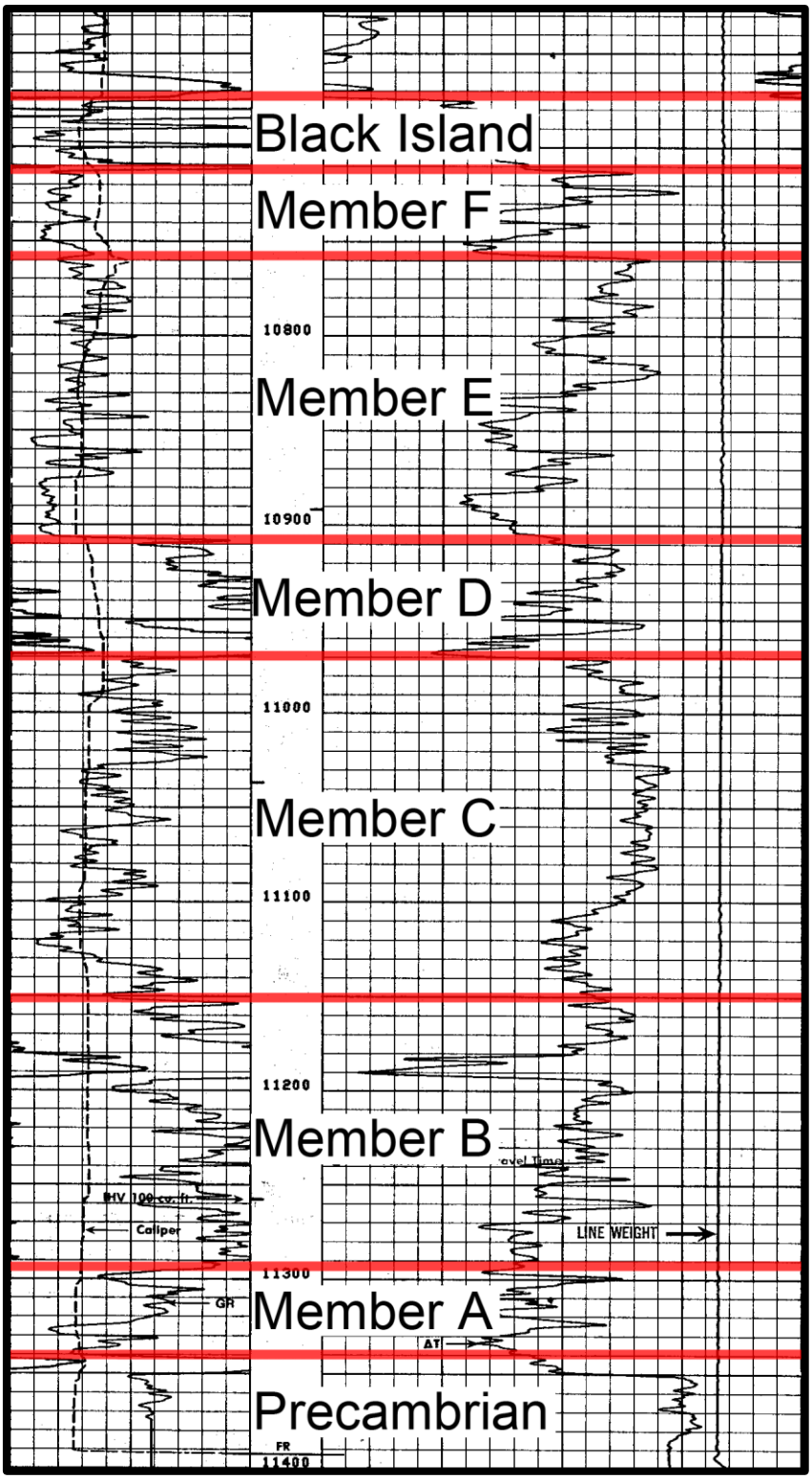

Figure 2. Example of the gamma ray signature used to correlate the wells in this study. Example is a borehole compensated sonic log from NDGS #7340.

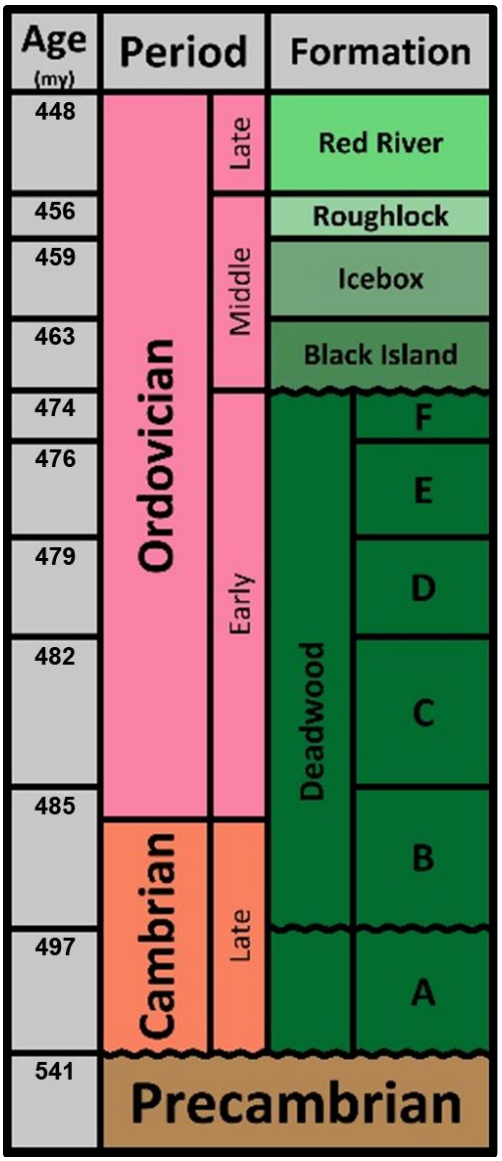

Figure 3. Stratigraphic column for the Early Paleozoic section of the Williston Basin in North Dakota. (Modified from Murphy et al., 2009; Cohen et al., 2013).

The isopach map of the Deadwood Formation closely resembles the general structure of the basin. The Williston Basin is northwest-southeast trending and has a roughly oval shape with various structures (Figure 4). It has a maximum thickness slightly greater than 16,000 feet and its oblong shape has an area of roughly 150,000 square miles. It is located in the western three-fourths of North Dakota, northwestern

South Dakota, eastern Montana, southeastern Saskatchewan, and the extreme southwest corner of Manitoba. The major features that affect Deadwood deposition are the Nesson and Cedar Creek anticlines and the Newporte impact structure (Figure 5). The Williston Basin is not tectonically active and the Nesson and Cedar Creek anticlines are believed to be caused by preexisting fault systems in the Precambrian basement rocks underneath the basin. Early oil exploration was focused on these and other smaller scale structures throughout the basin.

Figure 4. A map displaying the general outline of the Williston Basin. (Modified from Pitman et al., 2001).

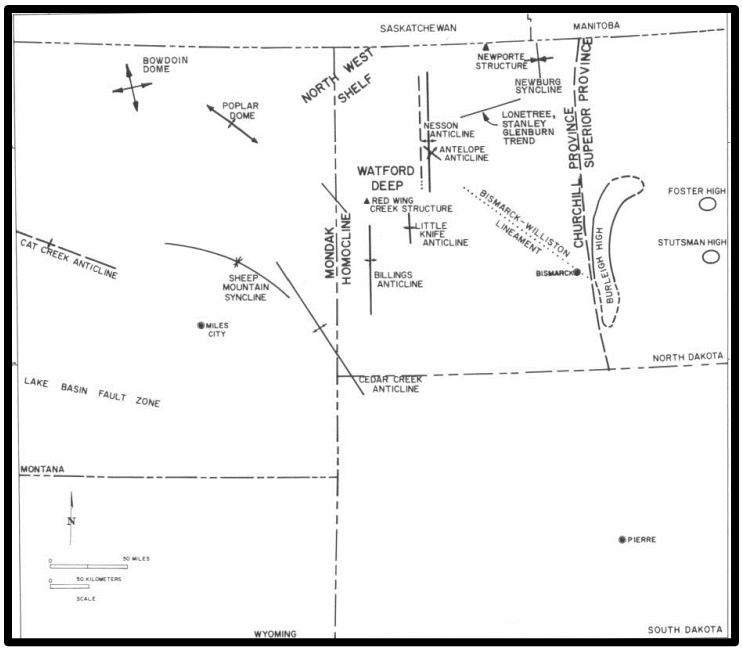

Figure 5. A map displaying the major structural features found within the Williston Basin and the surrounding areas. (Modified from Gerhard et al., 1982).

The Newporte structure is a three kilometer wide impact structure located in Renville County, North Dakota, near the border with Saskatchewan (Clement and Mayhew, 1979). The impact either occurred during the deposition of Member B or at the beginning of deposition of Member C of Deadwood Formation. Stratigraphic analysis of the Deadwood in Renville County is difficult because all of the cored intervals of the Deadwood Formation in Renville County were drilled in the impact structure. There are not any other cored intervals nearby to correlate with. A lot of attention was spent in this area in the 1970's because oil was produced from the Deadwood within the impact structure. These cores display an intense breccia of metamorphosed early Deadwood deposits and Precambrian basement rock, intermixed with unaltered siltstones and sandstones. The brecciated texture of the rock allows for an increase in porosity and permeability, creating a good reservoir unit. This is similar to the Red Wing Creek impact structure located in McKenzie County, North Dakota (Barton et al., 2010),

although the Red Wing Creek impact affects Mississippian through Triassic strata (Brenan et al., 1975).

Resting nonconformably above the Precambrian basement rock is the first evidence of deposition in the Phanerozoic Eon. These rocks represent the Upper Cambrian to Lower Ordovician Deadwood Formation. The Deadwood Formation was deposited as global sea level began to rise, slowly submerging the craton with a shallow sea. This rise in sea level is referred to as the Sauk sequence, one of the six major depositional sequence during the Phanerozoic Eon (Sloss, 1963).

At the top of Deadwood Formation there is a major unconformity, representing the end of the Sauk sequence and characterized by extensive erosion and non-deposition. Overlying this unconformity is the Middle Ordovician Winnipeg Group, in ascending order, the Black Island, Icebox, and Roughlock Formations. The Deadwood Formation extends wider than the depositional limits of Winnipeg Group in central Montana and Saskatchewan, in those areas the Deadwood Formation is unconformably overlain by the Ordovician Red River Formation or its lithostratigraphic equivalent, the Bighorn Dolomite (Anderson, 1988).

Wells that reach the underlying Precambrian basement rocks are scattered throughout the study area but most of these wells are located near the edge of Williston Basin, where the Precambrian is much shallower. The composition of the basement rock underneath the Williston Basin is not continuous throughout the entire basin, with a major transition underneath the deepest area (Figure 6).

The Precambrian basement consists of two Archean cratons, the Wyoming Craton to the west and the Superior Craton to the east, which are separated by Proterozoic

oceanic sediments of the Trans-Hudson Orogenic Belt (Green et al., 1985). The Wyoming Craton underlies Wyoming, Montana, western Saskatchewan, the western one-fourth of South Dakota, and the extreme southwestern corner of North Dakota. The Wyoming Craton is composed of middle Archean gneisses (Mueller et al., 1993). The Superior Craton occurs beneath eastern North Dakota, eastern South Dakota, and central and eastern Manitoba. The Superior Craton is the same age as the Wyoming Craton and consists of granites and granulite facies gneiss (Card, 1986). Dividing these two cratons is the Trans-Hudson Orogenic Belt which runs nearly north-south at about -102° longitude (Figure 6). This belt crosses through western North Dakota and South Dakota and along the border of Saskatchewan and Manitoba.

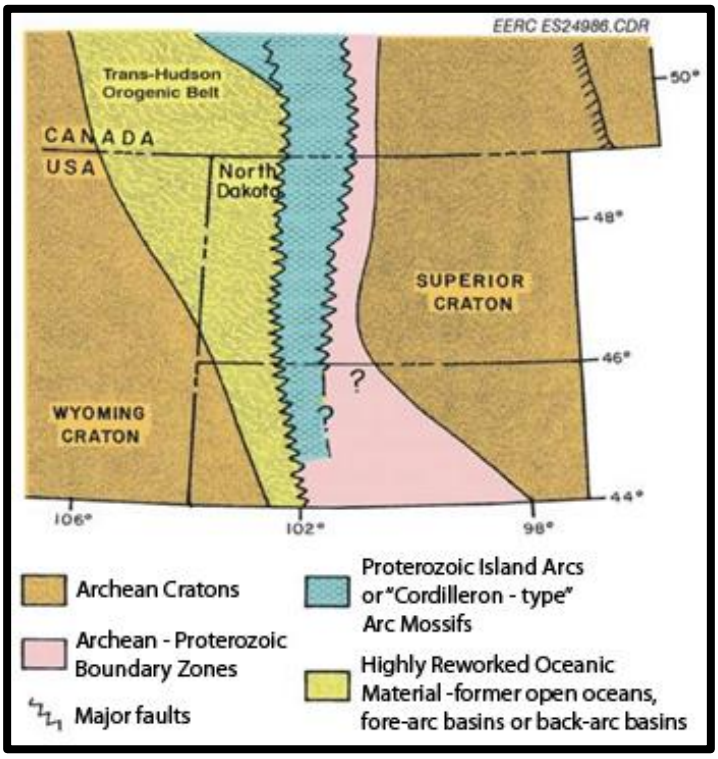

Figure 6. A map displaying the Precambrian basement rocks underlying the Williston Basin and the surrounding areas. (Modified from Fischer et al., 2005; after Green et al., 1985).

The deepest well to reach the Precambrian, NDGS #6228, is located in the northeastern corner of Billings County. The top of the Precambrian is at a depth of 15,265 feet. This well also penetrates the maximum thickness of the Deadwood Formation, 906 feet. The top of the Precambrian is estimated to be even deeper than this. NDGS #6228 is not at the center of the basin, but there are no wells closer to the center that penetrate the Precambrian. NDGS #8626 is located 47 miles closer to the center, in north-central McKenzie County, and the top of the Black Island Formation is at 15,188 feet, with a total depth of 15,300 feet. The top of the Black Island Formation is 906 feet deeper than it is in NDGS #6228, unfortunately this well does not reach the Deadwood Formation nor the Precambrian. Using the slope of the basin near the center of the basin, the Precambrian would be reached at a depth of around 16,170 feet, this is an estimate.

Purpose

In the past studies of the Deadwood Formation have been quite rare (Carlson, 1960; Lochman-Balk and Wilson, 1967; Anderson, 1988; Greggs, 2000). The two more recent studies were regional, with Anderson (1988) focusing on North Dakota and Greggs (2000) focusing on Western Canada. With the increase in drilling and exploration in the Williston Basin and surrounding areas an abundance of new information has become available, mostly due to the wireline logs associated with these new wells allowing for more accurate correlations across larger areas. There are also five new cored intervals that were not previously available. Cored intervals produce the most useful information; unfortunately they are very uncommon; only about 10% of the wells drilled to the Deadwood have cored intervals available and none capture the entire Deadwood Formation.

The growth of technology has also played an immense part in making this study more informative. In the nearly 30 years since Anderson's study, internet databases have allowed for a more expansive study to be performed and the growth of computing power has allowed for programs, such as Petra®, Surfer®, and Novva®, to offer much more accurate results.

Previous Works

Surface Stratigraphy

Discussions of the Lower Paleozoic rocks in the Williston Basin and the northern Black Hills have been challenged by many authors. The stratigraphy has been described and reassessed numerous times and with the classification and age of these units debated heavily. Early studies lack of subsurface data, missing fossiliferous intervals, and a lack of continuous outcrop data were the main reasons for differing opinions. With the addition of new wells and information these early hypothesis' are being confirmed or proven wrong and the Deadwood Formation is being understood even better.

The first mention of the Cambrian and Ordovician rocks in the study area was by Newton and Jenney (Newton, 1879). They went to the Black Hills on a United States Geological Survey scientific expedition to map the Black Hills and to confirm claims of gold in the region. In their geologic assessment they grouped all of the Lower Paleozoic units together and determined that they were correlative to the Potsdam sandstone and placed in the Potsdam Period, which is Silurian in age.

In 1901 Thomas Jaggar (Jaggar and Howe, 1901) came to the Black Hills to map the underlying igneous intrusions of South Dakota and Wyoming. He did not apply a name to the strata overlying the intrusions but he noted that along the west side of

Whitewood Creek outside of Deadwood, South Dakota, was the type locality for the strata. The units that make up the outcrop along Whitewood Creek were officially named by Darton, 1901, the same year as Jaggar's publication. In this publication Darton labeled the Ordovician units as the Whitewood Limestone and the Cambrian units as the Deadwood Formation. His publication in 1904 makes a minor change by stating that the top of the Deadwood was overlain by a twenty-five foot section of siltstone, which was directly overlain by the Whitewood Dolomite (Darton, 1904). He compared fossils found throughout the unit with ages produced by Charles Walcott and labeled the Deadwood Formation as Middle Cambrian. In 1925 Darton, along with Sidney Paige, reevaluated the outcrops in the Black Hills and determined that the siltstone was a part of the Deadwood Formation and also determined that the unit was Late Cambrian instead of Middle Cambrian (Darton and Paige, 1925).

The first major difference in opinion came in 1936 when William Furnish, Edward Barragy, and Arthur Miller published a paper on fossils they found in the type section of the Deadwood Formation. They discovered that the fossils in the upper siltstone and gray shale beds were of Ordovician age (Furnish et al., 1936). These fossiliferous beds are between the Whitewood Dolomite and the *Skolithos*-burrowed sandstone. They noted that no diagnostic fossils occur in the *Skolithos*-burrowed sandstone; therefore the age is unknown. They still decided to combine it with the underlying strata and refer to it as part of the Deadwood Formation. During the same time Harold Meyerhoff and Christina Lochman also studied the fossils in the Black Hills as well. They published three abstracts reporting that they only found Upper Cambrian fossils in the Deadwood rocks of the Black Hills. They suggested that the thinning of the

formation was due to erosion of the younger Deadwood deposits (Meyerhoff and Lochman, 1935). In 1950 Lochman published another paper with Donald Duncan; they discovered Early Ordovician fossils in the sandstone of Crook County, Wyoming and in Spearfish Canyon, South Dakota, which are located in the Black Hills. They believed that these sandstone units were correlative to the *Skolithos*-burrowed sandstone at the Deadwood type section. They suggested that sedimentation was continuous from the Late Cambrian through the Early Ordovician (Lochman and Duncan, 1950).

The next major change came in 1952 when Melville McCoy published a paper on the Ordovician sediments in the Black Hills. In this publication he removes the *Skolithos*-burrowed sandstone from the Deadwood Formation and names it the Aladdin sandstone (McCoy, 1952). The shale above that was given the name Ice Box shale and the Roughlock siltstone refers to the siltstone beds in between the shale and Whitewood Dolomite. With this separation of the Deadwood Formation and the other overlying units, work was now focused on classifying the different lithologies of the Deadwood. In 1955 Robert Butler, Raymond Battin, Robert Plank, and George Winston published a paper attempting to correlate Middle and Lower Paleozoic rocks throughout the southern Williston Basin and the northern Black Hills. With these correlations they were the first to divide the Deadwood Formation into three members; a basal conglomerate, middle shale and limestone, and upper glauconitic quartz sandstone (Butler et al., 1955). This report did not agree with McCoy's classification and only separated the Lower Paleozoic beds into the Deadwood Formation and the Whitewood Formation. He included the *Skolithos*-burrowed sandstone and the underlying limestone conglomerate in with the Whitewood. He divided the Whitewood into five members, where the Whitewood,

Roughlock, Icebox, Aladdin, and the top of the Deadwood are equivalent to members E, D, C, B, and A, respectively.

The confusion continued with the first paper presented by Clarence Carlson in 1958 where he bases his stratigraphy on McCoy, 1952. Carlson kept the Whitewood Formation unchanged and changed the Roughlock and Icebox Formations into the Roughlock and Icebox members of the Winnipeg Formation. He also added the Aladdin Formation and members B and A (Butler et al, 1955) back into the Deadwood Formation.

The first comprehensive study of the paleogeography and paleoecology of the Deadwood Formation in the Black Hills was by Joseph Kulik in 1965. In his thesis he divided the rock units in a similar fashion to Furnish et al. (1936). He separated the Whitewood and Winnipeg Formations from the Deadwood Formation (Kulik, 1965), with the Winnipeg Formation containing the beds that make up the Roughlock and Icebox Formations (McCoy, 1952). He then divided the Deadwood Formation into three members. An upper sandstone, limestone, and minor conglomerate, which included the *Skolithos*-burrowed sandstone, a middle interbedded shale and limestone, and a basal sandstone, limestone and limestone pebble conglomerate. He concluded that three members comprised of 25 sedimentary facies that he interpreted to have been deposited in various near shore, tidal-flat, lagoonal, and deltaic environments during three transgressive-regressive sequences.

In 1972 Ladle finished an unpublished thesis of a detailed description of the rocks and sedimentation in the Deadwood Formation in the Black Hills. He placed the boundary of the Cambrian and Ordovician at the base of the *Skolithos*-burrowed sandstone. He then divided the portion of the Deadwood underneath this sandstone into

five members (Ladle, 1972). Similarly to Kulik, he interpreted through his petrographic study that the Deadwood was deposited in nearshore, deltaic, tidal-flat, off-shore-bar, lagoonal, and bay environments and that the different facies changes were due to multiple transgressive-regressive sequences.

A more detail paleoecological and paleoenvironmental study was completed by Stanley, 1984. He used ichnofossils of the Deadwood in the Black Hills to separate the Deadwood into six lithologic units. He used *Skolithos* and *Cruziana* ichnofacies and determined that they represented deposition in upper and lower intertidal sand flats, shallow near shore settings, and localized carbonate flats and restricted subtidal lagoons (Stanley, 1984).

Subsurface Stratigraphy

As stated earlier, the Deadwood Formation occurs almost completely in the subsurface. The first mention of the Deadwood Formation in the subsurface was by Wilson Laird, referring to strata encountered in shallow wells of eastern North Dakota, the majority of these were water wells (Laird, 1941). Interbedded sandstones and shales of NDGS #8 were classified by Virginia Kline as Cambrian and assigned to the Deadwood Formation. NDGS #8 had a total depth of 3,884' while more recent surrounding wells did not reach the top of the Deadwood Formation until at least 5,000'. Seager and others decided that the strata mention above was more likely Ordovician and not Cambrian (Seager, 1942).

In North Dakota the first well to reach the Ordovician section of the Deadwood Formation was NDGS #15 in 1942. This well, located in Oliver County in central North Dakota, allowed for new information that was previously unattainable. Descriptions of

the Deadwood were no longer restricted to surface outcrops in the Black Hills. At a total depth of 8,850', NDGS #15 reached the Precambrian and encountered all members of the Deadwood Formation except Member F. Core was not taken from the Deadwood, but drill cuttings recovered provided information about the stratigraphy and lithology.

Oil exploration was just beginning in North Dakota in the 1950s and wells reaching the Deadwood Formation were uncommon. Interest in the stratigraphy of the Cambrian and Ordovician units was not discussed until the mid-1950s. By 1960 more than 85 wells reached the Deadwood Formation in North Dakota.

Early stratigraphic studies were completed by Ross (1957) on five wells in eastern Montana. The study focused on brachiopods and corals from the Late Ordovician and trilobites from the Early Ordovician. He stated that lithologic features in the cores closely resembled the upper Deadwood strata found in the northern Black Hills and were assigned to the formation (Ross, 1957). With no significant separation between Ordovician and Cambrian strata, the boundary is located based on fossil evidence.

Wire-line logs were useful in describing the Winnipeg and Deadwood Formations by Carlson (Carlson, 1958; 1960), he noted three distinct units found within the pre-Winnipeg strata, a lower sandstone unit, a middle carbonate and shale unit, and an upper sandstone unit. Well control was too poor to conclude anything about these divisions and he kept the Deadwood Formation undivided. He also included the Skolithos burrowed sandstones within the Deadwood Formation.

Based on the work by LeFever, Thompson, and Anderson (LeFever et al., 1987). Anderson (1988) master's thesis was a detailed stratigraphic report from 363 wells throughout North Dakota, South Dakota, Montana, Wyoming, Saskatchewan, and

Manitoba. Using primarily gamma ray response signatures, the Deadwood Formation was divided into six informal members; in vertical succession A-F. More detail of the six members was later provided by LeFever (LeFever, 1992; LeFever, 1996), similar work was completed for the Canadian section of the Deadwood Formation by Greggs (2000).

Basin Subsidence

The location of the initiation of the Williston Basin has been discussed by various authors, (Ross, 1957; Carlson, 1960; Carlson and Anderson, 1965; Lochman-Balk and Wilson, 1967). These early reports relied on well data and descriptions from cored intervals of the Precambrian basement rock and Lower Paleozoic units to determine that downwarping occurred around the center of the basin. These reports were very limited, due to poor well control, however they introduced several questions and ideas that could be answered and expanded on when more well data was recovered.

Sleep, (1971) was the first author to factor in isostasy and to correct for sediment loading, this technique is referred to as backstripping. It is crucial in understanding basin subsidence. Sleep's study did not focus on the Williston Basin but his methods can be used in basins across the world. The results from these new calculations allowed the tectonic effects on subsidence to be isolated. A few authors improved on this equation by adding variables to the equations to make them more accurate (Watts and Ryan, 1976; Steckler and Watts, 1978).

There are two main ideas for subsidence throughout the basin, both of which have been studied by numerous authors: continuous subsidence throughout the basin's history (Ahern and Mrkvicka, 1984; Fowler and Nisbet, 1985, Sleep, 1971; Klein and Hsui, 1987) or episodic subsidence (DeRito et al., 1983; Bond and Kominz, 1991; Gerhard et

al, 1982; Kent, 1987). These models have proposed various basin origin mechanisms including thermal contraction of the lithosphere, phase change of the lithosphere, and crustal warping related to shear zones. In the Williston Basin there is no evidence of orogenic deformation or peripheral tectonic distortion.

Basin subsidence in the Williston Basin was not well understood until LeFever et al. (1987) used backstripping methods developed by Sleep (1971). Previous reports relied on analyzing depositional trends and theoretical models. From there more detailed discussions were developed by Anderson (1988), LeFever (1996), and this report.

Methods

Isopach Maps

Isopach maps are an important tool to understanding how the rock units of the subsurface are oriented. They are constructed by determining the thickness of the unit for numerous wells and then filling in areas of poor well control through geostatistical analysis. The maps are produced by displaying thickness as contour lines of equal thickness of an area. For this study the unknown values were interpolated using the Kriging method, which gives the best linear unbiased prediction for the unknown values. Variograms were used to ensure that results of the Kriging were tailored to each unique data set. The variogram describes how the thickness values change between two points (Cressie, 1991). A linear variogram model was produced for each member. When combined, the resulting model produces the most accurate estimation of thickness trends in the Deadwood Formation and presents them as an isopach map. The rock units of the Williston Basin have an average regional dip ranging from 1% to 3% (Sandberg, 1962), all of the wells that reach the Deadwood Formation have only vertical wellbores and

therefore calculations were not needed to convert stratigraphic thickness to true vertical thickness.

The tops of overlying formations and the members of the Deadwood Formation were picked in LogSleuth® and Petra®. Early work was performed in LogSleuth® and then the whole project was imported into Petra® and was completed using only Petra®. The data collected in Petra® are easily exported as a text file. The text file includes an American Petroleum Institute number (API) for any well in the United States or Unique Well Identifier (UWI) number for Canadian wells. Wells in North Dakota, Saskatchewan, and Manitoba also have shorter well labels. Also included in the text file for each well are latitude and longitude coordinates, Kelly Bushing elevations, and the top of each formation or member, from the Red River Formation to the Precambrian basement rock. The text file can be imported into Microsoft Excel® where all of the data are easily visible and available to manipulate if needed. The main use of this Excel data sheet is to calculate the thickness of each formation or member when possible. To calculate unit thickness the depth of the top of the member is subtracted from the depth of the top of the underlying member.

To create isopach maps the thicknesses calculated are imported into Surfer®, a contour mapping program developed by Golden Software. An issue that is encountered when mapping the wells is that the coordinates provided in Petra® are in latitude and longitude. Latitude and longitude are good for referencing wells in relation to one another but produce a flat, not realistic map. For this study the coordinates were converted to UTM, using the Lambert Conformal Conic Projection. Conic projections are the best for displaying large areas in the middle latitudes, with the central latitude at

45° N and the central longitude at 110° W. The large majority of wells in this study fall between the latitudes of 46° N and 50° N and the longitudes of 97° and 105° W. The study area is fairly large and using a more localized projection would have caused too much distortion.

As mentioned earlier, to the east and north Member B becomes increasingly sandier. Near the erosional limits of the member the gamma-ray response becomes very similar to the underlying Member A. This makes it difficult to accurately pick the top of Member A. In this area the two members are combined and referred to as Member AB. When looking at the whole study area it is important to be able to map members A and B separately but it would not be useful to map Member AB by itself since it would just show a very thin map on the edge of Member B. To include as much data as possible Member A, Member B, and Member AB are combined, whenever the Precambrian was reached, to produce the isopach map for Member AB. This map is displaying the thickness between the top of Member B and the top of the Precambrian basement rock.

Basin Subsidence

The wells for this part of the study were chosen based on their completeness of the stratigraphic column. An important factor was that the well reached the Precambrian basement rock below the basin. This allowed for analysis of the entire Deadwood section available in that area. There are 253 available wells in the study area that reach the Precambrian. These wells span the entire study area; the completeness of the stratigraphic column varies due to pre-Winnipeg erosion. The amount of information available varies greatly well to well. For example some wells only include basic electrical logs, where others include many different types of porosity and lithological

logs. The NDIC website was also very helpful in getting information from well files that was more difficult or even impossible to obtain from the other states and provinces. The most beneficial wells were determined after reviewing information from the oil and gas websites for the respective states and provinces, in addition to well data made available by the North Dakota Geological Society.

Seven wells penetrated all of the members of the Deadwood Formation and the Precambrian basement rock below; NDGS #1385, #2373, #3844, #4321, #6228, #7340, and #8169. A cross section was produced to show their relation to each other (Figure 7 and 8). These are the most important wells for this study not only because these wells offer the most complete package of data but also because they are located near the center of the basin, where subsidence initially began. Subsidence rates will be calculated from sedimentation which is more accurate that trying to calculate sedimentation rates from areas where erosion or possible nondeposition took place.

In this study understanding the subsidence history of the basin is approached in two ways; reviewing isopach maps and utilizing 1-D basin subsidence modeling software.

Reviewing isopach maps was the first method used to begin to understand the subsidence history of the Early Paleozoic of the Williston Basin. These were the same isopach maps used in the stratigraphy section of this paper and the methods are described above. Isopach illustrate thickness variations across entire units and variations in thickness of a unit can be due to a change in deposition. There are many different factors that can influence a shift in deposition, one of them being the onset of subsidence. In an

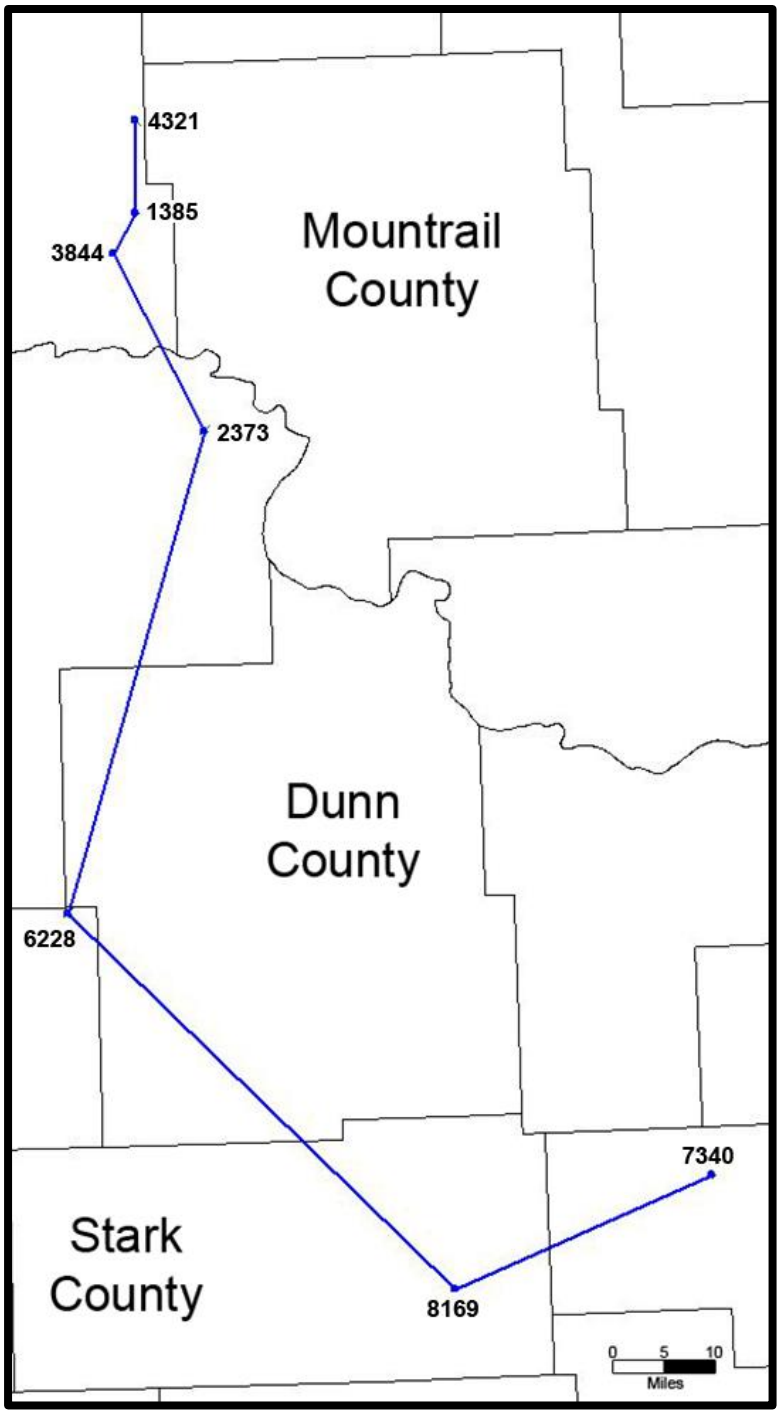

Figure 7. A map showing all seven wells used in the basin subsidence study and how they are orientated in the cross section. The numbers correspond to NDGS well labels.

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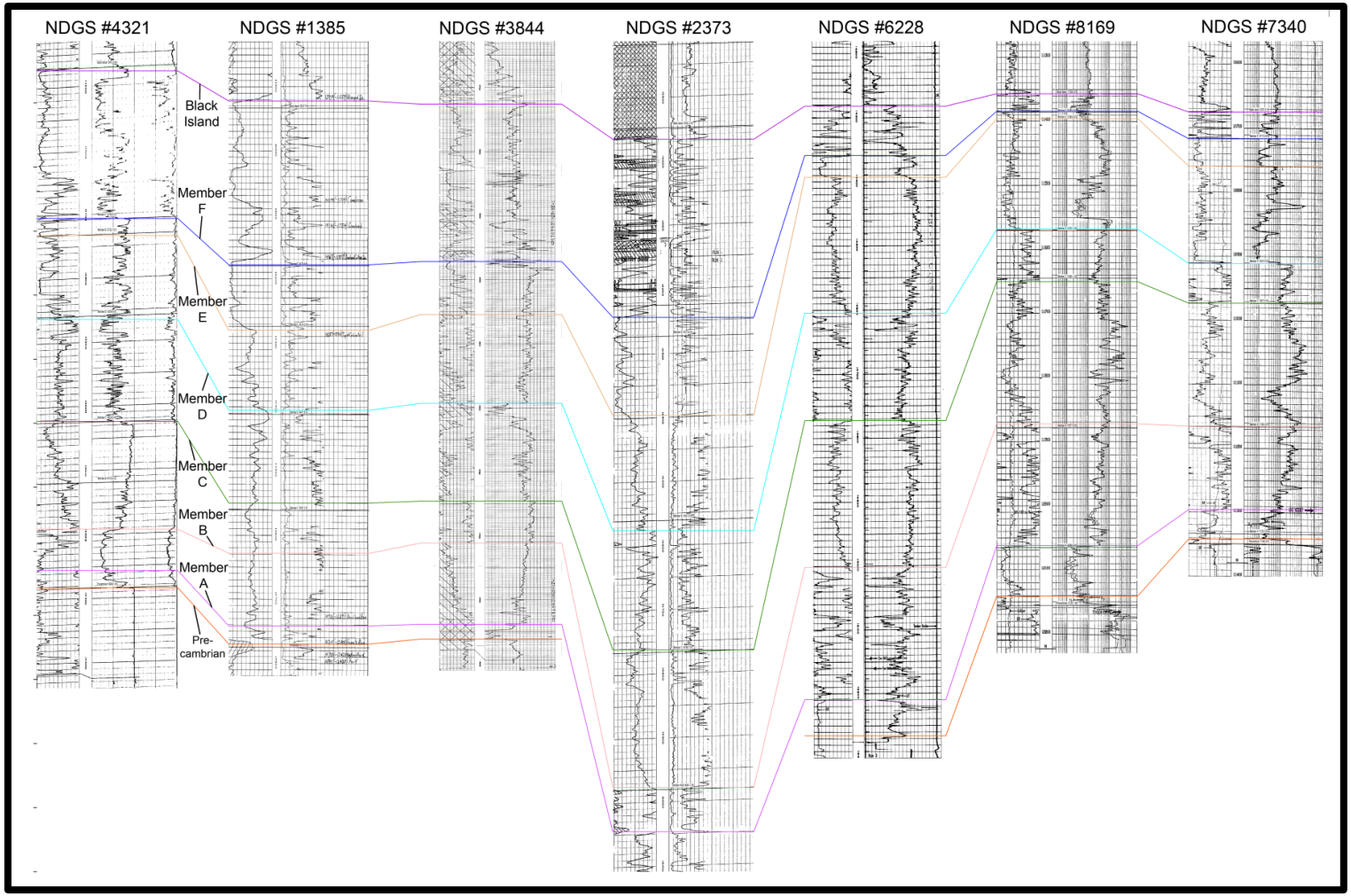

Figure 8. A cross section of all seven wells used in the basin subsidence study, display their relationship to each other. The labels represent the tops of each unit. The numbers correspond to NDGS well labels.

isopach map the onset of subsidence would be represented as a localized increase in unit thickness. This area in the focal point of subsidence and unit thickness would increase at the focal point of subsidence because this area would develop the most accommodation space, allowing for the most deposition.

The second method for analyzing basin subsidence is using basin subsidence modeling software. This study utilizes Novva®, a 1-D geologic modeling software released by Sirius Exploration Geochemistry. This software combines numerous variables, including unit thickness; porosity; temperature; depositional environments; and others, with calculations, including original depositional thickness; subsurface porosity; and bottom hole temperature, to develop a detailed understanding of the burial history of the study area. The variables and calculations used were discovered by the author's research, displayed on well logs, presented by other researchers, or supplied by the software itself.

To get the most out of this software it is important to ask what variables are needed, why are they important, and how are they found? Understanding which calculations are used and why is also important. Novva® is set up as an assortment of steps, each one needs to be filled out before you can move on to the next step. This makes sure that all variables are completed and that each model can be compared to other wells because they use the same variables. The beginning steps are for basic well information, latitude and longitude, ground elevations, kelly bushing elevation, and total depth of the well. This information is on the well's scout ticket and is used as a datum for all of the geologic data. It is also important to enter the basin type and basin forming events, which have been identified by previous authors. The Williston Basin is also

known as an interior sag basin, as it is referred to in Novva® (Einsele, 2000), which is formed due to continental sagging.

Geologic data for each well are entered after the basic well information. The top of thirty four units were added, these units completed the entire stratigraphic column of the Williston Basin. The author picked the top of the Red River Formation, Roughlock Formation, Icebox Formation, and Black Island Formations, the six members of the Deadwood Formation, and the Precambrian. The tops of the units above the Red River Formation were collected from the NDIC Oil and Gas Division's scout ticket website. Not all of the formations are recorded but there are enough there to represent the overburden as a heterogeneous mixture of lithologies. Using this data, present day thicknesses for each unit was calculated.

When dealing with subsidence modeling age is an important variable. This is stressed even more with this study because deposition of the Deadwood Formation only lasted about twenty-five million years. The division of the formation into six members results in very short timespans for each member. Age combined with the thicknesses allows us to estimate the rate of deposition for each unit. Since these are small time frames the addition or subtraction of one to two million years can greatly affect the subsidence rate. For the formations above the Deadwood the ages were derived from the USGS National Geologic Names Lexicon (USGS, 2015). These ages are used as general guidelines, so the results should only be interpreted for the Early Paleozoic history. Ages of the members of the Deadwood Formation are based on fossil research completed by Lochman (Lochman, 1964a; 1964b; 1966; Lochman-Balk and Wilson, 1967). Their results from Montana and North Dakota were compared with the data available to this

study to get the best estimates for time intervals. The Cambrian-Ordovician boundary is placed in the upper portion of Member B.

The point of this study was not to model the entire stratigraphic section of the study area, therefore only three unconformities are incorporated into the model. There are six major unconformities throughout the basin, representing the six major stratigraphic sequences (Sloss, 1984). This study is focused on the Early Paleozoic history, which is only influenced by three unconformities; the minor disconformity between members A and B of the Deadwood Formation, the major unconformity between the top of the Deadwood Formation and the Winnipeg Group, and the major nonconformity between base of the Deadwood Formation and the underlying Precambrian metamorphic and igneous rock (Figure 3). In order to get an accurate model of the entire history of the basin more recent unconformities should be added. The ages and erosion rates for these unconformities are estimated through known sedimentation rates of the units involved.

Lithologies of the units above the Deadwood Formation were found on the NDGS's North Dakota Stratigraphic Column and detailed lithologies for the Deadwood Formation were determined through detailed core and thin section descriptions by the author. Nearly all general lithologies, in addition to numerous variations, are built into Novva®. These can be combined together to specifically mimic the lithology seen in core. The lithologies that are found in Novva® already have many variables built into them including general porosity and permeability, compaction coefficients, and depositional characteristics. Understanding the detailed lithologies allows for

paleobathymetry, paleoelevation, and original depositional environments to be interpreted.

Present porosity data was obtained through either borehole compensated sonic or compensated neutron density logs, depending on available log types. Calculations were used to correct for changes in lithology. For porosity at a subsurface depth a few different equations are used depending on lithology, these equations are built into the software. When dealing with sandstones a modified equation from (Scherer, 1987) is used (Equation 1). This equation considers porosity (ϕ_z) to be a function of five factors; quartz content (Q), the Trask sorting coefficient (S_o), maximum burial depth of the rock, in meters, (Z), age of the rock, in millions of years (A), and the overpressure, in psi, (OP).

(E.1)

$$\phi_z = 0.186 + 0.0473 * \ln(Q) + 0.1737 / S_o - 0.000038 * Z - 0.0465 * \ln(A) + 0.019 * OP / 1000$$

For siltstones, dolomites, conglomerates, and other mixed lithologies the equation from (Athy, 1930) is used (Equation 2). This equation considers porosity (ϕ_z) to reduce exponentially, from the depositional porosity (ϕ_o), as maximum burial depth (Z) increases. A constant (b) is used depending on the depth of the unit.

(E.2)

$$\phi_z = \phi_o * e^{(-bZ)}$$

When calculating the subsurface porosity (ϕ_z) for shales an equation from Baldwin and Butler (1985) is used. As maximum burial depth (Z) increases porosity of the rock is reduced as an exponential function.

(E.3)

$$\phi_z = 1 - (Z/6020)^{(1/6.35)}$$

The last equation that was used is to determine the subsurface porosity of limestones. Three different equations were determined empirically by Sirius Exploration Geochemistry, for their Novva® software, to better fit the measured porosities at different burial depths than one equation could. The first equation is used for very shallow units and derived from Athy (1930) (Equation 2). The wells used in this study were deeper than 500 meters, so only Equation 4 and 5 were needed. At depths between 0.1 and 3.5 kilometers the subsurface porosity (ϕ_z) is determined by a third-order polynomial using maximum burial depth (Z) and a constant (b_n).

(E.4)

$$\textit{Under 3.5km } \phi_z = b_3 * Z^3 + b_2 * Z^2 + b_1 * Z + b_o$$

(E.5)

$$\textit{Over 3.5km } \phi_z = 0.02$$

Temperature is another important aspect of basin development because temperature influences the rate of chemical reactions, most notably cementation rates (Dotsey and Deighton, 2012). The majority of temperature readings are recorded on well logs as bottom hole temperature readings (BHTs). Temperature readings can also be found on drill stem tests and specific temperature logs, although these types of logs are not run for every well. Bottom hole temperatures are recorded at the completion of the well, after the drillstring is removed and the logging tools are lowered into the well. The well is

filled with a mixture of drilling fluid and formation fluid. The drilling fluid is cooler than the original formation fluid so the temperature recorded at the bottom is not representative of the actual temperature of the formation and a correction needs to be applied. Novva® has a default temperature correction built into the software, referred to as the MX-DX-EX, which is a combination the Denmark, Malaysia, and Mexico correction methods, determined by Doug Waples and others. The results from this correction are similar to the values received by using the Kehle correction. The MX-DX-EX correction is an unpublished method that has the following equation:

(E.6)

$$T_{corr} = (1 + 0.71938*e^{-000378*Z}) * (T_{meas} - T_{surf}) + T_{surf} + 0.002481*Z - 0.7061 * TSC + 3.955$$

(E.7)

$$2\sigma = -0.00000021972 * Z^2 + 0.0020112 * TSC^2 + 0.2702*TSC + 10.6397$$

Where Z is true vertical depth of the measurement, TSC (time since circulation) is the time it takes to stop drilling until the first measurement on the log takes place, T_{meas} is the measured temperature in °C, and T_{surf} is the surface temperature in °C calculated by Novva®'s proprietary equations for surface temperature as a function of latitude, global climate, and elevation. This equation is similar to Barker's (2000) equation, where L is latitude in degrees:

(E.8)

$$\text{Temperature (C)} = 27.6 - 0.0414*L - 0.00599*L^2$$

CHAPTER II

DESCRIPTION OF THE DEADWOOD FORMATION

General Surface Stratigraphy

The only outcrops of the Deadwood Formation are in the Black Hills of South Dakota and they were not directly observed by the author. Photographs and detailed descriptions by previous authors were used to gain an understanding of the outcrops and how they correlate to the units studied in the subsurface. The Black Hills region is an irregular anticline formed by a localized uplift of the underlying Precambrian basement rocks. Subsequent erosion has exposed the Deadwood Formation as a relatively thin ring around the exposed metamorphic and igneous Precambrian (Figure 9). Figure 9 is modified from a map produced by Newton in 1879. The Deadwood Formation is presented as the light brown color outlining the light gray Precambrian rocks in the center. In the explanation of colors it is referred to as Potsdam. This map was created prior to the naming of the Deadwood Formation and Potsdam refers to the Late Cambrian to Early Ordovician Potsdam Sandstone found in New York. The Deadwood Formation and the Potsdam Sandstone are chronostratigraphic equivalents.

The exposures of the Deadwood Formation range from about 500 feet thick in the northern area to less than 50 feet thick toward the south and continue to thin out to the southeast (Darton and Paige, 1925). The exposed Deadwood Formation has been divided into three members (Figure 10); an upper sandstone, limestone, and minor conglomerate

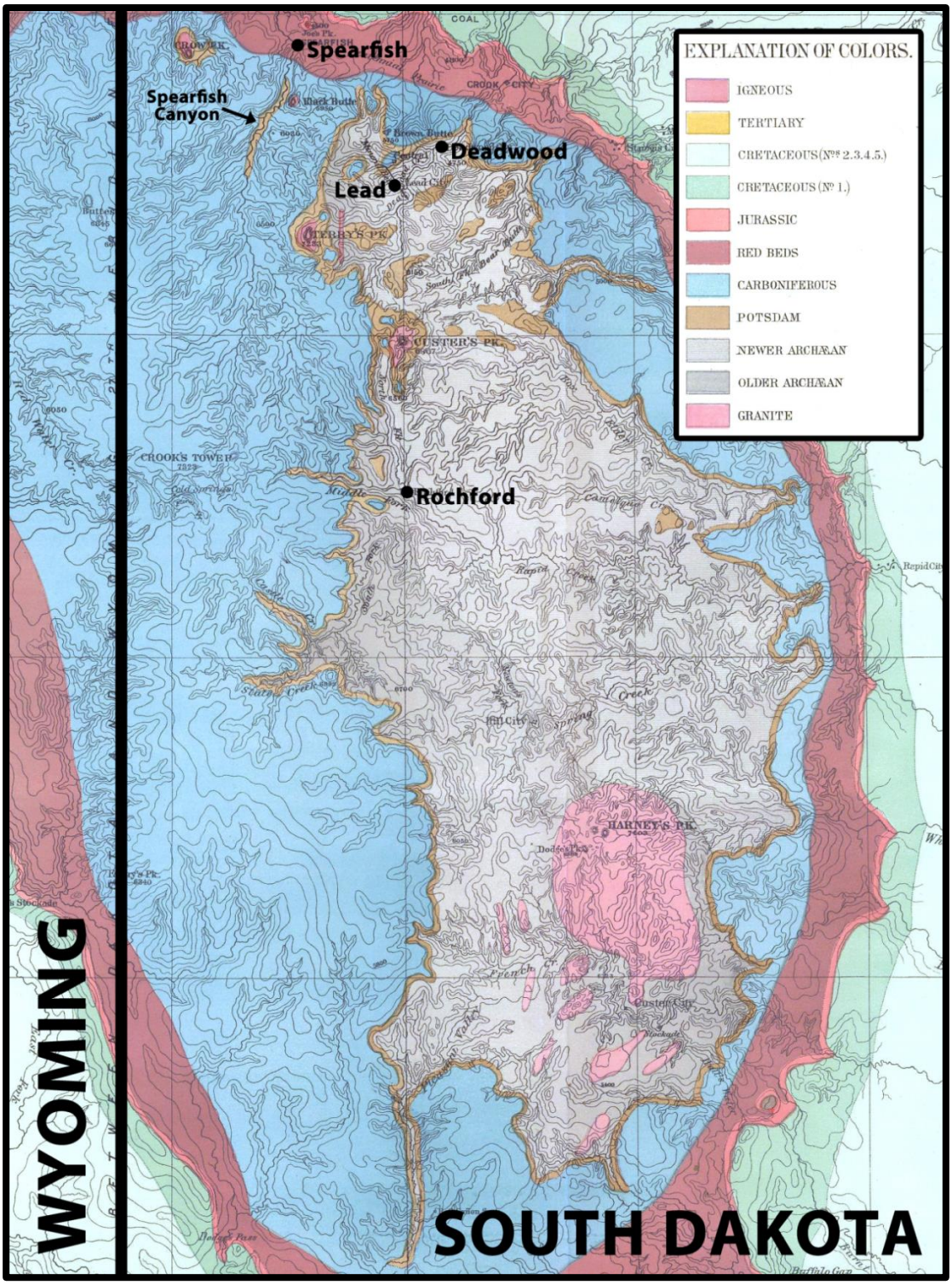

Figure 9. Geologic map of the South Dakota region of the Black Hills. Deadwood Formation outcrops are represented by the dull orange color dividing the blue Carboniferous deposits from the gray Precambrian rocks. It is labeled as Potsdam on the explanation of colors. (Modified from Newton, 1879).

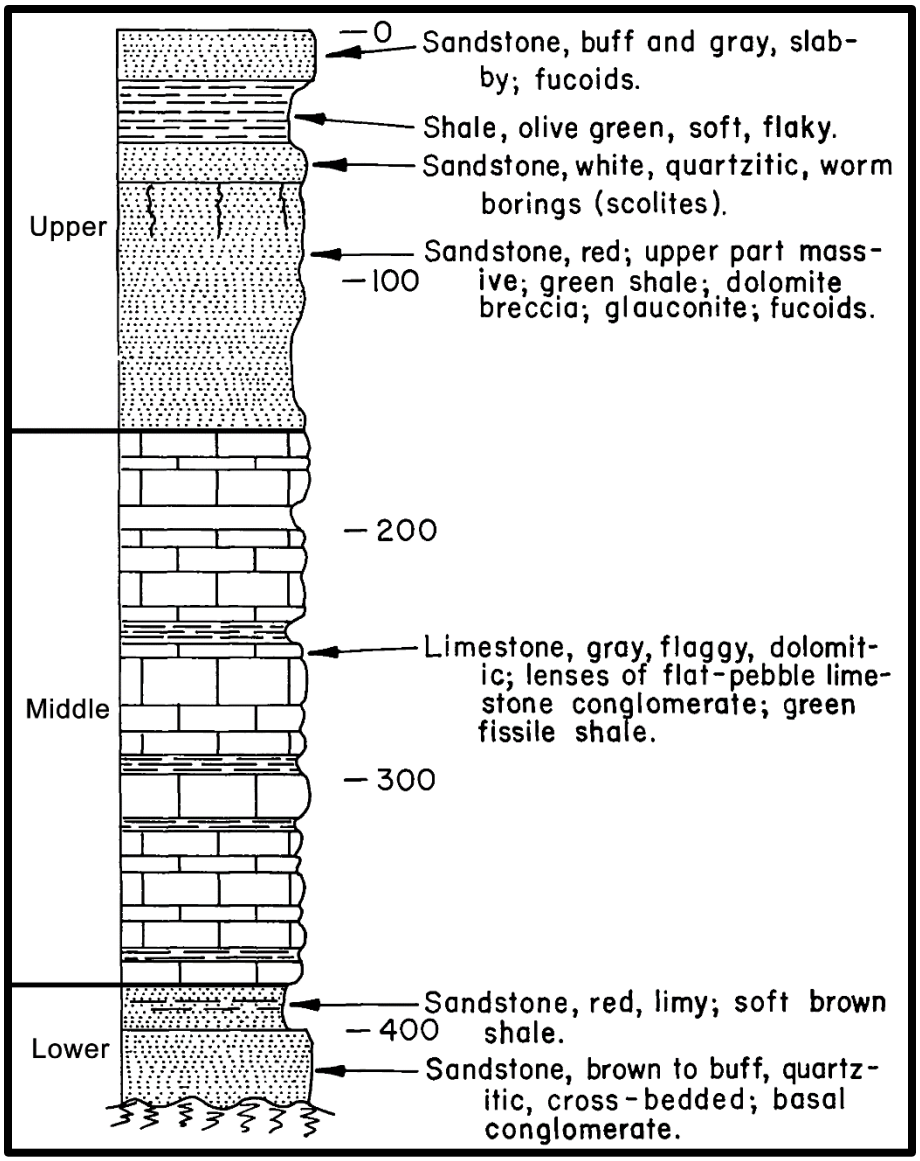

Figure 10. Description of the type section of the Deadwood Formation as described by Nelson Darton and Sidney Paige in 1925 (Modified from Steece, 1978).

member; a middle interbedded shale and limestone member; and a lower sandstone, limestone, and limestone-pebble conglomerate (Kulik, 1965). The upper member consists of brown to buff sandstone, containing commonly Skolithos borings and plant fossils, mostly fucoids (Steece, 1978). Towards the south it is overlain by greenish papery shale and in some places the shale is overlain by a thin bed of sandstone (Darton

and Paige, 1925). Comparing it to the subsurface the upper member of the Deadwood Formation at the type section can be correlated to Member C.

The middle member is mostly gray shale, containing considerable reddish-brown to tan sandstone and limestone, limestone conglomerate, and limestone breccia (Darton and Paige, 1925). This shale was correlated to the shale resulting in the high gamma values of Member B in the subsurface.

The lower member of the exposed Deadwood Formation is mostly quartzitic sandstone with abundant conglomerates. It ranges from 5 to 40 feet thick with an average thickness of 25 feet. The conglomerates consist of rounded pebbles, 4 to 6 inches in diameter, of white quartz and varying proportions of angular fragments of schist in a quartzitic, sandy brown matrix. The conglomerate merges upwards and laterally into reddish-brown sandstone and quartzite (Darton and Paige, 1925). This same lithology is found in the subsurface of Member A.

General Subsurface Stratigraphy

Using gamma ray signatures from well logs the Deadwood Formation is separated into six members. The members are separated by significant changes in the gamma ray response. The changes relate to changes in lithology but minor changes in lithology are common throughout. During the deposition of the Deadwood small scale transgressions and regressions were common. Depositional environments correspond to sea level, as the sea transgressed environments shifted towards the center of the craton and as the sea regressed the environments shifted away from the center. Due to this similar lethargies repeat throughout the entire stratigraphic column of the Deadwood Formation

Stratigraphy of the Members of the Deadwood Formation

Member A

Member A was cored in seven wells throughout North Dakota; NDGS #3268 (14') in Billings County; NDGS #6401 (53'), NDGS #6473 (67'), NDGS #6624 (10'), NDGS #6684 (25'), NDGS #14725 (36') and NDGS #17467 (16') in Renville County. It was also cored in three wells throughout Saskatchewan; 58I075 (20'), 78L010 (31') and 97I438 (22'), and 98E189 (19').

Member A is the oldest member in the Deadwood Formation and is the basal sedimentary unit of the Williston Basin. It was previously described in the subsurface as the thin basal sandstone by Carlson (1960) and at the type section in South Dakota it was described at the lower member of the Deadwood Formation by Kulik (1965). It was deposited on top of the exposed Precambrian igneous and metamorphic basement rock, creating a nonconformity. For the most part this contact is easily recognizable by a sharp increase in gamma ray response and a sharp decline in resistivity. There are occurrences where the contact is masked by either in situ weathered Precambrian rock or Precambrian breccia that may have been deposited.

The contact between Member A and the overlying Member B has been challenged in previous studies. Evidence from the surrounding region (Lochman-Balk and Wilson, 1967) and evidence of hematite precipitation (Anderson, 1988), suggests that a very brief interval of subaerial exposure and possible erosion took place prior to the deposition of Member B. This created a disconformity between the two members. Towards the east and north Member B becomes sandier, making the log signature similar to Member A causing the contact between the two members difficult to identify.

Member A was reached in 150 wells and in five cores in North Dakota and four cores in Saskatchewan. Three dominant lithotypes are seen throughout this member: quartz arenite with varying degrees of calcite and glauconite; conglomerate; and granite breccia. This member is traced through well logs by having a clean, low gamma ray response, compared to Member B and the Precambrian.

Quartz arenite. The dominant lithology within core of Member A is quartz arenite. The arenite is commonly a very clean, white to light gray, fine to coarse grained, well sorted, rounded to well rounded, silica cemented sandstone. These characteristics give the member its identifiable low gamma ray response in logs.

Faint cross bedding is visible in some cored intervals but overall quite rare. The opposite is true in outcrops of the Black Hills, where cross beds are apparent in the exposed surfaces (Anderson, 1988). This can be due to a slight difference in mineral composition between the outcrop and subsurface, but more likely is due to differential weathering of the exposed unit, emphasizing the cross beds.

Fossil debris is very uncommon in the cored intervals, this is again different from the exposed outcrop sections. The type section contains abundant thin layers of phosphatic shell fragments (Anderson, 1988). Lochman (1964a) described thin intervals of interbedded shales and dolomites containing fossil fragments of hyoliths and brachiopods.

Towards the top of the member there is a shift from clean, quartz arenite to a calcareous, glauconitic arenite, with up to 40% glauconite grains (Figure 11). This becomes apparent in northern North Dakota and Canada. At the top of the member the

Figure 11. A photograph of core from NDGS #7087 at a depth of 11,669'. Displaying the glauconitic quartz arenite found in the upper section of Member A.

iron in the glauconite grains has been oxidized and produced hematite, resulting in a reddish brown, rust colored appearance (Figure 12).

Conglomerate. In some areas a basal conglomerate occurs and overlies the Precambrian basement (Figure 13). It consists of yellowish tan to brown, moderately poor to poorly sorted conglomerate, which contains subangular to rounded, limonite-stained pebbles and granules of metamorphic and sedimentary rocks. Unidentifiable fossil debris also occurs throughout the conglomerate. Further from the bottom, the conglomerate changes to grayish green in color and contain larger clasts of glauconitic quartz arenite (Figure 14). Very thin glauconitic and hematitic shale is found interbedded with the conglomerate.

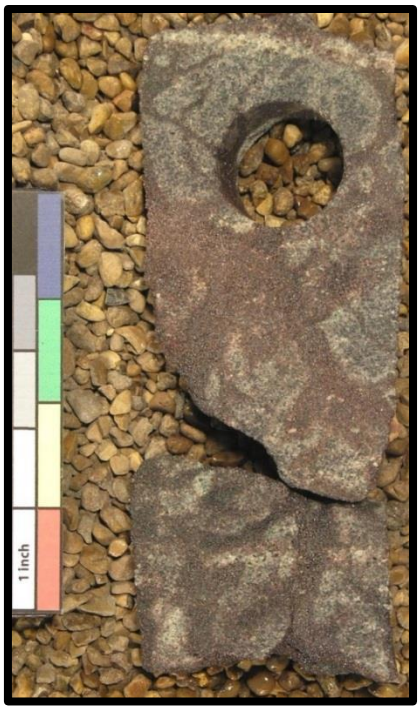

Figure 12. A photograph of core from NDGS #7087 from a depth of 11,663'. Displaying the transformation of glauconite grains to hematite.

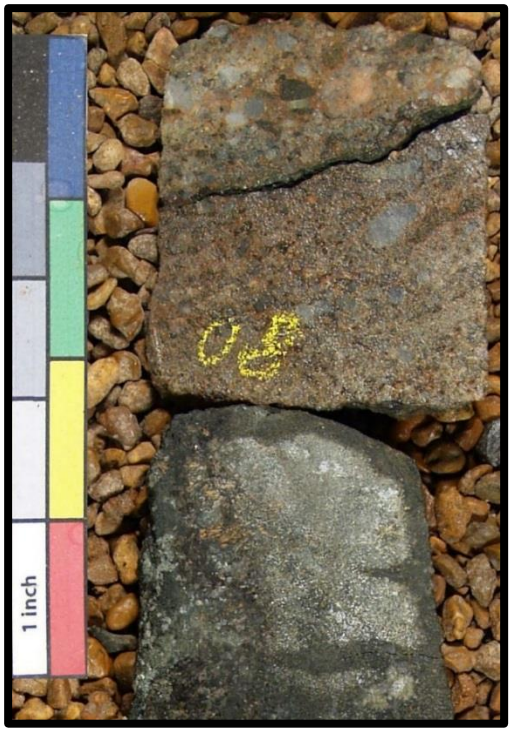

Figure 13. A photograph of core from NDGS #6624 at a depth of 9,308'. Displaying a basal conglomerate directly overlying the Precambrian gneiss.

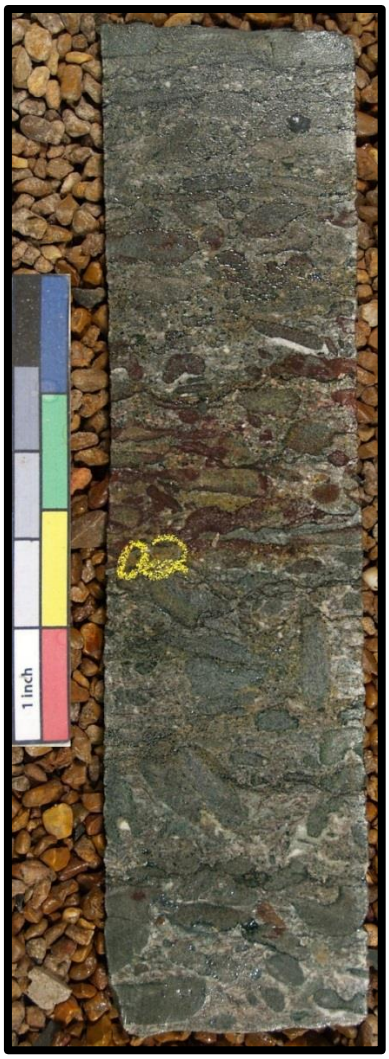

Figure 14. A photograph of core from NDGS #6624 at a depth of 9,302'. Displaying a conglomerate from above the contact with the Precambrian gneiss. It is dominated by glauconitic quartz arenite.

Separating the conglomeratic intervals are fine grained, well sorted glauconitic arenite to horizontally bedded wacke. The conglomerate is also found in outcrop exposures at the type section, where clasts up to boulder size were found (Anderson, 1988).

Granite breccia. Member A is present over all of the areal extent of Deadwood in the study area and is underlain by the Precambrian basement rock. It some cores a weathered breccia of these metamorphic and igneous rocks occurs and in previous works

was labeled as a granite wash. This is different from the previously mentioned conglomerate. This section is described in core as large clasts of slightly weathered gneiss. These clasts have random orientations and are bonded together by a fine grained quartz matrix, with an abundant amount of glauconite.

Member B

Member B was cored in seven wells throughout North Dakota; NDGS #6401 (131'), NDGS #6473 (100'), NDGS #6624 (104'), NDGS #6684 (47'), NDGS #14725 (110'), NDGS #17317 (32') and NDGS #17467 (43') in Renville County. It was also cored in six wells throughout Saskatchewan; 54F047 (2'), 57G023 (41'), 78L010 (38'), 94G082 (80'), 97I438 (80'), and 98E189 (19').

Member B lays unconformably on top of Member A and in some rare instances the Precambrian basement and conformably underlies Member C with a gradational contact. Outside of the erosional limit of Member C, it is overlain by the Ordovician Winnipeg Group. Deposition of this member is still largely influenced by Precambrian topography.

The majority of this member is glauconitic siltstone to very fine-grained sandstones and minor amounts of claystones. The abundant amounts of clay and glauconite in the member yield the characteristically high gamma ray response found on well logs. To the east and north of the center of the basin the member becomes increasingly sandy and near the edge of its extent it becomes difficult to differentiate Member B from Member A in well logs. In areas where this occurs, the unit is labeled as Member AB.

In exposures in the Black Hills, this member is equivalent to what Kulik (1965) described as the middle and upper members, representing most of the Deadwood type section. It is also equivalent to what Carlson (1960) describes as the shale and carbonate unit.

The source of the sediment supply for Member B was erosion of the granites that make up the Superior Craton to the east. The sediment was transported westward into the sea. A lateral transition in grains size occurred as the sediment began to drop out of suspension, resulting in the transformation of the sandstone in the east to the siltstone in the west.

Siltstone. This lithology was found in three cores, NDGS #7087, #6401, and #6624. This lithology is described as a gray to green, glauconitic to quartzose siltstone that grades to a mudstone due to an increase in clay matrix. The grains range from coarse silt to a fine grained sand and are subrounded to rounded. Glauconite grains comprise between 5 to 60% of the siltstone. The glauconite does not appear to be compacted and is occasionally associated with pyrite. In areas that have been oxidized to hematite, this oxidation is what forms the thin reddish brown layers throughout the member. The dominant cement in this facies is calcite but there are minor amounts of silica cement and rare anhydrite cement in Renville County.

Commonly the siltstones have planar laminations and minor cross beds (Figure 15). The laminations are commonly visible due to alternating quartz and glauconite grains. Within these alternations are occasional laminae composed of finely crystalline calcite. Soft-sediment deformation and bioturbation have disrupted the majority of these laminations. There are also very thin (less than 2mm) wispy clayshale laminae and less

common thicker clayshale laminae. Since claystones tend to degrade easily, these thicker claystones are harder to recover in core but can range up to two meters thick. Claystones contain minor amounts of scattered coarse quartz grains, very fine sand-sized glauconite grains, unidentifiable fossil debris, and occasionally bedding planes are outlined in very dark gray to black, argillaceous material.

Figure 15. A photograph of core from NDGS #6624 at a depth of 9,238'. Displaying planar laminated glauconitic siltstone, with minor cross beds.

Sandstone in the western part of North Dakota is less common but still present. The sandstones are very fine to medium grained, subrounded to well-rounded green to gray, glauconitic quartz arenites to wackes. The sandstones are predominantly quartz with minor amounts of feldspars. The glauconite content of the sandstones tends to be less than in the siltstones, but can still reach up to 40%. Similar interbedded glauconitic siltstones and sandstones were described by (McCabe, 1978). There is some evidence of compaction and also evidence of oxidation of glauconite grains, staining the surrounding sandstone reddish brown. There are also minor thin beds of green to gray glauconitic dolostone grading to dolomitic quartz arenite in Renville County. In some areas alteration is severe giving the entire layer a reddish brown color. In thin section phosphatic shell fragments are present. Various structures occur throughout the sandstone, including soft-sediment deformation, distinct water escape structures, abundant wispy clayshale laminae, and bioturbation. The clayshale laminae separate the alternating quartz and glauconite layers.

Cements found with the sandstone vary throughout, containing quartz overgrowths, calcite, and minor amounts of anhydrite. They are most commonly consistent throughout layers but occasionally will be interfingered with each other.

Member B is limited in Saskatchewan and is restricted to only this lithotype. It is fine to medium grained and is minor to heavily bioturbated. Glauconite grains vary and reach 75%.

Sandstone. As the member extends eastward from the center of the basin the dominant lithology changes from siltstone to sandstone. The problem with the eastern part of North Dakota is well control, especially cored wells. The majority of geologic

data comes from core chips, not whole cores. Due to core chips being broken up and not labeled at specific depths, they are not as accurate as cored intervals but still allow for examination of the rock at the general depth in question. The sandstones found in the east are fine to medium grained, well-sorted, rounded to well-rounded, greenish gray to red, glauconitic quartz arenites to moderately sorted wackes. Another disadvantage of core chips is that structures are not easily preserved.

In some sandstone the feldspar content can be up to 30% and glauconite can range from 5 to 60%. The color of the glauconite ranges from green to brown depending on if it has been altered to hematite. There are also minor amounts of phosphatic shell debris.

The eastern part of Member B is unconformably overlain by the Winnipeg Group. The upper part of the member displays evidence of being subaerially exposed prior to the deposition of the Winnipeg Group. The sandstone in this area has a dominant grayish-red color and has common oversized pores and vugs, lined with crystalline dolomite rhombs. These alterations can be the result of expansion of the grain boundary due to cement crystallization and dissolution of glauconite, feldspar, and calcite. In this area hematite is not only seen as a replacement of glauconite but does mark multiple growth stages of rhombic dolomite cement.

This facies is correlated to the burrowed to laminated, calcite-cemented, glauconitic siltstone and sandstone, limestone, and interbedded limestone-pebble conglomerate and green shale that occurs at outcrops. High glauconite content is present in all lithotypes. As with the siltstone, the clayshale laminae separate the alternating quartz and glauconite layers. Glauconite grains have the same alterations as in the siltstone facies.

An equivalent lithostratigraphic interval is described in Montana as a glauconitic green shale and limestone, siltstone, and fine grained sandstone by Lochman (1964a).

Member C

Member C was encountered in 185 wells throughout the study area, including 5 cored interval; NDGS #291 (85') in Billings County; NDGS #6264 (53') in Burleigh County; NDGS #6624 (56') and #6684 (32') in Renville County; and NDGS #7146 (10') in Emmons County.

Throughout much of areal extent of Member C the contact between the underlying Member B and overlying Member D is conformable and gradational. Farther to the east and south a possible unconformity develops between the two members. In the west this unconformity is lower in the member between the mixed sandstone-limestone lithotype and the quartz arenite. Beyond the erosional boundary of member D it is unconformably overlain by the Winnipeg Group.

Lithologies throughout the basin vary to minor degrees. Near the center of the basin in western North Dakota Member C consists of three main lithotypes. A basal quartz arenite; a mixed quartz sandstone-limestone; and an upper limestone. The upper limestone lithotype is comprised of three secondary lithotypes, containing differing amounts of mudstones, wackestones, packstones, and grainstones. Along the border of North Dakota and Montana, and into Montana, the entire section is composed of nearly all limestone. In southern and central North Dakota Member C consists of a basal quartz arenite that is overlain by a quartz wacke and a silty, laminated dolomudstone. Wells from South Dakota only contain the basal quartz arenite.

Log characteristics of sandstone and limestone and the lack of abundant amounts of glauconite and clay give this member its distinctive low gamma-ray signature, especially when compared to the much higher readings of members B and D. This member also has low resistivity reading which is due to an increase in porosity as the arenite lithotype increases in thickness. A moderate increase in gamma-ray response occurs in the member from west to east due to a change from limestone in the west to dolomudstone in the east and south. In areas to the southeast the log signature can closely resemble the signature of the overlying Member D.

The first evidence of a depositional trend not directly controlled by the transgression onto the Precambrian topography occurs within this member. Depositional thinning towards the craton is no longer the only process controlling the thickness of Member C. Subsidence in western North Dakota is increasing accommodation space allowing for an increase in deposition near the center of the basin. Preserved thicknesses of Member C are controlled by Middle Ordovician erosion.

Quartz arenite. In the Black Hills of South Dakota the basal quartz lithotype is almost entirely composed of quartz arenite and conglomerate, with minor amounts of shale (Carlson and Thompson, 1987). In eastern Montana and western North Dakota Lochman, (1966) correlated the interval equivalent to Member C to the shelly faunal zones A through D from the previous work of (Ross, 1951), which were determined to be from the Lower Ordovician Tremadocian Series. It is described as Skolithos-bored, white, very fine to medium grained, well sorted, round to well-rounded quartz arenite (Anderson, 1988). There are minor amounts of glauconite and feldspar grains

throughout. This lithology is typically described as massive with vertical burrows with occasional faint cross beds present (Kulik, 1965).

The basal quartz arenite has been cored in multiple wells and is preserved in well cuttings and core chips. It consists of a very fine to coarse grained quartz arenite, with occasional interbeds of quartz wacke. Quartz and minor amounts of feldspar grains are very fine to coarse grained, rounded to well rounded, and show good sorting. Unlike at the type section Skolithos burrows are less prevalent and sedimentary structures that include planar laminations and cross beds are present. Massive, structureless sandstone and highly bioturbated sandstones, which approach quartz wacke in composition, are common. Well cuttings are not a very accurate way of determining lithologies and are not used to make any concluding statements, but they contain unconsolidated, well rounded, well sorted, fine to coarse-grained sand. This is the same characteristics present in the arenite lithology.

The arenites range from porous and friable to well cemented. The cements that were found consist of calcite, dolomite, quartz, and minor amounts of anhydrite. These cements appear to have replaced anhydrite cement, which typically only occurs as a remnant (Anderson, 1988). Quartz overgrowths do not display a trend and are found throughout to a varying degree. Medium to coarsely crystalline dolomite and calcite cements generally increase upward in section. These cements have resulted in the corrosion of quartz and feldspar grains. Glauconite also occurs through this lithology at about 15% and has been partially compacted and oxidized.

In Saskatchewan Member C was recovered in one core, SK #57G023 just across the Canadian border. This shows the erosional limit of Member C. Late Ordovician

erosion has left only the lower quartz arenite unit of the member. It is very similar to the arenite found in wells in the United States, with heavily bioturbated zones corresponding to the Skolithos burrow occurring in equivalent units. The majority of what is present in Saskatchewan is very light to light tan sandstone and siltstone, with minor amounts of shale.

Quartz wacke. Quartz wackes are interbedded with and overlie the quartz arenite. The increase in clay content in the wacke leads to a gradual increase in the gamma-ray response. This lithology consists of a very fine to coarse-grained, poorly to moderately sorted, subrounded to well rounded, gray to yellow quartz wacke with abundant clayshale laminae and a few interbedded quartz arenites. Bioturbation is prevalent and most of the original bedding has been disrupted by burrows and soft sediment deformation. Skolithos burrows only occur within the interbedded arenites.

Fossil debris is abundant within the wacke, including echinoderm, trilobite, and brachiopod fragments. With this increase in fossil debris there is also an increase in carbonate cement. This increase is generally associated with a decrease in clay amount and a gradation to an arenite. As the carbonate content increases the wacke and arenite may grade into a sandy grainstone with areas of coarse quartz grains supported by a crystalline dolomite or calcite cement.

Mixed Sandstone-Limestone Lithotype. In Billings County a sandstone-limestone transitional lithotype has been described in core. It consists of bioturbated, quartz sand bearing limestone that grade to a less common fossiliferous quartz arenite. The limestone ranges from packstone to grainstone. This lithology contains varying

amounts of quartz sand, carbonate fossil allochems, and occasionally some glauconite. These clasts are cemented by very finely to medium crystalline calcite.

Fossil debris is most commonly Nuia, which is restricted to the Lower and Middle Ordovician (Wray, 1977; Ruppel and Walker, 1982), and lesser amounts of trilobites, echinoderms, and phosphatic shell debris. The fossil Nuia, is described as straight to curved calcareous tubes with a radial, hyaline wall-structure and a dark central core, assigned to the codiacean algae (Wray, 1977).

There is a subordinate lithotype interbedded within that consists of an intraclastic, fossiliferous, quartz wackestone to packstone. The texture is very similar to the mixed sandstone-limestone lithotype but contains more carbonate mud, less quartz and silt, and fewer fossil fragments. Intraclasts of mudstone and wackestone, up to pebble size, occur throughout. These intraclasts also contain glauconite grains, minor amounts of peloids, and trilobite, brachiopod, and echinoderm fossil debris. They are all cemented by finely to very coarsely crystalline calcite, which appears in some places to be replaced by micrite. The quartz content decreases gradually towards the top in these lithotypes, gradually transitioning into the overlying limestone lithotype.

Packstone to grainstone. The most dominant limestone secondary lithotype consists of a light to medium gray, packstone to grainstone, containing abundant trilobite, brachiopod, and echinoderm fossil debris (Figure 16). This lithotype also contains varying amounts of micritic intraclasts, quartz silt and sand grains, and minor amounts of glauconite. The micritic intraclasts range up to pebble size and are often rimmed with glauconite and pyrite.

Figure 16. A photograph of core from NDGS #291 at a depth of 13,322'. Characteristic light gray, packstone to grainstone limestone occurring in Member C.

The limestone also commonly contain medium sized crystalline dolomite rhombs. There are small, elongate, finely crystalline calcite fragments that have been interpreted as possible algal material (Anderson, 1988). These allochems are cemented by medium to coarsely crystalline calcite. The relationship with the cement and preexisting calcite makes the echinoderm fragments difficult to distinguish; the only remaining characteristic is their radially bored rims. In the packstones micrite acts as the matrix between allochems, most commonly gastropods. This lithotype is susceptible to pressure solution and has both horizontal and vertical low amplitude stylolites. Along the stylolite seams are concentrations of dolomite, terrigenous clay, and quartz silt; giving the stylolites a dark color.

Burrow-mottled limestone. The burrow-mottled limestone is the second most common lithotype in the limestone unit. This lithotype has a very variable texture and composition, commonly comprising of wispy siliciclastic mudstone laminations (Figure 17). The unit is very thinly bedded, with alternating layers, only centimeters thick, of dark gray, siliciclastic mudstone to clayshale and a lighter gray, intraclastic wackestone to packstone. As with the other lithotypes, trilobite, brachiopod, and echinoderm debris is common, although echinoderms are less abundant and trilobites are the dominant fossil type. Small micrite intraclasts and peloids allochems also occur. These allochems are supported in carbonate mud and crystalline calcite cement. The siliciclastic mudstone and clayshale layers contain varying amounts of clay, silt-sized quartz grains and micritic peloids.

Mudstone to wackestone. This third lithotype in the upper limestone unit is the light bluish-gray mudstone to wackestone. This lithotype generally occurs as thin nodular beds. It is seen at the bottom of Figure 17. It is also occurs in very minor amounts in the underlying sandstone to limestone transition zone and is most likely the source of the intraclasts found within. The majority of this lithotype consists of carbonate mud and micrite but in some areas contains up to 10% allochems and grades into wackestone. The allochems found within this lithotype include fragments of trilobites and echinoderms with occasional radially-bored rims, possible algal material, rare phosphatic debris, and trace amounts of quartz silt. This lithotype is susceptible to pressure solution, the compaction of the grains has resulted has formed created abundant nodules, as well as highly dolomitic stylolites. In some areas the mudstone to

Figure 17. A photograph of core from NDGS #291 at a depth of 13,286'. An example of the burrow-mottled limestone found in Member C, contain siliciclastic mudstone laminae and intraclastic wackestone and packstone.

wackestone lithotype occurs in a sharp lateral contact with the grainstone to packstone lithotype. The contact typically has a dark green glauconitic coating; similar coatings on micrite intraclasts were reported by Sepkoski (1982) in the Cambrian of Montana.

Member D

Member D was cored in two wells in North Dakota; NDGS #291 (108') and #3268 (71') in Billings County.

Member D exhibits a gradual transition from a basal siliciclastic mudstone to a fine-grained siltstone and sandstone near the top of the member. This transition demonstrates an increase in grain size and a decrease in bioturbation. The fine-grained siltstones and mudstones contain abundant amounts of clay, which result in a characteristically high gamma-ray response. The response is not as high as Member B,

even though they have similar clay contents. Gamma ray response is slightly lower in Member D due to glauconite being less common along with occasional layers of interbedded sandstone. This unit is correlated to faunal zone E, of the Tremadocian series, in eastern Montana (Lochman, 1966).

In western North Dakota Member D conformably overlies Member C, when Member C consists of limestone. As the formation moves eastward and southward Member C becomes more dolomitic and sandier, possibly suggesting a minor unconformity between the two members. While within the erosional limit of Member E the contact above is conformable and gradational; outside of this area the contact with the overlying Winnipeg Group is a significant disconformity.

Similarly to Member C, the isopach pattern of Member D conforms to the shape of the basin, deepest near the center of the basin and thinning outward in every direction. Deposition is no longer influenced significantly by the Precambrian topography. Due to Middle Ordovician erosion this member is restricted towards the center of the basin and only found in the subsurface.

The base of Member D contains both calcareous and siliciclastic mudstone and wackestone. The lower most part of the member is burrow-mottled silty calcareous mudstone and wackestone (Figure 18) and grades slightly up to siliciclastic mudstone (Figure 19). The unit contains abundant clay and silt and is extensively burrowed. The abundance of burrows has destroyed nearly all of the sedimentary features. As the grain size of Member D increases the calcareous and siliciclastic mudstones transition into calcareous siltstones and very fine-grained sandstones (Figure 20).

Figure 18. A photograph of core from NDGS #291 at a depth of 13,233’. An example of the burrow-mottled, silty, calcareous mudstone at the base of Member D. The ruler is in inches.

Figure 19. A photograph of core from NDGS #291 at a depth of 13,193'. An example of the gradation upwards to a fine-grained, siliciclastic burrow-mottled mudstone. The ruler is in inches.

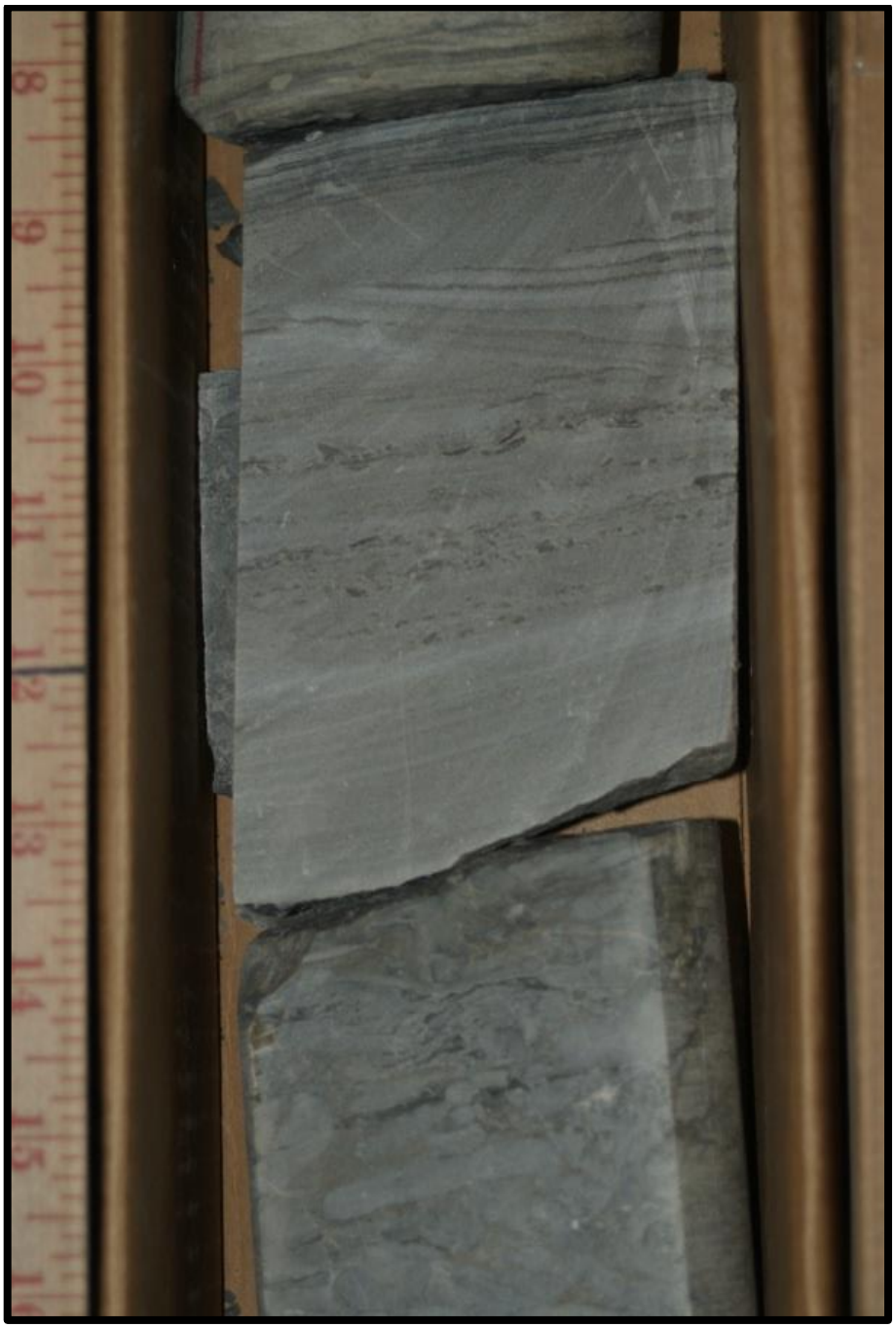

Figure 20. A photograph of core from NDGS #291 at a depth of 13,171'. An example of the siltstone and sandstone overlying the mudstone. The ruler is in inches.

Above the mudstone is a calcareous siltstone to very fine-grained sandstone. As with the underlying lithotype most of the sedimentary structures have been destroyed due to intense bioturbation and soft sediment deformation. A minor amount of fossil debris is present with calcite cement.

The top of the member consists of interbedded siltstone and very fine to medium-grained sandstone (Figure 21). The sandstone is dominantly clean arenite with minor amounts of bioturbated quartz wackes. Bioturbation is not as prevalent as it is in the underlying lithotypes and is dominated by horizontal bedding planes, with minor amounts of cross beds. Where bioturbation occurs it is a mixture of burrowing, soft sediment deformation, and water escape structures. In areas the deformation is so intense that some of the laminated beds are separated and look very similar to a conglomerate, where the clasts are laminated siltstones and sandstones in a sand and silt matrix with calcite cement (Lowe, 1975).

Throughout the member thin packstone to grainstone layers occurs. The allochems within the packstones and grainstones are glauconite grains and fossil debris which are cemented with crystalline calcite. Fossil debris is commonly trilobites, echinoderms, and brachiopods. The glauconite occurs either unaltered or with minor degradation.

Member E

Member E was cored in eight wells throughout North Dakota; NDGS #291 (130'), #3268 (146'), and #6228 (11') in Billings County; NDGS #9257 (37') in Stark County; NDGS #1385 (11'), #1403 (133'), #12831 (60'), and #1636 (33') in Williams County.

Figure 21. A photograph of core from NDGS #291 at a depth of 13,124'. Example of the interbedded siltstone and sandstone occurring at the top of Member D. The contact with the overlying Member E is also visible, at the 30 inch mark on the ruler. The ruler is in inches.

The log characteristics of Member E are very similar to Member C, very low and clean gamma ray response. Not surprisingly the lithologies are quite similar in the two members. Member E consists of quartz arenite, mixed sandstone and limestone, limestone, and siliciclastic mudstone lithotypes and in some areas dolomudstones.

Member E conformably overlies Member D over its entire extent and is conformably overlain by Member F, within Member F's erosional limit. Outside of the erosional limits of Member F, Member E is disconformably overlain by the Middle Ordovician, Black Island Formation. The maximum thickness in well logs is 255 feet in southern Dunn County, North Dakota.

The base of the member consists of quartz arenite and minor amounts of quartz wacke (Figure 22). In core samples it is similar to the quartz arenite found in Member C. The sandstone ranges from very fine to coarse grained and well sorted and rounded. The contact with the underlying Member D is gradational and the coarsening upward trend continues through the arenite.

Both massive, structureless sandstones and horizontally or cross bedded laminations are common. Minor amounts of quartz wackes are present, most likely the result of thin silt and clay laminations being mixed with the arenites, either due to soft sediment deformation or bioturbation. There are also clear bioturbated zones where sedimentary structures have been destroyed. In these zones cements are commonly calcite or dolomite.

Above the arenite is a transition zone containing a mixture of sandstone and limestone. This lithotype is present in NDGS #291. As with the arenite, a similar

Figure 22. A photograph of core from NDGS #3268 at a depth of 12,797'. Cross-bedded quartz arenite which occurs at the base of Member E.

lithotype occur in Member C. Fossil debris is the dominant grain in the lithotype, making up roughly of 50% to 80% of the grains, with the remaining amounts being quartz.

Following the transition zone is the limestone lithotype, again very similar to Member C (Figure 23). The limestone ranges from wackestone to grainstone, with allochems containing fossil debris of echinoderms, brachiopods, and trilobites.

Intraclastic packstones and grainstones are also found throughout the lithotype. These intraclasts are composed of micrite and most likely derived from the mudstone lithotype.

In some areas, towards the east and south, a dolomudstone occurs above the limestone lithotype. In other areas the limestone is overlain by a burrowed siltstone to sandstone. The dolomudstone is also present at the top of Member C. It consists of alternating laminations of dolomite and quartz silt.

Member F

Due to pre-Winnipeg erosion, Member F is restricted to west central North Dakota and has the smallest areal extent of all of the members of the Deadwood Formation; it occurs around the center of the basin. It is thickest in Williams County, ranging up to 51 meters (168 feet) and occurs in a couple of counties to the south. Since Member F is the youngest member in the Deadwood it is unconformably overlain by the Black Island Formation of the Winnipeg Group and conformably overlies Member E over its entire extent.

The dominant lithology is a quartz arenite to wacke, with very minor amounts of siltstones, shales, and carbonates. The large majority of the member is composed of clean quartz sandstone, so the gamma-ray signature is very low. It is the lowest in the Deadwood Formation. Member F was cored in thirteen wells throughout North Dakota; NDGS #6228 (15') in Billings County; NDGS #6148 in Dunn County; NDGS #2373 (116'), #8090 (20'), and #13405 (116'), in McKenzie County; NDGS #8088 (50'), #8169 (7'), and #9257 (20') in Stark County; NDGS #1385 (81'), #1403 (41'), #1514 (45'), #1636 (46'), and #18631 (23') in Williams County. The age of this member was

Figure 23. A photograph of core from NDGS #3268 at a depth of 12,643'. An example of the fossiliferous limestone lithotype which occurs at the top of Member E.

determined by Lochman (1964b) who correlated Member F to the shelly faunal zone G2, which was dated to be Arenigian (478.6± 1.7 Ma to 471.8 ± 1.6 Ma).

One of the wells with the thickest Member F is NDGS #13405, located in McKenzie County. A little more than 111 feet of Member F was cored in this well. In this particular well Member F was 144 feet thick. The majority of the member was cored, except the top 5 feet and the bottom 28 feet. The issue with this core is that the contacts with the overlying or underlying units were not preserved, which would have allowed for a better understanding of how the Member E transitioned to Member F and any evidence of erosion or nondeposition prior to the deposition of the Black Island Formation.

In NDGS #13405, Member F is a light to medium gray quartz arenite to wacke, with occasional mild to severe hydrogen sulfide staining. Zones of hydrogen sulfide staining are common in areas of very little bioturbation (Figure 24). It is most commonly medium grained with occasional zones of fine to very fine grain, which are subrounded to rounded. The grains are commonly well sorted with minor areas of moderate to poor sorting. Member F has zones of no bioturbation with very faint to distinct, near horizontal to horizontal beds, wavy beds, and cross beds and grades to very intense bioturbation. The majority of this bioturbation is vertical burrows of Skolithos and wavy horizontal burrows (Figure 25), although there are minor amounts of escape structures and soft sediment deformation. These burrows are most commonly outlined in very fine dark argillaceous material. The cement is most commonly silica but there are areas of carbonate cement and large fractures filled with crystalline calcite.

Figure 24. A photograph of core from NDGS #13405 at a depth of 14,329. Displaying hydrogen sulfide staining.

Figure 25. A photograph of core from NDGS #13405 at a depth of 14,330'. Displaying intense horizontal and vertical burrows.

Interlayered with the sandstone are zones of thinly bedded, very fine grained, dark gray to black carbonaceous shale (Figure 26). Between the layers of shale are thin, highly fossiliferous zones that pinch out on both sides. The fossiliferous zones contain fragments of echinoderms, trilobites, and brachiopods. The contact between the medium grained sandstone and the very fine grained shale is very sharp and displays soft sediment deformation, most likely load casts. In some areas of minimal bioturbation there are what appear to be clasts of horizontally bedded sandstone and siltstone. These are not clasts but appear to be originally bedded areas that are displaced by water escape structures. The abundance of escape structures and soft sediment deformation causes the brecciated look.

In well NDGS #18631, which is located 20 miles northwest of NDGS well 13405 in Williams County, lithologies are very similar. The contact with the overlying Black Island Formation of the Winnipeg Group is clearly visible in core. Member F only has 24 feet of core in this well. Member F as a whole is much thinner in this well, as it is farther from the center of the basin.

Only the quartz arenite to quartz wacke lithotype was present in this core. The very fine grained dark shales were not present in this core. Near the bottom of the core the lithology slightly grades to wacke.

Figure 26. A photograph of core from NDGS #13405 at a depth of 14,301'. Displaying interlayered carbonaceous shale with fossiliferous zones.

CHAPTER III

RESULTS

Isopach Maps

Unit thickness was determined for all of the members of Deadwood Formation where it was possible. The limitation for unit thickness determination is that the top of the underlying member needs to be present. Unit thicknesses were calculated for at least one member of Deadwood Formation in 333 wells, roughly half of the wells where the Deadwood is present. With 53 for Member F (Figure 33), 83 for Member E (Figure 32), 82 for Member D (Figure 31), 119 for Member C (Figure 30), 173 for Member B (Figure 29), 151 for Member A (Figure 28), and 210 for the combination of members B and A (Figure 27). Of these 333 wells only 7 included thicknesses for all 6 members.

Without prior knowledge of the units in focus it can be seen from isopach maps that a severe change occurred during the deposition of Member C of the Deadwood Formation. Prior to the deposition of Member A the igneous and metamorphic rocks of the Precambrian were exposed to erosion for hundreds of millions of years. This left the landscape irregular and as the sea began to transgress onto the craton, the rise in sea-level increased accommodation space allowing for the sediments of Member A to deposit onto the exposed craton and in some areas in the topographical lows of the irregular surfaces. This is evident on the isopach map of Member A (Figure 28); the only depositional trend that can be seen is a weak east to west thickening trend. This trend continues on the

isopach map of Member B (Figure 29) where the sea has transgressed completely onto the craton. Most of the topographic highs and lows have been covered making the map smoother. The east to west depositional trend is also more evident. The large shift in depositional trend is seen in the isopach map for Member C (Figure 30). There is significant thickening to a depocenter in western North Dakota and eastern Montana. The thickening trend is bowl-shaped, characteristic of point load subsidence. Point load subsidence is the isostatic response to sediment accumulation in an area. Over periods of tens to hundreds of thousands of years the upper part of the mantle begins to act elastically in response to continuous accumulation of sediment. This results in the crust slow sinking into the upper part of the mantle, producing a basin. This is seen on the isopach maps of members D (Figure 31), Member E (Figure 32), and Member F (Figure 33). The depositional center of the basin shifts slightly with each member but all three are near the present day center of the basin.

Basin Subsidence

The results from Novva® can be analyzed in three ways; tectonic subsidence, subsidence caused by loading, and total subsidence. This study will focus on tectonic subsidence, defined as the sinking of the Earth's crust caused by the tectonic forces driving basin formation, which eliminates the effects of nontectonic processes. The major nontectonic process that needs to be eliminated is sediment loading and this is done by backstripping (Lindsay et al., 1987). The most common mechanisms behind tectonic subsidence are crustal stretching, thermal contraction of the lithosphere, thermal contraction of an intrusive body in the lithosphere, or a phase change and metamorphic reaction in part of the lithosphere (Sleep et al., 1980). The effects of loading are

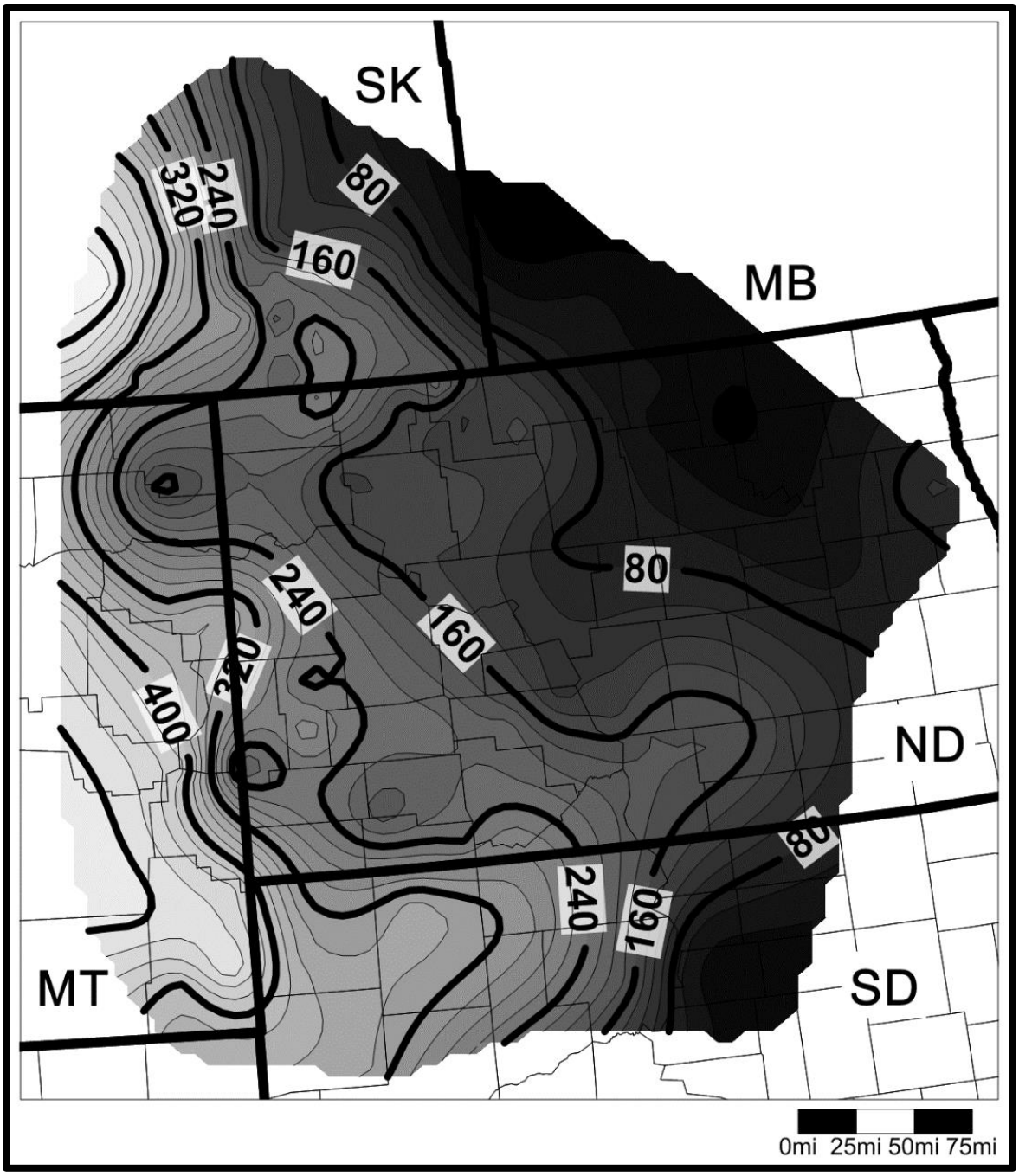

Figure 27. Isopach map for Member AB of the Deadwood Formation, displaying change in unit thickness. The contour interval is 20 feet. The shades of gray get lighter as the member becomes thicker.

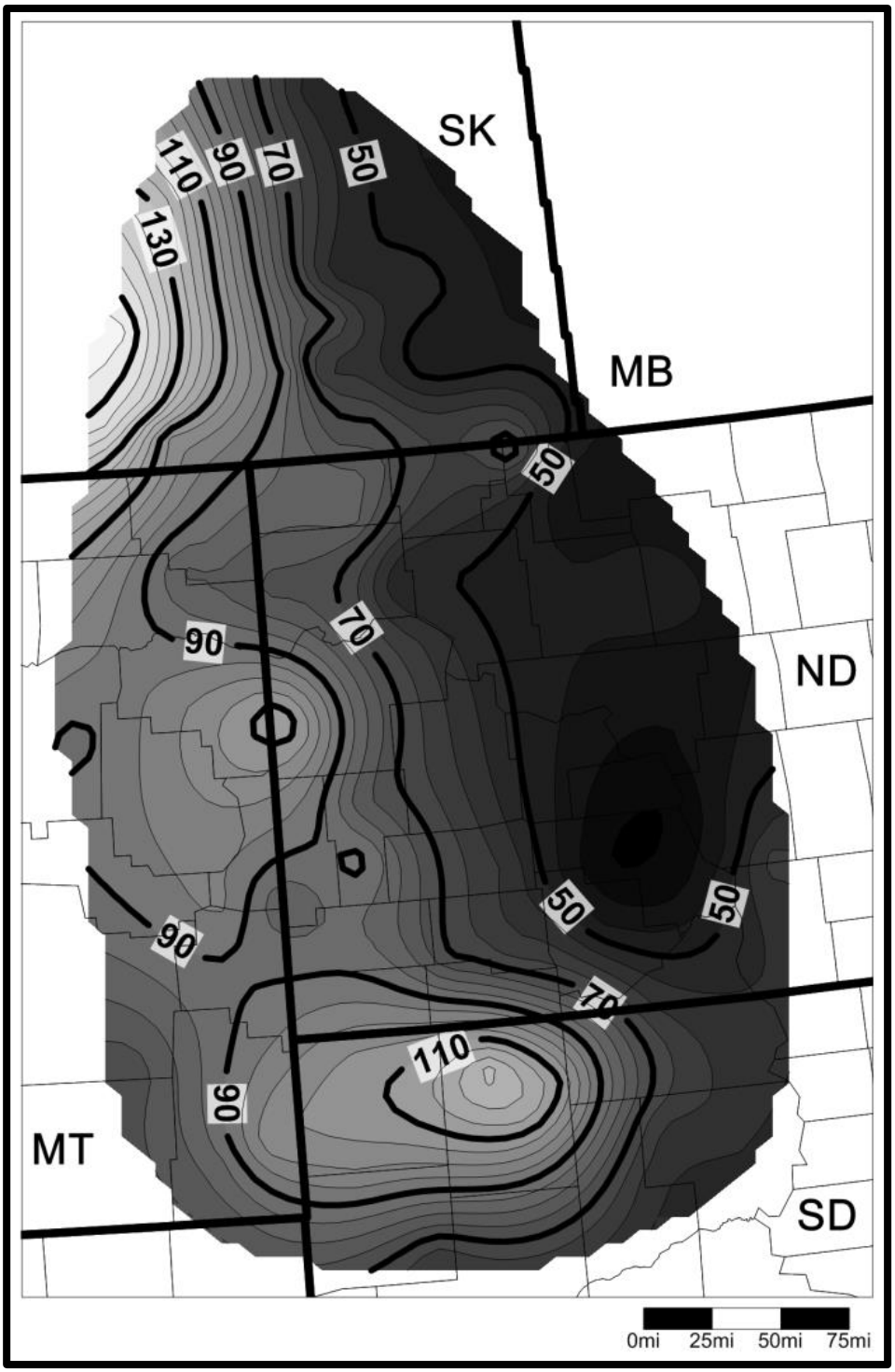

Figure 28. Isopach map for Member A of the Deadwood Formation, displaying change in unit thickness. The contour interval is 5 feet. The shades of gray get lighter as the member becomes thicker.

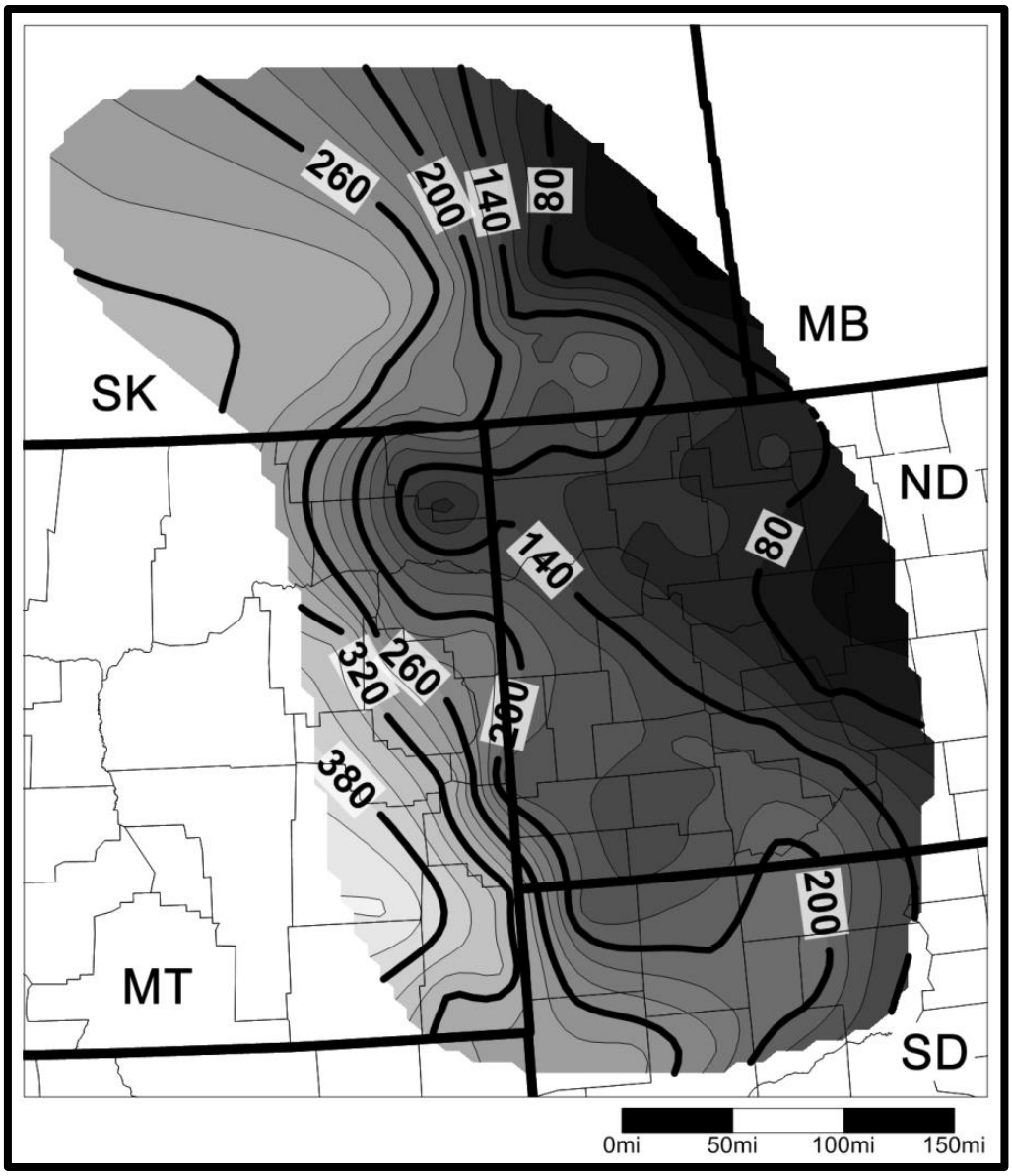

Figure 29. Isopach map for Member B of the Deadwood Formation, displaying change in unit thickness. The contour interval is 20 feet. The shades of gray get lighter as the member becomes thicker.

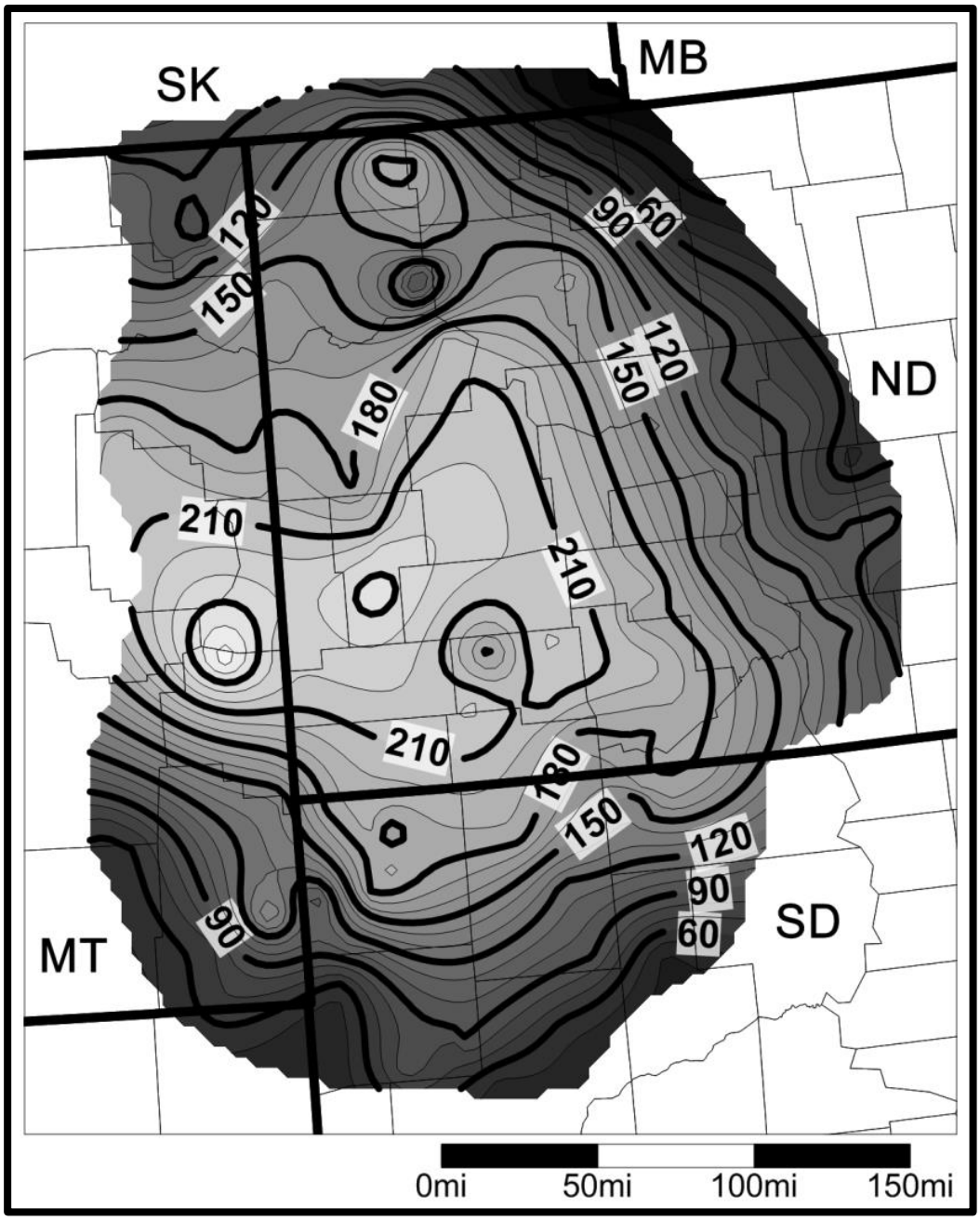

Figure 30. Isopach map for Member C of the Deadwood Formation, displaying change in unit thickness. The contour interval is 10 feet. The shades of gray get lighter as the member becomes thicker.

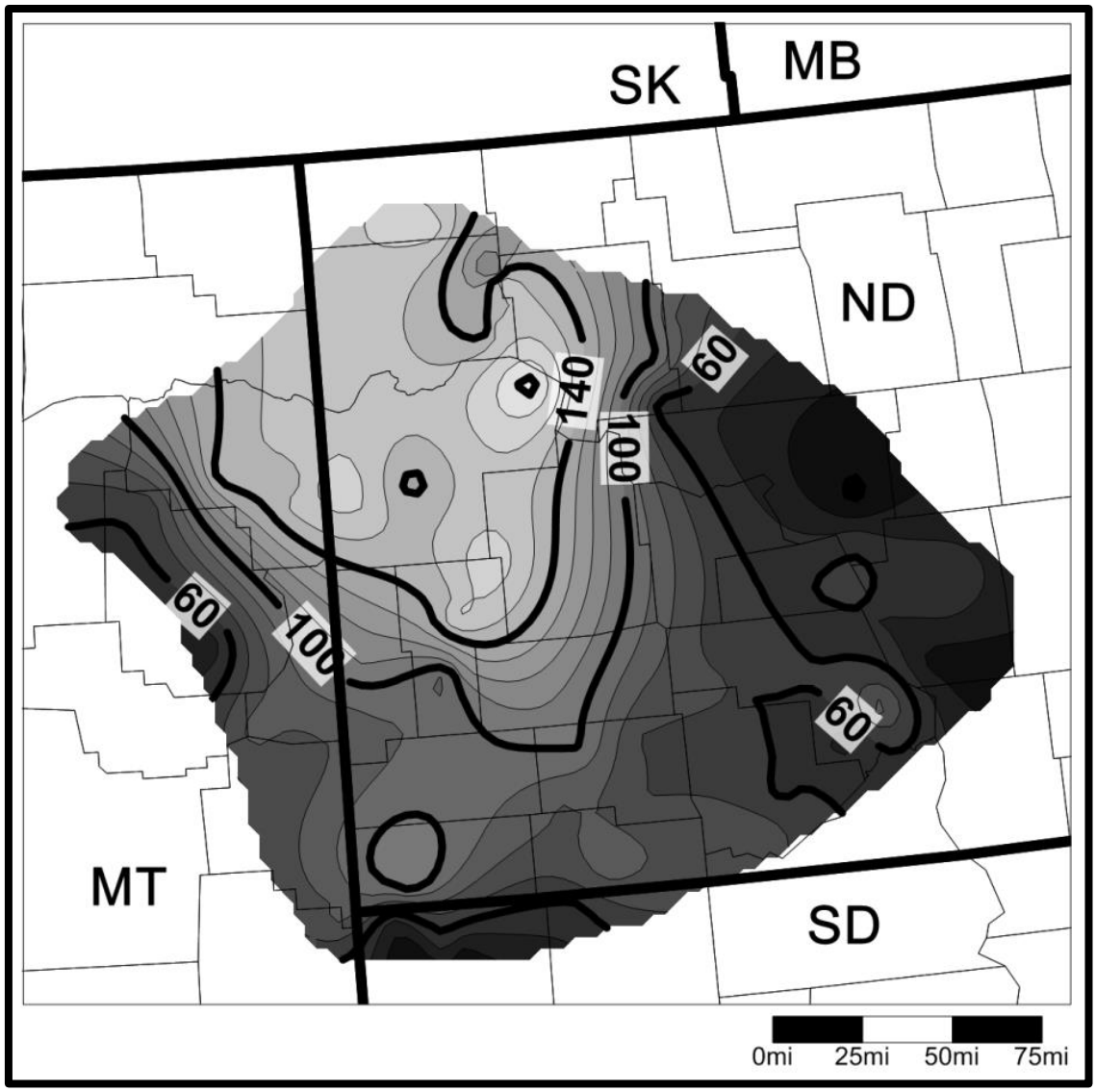

Figure 31. Isopach map for Member D of the Deadwood Formation, displaying change in unit thickness. The contour interval is 10 feet. The shades of gray get lighter as the member becomes thicker.

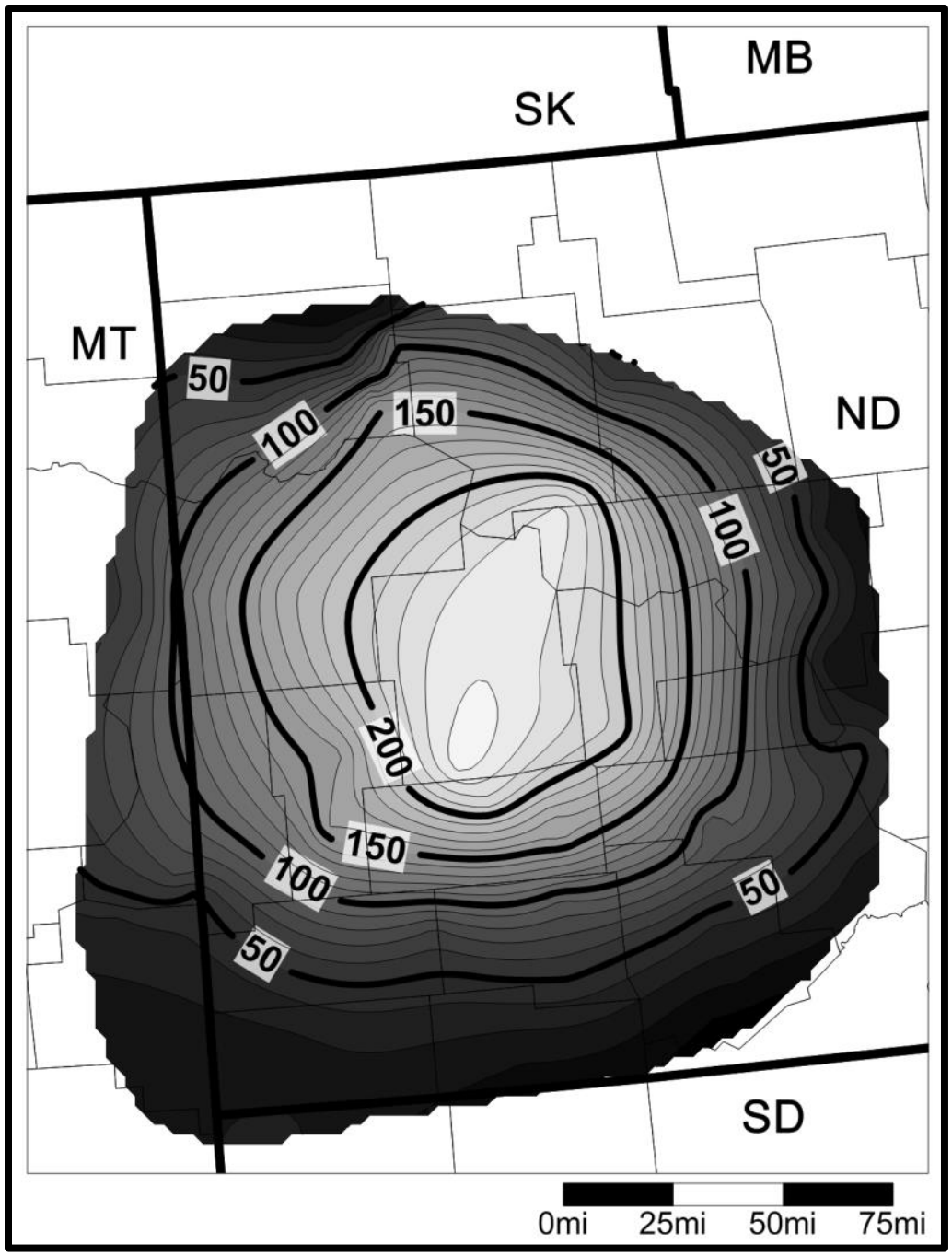

Figure 32. Isopach map for Member E of the Deadwood Formation, displaying change in unit thickness. The contour interval is 10 feet. The shades of gray get lighter as the member becomes thicker.

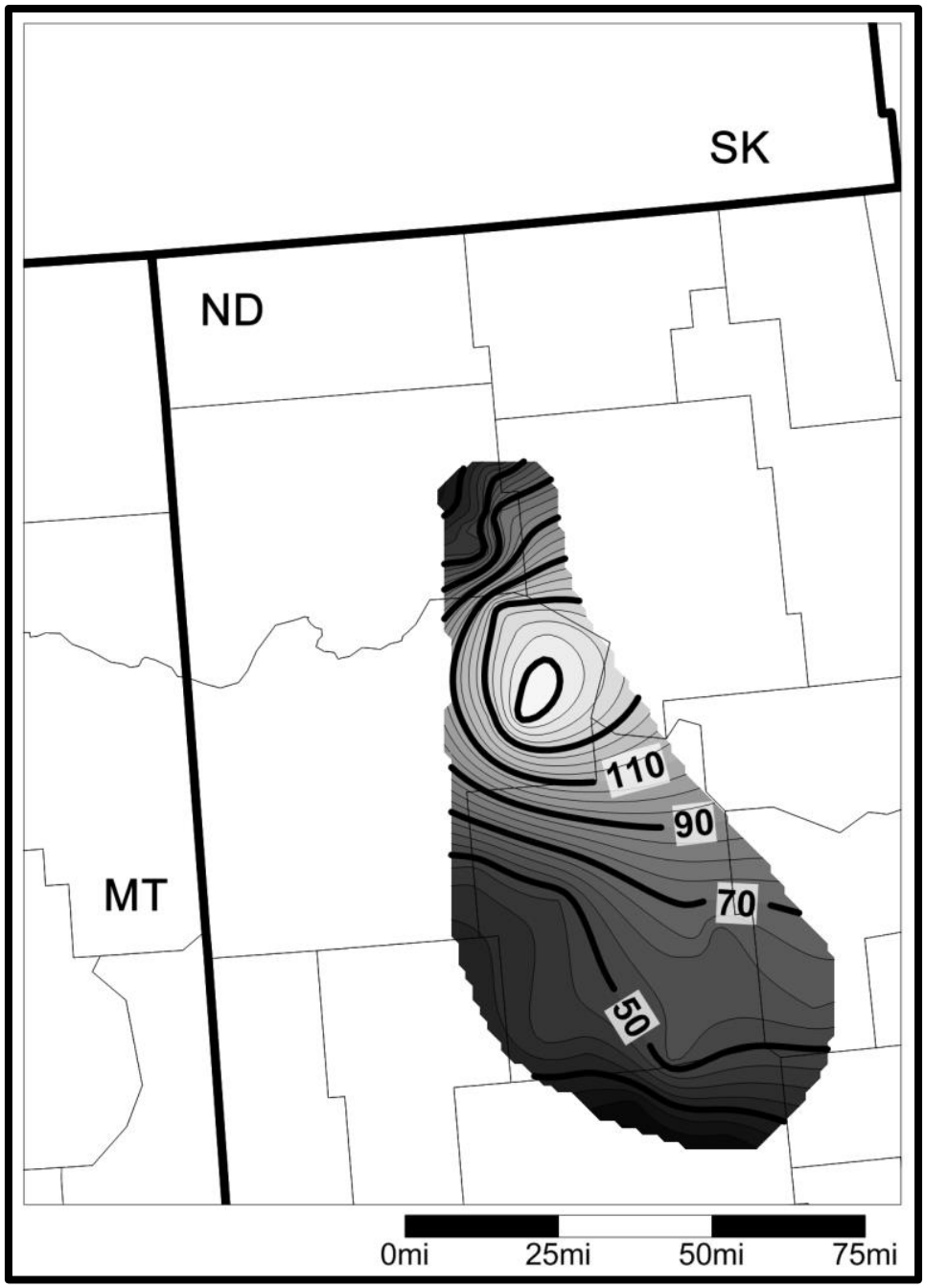

Figure 33. Isopach map for Member F of the Deadwood Formation, displaying change in unit thickness. The contour interval is 5 feet. The shades of gray get lighter as the member becomes thicker.

separated from this because their effects are not significant until after the onset of subsidence.

For each well a burial history diagram is produced (Figure 34). This diagram incorporates all of the information imported into Novva® and displays how each unit in the stratigraphic section responded to erosion and sedimentation throughout the development of the Williston Basin. The response is displayed in relation to the paleo-water surface or the paleo-ground surface. Again this study only focused on the Early Paleozoic history of the Williston Basin and the incorporation of more recent unconformities would need to be added to obtain a burial history diagram for the entire history of the basin.

The data used to determine the early subsidence history of the Williston Basin was collected from the tectonic subsidence (Figure 35 through Figure 41). Tectonic subsidence diagrams display the changes in tectonic subsidence throughout time and the data can then be imported into Microsoft Excel, as tectonic subsidence in feet at specific dates in time (Chart 1). The important data points are the tectonic subsidence values at the top and bottom of each geologic unit. With these time constraints the total tectonic subsidence for the unit can be calculated and with the addition of an age range for each unit the average tectonic subsidence per million years can be computed (Chart 2).

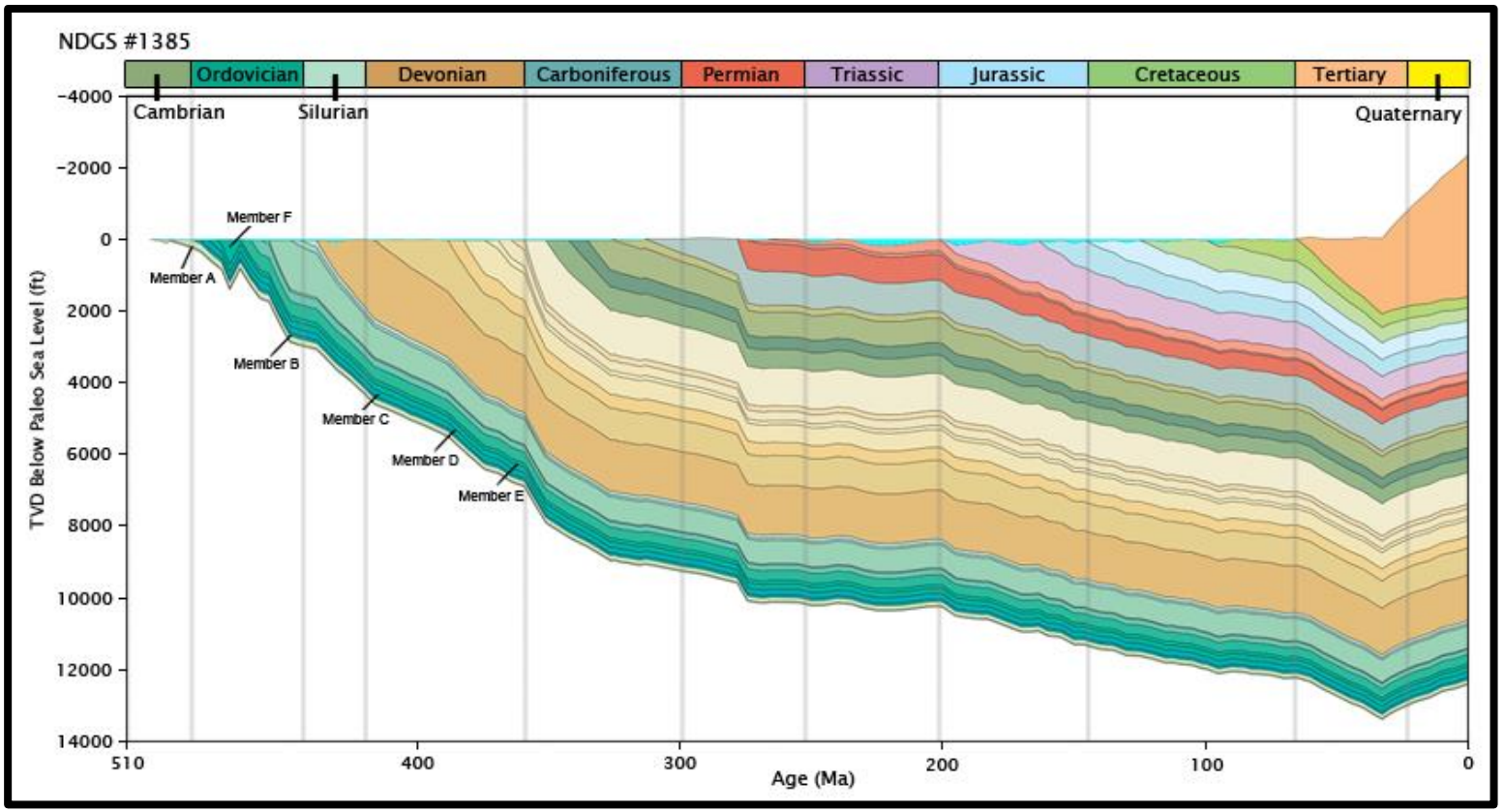

Figure 34. Burial history plot from NDGS# 1385. The x-axis is time in millions of years and the y-axis is depth below the paleo sea level in feet. The large dip near Member F represents the deposition of Member F and then the exposure and subaerial erosion at the end of the Sauk sequence.

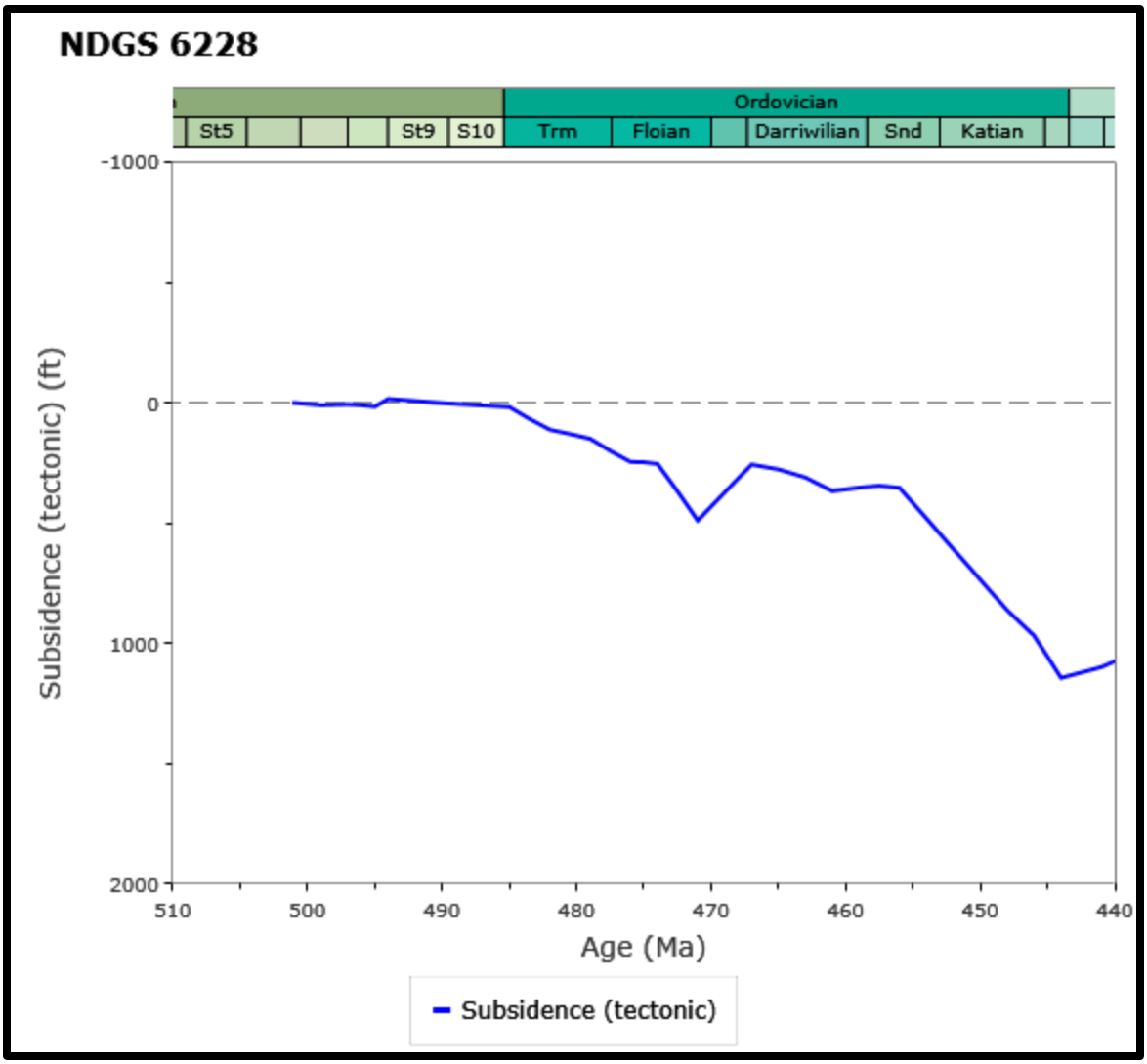

Figure 35. Tectonic subsidence curves for NDGS #6228. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

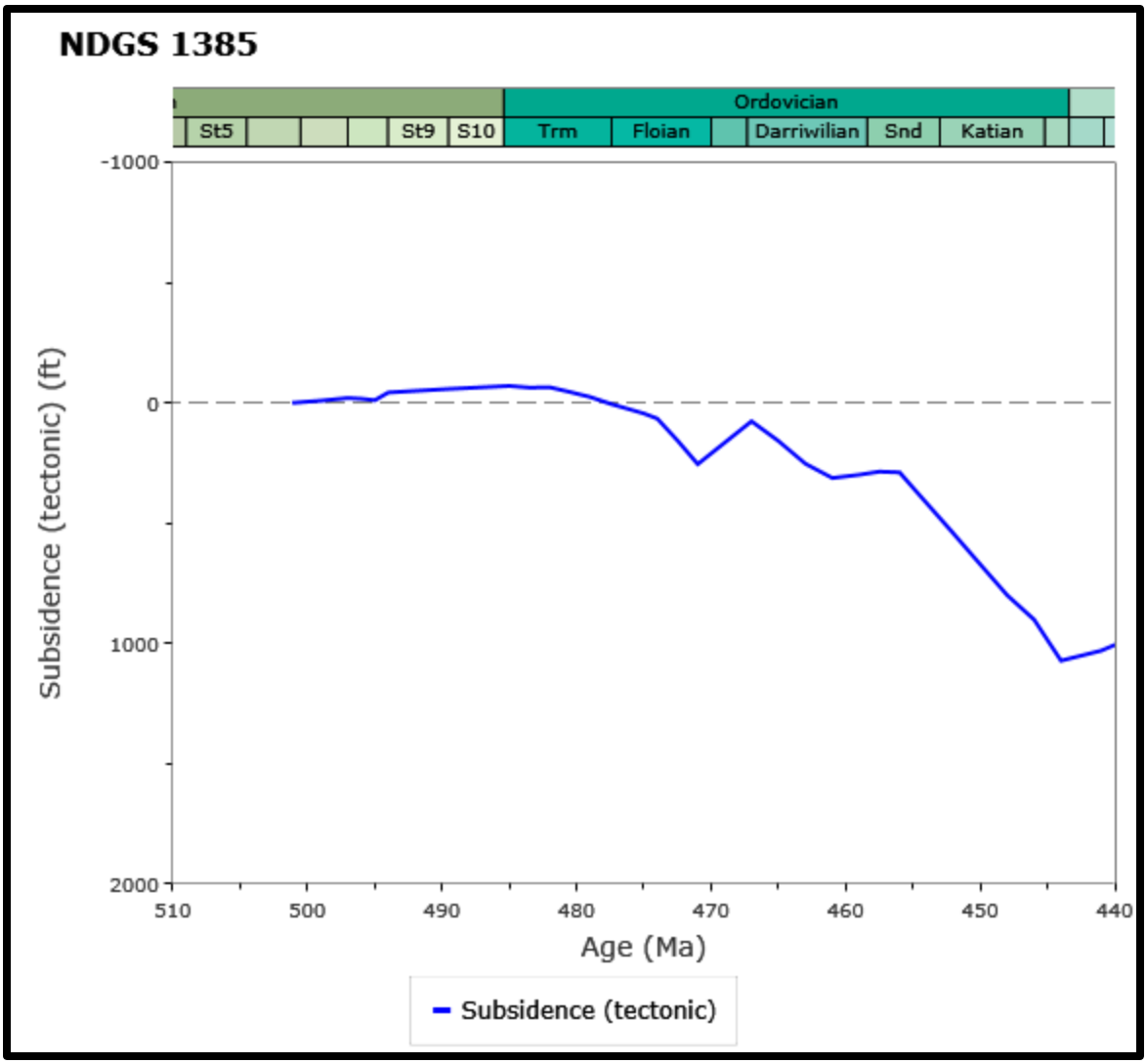

Figure 36. Tectonic subsidence curves for NDGS #1385. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

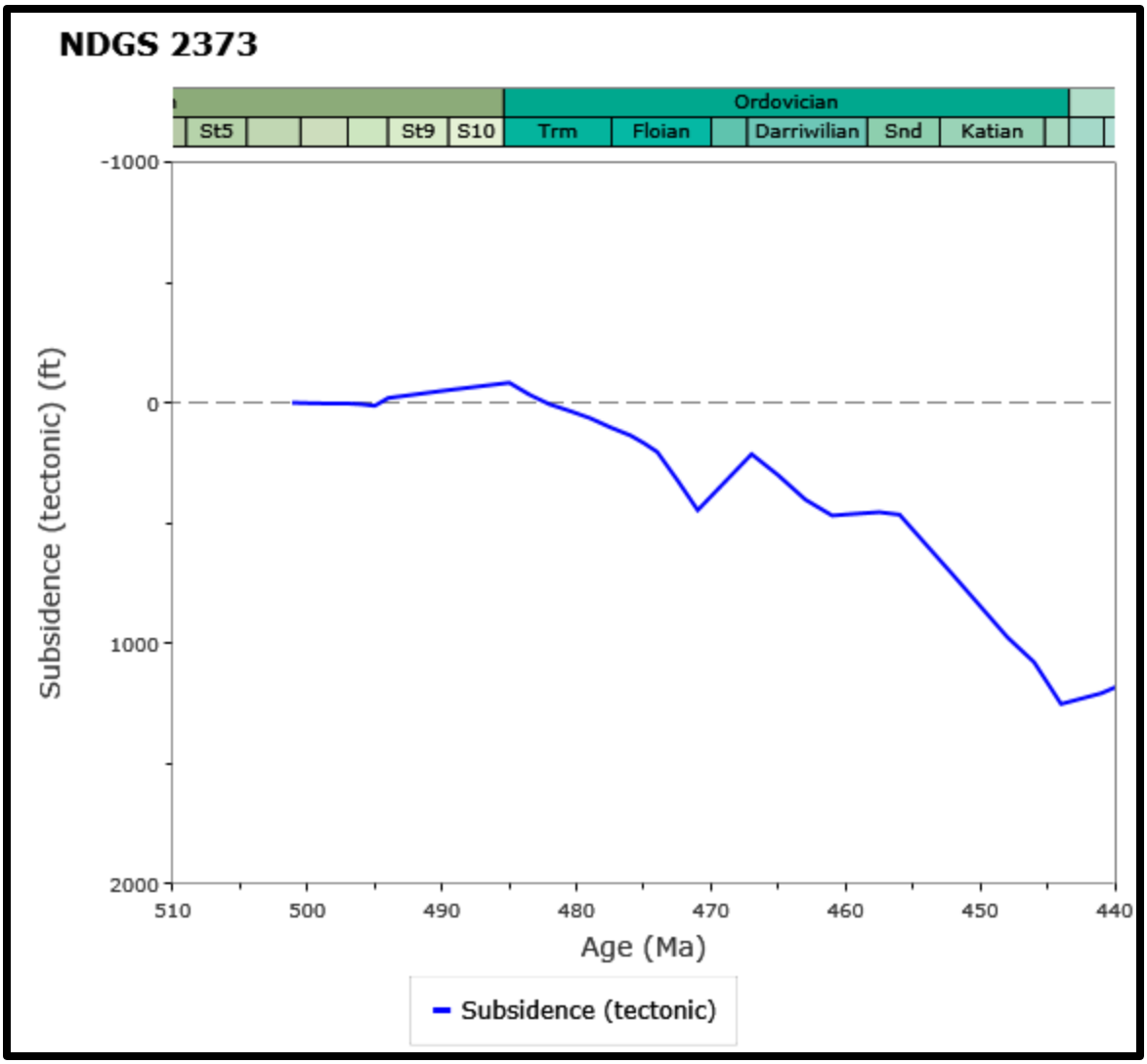

Figure 37. Tectonic subsidence curves for NDGS #2373. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

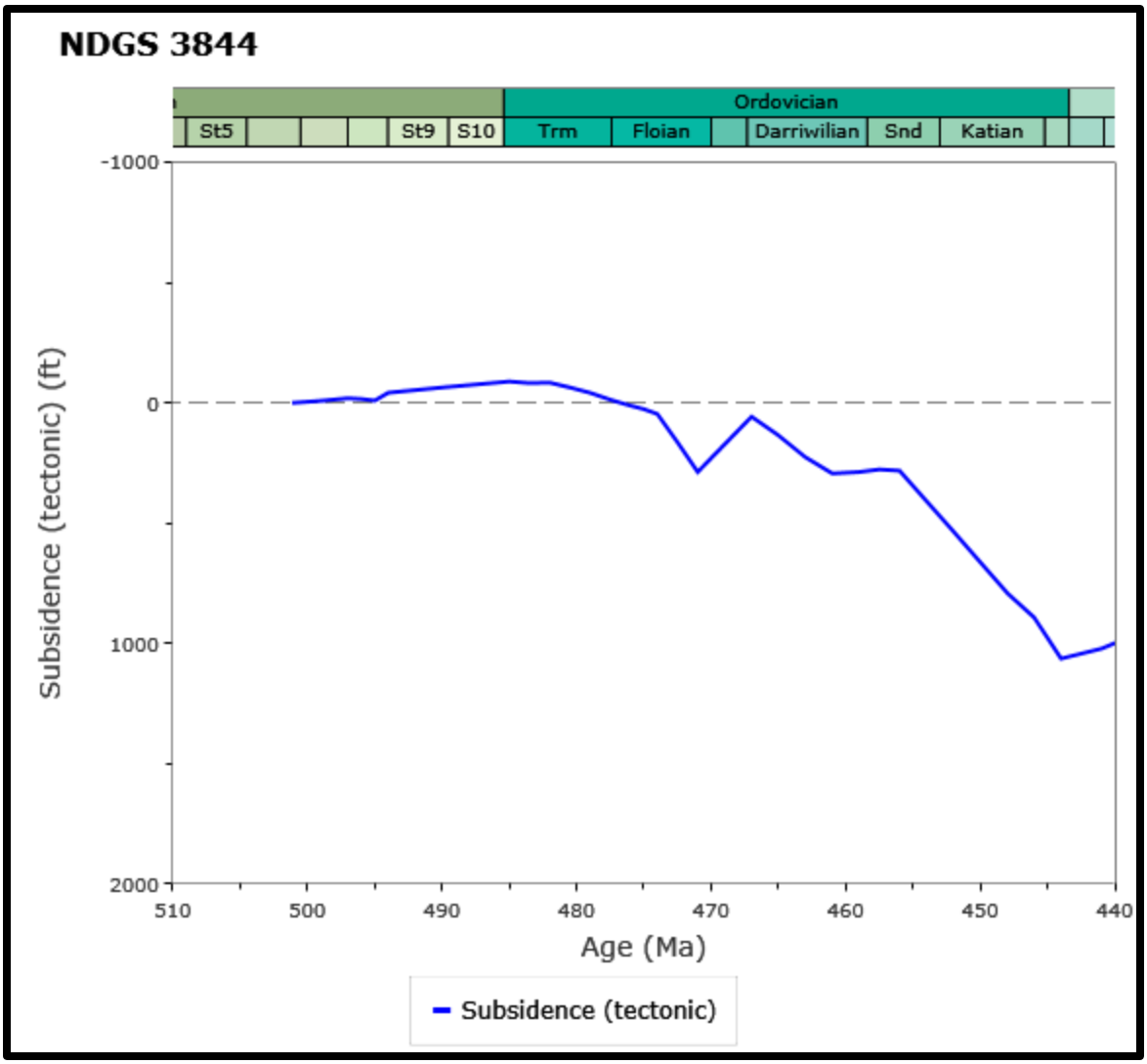

Figure 38: Tectonic subsidence curves for NDGS #3844. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

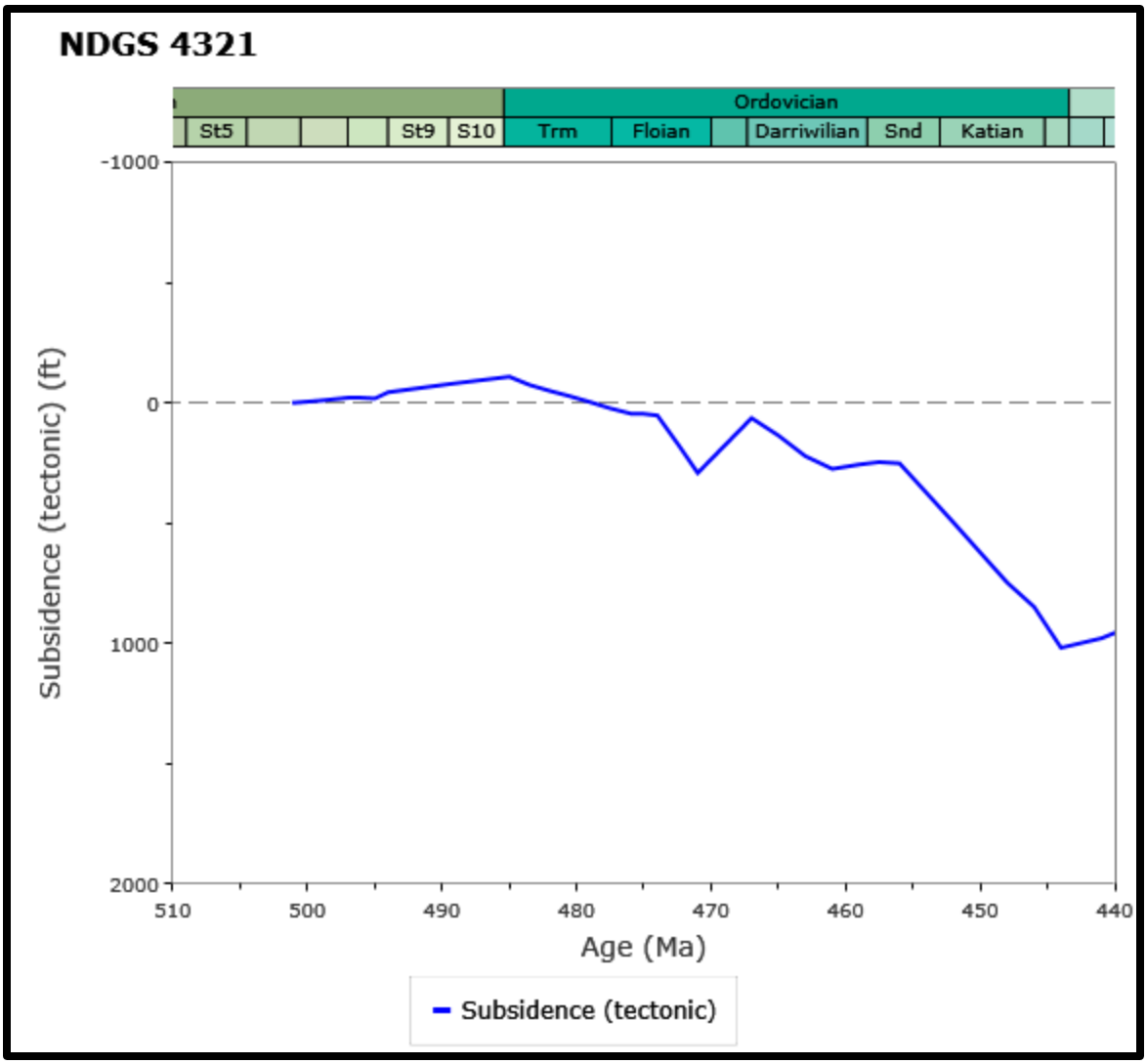

Figure 39. Tectonic subsidence curves for NDGS #4321. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

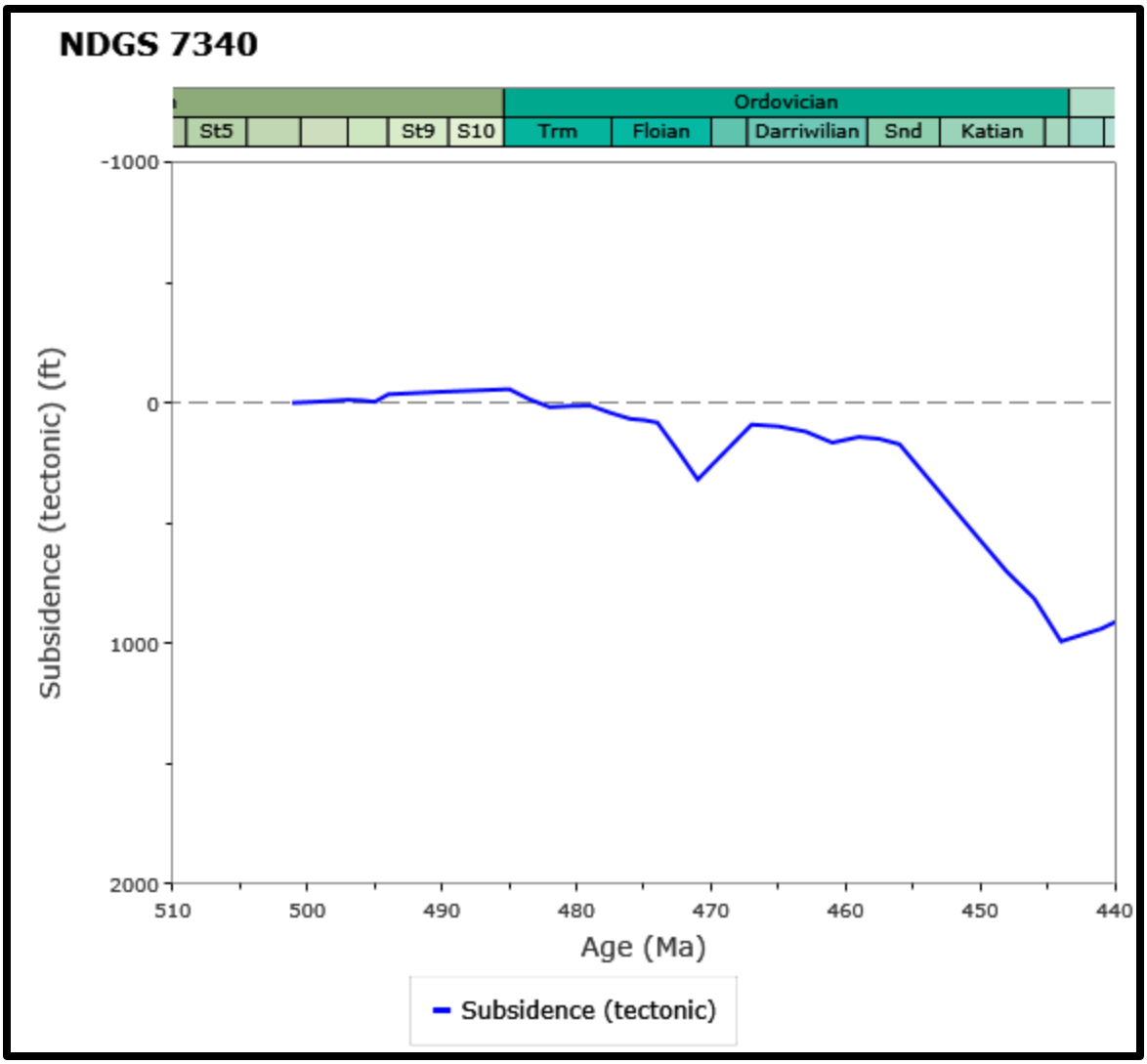

Figure 40. Tectonic subsidence curves for NDGS #7340. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

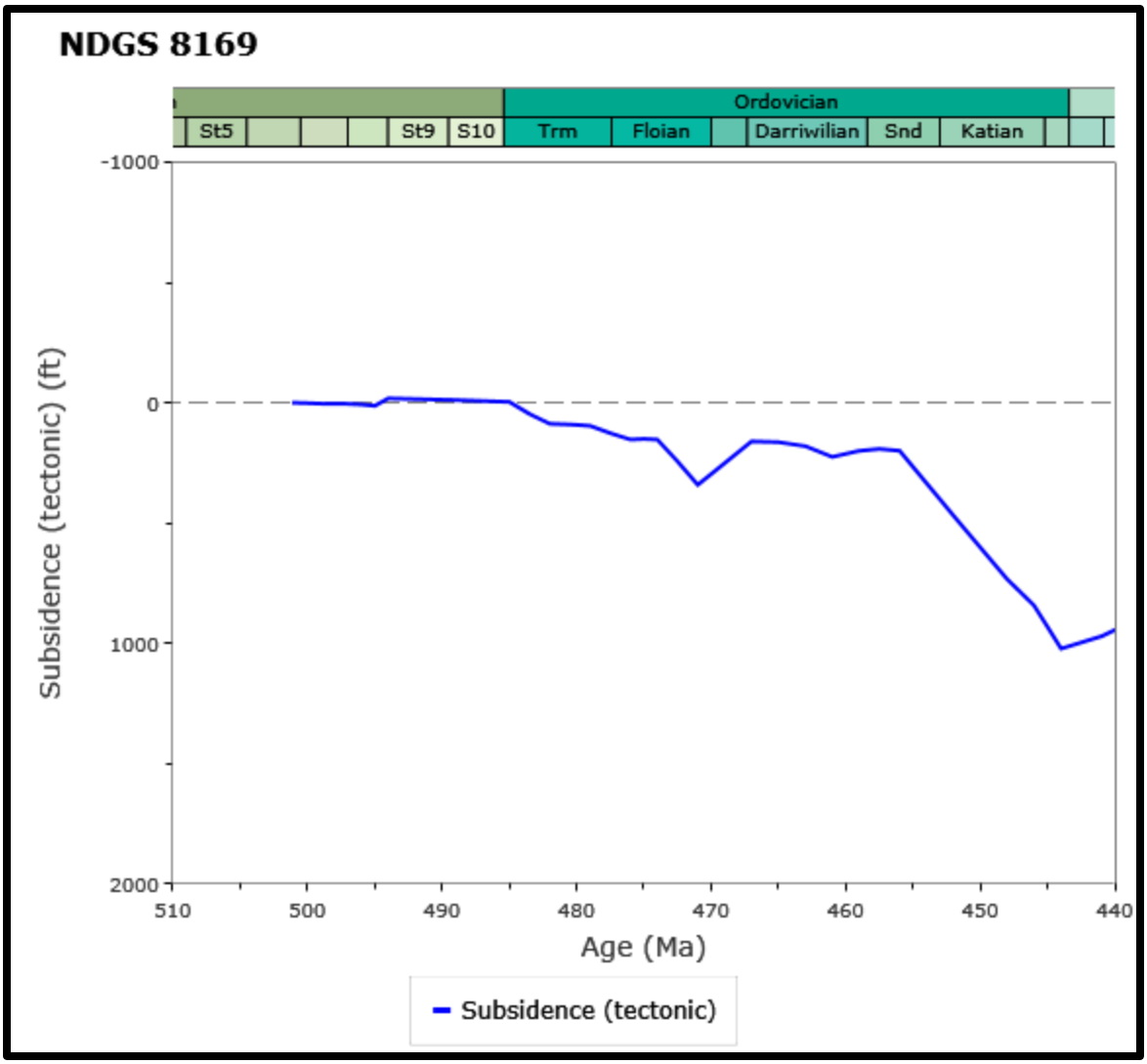

Figure 41: Tectonic subsidence curves for NDGS #8169. The x-axis is age, millions of years ago and the y-axis is feet of tectonic subsidence.

Table 1. Raw Tectonic Subsidence Data From NDGS #1385. The ~ Symbol Represents an Unconformity.

Formation		1385	
		Age (Ma)	Tectonic Subsidence (ft)
Red River		448	789.87
		450	661.39
		452	532.91
		455	342.57
		456	279.12
Roughlock		457.5	276.07
		459	288.96
Icebox		460	295.72
		461	302.49
		463	243.01
Black Island		465	148.64
		467	66.83
~~		470	200.32
		471	244.81
		472.5	146.99
		474	55.86
Deadwood	F	475	34.3
		475	18.09
	E	477.5	-6.04
		479	-34.36
	D	480	-48.32
		480.5	-55.3
		482	-74.73
	C	483.5	-73.23
		485	-80.3
	B	489.5	-67.92
		490	-66.27
		494	-53.04
	~~	495	-20.82
		496	-27.11
		497	-30.1
	A	499	-19.09
		500	-9.54
		501	0

Table 2. Results From the 7 Central Wells. Total Tectonic Subsidence Values, in Feet, for Member F Through Member A of the Deadwood Formation.

Member	1385	2373	3844	4321	6228	7340	8169
F	37.78	69.00	34.60	7.65	8.30	15.25	0.21
E	52.45	72.05	53.56	47.89	95.99	55.32	57.12
D	40.37	57.19	42.12	46.89	37.92	-6.38	8.40
C	5.57	89.95	4.59	58.66	93.95	74.44	90.97
B	-27.26	-63.32	-46.46	-64.52	33.86	-21.18	14.81
A	-30.10	-7.21	-29.01	-31.10	-3.28	-22.40	-5.81

Table 3. Average Tectonic Subsidence Values, in Feet, Per Million Year for Member F Through Member A of the Deadwood Formation.

Member	1385	2373	3844	4321	6228	7340	8169
F	18.89	34.50	17.30	3.82	4.15	7.63	0.11
E	17.48	24.02	17.85	15.96	32.00	18.44	19.04
D	13.46	19.06	14.04	15.63	12.64	-2.13	2.80
C	1.86	29.98	1.53	19.55	31.32	24.81	30.32
B	-3.03	-7.04	-5.16	-7.17	3.76	-2.35	1.65
A	-7.52	-1.80	-7.25	-7.77	-0.82	-5.60	-1.45

In all seven of the wells near the center of the basin a distinguishable pattern is evident. For members A and B the tectonic subsidence per million years averaged was -4.6 feet per million years and -2.8 feet per million years respectively. A large change occurs in Member C, where the subsidence rate increase significant to an average of 19.9 feet per million years over the seven wells. The subsidence rates continue to be positive throughout the remainder of Deadwood deposition. The rate decreases in Member F, to

an average of 12.3 feet per million years, mostly likely due to the unconformity between Member F and the overlying Black Island Formation. As stated earlier the two most important variables to getting accurate basin subsidence results are age and unit thickness. Since the unconformity between the top of the Deadwood Formation and the bottom of the Winnipeg Group represents a period of erosion or non-deposition, it is difficult to accurately determine the exact length of Deadwood deposition and the exact duration of Middle Ordovician erosion. After deposition of Member F, and prior to the deposition of the Winnipeg Group, there were two more transgressive-regressive cycles in North America (Barnes, 1984). The evidence of these events in the Williston Basin was erased by Middle Ordovician erosion. Approximately 295 feet of sediment was deposited by the previous transgressive and regressive cycles. Which means that up to 590 feet of Deadwood Formation may have been removed from the center of the basin prior to the deposition of the Winnipeg Group (Anderson, 1988). This model used an average thickness of 400 feet to represent the sediments that were removed due to Middle Ordovician erosion.

CHAPTER IV

INTERPRETATIONS

Deposition

Data recovered from well log, core, and thin section analysis has allowed for an accurate model of the depositional history and depositional environments of the Deadwood Formation throughout the study area. The deposition of the Deadwood Formation is a representation of the very end of the Sauk subsequence II and the entirety of the Sauk subsequence III (Sloss, 1962).

The transgression onto the craton began towards the end of the Precambrian, but it did not reach the middle of the craton, where the study area is, until the end of the unnamed 3rd Epoch (501 Ma) of the Middle Cambrian Period (Gradstein et al., 2012). Member A of the Deadwood Formation is the first preserved record of a transgression onto the craton in the Phanerozoic Eon.

As the shallow sea began to submerge the craton (Figure 42), minor fluctuations in sea level and sedimentation rates influenced deposition and restricted the Deadwood Formation to middle carbonate and inner detrital settings (Palmer, 1960). During the Cambrian, North America was divided by the equator and the study area was located adjacent to the equator.

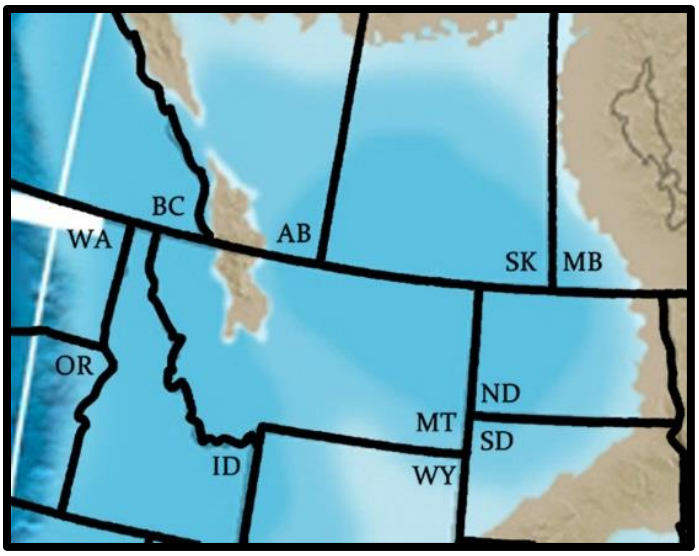

Figure 42. A map displaying the shoreline and general basin outline during the Late Cambrian period. (Modified from R. Blakely, 2013)

The first deposits were the conglomerates of the Member A. In some wells conglomerates consist of reworked Precambrian material. Prior to the transgression the entire surface of the craton was subaerially exposed (Figure 43) and subjected to the tropical to temperate climate of the Cambrian with no land plants for protection. This environment promoted chemical and mechanical weathering and the surface was extensively eroded, leaving it irregular.

These conglomerates represent alluvial deposits in low spots of the eroded surface. This is similar to the cobble and gravel conglomerates found in the Illinois Basin that were believed to be distal alluvial fan deposits, shed from the adjacent Precambrian uplands. In the Illinois Basin the conglomerates are overlain by sandstones with interbedded shales representing a transition to braided fluvial streams and other marginal marine environments (Bowen et al., 2011). Interbeds of sandstone and siltstone are most likely the result of storm surges. Pyrite occurs in small zones and is surrounded by shale beds; this is characteristic of the anoxic environment found in poorly circulated marginal

marine lagoons (Bowen et al., 2011). Skolithos burrows and fossil debris are characteristic of marine foreshore and shoreface environments (Driese et al., 1981).

Figure 43. A map displaying the shoreline during the Precambrian Era. (Modified from R. Blakely, 2013).

Unlike in the Illinois Basin the conglomerates of Member A contain grains of glauconite. Glauconite is commonly considered a diagnostic mineral and is deposited in shallow marine environments along the continental shelf with slow rates of accumulation. In near shore environments detrital deposition inhibits glauconite (Odin and Matter, 1981), suggesting that these conglomerates have been reworked into a marine environment. Zones of glauconite are also found in the overlying quartz arenite. These grains were most likely transported shoreward from an open marine environment (Anderson, 1988). Glauconite is more prevalent near the top of Member A and right at the contact with the overlying Member B it is heavily oxidized and the precipitation of hematite has occurred. This is the result of a brief but widespread unconformity between the two members.

Overlying Member A is the glauconite-rich siltstone and sandstone Member B. This member is easily identified on well logs due to its high gamma ray response, caused by the abundance of potassium rich, glauconite grains found within the sandstones and siltstones of the member and occasional shale beds. As stated above, glauconite is a great indicator mineral because it is only formed in a specific range of environmental conditions. Glauconite is most commonly found in low energy environments of shallow marine sands. It is formed by replacing dead organic matter in a reducing environment, usually organisms within a shell or fecal matter. The abundance of the mineral suggests that the depositional environment for Member B shares a similar environment, unlike Member A which includes reworked glauconite grains.

Grain sizes in Member B increase eastward, this represents the larger sediments dropping out of bedload as the sediment travels westward into the deeper and calmer waters. The source is the exposed craton to the east and north. Glauconite formation would not be likely near the shoreline, glauconite grains in the coarser grained sandstones near the fringe are thought to be due to shoreward transport of these grains, similarly to Member A (Anderson, 1988). Since the glauconite is being transported, not generated, glauconite is less prevalent in the coarser grained sandstones. The combination of coarser grains and less glauconite cause the gamma ray response signature of Member B to closely resemble Member A in well logs, making the distinction between the two difficult. In this study the two members are combined and referred to as Member AB in the distant east and northeast edges of the study area. The boundary between the Cambrian and Ordovician is located near the top of Member B.

Due to continental drift the craton is continuously moving and by the start of deposition of Member C it had drifted about five degrees south. At this time the craton was also rotated a little more than 90 degrees counter-clockwise, putting the equator in western Montana and the eastern border of the study area at a latitude of about 10 degrees south (Ross, 1976). An increase in sea level was forced by northeasterly winds driving water over the shelf in Montana and Wyoming (Anderson, 1988), as well as increased rainfall and low evaporation due to the tropical climate (Ross, 1976). These factors prompted a change in depositional environments between members A and B and the remaining four members.

Sedimentation was mostly continuous for the remainder of Deadwood deposition (Figure 44), with Members C through F being deposited in three repeating vertical successions (Figure 45). Referencing well logs, this trend is documented with low gamma ray response in Member C, followed by a high gamma ray response in Member D and then a low gamma ray response, similar to Member C, in Member E and F.

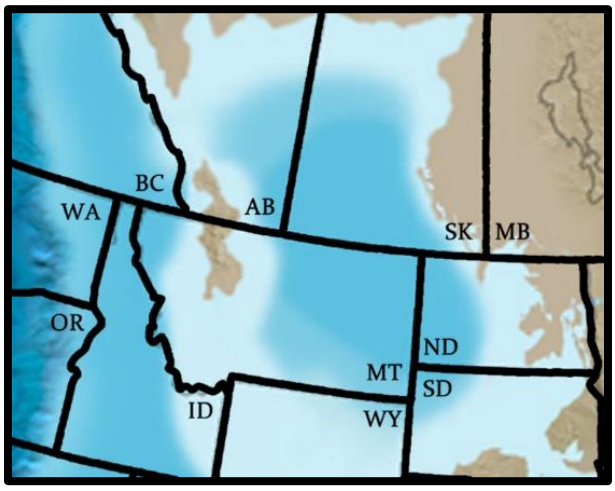

Figure 44. A map displaying the shoreline and basin outline during the Early Ordovician period. (Modified from Blakey, 2013)

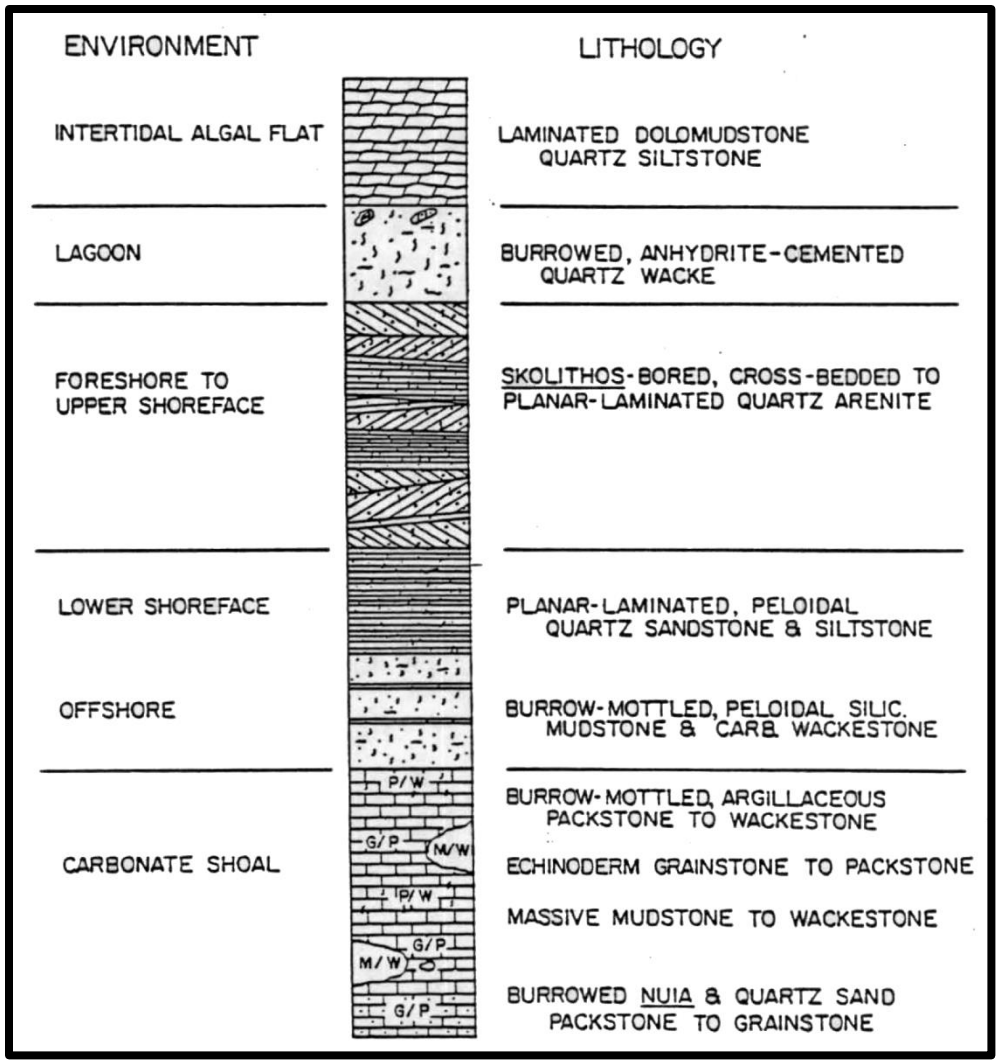

Figure 45. Simplified description of the progradational succession seen in member C through F. (Modified from Anderson, 1988).

The successions represent a progradation of a siliciclastic shoreline and back-barrier setting over a shallow shelf and a distal limestone shoal (Figure 46) (Anderson, 1988). All three are similar and begin with the progradation of the shoreline, advancing as far west as eastern Montana (LeFever, 1996). The progradation deposited well-sorted quartz arenites and wackes across the entire area (Figure 47a). These sandstone lithotypes are found at the bottom of Member C, Member E, and Member F.

Sea levels began to rise, transgressing eastward onto the craton, eroding some of the underlying deposits and depositing the foreshore to upper shoreface mixed sandstone-limestone and limestone lithotypes of Member C and E (Figure 47b). As sea level continues to rise lower shoreface to offshore limestones are deposited. The succession is finally capped by laminated dolomudstones and siliciclastic mudstones and calcareous siltstones that occur on carbonate shoals (Figure 47c). Pre-Winnipeg erosion limits the lateral extent of these deposits (Figure 47d).

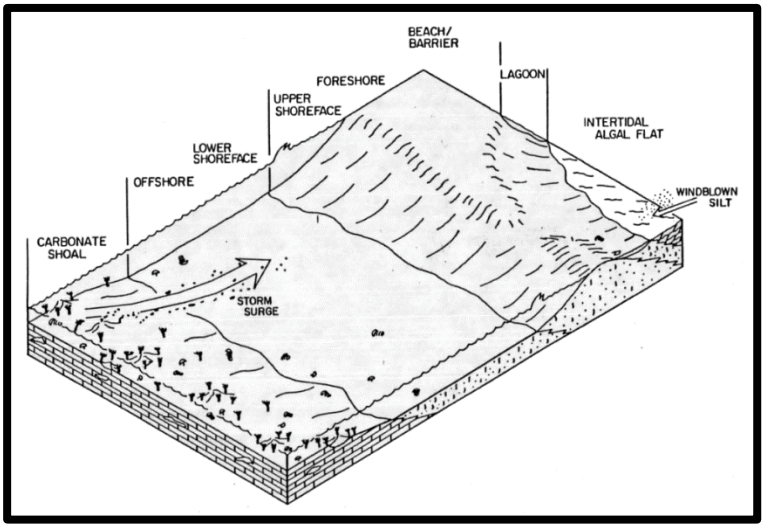

Figure 46. Model of the depositional environment for members C through F. Features in the model are not to scale. (Modified from Anderson, 1988).

Member F is the final member in the succession, it has be hypothesized that up to 590 feet of Member F sediments were eroded at the end of the Sauk Sequence (Anderson, 1988). This means that numerous Member F lithotypes were most likely lost with the erosion. Similarly to Member E, Member F includes siliciclastic mudstones to calcareous siltstones and quartz arenite. Deposition of the Deadwood Formation lasted until the end of the Early Ordovician, with the conclusion of deposition of Member F and the completion of the Sauk Sequence.

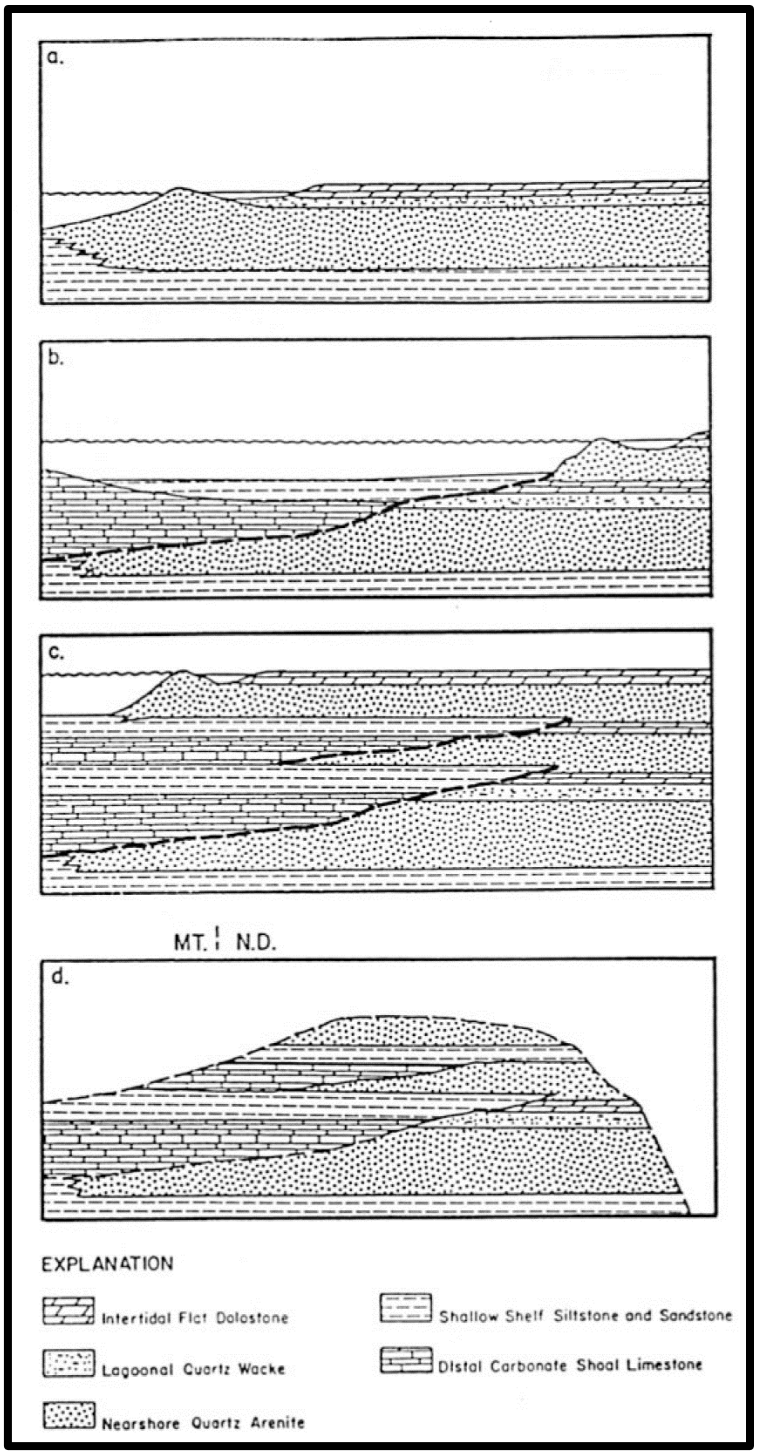

Figure 47. Diagram of the deposition of members C through F of the Deadwood Formation. Starting with the progradation of the shoreline (a), followed by the transgression of the sea onto the craton (b). The transgression deposits a succession of sandstones, limestones, dolomudstones, and siliciclastic mudstones (c). Erosion limits the lateral extent of the members. (Modified from LeFever, 1996).

The cores recovered from wells in Renville County, North Dakota do not fit this interpretation. This area represents a meteorite impact structure (Gerlach, 1994) that occurred near the end of the deposition of Member B. The impact instantaneously disrupted all previous deposits of the Deadwood Formation and the upper part of the Precambrian metaphoric rocks below.

There are seven wells that have recovered core from the Newporte structure. With four wells being drilled on the rim of the crater and the remaining three slightly outside of the crater; there are no wells inside of the crater. There are five main lithologies that are characteristic of impact structures; post-impact breccia; coarse conglomerate; conglomeratic sandstone; sandstone; and interbedded fine sandstones, siltstones, and shales (Kalleson et al., 2007).

The impact resulted in vast amounts of the Deadwood deposits and Precambrian basement rock to be ejected out of the crater. The material that was ejected into the air is deposited back down over the entire area as fallback breccia. The fallback breccia occurs in core as sandstone and siltstone clasts mixed with angular Precambrian gneiss clasts.

Further outside of crater rim, intense shockwaves induce rarefaction, sand liquefaction, and sand fluidization (Horton et al., 2008). These processes produce considerable deformation in the rocks. The increase in density due to rarefaction fragments preexisting deposits (Figure 48), producing the conglomerate seen in many wells (Figure 49). Intense folds and slumping due to liquefaction and fluidization also occurs in these wells.

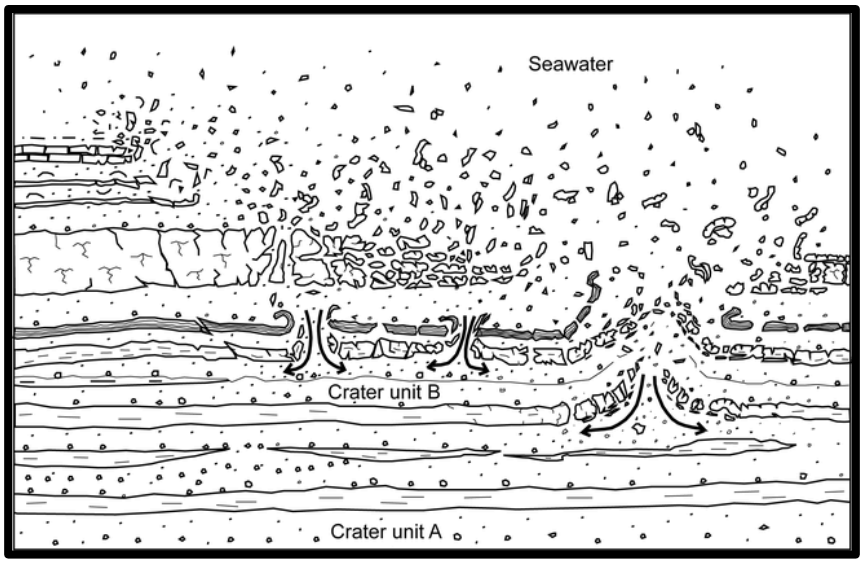

Figure 48. Illustration of an example of rarefaction-induced fragmentation and the ejection of these fragments and sediments that can produce the conglomerate and soft sediment deformation seen in cores around the Newporte structure. (Modified from Horton et al., 2008).

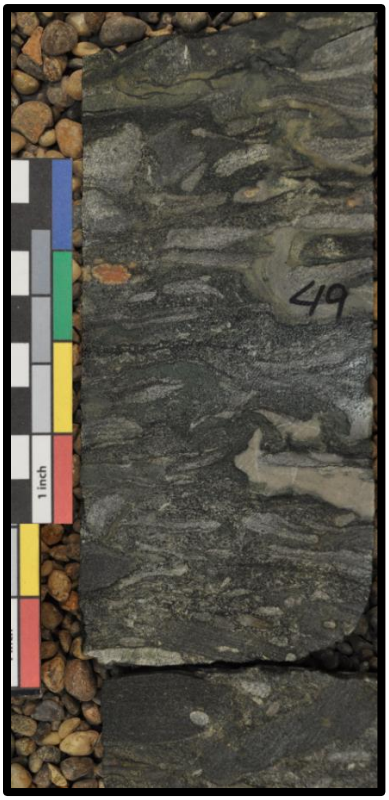

Figure 49. Example of conglomerate of sedimentary fragments, as well as intense soft sediment deformation. Taken from NDGS #6473 at a depth of 9,549'.

Basin Subsidence

The timeline for this model began 501 million years ago at the beginning of the Late Cambrian, when the first sediments were deposited in the study area. At this time the study area was near sea level and the depositional environments of members A and B of the Deadwood Formation ranged from marginal marine to nearshore. Isopach maps for members A and B show a weak westward thickening depositional trend (Figure 28 and Figure 29). This trend represents the eastward advance of the sea onto the exposed craton, with the shoreline moving eastward to eastern North Dakota.

Through the Upper Cambrian sea level continued to rise, increasing accommodation space which resulted in the deposition and preservation of these units. Since the accommodation space was the result of only a rise in sea level and not due to subsidence of the basement the tectonic subsidence values are negative.

Towards the end of Cambrian Period there was a short term significant drop in sea level (Figure 50). This drop briefly subaerially exposed the recently deposited Member A and resulted in minor erosion of the top of Member A and brief period of nondeposition. The unconformity is visible in cores due to oxidation near the contact of the overlying Member B. The data output for the time frame of the unconformity shows eight feet of tectonic subsidence. This is due to the removal of part of Member A as it was subaerially exposed.

The results from Novva for Member B are very similar to what was seen in Member A. From all seven wells there was an average tectonic subsidence of -2.8 feet per million year. After the brief drop in sea level that ended the deposition of Member A sea level began to slowly rise again and increased accommodation space allowing for

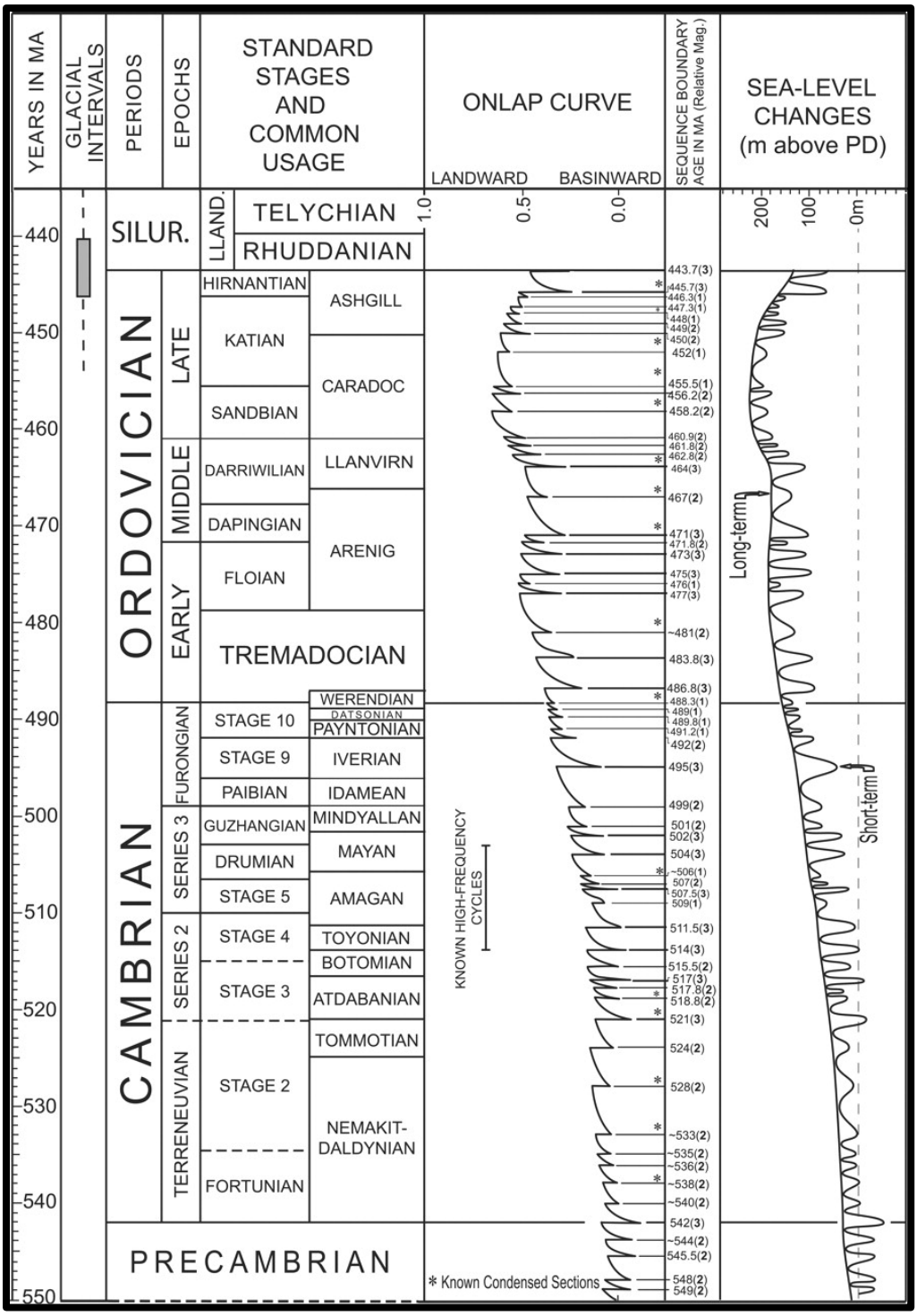

Figure 50. Sea-level changes throughout the Cambrian and Ordovician. These are modeled after the work (Gradstein et al., 2004) and (Ogg et al., 2008). Significant short term drop in sea level is visible at roughly 495 mill years ago. (Modified from (Haq and Schutter, 2008).

deposition of Member B. There was no subsidence so this increase in thickness results in negative tectonic subsidence values. There are two wells that show positive tectonic values, NDGS #6228 and #8169. The positive values are low, 3.8 and 1.8 feet per million year respectively. The thickness of Member B in these wells in much greater than in the other wells in the study. Variations in thickness is interpreted to be the result of the irregular surface of the underlying basement rock and not due to an early onset of subsidence.

The isopach for Member C displays an apparent basin shaped thickening trend in western North Dakota (Figure 30). A complete bowl shape is not fully seen, with a slight opening out westward into Montana. The center of the depression is near the current center of the Williston Basin. A significant change in tectonic subsidence values is occurs within Member C. Deposition for Member C occurred between 485 to 482 million years ago. Tectonic subsidence values average 19.9 feet per million years. This transformation from negative to positive tectonic subsidence verifies that subsidence has begun in the Williston Basin.

Results from the subsidence analysis are still negative up until the end of Member E for most of the wells but this does not represent a lack of negative subsidence. The change in tectonic subsidence for all of the wells is positive. This is compensating for up to 118 feet of deposition accumulated through at the end of Member B deposition. Deadwood deposition continued and sea level remained relatively steady with minor fluctuations throughout the Early Ordovician Period. As subsidence continues to progress tectonic values remain positive during the deposition of members D, E, and F.

CHAPTER V

CONCLUSIONS

1. Distinct and traceable changes in the gamma ray response throughout the Deadwood Formation allows the formation to be divided into six members, A-F in ascending order.
2. Deadwood deposition is the result of the Sauk cratonic sequence, the first large scaled transgressive-regressive cycle to occur in the North America. The Williston Basin is found near the center of the craton, which means that deposition only represents the later stages of the Sauk sequence. Within this sequence six smaller transgressive-regressive events took place. These cycles produced changes in lithologies being deposited through time, allowing for differentiation of the six members of the Deadwood Formation. The first cycle depositing Member A, the next two cycles resulting in Member B, and the final three cycles being responsible for members C through F.
3. Three important unconformities exist in relation to the Deadwood Formation.
    a. The major nonconformity between the base of the formation and the underlying igneous and metamorphic rocks of the Precambrian. This represents the first evidence of deposition during the Phanerozoic Eon.
    b. The major disconformity between the top of the Deadwood Formation and the overlying Ordovician sediments (most commonly the Winnipeg Group). This

occurred due to the complete withdrawal of the sea from the craton, exposing the recently deposited Deadwood Formation subjecting it to immense erosion. This represents the end of the Sauk cratonic sequence.

c. The minor disconformity between members A and B. Evidence for this is a widespread zone of oxidized glauconite grains and the presence of hematite near the contact between the two members. Other unconformities occur throughout the Deadwood but they are commonly localized.

4. Prior to and early in the deposition of, the Deadwood Formation the Williston Basin did not exist. A significant visible shift occurs in the isopach maps. The deposition of Member A and Member B are the result of an eastward transgressing shoreline at the end of Member B. The trend shifts in Member C corresponding to a localized thickening in western North Dakota, which continues through the remainder of Deadwood deposition. Tectonic subsidence per year values were derived in Novva®. Average values for members A and B are negative, which is associated with tectonic uplift. Uplift can be attributed to accumulation of sediments with no subsidence, due to a rising sea level. Average tectonic subsidence values for members C, D, E and F are all positive, identifying that subsidence occurred in those members. The shift that occurs represents the initiation of subsidence in the Williston Basin and puts the age of the basin to be roughly 482 to 485 million years old.

APPENDIX

Appendix A
General Well Information

Wells are listed by state or providence. Wells are also sorted by county in the United States or by location in Canada. The unique well identifier or American Petroleum Institute number, as well as the well label are used to identify the wells.

North Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Adams County				
3300100006	6322	2,453	-102.1142	46.0961
3300100009	7642	2,804	-102.5668	46.0519
Barnes County				
3300300004	4640	1,440	-98.1357	46.9521
Benson County				
3300500004	632	1,637	-99.7046	48.1134
Billings County				
3300700001	291	2,774	-103.3022	46.8742
3300700054	3268	2,540	-103.4129	46.8665
3300700221	6228	2,532	-103.0931	47.3187
3300700230	6303	2,642	-103.3846	47.1731
3300700323	6913	2,747	-103.2368	47.2216
3300700433	7307	2,772	-103.2037	47.1931
3300700505	7520	2,730	-103.2258	47.1955
3300700590	7934	2,726	-103.3258	47.1055
3300700642	8226	2,724	-103.3439	47.1715
3300700693	8487	2,344	-103.5444	47.1986
3300700715	8603	2,615	-103.1461	47.0691
3300700769	9070	2,731	-103.2762	46.9849
3300701042	11335	2,495	-103.5118	46.8701
3300701391	14763	2,658	-103.2500	46.9493
Bottineau County				
3300900002	38	1,526	-101.1768	48.6333
3300900003	64	1,520	-100.7055	48.9463
3300900004	110	2,205	-100.3560	48.9343
3300900418	2219	1,494	-100.9636	48.7939
3300901010	4655	1,486	-100.8321	48.8082
3300901034	4790	1,517	-101.1492	48.5762
3300901045	4846	1,518	-101.2039	48.9640
3300901087	5184	1,552	-100.6018	48.8585
3300901554	9522	1,474	-100.6613	48.7570
Bowman County				
3301100042	485	3,212	-103.6985	46.0013
3301100045	1575	2,953	-103.9489	46.0081
3301100382	9656	2,945	-103.2315	46.2039
3301100387	9805	3,122	-103.7143	46.0371
3301100905	14851	2,954	-103.5465	45.9634
Burke County				
3301300869	8893	1,950	-102.2588	48.8671
3301301316	15137	2,089	-102.8881	48.8460

North Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Burleigh County				
3301500001	19	1,909	-100.4529	46.9684
3301500002	145	1,869	-100.3105	46.6476
3301500003	151	1,922	-100.8286	46.9415
3301500004	155	1,912	-100.1411	46.9649
3301500005	174	1,981	-100.3885	46.9801
3301500006	701	2,023	-100.1159	47.2553
3301500008	756	1,891	-100.4196	46.6361
3301500009	763	1,947	-100.3915	47.2889
3301500010	765	2,027	-100.3652	47.0711
3301500011	772	2,007	-100.6205	46.9373
3301500014	1409	2,019	-100.3574	46.9587
3301500032	6264	1,938	-100.2692	46.8786
3301500042	7010	1,752	-100.5656	46.7343
3301500043	8674	1,874	-100.3443	47.0273
3301500046	12057	1,874	-100.6880	47.2745
Cavalier County				
3301900001	27	1,562	-99	48.5719
Dickey County				
3302100003	682	1,461	-98.5498	46.0264
3302100005	1394	2,196	-98.9402	45.9811
Divide County				
3302300024	2010	2,206	-103.9775	48.9655
3302300167	6798	2,141	-103.1382	48.8567
3302300171	7087	1,918	-103.0616	48.9396
3302300181	7942	2,349	-103.2623	48.6679
3302300210	9398	2,260	-103.7964	48.9403
3302300211	9413	2,072	-103.4013	48.9401
3302300221	9622	1,983	-103.3962	48.9650
3302300224	9677	1,980	-103.4128	48.9831
Dunn County				
3302500069	6086	2,327	-102.6973	47.3992
3302500079	6148	2,615	-102.8172	47.0550
3302500120	6530	2,595	-102.7595	47.0334
3302500155	7402	2,010	-102.2161	47.3087
3302500156	7412	2,218	-102.5847	47.3808
3302500164	7584	2,322	-102.8139	47.3991
3302500178	8077	2,417	-102.9003	47.5647
3302500179	8095	2,330	-102.6173	47.7260
3302500195	8313	2,151	-102.5208	47.3633
3302500211	8491	2,635	-102.8978	47.0870
3302500227	8613	2,412	-102.5019	47.2721
3302500232	8709	2,283	-102.5580	47.5644

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General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
3302500267	9027	2,204	-102.3894	47.2435
3302500269	9044	2,270	-102.4944	47.4834
3302500274	9080	2,221	-102.3478	47.2940
3302500310	9397	2,334	-102.4670	47.4326
3302500325	9527	2,492	-103.0956	47.4843
3302500358	10072	2,238	-102.4858	47.5593
3302500387	10606	2,146	-102.4586	47.1243
3302500388	10627	2,263	-102.4757	47.0157
3302500408	11363	2,203	-102.2669	47.2875
3302500438	12400	2,476	-102.9760	47.1300
3302500514	14636	2,246	-102.4059	47.0918
Eddy County				
3302700001	437	1,478	-99.2512	47.8163
3302700002	768	1,561	-98.9993	47.8305
3302700005	1274	1,584	-98.5667	47.6469
3302700009	7271	1,530	-98.9657	47.6511
Emmons County				
3302900001	16	2,026	-100.0821	46.2889
3302900002	23	2,012	-100.1909	46.2899
3302900003	43	1,820	-100.4629	46.2667
3302900018	7101	1,887	-100.1884	46.2629
3302900019	7146	1,908	-100.0919	46.6021
3302900021	7936	1,925	-100.0603	46.6020
3302900027	10173	1,956	-100.2078	46.5042
Foster County				
3303100002	287	1,518	-98.6460	47.4696
3303100003	295	1,496	-98.5283	47.3501
3303100004	334	1,547	-98.7575	47.3610
3303100008	1105	1,533	-98.9819	47.4735
3303100009	1112	1,536	-99.0341	47.4553
3303100013	1227	1,463	-98.7580	47.5278
Golden Valley County				
3303300001	410	2,513	-103.6798	47.1875
3303300002	470	2,867	-103.9046	46.9391
3303300044	6272	3,034	-104.0412	46.6701
3303300050	6513	2,841	-103.9014	46.9924
3303300053	6563	2,744	-103.9317	46.8888
3303300085	7969	2,692	-104.0117	47.0720
3303300102	8590	2,260	-103.7440	47.2648
3303300120	9148	2,836	-103.9260	46.8593
3303300129	9540	2,820	-103.8214	46.8949

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General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Grand Forks County				
3303500002	580	940	-97.4102	47.9022
3303500005	3191	841	-97.3604	48.0984
3303500006	3204	837	-97.2148	47.9896
3303500014	15343	1,084	-97.5683	47.6741
Grant County				
3303700020	5572	2,172	-101.4296	46.2318
3303700021	6420	2,285	-101.4973	46.2639
3303700022	6586	2,456	-102.0127	46.4272
3303700023	7020	2,342	-101.8051	46.7124
3303700024	8549	2,293	-101.6140	46.4173
3303700025	8680	2,498	-101.6587	46.1308
Griggs County				
3303900004	4719	1,471	-98.4649	47.4914
3303900008	9659	1,568	-98.3877	47.6663
Hettinger County				
3304100011	5783	2,548	-102.3254	46.5575
3304100015	7075	2,517	-102.3254	46.3005
3304100020	7453	2,669	-102.8126	46.3123
3304100027	8312	2,544	-102.7154	46.4621
3304100032	10522	2,620	-102.6685	46.5451
Kidder County				
3304300003	24	1,968	-99.8640	46.9902
3304300004	230	1,889	-99.6745	47.2028
3304300005	748	1,848	-100.0803	47.0814
Logan County				
3304700002	590	2,011	-99.9021	46.6194
3304700004	1347	1,917	-99.5561	46.5718
3304700020	5523	2,117	-99.8922	46.4847
McHenry County				
3304900001	39	1,480	-100.7248	48.4493
3304900002	61	1,570	-100.5906	48.0711
3304900125	8307	1,516	-100.6172	48.2088
3304900127	8803	1,915	-100.8882	47.8899
3304900151	11922	1,466	-100.8549	48.5983
McIntosh County				
3305100001	89	2,176	-99.7967	46.1711
3305100003	620	2,042	-99.2560	46.0759
3305100004	621	2,056	-99.3755	46.0689
3305100005	622	2,143	-99.3545	46.1667
McKenzie County				
3305300410	2373	2,117	-102.7747	48.0121
3305300688	6112	2,378	-102.8627	48.0621

North Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
3305300734	6387	2,321	-103.9754	47.6642
3305300739	6414	2,334	-103.9600	47.6609
3305301055	7571	2,486	-102.8848	47.8565
3305301056	7572	2,417	-102.8740	47.8491
3305300734	6387	2,321	-103.9754	47.6642
3305300739	6414	2,334	-103.9600	47.6609
3305301055	7571	2,486	-102.8848	47.8565
3305301056	7572	2,417	-102.8740	47.8491
3305301066	7607	1,951	-102.8978	48.1119
3305301071	7631	2,137	-103.3498	47.8611
3305301140	7873	2,141	-103.3396	47.8065
3305301167	7988	1,999	-102.9316	48.1000
3305301177	8023	2,242	-102.7554	47.9688
3305301187	8083	2,381	-102.8841	47.8285
3305301190	8090	2,331	-102.8782	48.0122
3305301202	8131	2,398	-103.3444	47.9078
3305301211	8165	2,050	-103.5647	47.8862
3305301220	8187	2,444	-103.5306	47.6586
3305301221	8193	2,185	-103.6637	47.4969
3305301256	8314	2,221	-103.8239	47.5698
3305301294	8468	2,357	-103.5258	47.4382
3305301311	8546	1,917	-104.0192	47.8462
3305301341	8663	2,360	-103.1039	47.5252
3305301358	8737	2,335	-103.6810	47.5792
3305301416	9004	2,329	-103.4570	47.8248
3305301417	9005	2,361	-103.4238	47.3606
3305301454	9217	2,390	-102.9544	47.7553
3305301623	9901	2,439	-103.7435	47.6157
3305301937	11110	2,402	-102.8685	47.9727
3305302077	11619	2,366	-103.4782	47.3848
3305302224	12345	2,514	-102.9103	47.7877
3305302267	12589	2,269	-102.8205	48.0430
3305302293	12699	2,287	-103.4565	47.6533
3305302397	13405	2,165	-102.7763	48.0186
3305302459	13647	2,274	-102.7893	48.0278
3305302492	14399	2,396	-102.8842	47.8436
3305302508	14724	2,001	-102.9415	48.1063
3305302669	15915	2,438	-102.9989	47.8495
3305302757	16376	2,499	-102.8681	47.9455
3305302778	16523	2,312	-102.8832	48.0176
McLean County				
3305500002	22	1,995	-100.9765	47.4838
3305500003	49	2,100	-100.9264	47.7783

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General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
3305500024	7783	2,212	-102.1426	47.8418
3305500025	8060	2,109	-102.0650	47.6552
3305500034	8711	1,900	-100.9100	47.4166
3305500035	8720	1,815	-100.9207	47.2567
3305500038	8993	1,995	-100.8774	47.6905
Mercer County				
3305700001	21	2,287	-101.9620	47.0952
3305700025	8712	2,167	-102.1808	47.3443
Morton County				
3305900002	26	2,005	-100.8947	46.5722
3305900007	1620	2,426	-102.0255	46.8245
3305900009	3859	2,124	-101.0927	46.4675
3305900026	7340	2,230	-101.7463	46.9111
3305900027	7691	2,094	-101.4604	46.7558
3305900029	7797	2,281	-101.6158	46.6765
3305900031	7937	1,965	-101.5761	46.7592
3305900032	8158	1,792	-101.0772	46.7941
3305900034	8553	1,994	-101.0633	46.9444
Mountrail County				
3306100218	6780	2,133	-102.0024	47.8857
3306100220	6872	2,108	-101.9891	48.0716
3306100282	9326	2,266	-102.4584	48.3650
3306100378	12597	2,474	-102.8781	48.4547
3306100471	14815	2,110	-102.0314	47.8784
3306100660	17058	2,112	-102.1420	48.0093
Nelson County				
3306300010	4664	1,473	-98.5015	47.8517
3306300015	4785	1,496	-98.3780	47.9317
3306300025	9143	1,471	-98.1471	47.6896
Oliver County				
3306500001	15	2,037	-100.9836	47.0278
3306500014	8144	1,973	-101.0476	47.0279
Pierce County				
3306900004	435	1,589	-99.5008	48.5249
3306900010	706	1,652	-99.6472	48.4015
3306900022	3920	1,605	-100.0927	47.9644
3306900031	5576	1,579	-100.0024	47.9362
3306900043	12125	1,622	-99.8876	48.5391
Ramsey County				
3307100001	20	1,544	-98.6665	48.4830
3307100002	196	1,487	-99.0079	48.1640

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General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
3307100004	383	1,556	-98.6849	48.5130
3307100005	407	1,487	-98.6943	48.0699
3307100007	411	1,557	-98.7391	48.5166
3307100008	422	1,534	-98.6575	48.4623
Renville County				
3307500718	6296	1,807	-101.9692	48.9566
3307500730	6349	1,636	-101.9520	48.9819
3307500737	6401	1,703	-101.9463	48.9570
3307500744	6436	1,822	-101.9816	48.9707
3307500750	6466	1,734	-101.9391	48.9767
3307500752	6473	1,809	-101.9598	48.9498
3307500753	6504	1,716	-101.8977	48.8881
3307500763	6624	1,715	-101.6418	48.8029
3307500766	6684	1,713	-101.6622	48.8050
3307500769	6749	1,645	-101.9415	48.9705
3307500798	7577	1,842	-101.7741	48.6857
3307501300	14429	1,773	-101.7836	48.9211
3307501312	14725	1,811	-101.9704	48.9558
3307501314	14758	1,823	-101.9824	48.9701
3307501325	14970	1,558	-101.1554	48.4961
3307501397	17317	1,646	-101.9443	48.9625
3307501398	17467	1,826	-101.9804	48.9716
Rolette County				
3307900001	83	1,627	-100.0867	48.7569
3307900002	316	1,691	-99.6642	48.6666
3307900051	13586	1,603	-99.9091	48.6156
3307900057	16095	1,721	-99.9168	48.7892
Sheridan County				
3308300002	665	1,792	-100.3335	47.6446
3308300003	684	1,849	-100.1632	47.5870
3308300004	693	1,984	-100.4137	47.4453
3308300005	735	1,994	-100.1152	47.4597
3308300014	9343	2,007	-100.3930	47.4422
Sioux County				
3308500001	631	1,731	-100.7238	46.1371
Slope County				
3308700104	8629	2,656	-102.9698	46.5496
3308700108	9244	2,780	-102.9546	46.6218
3308700120	11484	2,733	-102.9390	46.4951
Stark County				
3308900215	6447	2,496	-102.9548	46.8715
3308900242	8088	2,165	-102.4696	47.0085
3308900246	8169	2,372	-102.2985	46.7590

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General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
3308900249	8342	2,418	-102.6190	46.9018
3308900253	8665	2,339	-102.2983	46.7084
3308900254	8837	2,678	-102.6929	46.6751
3308900256	9056	2,436	-102.3614	46.8420
3308900259	9135	2,361	-102.1623	46.7427
3308900261	9256	2,458	-102.3768	46.8530
3308900262	9257	2,451	-102.3404	46.8380
3308900264	9322	2,633	-102.8135	46.8196
3308900266	9348	2,425	-102.3332	46.8224
3308900270	9407	2,391	-102.3217	46.8084
3308900274	9475	2,320	-102.4800	46.9308
3308900279	9684	2,755	-102.9065	46.7294
3308900306	10430	2,379	-102.2358	46.6435
3308900313	10570	2,534	-102.7316	46.7930
3308900397	13447	2,514	-102.8288	46.8987
3308900537	14652	2,719	-102.7089	46.6609
Steele County				
3309100002	8027	1,398	-97.8063	47.6246
3309100007	9922	1,303	-97.7883	47.2636
Stutsman County				
3309300001	40	1,870	-99.1401	47.0501
3309300003	120	1,493	-98.6707	47.1043
3309300004	134	1,552	-98.8978	47.1191
3309300005	370	1,673	-98.9023	46.9335
3309300006	406	1,576	-98.9063	46.9342
3309300008	644	1,945	-99.2811	46.8795
3309300009	668	1,907	-99.0836	46.6468
3309300010	669	1,880	-99.2292	46.8067
3309300012	671	1,900	-99.0855	46.9551
3309300013	672	1,867	-99.0867	46.8753
3309300021	7415	2,001	-99.1360	46.6578
3309300022	9776	1,545	-98.6868	47.2131
Towner County				
3309500002	171	1,597	-99.1179	48.9480
3309500003	194	1,499	-99.0656	48.4157
3309500004	227	1,465	-99.2240	48.4594
Ward County				
3310100004	47	1,595	-101.0494	48.2272
3310100235	7612	2,219	-101.8486	48.2417
3310100319	11055	1,612	-101.1354	48.3253
Wells County				
3310300001	207	1,933	-99.9499	47.4305
3310300006	609	1,612	-99.6793	47.6331

North Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
3310300008	642	1,599	-99.6480	47.7727
3310300009	689	1,702	-99.7591	47.5138
3310300010	1211	1,608	-99.3539	47.4848
3310300023	11599	1,857	-99.5901	47.3521
3310300024	11653	1,609	-99.5488	47.5993
3310300025	11654	1,620	-99.5710	47.7136
Williams County				
3310500495	1231	2,316	-102.9836	48.2802
3310500518	1385	2,360	-102.9087	48.3309
3310500519	1403	2,165	-103.0072	48.2505
3310500529	1514	2,286	-103.0050	48.2946
3310500534	1636	2,401	-102.9307	48.3311
3310500655	3844	2,370	-102.9605	48.2714
3310500665	4321	2,457	-102.9043	48.4649
3310500666	4323	2,460	-102.9213	48.4790
3310500682	4618	2,413	-103.9634	48.3409
3310500686	4716	2,294	-102.9948	48.2660
3310500696	5069	2,345	-102.9730	48.2949
3310500753	6098	2,022	-102.8745	48.1920
3310500768	6478	1,910	-103.5803	48.2719
3310500798	7005	2,333	-102.9619	48.2373
3310500853	7848	2,140	-103.5657	48.5372
3310500901	8316	2,157	-103.9146	48.5919
3310500934	8692	2,074	-103.5229	48.5705
3310500975	9100	2,119	-103.5778	48.6114
3310501044	9800	2,277	-103.1977	48.4795
3310501114	10772	2,475	-102.9662	48.5070
3310501291	12119	2,373	-102.9038	48.5228
3310501321	12270	2,369	-102.8997	48.5295
3310501324	12305	2,399	-102.9593	48.3395
3310501340	12363	2,365	-102.9204	48.4250
3310501346	12432	2,354	-102.9804	48.2705
3310501369	12592	2,349	-102.9508	48.3329
3310501389	12831	2,352	-103.0049	48.3163
3310501397	12971	2,417	-102.9333	48.3184
3310501411	13395	2,327	-102.9821	48.2777
3310501423	13682	2,341	-102.9898	48.3074
3310501429	13893	2,011	-103.0189	48.2086
3310501629	16629	2,291	-103.1159	48.3674
3310501691	17488	2,356	-103.1408	48.3997
3310501787	18631	2,197	-103.0059	48.2518
3310501794	18680	2,390	-102.9735	48.2563

Montana

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Carter County				
2501105004	MT1	3,557	-104.6379	45.0177
2501105009	MT2	3,559	-104.2688	45.0497
2501105064	MT3	3,708	-104.7403	45.3029
2501105065	MT4	3,684	-104.6420	45.3038
2501105082	MT5	3,365	-104.0808	45.7900
2501105091	MT6	3,160	-104.1787	45.9669
2501121279	MT7	3,149	-104.1530	45.9308
2501121323	MT8	3,375	-104.2699	45.4236
Custer County				
2501705018	MT9	3,017	-105.3243	45.8771
Daniels County				
2501921127	MT10	2,986	-105.8607	48.8117
Dawson County				
2502105101	MT11	2,258	-104.8076	47.0590
2502105124	MT12	2,390	-104.8983	47.1282
2502121057	MT13	2,579	-105.0721	47.6616
2502121059	MT14	2,245	-105.3235	47.6401
2502121082	MT15	2,725	-104.6305	47.6097
Fallon County				
2502505326	MT16	2,999	-104.3187	46.4312
2502505543	MT17	2,743	-104.4524	46.6250
McCone County				
2505505019	MT18	2,499	-105.5640	47.6253
Powder River County				
2507522030	MT19	2,937	-105.1127	45.7858
Richland County				
2508305016	MT20	2,337	-104.7137	47.8798
2508321201	MT21	1,909	-104.0908	47.7381
2508321244	MT22	1,953	-104.2425	47.6036
2508321320	MT23	2,466	-104.6604	47.7485
2508321516	MT24	2,244	-104.2418	47.7057
2508321866	MT25	2,495	-104.8468	47.7380
Roosevelt County				
2508521406	MT26	1,975	-104.2324	48.1469
2508521596	MT27	2,058	-104.2199	48.1840
Sheridan County				
2509105059	MT28	2,530	-104.9644	48.7205
2509105095	MT29	2,442	-104.8773	48.8291
2509105098	MT30	2,324	-104.7964	48.8327
2509121004	MT31	2,140	-104.4309	48.5819
2509121222	MT32	2,052	-104.4237	48.5079
2509121247	MT33	2,089	-104.4133	48.5155

Montana

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
2509121250	MT34	2,018	-104.4242	48.5024
2509121386	MT35	1,982	-104.4632	48.5708
2509121597	MT36	2,125	-104.6306	48.4781
2509121748	MT37	2,341	-104.8883	48.9803
Valley County				
2510521396	MT38	2,278	-106.3855	48.2467
Wibaux County				
2510905125	MT39	3,132	-104.1532	46.7522
2510921024	MT40	3,172	-104.0841	46.7085
2510921027	MT41	3,179	-104.0789	46.6731
2510921039	MT42	2,848	-104.1396	46.9338
2510921047	MT43	2,348	-104.2748	47.2424
2510921053	MT44	2,556	-104.2533	47.2843
2510921058	MT45	2,663	-104.5264	46.6905
2510921083	MT46	2,967	-104.2992	46.8435

South Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Bon Homme County				
4000905000	SD1	1,376	-97.8512	42.8803
4000905001	SD2	1,326	-97.9140	42.8803
Butte County				
4001905008	SD3	2,901	-103.4551	44.6674
4001905014	SD4	2,873	-103.1171	44.7482
4001905015	SD5	2,860	-103.0626	44.7612
4001905018	SD6	3,293	-103.9662	44.8124
4001905020	SD7	3,239	-103.8870	45.0411
4001905021	SD8	3,337	-103.8722	45.1492
4001905022	SD9	3,029	-103.6395	45.2053
4001920006	SD10	3,094	-103.8712	44.9991
4001920036	SD11	3,388	-103.8272	45.0872
4001920066	SD12	2,924	-103.6907	44.6612
Corson County				
4003105004	SD13	2,480	-101.7393	45.8834
4003105005	SD14	2,380	-101.4142	45.9365
4003120015	SD15	2,330	-101.3056	45.9363
4003120018	SD16	2,173	-101.5433	45.8173
4003120021	SD17	2,314	-101.7394	45.7482
4003120022	SD18	2,271	-101.5631	45.8712
4003120023	SD19	2,332	-101.7806	45.7885
4003120024	SD20	2,421	-101.5500	45.4850
Dewey County				
4004105000	SD21	2,356	-101.4640	45.0428
4004105003	SD22	2,300	-101.4271	45.0690
4004105004	SD23	2,280	-101.3655	45.3150
4004120001	SD24	2,319	-100.7691	45.0943
4004120006	SD25	2,251	-101.4486	45.0691
4004120030	SD26	2,173	-101.0201	45.4314
4004120031	SD27	2,138	-100.9329	45.4347
Fall River County				
4004705004	SD28	3,658	-103.4315	43.0273
4004705029	SD29	3,390	-103.2162	43.1461
4004705031	SD30	3,332	-103.1212	43.1487
4004720080	SD31	3,537	-103.6540	43.0413
4004720105	SD32	4,024	-104.0116	43.0316
4004720242	SD33	3,808	-103.9242	43.1811
Faulk County				
4004905000	SD34	1,940	-99.5336	45.0268
Gregory County				
4005320001	SD35	2,071	-99.4181	43.3262
4005320002	SD36	2,117	-99.2955	43.2287

South Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Haakon County				
4005505000	SD37	2,632	-101.8448	44.1704
4005505001	SD38	2,466	-101.5004	44.2498
4005505053	SD39	2,238	-101.3645	44.2425
4005505054	SD40	2,213	-101.2701	44.2681
4005520001	SD41	2,158	-101.5255	44.4355
4005520002	SD42	2,381	-101.6451	44.3286
Harding County				
4006305001	SD43	3,332	-103.8976	45.2152
4006305007	SD44	3,948	-103.9373	45.4174
4006305008	SD45	3,135	-103.6415	45.4380
4006305009	SD46	3,442	-103.9529	45.4604
4006305010	SD47	3,277	-103.9633	45.4825
4006305012	SD48	3,038	-103.5989	45.4857
4006305013	SD49	3,040	-103.0966	45.5147
4006305014	SD50	3,174	-103.9686	45.5151
4006305026	SD51	3,247	-103.7276	45.7280
4006305033	SD52	3,220	-103.7510	45.7604
4006305034	SD53	3,175	-104.0144	45.7606
4006305067	SD54	3,047	-103.8331	45.8907
4006320083	SD55	3,067	-103.7649	45.2550
4006320103	SD56	2,950	-103.4313	45.9435
4006320155	SD57	2,995	-103.5701	45.7926
4006320183	SD58	2,855	-103.4551	45.5835
4006320211	SD59	2,881	-103.4399	45.7634
4006320213	SD60	3,103	-103.9536	45.6407
Hughes County				
4006505002	SD61	1,718	-99.9494	44.4818
Hyde County				
4006905000	SD62	1,870	-99.6709	44.8180
4006905002	SD63	1,889	-99.5605	44.8469
Jackson County				
4007105001	SD64	2,332	-101.1575	43.8705
4007120001	SD65	2,407	-101.8325	43.8121
Jones County				
4007505000	SD66	2,080	-100.6285	43.7794
4007505003	SD67	1,920	-101.0146	44.1448
4007505054	SD68	2,071	-100.6134	44.0543
4007505056	SD69	2,132	-100.4449	43.8482
4007505057	SD70	2,012	-100.5448	43.8193
Lawrence County				
4008105000	SD71	3,690	-103.6778	44.5349

South Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Lyman County				
4008520001	SD72	1,840	-99.9964	43.7156
4008520002	SD73	1,850	-99.3927	43.5404
Meade County				
4009305032	SD74	2,788	-102.5241	44.5230
4009320020	SD75	2,630	-102.3939	44.7939
4009320025	SD76	2,592	-102.8707	44.5670
Mellette County				
4009505000	SD77	1,828	-100.7448	43.7058
4009505051	SD78	1,932	-100.7380	43.6826
Miner County				
4009705000	SD79	1,547	-97.6115	44.1359
Pennington County				
4010320006	SD80	2,458	-102.1810	43.7142
4010320012	SD81	2,677	-102.1395	44.1731
4010320015	SD82	2,620	-102.0255	44.1522
Perkins County				
4010505001	SD83	2,570	-102.1789	45.1097
4010505003	SD84	2,670	-102.3161	45.4455
4010505004	SD85	2,558	-102.0736	45.6230
4010505005	SD86	2,766	-102.5880	45.6954
4010505006	SD87	2,628	-102.3449	45.7595
4010505066	SD88	2,690	-102.7845	45.8832
4010520016	SD89	2,571	-102.0895	45.6011
Potter County				
4010705000	SD90	1,867	-100.2332	44.9978
4010705001	SD91	1,899	-100.2435	45.0992
Oglala Lakota (Shannon) County				
4011320004	SD92	3,401	-102.9359	43.0587
Spink County				
4011505001	SD93	1,285	-98.4136	44.9123
Stanley County				
4011705000	SD94	2,035	-101.0846	44.2099
4011705001	SD95	1,862	-100.8011	44.3493
4011705002	SD96	1,990	-100.6941	44.3627
4011705003	SD97	1,814	-100.5695	44.3989
4011705006	SD98	2,186	-100.8707	44.4862
4011705063	SD99	1,816	-100.8341	44.2358
4011705064	SD100	1,848	-100.7442	44.3254
4011705065	SD101	1,700	-100.9663	44.6417
4011720018	SD102	1,977	-100.7651	44.4065

South Dakota

General Well Information

American Petroleum Institute Number	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
Tripp County				
4012305000	SD103	2,365	-99.9512	43.0026
4012305001	SD104	2,289	-99.7478	43.1636
4012305002	SD105	2,335	-100.0497	43.2933
4012305003	SD106	2,165	-100.1295	43.3629
Walworth County				
4012905000	SD107	1,881	-100.1181	45.3026
4012905002	SD108	2,064	-99.9571	45.4258
Ziebach County				
4013705004	SD109	2,546	-101.7032	45.0765

Manitoba

General Well Information

Unique Well Identifier	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
100161600127W100	486	1,497	-101.0295	49.0422
100081500220W100	1537	1,914	-100.0638	49.1234
100022001124W100	1563	1,503	-100.7218	49.9329
100093500525W100	1666	1,425	-100.7395	49.4378
100163400629W100	2523	1,667	-101.3050	49.5301
100162901229W100	2532	1,721	-101.4048	50.0471
100112900125W100	2543	1,555	-100.7925	49.0681
100063400524W100	2593	1,442	-100.6351	49.4353
100090600226W100	2610	1,440	-100.9393	49.0976
100012800524W100	2612	1,450	-100.6511	49.4179
100021700425W100	2683	1,492	-100.8119	49.2974
100042500626W100	2695	1,431	-100.8692	49.5043
100081300529W100	2696	1,604	-101.2588	49.3900
100043200325W100	2700	1,521	-100.8243	49.2541
100083100223W100	2706	1,648	-100.5341	49.1681
100151101226W100	2741	1,490	-100.9284	50.0030
100052400226W100	2766	1,551	-100.8435	49.1384
100053300727W100	3183	1,482	-101.0955	49.6123
100011800825W100	3530	1,429	-100.8513	49.6525
102093200925W100	4495	1,441	-100.8277	49.7930
102083100223W100	4845	1,649	-100.5357	49.1683
100012500423W100	4859	1,646	-100.4457	49.3275
102161000928W100	5956	1,596	-101.1935	49.7366

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General Well Information

Unique Well Identifier	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
131111400710W200	00C037	1,980	-103.2646	49.5615
131070401109W200	00D072	2,128	-103.1757	49.8794
121122800519W200	00F396	2,392	-104.5147	49.4142
121152300923W200	00J189	2,388	-105.0188	49.7523
141031101016W200	01A024	1,887	-104.0728	49.8023
131060200321W200	01H069	2,532	-104.7318	49.1795
111070400507W200	01J006	1,964	-102.8864	49.3528
121120400421W200	01L133	2,470	-104.7828	49.2690
142112400910W200	02A161	2,018	-103.2373	49.7510
111030100425W200	02B012	2,307	-105.2458	49.2624
132021300711W200	02I016	1,997	-103.3699	49.5540
123091300711W200	02K012	1,997	-103.3643	49.5599
121150500507W200	03K283	1,966	-102.9114	49.3596
131151700716W200	03L284	2,025	-104.1385	49.5654
121150800507W200	04B015	1,968	-102.9122	49.3748
121120300320W200	05F018	2,406	-104.6271	49.1813
131151500709W200	06E087	2,013	-103.1453	49.5678
121090401011W200	07I073	2,021	-103.4341	49.7933
101043100601W200	08H567	1,972	-102.1377	49.5100
101130402508W300	50I013	2,166	-107.0713	51.1089
101050701410W300	51C004	2,654	-107.3670	50.1552
101151200321W200	51E001	2,520	-104.7044	49.2005
101103201803W300	51L011	2,217	-106.3800	50.5664
101133600112W300	51L083	2,686	-107.4944	49.0851
101160400332W100	52A006	1,690	-101.7336	49.1908
121150602310W200	52G001	2,206	-103.3960	50.9581
101163400706W200	53J044	2,012	-102.7313	49.6080
101053002301W300	54F047	1,917	-106.1409	50.9852
101012902311W300	54J036	2,411	-107.4957	50.9817
101122900202W200	55A052	1,722	-102.2490	49.1556
101053100211W300	55E024	2,735	-107.4723	49.1654
101102600113W300	55F097	2,692	-107.6391	49.0671
101031800332W100	55J059	1,733	-101.7900	49.2095
101150700308W200	56B004	1,923	-103.0681	49.2006
101120600503W200	56C013	1,938	-102.4068	49.3573
101092701410W300	56E085	2,591	-107.2817	50.2026
101032700808W200	56G008	2,058	-103.0135	49.6701
101061300219W200	57G023	2,459	-104.4235	49.1215
101012800326W200	57H002	2,749	-105.4376	49.2336
131093400304W200	57K043	1,935	-102.4577	49.2559
101043100127W200	58B029	2,734	-105.6087	49.0743
101021101526W200	58I075		-105.4748	50.2383
101061500922W200	58L009	2,429	-104.9105	49.7320

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General Well Information

Unique Well Identifier	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
101120601901W300	59B006	1,962	-106.1401	50.5812
101062701506W300	59G074		-106.7524	50.2863
101121000508W300	59L036	2,839	-107.0120	49.3725
101100300508w300	61I046		-107.0016	49.3585
101121201014W200	62B005	1,990	-103.7870	49.8084
101031001714W300	62H013	2,393	-107.8523	50.4137
141020700508W300	64K049	2,729	-107.0673	49.3662
101081701814W300	65C083		-107.8867	50.5193
101123300523W200	65F053	2,330	-105.0519	49.4301
101083000833W100	65K031	2,121	-101.9430	49.6833
101122800730W100	66A088	1,868	-101.5053	49.6009
101010600204W200	66F117	1,866	-102.5238	49.0898
101060500822W200	66I002	2,341	-104.9551	49.6161
101042201033W100	66J002	2,092	-101.8918	49.8429
101090500328W200	68B016	2,631	-105.7296	49.1829
101020400411W200	68F041	1,862	-103.4269	49.2626
121070901714W300	72I017	2,385	-107.8695	50.4173
101061100421W200	72K044	2,540	-104.7320	49.2804
101093500517W200	77H008	2,067	-104.1836	49.4299
101060300119W200	77J053	2,343	-104.4678	49.0052
101132400203W200	77J057	1,872	-102.2935	49.1441
101043200220W200	77L016	2,399	-104.6513	49.1611
141093100408W200	78B008	1,961	-103.0616	49.3432
101110800603W200	78C001	1,955	-102.3783	49.4592
111080200616W200	78H158	2,054	-104.0472	49.4398
131030801719W200	78L010	1,906	-104.5866	50.4132
141161900132W100	80B006	1,702	-101.7446	49.0569
101163600118W200	80F005	2,371	-104.2795	49.0854
121020700131W100	80G001	1,655	-101.6172	49.0148
101101800519W200	80I101	2,385	-104.5481	49.3860
101091100530W100	81H036	1,699	-101.4177	49.3792
101023400132W100	82D001	1,681	-101.6840	49.0747
101031600210W200	82I080	1,918	-103.2882	49.1175
121121301231W100	85B130	1,898	-101.6050	50.0139
141030800111W200	85B212	1,975	-103.4426	49.0160
111092900606W200	87G102	1,981	-102.7699	49.5021
111152900606W200	87L059	1,979	-102.7758	49.5059
101030600606W200	88D019	1,971	-102.8045	49.4371
101072800404W200	88K071	1,944	-102.4858	49.3247
121021400505W200	88L062	1,953	-102.5768	49.3782
101082001117W200	93D103	1,894	-104.2837	49.9214
141043500611W200	96B159	1,999	-103.3924	49.5109
121132100611W200	96E028	1,975	-103.4394	49.4916

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General Well Information

Unique Well Identifier	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
111153400611W200	96E124	2,008	-103.4022	49.5205
191151200611W200	96E258	1,985	-103.3602	49.4659
101120200711W200	96F283	2,009	-103.4036	49.5312
131012900611W200	96G281	1,985	-103.4454	49.4970
131113500611W200	96G312	1,999	-103.3884	49.5174
131113400611W200	96I068	2,017	-103.4124	49.5191
141102900611W200	96I131	1,987	-103.4490	49.5044
111070300711W200	96I227	2,006	-103.4134	49.5274
121072900611W200	96J008	1,984	-103.4509	49.4988
121070200711W200	96J367	1,999	-103.3922	49.5269
141021000711W200	96K164	2,000	-103.4122	49.5402
111152000711W200	96L066	2,018	-103.4590	49.5779
111092800611W200	96L309	1,997	-103.4202	49.5027
121132400505W200	97A128	1,961	-102.5649	49.4033
111091800711W200	97B227	2,026	-103.4750	49.5605
141070100934W100	97C251	2,166	-101.9689	49.7134
132113200611W200	97C300	1,993	-103.4572	49.5180
121101400911W200	97E002	2,010	-103.3942	49.7341
131142900509W200	97E046	1,969	-103.1860	49.4195
111122100711W200	97E081	2,016	-103.4464	49.5739
131071500611W200	97E085	1,960	-103.4027	49.4700
111111600707W200	97E213	2,003	-102.9000	49.5601
131081400407W200	97F067	1,947	-102.8393	49.2964
131083400611W200	97F120	2,003	-103.4011	49.5125
141012200419W200	97F182	2,479	-104.4734	49.3073
141053401208W200	97F195	2,192	-103.0239	50.0395
191070201009W200	97F392	2,051	-103.1226	49.7924
101080300711W200	97G199	2,016	-103.4093	49.5285
101141600711W200	97G315	2,017	-103.4427	49.5647
141043500705W200	97G432	1,982	-102.5883	49.5973
141041600613W200	97G483	1,906	-103.7066	49.4676
131023200810W200	97H295	2,018	-103.3252	49.6850
121160900711W200	97I354	2,014	-103.4333	49.5497
131032700132W100	97I431	1,649	-101.6906	49.0604
111162300201W200	97I438	1,830	-102.0303	49.1439
191051600910W200	97J331	2,029	-103.3132	49.7320
101012800810W200	97K205	2,021	-103.2953	49.6700
131040100913W200	97L095	2,017	-103.6518	49.7000
141070200913W200	97L298	2,010	-103.6612	49.7039
131121101209W200	97L301	2,125	-103.1414	49.9840
121052300813W200	97L305	1,979	-103.6746	49.6583
101010500619W200	97L327	2,429	-104.5201	49.4376
111150400710W200	97L361	1,996	-103.2990	49.5339

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General Well Information

Unique Well Identifier	Well Label	Kelly Bushing Elevation (ft)	Longitude	Latitude
141081700910W200	98A033	2,022	-103.3178	49.7334
141030700901W200	98A073	2,254	-102.1322	49.7146
101152400902W200	98A081	2,372	-102.1505	49.7537
141143200909W200	98A149	2,079	-103.1938	49.7830
111140600606W200	98A228	1,966	-102.8033	49.4474
111040401208W200	98B015	2,164	-103.0465	49.9610
121082200407W200	98B191	1,950	-102.8630	49.3082
132133600909W200	98B210	2,055	-103.1108	49.7836
132070201009W200	98C138	2,062	-103.1218	49.7913
111042400717W200	98C155	2,091	-104.1923	49.5681
111041401105W200	98C263	2,479	-102.5923	49.9028
131021800621W200	98C298	2,502	-104.8181	49.4670
101031800901W200	98D041	2,297	-102.1335	49.7285
142111200620W200	98E160	2,323	-104.5743	49.4591
142120101009W200	98E189	2,063	-103.1068	49.7944
121011901210W200	98G073	2,137	-103.3515	50.0049
121163201110W200	98G075	2,228	-103.3304	49.9571
101032701109W200	98G108	2,077	-103.1566	49.9322
111081201211W200	98G193	2,221	-103.3728	49.9787
101093401211W200	98G201	2,165	-103.4186	50.0421
121051101114W200	98H036	1,983	-103.8240	49.8914
101162301211W200	98H069	2,165	-103.3962	50.0163
141101800520W200	98K067	2,513	-104.6819	49.3879
111050800619W200	98K107	2,404	-104.5347	49.4548
111110200913W200	99A081	2,013	-103.6676	49.7058
101150200621W200	99C003	2,499	-104.7267	49.4484
102092600602W200	99C054	1,978	-102.1658	49.5022
131012701114W200	99E132	1,987	-103.8297	49.9339
141081400606W200	99E245	1,972	-102.7030	49.4705
141072400809W200	99F392	2,024	-103.0968	49.6597
111163300813W200	99G151	1,980	-103.7020	49.6945
121032400707W200	99I286	1,994	-102.8338	49.5689
121091300222W200	99J213	2,498	-104.8158	49.1246
121041501208W200	99K055	2,195	-103.0275	49.9903
133030600521W200	99K079	2,459	-104.8220	49.3511
141103000421W200	99L128	2,464	-104.8156	49.3285

Appendix B
Formation Tops

The formation tops were picked when possible for the Red River Formation, Roughlock Formation, Icebox Formation, Black Island Formation, and Members F through A of the Deadwood Formation, as well as the Precambrian basement rock.

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Adams County												
6322	8,268.8	8,816.3	8,878.1			8,991.0	9,014.3	9,092.7	9,258.0	9,399.4		9,463.7
7642	9,075.4	9,626.7	9,660.8			9,778.4	9,798.5	9,886.0				
Barnes County												
4640	1,495.0	1,691.6	1,775.8	1,914.6							1,928.5	
Benson County												
632	4,300.9	4,840.9	4,916.0	5,042.6							5,091.2	5,142.0
Billings County												
291	12,220.5	12,780.2	12,814.0	12,925.4		12,959.3	13,122.0	13,240.0				
3268	11,902.0	12,470.2	12,485.5	12,593.5		12,631.0	12,805.0	12,892.0	13,144.0	13,352.0		13,509.0
6228	13,476.7	14,110.4	14,150.7	14,282.0	14,359.0	14,393.0	14,605.3	14,773.0	15,002.0	15,208.4		15,265.0
6303	12,781.9	13,372.0	13,396.0	13,512.8		13,566.4	13,729.7	13,873.7	14,072.0	14,224.6		14,257.4
6913	13,451.4	14,053.5	14,093.8	14,215.6		14,272.1						
7307	13,463.1	14,070.2	14,110.3	14,226.2	14,277.5							
7520	13,417.5	14,034.7	14,066.6	14,182.6		14,244.5						
7934	12,817.4	13,412.8	13,442.8	13,553.9		13,603.0	13,752.1	13,915.8	14,152.0	14,314.0		14,389.0
8226	12,937.9	13,539.9	13,573.0	13,687.6		13,740.8						
8487	12,448.5	13,029.7	13,059.6	13,170.8		13,225.3						
8603	12,824.3	13,405.4	13,440.5	13,552.9		13,598.0						
9070	12,654.3	13,216.9	13,251.2	13,358.0		13,400.0						
11335	11,694.0	12,254.2	12,272.0	12,375.7		12,412.0	12,543.0					
14763	12,506.2	13,064.5	13,102.4	13,203.5		13,244.5						
Bottineau County												
38	7,239.0	7,767.9	7,846.6	7,966.3					8,046.8	8,193.7		8,226.0
64	5,608.3	6,115.0	6,189.6	6,282.5							6,337.0	6,407.0
110	5,654.3	6,166.2	6,216.8	6,338.0							6,382.0	6,423.6
2219	6,371.8	6,918.5	6,963.0	7,085.1							7,138.0	7,258.0
4655	5,948.0	6,408.1	6,467.0	6,588.9								6,602.0
4790	7,321.4	7,857.5	7,915.4	8,042.4				8,119.9				
4846	6,659.5	7,178.7	7,219.9	7,350.7							7,424.4	7,553.9
5184	5,556.9	6,083.2	6,127.9	6,239.3							6,305.0	6,360.0
9522	5,757.1	6,296.8	6,339.9	6,465.8							6,510.0	6,604.0
Bowman County												
485	9,157.8	9,678.0	9,712.2			9,799.6	9,826.0	9,918.0				
1575	8,198.5	8,663.0	8,741.5			8,839.0	8,857.1	8,949.0				
9656	10,130.5	10,651.7	10,693.0			10,797.0						
9805	9,147.2	9,662.7	9,689.7			9,783.0	9,797.0	9,908.9				
14851	8,931.8	9,444.2	9,469.3				9,559.0	9,639.8				
Burke County												
8893	9,854.0	10,385.9	10,425.4	10,516.5					10,773.6	10,844.5		10,880.5
15137	11,213.4	11,729.6	11,759.5	11,886.0				12,036.2	12,224.6	12,420.0		12,470.6

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Burleigh County												
19	5,851.6	6,453.6	6,536.7	6,665.4			6,686.7	6,743.3	6,831.7	6,894.7		6,950.0
145	5,023.7	5,589.1	5,679.5	5,800.1			5,828.4	5,861.8	5,962.0	6,050.0		6,170.0
151	6,898.5	7,529.8	7,595.4	7,717.6		7,715.0	7,776.9	7,826.0	7,944.9	8,061.0		8,092.0
155	5,080.9	5,603.1	5,732.0	5,860.3				5,883.5			5,981.6	6,144.0
174	5,776.8	6,320.5	6,399.7	6,575.9				6,642.7	6,727.2			
701	5,401.8	5,932.8	6,019.6	6,201.8				6,219.5			6,256.6	
756	5,314.5	5,858.1	5,913.5	6,105.2				6,131.0				
763	6,049.2	6,611.0	6,699.0	6,866.2				6,875.8				
765	5,876.9	6,435.7	6,510.5	6,675.7				6,710.1				
772	6,361.9	6,964.7	7,009.9	7,179.0			7,205.7					
1409	5,709.0	6,282.5	6,330.7	6,504.5				6,559.7				
6264	5,271.1	5,841.6	5,902.8	6,068.3				6,113.8			6,204.7	
7010	5,669.5	6,280.0	6,336.8	6,465.2			6,481.1	6,517.0	6,649.1	6,739.0		6,758.9
8674	5,623.9	6,250.4	6,297.8	6,421.5			6,444.8	6,500.4	6,569.6	6,646.7		6,698.9
12057	6,872.4	7,494.4	7,574.1	7,697.5				7,769.0				
Cavalier County												
27	2,680.0	3,203.7	3,267.5	3,393.3								3,406.6
Dickey County												
682	1,255.8	1,623.2	1,718.0	1,807.8							1,879.4	
1394	2,460.6	2,833.1	2,918.3	3,003.3							3,060.0	3,147.0
Divide County												
2010	10,388.8	10,788.9	10,823.8	10,900.0				11,036.5				
6798	11,113.0	11,630.3	11,662.8	11,779.5				11,908.0	12,104.0	12,251.0		12,350.0
7087	10,546.9	11,028.5	11,062.2	11,177.6				11,300.0	11,460.0	11,671.0		11,783.3
7942	12,227.9	12,742.8	12,771.0	12,901.0			13,062.0	13,150.4	13,380.0	13,480.0		13,616.0
9398	10,745.1	11,196.1	11,218.6	11,284.5				11,423.9				
9413	10,673.2	11,146.8	11,181.5	11,248.6				11,393.4				
9622	10,537.8	11,012.0	11,042.4	11,108.9				11,258.0				
9677	10,437.0	10,902.1	10,926.7	10,993.2				11,138.0				
Dunn County												
6086	13,250.0	13,868.9	13,929.7	14,036.1	14,185.0							
6148	12,610.1	13,229.7	13,276.2	13,392.2	13,440.0	13,480.0						
6530	12,440.1	13,059.8	13,108.5	13,228.9	13,280.0	13,312.0	13,567.0					
7402	11,876.6	12,524.1	12,576.3	12,703.3	12,823.1	12,888.5	13,107.3					
7412	12,982.6	13,644.8	13,677.4	13,798.2	13,921.3							
7584	13,480.7	14,131.7	14,175.6	14,309.6	14,426.0	14,465.0						
8077	13,898.8	14,564.1	14,597.2	14,735.9	14,904.7							
8095	13,969.0	14,647.0	14,680.0	14,822.0	15,040.0							
8313	12,848.5	13,493.2	13,542.9	13,666.8	13,824.0							
8491	12,800.7	13,424.0	13,464.7	13,586.6	13,634.8	13,681.9						
8613	12,857.1	13,499.3	13,547.5	13,673.0	13,796.0							
8709	13,405.4	14,065.3	14,103.7	14,239.1	14,377.0							

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
9027	12,347.9	12,986.8	13,036.9	13,170.7	13,278.5	13,337.3						
9044	13,128.7	13,773.8	13,823.0	13,953.5	14,071.0							
9080	12,465.0	13,112.1	13,160.6	13,291.1	13,416.4	13,491.7						
9397	13,165.7	13,814.9	13,866.3	13,997.3	14,103.0							
9527	13,784.2	14,409.3	14,458.2	14,590.7	14,703.1	14,740.4						
10072	13,421.6	14,073.8	14,124.4	14,259.3	14,383.0							
10606	12,107.1	12,764.8	12,803.3	12,930.2	13,002.0							
10627	11,651.9	12,282.1	12,326.9	12,447.7	12,498.0	12,550.0						
11363	12,287.0	12,937.7	12,995.0	13,116.4	13,237.3	13,283.0						
12400	12,731.5	13,349.3	13,387.9	13,507.3	13,561.9							
14636	11,883.1	12,520.9	12,564.1	12,689.4	12,748.7	12,803.6						
Eddy County												
437	3,333.8	3,888.9	3,964.6	4,102.0							4,128.9	
768	2,999.8	3,551.8	3,618.3	3,751.0							3,784.1	
1274	2,273.7	2,784.0	2,891.8	3,032.2							3,040.7	3,085.8
7271	2,855.1	3,408.3	3,479.7	3,611.6							3,668.1	3,710.8
Emmons County												
16	4,289.9	4,849.7	4,911.0					5,063.3			5,161.4	
23	4,482.3	5,036.3	5,111.3	5,223.4				5,241.5			5,342.7	
43	4,742.4	5,324.3	5,399.5	5,530.2				5,546.3			5,678.2	
7101	4,320.5	4,870.4	4,900.0	5,067.1				5,082.2			5,194.2	
7146	4,513.1	5,094.7	5,173.6	5,299.0				5,317.2			5,422.3	5,591.8
7936	4,477.5	5,063.8	5,143.1	5,269.3				5,283.5			5,334.6	
10173	4,739.8	5,282.8	5,324.3	5,524.7				5,537.1			5,665.4	
Foster County												
287	2,290.8	2,802.9	2,902.8	3,042.2							3,054.0	3,106.0
295	2,033.1	2,572.5	2,654.0	2,790.3							2,803.0	2,862.0
334	2,458.8	2,978.4	3,058.3	3,194.2							3,212.9	
1105	2,770.8	3,289.6	3,386.8	3,515.3							3,523.0	
1112	2,930.8	3,524.3	3,565.9	3,699.8							3,711.0	
1227	2,477.5	2,927.3	3,034.6	3,185.7							3,202.8	
Golden Valley County												
410	12,404.0	12,943.5	13,002.6	13,118.5		13,161.4	13,305.4					
470	11,707.2	12,216.7	12,270.2	12,377.2		12,414.0	12,520.0	12,630.0				
6272	10,453.0	10,922.4	10,972.0	11,065.9		11,080.5	11,131.1	11,212.5	11,427.6	11,483.1		11,502.8
6513	11,813.8	12,328.3	12,379.1	12,480.6		12,520.0						
6563	11,424.2	11,946.8	11,985.1	12,084.1		12,118.0						
7969	11,580.6	12,064.1	12,115.9	12,246.5		12,282.4						
8590	12,227.8	12,779.9	12,826.9	12,931.5		12,967.5						
9148	11,343.2	11,838.0	11,903.5	12,007.1		12,038.0						
9540	11,722.5	12,215.0	12,295.8	12,399.3		12,432.9						

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Grand Forks County												
580	484.6	640.6	670.4	728.1							760.6	892.0
3191	267.2	553.1	654.5	766.8							794.5	
3204	251.0	320.6	358.6	413.9							467.9	
15343	722.8	842.9	911.7	958.1							1,087.0	1,157.4
Grant County												
5572	7,101.0	7,739.0	7,796.7	7,862.3		7,902.0	7,914.0	7,980.0	8,170.0			
6420	7,396.2	7,990.7	8,061.0			8,190.0	8,220.0	8,276.0				
6586	9,046.0	9,627.5	9,680.8	9,818.8		9,851.0	9,910.3	9,977.0	10,193.2	10,347.5		10,424.0
7020	9,515.7	10,140.9	10,188.1	10,316.5		10,358.7	10,478.4	10,550.7	10,752.5	10,930.8		10,956.5
8549	8,116.1	8,709.1	8,751.8	8,893.7		8,919.0	8,953.3	9,015.8	9,224.9	9,415.0		9,439.8
8680	7,503.3	8,089.4	8,129.3	8,272.5		8,280.8	8,289.6	8,364.5	8,540.0	8,752.3		8,815.8
Griggs County												
4719	1,959.8	2,503.3	2,571.5	2,633.8							2,722.0	2,773.0
9659	1,939.0	2,478.2	2,504.0	2,605.7							2,627.9	
Hettinger County												
5783	10,280.7	10,889.2	10,940.2	11,041.2		11,109.1	11,193.8	11,263.8	11,488.5	11,620.3		11,676.0
7075	9,416.6	9,974.2	10,032.8	10,155.6		10,167.9	10,220.5	10,290.5	10,505.8	10,693.9		10,725.1
7453	9,991.0	10,549.3	10,584.6	10,693.0		10,705.4	10,751.7	10,831.0	11,059.0	11,171.0		11,194.3
8312	10,386.5	10,975.0	11,020.0	11,133.6		11,148.4						
10522	10,663.2	11,253.6	11,287.9	11,416.2		11,434.9	11,530.8	11,632.1	11,793.0			
Kidder County												
24	4,582.2	5,151.3	5,226.2	5,360.7				5,371.4			5,471.5	
230	4,234.7	4,798.0	4,880.7	5,011.1							5,076.4	
748	5,025.6	5,544.7	5,621.7	5,804.5				5,825.5				
Logan County												
590	4,310.9	4,842.5	4,890.7	5,083.4				5,095.3				
1347	3,569.3	4,121.9	4,171.7	4,335.7							4,352.0	4,551.7
5523	4,239.9	4,807.3	4,865.7	5,001.6				5,011.2			5,088.3	5,276.4
McHenry County												
39	6,276.0	6,872.0	6,904.5	7,023.0							7,097.8	7,210.0
61	6,339.2	6,875.5	6,949.1	7,094.5							7,169.0	
8307	6,312.0	6,868.2	6,933.1	7,049.5							7,109.9	
8803	7,684.3	8,310.0	8,349.4	8,470.0				8,543.7			8,645.3	8,689.6
11922	6,364.0	6,921.4	6,974.7					7,095.2				
McIntosh County												
89	3,818.6	4,373.3	4,423.0	4,547.8							4,560.0	
620	2,738.2	3,245.8	3,303.5	3,449.5							3,460.0	
621	2,939.9	3,452.0	3,495.0	3,642.0							3,650.9	
622	3,005.8	3,564.1	3,628.9	3,754.8							3,767.0	
McKenzie County												
2373	13,109.1	13,762.2	13,810.6	13,966.0	14,243.9	14,397.0	14,577.0	14,763.0	14,978.0	15,047.0		15,120.0
6112	13,511.6	14,176.4	14,216.2	14,350.5	14,610.0							

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
6387	12,754.7	13,246.3	13,321.0	13,454.3		13,505.0	13,631.6	13,800.5	13,988.5	14,186.7		14,360.0
6414	12,786.1	13,284.5	13,365.7	13,475.0		13,550.0						
7571	13,766.8	14,408.3	14,463.3	14,611.7	14,848.0							
7572	13,704.0	14,341.9	14,394.3	14,540.2	14,779.7							
6387	12,754.7	13,246.3	13,321.0	13,454.3		13,505.0	13,631.6	13,800.5	13,988.5	14,186.7		14,360.0
6414	12,786.1	13,284.5	13,365.7	13,475.0		13,550.0						
7571	13,766.8	14,408.3	14,463.3	14,611.7	14,848.0							
7572	13,704.0	14,341.9	14,394.3	14,540.2	14,779.7							
7607	12,932.6	13,588.3	13,620.9	13,768.2	14,034.1	14,166.7						
7631	13,817.9	14,379.9	14,423.9	14,535.1		14,652.0						
7873	13,957.0	14,554.5	14,593.5	14,736.3		14,864.1						
7988	12,956.1	13,585.7	13,614.4	13,758.6	14,012.8							
8023	13,539.7	14,220.6	14,252.7	14,406.5	14,667.1							
8083	13,728.0	14,381.8	14,418.2	14,564.4	14,804.0							
8090	13,533.2	14,179.4	14,205.2	14,357.6	14,622.7							
8131	14,299.0	14,857.2	14,946.5	15,077.6		15,227.9						
8165	13,432.3	13,957.9	14,022.9	14,145.8		14,243.2						
8187	13,637.1	14,194.9	14,227.0	14,357.2		14,443.5	14,621.7	14,756.9	14,928.0			
8193	12,845.2	13,399.6	13,447.7	13,557.8		13,630.5						
8314	12,790.0	13,300.5	13,337.9	13,488.7		13,561.4	13,701.4	13,860.9	14,050.5	14,241.8		14,385.4
8468	13,023.6	13,599.0	13,648.7	13,762.6		13,836.7						
8546	12,544.8	13,068.1	13,115.2	13,228.9		13,320.5						
8663	13,684.2	14,304.2	14,350.2	14,489.7	14,613.1							
8737	13,144.1	13,697.3	13,750.9	13,864.5		13,946.0						
9004	13,937.0	14,488.8	14,568.5	14,695.0		14,798.7						
9005	13,090.1	13,691.9	13,724.4	13,841.5		13,911.5						
9217	14,000.0	14,649.2	14,698.2	14,835.2	15,032.0							
9901	13,180.3	13,723.0	13,774.5	13,886.8		13,967.7						
11110	13,688.0	14,347.0	14,369.3	14,517.7	14,783.2							
11619	12,906.1	13,494.1	13,527.2	13,643.4		13,714.3	13,888.8	14,037.1	14,209.0			
12345	14,049.0	14,692.2	14,741.3	14,879.2	15,107.7							
12589	13,415.0	14,093.1	14,124.6	14,271.3	14,561.9							
12699	13,614.2	14,206.8	14,246.2	14,364.6		14,433.6						
13405	13,140.0	13,799.5	13,839.4	13,978.3	14,255.5	14,399.1						
13647	13,225.4	13,871.4	13,924.4	14,069.6	14,342.6	14,488.0						
14399	13,673.8	14,325.0	14,364.7	14,512.7	14,751.3	14,919.5						
14724	12,947.5	13,559.2	13,609.1	13,758.6	14,008.9	14,155.6						
15915	13,917.0	14,575.8	14,616.6	14,761.7	14,965.1	15,086.5						
16376	13,820.5	14,473.9	14,504.1	14,651.3	14,907.9	15,058.6						
16523	13,494.5	14,150.0	14,175.3	14,319.9	14,580.8	14,719.6						
McLean County												
22	8,084.5	8,701.3	8,747.7	8,896.2		8,943.5	9,014.4					
49	8,010.4	8,589.1	8,639.0	8,774.9		8,821.5	8,865.0					

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
7783	12,572.9	13,219.6	13,268.0	13,406.9		13,576.7	13,819.2	13,899.8	14,101.4	14,174.4		
8060	12,206.0	12,852.3	12,906.8	13,041.2		13,189.8						
8711	7,724.9	8,340.4	8,413.1	8,530.8		8,573.4	8,619.3	8,646.0	8,749.0	8,809.8		8,843.0
8720	7,490.3	8,114.8	8,198.0	8,309.3		8,340.0	8,354.9	8,412.0	8,545.3	8,617.0		8,659.9
8993	7,732.7	8,338.3	8,406.1	8,519.2		8,552.4	8,574.7	8,610.0	8,694.2	8,740.2		8,784.0
Mercer County												
21	11,160.1	11,848.2	11,895.4	12,010.7	12,067.0	12,130.0	12,343.0					
8712	12,119.7	12,764.4	12,819.4	12,948.2		13,070.2						
Morton County												
26	6,494.5	7,117.4	7,169.3	7,303.4		7,328.3	7,354.0	7,440.0	7,574.0	7,724.0		7,758.0
1620	10,342.4	10,983.9	11,021.4	11,163.5	11,192.0							
3859	6,922.7	7,555.0	7,614.5	7,733.9		7,751.1	7,784.1	7,830.0	8,004.9	8,164.0		8,195.7
7340	9,860.1	10,495.8	10,540.2	10,674.5	10,716.1	10,758.9	10,910.8	10,972.8	11,164.6	11,295.1		11,341.1
7691	8,494.8	9,145.4	9,194.8	9,310.6		9,344.4	9,446.7	9,509.6	9,693.1	9,851.8		9,867.0
7797	8,927.8	9,558.9	9,615.4	9,733.5		9,761.0	9,852.4	9,912.0	10,081.3	10,172.0		
7937	8,574.4	9,170.8	9,229.2	9,331.5		9,353.7	9,420.3	9,485.6	9,690.1	9,918.0		9,955.4
8158	7,157.4	7,777.0	7,819.0	7,959.1		7,972.0	8,040.0	8,100.0				
8553	7,744.8	8,349.3	8,391.7	8,523.9		8,557.4	8,611.8	8,664.3	8,788.2	8,829.0		8,856.7
Mountrail County												
6780	11,950.0	12,570.0	12,617.8	12,752.6		12,899.6	13,111.4	13,165.5	13,343.7	13,407.8		13,454.0
6872	11,630.6	12,242.4	12,304.6	12,428.9		12,584.0	12,722.7	12,823.0	12,982.7	13,130.0		13,177.0
9326	12,890.3	13,485.4	13,539.3	13,674.1		13,879.3						
12597	12,836.8	13,416.3	13,464.4	13,604.1	13,840.4	13,862.6						
14815	12,033.1	12,668.9	12,731.4	12,856.5		13,005.2						
17058	12,347.0	12,979.5	13,037.9	13,169.4		13,339.1						
Nelson County												
4664	2,323.2	2,661.2	2,729.6	2,861.5							2,882.9	
4785	1,965.0	2,511.5	2,588.5	2,707.9							2,746.2	
9143	1,586.0	2,078.0	2,096.0	2,205.0							2,237.7	
Oliver County												
15	7,654.2	8,293.0	8,355.4	8,458.7		8,495.2	8,532.2	8,600.2	8,732.3	8,802.2		8,835.0
8144	7,762.0	8,365.7	8,409.1			8,586.6	8,630.3					
Pierce County												
435	3,840.0	4,343.0	4,414.4	4,538.7							4,578.6	
706	4,191.5	4,721.6	4,786.5	4,912.6							4,958.8	4,994.0
3920	5,123.6	5,683.4	5,758.4	5,886.2							5,935.6	
5576	4,964.6	5,533.5	5,593.2	5,722.2							5,770.6	
12125	4,672.3	5,178.4	5,236.5	5,324.0							5,359.6	5,386.0
Ramsey County												
20	2,487.0	3,010.4	3,091.7	3,210.0								3,219.0
196	2,952.1	3,474.6	3,559.2	3,688.4							3,706.0	3,728.0

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
383	2,536.0	3,052.3	3,135.4	3,246.5								3,264.5
407	2,463.6	3,004.3	3,073.2	3,206.7							3,226.7	
411	2,604.8	3,122.6	3,203.3	3,318.2								3,339.0
422	2,456.5	2,991.4	3,057.4	3,185.8								3,194.8
Renville County												
6296	8,749.0	9,254.0	9,289.0	9,415.8					9,452.3	9,553.9		9,650.7
6349	8,435.0	8,918.0	8,959.1	9,036.8					9,050.9			
6401	8,592.0	9,117.2	9,159.9	9,273.3					9,289.0	9,432.1		9,528.9
6436	8,709.0	9,219.0	9,256.7	9,385.0					9,408.5	9,513.4		
6466	8,505.0	8,997.0	9,031.9	9,143.0					9,198.6			
6473	8,757.3	9,281.4	9,328.0	9,432.8					9,466.4	9,621.7		9,690.7
6504	8,780.0	9,314.0	9,361.4	9,478.0				9,576.4	9,630.0	9,763.3		9,827.0
6624	8,340.0	8,876.0	8,927.0	9,037.6				9,131.0	9,187.0	9,298.5		9,308.0
6684	8,365.0	8,894.0	8,938.7	9,050.2				9,144.0	9,186.0	9,233.0		9,258.0
6749	8,440.0	8,912.0	8,952.2	9,049.1					9,096.1	9,255.6		9,381.2
7577	9,161.0	9,702.0	9,759.2	9,874.0				9,984.6	10,079.7	10,135.9		10,166.0
14429	8,331.5	8,868.6	8,908.6	9,024.6				9,111.8	9,167.1	9,279.4		9,355.0
14725	8,739.5	9,261.7	9,297.7	9,414.0					9,444.7	9,551.1		9,601.0
14758	8,727.9	9,233.3	9,267.2	9,364.5					9,381.4	9,469.6		9,559.7
14970	7,507.6	8,079.4	8,134.8	8,250.2				8,324.2			8,363.8	
17317	8,485.0	8,991.0	9,030.0	9,150.0					9,189.0	9,334.7		9,428.8
17467	8,697.9	9,221.4	9,243.5	9,356.3					9,384.5	9,478.9		9,583.0
Rolette County												
83	4,769.4	5,298.0	5,343.1	5,464.0							5,485.0	5,503.0
316	4,182.6	4,705.8	4,768.4	4,897.1							4,922.0	4,942.0
13586	4,526.0	5,066.0	5,123.8	5,246.2							5,270.7	
16095	4,672.0	5,242.0	5,260.2	5,422.0							5,608.0	5,686.0
Sheridan County												
665	5,956.8	6,537.7	6,612.2	6,732.1				6,760.8				
684	5,545.3	6,093.9	6,165.4	6,324.1							6,345.5	
693	6,270.2	6,871.9	6,957.8	7,089.2				7,114.8				
735	5,501.5	6,073.3	6,156.1	6,286.8							6,309.7	
9343	6,216.3	6,845.8	6,896.7	7,018.6				7,043.3			7,134.4	7,234.0
Sioux County												
631	5,048.3	5,607.3	5,655.1	5,824.6				5,836.6				
Slope County												
8629	11,006.4	11,592.5	11,628.0	11,733.2		11,755.9						
9244	11,383.6	11,964.8	12,001.0	12,107.3		12,135.2						
11484	10,842.7	11,429.1	11,464.3	11,572.5		11,594.8	11,656.5					
Stark County												
6447	11,859.5	12,459.0	12,497.5	12,610.1		12,645.3						
8088	11,550.5	12,190.8	12,226.4	12,341.5	12,393.0	12,465.6						
8169	10,571.0	11,203.6	11,248.3	11,356.9	11,384.0	11,395.8	11,568.0	11,650.0	11,872.0	12,062.0		12,140.9

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
8342	11,889.3	12,515.3	12,557.6	12,668.1	12,712.3	12,722.0	12,943.4					
8665	10,344.5	10,968.2	11,020.4	11,125.0		11,151.2						
8837	11,203.2	11,821.9	11,850.8	11,936.2		11,960.0						
9056	10,971.6	11,606.8	11,658.2	11,769.0	11,808.3	11,833.5						
9135	10,423.4	11,061.1	11,117.3	11,230.9		11,265.3						
9256	11,110.6	11,747.2	11,793.5	11,908.0	11,945.6	11,972.3						
9257	10,969.1	11,606.5	11,657.4	11,768.3	11,810.2	11,829.9						
9322	11,829.8	12,444.5	12,482.6	12,598.7		12,630.7						
9348	10,877.5	11,509.1	11,557.3	11,668.5	11,704.2	11,730.6	11,887.7					
9407	10,798.0	11,432.8	11,485.0	11,598.8	11,630.5	11,646.0						
9475	11,695.6	12,324.9	12,366.7	12,482.0	12,530.6	12,570.0						
9684	11,746.2	12,334.7	12,373.6	12,479.7		12,507.8						
10430	10,129.8	10,750.2	10,798.3	10,908.5		10,937.5						
10570	11,606.9	12,220.1	12,255.9	12,371.0		12,410.9						
13447	12,009.7	12,623.8	12,663.2	12,777.1		12,814.2						
14652	11,258.2	11,854.6	11,894.3	11,998.2		12,027.3						
Steele County												
8027	1,204.0	1,584.0	1,611.6	1,728.0								1,736.0
9922	1,046.8	1,162.9	1,180.9	1,258.1							1,316.0	
Stutsman County												
40	3,221.4	3,783.8	3,851.9	3,987.0							3,994.1	
120	2,106.6	2,638.3	2,715.5	2,846.9							2,865.8	
134	2,552.3	3,098.5	3,175.9	3,316.8							3,333.0	
370	2,445.7	2,998.0	3,072.0	3,202.8							3,222.8	
406	2,457.0	3,013.7	3,086.5	3,218.0							3,236.1	
644	3,378.3	3,948.6	4,018.0	4,154.5							4,178.1	
668	2,711.0	3,370.3	3,433.7	3,587.7							3,592.8	
669	3,173.6	3,742.7	3,813.3	3,953.0							3,961.0	
671	3,057.0	3,627.7	3,699.0	3,829.2							3,834.0	
672	3,003.0	3,561.4	3,631.9								3,764.0	
7415	3,013.9	3,546.3	3,601.4	3,767.2							3,775.9	
9776	2,249.5	2,799.5	2,876.7	3,007.9							3,025.9	
Towner County												
171	3,067.6	3,578.4	3,635.4	3,765.8								3,787.0
194	3,023.2	3,547.4	3,616.5	3,745.0								3,761.0
227	3,274.3	3,800.0	3,857.1	3,996.4							4,022.6	4,030.0
Ward County												
47	7,561.4	8,168.9	8,206.5	8,325.7				8,420.7	8,490.1	8,550.5		8,618.3
7612	10,914.2	11,524.2	11,580.1	11,699.5		11,842.0	11,893.0	11,972.0	12,155.0	12,270.0		12,317.0
11055	7,775.7	8,375.0	8,419.9	8,537.9				8,633.6				
Wells County												
207	5,032.3	5,601.6	5,671.4	5,808.7							5,827.5	
609	4,221.4	4,810.8	4,870.4	5,001.5							5,023.3	

North Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
642	4,191.8	4,788.6	4,841.0	4,974.0							5,007.3	
689	4,406.4	4,963.9	5,022.6	5,186.2							5,206.7	
1211	3,508.5	4,101.3	4,157.8	4,289.0							4,303.3	4,391.0
11599	4,167.5	4,755.6	4,819.5	4,960.1							4,978.3	
11653	3,950.3	4,541.5	4,601.6	4,734.2							4,764.1	
11654	4,049.7	4,631.7	4,687.4	4,821.5							4,852.4	
Williams County												
1231	12,676.7	13,211.7	13,250.3	13,384.1	13,613.5							
1385	13,125.0	13,749.3	13,780.8	13,922.2	14,177.9	14,280.0	14,405.0	14,550.0	14,628.1	14,741.5		14,769.8
1403	12,642.3	13,229.0	13,267.9	13,416.8	13,669.0	13,710.0	13,882.0	14,017.0				
1514	12,894.7	13,495.5	13,541.0	13,690.7	13,928.0	14,022.0	14,157.0	14,295.0	14,409.6			
1636	12,994.2	13,597.3	13,629.3	13,776.3	14,014.6	14,061.2						
3844	12,923.8	13,537.9	13,573.8	13,725.8	13,971.5	14,054.4	14,193.0	14,345.8	14,411.0	14,538.1		14,561.0
4321	12,725.9	13,314.7	13,351.0	13,476.0	13,706.6	13,733.0	13,864.0	14,023.0	14,191.3	14,256.0		14,282.9
4323	12,590.2	13,139.7	13,185.1	13,317.6		13,543.2	13,632.8	13,735.1				
4618	12,767.0	13,260.7	13,299.5	13,373.1		13,532.0	13,593.0	13,750.0	13,918.0	14,088.0		14,125.0
4716	12,724.7	13,300.3	13,339.2	13,489.7	13,710.0	13,749.3						
5069	12,878.4	13,462.3	13,507.8	13,656.4	13,900.6							
6098	13,304.3	13,945.8	13,986.8	14,129.0	14,380.6							
6478	13,236.3	13,796.7	13,838.1	13,971.6		14,120.0	14,178.0					
7005	12,943.4	13,560.3	13,611.7	13,758.3	14,025.0	14,059.7						
7848	12,559.0	13,066.0	13,101.5	13,171.9		13,311.6						
8316	11,851.0	12,308.4	12,340.0	12,401.3		12,572.2						
8692	12,283.7	12,801.0	12,832.1	12,900.0		13,043.5						
9100	12,068.6	12,567.6	12,597.0	12,665.6		12,798.2						
9800	13,275.9	13,855.3	13,884.1	14,019.8		14,182.6	14,204.2					
10772	12,585.0	13,119.0	13,151.3	13,285.9		13,478.2	13,499.4					
12119	12,558.5	13,086.5	13,127.8	13,249.2		13,430.5	13,453.2					
12270	12,560.3	13,111.7	13,137.4	13,250.5		13,444.4	13,467.1					
12305	13,013.7	13,590.0	13,613.6	13,745.9	13,926.0	13,958.8	14,027.5					
12363	12,701.0	13,268.8	13,310.5	13,448.0	13,689.1	13,749.7						
12432	12,708.4	13,262.4	13,302.2	13,430.9	13,639.6	13,662.9						
12592	12,919.2	13,479.0	13,510.1	13,646.9	13,826.4	13,852.7						
12831	12,967.2	13,522.1	13,564.2	13,698.5	13,894.9	13,919.9	14,023.8					
12971	13,129.8	13,749.6	13,774.8	13,917.5	14,160.1	14,252.8						
13395	12,697.0	13,262.6	13,306.0	13,452.5	13,685.1	13,721.4	13,803.9					
13682	12,821.2	13,381.8	13,422.6	13,564.9	13,746.8	13,771.7	13,895.1					
13893	12,667.8	13,271.4	13,309.9	13,460.3	13,726.3	13,774.2						
16629	13,252.0	13,843.2	13,875.0	14,011.5	14,231.0	14,252.0	14,300.0					
17488	13,371.1	13,959.2	13,991.1	14,127.2		14,335.5						
18631	12,697.7	13,282.7	13,328.0	13,476.8	13,703.0	13,739.2	13,880.1					
18680	12,901.4	13,499.2	13,547.7	13,693.9	13,934.7	13,969.5	14,110.3					

Montana

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Carter County												
MT1	3,591.3	4,038.5	4,066.0					4,142.3	4,309.0	4,640.4		4,829.2
MT2	4,461.3	4,933.4	4,957.8	5,034.2				5,089.2				
MT3	5,942.2	6,405.1	6,428.8	6,505.1				6,626.0	6,689.4	6,959.9		7,040.7
MT4	5,900.8	6,371.6	6,395.9	6,441.0				6,516.8	6,583.3	6,912.5		6,980.9
MT5	8,554.1	9,039.4	9,069.3	9,152.0				9,319.9				
MT6	9,016.0	9,508.8	9,542.2	9,625.7			9,685.9	9,764.5	9,901.8			
MT7	8,903.8	9,392.2	9,435.2	9,516.2		9,536.7	9,564.2	9,649.0	9,787.9	10,171.2		10,262.4
MT8	6,950.2	7,415.5	7,458.2					7,529.3	7,699.5	8,101.0		8,255.3
Custer County												
MT9	8,595.0	9,005.0	9,040.0	9,133.7				9,153.3	9,341.0	9,730.0		9,782.0
Daniels County												
MT10	8,259.8	8,704.9	8,833.8	9,004.8				9,062.2	9,372.6			
Dawson County												
MT11	9,395.4	9,822.8	9,857.0	9,960.8			9,988.0	10,030.0				
MT12	9,533.0	9,947.4	9,984.9	10,089.0			10,160.4					
MT13	10,639.0	10,984.1	11,045.5	11,152.0			11,202.0	11,270.0	11,480.0	11,654.8		
MT14	9,792.9	10,117.6	10,159.6	10,273.8			10,315.1	10,377.7				
MT15	11,824.0	12,243.0	12,299.2	12,411.7			12,455.6					
Fallon County												
MT16	8,599.5	9,037.8	9,110.0	9,219.0			9,257.0	9,322.0	9,597.0	9,819.0		9,916.9
MT17	8,954.3	9,412.4	9,478.6	9,554.1		9,583.1	9,620.7	9,690.8	9,971.1	10,201.6		10,298.3
McCone County												
MT18	9,598.0	9,906.2	9,953.1	10,025.9			10,102.0	10,165.0	10,342.0	10,736.0		10,801.7
Powder River County												
MT19	8,237.8	8,694.4	8,710.2	8,798.7				8,812.7	8,995.4	9,386.7		9,454.1
Richland County												
MT20	11,458.0	11,859.0	11,905.6	12,049.0			12,119.0					
MT21	12,157.0	12,625.5	12,706.4	12,810.9		12,886.2						
MT22	11,820.0	12,281.0	12,360.8	12,469.0		12,533.0	12,596.0	12,749.0	12,922.0	13,198.8		13,308.7
MT23	11,680.0	12,084.0	12,130.0	12,262.0			12,332.5	12,478.8	12,656.0	12,846.8		12,953.0
MT24	12,247.0	12,715.0	12,769.5	12,889.0		12,961.0	13,023.5	13,168.0				
MT25	11,152.4	11,556.3	11,611.9	11,715.0			11,770.6					
Roosevelt County												
MT26	12,114.9	12,606.8	12,624.9	12,710.0		12,751.0						
MT27	12,148.6	12,612.5	12,651.5	12,784.1			12,869.7					
Sheridan County												
MT28	10,033.0	10,335.0	10,378.7	10,516.0			10,561.3					
MT29	9,763.0	10,076.0	10,104.4	10,261.0			10,304.8	10,601.5	10,720.9	10,813.0		
MT30	9,799.7	10,111.0	10,133.8	10,252.9			10,316.1	10,729.0	10,828.9	11,015.7		
MT31	10,974.0	11,375.0	11,411.8	11,537.0			11,621.0	11,951.7	12,026.9	12,150.1		12,257.0
MT32	11,060.5	11,461.4	11,480.5	11,608.9			11,684.5					
MT33	11,183.2	11,579.4	11,606.3	11,734.2			11,806.7	12,134.6	12,224.5	12,261.2		12,343.1

Montana

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
MT34	10,986.0	11,376.0	11,412.4	11,528.0			11,603.8	11,831.0	11,966.0			
MT35	10,749.5	11,141.9	11,171.8	11,301.8			11,379.4					
MT36	10,818.0	11,187.6	11,231.3	11,358.2			11,438.3	11,762.0	11,856.1	11,906.7		11,930.2
MT37	9,447.5	9,769.4	9,782.6	9,928.8			9,983.8	10,346.0	10,426.7	10,551.1		10,672.2
Valley County												
MT38	7,242.2	7,547.8	7,553.2	7,659.6								7,740.1
Wibaux County												
MT39	10,624.0	11,108.0	11,151.5	11,260.1		11,285.4	11,366.3					
MT40	10,634.0	11,112.0	11,164.1	11,271.0		11,290.6						
MT41	10,523.2	10,999.0	11,046.9	11,152.2		11,167.7	11,206.4					
MT42	10,964.0	11,415.0	11,476.4	11,586.0		11,612.7						
MT43	11,162.0	11,597.0	11,659.3	11,761.0		11,800.0						
MT44	11,604.0	12,051.0	12,127.3	12,212.0		12,271.1						
MT45	8,860.4					9,480.0	9,529.0	9,618.0	9,873.0	10,262.0		10,390.0
MT46	10,326.3	10,811.6	10,848.2	10,945.7		10,979.0						

South Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Bon Homme County												
SD1												852.0
SD2												842.0
Butte County												
SD3	4,970.0	5,283.3	5,323.7	5,407.6				5,517.1	5,611.3			
SD4	5,356.2	5,738.6	5,761.2					5,850.3	5,940.0	6,271.1		6,315.0
SD5	6,058.6	6,522.9	6,542.1					6,627.4	6,724.6	7,051.7		7,089.7
SD6	4,010.5	4,337.6	4,370.0					4,453.4	4,491.0			
SD7	5,975.0	6,397.5	6,425.9					6,489.7	6,544.0			
SD8	6,389.1	6,826.3	6,829.0					6,937.0				
SD9	6,750.0	7,190.5	7,224.9					7,316.0	7,416.0	7,666.7		7,777.1
SD10	5,694.5	6,098.0	6,121.5					6,211.4	6,256.0			
SD11	6,295.0	6,738.1	6,750.0					6,866.0	6,922.0			
SD12	3,331.0	3,560.0	3,601.5	3,666.3				3,731.8				
Corson County												
SD13	7,165.8	7,725.9	7,760.8	7,911.2				7,944.1	8,129.9	8,335.1		8,425.4
SD14	6,641.1	7,199.5	7,246.1	7,347.3				7,399.5				
SD15	6,437.4	7,011.4	7,028.1	7,140.2				7,173.1	7,352.4	7,577.0		7,623.7
SD16	6,300.2	6,877.1	6,893.2	6,976.1				7,035.8	7,213.1			
SD17	6,731.0	7,284.7	7,336.5					7,446.6	7,607.2			
SD18	6,503.4	7,062.4	7,088.3	7,217.2				7,250.1	7,428.4	7,648.6		7,722.6
SD19	6,911.6	7,464.6	7,489.3	7,624.2				7,696.7	7,814.9			
SD20	5,965.8	6,507.0	6,520.4						6,705.2	6,925.7		7,018.8
Dewey County												
SD21	5,032.2	5,571.9	5,595.2						5,692.5	5,907.3		5,944.8
SD22	5,012.1	5,557.9	5,569.5						5,690.1			
SD23	5,305.6	5,860.4	5,882.2	5,976.1					6,030.0	6,283.0		6,303.0
SD24	4,180.5	4,667.5	4,691.2	4,782.0					4,830.1	4,970.6		5,032.0
SD25	4,983.7	5,511.9	5,529.3						5,651.3			
SD26	4,893.7	5,443.9	5,474.9						5,619.7	5,781.5		5,850.7
SD27	4,734.3	5,282.9	5,313.5						5,440.7	5,607.2		5,668.8
Fall River County												
SD28												4,048.0
SD29												4,120.0
SD30												3,808.0
SD31												4,060.0
SD32	4,147.0	4,532.3	4,545.9									4,594.0
SD33												2,532.3
Faulk County												
SD34	2,400.0		2,618.1	2,697.4							2,718.2	2,744.0
Gregory County												
SD35	2,019.2	2,133.0	2,148.8									2,199.2
SD36	2,140.7	2,181.5	2,192.8									2,221.2

South Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Haakon County												
SD37	4,888.7	5,151.2	5,175.3	5,245.3					5,338.1	5,376.9		5,418.9
SD38	4,173.6	4,328.9	4,334.3						4,470.0			
SD39	4,180.6	4,396.0	4,400.0	4,438.8								4,470.0
SD40	3,651.5	3,794.1	3,809.8	3,834.4								3,862.3
SD41	4,261.1	4,668.7	4,676.1									4,755.0
SD42	4,594.5	4,912.0	4,923.7	4,996.8								5,005.9
Harding County												
SD43	6,650.0		6,940.0					6,990.0				
SD44	7,714.5	8,195.4	8,210.0					8,290.6				
SD45	7,536.7	8,010.3	8,053.3					8,132.2				
SD46	6,786.1		7,296.0					7,374.8				
SD47	7,250.0		7,740.0					7,835.4	7,909.4			
SD48	7,520.5	7,996.6	8,037.8					8,117.0	8,305.7	8,522.8		8,630.3
SD49	8,155.3	8,651.4	8,703.1					8,791.1				
SD50	7,247.3	7,720.6	7,751.3					7,834.1				
SD51	8,355.3	8,851.0	8,886.0	8,948.8				8,976.2				
SD52	8,284.9	8,761.1	8,810.8				8,904.9	8,934.5				
SD53	8,242.8	8,694.4	8,727.3				8,808.0	8,862.7				
SD54	8,398.7	8,898.0	8,926.5			9,013.4	9,059.8	9,103.0	9,289.4			
SD55	6,604.8	7,059.5	7,099.9					7,176.4	7,291.0			
SD56	8,920.3	9,409.0	9,437.0				9,526.0					
SD57	8,556.2	9,075.7	9,099.5				9,190.0	9,247.0	9,447.5	9,629.6		9,748.0
SD58	7,863.0	8,357.0	8,392.2					8,474.3	8,673.2			
SD59	8,448.3	8,945.9	8,981.1				9,062.7	9,101.5	9,262.0	9,381.6		
SD60	7,830.9	8,308.3	8,337.5					8,422.5				
Hughes County												
SD61	2,112.0	2,429.4	2,455.3	2,541.1								2,560.0
Hyde County												
SD62	2,300.0	2,562.7	2,575.0	2,654.4							2,674.4	2,700.0
SD63	2,270.0	2,428.2	2,432.0	2,516.6							2,538.9	2,569.0
Jackson County												
SD64	3,948.0		4,104.7	4,165.8					4,180.1			
SD65	3,773.0		3,985.0									4,120.0
Jones County												
SD66	2,951.0	3,155.3	3,164.0								3,235.6	
SD67	3,715.0		3,877.0	3,924.0								3,952.0
SD68	2,350.0											3,010.3
SD69	2,100.0											2,873.7
SD70	2,600.0											2,367.9
Lawrence County												
SD71	2,700.0	2,858.9	2,900.7	2,968.0				3,033.5	3,085.6			

South Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Lyman County												
SD72	2,290.0		2,345.0									2,410.0
SD73												2,380.0
Meade County												
SD74	5,667.7	6,157.9	6,177.1					6,267.8	6,423.1			
SD75	5,910.1	6,382.3	6,401.5					6,606.2	6,790.0			
SD76	5,264.6	5,673.5	5,689.1					5,782.5	5,937.3			
Mellette County												
SD77	3,022.0		3,098.7								3,144.7	3,172.8
SD78	3,111.3	3,180.1	3,185.9	3,210.6							3,234.9	3,270.0
Miner County												
SD79												2,580.0
Pennington County												
SD80	4,082.7	4,280.0	4,292.3						4,380.9	4,557.9		4,593.0
SD81	4,975.0		5,360.0	5,397.7					5,450.0			
SD82	4,977.6	5,237.6	5,242.8	5,326.7					5,385.9			
Perkins County												
SD83	6,273.0	6,786.2	6,807.5					6,936.3	7,031.9	7,238.5		
SD84	7,124.6	7,637.0	7,656.0					7,787.8	7,899.7	8,086.0		8,229.7
SD85	7,114.4	7,670.8	7,709.9					7,805.3				
SD86	8,043.2	8,561.9	8,597.2					8,736.8	8,927.2	9,118.4		9,321.9
SD87	7,841.3	8,380.0	8,411.3					8,535.3				
SD88	8,669.8	9,192.0	9,227.8				9,348.0	9,404.3				
SD89	7,113.1	7,648.0	7,665.4					7,797.5	7,937.9	8,134.3		8,286.6
Potter County												
SD90	3,000.0	3,409.3	3,457.1	3,537.7							3,563.9	3,602.7
SD91	3,215.0	3,546.6	3,584.0	3,655.2							3,683.8	3,715.0
Oglala Lakota (Shannon) County												
SD92	3,294.0	3,432.0	3,437.8	3,498.0								3,540.0
Spink County												
SD93												2,640.0
Stanley County												
SD94	3,715.0		3,877.0	3,924.0								3,952.0
SD95	2,201.7		2,569.7	2,609.6								2,695.0
SD96	2,050.0											2,793.0
SD97	3,086.5	3,172.2	3,185.1	3,242.0								3,308.0
SD98	3,815.0											2,950.0
SD99	2,450.0											3,358.0
SD100	2,666.9											2,930.7
SD101	3,479.2	3,806.7	3,846.5									3,940.6
SD102	2,821.0		3,153.2	3,164.3								3,203.5

South Dakota

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
Tripp County												
SD103	2,800.0		2,857.0									2,873.0
SD104	2,564.0		2,690.0									2,722.0
SD105												2,970.0
SD106												3,209.4
Walworth County												
SD107	3,210.0	3,572.3	3,616.3	3,733.8							3,774.6	3,807.5
SD108	3,251.0	3,634.9	3,690.0	3,819.5							3,862.7	3,910.0
Ziebach County												
SD109	5,598.2	6,100.3	6,120.0					6,220.0	6,242.0			

Manitoba

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
486	6,069.0	6,585.6	6,613.0	6,743.0							6,800.0	
1537	4,655.0	5,170.1	5,195.8	5,295.9							5,355.0	
1563	3,942.0	4,421.7	4,422.0	4,537.4							4,552.8	4,565.0
1666	4,682.0	5,161.1	5,170.0	5,308.0							5,337.5	5,378.0
2523	5,679.3	6,150.5	6,180.1	6,288.7							6,343.0	6,401.0
2532	4,815.9	5,245.5	5,270.1	5,392.0							5,408.5	5,420.9
2543	5,590.7	6,127.2	6,148.1	6,249.4							6,315.6	6,372.0
2593	4,356.6	4,912.2	4,927.8	5,042.2							5,074.8	5,088.0
2610	5,690.6	6,211.1	6,240.0	6,359.9							6,417.0	6,486.0
2612	4,490.4	4,856.0	4,870.8	4,980.6							5,043.7	5,101.2
2683	5,134.0	5,622.9	5,654.3	5,743.8							5,807.4	5,866.1
2695	4,795.1	5,279.8	5,299.1	5,413.0							5,435.4	5,463.0
2696	5,849.7	6,334.5	6,367.9	6,476.5							6,535.2	6,581.0
2700	5,301.1	5,794.6	5,810.0	5,904.0							5,999.2	6,024.0
2706	5,081.0	5,581.2	5,603.3	5,700.6							5,770.2	
2741	4,064.6	4,500.8	4,527.9	4,657.4								4,688.0
2766	5,563.1	6,086.8	6,106.0	6,207.5							6,273.0	6,355.0
3183	5,017.6	5,486.2	5,500.7	5,609.0							5,624.5	5,650.0
3530	4,514.7	4,981.2	4,992.9	5,115.0							5,137.1	5,154.0
4495	4,223.7	4,668.1	4,696.5	4,809.5								4,859.0
4845	5,068.7	5,586.7	5,605.2	5,715.4							5,766.5	
4859	4,673.7	5,172.8	5,198.0	5,293.3							5,348.8	5,416.6
5956	4,990.8	5,469.6	5,489.8	5,602.3							5,629.0	5,638.0

Saskatchewan

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
00C037	8,114.0	8,508.7	8,532.2	8,579.8					8,699.0			
00D072	7,313.6	7,703.1	7,738.8	7,775.3					7,899.6			
00F396	8,840.0	9,168.0	9,187.6	9,248.1					9,382.0	9,600.0		9,731.0
00J189	7,999.9	8,245.9	8,253.9	8,307.6					8,432.0	8,786.4		8,984.9
01A024	7,641.0	7,954.5	7,995.6	8,045.0					8,181.0			
01H069	9,296.0	9,624.2	9,648.4	9,713.2					9,851.7	9,952.8		9,989.9
01J006	8,646.1	9,078.4	9,095.6	9,145.5					9,271.0			
01L133	9,136.8	9,333.5	9,352.5	9,401.4					9,554.0	9,809.7		9,902.0
02A161	7,654.0	8,063.5	8,092.6	8,140.2					8,274.0	8,408.5		8,512.0
02B012	8,615.4	8,808.4	8,816.0						8,992.0	9,272.1		9,463.4
02I016	8,318.0	8,702.4	8,706.0	8,778.0					8,902.0			
02K012	8,292.0	8,681.3	8,684.0	8,760.0					8,894.0			
03K283	8,635.4	9,078.2	9,098.2	9,147.6					9,273.7			
03L284	8,439.4	8,658.6	8,696.9	8,747.2					8,883.4			
04B015	8,638.9	9,079.6	9,107.4	9,166.4					9,282.7			
05F018	9,325.0	9,615.2	9,630.4	9,696.9					9,829.3			
06E087	8,186.7	8,603.5	8,622.4	8,672.6					8,805.9			
07I073	7,658.0	8,015.5	8,044.0	8,087.9					8,209.7	8,340.5		
08H567	7,316.9	7,798.3	7,824.4	7,893.1					8,010.7			
50I013	5,834.0								6,066.3			
51C004	6,705.0								6,884.7			
51E001	9,394.0	9,678.7	9,716.0	9,768.4					9,913.0			
51L011	6,434.0			6,630.0					6,636.0			
51L083	6,635.8								6,881.3			
52A006	7,406.5	7,904.5	7,940.7	8,045.5				8,114.0	8,132.1	8,220.0		8,272.7
52G001	5,344.0		5,657.0	5,710.0					5,800.0	5,881.2		5,903.4
53J044	7,717.9	8,140.0	8,171.6	8,237.9					8,366.0	8,519.2		8,560.0
54F047	5,765.0	5,937.0	5,955.0						5,969.0			
54J036	6,084.0								6,378.7			
55A052	8,458.3	8,959.8	8,987.0	9,101.0				9,176.0	9,230.0	9,366.0		
55E024	6,755.4								6,977.9	7,950.7		
55F097	6,175.3								6,701.2	7,617.1		7,730.6
55J059	7,480.1	7,974.6	8,021.7	8,129.4				8,190.0	8,211.7	8,297.0		8,353.0
56B004	9,346.7	9,806.6	9,823.6	9,898.0				10,030.0	10,103.0	10,296.0		10,400.0
56C013	8,125.0	8,585.0	8,601.5	8,676.0					8,802.1			
56E085	6,752.0								6,947.1			
56G008	7,797.7	8,230.8	8,247.3	8,308.7					8,432.9	8,594.2		8,671.0
57G023	9,764.0	10,102.8	10,128.4	10,189.0					10,328.6			
57H002	8,824.0	9,072.4	9,078.0						9,109.7	9,421.4		
57K043	8,511.3	8,993.9	9,014.0	9,098.0					9,218.0			
58B029	8,746.0		8,990.0	9,037.0					9,156.0			
58I075	6,619.0	6,823.8	6,849.7	6,875.6					6,968.0	7,490.4		7,683.0
58L009	8,096.0	8,348.2	8,363.0	8,428.0					8,472.8			

Saskatchewan

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
59B006	6,154.0	6,350.4		6,380.0					6,395.0			
59G074	6,775.0								6,965.9	7,499.1		7,695.8
59L036	7,483.3	7,724.0							7,734.7	8,420.8		
61I046	7,463.3	7,682.6							7,710.9	8,390.0		
62B005	7,660.0	8,003.1	8,018.0	8,082.0					8,198.0			
62H013	6,146.0								6,311.7	6,613.1		
64K049	7,382.1	7,604.4							7,621.8	8,359.1		
65C083	6,122.0								6,607.4	7,491.0		7,557.3
65F053	8,372.8		8,766.0	8,813.0					8,948.0	9,193.5		
65K031	6,713.0	7,159.3	7,182.0	7,259.0					7,367.0	7,400.0		7,443.0
66A088	6,056.0	6,523.1	6,547.2	6,607.0							6,720.0	6,760.0
66F117	9,271.0	9,747.7	9,768.0	9,854.0				9,989.7				
66I002	8,214.6		8,490.6	8,552.0					8,676.0			
66J002	6,216.0	6,644.9	6,664.4	6,744.0					6,853.0	6,887.8		6,923.3
68B016	8,398.0		8,631.1	8,688.0					8,796.0			
68F041	9,200.0	9,614.2	9,628.0	9,700.0					9,825.0			
72I017	6,122.0								6,283.6			
72K044	9,225.4	9,431.9	9,448.9	9,499.1					9,652.0	9,905.5		10,055.0
77H008	8,736.0	9,066.7	9,088.4	9,159.0					9,290.3			
77J053	9,939.0	10,292.1	10,300.0	10,374.0					10,512.0			
77J057	8,738.2	9,221.8	9,253.6	9,368.6				9,449.7	9,499.7	9,638.7		9,714.0
77L016	9,401.6	9,672.3	9,690.8	9,744.7					9,888.0	10,167.8		10,231.0
78B008	8,804.1	9,259.8	9,286.9	9,341.8					9,476.0	9,744.0		9,811.9
78C001	7,730.3	8,203.2	8,232.0	8,301.8					8,416.0	8,590.1		8,624.0
78H158	8,694.0	9,028.2	9,054.8	9,125.0					9,252.3			
78L010	6,393.0	6,642.1	6,673.0	6,709.0					6,834.0	7,087.5		7,247.0
80B006	7,820.0	8,330.5	8,367.1	8,480.3				8,551.5	8,560.0	8,669.9		8,725.7
80F005	9,902.0	10,252.9	10,273.0	10,348.0					10,478.0	10,769.1		
80G001	7,597.8	8,124.3	8,157.2	8,267.7				8,343.6	8,356.0	8,471.9		8,520.0
80I101	8,944.0	9,250.0	9,269.0	9,332.5					9,465.0			
81H036	6,253.0	6,728.5	6,759.0	6,874.0							6,927.0	6,975.0
82D001	7,533.7	8,035.9	8,051.6	8,137.7					8,142.3			
82I080	9,839.0	10,275.0	10,292.0	10,361.0				10,502.0	10,614.7	10,678.4		10,718.7
85B130	5,278.0	5,736.0	5,755.0	5,842.0								5,905.0
85B212	10,295.0	10,733.3	10,747.0	10,822.0				10,969.0	11,088.3			
87G102	7,995.2	8,430.5	8,458.4	8,511.7					8,633.8			
87L059	8,066.3	8,528.1	8,555.7	8,612.2					8,742.0			
88D019	8,321.2	8,766.8	8,785.5	8,839.4					8,947.6	9,102.7		9,134.9
88K071	8,352.3	8,821.9	8,841.0	8,922.0					9,047.0			
88L062	8,311.7	8,792.1	8,800.0	8,878.0					8,998.0			
93D103	7,228.0	7,651.0	7,674.1	7,721.6					7,856.0	8,151.2		8,256.7
96B159	8,318.3	8,715.1	8,734.2	8,781.0					8,912.6			
96E028	8,362.1	8,759.3	8,765.0	8,833.0					8,955.0			

Saskatchewan

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
96E124	8,350.0	8,726.9	8,744.1	8,808.0					8,924.0			
96E258	8,586.1	9,023.5	9,025.0	9,099.0					9,223.1	9,337.9		9,369.1
96F283	8,336.0	8,711.1	8,736.8	8,791.0					8,907.0			
96G281	8,382.2	8,787.9	8,810.7	8,863.0					8,983.0			
96G312	8,373.0	8,749.0	8,773.0	8,826.0					8,944.0			
96I068	8,410.0	8,788.6	8,796.0	8,875.0					8,999.0	9,148.4		9,251.6
96I131	8,410.9	8,816.3	8,837.1	8,883.4					9,005.9	9,162.8		9,175.2
96I227	8,338.0	8,707.9	8,722.9	8,779.0					8,894.0			
96J008	8,416.1	8,816.1	8,842.9	8,886.7					9,009.0	9,112.3		9,143.8
96J367	8,359.2	8,779.5	8,805.5	8,854.5					8,985.0	9,171.3		9,236.0
96K164	8,340.0	8,716.6	8,727.2	8,787.0					8,897.0			
96L066	8,230.3	8,641.8	8,661.3	8,705.9					8,830.0	8,958.6		8,988.0
96L309	8,421.6	8,833.3	8,861.7	8,904.5					9,028.0	9,161.2		9,186.0
97A128	8,175.0	8,635.2	8,652.0	8,713.6					8,818.3	9,021.7		9,047.7
97B227	8,296.6	8,715.2	8,741.4	8,789.8					8,920.0	9,086.6		9,113.0
97C251	6,732.0	7,165.3	7,186.0	7,264.0					7,369.0	7,406.2		7,450.0
97C300	8,417.4	8,836.3	8,855.2	8,910.3					9,032.7	9,193.4		9,251.3
97E002	7,721.5	8,144.2	8,166.6	8,209.9					8,350.0	8,505.3		8,636.0
97E046	8,573.0	9,016.5	9,033.0	9,105.0					9,232.0			
97E081	8,281.0	8,662.8	8,663.0	8,737.0					8,859.6			
97E085	8,438.8	8,850.3	8,865.9	8,926.1					9,060.0	9,149.1		9,195.0
97E213	7,960.2	8,382.9	8,411.0	8,462.8					8,567.2			
97F067	8,746.5	9,181.5	9,203.3	9,274.8					9,399.4			
97F120	8,392.0	8,751.5	8,776.8	8,829.0					8,941.0			
97F182	9,284.0	9,599.5	9,618.0	9,688.0					9,816.0			
97F195	6,849.1	7,259.5	7,284.3	7,332.1					7,441.9			
97F392	7,395.0	7,794.6	7,813.1	7,864.0					7,957.1			
97G199	8,382.0	8,769.4	8,778.0	8,855.0					8,983.0			
97G315	8,318.0	8,702.9	8,705.0	8,780.0					8,902.0			
97G432	7,535.3	7,966.3	7,985.0	8,049.4					8,171.7			
97G483	8,522.4	8,893.6	8,931.1	8,993.1					9,136.0	9,397.9		9,570.0
97H295	7,729.6	8,132.8	8,155.0	8,213.6					8,350.0			
97I354	8,347.1	8,766.4	8,791.3	8,839.8					8,971.0	9,224.1		9,326.0
97I431	7,468.6	7,937.5	7,964.9	8,021.8					8,058.9			
97I438	8,224.2	8,736.2	8,767.0	8,880.3				8,960.7	8,983.0	9,122.4		9,183.0
97J331	7,682.1	8,105.6	8,080.0	8,153.0					8,284.4			
97K205	7,930.0	8,311.4	8,337.5	8,392.3					8,520.0			
97L095	7,897.2	8,282.3	8,299.7	8,350.1					8,472.8	8,558.8		8,643.4
97L298	7,867.4	8,253.6	8,270.3	8,320.3					8,439.4	8,546.5		8,620.9
97L301	7,029.0	7,441.5	7,468.0	7,508.5					7,643.0	7,685.6		7,722.0
97L305	8,004.0	8,356.2	8,360.0	8,422.0					8,541.0			
97L327	8,810.9	9,141.4	9,158.4	9,213.2					9,354.0	9,564.4		9,685.0
97L361	8,245.6	8,661.7	8,680.1	8,722.8					8,849.0			

Saskatchewan

Formation Tops (Depths in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation							Pre-cambrian
		Rough-lock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB	
98A033	7,704.0	8,122.6	8,138.3	8,188.2					8,327.0			
98A073	6,946.3	7,413.7	7,435.9	7,502.0					7,617.1			
98A081	7,050.0	7,490.4	7,511.1	7,581.4					7,699.3	7,772.3		7,846.0
98A149	7,583.4	8,000.7	8,017.7	8,062.4					8,187.8			
98A228	8,250.8	8,698.1	8,708.0	8,781.0					8,905.8			
98B015	7,015.6	7,417.7	7,437.1	7,489.5					7,597.5			
98B191	8,795.5	9,226.9	9,257.1	9,317.7					9,436.0			
98B210	7,454.7	7,855.7	7,869.8	7,913.4					8,010.2			
98C138	7,411.7	7,821.6	7,837.7	7,890.3					8,018.5			
98C155	8,343.0	8,669.0	8,691.0	8,758.0					8,894.0			
98C263	7,205.7	7,635.6	7,659.5	7,719.8					7,844.3	7,914.9		7,991.0
98C298	8,658.5	9,012.9	9,028.3	9,087.8					9,220.0			
98D041	6,949.2	7,415.5	7,436.4	7,502.8					7,609.3			
98E160	8,716.0	8,996.2	9,023.0	9,091.0					9,219.0	9,423.2		
98E189	7,420.0	7,829.0	7,844.9	7,889.0					8,015.1			
98G073	7,124.5	7,521.7	7,541.2	7,586.9					7,721.0	7,807.8		7,841.0
98G075	7,298.6	7,688.2	7,707.7	7,747.1					7,877.0			
98G108	7,125.7	7,529.6	7,545.7	7,593.7					7,723.0	7,787.6		7,818.0
98G193	7,261.1	7,658.6	7,677.5	7,724.5					7,849.0	7,910.6		7,943.0
98G201	7,078.1	7,463.9	7,482.6	7,526.8					7,648.8	7,728.9		
98H036	7,419.6	7,687.6	7,714.7	7,759.3					7,891.2			
98H069	7,117.6	7,518.2	7,539.2	7,580.0					7,710.0			
98K067	8,869.5	9,285.2	9,298.0	9,354.0					9,488.0	9,707.2		
98K107	8,782.0	9,084.4	9,103.0	9,164.0					9,296.0			
99A081	7,915.0	8,264.7	8,265.0	8,327.0					8,446.2			
99C003	8,627.5	9,029.3	9,039.0	9,098.0					9,229.0			
99C054	7,393.0	7,847.3	7,865.0	7,944.0					8,066.0	8,190.1		8,211.2
99E132	7,368.0	7,695.5	7,713.0	7,772.0					7,898.0			
99E245	8,056.2	8,491.1	8,514.1	8,564.6					8,679.6			
99F392	7,803.3	8,218.5	8,227.0	8,298.0					8,415.0			
99G151	7,875.0	8,232.3	8,235.0	8,299.0					8,419.0			
99I286	7,992.0	8,407.2	8,434.9	8,483.2					8,587.2			
99J213	9,555.3	9,755.5	9,776.5	9,848.6					9,982.1	10,290.2		10,417.5
99K055	6,971.5	7,363.1	7,391.5	7,446.2					7,544.9			
99K079	8,946.1	9,141.8	9,164.5	9,216.6					9,358.0	9,606.4		9,795.0
99L128	8,938.1	9,148.7	9,153.9	9,201.3					9,337.0			

Appendix C
Formation Thickness

Thicknesses were calculated for all members of the Deadwood Formation when possible. This was done by subtracting the top of the formation from the top of the underlying formation. These results were used to produce isopach maps.

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Adams County											
6322	547.5	61.8	112.9			23.3	78.4	165.3	141.4	64.2	205.7
7642	551.3	34.1	117.6			20.1	87.5				
Barnes County											
4640	196.6	84.2	138.8	13.9							
Benson County											
632	540.0	75.1	126.6	48.6							50.8
Billings County											
291	559.7	33.8	111.4	33.9		162.7	118.0				
3268	568.2	15.3	108.0	37.5		174.0	87.0	252.0	208.0	157.0	365.0
6228	633.7	40.3	131.3	77.0	34.0	212.3	167.7	229.0	206.4	56.6	263.0
6303	590.1	24.0	116.8	53.6		163.3	144.0	198.4	152.6	32.9	185.4
6913	602.1	40.3	121.8	56.4							
7307	607.1	40.1	115.9	51.3							
7520	617.2	31.9	116.0	61.9							
7934	595.4	30.0	111.1	49.1		149.1	163.7	236.2	162.0	75.0	237.0
8226	602.0	33.1	114.6	53.3							
8487	581.2	29.9	111.2	54.5							
8603	581.1	35.1	112.4	45.1							
9070	562.6	34.3	106.8	42.0							
11335	560.2	17.8	103.7	36.3		131.0					
14763	558.3	37.9	101.1	41.0							
Bottineau County											
38	528.9	78.7	119.7	80.5					146.8	32.3	179.2
64	506.7	74.6	92.9	54.5							70.0
110	511.9	50.6	121.2	44.0							41.6
2219	546.7	44.5	122.1	52.9							120.0
4655	460.1	58.9	121.9	13.1							
4790	536.1	57.9	127.0	77.5							
4846	519.2	41.2	130.8	73.7							129.5
5184	526.3	44.7	111.4	65.7							55.0
9522	539.7	43.1	125.9	44.2							94.0
Bowman County											
485	520.2	34.2	87.4			26.4	92.0				
1575	464.5	78.5	97.5			18.1	91.9				
9656	521.2	41.3	104.0								
9805	515.5	27.0	93.3			14.0	111.9				
14851	512.4	25.1	89.8				80.8				
Burke County											
8893	531.9	39.5	91.1	257.1					70.9	36.0	106.9
15137	516.2	29.9	126.5	150.2				188.4	195.4	50.5	246.0

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Burleigh County											
19	602.0	83.1	128.7	21.3			56.6	88.4	63.0	55.3	118.3
145	565.4	90.4	120.6	28.3			33.4	100.2	88.0	120.0	208.0
151	631.3	65.6	122.2	5.0		61.9	49.1	118.9	116.1	31.0	147.1
155	522.2	128.9	128.3	23.2				98.1			162.4
174	543.7	79.2	176.2	66.8				84.5			
701	531.0	86.8	182.2	17.7				37.1			
756	543.6	55.4	191.7	25.8							
763	561.8	88.0	167.2	9.6							
765	558.8	74.8	165.2	34.4							
772	602.8	45.2	169.1	26.7							
1409	573.5	48.2	173.8	55.2							
6264	570.5	61.2	165.5	45.5				90.9			
7010	610.5	56.8	128.4	15.9			35.9	132.1	90.0	19.9	109.9
8674	626.5	47.4	123.7	23.3			55.7	69.2	77.1	52.2	129.3
12057	622.0	79.7	123.4	71.5							
Cavalier County											
27	523.7	63.8	125.8	13.3							
Dickey County											
682	367.5	94.7	89.8	71.6							
1394	372.5	85.2	85.0	56.7							87.0
Divide County											
2010	400.1	34.9	76.2	136.5							
6798	517.3	32.5	116.7	128.5				196.0	147.0	99.0	246.0
7087	481.6	33.7	115.4	122.4				160.0	211.0	112.3	323.3
7942	514.9	28.2	130.0	161.0			88.4	229.6	100.0	136.0	236.0
9398	451.0	22.5	65.9	139.3							
9413	473.6	34.7	67.1	144.8							
9622	474.2	30.4	66.5	149.1							
9677	465.1	24.6	66.5	144.8							
Dunn County											
6086	618.9	60.8	106.4	148.9							
6148	619.6	46.5	116.0	47.8	40.0						
6530	619.7	48.7	120.4	51.1	32.0	255.0					
7402	647.5	52.2	127.0	119.8	65.4	218.8					
7412	662.2	32.6	120.8	123.1							
7584	651.0	43.9	134.0	116.4	39.0						
8077	665.3	33.1	138.7	168.8							
8095	678.0	33.0	142.0	218.0							
8313	644.7	49.7	123.9	157.2							
8491	623.3	40.7	121.9	48.2	47.1						
8613	642.2	48.2	125.5	123.0							
8709	659.9	38.4	135.4	137.9							

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
9027	638.9	50.1	133.8	107.8	58.8						
9044	645.1	49.2	130.5	117.5							
9080	647.1	48.5	130.5	125.3	75.3						
9397	649.2	51.4	131.0	105.7							
9527	625.1	48.9	132.5	112.4	37.3						
10072	652.2	50.6	134.9	123.7							
10606	657.7	38.5	126.9	71.8							
10627	630.2	44.8	120.8	50.3	52.0						
11363	650.7	57.3	121.4	120.9	45.7						
12400	617.8	38.6	119.4	54.6							
14636	637.8	43.2	125.3	59.3	54.9						
Eddy County											
437	555.1	75.7	137.4	26.9							
768	552.0	66.5	132.7	33.1							
1274	510.3	107.8	140.4	8.5							45.1
7271	553.2	71.4	131.9	56.5							42.7
Emmons County											
16	559.8	61.3	152.3					98.1			
23	554.0	75.0	112.1	18.1				101.2			
43	581.9	75.2	130.7	16.1				131.9			
7101	549.9	29.6	167.1	15.1				112.0			
7146	581.6	78.9	125.4	18.2				105.1			169.5
7936	586.3	79.3	126.2	14.2				51.1			
10173	543.0	41.5	200.4	12.4				128.3			
Foster County											
287	512.1	99.9	139.4	11.8							52.0
295	539.4	81.5	136.3	12.7							59.0
334	519.6	79.9	135.9	18.7							
1105	518.8	97.2	128.5	7.7							
1112	593.5	41.6	133.9	11.2							
1227	449.8	107.3	151.1	17.1							
Golden Valley County											
410	539.5	59.1	115.9	42.9		144.0					
470	509.5	53.5	107.0	36.8		106.0	110.0				
6272	469.4	49.6	93.9	14.6		50.6	81.3	215.1	55.5	19.7	75.2
6513	514.5	50.8	101.5	39.4							
6563	522.6	38.3	99.0	33.9							
7969	483.5	51.8	130.6	35.9							
8590	552.1	47.0	104.6	36.0							
9148	494.8	65.5	103.6	30.9							
9540	492.5	80.8	103.5	33.6							

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Grand Forks County											
580	156.0	29.8	57.7	32.5							131.4
3191	285.9	101.4	112.3	27.7							
3204	69.6	38.0	55.3	54.0							
15343	120.1	68.8	46.4	128.9							70.4
Grant County											
5572	638.0	57.7	65.6	39.7		12.0	66.0	190.0			
6420	594.5	70.3	129.0			30.0	56.0				
6586	581.5	53.3	138.0	32.2		59.3	66.7	216.3	154.3	76.5	230.8
7020	625.2	47.2	128.4	42.2		119.6	72.4	201.8	178.3	25.7	204.0
8549	593.0	42.7	141.9	25.3		34.3	62.5	209.1	190.2	24.8	214.9
8680	586.1	39.9	143.2	8.3		8.8	74.9	175.5	212.3	63.5	275.8
Griggs County											
4719	543.5	68.2	62.3	88.2							51.0
9659	539.2	25.8	101.8	22.2							
Hettinger County											
5783	608.5	51.0	101.0	67.9		84.7	70.0	224.7	131.8	55.7	187.5
7075	557.6	58.6	122.8	12.4		52.6	69.9	215.4	188.1	31.2	219.3
7453	558.3	35.3	108.4	12.5		46.3	79.3	228.0	112.0	23.3	135.3
8312	588.5	45.0	113.6	14.8							
10522	590.4	34.3	128.3	18.7		95.9	101.3	161.0			
Kidder County											
24	569.1	74.9	134.5	10.7				100.1			
230	563.3	82.7	130.4	65.3							
748	519.1	77.0	182.8	21.0							
Logan County											
590	531.6	48.2	192.7	11.9							
1347	552.6	49.8	164.0	16.3							199.7
5523	567.4	58.4	135.9	9.6				77.1			188.1
McHenry County											
39	596.0	32.5	118.5	74.8							112.2
61	536.3	73.6	145.4	74.5							
8307	556.2	64.9	116.4	60.4							
8803	625.7	39.4	120.6	73.7				101.6			44.3
11922	557.4	53.3	120.5								
McIntosh County											
89	554.7	49.7	124.8	12.2							
620	507.6	57.7	146.0	10.5							
621	512.1	43.0	147.0	8.9							
622	558.3	64.8	125.9	12.2							
McKenzie County											
2373	653.1	48.4	155.4	277.9	153.2	180.0	186.0	215.0	69.0	73.0	142.0
6112	664.8	39.8	134.4	259.5							

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
6387	491.6	74.7	133.3	50.7		126.6	168.9	188.0	198.2	173.3	371.5
6414	498.4	81.2	109.3	75.0							
7571	641.5	55.0	148.4	236.3							
7572	637.9	52.4	145.9	239.5							
6387	491.6	74.7	133.3	50.7		126.6	168.9	188.0	198.2	173.3	371.5
6414	498.4	81.2	109.3	75.0							
7571	641.5	55.0	148.4	236.3							
7572	637.9	52.4	145.9	239.5							
7607	655.7	32.6	147.3	265.9	132.6						
7631	562.0	44.0	111.2	116.9							
7873	597.5	39.0	142.7	127.9							
7988	629.6	28.7	144.2	254.2							
8023	680.9	32.1	153.8	260.6							
8083	653.8	36.4	146.2	239.6							
8090	646.2	25.9	152.4	265.1							
8131	558.2	89.3	131.0	150.3							
8165	525.6	65.0	122.9	97.4							
8187	557.8	32.1	130.2	86.3		178.2	135.2	171.1			
8193	554.4	48.0	110.1	72.7							
8314	510.5	37.4	150.8	72.7		140.0	159.5	189.6	191.3	143.6	334.9
8468	575.4	49.7	113.9	74.1							
8546	523.3	47.1	113.7	91.6							
8663	620.0	46.0	139.5	123.3							
8737	553.2	53.6	113.6	81.5							
9004	551.8	79.7	126.5	103.7							
9005	601.8	32.5	117.1	70.0							
9217	649.2	49.0	137.0	196.8							
9901	542.7	51.5	112.3	80.9							
11110	659	22.3	148.4	265.4							
11619	588	33.1	116.2	70.92		174.47	148.3	171.86			
12345	643.2	49.1	137.9	228.5							
12589	678.0	31.6	146.7	290.6							
12699	592.6	39.4	118.4	69.0							
13405	659.5	39.9	138.9	277.2	143.6						
13647	646.0	53.0	145.2	273.0	145.4						
14399	651.2	39.7	148.0	238.5	168.3						
14724	611.7	49.9	149.5	250.3	146.7						
15915	658.8	40.8	145.1	203.4	121.4						
16376	653.4	30.3	147.2	256.6	150.6						
16523	655.5	25.3	144.6	260.9	138.8						
McLean County											
22	616.8	46.4	148.5	47.3		70.9					
49	578.7	49.9	135.9	46.6		43.5					

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
7783	646.7	48.4	138.9	169.8		242.6	80.6	201.6	72.9		
8060	646.3	54.5	134.4	148.6							
8711	615.5	72.7	117.7	42.6		45.9	26.7	103.0	60.8	33.2	94.0
8720	624.5	83.2	111.3	30.7		14.9	57.1	133.3	71.7	42.9	114.6
8993	605.6	67.8	113.1	33.3		22.3	35.3	84.2	46.0	43.8	89.8
Mercer County											
21	688.1	47.2	115.3	56.3	63.0	213.0					
8712	644.7	55.0	128.8	121.9							
Morton County											
26	622.9	51.9	134.1	24.9		25.7	86.0	134.0	150.0	34.0	184.0
1620	641.5	37.5	142.1	28.5							
3859	632.3	59.5	119.4	17.2		33.1	45.9	174.9	159.1	31.7	190.8
7340	635.7	44.4	134.3	41.6	42.8	151.9	62.0	191.8	130.4	46.0	176.5
7691	650.6	49.4	115.8	33.7		102.3	62.8	183.6	158.7	15.2	173.9
7797	631.1	56.5	118.1	27.5		91.4	59.6	169.3	90.7		
7937	596.4	58.4	102.3	22.2		66.6	65.3	204.5	227.9	37.4	265.3
8158	619.6	42.0	140.1	12.9		68.0	60.0				
8553	604.5	42.4	132.2	33.5		54.3	52.6	123.9	40.9	27.6	68.5
Mountrail County											
6780	620.0	47.8	134.8	146.9		211.9	54.1	178.1	64.1	46.2	110.3
6872	611.8	62.2	124.3	155.1		138.7	100.3	159.7	147.3	47.0	194.3
9326	595.1	53.9	134.8	205.2							
12597	579.5	48.1	139.7	236.3	22.2						
14815	635.8	62.5	125.1	148.7							
17058	632.5	58.4	131.5	169.7							
Nelson County											
4664	338.0	68.4	131.9	21.4							
4785	546.5	77.0	119.4	38.3							
9143	492.0	18.0	109.0	32.7							
Oliver County											
15	638.8	62.4	103.3	36.5		37.0	68.0	132.1	69.9	32.8	102.7
8144	603.7	43.4	177.5			43.6					
Pierce County											
435	503.0	71.4	124.3	39.9							
706	530.1	64.9	126.1	46.1							35.2
3920	559.8	75.0	127.8	49.4							
5576	568.9	59.7	129.0	48.4							
12125	506.1	58.1	87.5	35.6							26.4
Ramsey County											
20.0	523.4	81.3	118.3	9.0							
196	522.5	84.6	129.2	17.6						22.0	

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
383	516.3	83.1	111.1	18.0							
407	540.7	68.9	133.5	20.0							
411	517.8	80.7	114.9	20.8							
422	534.9	66.0	128.4	9.0							
Renville County											
6296	505.0	35.0	126.8	36.5					101.6	96.8	198.4
6349	483.0	41.1	77.7	14.1							
6401	525.2	42.7	113.4	15.7					143.0	96.8	239.8
6436	510.0	37.7	128.3	23.5					104.9		
6466	492.0	34.9	111.1	55.5							
6473	524.1	46.6	104.8	33.6					155.3	69.0	224.3
6504	534.0	47.4	116.6	98.4				53.6	133.3	63.7	197.0
6624	536.0	51.0	110.6	93.4				56.0	111.5	9.5	121.0
6684	529.0	44.7	111.5	93.8				42.0	47.0	25.0	72.0
6749	472.0	40.2	96.9	47.0					159.6	125.6	285.2
7577	541.0	57.2	114.8	110.6				95.1	56.2	30.1	86.3
14429	537.1	40.0	116.0	87.2				55.3	112.3	75.5	187.9
14725	522.2	36.0	116.3	30.7					106.4	49.8	156.3
14758	505.4	33.9	97.3	16.9					88.2	90.1	178.3
14970	571.8	55.4	115.4	74.0				39.6			
17317	506.0	39.0	120.0	39.0					145.6	94.2	239.8
17467	523.5	22.1	112.8	28.2					94.4	104.2	198.5
Rolette County											
83	528.6	45.1	120.9	21.0							18.0
316	523.2	62.6	128.7	24.9							20.0
13586	540.0	57.8	122.4	24.5							
16095	570.0	18.2	161.8	186.0							78.0
Sheridan County											
665	580.9	74.5	119.9	28.7							
684	548.6	71.5	158.7	21.4							
693	601.7	85.9	131.4	25.6							
735	571.8	82.8	130.7	22.9							
9343	629.5	50.9	121.9	24.7				91.1			99.6
Sioux County											
631	559.0	47.8	169.5	12.0							
Slope County											
8629	586.1	35.5	105.2	22.7							
9244	581.2	36.2	106.3	27.9							
11484	586.4	35.2	108.2	22.3		61.7					
Stark County											
6447	599.5	38.5	112.6	35.2							
8088	640.3	35.6	115.1	51.5	72.6						
8169	632.6	44.7	108.6	27.1	11.8	172.2	82.0	222.0	190.0	78.9	268.9

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
8342	626.0	42.3	110.5	44.2	9.7	221.4					
8665	623.7	52.2	104.6	26.1							
8837	618.7	28.9	85.4	23.8							
9056	635.2	51.4	110.8	39.3	25.2						
9135	637.7	56.2	113.6	34.4							
9256	636.6	46.3	114.5	37.6	26.7						
9257	637.4	50.9	110.9	41.9	19.7						
9322	614.7	38.1	116.1	32.0							
9348	631.6	48.2	111.2	35.7	26.4	157.1					
9407	634.8	52.2	113.8	31.7	15.5						
9475	629.3	41.8	115.3	48.6	39.4						
9684	588.5	38.9	106.1	28.1							
10430	620.4	48.1	110.2	29.0							
10570	613.2	35.8	115.1	39.9							
13447	614.1	39.4	113.9	37.1							
14652	596.4	39.7	103.9	29.1							
Steele County											
8027	380.0	27.6	116.5	8.0							
9922	116.1	18.0	77.2	57.9							
Stutsman County											
40	562.4	68.1	135.1	7.1							
120	531.7	77.2	131.4	18.9							
134	546.2	77.4	140.9	16.2							
370	552.3	74.0	130.8	20.0							
406	556.7	72.8	131.5	18.1							
644	570.3	69.4	136.5	23.6							
668	659.3	63.4	154.0	5.1							
669	569.1	70.6	139.7	8.0							
671	570.7	71.3	130.2	4.8							
672	558.4	70.5	132.1								
7415	532.4	55.1	165.8	8.7							
9776	550.0	77.2	131.2	18.0							
Towner County											
171	510.8	57.0	130.4	21.2							
194	524.2	69.1	128.5	16.0							
227	525.7	57.1	139.3	26.2							7.4
Ward County											
47	607.5	37.6	119.2	95.0				69.4	60.4	67.8	128.2
7612	610.0	55.9	119.4	142.5		51.0	79.0	183.0	115.0	47.0	162.0
11055	599.3	44.9	118.0	95.7							
Wells County											
207	569.3	69.8	137.3	18.8							
609	589.4	59.6	131.1	21.8							

North Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
642	596.8	52.4	133.0	33.3							
689	557.5	58.7	163.6	20.4							
1211	592.8	56.5	131.2	14.3							87.7
11599	588.1	63.9	140.6	18.2							
11653	591.2	60.1	132.6	29.9							
11654	582.0	55.7	134.1	30.9							
Williams County											
1231	535.0	38.6	133.8	229.4							
1385	624.3	31.5	141.4	255.7	102.1	125.0	145.0	78.1	113.4	28.3	141.7
1403	586.7	38.9	148.9	252.2	41.0	172.0	135.0				
1514	600.8	45.5	149.7	237.3	94.0	135.0	138.0	114.6			
1636	603.1	32.0	147.0	238.4	46.6						
3844	614.1	35.9	152.0	245.7	82.9	138.6	152.8	65.2	127.1	22.9	150.0
4321	588.8	36.3	125.0	230.6	26.4	131.0	159.0	168.3	64.7	26.9	91.6
4323	549.5	45.4	132.5	225.6		89.6	102.3				
4618	493.7	38.8	73.6	158.9		61.0	157.0	168.0	170.0	37.0	207.0
4716	575.6	38.9	150.5	220.3	39.3						
5069	583.9	45.5	148.6	244.2							
6098	641.5	41.0	142.2	251.6							
6478	560.4	41.4	133.5	148.4		58.0					
7005	616.9	51.4	146.6	266.7	34.7						
7848	507.0	35.5	70.4	139.7							
8316	457.4	31.6	61.3	170.9							
8692	517.3	31.1	67.9	143.5							
9100	499.0	29.4	68.6	132.6							
9800	579.4	28.8	135.7	162.8		21.7					
10772	534.0	32.3	134.5	192.3		21.2					
12119	528.0	41.3	121.4	181.3		22.7					
12270	551.4	25.7	113.1	193.9		22.7					
12305	576.3	23.6	132.3	180.1	32.8	68.7					
12363	567.8	41.7	137.5	241.1	60.6						
12432	554.0	39.8	128.7	208.7	23.3						
12592	559.8	31.1	136.8	179.5	26.3						
12831	554.9	42.1	134.3	196.4	25.0	103.9					
12971	619.7	25.2	142.7	242.6	92.7						
13395	565.6	43.4	146.5	232.6	36.3	82.5					
13682	560.6	40.8	142.3	181.9	24.9	123.4					
13893	603.6	38.5	150.4	266.0	47.9						
16629	591.2	31.8	136.5	219.5	21.0	48.0					
17488	588.0	32.0	136.1	208.3							
18631	585.0	45.3	148.8	226.2	36.2	140.8					
18680	597.8	48.5	146.2	240.8	34.8	140.9					

Montana

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Carter County											
MT1	447.2	27.5	76.3					166.7	331.4	188.8	520.2
MT2	472.1	24.4	76.4	55.0							
MT3	462.9	23.7	76.3	120.9				63.4	270.5	80.8	351.3
MT4	470.8	24.3	45.1	75.8				66.5	329.2	68.4	397.6
MT5	485.3	29.9	82.7	167.9							
MT6	492.8	33.4	83.5	60.2			78.7	137.2			
MT7	488.4	43.0	81.0	20.5		27.5	84.8	138.9	383.3	91.2	474.5
MT8	465.3	42.7	71.1					170.2	401.5	154.3	555.8
Custer County											
MT9	410.0	35.0	93.7	19.6				187.7	389.0	52.0	441.0
Daniels County											
MT10	445.1	128.9	171.0	57.5				310.4			
Dawson County											
MT11	427.4	34.2	103.8	27.2			42.0				
MT12	414.4	37.4	104.1	71.4							
MT13	345.1	61.4	106.5	50.0			68.0	210.0	174.8		
MT14	324.7	42.0	114.2	41.3			62.7				
MT15	419.0	56.2	112.5	43.9							
Fallon County											
MT16	438.3	72.2	109.0	38.0			65.0	275.0	222.0	97.9	319.9
MT17	458.1	66.3	75.5	29.0		37.7	70.1	280.3	230.5	96.7	327.2
McCone County											
MT18	308.2	46.9	72.8	76.1			63.0	177.0	394.0	65.7	459.7
Powder River County											
MT19	456.6	15.8	88.5	14.0				182.7	391.3	67.4	458.7
Richland County											
MT20	401.0	46.6	143.4	70.0							
MT21	468.5	80.9	104.5	75.3							
MT22	461.0	79.8	108.2	64.0		63.0	153.0	173.0	276.8	109.9	386.7
MT23	404.0	46.0	132.0	70.5			146.4	177.2	190.8	106.2	297.0
MT24	468.0	54.5	119.5	72.0		62.5	144.5				
MT25	403.9	55.6	103.1	55.6							
Roosevelt County											
MT26	491.9	18.1	85.1	41.0							
MT27	463.9	39.0	132.6	85.6							
Sheridan County											
MT28	302.0	43.7	137.3	45.3							
MT29	313.0	28.4	156.6	43.8			296.7	119.4	92.1		
MT30	311.3	22.8	119.1	63.2			413.0	99.9	186.7		
MT31	401.0	36.8	125.2	84.0			330.7	75.3	123.2	106.9	230.1
MT32	400.9	19.1	128.4	75.5							
MT33	396.2	26.9	127.9	72.5			327.8	89.9	36.7	81.9	118.6

Montana

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
MT34	390.0	36.4	115.6	75.8			227.2	135.0			
MT35	392.4	29.9	130.0	77.6							
MT36	369.6	43.7	126.9	80.1			323.7	94.1	50.6	23.5	74.0
MT37	321.9	13.2	146.2	55.0			362.2	80.6	124.5	121.0	245.5
Valley County											
MT38	305.6	5.4	106.4								7,740.1
Wibaux County											
MT39	484.0	43.5	108.5	25.3		80.9					
MT40	478.0	52.1	106.9	19.6							
MT41	475.8	47.9	105.3	15.5		38.8					
MT42	451.0	61.4	109.6	26.7							
MT43	435.0	62.3	101.7	39.0							
MT44	447.0	76.3	84.7	59.1							
MT45						49.0	89.0	255.0	389.0	128.0	517.0
MT46	485.3	36.6	97.5	33.3							

South Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Bon Homme County											
SD1											
SD2											
Butte County											
SD3	313.3	40.4	83.9	109.5				94.2			
SD4	382.4	22.6	89.1					89.7	331.1	43.9	375.0
SD5	464.3	19.2	85.3					97.2	327.2	38.0	365.1
SD6	327.1	32.4	83.4					37.6			
SD7	422.5	28.4	63.8					54.3			
SD8	437.2	2.7	108.0								
SD9	440.5	34.3	91.1					100.0	250.7	110.4	361.1
SD10	403.5	23.4	90.0					44.6			
SD11	443.1	11.9	116.0					56.0			
SD12	229.0	41.5	64.8	65.5							
Corson County											
SD13	560.1	34.9	150.4	32.9				185.8	205.2	90.3	295.5
SD14	558.4	46.6	101.2	52.2							
SD15	574.0	16.7	112.1	32.8				179.3	224.6	46.7	271.3
SD16	576.9	16.1	82.9	59.7				177.3			
SD17	553.7	51.8	110.1					160.6			
SD18	559.0	25.9	128.9	32.9				178.3	220.2	74.0	294.2
SD19	553.0	24.7	134.9	72.5				118.2			
SD20	541.2	13.4	184.8						220.5	93.1	313.6
Dewey County											
SD21	539.7	23.3	97.3						214.8	37.5	252.4
SD22	545.8	11.6	120.6								
SD23	554.8	21.8	93.9	53.9					253.0	20.0	273.0
SD24	487.0	23.7	90.8	48.1					140.6	61.4	201.9
SD25	528.2	17.4	122.0								
SD26	550.2	31.0	144.8						161.8	69.2	231.0
SD27	548.6	30.6	127.2						166.5	61.6	228.1
Fall River County											
SD28											
SD29											
SD30											
SD31											
SD32	385.3	13.6	48.1								
SD33											
Faulk County											
SD34	218.1		79.3	20.8							25.8
Gregory County											
SD35	113.8	15.8	50.4								
SD36	40.8	11.3	28.4								

South Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Haakon County											
SD37	262.5	24.1	70.0	92.8					38.8	41.9	80.7
SD38	155.3	5.4	135.7								
SD39	215.4	4.0	38.8	31.2							
SD40	142.6	15.7	24.6	27.9							
SD41	407.6	7.4	78.9								
SD42	317.5	11.7	73.1	9.1							
Harding County											
SD43	290.0		50.0								
SD44	480.9	14.6	80.6								
SD45	473.6	43.0	78.9								
SD46	509.9		78.9								
SD47	490.0		95.4					74.0			
SD48	476.1	41.2	79.2					188.7	217.2	107.5	324.7
SD49	496.1	51.6	88.1								
SD50	473.3	30.7	82.8								
SD51	495.7	35.0	62.8	27.4							
SD52	476.2	49.7	123.7				29.6				
SD53	451.6	32.9	135.4				54.7				
SD54	499.3	28.5	176.5			46.3	43.3	186.4			
SD55	454.7	40.4	76.5					114.6			
SD56	488.7	28.0	89.0								
SD57	519.5	23.8	147.5				57.0	200.5	182.1	118.4	300.5
SD58	494.0	35.2	82.1					198.9			
SD59	497.6	35.2	120.4				38.8	160.5	119.6		
SD60	477.4	29.2	85.0								
Hughes County											
SD61	317.4	25.9	85.8	18.9							
Hyde County											
SD62	262.7	12.3	79.4	20.0							25.6
SD63	158.2	3.8	84.6	22.3							30.0
Jackson County											
SD64	156.7		61.1	14.3							
SD65	212.0		135.0								
Jones County											
SD66	204.3	8.7	71.6								
SD67	162.0		47.0	28.0							
SD68											
SD69											
SD70											
Lawrence County											
SD71	158.9	41.8	67.3	65.5				52.1			

South Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Lyman County											
SD72	55.0		65.0								
SD73											
Meade County											
SD74	490.2	19.2	90.7					155.3			
SD75	472.2	19.2	204.6					183.9			
SD76	408.9	15.6	93.4					154.8			
Mellette County											
SD77	76.7		46.0								28.1
SD78	68.8	5.8	24.7	24.3							35.1
Miner County											
SD79											
Pennington County											
SD80	197.3	12.3	88.5						177.1	35.1	212.2
SD81	385.0		37.7	52.3							
SD82	260.0	5.2	83.8	59.3							
Perkins County											
SD83	513.2	21.3	128.7					95.7	206.6		
SD84	512.4	19.0	131.8					111.9	186.3	143.7	330.0
SD85	556.4	39.1	95.4								
SD86	518.7	35.3	139.5					190.4	191.3	203.4	394.7
SD87	538.7	31.3	124.0								
SD88	522.2	35.8	176.5				56.3				
SD89	534.9	17.4	132.1					140.4	196.4	152.3	348.7
Potter County											
SD90	409.3	47.8	80.7	26.1							38.8
SD91	331.6	37.3	71.2	28.6							31.2
Oglala Lakota (Shannon) County											
SD92	138.0	5.8	60.2	42.0							
Spink County											
SD93											
Stanley County											
SD94	162.0		47.0	28.0							
SD95	368.0		39.9	85.4							
SD96											
SD97	85.7	12.9	56.9	66.0							
SD98											
SD99											
SD100											
SD101	327.5	39.8	94.1								
SD102	332.2		11.1	39.1							

South Dakota

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
Tripp County											
SD103	57.0		16.0								
SD104	126.0		32.0								
SD105											
SD106											
Walworth County											
SD107	362.3	44.1	117.5	40.8							32.8
SD108	383.9	55.1	129.5	43.2							47.3
Ziebach County											
SD109	502.1	19.7	100.0					22.0			

Manitoba

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
486	517	27.45	130	57							
1537	515.1	25.7	100.1	59.1							
1563	479.7	0.3	115.4	15.4							12.17
1666	479.1	8.9	138.0	29.4							40.55
2523	471.2	29.6	108.6	54.3							58
2532	429.6	24.6	121.9	16.5							12.4
2543	536.5	20.9	101.3	66.3							56.39
2593	555.6	15.6	114.4	32.6							13.17
2610	520.5	28.9	119.9	57.1							69
2612	365.7	14.8	109.8	63.0							57.57
2683	488.9	31.4	89.5	63.6							58.77
2695	484.7	19.3	113.9	22.4							27.63
2696	484.8	33.4	108.6	58.7							45.82
2700	493.5	15.4	94.0	95.2							24.79
2706	500.2	22.1	97.3	69.6							
2741	436.2	27.1	129.5	30.6							
2766	523.7	19.2	101.5	65.5							82
3183	468.6	14.5	108.3	15.5							25.5
3530	466.5	11.7	122.1	22.1							16.9
4495	444.4	28.4	113.0	49.5							
4845	518.0	18.5	110.2	51.1							
4859	499.1	25.2	95.3	55.6							67.72
5956	478.8	20.3	112.5	26.8							8.92

Saskatchewan

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
00C037	395	23.5	47.57	119							
00D072	390	35.7	36.5	124							
00F396	328	19.61	60.56	134					218	131	349
00J189	246	8	53.7	124					354.41	198.48	552.89
01A024	314	41.09	49.37	136							
01H069	328	24.2	64.72	139					101.11	37.05	138.16
01J006	432	17.25	49.84	126							
01L133	197	19.07	48.86	153					255.66	92.34	348
02A161	410	29.1	47.6	134					134.5	103.5	238
02B012	193	7.6	176						280.12	191.23	471.35
02I016	384	3.63	72	124							
02K012	389	2.67	76	134							
03K283	443	20	49.36	126							
03L284	219	38.26	50.33	136							
04B015	441	27.8	59	116							
05F018	290	15.2	66.52	132							
07I073	358	28.5	43.9	122					130.78		
08H567	481	26.1	68.7	118							
50I013	232										
51C004	180										
51E001	285	37.35	52.41	145							
51L011	196			6							
51L083	245										
52A006	498	36.2	104.8	68.5				18.05	87.95	52.68	140.63
52G001	313		53	90					81.17	22.25	103.42
53J044	422	31.66	66.27	128					153.16	40.83	193.99
54F047	172	18.05	14								
54J036	295										
55A052	502	27.2	114	75				54	136		
55E024	222								972.85		
55F097	526								915.94	113.46	1029.4
55J059	495	47.06	107.8	60.6				21.67	85.33	56	141.33
56B004	460	16.95	74.41	132				73.07	192.96	104	296.96
56C013	460	16.5	74.5	126							
56E085	195										
56G008	433	16.5	61.4	124					161.26	76.85	238.11
57G023	339	25.58	60.62	140							
57H002	248	5.6	31.67						311.68		
57K043	483	20.1	84	120							
58B029	244		47	119							
58I075	205	25.88	25.88	92.4					522.43	192.57	715
58L009	252	14.8	65	44.8							
59B006	196			15							

Saskatchewan

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
59G074	191								533.24	196.68	729.92
59L036	241								686.12		
60E086	417	18.94	50.22	133							
61I046	219								679.13		
62B005	343	14.9	64	116							
62H013	166								301.37		
64K049	222								737.24		
65C083	485								883.63	66.28	949.91
65F053	393		47	135					245.52		
65K031	446	22.7	77	108					32.98	43.02	76
66A088	467	24.1	59.84	113							40
66F117	477	20.3	86	136							
66I002	276		61.4	124							
66J002	429	19.5	79.6	109					34.86	35.47	70.33
68B016	233		56.9	108							
68F041	414	13.8	72	125							
72I017	162										
72K044	207	16.95	50.18	153					253.46	149.54	403
77H008	331	21.68	70.58	131							
77J053	353	7.9	74	138							
77J057	484	31.8	114.9	81.2				50.04	138.93	75.33	214.26
77L016	271	18.46	53.9	143					279.8	63.2	343
78B008	456	27.1	54.9	134					267.97	67.95	335.92
78C001	473	28.79	69.8	114					174.09	33.91	208
78H158	334	26.6	70.2	127							
78L010	249	30.89	36	125					253.53	159.47	413
80B006	511	36.6	113.2	71.2				8.55	109.94	55.71	165.65
80F005	351	20.11	75	130					291.14		
80G001	527	32.9	110.5	75.9				12.44	115.91	48.09	164
80I101	306	19	63.5	133							
81H036	476	30.5	115	53							48
82D001	502	15.7	86.05	4.64							
82I080	436	17	69	141				112.7	63.73	40.27	104
85B130	458.0	19.0	87.0	63.0							
85B212	438	13.7	75	147				119.3			
87G102	435	27.9	53.3	122							
87L059	462	27.6	56.5	130							
88D019	446	18.7	53.9	108					155.06	32.26	187.32
88K071	470	19.09	81	125							
88L062	480	7.9	78	120							
93D103	423	23.1	47.48	134					295.21	105.47	400.68
96B159	397	19.1	46.8	132							
96E028	397	5.7	68	122							

Saskatchewan

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
96E124	377	17.17	63.93	116							
96E258	437	1.49	74	124					114.8	31.22	146.02
96F283	375	25.72	54.18	116							
96G281	406	22.8	52.3	120							
96G312	376	23.99	53.01	118							
96I068	379	7.4	79	124					149.41	103.22	252.63
96I131	405	20.8	46.3	122					156.88	12.46	169.34
96I227	370	15.03	56.07	115							
96J008	400	26.8	43.8	122					103.28	31.48	134.76
96J367	420	26	49	131					186.34	64.66	251
96K164	377	10.59	59.8	110							
96L066	412	19.5	44.6	124					128.63	29.37	158
96L309	412	28.4	42.8	124					133.24	24.76	158
97A128	460	16.8	61.6	105					203.38	25.95	229.33
97B227	419	26.2	48.4	130					166.64	26.36	193
97C251	433	20.7	78	105					37.23	43.77	81
97C300	419	18.9	55.1	122					160.64	57.96	218.6
97E002	423	22.4	43.3	140					155.31	130.69	286
97E046	444	16.5	72	127							
97E081	382	0.2	74	123							
97E085	412	15.61	60.21	134					89.11	45.89	135
97E213	423	28.1	51.82	104							
97F067	435	21.79	71.52	125							
97F120	360	25.25	52.24	112							
97F182	315	18.55	70	128							
97F195	410	24.79	47.8	110							
97F392	400	18.46	50.95	93.1							
97G199	387	8.6	77	128							
97G315	385	2.13	75	122							
97G432	431	18.7	64.4	122							
97G483	371	37.55	62.02	143					261.87	172.13	434
97H295	403	22.21	58.56	136							
97I354	419	24.9	48.5	131					253.1	101.9	355
97I431	469	27.4	56.91	37.1							
97I438	512	30.8	113.3	80.4				22.3	139.35	60.65	200
97J331	398		73	131							
97K205	381	26.01	54.82	128							
97L095	385	17.4	50.37	123					86	84.55	170.55
97L298	386	16.7	50	119					107.14	74.35	181.49
97L301	413	26.5	40.47	135					42.63	36.37	79
97L305	352	3.82	62	119							
97L327	331	17.05	54.72	141					210.39	120.61	331
97L361	416	18.4	42.7	126							

Saskatchewan

Unit Thickness (in Feet)

Well Label	Red River	Winnipeg Group			Deadwood Formation						
		Roughlock	Icebox	Black Island	Member F	Member E	Member D	Member C	Member B	Member A	Member AB
98A033	419	15.7	49.9	139							
98A073	467	22.2	66.1	115							
98A081	440	20.7	70.32	118					73.01	73.66	146.67
98A149	417	17	44.7	125							
98A228	447	9.9	73	125							
98B015	402	19.45	52.4	108							
98B191	431	30.22	60.64	118							
98B210	401	14.1	43.6	96.8							
98C138	410	16.1	52.57	128							
98C155	326	22.05	67	136							
98C263	430	23.9	60.3	124					70.63	76.09	146.72
98C298	354	15.4	59.5	132							
98D041	466	20.9	66.43	107							
98E160	280	26.78	68	128					204.2		
98E189	409	15.9	44.05	126							
98G073	397	19.5	45.7	134					86.75	33.25	120
98G075	390	19.5	39.4	130							
98G108	404	16.1	48	129					64.62	30.38	95
98G193	398	18.9	47	125					61.55	32.45	94
98G201	386	18.7	44.2	122					80.12		
98H036	268	27.11	44.61	132							
98H069	401	21	40.8	130							
98K067	416	12.8	56	134					219.2		
98K107	302	18.61	61	132							
99A081	350	0.3	62	119							
99C003	402	9.7	59	131							
99C054	454	17.7	79	122					124.1	21.14	145.24
99E132	328	17.5	59	126							
99E245	435	23	50.5	115							
99F392	415	8.5	71	117							
99G151	357	2.71	64	120							
99I286	415	27.68	48.31	104							
99J213	200	21	72.1	134					308.06	127.36	435.42
99K055	392	28.39	54.7	98.7							
99K079	196	22.68	52.1	141					248.44	188.56	437
99L128	211	5.2	47.39	136							

Appendix D
Core and Thin Section Descriptions

North Dakota drill core samples and thin sections were viewed at the Wilson M. Laird Core and Sample Library in Grand Forks, North Dakota. Drill core samples from Saskatchewan were viewed at the Subsurface Geological Laboratory in Regina, Saskatchewan. Cores are described with a minimum increment of half a foot and the depths were recorded from what was written on the core itself or the box that they are stored in.

Well Number: 105

API Number: 33-101-00006

Well Name: Walter & Ingeberg Waswick #1

Well Operator: Stanolind Oil & Gas Co.

Location: SWNE Sec2 T153N R85W. Ward County, ND.

Cored Intervals: 10,960' – 11,008'

Top of Deadwood Formation: Did not reach Deadwood

Winnipeg Group

Black Island Formation

Ordovician

TS 10,978' SANDSTONE. Medium grained, moderate to well sorted, subangular to subrounded, moderate clay matrix, minor anhydrite cement.

TS 10,989' SANDSTONE. Medium grained, moderate to well sorted, subangular to rounded, moderate clay matrix, minor compacted grains.

TS 11,001' SANDSTONE. Fine to medium grained, moderate to well sorted, subangular to rounded, quartz overgrowths, very low porosity, moderate compacted grains.

TS 11,005' SANDSTONE. Medium grained, well sorted, subrounded, minor glauconite, moderate pyrite, quartz overgrowths, moderate clay, minor compacted grains.

TS 11,007' SANDSTONE. Fine to medium grained, moderate to poorly sorted, angular to subrounded, quartz overgrowths, minor pyrite, occasional cement replaced with pyrite.

Well Number: 291

API Number: 33-007-00001

Well Name: Herman May U. #1

Well Operator: Amerada Petroleum Corp.

Location: NWNE Sec9 T139N R100W. Billings County, ND.

Cored Intervals: 12,992' – 13,172'

13,182' – 13,325'

Top of Deadwood Formation: 12,959'

Deadwood Formation

Member E

Ordovician

TS 12,995' LIMESTONE. Minor quartz grains, subrounded to rounded, moderately mostly calcite, minor dolomite, sorted, very low porosity, slightly increased porosity along fractures, fractures are filled with clay.

TS 12,998' SANDSTONE. Medium grained, well sorted, subrounded, dolomite cement, low amplitude stylolites.

TS 13,066' SANDSTONE. Fine to medium grained, moderately sorted, subrounded, low amplitude stylolites, minor calcite, abundant intergranular porosity.

TS 13,077' SANDSTONE. Fine to medium grained, moderate to poorly sorted, angular to subrounded, abundant intergranular porosity, low amplitude stylolite, minor anhydrite near stylolite.

TS 13,106' SANDSTONE. Medium grained, moderate to well sorted, subangular to rounded, minor calcite and anhydrite cement, abundant intergranular porosity.

TS 13,115' SANDSTONE. Medium grained, moderate to well sorted, subrounded, low amplitude stylolite, minor anhydrite.

Deadwood Formation

Member D

Ordovician

TS 13,175 LIMESTONE. Mostly calcite, occasional dolomite rhombs, minor unidentifiable fossil debris, abundant glauconite, minor hematite.

Well Number: 1403

API Number: 33-105-00519

Well Name: BOE-Olson #1

Well Operator: Amerada Petroleum Corp.

Location: SWNE Sec15 T155N R96W. Williams County, ND.

Cored Intervals: 13,586' – 13,843'

Top of Deadwood Formation: 13,669'

Deadwood Formation

Member F

Ordovician

TS 13,686' SANDSTONE. Fine to medium grained, well sorted, subrounded to rounded, calcite cement, high porosity, minor quartz overgrowths.

Deadwood Formation

Member E

Ordovician

TS 13,786' LIMESTONE. Abundant fossil debris, gastropods, echinoderms, trilobite, mostly calcite, some fossils filled with dolomite, poorly sorted, no strong orientation.

TS 13,812' LIMESTONE. Abundant fossil debris, mostly calcite, minor dolomite, some dolomite rhombs.

Well Number: 1514

API Number: 33-105-00529

Well Name: Ulven Unit #1

Well Operator: Amerada Petroleum Corp.

Location: CNE Sec34 T156N R96W. Williams County, ND.

Cored Intervals: 13,930' – 13,967'

14,016' – 14,022'

Top of Deadwood Formation: 13,928'

Deadwood Formation

Member F

Ordovician

TS 13,965' SANDSTONE. Fine to medium grained, well sorted, subrounded to rounded, dolomite cement, occasional dolomite rhombs, minor calcite, minor clay laminae.

Well Number: 2373

API Number: 33-053-00410

Well Name: Antelope Unit "A" 1

Well Operator: Amerada Petroleum Corp.

Location: NESE Sec1 T152N R95W. McKenzie County, ND.

Cored Intervals: 14,146' – 14,209'
14,221' – 14,222'
14,253' – 14,369'
15,113' – 14,135'

Top of Deadwood Formation: 14,244'

Winnipeg Group

Black Island Formation

Ordovician

TS 14,165' SANDSTONE. Medium grained, well sorted, subrounded, high porosity, highly fractured, most of the porosity in in the fractures, occasional dissolution porosity, minor clay.

Deadwood Formation

Member F

Ordovician

TS 14,253' SANDSTONE. Fine to medium grained, moderate to well sorted, subrounded to rounded, quartz overgrowths, moderate intergranular porosity, minor calcite and dolomite cement.

TS 14,302' SANDSTONE. Fine to medium grained, poorly sorted, subrounded to rounded, abundant calcite cement, moderate zoned dolomite rhombs, minor unidentifiable fossil debris, some grains are lined with dolomite, minor quartz overgrowths.

TS 14,348’ SANDSTONE. Fine to medium grained, poorly sorted, angular to subrounded, calcite and micrite cement, some dolomite lined grains, abundant fossils, crinoid, brachiopod, trilobite, minor clay.

TS 14,357’ SANDSTONE. Fine to medium grained, poorly sorted, subrounded, calcite and micrite cement, minor anhydrite and dolomite cement, occasional dolomite rhombs, moderate fractures, increased porosity due to fractures.

Deadwood Formation

Member A

Cambrian

TS 15,116’ SANDSTONE. Fine to medium grained, poorly sorted, subangular to subrounded, quartz overgrowths, some grains corroded, high porosity, minor dolomite cement.

Well Number: 3268

API Number: 33-023-00171

Well Name: Svangstu #24-18

Well Operator: Shell Oil Co.

Location: SESW Sec18 T163N R95W. Divide County, ND.

Cored Intervals: 12,605' – 12,652'
12,677' – 12,739'
12,742' – 12,876'
13,363' – 13,373'
13,377' – 13,381'

Top of Deadwood Formation: 12,631'

Deadwood Formation

Member E

Ordovician

TS 12,627' SANDSTONE. Fine to medium grained, moderate to well sorted, subangular to subrounded, calcite cement.

TS 12,678' SANDSTONE. Very fine to medium grained, poorly sorted, subangular to subrounded, abundant clay laminae, minor dolomite cement.

TS 12,682' SANDSTONE. Medium grained, well sorted, subrounded, rare anhydrite, quartz overgrowths.

TS 12,700' SANDSTONE. Fine to medium grained, moderate to poorly sorted, subangular to subrounded, increase porosity due to voids, arenitic.

TS 12,702' SANDSTONE. Very fine to fine grained, very well sorted, angular to subrounded, minor calcite cement.

TS 12,707’ SANDSTONE. Fine to medium grained, poorly sorted, angular to subrounded, calcite cement, rare fractured quartz grains, moderate clay laminae, occasional horizontal fractures, hematite stained.

TS 12,709’ SANDSTONE. Fine to medium grained, moderate to well sorted, subangular to rounded, minor calcite cement.

TS 12,713’ SANDSTONE. Medium grained, well sorted, subangular to rounded, minor calcite cement.

TS 12,722’ SANDSTONE. Medium grained, well sorted, subangular to rounded, minor calcite cement, minor intergranular clay.

TS 12,724’ SANDSTONE. Top half quart arenite similar to above. Stylolite goes through the middle. Bottom half is very fine to medium grained, poorly sorted, subangular to subrounded, dolomite cement, abundant dolomite rhombs, moderate glauconite grains.

TS 12,742’ SANDSTONE. Fine to medium grained, well sorted, subangular to subrounded, minor calcite cement.

TS 12,749’ SANDSTONE. Fine to medium grained, moderate to poorly sorted, subangular to subrounded, dolomite cement, abundant dolomite rhombs.

TS 12,752’ SANDSTONE. Fine to medium grained, poorly sorted, subangular to rounded, dolomite cement, abundant dolomite rhombs.

TS 12,757’ SANDSTONE. Fine to medium grained, moderately sorted, subangular to subrounded, rare calcite cement.

TS 12,759’ SANDSTONE. Fine to medium grained, moderate to well sorted, angular to subrounded, significant stylolite through the middle, lithology remains consistent on both sides, besides minor anhydrite and minor dolomite cement and rhombs near the stylolite.

TS 12,768 SANDSTONE. Fine grained, well sorted, subangular to subrounded, dolomite cement, abundant dolomite rhombs.

TS 12,775’ SANDSTONE. Medium grained, well sorted, subrounded, dolomite cement, abundant dolomite rhombs, minor clay laminations, increased dolomite near clay.

TS 12,783’ SANDSTONE. Medium grained, well sorted, angular to subrounded, dolomite cement, abundant dolomite rhombs, moderate clay laminations, increased dolomite near clay, possible low amplitude stylolite.

TS 12,789’ SANDSTONE. Medium grained, well sorted, subrounded, dolomite cement, minor anhydrite cement, increase dolomite near bottom.

TS 12,803’ SANDSTONE. Fine to medium grained, well sorted, angular to subrounded, abundant dolomite cement, abundant dolomite rhombs, moderate clay laminations, increased dolomite near clay, low amplitude stylolite.

Deadwood Formation

Member D

Cambrian

TS 12,827’ SILTSTONE. Very fine to fine grained, well sorted, subrounded, very abundant dolomite cement, abundant calcite and dolomite rhombs, minor anhydrite.

TS 12,846’ LIMESTONE. Minor fine quartz grains, subrounded, moderate unidentifiable fossil debris, some trilobite debris, abundant glauconite, abundant dolomite, moderate calcite, minor clay along fractures, minor low amplitude stylolite.

TS 12,875’ LIMESTONE. Minor fine quartz grains, moderate to abundant glauconite, dolomite cement, occasional dolomite rhombs, moderate unidentifiable fossil debris, some echinoderm debris, possible burrow evidence, minor clay.

Deadwood Formation

Member A

Cambrian

TS 13,365’ SANDSTONE. Fine to medium grained, moderate to well sorted, subrounded, minor calcite cement, minor microcline.

TS 13,368’ SANDSTONE. Fine grained, moderate to well sorted, subrounded, some grains are fractured, minor calcite cement, some cement replaced with pyrite, minor small scale horizontal fractures.

TS 13,369’ SANDSTONE. Fine grained, moderate to well sorted, angular to subrounded, minor calcite cement.

TS 13,371’ SANDSTONE. Fine to medium grained, moderate to well sorted, subangular to subrounded, minor calcite cement.

TS 13,378’ SANDSTONE. Fine to medium grained, moderate to poorly sorted, subangular to subrounded, some grains are fractured, minor calcite cement.

Well Number: 6436

API Number: 33-075-00744

Well Name: Duerre #43-5

Well Operator: Shell Oil Co.

Location: NESE Sec5 T163N R87W. Renville County, ND.

Cored Intervals: 9,418' – 9,444'

9,491' – 9,494'

9,550' – 9,596'

Top of Deadwood Formation: 9,444'

Winnipeg Group

Black Island Formation

Ordovician

9,418' – 9,420.5' SILTSTONE. Light to medium gray, very fine to fine grained, mostly massive, shaly in part, interbedded with very thin to two inch sandstone beds, occasional zones where the cement has been replaced with pyrite, small horizontal fractures.

9,420.5' – 9,426' SILTSTONE. Medium to dark gray, very fine to fine grained, well sorted, horizontally laminated, some laminated are lined with pyrite and sometimes with fine to medium quartz grains, occasional zones where the cement has been replaced with pyrite, minor hematite staining, occasional thin zones of massive quartz sandstone.

9,426' – 9,426.5' SILTSTONE. Light to medium gray, very fine to fine grained, well sorted, mostly massive, shaly in part, interbedded with very thin to two inch sandstone beds, occasional zones where the cement has been replaced with pyrite, small horizontal fractures, some minor large white angular quartz clasts.

9,426.5' – 9,450' SILTSTONE. Medium gray, light brown, tan, very fine to fine grained, well sorted, horizontally laminated, some laminated are lined with pyrite and sometimes with fine to medium

quartz grains, moderate glauconite, occasional zones where the cement has been replaced with pyrite, minor hematite staining, occasional thin zones of massive quartz sandstone.

Deadwood Formation

Member B

Ordovician/Cambrian

9,450' – 9,454' SANDSTONE. Light to medium tan, light green gray, fine to medium grained, slightly dolomitic cement, alternates between well sorted horizontally laminated sandstone and poorly sorted glauconitic breccia, clasts are slightly rounded, minor pyrite, moderate glauconitic throughout more in brecciated areas, minor thin clay laminae.

9,454' – 9,458' SANDSTONE. Light to medium tan, light gray, green gray, very fine to medium grained, poorly sorted, abundant glauconite throughout, intense deformation, mostly soft sediment deformation, a lot of rip up clasts, abundant Precambrian rip up clasts, size increases with depth, very minor dolomite cement.

9,458' – 9,482' BRECCIA. Light to medium tan, all clasts are Precambrian, most are pink, some are gray, very angular, very poorly sorted.

TS 9,461' SANDSTONE. Very fine to medium grained, poorly sorted, quartz grains, rare microcline, angular to subrounded, mostly calcite cement, minor anhydrite cement, minor quartz overgrowths, very minor biotite.

TS 9,466' SANDSONE. Fine to medium grained, moderate to poorly sorted, subangular to subrounded, quartz grains, abundant glauconite, calcite and anhydrite cement, some grains are rimmed with calcite.

TS 9,469’ BRECCIA. Very fine to coarse grained, poorly sorted, highly fragment, sutured quartz grains, abundant microcline, calcite and anhydrite cement, occasional quartz overgrowths.

9,482 – 9,494’ SILTSTONE. Light to medium gray, green gray, green in some areas, very fine to fine grained, well sorted, abundant glauconite, upper section is mostly massive, occasional horizontal fractures, minor dolomite cement, below has alternating zones of wavy horizontal laminations and intensive deformation, abundant burrows creating a mottled texture, small scale faulting, soft sediment deformation, occasional producing rounded clasts of horizontally laminated siltstone, very rare Precambrian rip up clasts.

9,494’ – 9,550’ No core.

Precambrian

9,550’ – 9,596’ METAMORPHIC. Gneiss.

TS 9,550’ METAMORPHIC. Abundant biotite, fractured quartz grains, low intergranular porosity.

Well Number: 6466

API Number: 33-075-00750

Well Name: Mott #32X-3

Well Operator: Shell Oil Co.

Location: SWNE Sec3 T163N R87W. Renville County, ND.

Cored Intervals: 9,155' – 9,234'

Top of Deadwood Formation: 9,193'

Winnipeg Group

Black Island Formation

Ordovician

TS 9,156' SANDSTONE. Medium grained, well sorted, subangular to subrounded, very low porosity, quartz overgrowth, rare clay.

Deadwood Formation

Member B

Ordovician/Cambrian

TS 9,174' SANDSTONE. Very fine to medium grained, subangular to rounded, moderate to poorly sorted, some quartz overgrowths, occasional anhydrite cement, occasional calcite cement.

TS 9,191' SANDSTONE. Very fine to fine, poorly sorted, angular to subrounded, fragmented, anhydrite and calcite cement.

Precambrian

TS 9,196’ METAMORPHIC. Fine to medium grained, poorly sorted, angular to subrounded, fragmented, quartz overgrowths, anhydrite and calcite cement, minor microcline, possible fractured quartz grains.

TS 9,200’ METAMORPHIC. Very fine to medium grained, poorly sorted, angular to subrounded, fragmented, minor biotite, abundant clay, anhydrite and calcite cement, less quartz grains.

TS 9,209’ METAMORPHIC. Very fine to medium grained, poorly sorted, angular to subrounded, highly fragmented, silica cement, moderate anhydrite, muscovite, abundant clay.

TS 9,216’ METAMORPHIC. Very fine to medium grained, poorly sorted, angular to subrounded, highly fragmented, calcite cement, fractures filled with calcite, minor anhydrite, muscovite, abundant microcline, moderate clay.

Well Number: 6624

API Number: 33-075-00763

Well Name: Osterberg #22X-1

Well Operator: Shell Oil Co.

Location: SWNW Sec1 T161N R85W. Renville County, ND.

Cored Intervals: 9,114' – 9,323'

Top of Deadwood Formation: 9,131'

Winnipeg Group

Black Island Formation

Ordovician

9,114' – 9,123' SANDSTONE. Light tan, off white, light gray, medium grained, mostly massive, with very few sedimentary structures visible, occasional well-defined Skolithos burrows, some zones of intense bioturbation resulting in a mottled texture, burrows are outlined in very dark gray to black clay, minor amounts of glauconite are present and in some areas altered to a hematite, hydrogen sulfide staining in prevalent throughout.

9,123' – 9,126.5' CLAYSTONE. Very light to dark gray, off white, very fine to medium grained, moderate to well sorted, intermixed and interbedded shale to claystone and sandstone, abundant soft sediment deformation, slumping and some water displacement structures, horizontal beds are still visible, minor burrows, glauconite up to 15%, occasional thicker zones of sandstones, arenite, minor deformation, mostly massive.

9,126.5' – 9,127.5' No core.

9,127.5' – 9,129.5' SANDSTONE. Light to medium gray, light tan, very fine to coarse grain, moderate to well sorted, soft sediment deformation due to slumping, producing some breccia texture,

minor dolomite cement, occasional voids filled with dolomite, minor glauconite, minor dark gray clay intermixed, thin layer of claystone similar to above.

Deadwood Formation

Member C

Ordovician

9,129.5’ – 9,141.5’ SANDSTONE. Quartz wacke, light to medium gray, light tan, fine to medium grained, we sorted, subrounded, dolomitic cement, repeating intervals of extensively deformed and minor deformation, majority is soft sediment deformation due to slumping and loading, occasional horizontal burrows, zones of conglomerate containing subrounded to sub angular limestone and sandstone clasts, abundant glauconite in the conglomerate, occasional minor water escape structures, minor subvertical and subhorizontal fractures and voids filled with dolomite, occasional vertical Skolithos burrows found in less deformed areas, glauconite grains found throughout, some burrows and voids are filled with calcite.

9,141.5 – 9,160' SANDSTONE. Light to medium gray, fine to coarse grained, subrounded, well sorted, up to 20% glauconite, calcite and silica cement, alternating zones of planar laminations and extensive deformation, laminations have very minor deformation, minor faint cross beds, common soft sediment deformation due to slumping and loading, some zones of conglomerate and near breccia, minor well defined vertical Skolithos burrows, occasional horizontal burrows, abundant intermixed dark gray clay.

9,160' – 9,161.5' SANDSTONE. Gray, light tan, very fine to medium grained, well sorted, subrounded, mostly near horizontally bedded, minor soft sediment deformation between laminations, minor bioturbation, minor zone of intense deformation, nearly conglomeratic with very coarse angular grains, minor glauconite around 2% with up to 15% in bioturbated areas.

9,161.5' – 9,171.5' SANDSTONE. Quartz wacke, light to medium tan, green gray, light gray, fine grained, moderate to well sorted, subangular to subrounded, slightly calcareous, extensively bioturbated for the most part, abundant dark gray to black clay mixed with bioturbation outlining burrows, occasional zones of massive to faintly horizontal bedded with well-defined Skolithos burrows, minor cross beds, moderate glauconite between 5-10% overall with some areas up to 20%.

9,171.5' – 9,173.5' SANDSTONE. Quartz arenite, very light to medium tan, light gray, light brown, very fine to fine grained, well sorted, subrounded to rounded, mostly horizontally bedded, occasional cross beds, minor soft sediment deformation noticeable between laminations, massive zone near the bottom with well-defined Skolithos burrows, minor glauconite throughout, below 5% but some zones up to 15%.

9,173.5' – 9,179' SANDSTONE. Quartz wacke, light to medium tan, light gray, very fine to fine grained, subrounded to rounded, well cemented, slightly calcareous, extensively bioturbated, horizontal and vertical burrows producing a mottled texture, occasional massive areas with well-defined Skolithos burrows, abundant very dark gray to black clay mixed with bioturbated areas.

9,179' – 9,180.5' SANDSTONE. Quartz arenite, light to medium tan, light brown, light green gray, fine to medium grained, moderate to well sorted, subrounded, moderate glauconite 10%, mostly horizontally bedded, occasional cross beds, soft sediment deformation noticeable between laminations, some zones of extensive bioturbation, occasional small scale fractures.

9,180.5' – 9,187.5' SILTSTONE. Quartz wacke, light to medium gray, light tan, off white, very fine to fine grained, moderate to well sorted, subangular to subrounded, minor glauconite up to 10% in some areas, trace pyrite, slightly calcareous, heavily bioturbated, zones of bioturbation

9,187.5' – 9,190' SILTSTONE. Very light to light tan, light gray, fine grained, well sorted, subrounded, horizontally bedded, minor glauconite, very thin shale laminae between siltstone beds, minor soft sediment deformation, zones of heavy bioturbation, contain moderate amount of shale.

Deadwood Formation

Member B

Ordovician/Cambrian

9,190' – 9,202.5' SILTSTONE. Quartz wacke, light to dark gray, light tan, very fine to medium grained, well sorted, subangular to subrounded, minor glauconite 5%, heavily bioturbated, occasional zones of wavy to horizontal bedded siltstone, bioturbated areas contain moderate amounts of shale.

9,202.5' – 9,203' CONGLOMERATE. Very light to medium gray, green gray, light tan, matrix is very fine to fine quartz, fine to medium grained glauconite, and shale, poorly sorted, subangular to rounded, clasts are elongated horizontal bedded siltstone, moderate unidentifiable fossil fragments, slightly calcareous, abundant glauconite, minor amounts of hematite.

9,203' – 9,210.5' SILTSTONE. Very light to medium tan, light brown, light gray, very fine to fine grained, well sorted, subangular to subrounded, calcareous, moderate unidentifiable fossil debris, horizontal to near horizontal beds, bioturbation and deformation are minor, cross beds are rare, glauconite is very minor at 5%, occasional zones of increased deformation, mostly soft sediment deformation, occasional minor fractures.

9,210.5’ – 9,212.5’ CONGLOMERATE. Very light to medium gray, green gray, light tan, matrix is very fine to fine quartz, fine to medium grained glauconite, and shale, poorly sorted , subangular to rounded, clasts are elongated horizontal bedded siltstone, orientation of clasts appears random, moderate unidentifiable fossil fragments, slightly calcareous, abundant glauconite, minor amounts of hematite.

9,212.5’ – 9,223’ SILTSTONE. Very light to medium tan, light gray, very fine to fine grained, well sorted, horizontal beds, interlaminated with thin shale beds, glauconite found in occasional zones but minor throughout, abundant soft sediment deformation and water escape structures, occasional faint vertical burrows. A few zones of conglomerate with subrounded to well rounded elongated siltstone clasts, abundant glauconite, minor amounts of hematite, poorly sorted.

9,223’ – 9,228’ SHALE. Medium to dark gray, green gray, very fissile, very fine grained, horizontally bedded, moderate unidentifiable fossil fragments, abundant glauconite grains up to 90%, occasional interlaminated quartz arenite sandstone to siltstone, slightly calcareous, minor soft sediment deformation.

9,228’ – 9,235’ No core.

9,235’ – 9,236’ SANDSTONE. Light to medium gray, light tan, light green gray, very fine to medium grained, well sorted, subrounded, 5% to 30% medium grained glauconite, trace pyrite, trace anhydrite, massive to near horizontal bedded, abundant bioturbation from burrows and soft sediment deformation, in zones of deformation hematite is abundant.

9,236’ – 9,248.5’ SILTSTONE. Light gray, light to medium green gray, fine to medium grained, moderate to well sorted, subrounded to well rounded, glauconite up to 60%, slightly calcareous, minor unidentifiable fossil fragments, horizontal beds, occasional soft sediment deformation, minor cross beds, occasional thin clayshale laminae.

9,248.5’ – 9,249’ SHALE. Medium to dark gray, very fine grained, moderate glauconite grains 20%, occasional coarse grained quartz sand, fissile, occasional faint horizontal beds, noncalcareous.

9,249’ – 9,254’ SILTSTONE. Light gray, light to medium green gray, fine to medium grained, moderate to well sorted, subrounded to well rounded, glauconite up to 30%, clasts similar to the underlying

conglomerate found in multiple zones with no oxidation, faint horizontal beds, abundant deformation due to burrows and minor soft sediment deformation

9,254' – 9,255' CONGLOMERATE. Brick red, medium olive green, light gray, medium tan, matrix is very fine to fine grained quartz silt and fine to medium grained glauconite, up to 40% glauconite, poorly sorted, subangular to well rounded, elongated clasts of quartz siltstone, abundant hematite staining.

9,255' – 9,270.5' SILTSTONE. Light to medium green gray, light gray, off white, very fine to fine grained, very well to well sorted, subrounded, up to 5% to 75% glauconite, moderate unidentifiable fossil fragments, some areas where glauconite is altered to hematite, minor amounts of pyrite, mostly horizontal to near horizontal beds with minor cross beds, very minor bioturbations, occasional horizontal burrows and minor soft sediment deformation,

9,270.5' – 9,271' LIMESTONE. Brick red, brown, massive, abundant fossil fragments, red color due to intense oxidation.

9,271' – 9,296' SILTSTONE to SHALE: Light to dark green gray, medium to dark gray, very fine to fine grained, well to very well sorted, abundant glauconite 30% to over 75%, wavy to near horizontal bedded, slightly carbonaceous, areas of minor soft sediment deformation and minor burrows, mudstone is noncalcareous, very dark gray, fissile, and horizontally bedded.

Deadwood Formation

Member A

Cambrian

9,296' – 9,298.5' SANDSTONE. Glauconitic quartz arenite, light tan, light brown, reddish brown, light green gray, heavily oxidized, very fine to medium grained, subangular to subrounded,

carbonaceous in part, faint horizontal laminations, abundant hematite, abundant limonite and hematite staining.

9,298.5’ – 9,299’ LIMESTONE. Brick red, brown, yellow red, highly deformed from soft sediment deformation, moderate fossil fragments, most likely trilobites, red color due to intense oxidation, hematite and limonite staining throughout, glauconite sandstone found at the bottom.

9,299’ – 9,301.5’ SILTSTONE. Light gray, light to medium gray green, very fine to medium grained, well sorted, subrounded to rounded, up to 40% glauconite grains, wavy to near horizontal laminated, upper section is more deformation are contains glauconitic quartz clasts similar to the underlying conglomerate.

9,301.5’ – 9,303.5’ CONGLOMERATE. Light to medium gray green, light gray, matrix is mostly fine grained quartz and medium grained glauconite, rounded to well rounded, poorly sorted, clasts are lined in glauconite, carbonaceous in part.

9,303.5’ – 9,304.5’ SANDSTONE. Quartz arenite. Very light to light tan, light gray, off white, light brown, very fine to medium grained, very well to well sorted, less than 5% medium grained glauconite, massive with some vertical burrows

9,304.5’ – 9,306.5’ SANDSTONE. Quartz wacke. Very light to medium gray, light tan, very fine to medium grained, 10% medium grained glauconite grains, glauconite content increases towards the top to about 20%, some grains weathered to hematite and stained the surrounding grains, faint horizontal bedding.

9,306.5’ – 9,307’ CONGLOMERATE. Light to medium brown, fine to very coarse grained, poorly sorted, grains up to 0.25”, subrounded to rounded, clasts are mostly quartz sand grains with some limonite stained metamorphic clasts, 20% to 25% fine to medium grained glauconite.

9,307’ – 9,307.5’ SANDSTONE. Quartz arenite. Light tan, very light gray green, fine to coarse grained, subrounded to rounded, well sorted, 10% glauconite grains, upper part horizontally bedded and lower part mostly massive, a few sub horizontal fractures, sharp uneven upper contact.

9,307.5’ – 9,308’ CONGLOMERATE. Light to medium brown, fine to very coarse grained, poorly sorted, grains up to 0.25”, subrounded to rounded, clasts are mostly quartz sand grains with some limonite stained metamorphic clasts, 20% to 25% fine to medium grained glauconite.

Precambrian

9,308’ – 9,322.5’ PRECAMBRIAN. Quartz gneiss, dark gray to black, occasionally weathered green, abundant biotite, subvertical fractures.

Well Number: 7087

API Number: 33-023-00171

Well Name: Svangstu #24-18

Well Operator: Shell Oil Co.

Location: SESW Sec18 T163N R95W. Divide County, ND.

Cored Intervals: 11,637' – 11,669'

Top of Deadwood Formation: 11,300'

Deadwood Formation

Member B

Ordovician/Cambrian

TS 11,652' SANDSTONE. Medium grained, well sorted, subrounded to rounded, porosity low, slightly increased porosity near fractures, fractures filled with clay, abundant glauconite, anhydrite cement.

TS 11,665' SANDSTONE. Fine to medium grained, poorly sorted, subrounded to rounded, abundant intergranular porosity, slightly increased porosity near fractures, abundant glauconite, anhydrite cement.

TS 11,637' SANDSTONE. Fine to medium grained, subrounded, moderate to well sorted, occasional angular to subangular microcline, very low porosity, calcite cement, abundant glauconite.

TS 11,669' SANDSTONE. Medium grained, subrounded, well sorted, occasional microcline, occasional dolomite rhombs, moderate intergranular porosity, minor anhydrite cement, minor quartz overgrowths, abundant glauconite, occasional hematite, trace feldspar.

Well Number: 8088

API Number: 33-089-00242

Well Name: William Bernhardt #1

Well Operator: Shell Oil Co.

Location: NWNE Sec28 T141N R93W. Stark County, ND.

Cored Intervals: 12,386' – 12,443'

Top of Deadwood Formation: 12,466'

Winnipeg Group

Black Island Formation

Ordovician

TS 12,387' SANDSTONE. Arenite, fine grained, well sorted, subrounded, low porosity, occasional zones of increased porosity, increase porosity usually caused by fractures, silica cement.

TS 12,396' SANDSTONE. Arenite, fine to medium grained, moderate to well sorted, subangular to subrounded, increased fracture porosity, still low porosity, very fine grained clay matrix, some fractures filled with calcite.

TS 12,399' SANDSTONE. Arenite, medium grained, moderate sorted, subrounded to rounded, moderate porosity, some quartz overgrowths.

TS 12,401.5' SANDSTONE. Arenite, medium grained, moderate to well sorted, subangular to subrounded, high porosity, low amplitude stylolite, minor calcite cement.

TS 12,402.5' SANDSTONE. Arenite, medium grained, moderate to well sorted, subangular to subrounded, high porosity, minor calcite cement.

TS 12,435' SANDSTONE. Medium grained, poorly sorted, subrounded, high intergranular porosity, abundant dolomite cement.

Well Number: 8090

API Number: 33-053-01190

Well Name: Grimestad #4-6

Well Operator: Amerada Hess Corporation

Location: NESE Sec6 T152N R95W. McKenzie County, ND.

Cored Intervals: 14,615' – 14,627'

14,631' – 14,643'

Top of Deadwood Formation: 14,621'

Winnipeg Group

Black Island Formation

Ordovician

14,615' – 14,615.5' SHALE. Green, very fine grained with occasional laminations of coarser, occasional black grains.

14,615.5' – 14,617.5' SILTSTONE. Gray to dark gray, fine to very fine grained. Soft sediment deformation and wavy clay lamination visible.

Deadwood Formation

Member F

Ordovician

14,617.5' – 14,618.5' SANDSTONE. Arenite, light gray to gray, medium to fine grained. Evidence of soft sediment deformation and bioturbation, burrows, fossils debris, and cross bedding.

14,618.5' – 14,627' SANDSTONE. Wacke, light to dark gray, fine to medium grained and mostly well sorted. Evidence of soft sediment deformation and possible bioturbation, as well as burrows and fossils debris. Darker and finer grains found within thin clay laminations. Predominantly noncalcareous with occasional quartz filled fractures.

14,627’ – 14,631’ No core.

14,631’ – 14,643’ SANDSTONE. Wacke, light gray to dark gray, fine to medium grained, and poorly to moderately sorted, darker, finer grains are found within wavy clay laminations, soft sediment deformation and bioturbation, as well as fossil debris.

TS 14,640’ SANDSTONE. Fine to medium grained, poorly sorted, quartz grains, some grains are rimmed in dolomite, cement is dolomitic, occasional silica cement, minor anhydrite and calcite cement, smaller grains are subangular to subrounded, larger grains are subrounded to rounded, minor very fine brown clay, low porosity,

Well Number: 9257

API Number: 33-089-00262

Well Name: Hamann #1-19-4B

Well Operator: Gulf Oil Corp.

Location: NESW Sec19 T139N R92W. Stark County, ND.

Cored Intervals: 11,780' – 11,867'

Top of Deadwood Formation: 11,810'

Winnipeg Group

Black Island Formation

Ordovician

11,799' – 11,801' SANDSTONE. Off white, light to medium gray, pale yellow, orange brown, fine grained, rounded to well rounded, well sorted, extensively bioturbated, mostly horizontal wavy burrows, minor dolomite cement, some cement replaced with pyrite, large voids lined with dolomite crystals and some pyrite crystals, interbedded shale, up to six inches thick, horizontal to wavy beds, minor amounts of fine to medium sand.

11,801' – 11,801.5' LIMESTONE. Gray, very fine to medium grained, subrounded, well sorted, minor subhorizontal and subvertical fractures, occasional zones of bioturbation, mostly horizontal burrows, minor zones where the cement has been replaced with pyrite, medium grain sand found within.

11,801.5' – 11,803' SANDSTONE. Tan, medium to dark gray, very fine to fine grained, well sorted, bioturbation increases in lighter colored zones, occasional intermixed very dark gray clay laminae, near the bottom deformation increases, three inch zone of black shale.

11,803' – 11,807' SANDSTONE. Arenite, very light to light tan, off white, very fine to fine grained, well sorted, mostly massive, rare horizontal Skolithos burrows, occasional intervals of dark gray clay laminae, nearly horizontal with some soft sediment deformation, occasional thicker clay intervals.

11,807’ – 11,808’ SHALE. Dark gray to black, very fine grained, well sorted, no deformation, horizontal beds.

Deadwood Formation

Member F

Ordovician

11,808’ – 11,809.5’ SANDSTONE. Arenite, very light to light tan, off white, light gray, pale yellow, fine grained, well sorted, rounded to well rounded, heavily deformed, mostly horizontal burrows, occasional small zones where the cement has been replaced with pyrite, occasional zones where the grains are stained orange due to the oxidation of hematite, very minor effervescence, minor dolomite cement, large voids are lined with dolomite crystals and minor amounts of pyrite crystals.

11,809.5’ – 11,810’ LIMESTONE. Light to medium tan, light brown, very fine to fine grained, subrounded to subangular, well sorted, intense effervescence, clusters of hematite and pyrite, horizontal fractures are stained very dark brown to red, due to the oxidation of hematite.

11,810’ – 11,832.5’ SANDSTONE. Arenite, very light to light tan, off white, light gray, pale yellow, fine grained, well sorted, rounded to well rounded, heavily deformed, mostly horizontal burrows, occasional small zones where the cement has been replaced with pyrite, occasional zones where the grains are stained orange due to the oxidation of hematite, very minor effervescence, minor dolomite cement, large voids are lined with dolomite crystals and minor amounts of pyrite crystals.

Deadwood Formation

Member E

Ordovician

11,832.5’ – 11,833’ SHALE. Medium to dark gray, black, very fine grained, well sorted, horizontal beds, rare soft sediment deformation.

11,833’ – 11,833.5’ SANDSTONE. Tan, light green, light gray, very fine grained, well sorted, subangular, dolomitic cement, occasional horizontal fractures, small shale interval at the bottom.

11,833.5’ – 11,834’ SILSTONE. Light pink tan, light tan, very fine to fine grained, well sorted, subangular, dolomitic cement, minor anhydrite, heavily deformed, mostly horizontal burrows, filled with glauconitic siltstone, thin glauconitic wavy clay laminae throughout.

11,834’ – 11,837.5’ SILSTONE. Light pink tan, light tan, very fine to fine grained, well sorted, subangular, dolomitic cement, minor anhydrite, horizontal laminations, conglomerate towards the bottom, unidentifiable fossil debris, coarser grains, minor carbonate zones, thick glauconite beds.

11,837.5’ – 11,840’ SILTSTONE. Light pink, light pink tan, off white, fine grained, subrounded, heavily burrowed, mostly horizontal burrows, anhydrite cement, carbonate cement, intense effervescence in some areas, abundant unidentified fossil debris, hematite oxidation staining, minor glauconitic laminations.

11,840’ – 11,848.5’ SILTSTONE. Light to medium pink, off white, fine grained, subrounded, heavily burrowed, mostly horizontal burrows, moderate anhydrite, carbonate cement, intense effervescence in some areas, abundant unidentified fossil debris and intact brachiopods, gastropods, and crinoids, hematite oxidation staining, minor glauconitic laminations.

11,848.5’ – 11,868’ CONGLOMERATE. Deep brownish red, coarse grained, fine grained matrix, poorly sorted, carbonaceous, intense effervescence, , abundant unidentified fossil debris and intact Maclurea gastropod and hylolithes, abundant glauconite found in clay laminae, hematite oxidation staining, minor quartz overgrowths, clay content increases towards the bottom.

Well Number: 12831

API Number: 33-105-01389

Well Name: Nelson #22-44

Well Operator: Amerada Hess Corporation

Location: SESE Sec22 T156N R96W. Williams County, ND.

Cored Intervals: 13,839' – 13,849'

13,944' – 14,004'

Top of Deadwood Formation: 13,895'

Winnipeg Group

Black Island Formation

Ordovician

13,839' – 13,846.5' SANDSTONE. Light gray, fine to medium grained, subrounded, mostly massive, occasional soft sediment deformation, thin horizontal fractures, occasional vertical fractures that offset bedding planes, occasional pyrite nodules, minor hematite staining, minor low amplitude stylolite.

13,846.5' – 13,849.5' SANDSTONE. Light to medium gray, light tan, fine to medium grained, subrounded, well sorted, mostly massive, occasional faint horizontal laminations with occasional cross beds, occasional vertical Skolithos burrow, larger vertical fractures filled with quartz, fractures have minor hematite staining, minor low amplitude stylolites.

13,849.5' – 13,944' No core.

Deadwood Formation

Member E

Ordovician

13,944' – 13,952.5' LIMESTONE. Gray, very fine to fine grained, thin beds of sandstone, mostly horizontally laminated with occasional cross beds, some areas of bioturbation producing a mottled texture,

some soft sediment deformation producing clasts of surrounding limestone, minor water escape structures, occasional massive areas, unidentifiable fossil debris, fractures filled with calcite, rare large nodules of pyrite, up to 4mm in size.

13,952.5’ – 13,961.5’ SANDSTONE. Light gray, very light to light tan, off white, fine to coarse grained, subangular to subrounded, moderate to well sorted, minor amounts of dolomitic cement, extensively bioturbated, multiple subvertical fractures that offset bedding planes, fractures are filled with quartz, some wavy horizontal fractures, filled with dark gray to black clay, minor amounts of pyrite near the bottom.

13,961.5’ – 13,963.5’ LIMESTONE. Medium to dark gray, very fine to coarse grained, angular to subrounded, poorly sorted, soft sediment deformation produces abundant areas of breccia, clasts are similar to the surrounding unit, large clasts of shale and occasional sandstone, rectangular in shape with horizontal laminations and faint cross bedding, occasional rounded clasts, pyritic, large subvertical fractures that do not offset bedding planes.

13,963.5’ – 13,964’ LIMESTONE. Light to medium gray, fine to medium grained, well sorted, subrounded, fossiliferous, slightly pyritic, interfingered with siltstone, mostly massive, some areas of bioturbation producing a mottled texture, very thin black clay laminae throughout.

13,964’ – 13,964.5’ LIMESTONE. Light to medium gray, very fine to fine grained, well sorted, subrounded, wavy to near horizontally bedded, oily, very dark gray to black non calcareous clay laminae, minor amounts of pyrite, minor unidentifiable fossil debris, minor soft sediment deformation, deformation produces large clasts of surrounding limestone.

13,964.5’ – 13,967.5’ SANDSTONE. Gray, very fine to fine grained, moderate to well sorted, subrounded to rounded, minor amounts of dolomitic cement, extensively bioturbated, thin beds of dark gray to black shale, horizontal laminations near the bottom, large near vertical fractures.

13,967.5’ – 13,968.5’ LIMESTONE. Medium to dark gray, very fine to medium grained, soft sediment deformation abundant in the upper half, deformation producing clasts of surrounding limestone up to 50mm, clasts display planar laminations, lower section mostly massive with occasional faint laminations, minor small clasts near the bottom.

13,968.5’ – 13,972.5’ SHALE. Medium to dark gray, brown, very fine to fine grained, occasional medium grain, upper part soft sediment deformation, wavy bedding, interbedded with abundant limestone, bottom half near horizontal beds, oily, abundant pyrite at the bottom.

13,972.5’ – 13,974’ LIMESTONE. Light gray, very fine to medium grained, extensive soft sediment deformation, pyritic near the top, upper section, deformation producing large clasts of surrounding limestone, very thin dark gray to black wavy clay laminae, middle section, poorly sorted, very fine to coarse grained, large clasts, matrix mostly medium grained, bottom section, siltstone laminations with abundant limestone clasts.

13,974’ – 13,979.5’ LIMESTONE. Gray, very fine to fine grained, wavy laminations, horizontal laminations near the bottom occasional soft sediment deformation, deformation producing clasts, occasional slump features, occasional thin very dark gray to black clay laminae.

13,979.5’ – 13,982.5’ LIMESTONE. Medium to dark gray, dark brown, black, very fine to fine grained, well sorted, subrounded to subangular, mostly horizontal to slightly wavy beds, interbedded with shale, calcite found throughout, minor amounts of pyrite, oily in part.

13,982.5’ – 13,983’ LIMESTONE. Gray, very fine to coarse grained, subrounded to rounded, very poorly sorted, extensive soft sediment deformation, deformation producing abundant limestone clasts, abundant bioturbation producing mottled texture.

13,983’ – 13,989’ LIMESTONE. Medium to dark gray, color is very inconsistent and goes against stratigraphy, very fine to medium grained, mostly horizontal beds, minor deformation, abundant fractures, very large vertical fracture over a foot, filled with pink calcite.

13.989’ – 13,993.5’ LIMESTONE. Medium to dark gray, very fine to coarse grained, extensive soft sediment deformation, occasional horizontal burrows, deformation producing limestone clasts, angular to rounded, poorly sorted, moderate unidentifiable fossil debris.

13,993.5’ – 13,995.5’ LIMESTONE. Gray, brown, fine to medium grained, minor amounts of pyrite, very mottled due to burrows, occasional zones of limestone clasts produced by soft sediment deformation, occasional thin vertical and horizontal fractures.

13,995.5’ – 13,999’ LIMESTONE. Light gray, fine to medium grained, very mottled due to burrows, occasional zones of limestone clasts produced by soft sediment deformation, very thin dark gray to black clay laminae, rare thick black shale beds, large vertical fractures filled with calcite.

13,999’ – 14,004’ SANDSTONE. Light to medium gray, fine to coarse grained, subrounded, moderate to well sorted, wavy laminations, large fractures filled with calcite, minor soft sediment deformation.

Well Number: 13405

API Number: 33-053-02397

Well Name: Brenna-Lacey 1 #32

Well Operator: Amerada Hess Corporation

Location: SWNE Sec1 T152N R95W, McKenzie County, ND.

Cored Intervals: 14,260' – 14,371'

Top of Deadwood Formation: 14,255'

Deadwood Formation

Member F

Ordovician

14,260' – 14,262.5' SANDSTONE. Grey, medium grained, well sorted, subrounded to rounded, carbonate cement, mostly massive, occasional zones of extensive bioturbation.

14,262.5' – 14,264.5' SANDSTONE. Quartz wacke, light gray, tan, some yellow hydrogen sulfide staining, medium grained, well sorted, subrounded to rounded, mostly horizontal beds with some cross beds, occasional vertical Skolithos burrows,

14,264.5' – 14,266.5' SANDSTONE. Quartz wacke, light to medium gray, medium grained, subrounded to rounded, well sorted, carbonate cement, horizontally bedded with minor cross beds, some horizontal low amplitude stylolites, occasional vertical burrows.

14,266.5' – 14,269' SANDSTONE. Quartz wacke, light to medium gray, light tan, brown, medium grained, subrounded, well sorted, carbonate cement, extensively bioturbated, burrows are lined by brown clay, the majority are horizontal burrows, occasional low amplitude stylolite, some areas on less bioturbation, hydrogen sulfide minor in these areas, well defined vertical Skolithos burrows occur.

14,275’ – 14,282.5’ SANDSTONE. Quartz wacke, light to dark gray, very fine to medium grained, poorly sorted, general fines towards the bottom, extensively bioturbated, mostly wavy horizontal burrows and some water escape structures, occasional areas of horizontal beds with faint cross beds.

14,282.5’ – 14,293.5’ SANDSTONE. Quartz wacke, light gray, light tan, occasional yellow hydrogen sulfide staining, medium grained, well sorted, subrounded to rounded, well cemented, silica cement, large vertical fractures, filled with minor amounts of calcite, mostly massive, faint horizontal beds with low angle cross beds, occasional vertical Skolithos burrows.

14,293.5’ – 14,300.5’ SANDSTONE. Quartz wacke, light to dark gray, tan, medium grained, well sorted, minor carbonate cement, extensively bioturbated, abundant soft sediment deformation, horizontal burrows, slump structures, small scale faulting, occasional low amplitude horizontal stylolites, small zones of massive, silica cemented sandstone, minor vertical Skolithos burrows, very faint cross beds.

14,300.5’ – 14,301.5’ SHALE. Black, very dark gray, very fine grained, well sorted, minor larger quartz grains, carbonaceous, planar laminated, upper contact has shale injected into the overlying sandstone, minor soft sediment deformation, unidentifiable fossil debris is minor throughout, there are beds of abundant fossil debris, these beds pinchout on both sides.

14,301.5’ – 14,307’ LIMESTONE. Light to dark gray, very fine to medium grained, well sorted, subrounded, extensively deformed, carbonate cement, mostly soft sediment deformation, slumping, abundant mixing of shale and sand layers, some load deformation, occasional burrows, minor faint cross beds, minor small scale subvertical and subhorizontal fractures.

14,307’ – 14,311.5’ SHALE. Medium to dark gray, dark brown, black, very fine grained, minor larger quartz grains, well sorted, carbonaceous, mostly planar laminated, moderate soft sediment deformation, mostly caused by loading and slumping, minor water escape structures, minor fossil debris throughout, minor amounts of pyrite.

14,311.5’ – 14,315.5’ LIMESTONE. Light to dark gray, medium tan, brown, very fine to medium grained, well sorted, subrounded, extensively deformed, carbonate cement, mostly soft sediment deformation, slumping, abundant mixing of shale and sand layers, some load deformation, minor water escape structures, minor faint cross beds, minor small scale subvertical and subhorizontal fractures.

14,315.5’ – 14,316’ SHALE. Medium to dark gray, dark brown, black, very fine grained, minor larger quartz grains, well sorted, carbonaceous, mostly planar laminated, moderate soft sediment deformation, mostly caused by loading and slumping, minor fossil debris throughout.

14,316’ – 14,317.5’ CONGLOMERATE. Very light to medium tan, medium to dark gray, very fine to medium grained, poorly sorted, large rounded clasts of limestone, in calcite cemented sandstone, clasts are subrounded to rounded.

14,317.5’ – 14,327’ SANDSTONE. Light to dark gray, fine to medium grained, well sorted, subrounded, well cemented, carbonate cement, extensively bioturbated, mottled, wavy burrows, conglomerate zone, darker colored sandstone clasts, surrounded by clean carbonate cemented sandstone, minor yellow hydrogen sulfide staining, trace anhydrite.

14,327’ – 14,329.5’ SANDSTONE. Light gray, light tan, medium grained, well sorted, subrounded to rounded, mostly massive, minor amounts of calcite cement, occasional horizontal laminations, minor bioturbation, vertical Skolithos burrows, minor yellow hydrogen sulfide staining.

14,329.5’ – 14,332’ SANDSTONE. Light to medium gray, light tan, fine to medium grained, well sorted, subrounded, carbonaceous cement, moderate bioturbation, sedimentary structures are not present, mostly horizontal burrows with some well-defined vertical Skolithos burrows, occasional subangular to subrounded limestone clasts, subvertical fracture filled with calcite,

14,332’ – 14,333’ SANDSTONE. Light gray, medium grained, well sorted, subrounded to rounded, carbonate cement, extensively bioturbated, burrows outlined in dark gray to black clay, occasional massive areas with vertical Skolithos burrows, few horizontal and vertical fractures filled with calcite, minor yellow hydrogen sulfide staining.

14,333’ – 14,336’ SANDSTONE. Very light to medium gray, fine to medium grained, moderate to well sorted, subrounded, extensively deformed, mostly soft sediment deformation, some limestone clasts intermixed.

14,336’ – 14,337.5’ SANDSTONE. Quartz wacke, very light to medium gray, fine to medium grained, well sorted, subrounded, horizontal beds with obvious cross beds, minor soft sediment deformation towards the bottom.

14,337.5’ – 14,338’ SANDSTONE. Light gray, medium grained, well sorted, subrounded to rounded, carbonate cement, crystalline dolomite, soft sediment deformation, sandstone intermixed with limestone, minor bioturbation, small zone near the bottom, massive to wavy horizontal beds, occasional dolomitized horizontal beds with faint cross beds, minor low amplitude stylolites, minor areas of clasts.

14,338’ – 14,357’ LIMESTONE. Dark gray to black, very fine to fine grained, horizontal laminations, occasional fossiliferous zones, unidentifiable fossil debris, some soft sediment deformation, obvious slumping and loading, water escape structures, minor faulting, occasional zones of bioturbation, rip up clasts with horizontal laminations, matrix is medium grained, fossiliferous, carbonate cement, some vertical fractures filled with calcite.

14,357’ – 14,357.5’ SHALE. Medium to dark gray, tan, very fine to fine grained, well sorted, shale interbedded with limestone, moderately deformed, soft sediment deformation, most of the planar laminations are still visible, slumping and loading,

14,357.5’ – 14,358’ CONGLOMERATE. Very dark gray, very dark brown, very fine to coarse grained, heavily deformed carbonaceous shale, large clasts of shale are in a mix of limestone, shale, and fossil debris, minor subhorizontal fractures, possible low amplitude stylolite.

14,358’ – 14362’ LIMESTONE. Light to medium gray, zones of medium sand intermixed with the limestone, extensively bioturbated, fossiliferous, soft sediment deformations, rip up clasts, water escape structures, occasional horizontal wavy beds.

14,362’ – 14,371’ LIMESTONE. Light gray, medium grained, minor amounts of quartz and dolomite, moderate soft sediment deformation, slumping, some shale intermixed, minor subvertical fractures filled with calcite.

Well Number: 17317
API Number: 33-075-01397
Well Name: E-M Emmel 10-3
Well Operator: Eagle Operating, Inc.
Location: NENW Sec10 T163N R87W. Renville County, ND.
Cored Intervals: 9,235' – 9,267'
Top of Deadwood Formation: 9,189'

Deadwood Formation

Member B

Ordovician/Cambrian

9,235' – 9,239' SANDSTONE. Very light to light gray, light green gray, fine to very fine grained, medium sized grains near the bottom, well sorted, subrounded, 10-15% fine grained glauconite, soft sediment deformation due to slumping, mottled texture, multiple subvertical fractures, filled with dark gray clay, some fractures offset surrounding structures, occasional horizontal burrows, glauconitic sandstone interfingers underlying glauconite free sandstone at the bottom contact.

9,239' – 9,255.5' SANDSTONE. Light to dark brown, tan, fine grained, well sorted, subangular, no glauconite, severely oil stained, occasional subvertical and subhorizontal fractures, soft sediment deformation due to slumping, core has salt precipitate on it, zones of extensive deformation are usually lighter in color, some large angular clasts, very fine silica cement, some hematite staining.

9,255.5' – 9,258.5' SANDSTONE. Very light to light gray, some areas are darker gray, fine grained, subangular, well sorted, not deformed areas are massive, silica cement, most is extensively deformed, some areas are a breccia, very mottled textures, soft sediment deformation due to slumping, off set fractures, minor water escape structures, abundant dark gray clay intermixed with the sandstone, everything is folded together.

9,258.5’ – 9,262.5’ SANDSTONE. Very light to light gray, light green gray, fine grained, subangular, very well sorted, 5-25% glauconite, up to 40% glauconite in wavy bands, extensive soft sediment deformation due to slumping, multiple subvertical and subhorizontal offsetting fractures, abundant intermixed dark gray clay, some hematite clasts.

9,262.5’ – 9,267.5’ SANDSTONE. Very light to light gray, light brownish yellow, light green gray, medium to fine grained, subangular, well sorted, faint soft sediment deformation, 5-10% glauconite, possible horizontal beds, glauconite grains seem to be orientated in the same direction, minor oil saturation, minor intermixed dark gray clay, occasional subvertical and subhorizontal offset fractures.

Well Number: 17467

API Number: 33-075-01398

Well Name: E-M Flying H 5-9

Well Operator: Eagle Operating, Inc.

Location: NESE Sec5 T163N R87W. Renville County, ND.

Cored Intervals: 9,380' – 9,387'

9,438' – 9.502'

Top of Deadwood Formation: 9,385'

Deadwood Formation

Member B

Ordovician/Cambrian

9,438' – 9,460.5' SANDSTONE. Light to medium green gray, light gray, very fine grained, well sorted, subrounded, carbonate cement, abundant glauconite, alternating zones of horizontal to wavy laminations and intense bioturbation.

9,460.5' – 9,462' CONGLOMERATE. Light to medium gray, light tan, green gray, very fine to coarse grained, poorly sorted, angular to subrounded, abundant glauconite, small area of massive sandstone, distinct vertical Skolithos burrows, rip up clasts up to three inches wide, some are massive sandstone others are glauconitic sandstone similar to what is found above.

9,462' – 9,467.5' SANDSTONE. Light to medium tan, light brown, fine to medium grained, well sorted, minor dolomite cement near the top, mostly massive, faint horizontal and possible cross beds, rare bioturbation, just a few vertical Skolithos burrows, occasional soft sediment deformation, some vertical fractures that offset bedding planes, occasional cement replaced with pyrite, brown color is caused by the matrix in some areas the matrix is quartz and the unit is a light gray color, usually around fractures.

9,467.5' – 9,469' SANDSTONE. Light to medium tan, light to medium brown, fine to medium grained, moderate to well sorted, extensive bioturbation, occasional well defined vertical Skolithos

burrows, most are horizontal wavy burrows, some soft sediment deformation, some vertical and near horizontal burrows.

9,469’ – 9,470.5’ CONGLOMERATE. Light to medium gray, light tan, green gray, very fine to coarse grained, poorly sorted, subrounded, carbonate cement, abundant to moderate glauconite, small area of massive sandstone, distinct vertical Skolithos burrows, rip up clasts up to three inches wide, some are massive sandstone others are glauconitic sandstone similar to what is found above, occasional voids filled with calcite.

9,470.5’ – 9,472’ SANDSTONE. Wacke, light to medium tan, very light brown, light blue green gray, very fine to medium grained, moderate to well sorted, subrounded, carbonate cement, abundant medium sized glauconite grains, glauconite grains are subangular, 5% to 30%, extensively deformed, sharp upper contact, mottled texture due to bioturbation, abundant soft sediment deformation, small scale subhorizontal and subvertical fractures, abundant shale intermixed with burrows, glauconite founded within shale intervals.

9,472’ – 9,477’ SANDSTONE. Light brown, light to medium tan, light blue green gray, fine to medium grained, carbonate cement, well sorted, subrounded, contact above is gradational, glauconite grains grade to about >1% shortly after contact, mostly massive with some faint horizontal beds present, faint bioturbation.

9,477’ – 9,478’ SANDSTONE. Light brown, light to medium tan, light blue green gray, fine to medium grained, carbonate cement, well sorted, subrounded, interbedded with very dark gray shale wavy beds, glauconite in the sandstone is about 10%, shale contains rip up clasts of glauconitic sandstone, shale beds contain minor medium quartz and glauconite grains.

9,478’ – 9,482’ CLAYSTONE. Dark to very dark gray, black, very fine to medium grained, moderately sorted, subrounded to subangular, abundant individual grains of glauconite and quartz sand, tiny rip of clasts of shale also occur, shale is horizontally bedded and very fissile, abundant soft sediment deformation, angular clasts of shale are mixed with massive poorly sorted sandy claystone.

Deadwood Formation

Member A

Cambrian

9,482’ – 9,484’ SANDSTONE. Wacke, very light to medium tan, light brown, light gray, fine to medium grained, sandstone is mostly massive, abundant soft sediment deformation, abundant blue gray shale streaks, they are very deformed and random to subhorizontal in orientation, glauconite is minor in sandstone areas but abundant in shale.

9,484’ – 9,487.5’ SANDSTONE. Light to medium tan, light to medium brown, medium grained, well sorted, subrounded to rounded, mostly massive with abundant bioturbation throughout, most is burrows, occasional well defined vertical burrows, moderate soft sediment deformation, minor small scale fractures.

9,487.5’ – 9,493.5’ SANDSTONE. Wacke, very light to light blue gray, light tan, off white, brown, very fine to medium grain, occasional coarse grains, moderate to poorly sorted, subangular to subrounded, repeating intervals of blue gray sandstone and brown sandstone, differences has to do with the matrix, blue gray areas are more mottles, sedimentary structures are rare, occasional cross beds, abundant soft sediment deformation, abundant burrows.

9,493.5’ – 9,494.5’ SILTSTONE. Light to medium blue gray, light tan, light gray, fine to medium grained, moderate to well sorted, subrounded, similar to above but not as mottled, abundant glauconite,

mostly soft sediment deformation, slump structures, burrows and soft sedimentation has a subhorizontal orientation, faint beds and cross beds.

Precambrian

9,494.5’ – 9,502’ METAMORPHIC. Gneiss.

Well Number: 18631

API Number: 33-105-01787

Well Name: Blou 12

Well Operator: Hess Corporation

Location: NWNE Sec15 T155N R96W. Williams County, ND.

Cored Intervals: 13,671' – 13,707'

13,709' – 13,728'

Top of Deadwood Formation: 13,703'

13,671' – 13,678' MUDSTONE. Light to medium gray, light green gray, light to medium red brown, very fine grained, well sorted, horizontal to wavy laminated, some zones of bioturbation, mostly horizontal burrows, some areas have occasional subvertical fractures, occasional zones with abundant unidentified fossil debris, fossiliferous zones are commonly gray in color.

13,678' – 13,682.5' SILTSTONE. Wacke, medium to dark purple brown, red brown, light tan, very fine to medium grained, moderately sorted, similar to overlying mudstone but contains coarser grains, extensively bioturbated, all sedimentary structures are destroyed, burrows are faint, bottom grades into a massive, light tan, sandstone.

13,682.5' – 13,683.5' SANDSTONE. Light to dark gray, fine to medium grained, well sorted, subrounded, dolomite cement, occasional dark gray clasts of limestone, rare glauconite, very light limestone, dark gray to black clay laminae, some pyrite.

13,683.5' – 13,684.5' SANDSTONE. Very light to medium gray, dolomite cement, calcitic along fractures and in occasional voids, occasional zones of limestone breccia, limestone is very dark gray to black, subangular, clasts are up to a cm, bottom is massive, arenite, silica cement, minor limestone interclast, carbonaceous along fractures.

13,684.5' – 13,687' SANDSTONE. Light gray, light to medium tan, very light brown, fine to medium grained, moderately well sorted, subrounded to rounded, calcite cement, mostly massive, some

horizontal beds, beds are difficult to see because they are formed by slight changes in color, possible faint cross beds near the top, small subhorizontal fractures throughout, minor hydrogen sulfide staining.

13,687 – 13,702.5’ SANDSTONE. Dark to very dark tan, brown, dark gray, extensively oil stained, fine to medium grain, moderately well sorted, subrounded, calcite cement, upper contact very sharp, contact is a low amplitude stylolite, bioturbated with faint horizontal and minor cross beds.

13,702.5’ – 13,707’ SANDSTONE. Light gray, light to medium tan, very light brown, fine to medium grained, moderately well sorted, subrounded to rounded, calcite cement, massive, moderate horizontal beds, occasional cross beds, beds are difficult to see because they are formed by slight changes in color, small subhorizontal and subvertical fractures throughout, some fractures are oil stained.

13,707’ – 13,709’ No core.

13,709’ – 13,723.5’ SANDSTONE. Wacke, light to medium gray, very light tan, fine to medium grained, well sorted, subrounded, massive but extensively bioturbated, occasional vague horizontal bedding planes, occasional subhorizontal fractures.

13,723.5’ – 13,728’ LIMESTONE. Medium to dark gray, tan, extensively deformed, soft sediment deformation due to slumping, subvertical and subhorizontal fractures filled with calcite, moderate fossil debris throughout, occasional horizontal burrows.

Well Number: 54F047

UWI: 101-05-30-023-01-W3

Well Name: Tide Water Eyebrow Crown #2

Location: Saskatchewan, Canada

Cored Interval: 5,966' – 5,971'

Top of Deadwood on Log: 5,968'

Winnipeg Group

Black Island Formation

Ordovician

5,966' – 5,967.5' SANDSTONE. White, off white, very light tan, very fine to medium grained, subrounded to rounded, well sorted, poorly cemented, porous, mostly massive, minor faint cross beds, occasional small scale fractures, abundant pyrite near the bottom, pyrite is found in nodules, some pyrite is altered to hematite.

5,967.5' – 5,968' SHALE. Light brownish red, very fine grained, well sorted, wavy horizontal beds, occasional pyrite nodules.

Deadwood Formation

Member B

Ordovician/Cambrian

5,968' – 5,970' SHALE. Dark green, brown, very fine grained, well sorted, platy, mostly horizontal beds with occasional wavy beds, glauconitic, minor fractures filled with very dark gray to black clay.

5,970' – 5,971' SILTSTONE. Very light to light green, very light tan, off white, glauconitic layers are interbedded with quartz silt layers, very fine to fine grained, well sorted, well cemented, mostly

horizontal beds, minor amounts of wavy beds and cross beds, occasional thin beds of dark green shale, minor small scale horizontal fractures, occasional zones of hematite staining.

Well Number: 57G023
UWI: 101-06-13-002-19-W2
Well Name: Imperial Hummingbird
Location: Saskatchewan, Canada
Cored Interval: 10,320' – 10,370'
Top of Deadwood on Log: 10,327'

Winnipeg Group

Black Island Formation

Ordovician

10,320' – 10,322' SANDSTONE. Very light to light tan, light gray, very light brown, very fine grained, well sorted, subangular to subrounded, well cemented, alternating zones of heavy bioturbation and massive sandstone, minor faint horizontal beds in massive zones, fractures and burrows outlined in very dark gray to black clay an occasionally pyrite.

10,322' – 10,323.5' SILTSTONE to SHALE. Very light to medium tan, light to medium brown, very fine grained, well sorted, subrounded to rounded, upper and lower contacts are very sharp, heavily bioturbated, mix of siltstone and shale, large clasts of siltstone surrounded by shale, possibly rip up clasts from underlying unit.

Deadwood Formation

Member B

Ordovician/Cambrian

10,323.5' – 10,327.5' SILTSTONE. Very light tan, off white, very fine grained, well sorted, subrounded to subangular, well cemented, mostly massive, minor glauconite 2%, occasional rip up clasts of the underlying green shale found near the bottom.

10,327.5’ – 10,348’ SILTSTONE. Very light to light tan, light gray, very fine grained, well sorted, subangular, well cemented, abundant calcite cement, moderate glauconite 5%, interbedded with green shale. Shale is dark green, extremely fine grained, noncalcareous, well sorted, faint horizontal beds are visible, occasional burrows, minor pyrite, occasional siltstone rip up clasts are found in the shale zones, horizontally bedded and random orientation.

10,348’ – 10,370’ SILTSTONE. Very light to light tan, gray tan, very fine grained, subangular, well sorted, well cemented, carbonate cement, horizontal beds, minor faint cross beds, glauconite about 5%, interbedded with dark green shale, abundant glauconite in the shale, occasional horizontal burrows, minor amounts of pyrite, some soft sediment deformation, rip up clasts making it look like a conglomerate, occasional beds of fine to medium grained sandstone.

Well Number: 58I075
UWI: 101-02-11-015-26-W2
Well Name: Ceepee Baildon 2-11
Location: Saskatchewan, Canada
Cored Interval: 7,502' – 7,512'
7,730' – 7,740'
Top of Deadwood on Log: 6,968'

Deadwood Formation

Member A

Cambrian

7,502' – 7,503' SANDSTONE. Very light to medium tan, very light to dark gray, fine to medium grained, minor coarse grains, moderately sorted, moderately cemented, highly fractured, fractures filled with dark gray to black clay, small scale fractures have hematite staining.

7,503' – 7,508.5' SANDSTONE. Light to medium gray, very light tan, fine to coarse grained, zones of coarse grains are surrounded by fine grains, subrounded, poorly sorted, well cemented, minor amounts of bioturbation, massive to horizontal beds, visible cross beds.

7,508.5' – 7,512' SANDSTONE. Very light to light tan, very light to light gray, very fine to coarse grained, subangular, moderately sorted, heavily bioturbated.

Precambrian

7,730' – 7,740' IGNEOUS. Precambrian basement granite.

Well Number: 78L010
UWI: 131-03-08-017-19-W2
Well Name: University of Regina
Location: Saskatchewan, Canada
Cored Interval: 6,709' – 6,768.5'
6,781.5' – 6,840.5'
6,874.5' – 6,905.5'
7,224.5' – 7,256'
Top of Deadwood on Log: 6,834'

Winnipeg Group

Black Island Formation

Ordovician

6,709' – 6,712.5' SANDSTONE. Brownish red, light to medium tan, blue green, fine to medium grained, moderately sorted, subangular to subrounded, moderately cemented, extensively bioturbated, horizontal and vertical burrows, burrows outlined in very dark gray to black clay.

6,712.5' – 6,714' SANDSTONE. Quartz wacke, Very dark brown, medium to dark gray, very fine to medium grained, poor to moderate sorting, subangular to subrounded, very argillaceous, extensive bioturbation, no vertical burrows, occasional nodules of pyrite replaced cement, quartz grains found within the pyrite.

6,714' – 6,721' SANDSTONE. Very light to medium tan, very light to dark gray, light brown, fine grained, well sorted, subangular to subrounded, moderately cemented, heavily bioturbated, burrows outlined in very dark gray to black clay, hematite stained siltstone rip up clasts found near the bottom.

6,721' – 6,722' SILTSTONE. Very light to medium gray, light tan, gray tan, minor hydrogen sulfide staining, very fine to fine grained, well sorted, subangular to subrounded, well cemented, moderate

soft sediment deformation, minor bioturbation, occasional zones of fine grained sandstone, a few sandstone rip up clasts found near the bottom.

6,722’ – 6,729.5’ SANDSTONE. Very light to dark tan, very light to medium brown, very light to light gray, fine to medium grained, occasional coarse grains, moderately sorted, subangular to subrounded, moderately sorted, moderately cemented, heavily bioturbated, burrows outlined in very dark gray to black clay, occasional very thin horizontal clay laminae, sharp lower contact with a lot argillaceous material.

6,729.5’ – 6,731.5’ SANDSTONE. Quartz arenite, very light to light tan, off white, very light gray, very fine to fine grained, well sorted, subrounded to rounded, moderately cemented, minor bioturbation, occasional large well preserved vertical burrows, occasional nodules of pyrite replaced cement, quartz grains found within the pyrite. Core contained a lot of crystalized salt on the outside, most likely from the drilling fluid, indicating the unit is porous.

6,731.5’ – 6,750’ SANDSTONE. Quartz arenite, off white, very light gray, very light tan, very clean, very fine to fine grained, well sorted, subrounded, moderately cemented, porous, moderate faint horizontal beds with occasional cross beds, minor amounts of bioturbation, occasional zones of hematite staining with 40% pyrite.

6,750’ – 6,764’ SANDSTONE. Off white, very light to light tan, light gray, very light to light green blue, very fine to medium grained, moderate to poorly sorted, subangular to subrounded, moderately cemented, horizontal and wavy bedded with occasional cross beds, pyritic, occasional zones of extensive bioturbation, darker green in color, occasional zones of medium brown bioturbation similar to the underlying unit.

6,764’ – 6,770’ SANDSTONE. Very light to medium tan, very light to light brown, off white, very fine to fine grained, well sorted, subrounded, moderately cemented, minor pyrite, extensively bioturbated, horizontal and vertical burrows, burrows outlined in very dark gray to black clay.

6,770’ – 6,773.5’ SANDSTONE. Quartz wacke, medium to dark gray, light to medium tan brown, very fine to medium grained, subrounded, well sorted, moderately cemented, extensively bioturbated, vertical and horizontal burrows, burrows outlined in very dark gray to black clay.

6,773.5 – 6,781.5’ No core.

6,781.5’ – 6,793.5’ SANDSTONE. Very light to medium tan, light to medium gray, occasional very dark gray, fine to medium grained, rounded to well rounded, moderately sorted, moderately cemented, pyritic, occasional zones where pyrite has oxidized to hematite.

6,793.5’ – 6,796.5’ SANDSTONE. Quartz wacke, very light to medium gray, very fine to medium grained, subrounded to subangular, moderate to well sorted, moderately cemented, very minor amounts of pyrite, extensively bioturbated, mostly burrows, minor amounts of soft sediment deformation and water escape structures, occasional horizontal beds some disturbed by burrows, some very thin horizontal clay laminae, burrows and fractures are outlined in light brown clay.

6,796.5’ – 6,798.5’ SANDSTONE. Very light to medium tan, light to medium gray, occasional dark gray, fine to medium grained, rounded to well rounded, moderately sorted, moderately cemented, moderate bioturbation, moderately calcareous, pyritic, occasional zones where pyrite has oxidized to hematite.

6,798.5’ – 6,801.5’ SANDSTONE. Quartz arenite, very light to light tan, light brown, very light gray, fine to medium grained, minor coarse grains, subrounded to rounded, moderately sorted, moderate to well cemented, dolomite cement with minor calcite cement, extensively bioturbated, some horizontal bedding plane with some faint cross beds, fractures filled with dark brown clay.

6,801.5’ – 6,803.5’ SANDSTONE. Light to dark tan, medium brown, tan gray, fine to coarse grained, subrounded to rounded, moderate to poorly sorted, moderate to well cemented, dolomite cement,

horizontal to wavy beds, occasional soft sediment deformation and burrows, occasional zones of limestone mud, dark to medium gray in color.

6,803.5’ – 6,808’ SANDSTONE. Quartz arenite, very light to light tan, light gray, gray tan, fine to medium grained, well sorted, subangular to subrounded, moderately cemented, upper half has dolomitic cement, wavy horizontal lamination, very thin light to medium brown clay laminae, occasional pyrite clusters.

6,808’ – 6,811.5’ SANDSTONE. Quartz wacke, light to dark tan, medium brown, gray tan, fine grained, well sorted, subangular to subrounded, moderately cemented, noncalcareous, extensively bioturbated, mostly horizontal burrows, significant argillaceous material, contacts with overlying and underlying sections are sharp.

6,811.5’ – 6,817’ SANDSTONE. Light tan, pale green, very fine to medium grained, subrounded to rounded, moderate to poorly sorted, moderately cemented, minor dolomite cement, occasional thin clay laminae, minor bioturbation, occasional zones of hematite staining.

6,817’ – 6,820’ SANDSTONE. Quartz wacke, dark brown, dark gray, very fine to fine grained, occasional coarse grains found in bioturbated areas, well sorted, subangular to subrounded, top transitions from overlying section, noncalcareous, very thin horizontal clay laminae, abundant extensive bioturbated areas, mostly horizontal burrows,

6,820’ – 6,831’ SANDSTONE. Very light to medium pale green, very light tan, off white, very fine to medium grained, moderately sorted, subrounded, heavily bioturbated, horizontal and vertical burrows, abundant pyrite clusters near the top, rare clusters throughout, occasional staining from pyrite oxidizing to hematite.

6,831’ – 6,834’ SANDSTONE. Quartz arenite, very light to medium brown, fine to coarse grained, poorly sorted, subrounded to rounded, poorly cemented, calcite cement, small inclusions of pale blue green sandstone, no bioturbation, interfingered bottom contact.

Deadwood Formation

Member B

Ordovician/Cambrian

6,834’ – 6,849.5’ SANDSTONE. Light to dark green, light to medium tan, light brown, very fine grained, well sorted, subangular to subrounded, well cemented, glauconitic 40%, occasional light tan areas with no glauconite, minor amounts of pyrite, horizontally bedded with some cross beds, occasional very thin clay laminae, occasional areas of bioturbation and soft sediment deformation with minor faults and escape structures.

6,849.5’ – 6,875’ No core.

6,875’ – 6,885.5’ SILTSTONE. Very light to medium tan, light brown, light gray, occasional areas of very dark brown, very fine to fine grained, well sorted, subrounded with very minor subangular grains, well cemented, extensively bioturbated, some soft sediment deformation, fractures and burrows are outline in dark brown clay.

6,885.5’ – 6,894.5’ SANDSTONE. Very light to medium gray, light tan, fine to medium grained, well sorted, subrounded, well cemented, intermixed dolomite and silica cement, silica cement is cement better, horizontal beds with occasional cross beds, very thin clay laminae, occasional thin shale beds, minor bioturbation.

6,894.5’ – 6,899.5’ No core.

6,899.5’ – 6,902’ SANDSTONE. Very light to medium gray, light tan, fine to medium grained, well sorted, subrounded, well cemented, intermixed dolomite and silica cement, silica cement is cement better, horizontal beds with occasional cross beds, very thin clay laminae, occasional thin shale beds, minor bioturbation.

6,902’ – 6,905.5’ SILTSTONE. Very light to light tan, light gray, stained light purple to red towards the top, very fine to fine grained, well sorted, subangular to subrounded, well cemented, horizontal beds with minor cross beds, abundant very thin clay laminae, no bioturbation, noncalcareous.

6,905.5’ – 7,224.5’ No core.

Deadwood Formation

Member A

Cambrian

7,224.5’ – 7,226.5’ SANDSTONE. Very light to medium pale green, fine to coarse grained, subrounded, poorly sorted, poorly cemented, very fine shaly green cement, mostly massive, occasional horizontal beds with some cross beds.

7,226.5’ – 7,228’ SANDSTONE. Very light to medium tan, occasional reddish brown hematite staining, very fine to coarse grained, not well sorted, subangular to subrounded, moderate to well sorted, wavy horizontal beds, minor very thin clay laminae, minor amounts of bioturbation with occasional soft sediment deformation.

7,228’ – 7,255.5’ SANDSTONE. Very light to medium pale green, fine to coarse grained, poorly sorted, subrounded, poorly cemented, very fine shaly green cement, no bioturbation, mostly massive, faint horizontal beds with some cross beds, rip up clasts of the Precambrian near the bottom contact.

Precambrian

7,255.5’ – 7,256’ IGNEOUS. Granite.

Well Number: 94G082

UWI: 141-02-28-033-23-W2

Well Name: PCS Lanigan SWD

Location: Saskatchewan, Canada

Cored Interval: 4,655.5' – 4,677'
5,055' – 5,114'

Top of Deadwood on Log: 4,648'

Deadwood Formation

Member B

Ordovician/Cambrian

4,655.5' – 4,667' SILTSTONE. Interbedded with shale. Siltstone: very light to medium tan, light gray, light brown, very fine grained, very well sorted, subrounded, well cemented, mostly horizontal beds with occasional faint cross beds, minor bioturbation, occasional vertical burrows, rare soft sediment deformation, occasional orange hematite stained areas. Shale: thin horizontal beds within the siltstone with minor larger beds, blue green to dark green, occasionally transitions to dark brown to purple due to oxidation, extremely fine grained, occasional vertical burrow from overlying siltstone, burrows are filled with siltstone, not all contacts have burrows and some have soft sediment deformation, coarser grains and more bioturbation near the bottom.

4,667 – 5,055' No core.

5,055' – 5,114' SANDSTONE/SILTSTONE. Very light green, very light to medium tan, fine to coarse grained, subangular to rounded, for the most part poor to moderately sorted, porous, some interbedded red shale, extremely fine grained, mild bioturbation, filled with fine grained sand.

Well Number: 97G483
UWI: 141-04-16-006-13-W2
Well Name: PCP Weyburn DD
Location: Saskatchewan, Canada
Cored Interval: 9,052' – 9,086'
9,474' – 9,497'
Top of Deadwood on Log: 9,136'

Winnipeg Group

Black Island Formation

Ordovician

9,052' – 9,058.5' SANDSTONE. Very light to medium gray, occasional yellow hydrogen sulfide staining, very fine to fine grained, subangular to subrounded, well sorted, extensively bioturbated, burrows are outlined in very dark gray to black clay, vertical Skolithos burrows are found near the bottom.

9,058.5' – 9,067.5' SANDSTONE. Very light to medium tan, light brown, occasional areas of reddish brown hematite staining, fine to medium grained, subrounded to rounded, well sorted, poorly cemented, extensively bioturbated.

9,067.5' – 9,074.5' SANDSTONE. Very light to medium gray, light to medium brown and tan near fractures, very fine to fine grained, subangular to subrounded, well cemented, extensively bioturbated, vertical Skolithos burrows, abundant fractures, minor amounts of pyrite, this shale zone, very dark gray to black, extremely fine grained, zones of pyrite, rip up clasts of surrounding sandstone.

9,074.5' – 9,085' SILTSTONE. Very light to medium tan, light brown, light gray, very fine to fine grained, very fine grained areas are darker brown and have an increase in pyrite content, extensively bioturbated, occasional fractures, fractures are filled with dark gray to black clay.

9,085’ – 9,086’ SANDSTONE. Very light to light gray, off white, fine grained, well sorted, subrounded to rounded, very well cemented, noncalcareous, mostly massive, occasional fractures, fractures are filled with dark gray to black clay, some hematite staining along fractures.

9,086’ – 9,474’ No core.

Deadwood Formation

Member A

Cambrian

9,474’ – 9,497’ SANDSTONE. Very light to medium tan, light brown, light gray, very fine to fine grained, well sorted, subrounded to rounded, well cemented, mostly horizontal beds with occasional cross beds, very minor amounts of bioturbation, zones of bioturbation have an increase in glauconite and grainsize, very thin dark gray to black clay laminae found in bioturbated areas.

Well Number: 97I438
UWI: 111-16-23-002-01-W2
Well Name: Vista Glen Ewan
Location: Saskatchewan, Canada
Cored Interval: 9,104.5' – 9,185'
Top of Deadwood on Log: 8,961'

Deadwood Formation

Member B

Ordovician/Cambrian

9,104.5' – 9,106.5' BRECCIATED SANDSTONE. Light green gray, light tan, light gray, fine to medium grained, well to poorly sorted, subangular, glauconitic 40-75%,highly bioturbated caused by burrows, glauconite grains are larger in the deformed zones, hematite staining is found in bioturbated areas, clasts of very fine to fine grained, planar laminated glauconitic sandstone, sharp contact between grain sizes.

9,106.5' – 9,115.5' SANDSTONE. Light gray, green gray, light tan, fine grained, subrounded to subangular, well sorted, glauconitic 40-60%, minor bioturbation, mostly massive with faint planar laminations, dark gray to black horizontal clay laminations, rare cross beds.

9,115.5' – 9,124.5' SANDSTONE. Light gray, light green gray, light tan, fine grained, subrounded to subangular, well sorted, glauconitic 40%, heavily bioturbated, finer grains found in deformed areas, occasional massive zones.

Deadwood Formation

Member A

Cambrian

9,124.5’ – 9,135’ SANDSTONE. Light green gray, light gray, fine grained, subangular to subrounded, moderately sorted, mostly massive, 40-60% glauconite grains, minor zones of deformation, rip up clasts of medium grained dolomitic sandstone, minor unidentified fossil debris.

9,135’ – 9,143.5’ SANDSTONE. Off white, light gray, medium grained, very well sorted, subangular to subrounded, mostly massive, faint horizontal laminations and minor cross beds, minor glauconite 2-3%, slightly dolomitic.

9,143.5’ – 9,152’ SANDSTONE. Off white, tan, yellowish tan, fine grained, subangular, well sorted, heavily bioturbated, burrows outlined in dark gray to black clay, trace glauconite, minor hematite staining.

9,152’ – 9,160.5’ SANDSTONE. Off white, light tan, light green gray, fine grained, moderately sorted, subangular to subrounded, 35-65% glauconite, horizontal beds with very pronounced cross beds, minor amounts of soft sediment deformation, fractures are filled with glauconite.

9,160.5’ – 9,166.5’ SANDSTONE. Light tan, off white, light green gray, fine grained, subangular to subrounded, moderately sorted, 20-85% glauconite grains, heavily bioturbated, occasional areas of shale.

9,166.5’ – 9,167.5’ SANDSTONE. Light tan, off white, light gray, fine to medium grained, well sorted, subrounded, massive with interbedded oxidized clay laminae, occasional faint crossbeds, very fine glauconite grains about 2%.

9,167.5’ – 9,185’ SANDSTONE. Light tan, off white, light to medium green gray, fine to medium grained, subrounded, moderately sorted, slightly calcareous, heavily bioturbated, large subangular rip up clasts at the bottom.

Precambrian

9,185’ – 9,199.5’ IGNEOUS and METAMORPHIC. Granite with green schist near the top.

Well Number: 98E189

UWI: 142-12-01-010-09-W2

Well Name: Founders et al Hartaven

Location: Saskatchewan, Canada

Cored Interval: 7,897' – 8,034'

Top of Deadwood on Log: 8,015'

Winnipeg Group

Black Island Formation

Ordovician

7,978.5' – 7,996' SANDSTONE. Very light to medium gray, fine to medium grained, grainsize fines downwards, subrounded, well sorted, glauconite content decreases downwards, pyrite content decreases downwards, hematite content decreases downwards, extensively bioturbated, vertical Skolithos burrows, horizontal burrows, burrows outlined in fine grained, reddish brown clay.

7,996' – 8,015' No core.

Deadwood Formation

Member B

Ordovician/Cambrian

8,015' – 8,020.5' SANDSTONE. Gray, very fine to fine grained, well sorted, subangular to angular, extensively bioturbated, occasionally burrows are filled with pyrite, oxidized to hematite causing staining.

8,020.5' – 8,034' SANDSTONE, Light gray, light to medium gray green, light tan, very fine grained, well sorted, subangular to subrounded, very glauconitic up to 70%, mostly horizontally bedded, very rare deformation.

Appendix E
General Information for the Novva® Software

The software has a step by step process and the following information is what was entered or selected while working through the software. These include general stratigraphy, sedimentology, and ages.

Information For All Wells	
Depth Unit	Feet (ft)
Temperature Unit	Fahrenheit (°F)
Depth Step Thickness	150 ft
Original Basin Type	Interior Sag Basin
Basin-Forming Event	Sagging
Event Start	501 Ma
Event End	0 Ma
Initial Water Depth	Offshore / 30 ft
No other tectonic events	
No TVD conversion needed	
No subsurface dissolution or plastic deformation	
Include paleobathymetry and paleoelevation	
Include isostasy	
Include eustatic sea-level change	
Enter verbal information about depositional environments for entire rock units	
Temperature Correction Method	MY-MX-DK
Do not enter thermal-indicator data	
Do not include source rocks and kerogens	
Skip Expulsion section	
Skip Cracking section	

Unconformities				
Surface Event Type	**Rock Layer Affected**	**Start Time (Ma)**	**End Time (Ma)**	**Thickness Change (ft)**
Erosion	Deadwood F	471	467	-400
Deposition	Deadwood F	474	471	400
Surface Event Type	**Rock Layer Affected**	**Start Time (Ma)**	**End Time (Ma)**	**Thickness Change (ft)**
Erosion	Deadwood A	495	494	-50
Deposition	Deadwood A	497	495	50

Custom Lithologies		
Name	**Pure Lithology Type**	**Present Day %**
Sandstone/Siltstone Clay	Sandstone, clay-rich	65
	Siltstone, organic-rich	35
50% Limestone/Sandstone	Limestone (micrite)	50
	Sandstone	50
Siliciclastic Mudstone	Shale, organic-lean	10
	Sandstone, subarkose, clay-rich	60
	Limestone, shaly	30
Carbonaceous Sandstone	Sandstone	60
	Limestone, organic-rich	40

Appendix F
Specific Information for the Novva® Software

Specific information for each of the seven wells that were used in the study. These include the thicknesses, depths, temperatures, and data that was entered into the software.

General Well Information for NDGS #1385	
Latitude	48.330861 North
Longitude	102.908685 West
Present-Day Onshore Ground Elevation	2,352 feet
Total Depth	14,828 feet
Kelly Bushing Elevation	2,360 feet

Temperature for NDGS #1385		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
8,811	176	4
14,105	269	8

Stratigraphy for NDGS #1385			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	**0**	3,974
Rock Layer	Greenhorn	3,974	301
Rock Layer	Mowry	4,275	355
Rock Layer	Inyan Kara	4,630	440
Rock Layer	Swift	5,070	424
Rock Layer	Rierdon	5,494	572
Rock Layer	Spearfish	6,066	233
Rock Layer	Minnekahta	6,299	44
Rock Layer	Opeche	6,343	357
Rock Layer	Broom Creek	6,700	732
Rock Layer	Kibbey	7,432	142
Rock Layer	Madison	7,574	596
Rock Layer	Charles Ratcliffe	8,170	273
Rock Layer	Mission Canyon FA	8,443	417
Rock Layer	Lodgepole	8,860	880
Rock Layer	Bakken	9,740	126
Rock Layer	Three Forks	9,866	220
Rock Layer	Birdbear	10,086	100
Rock Layer	Duperow	10,186	446
Rock Layer	Souris River	10,632	330
Rock Layer	Dawson Bay	10,962	748
Rock Layer	Interlake	11,710	1,268
Rock Layer	Gunton	12,978	84
Rock Layer	Stoughton	13,062	63
Rock Layer	Red River	13,125	624
Rock Layer	Roughlock	13,749	32
Rock Layer	Icebox	13,781	141
Rock Layer	Black Island	13,922	256
Unconformity			
Rock Layer	Deadwood F	14,178	102
Rock Layer	Deadwood E	14,280	125
Rock Layer	Deadwood D	14,405	145
Rock Layer	Deadwood C	14,550	78
Rock Layer	Deadwood B	14,628	113
Unconformity			
Rock Layer	Deadwood A	14,741	29
Unconformity			
Rock Layer	Precambrian	14,770	

General Well Information for NDGS #2373	
Latitude	48.012115 North
Longitude	102.774689 West
Present-Day Onshore Ground Elevation	2,102 feet
Total Depth	15,135 feet
Kelly Bushing Elevation	2,117 feet

Temperature NDGS #2373		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
8,811	176	4
14,105	269	8

Stratigraphy NDGS #2373			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	0	4,065
Rock Layer	Greenhorn	4,065	336
Rock Layer	Mowry	4,401	356
Rock Layer	Inyan Kara	4,757	498
Rock Layer	Swift	5,255	426
Rock Layer	Rierdon	5,681	612
Rock Layer	Spearfish	6,293	269
Rock Layer	Minnekahta	6,562	39
Rock Layer	Opeche	6,601	362
Rock Layer	Broom Creek	6,963	826
Rock Layer	Kibbey	7,789	135
Rock Layer	Madison	7,924	566
Rock Layer	Charles Ratcliffe	8,490	246
Rock Layer	Mission Canyon FA	8,736	498
Rock Layer	Lodgepole	9,234	873
Rock Layer	Bakken	10,107	83
Rock Layer	Three Forks	10,190	208
Rock Layer	Birdbear	10,398	85
Rock Layer	Duperow	10,483	383
Rock Layer	Souris River	10,866	248
Rock Layer	Dawson Bay	11,114	590
Rock Layer	Interlake	11,704	1,246
Rock Layer	Gunton	12,950	81
Rock Layer	Stoughton	13,031	78
Rock Layer	Red River	13,109	653
Rock Layer	Roughlock	13,762	49
Rock Layer	Icebox	13,811	155
Rock Layer	Black Island	13,966	278
Unconformity			
Rock Layer	Deadwood F	14,244	153
Rock Layer	Deadwood E	14,397	180
Rock Layer	Deadwood D	14,577	186
Rock Layer	Deadwood C	14,763	215
Rock Layer	Deadwood B	14,978	69
Unconformity			
Rock Layer	Deadwood A	15,047	73
Unconformity			
Rock Layer	Precambrian	15,120	

Porosity NDGS #2373		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	14,240	0.079
Sandstone	14,250	0.026
Sandstone	14,260	0.033
Sandstone	14,270	0.056
Sandstone	14,280	0.041
Sandstone	14,290	0.002
Sandstone	14,300	0.002
Sandstone	14,310	0.011
Sandstone	14,320	0.041
Sandstone	14,330	0.011
Sandstone	14,340	0.026
Sandstone	14,350	0.026
Sandstone	14,360	0.018
Sandstone	14,370	0.002
Sandstone	14,380	0.001
Sandstone	14,390	0.002
Sandstone	14,400	0.026
Sandstone	14,410	0.041
Sandstone	14,420	0.048
Sandstone	14,430	0.064
Sandstone	14,440	0.079
Limestone	14,450	0.094
Limestone	14,460	0.071
Limestone	14,470	0.064
Limestone	14,480	0.064
Limestone	14,490	0.079
Limestone	14,500	0.056
Limestone	14,510	0.071
Limestone	14,520	0.094
Limestone	14,530	0.086
Sandstone	14,540	0.071
Sandstone	14,550	0.079
Sandstone	14,560	0.071
Sandstone	14,570	0.086
Sandstone	14,580	0.132
Sandstone	14,590	0.147
Sandstone	14,600	0.102
Sandstone	14,610	0.071
Sandstone	14,620	0.102
Sandstone	14,630	0.064
Sandstone	14,640	0.086

Porosity NDGS #2373		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	14,650	0.071
Sandstone	14,660	0.124
Sandstone	14,670	0.102
Sandstone	14,680	0.071
Sandstone	14,690	0.064
Sandstone	14,700	0.109
Sandstone	14,710	0.079
Sandstone	14,720	0.079
Sandstone	14,730	0.056
Sandstone	14,740	0.064
Sandstone	14,750	0.071
Sandstone	14,760	0.079
Limestone	14,770	0.086
Limestone	14,780	0.064
Limestone	14,790	0.086
Limestone	14,800	0.064
Limestone	14,810	0.056
Sandstone	14,820	0.056
Sandstone	14,830	0.071
Sandstone	14,840	0.048
Sandstone	14,850	0.041
Sandstone	14,860	0.048
Sandstone	14,870	0.056
Sandstone	14,880	0.071
Sandstone	14,890	0.048
Sandstone	14,900	0.041
Sandstone	14,910	0.041
Sandstone	14,920	0.033
Sandstone	14,930	0.041
Sandstone	14,940	0.048
Sandstone	14,950	0.056
Sandstone	14,960	0.048
Sandstone	14,970	0.056
Sandstone	14,980	0.079
Sandstone	14,990	0.132
Sandstone	15,000	0.147
Sandstone	15,010	0.132
Sandstone	15,020	0.041
Sandstone	15,030	0.071
Sandstone	15,040	0.155
Sandstone	15,050	0.011

Porosity NDGS #2373		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	15,060	0.003
Sandstone	15,070	0.033
Sandstone	15,080	0.011
Sandstone	15,090	0.003
Sandstone	15,100	0.041
Sandstone	15,110	0.033
Sandstone	15,120	0.018

General Well Information for NDGS #3844	
Latitude	48.27141 North
Longitude	102.960522 West
Present-Day Onshore Ground Elevation	2,366 feet
Total Depth	14,600 feet
Kelly Bushing Elevation	2,370 feet

Temperature for NDGS #3844		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
14044	285	3.5

Stratigraphy for NDGS #3844			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	0	3,825
Rock Layer	Greenhorn	3,825	410
Rock Layer	Mowry	4,235	334
Rock Layer	Inyan Kara	4,569	464
Rock Layer	Swift	5,033	427
Rock Layer	Rierdon	5,460	559
Rock Layer	Spearfish	6,019	281
Rock Layer	Minnekahta	6,300	80
Rock Layer	Opeche	6,380	395
Rock Layer	Broom Creek	6,775	698
Rock Layer	Kibbey	7,473	174
Rock Layer	Madison	7,647	563
Rock Layer	Charles Ratcliffe	8,210	257
Rock Layer	Mission Canyon FA	8,467	675
Rock Layer	Lodgepole	9,142	653
Rock Layer	Bakken	9,795	99
Rock Layer	Three Forks	9,894	190
Rock Layer	Birdbear	10,084	89
Rock Layer	Duperow	10,173	437
Rock Layer	Souris River	10,610	256
Rock Layer	Dawson Bay	10,866	697
Rock Layer	Interlake	11,563	1,210
Rock Layer	Gunton	12,773	87
Rock Layer	Stoughton	12,860	64
Rock Layer	Red River	12,924	614
Rock Layer	Roughlock	13,538	36
Rock Layer	Icebox	13,574	152
Rock Layer	Black Island	13,726	245
Unconformity			
Rock Layer	Deadwood F	13,971	83
Rock Layer	Deadwood E	14,054	139
Rock Layer	Deadwood D	14,193	153
Rock Layer	Deadwood C	14,346	65
Rock Layer	Deadwood B	14,411	127
Unconformity			
Rock Layer	Deadwood A	14,538	23
Unconformity			
Rock Layer	Precambrian	14,561	

Porosity for NDGS #3844		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	13,730	0.06
Sandstone	13,735	0.09
Sandstone	13,740	0.11
Sandstone	13,745	0.10
Sandstone	13,750	0.13
Sandstone	13,755	0.11
Sandstone	13,760	0.09
Sandstone	13,765	0.10
Sandstone	13,770	0.08
Sandstone	13,775	0.09
Sandstone	13,780	0.12
Sandstone	13,785	0.08
Sandstone	13,790	0.09
Sandstone	13,795	0.09
Sandstone	13,800	0.10
Sandstone	13,805	0.07
Sandstone	13,810	0.13
Sandstone	13,815	0.09
Sandstone	13,820	0.08
Sandstone	13,825	0.07
Sandstone	13,830	0.07
Sandstone	13,835	0.13
Sandstone	13,840	0.07
Sandstone	13,845	0.09
Sandstone	13,850	0.13
Sandstone	13,855	0.12
Sandstone	13,860	0.09
Sandstone	13,865	0.10
Sandstone	13,870	0.10
Sandstone	13,875	0.11
Sandstone	13,880	0.07
Sandstone	13,885	0.07
Sandstone	13,890	0.08
Sandstone	13,895	0.10
Sandstone	13,900	0.10
Sandstone	13,905	0.07
Sandstone	13,910	0.13
Sandstone	13,915	0.19
Sandstone	13,920	0.13
Sandstone	13,925	0.10
Sandstone	13,930	0.10

Porosity for NDGS #3844		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	13,935	0.08
Sandstone	13,940	0.07
Sandstone	13,945	0.06
Sandstone	13,950	0.05
Sandstone	13,955	0.08
Sandstone	13,960	0.10
Sandstone	13,965	0.07
Sandstone	13,970	0.16
Sandstone	13,975	0.16
Sandstone	13,980	0.14
Sandstone	13,985	0.01
Sandstone	13,990	0.01
Sandstone	13,995	0.03
Sandstone	14,000	0.03
Sandstone	14,005	0.03
Sandstone	14,010	0.03
Sandstone	14,015	0.04
Sandstone	14,020	0.01
Sandstone	14,025	0.05
Sandstone	14,030	0.04
Sandstone	14,035	0.04
Sandstone	14,040	0.04
Sandstone	14,045	0.03
Sandstone	14,050	0.06
Sandstone	14,055	0.01
Sandstone	14,060	0.08
Sandstone	14,065	0.04
Sandstone	14,070	0.02
Sandstone	14,075	0.04
Sandstone	14,080	0.03
Sandstone	14,085	0.02
Sandstone	14,090	0.06
Sandstone	14,095	0.04
Sandstone	14,100	0.04
Sandstone	14,105	0.01
Sandstone	14,110	0.06
Sandstone	14,115	0.03
Sandstone	14,120	0.03
Sandstone	14,125	0.02
Sandstone	14,130	0.04
Sandstone	14,135	0.04

Porosity for NDGS #3844		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	14,140	0.03
Sandstone	14,145	0.06
Sandstone	14,150	0.05
Sandstone	14,155	0.06
Sandstone	14,160	0.07
Sandstone	14,165	0.07
Sandstone	14,170	0.06
Sandstone	14,175	0.04
Sandstone	14,180	0.05
Sandstone	14,185	0.05
Sandstone	14,190	0.04
Sandstone	14,195	0.12
Sandstone	14,200	0.11
Sandstone	14,205	0.19
Sandstone	14,210	0.18
Sandstone	14,215	0.10
Sandstone	14,220	0.07
Sandstone	14,225	0.07
Sandstone	14,230	0.08
Sandstone	14,235	0.04
Sandstone	14,240	0.02
Sandstone	14,245	0.02
Sandstone	14,250	0.01
Sandstone	14,255	0.04
Sandstone	14,260	0.02
Sandstone	14,265	0.01
Sandstone	14,270	0.05
Sandstone	14,275	0.08
Sandstone	14,280	0.08
Sandstone	14,285	0.05
Sandstone	14,290	0.05
Sandstone	14,295	0.03
Sandstone	14,300	0.07
Sandstone	14,305	0.06
Sandstone	14,310	0.04
Sandstone	14,315	0.05
Sandstone	14,320	0.05
Sandstone	14,325	0.05
Sandstone	14,330	0.06
Sandstone	14,335	0.04
Sandstone	14,340	0.04

Porosity for NDGS #3844		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	14,345	0.04
Sandstone	14,350	0.01
Sandstone	14,355	0.03
Sandstone	14,360	0.01
Sandstone	14,365	0.02
Sandstone	14,370	0.01
Sandstone	14,375	0.01
Sandstone	14,380	0.01
Sandstone	14,385	0.02
Sandstone	14,390	0.04
Sandstone	14,395	0.02
Sandstone	14,400	0.01
Sandstone	14,405	0.02
Sandstone	14,410	0.01
Sandstone	14,415	0.04
Sandstone	14,420	0.03
Sandstone	14,425	0.03
Sandstone	14,430	0.04
Sandstone	14,435	0.04
Sandstone	14,440	0.04
Sandstone	14,445	0.05
Sandstone	14,450	0.04
Sandstone	14,455	0.04
Sandstone	14,460	0.04
Sandstone	14,465	0.05
Sandstone	14,470	0.06
Sandstone	14,475	0.05
Sandstone	14,480	0.06
Sandstone	14,485	0.06
Sandstone	14,490	0.06
Sandstone	14,495	0.07
Sandstone	14,500	0.06
Sandstone	14,505	0.10
Sandstone	14,510	0.08
Sandstone	14,515	0.09
Sandstone	14,520	0.15
Sandstone	14,525	0.03
Sandstone	14,530	0.04

General Well Information for NDGS #4321	
Latitude	48.464864 North
Longitude	102.904315 West
Present-Day Onshore Ground Elevation	2,446 feet
Total Depth	14,426 feet
Kelly Bushing Elevation	2,457 feet

Temperature for NDGS #4321		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
14,282	243	11

Stratigraphy for NDGS #4321			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	0	4,158
Rock Layer	Greenhorn	4,158	306
Rock Layer	Mowry	4,464	336
Rock Layer	Inyan Kara	4,800	415
Rock Layer	Swift	5,215	442
Rock Layer	Rierdon	5,657	594
Rock Layer	Spearfish	6,251	151
Rock Layer	Minnekahta	6,402	42
Rock Layer	Opeche	6,444	107
Rock Layer	Broom Creek	6,551	764
Rock Layer	Kibbey	7,315	145
Rock Layer	Madison	7,460	540
Rock Layer	Charles Ratcliffe	8,000	280
Rock Layer	Mission Canyon FA	8,280	586
Rock Layer	Lodgepole	8,866	692
Rock Layer	Bakken	9,558	102
Rock Layer	Three Forks	9,660	193
Rock Layer	Birdbear	9,853	93
Rock Layer	Duperow	9,946	462
Rock Layer	Souris River	10,408	270
Rock Layer	Dawson Bay	10,678	812
Rock Layer	Interlake	11,490	1,083
Rock Layer	Gunton	12,573	93
Rock Layer	Stoughton	12,666	60
Rock Layer	Red River	12,726	589
Rock Layer	Roughlock	13,315	36
Rock Layer	Icebox	13,351	125
Rock Layer	Black Island	13,476	231
Unconformity			
Rock Layer	Deadwood F	13,707	26
Rock Layer	Deadwood E	13,733	131
Rock Layer	Deadwood D	13,864	159
Rock Layer	Deadwood C	14,023	168
Rock Layer	Deadwood B	14,191	65
Unconformity			
Rock Layer	Deadwood A	14,256	27
Unconformity			
Rock Layer	Precambrian	14,283	

Porosity for NDGS #4321		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	13,700	0.15
Sandstone	13,710	0.02
Sandstone	13,720	0.01
Sandstone	13,730	0.13
Sandstone	13,740	0.01
Sandstone	13,750	0.01
Sandstone	13,760	0.01
Sandstone	13,770	0.01
Sandstone	13,780	0.01
Sandstone	13,790	0.04
Sandstone	13,800	0.02
Sandstone	13,810	0.03
Sandstone	13,820	0.01
Sandstone	13,830	0.01
Sandstone	13,840	0.02
Sandstone	13,850	0.01
Sandstone	13,860	0.02
Sandstone	13,870	0.08
Sandstone	13,880	0.13
Sandstone	13,890	0.01
Sandstone	13,900	0.02
Sandstone	13,910	0.07
Sandstone	13,920	0.01
Sandstone	13,930	0.01
Sandstone	13,940	0.01
Sandstone	13,950	0.04
Sandstone	13,960	0.12
Sandstone	13,970	0.01
Sandstone	13,980	0.03
Sandstone	13,990	0.04
Sandstone	14,000	0.06
Sandstone	14,010	0.02
Limestone	14,023	0.07
Limestone	14,030	0.03
Limestone	14,040	0.01
Limestone	14,050	0.01
Limestone	14,060	0.01
Limestone	14,070	0.03
Limestone	14,080	0.01
Limestone	14,090	0.03
Limestone	14,100	0.03

Porosity for NDGS #4321		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Limestone	14,110	0.01
Limestone	14,120	0.06
Limestone	14,130	0.07
Limestone	14,140	0.05
Sandstone	14,150	0.04
Sandstone	14,160	0.07
Sandstone	14,170	0.05
Sandstone	14,180	0.01
Sandstone	14,190	0.01
Sandstone	14,200	0.13
Sandstone	14,210	0.13
Sandstone	14,220	0.13
Sandstone	14,230	0.16
Sandstone	14,240	0.16
Sandstone	14,250	0.16
Sandstone	14,260	0.11
Sandstone	14,270	0.11
Sandstone	14,280	0.02

General Well Information for NDGS #6228	
Latitude	47.318737 North
Longitude	103.093066 West
Present-Day Onshore Ground Elevation	2,521 feet
Total Depth	15,380 feet
Kelly Bushing Elevation	2,532 feet

Temperature for NDGS #6228		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
11,731	230	15
13,882	276	38
15,264	300	14

Stratigraphy for NDGS #6228			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	0	4,737
Rock Layer	Greenhorn	4,737	455
Rock Layer	Mowry	5,192	378
Rock Layer	Inyan Kara	5,570	365
Rock Layer	Swift	5,935	531
Rock Layer	Rierdon	6,466	498
Rock Layer	Spearfish	6,964	386
Rock Layer	Minnekahta	7,350	46
Rock Layer	Opeche	7,396	352
Rock Layer	Broom Creek	7,748	992
Rock Layer	Kibbey	8,740	147
Rock Layer	Madison	8,887	409
Rock Layer	Charles Ratcliffe	9,296	259
Rock Layer	Mission Canyon FA	9,555	506
Rock Layer	Lodgepole	10,061	853
Rock Layer	Bakken	10,914	39
Rock Layer	Three Forks	10,953	254
Rock Layer	Birdbear	11,207	88
Rock Layer	Duperow	11,295	383
Rock Layer	Souris River	11,678	218
Rock Layer	Dawson Bay	11,896	385
Rock Layer	Interlake	12,281	1,039
Rock Layer	Gunton	13,320	76
Rock Layer	Stoughton	13,396	81
Rock Layer	Red River	13,477	633
Rock Layer	Roughlock	14,110	41
Rock Layer	Icebox	14,151	131
Rock Layer	Black Island	14,282	77
Unconformity			
Rock Layer	Deadwood F	14,359	34
Rock Layer	Deadwood E	14,393	212
Rock Layer	Deadwood D	14,605	168
Rock Layer	Deadwood C	14,773	229
Rock Layer	Deadwood B	15,002	206
Unconformity			
Rock Layer	Deadwood A	15,208	57
Unconformity			
Rock Layer	Precambrian	15,265	

Porosity for NDGS #6228		
Lithology	Depth (ft)	Porosity (fractional)
Sandstone	14,300	0.06
Sandstone	14,310	0.04
Sandstone	14,320	0.10
Sandstone	14,330	0.05
Sandstone	14,340	0.10
Sandstone	14,350	0.03
Sandstone	14,360	0.05
Sandstone	14,370	0.01
Sandstone	14,380	0.05
Sandstone	14,390	0.04
Limestone	14,400	0.06
Limestone	14,410	0.05
Limestone	14,420	0.05
Limestone	14,430	0.05
Limestone	14,440	0.04
Limestone	14,450	0.05
Limestone	14,460	0.04
Limestone	14,470	0.04
Limestone	14,480	0.03
Limestone	14,490	0.03
Limestone	14,500	0.06
Limestone	14,510	0.05
Limestone	14,520	0.06
Limestone	14,530	0.03
Limestone	14,540	0.06
Limestone	14,550	0.06
Limestone	14,560	0.07
Limestone	14,570	0.07
Limestone	14,580	0.06
Limestone	14,590	0.07
Sandstone	14,600	0.00
Sandstone	14,610	0.02
Sandstone	14,620	0.08
Sandstone	14,630	0.10
Sandstone	14,640	0.01
Sandstone	14,650	0.02
Sandstone	14,660	0.02
Sandstone	14,670	0.02
Sandstone	14,680	0.01
Sandstone	14,690	0.01
Sandstone	14,700	0.01

Porosity for NDGS #6228		
Lithology	Depth (ft)	Porosity (fractional)
Sandstone	14,710	0.03
Sandstone	14,720	0.03
Sandstone	14,730	0.06
Sandstone	14,740	0.04
Sandstone	14,750	0.04
Sandstone	14,760	0.05
Sandstone	14,770	0.06
Limestone	14,780	0.08
Limestone	14,790	0.04
Limestone	14,800	0.06
Limestone	14,810	0.07
Limestone	14,820	0.10
Limestone	14,830	0.04
Limestone	14,840	0.03
Limestone	14,850	0.06
Limestone	14,860	0.08
Limestone	14,870	0.04
Limestone	14,880	0.05
Limestone	14,890	0.06
Limestone	14,900	0.10
Limestone	14,910	0.07
Limestone	14,920	0.09
Limestone	14,930	0.08
Limestone	14,940	0.08
Limestone	14,950	0.07
Limestone	14,960	0.09
Limestone	14,970	0.09
Limestone	14,980	0.10
Limestone	14,990	0.09
Limestone	15,000	0.08
Sandstone	15,010	0.04
Sandstone	15,020	0.07
Sandstone	15,030	0.04
Sandstone	15,040	0.06
Sandstone	15,050	0.04
Sandstone	15,060	0.06
Sandstone	15,070	0.03
Sandstone	15,080	0.13
Sandstone	15,090	0.18
Sandstone	15,100	0.05
Sandstone	15,110	0.01

Porosity for NDGS #6228		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	15,120	0.06
Sandstone	15,130	0.07
Sandstone	15,140	0.04
Sandstone	15,150	0.06
Sandstone	15,160	0.08
Sandstone	15,170	0.03
Sandstone	15,180	0.01
Sandstone	15,190	0.04
Sandstone	15,200	0.10
Sandstone	15,210	0.13
Sandstone	15,220	0.02
Sandstone	15,230	0.04
Sandstone	15,240	0.07
Sandstone	15,250	0.10
Sandstone	15,260	0.08

General Well Information for NDGS #7340	
Latitude	46.911145 North
Longitude	101.746294 West
Present-Day Onshore Ground Elevation	2,210 feet
Total Depth	11,402 feet
Kelly Bushing Elevation	2,230 feet

Temperature for NDGS #7340		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
11,341	175	7.5

Stratigraphy for NDGS #7340			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	0	3,529
Rock Layer	Greenhorn	3,529	400
Rock Layer	Mowry	3,929	336
Rock Layer	Inyan Kara	4,265	370
Rock Layer	Swift	4,635	379
Rock Layer	Rierdon	5,014	209
Rock Layer	Spearfish	5,223	147
Rock Layer	Minnekahta	5,370	35
Rock Layer	Opeche	5,405	120
Rock Layer	Broom Creek	5,525	919
Rock Layer	Kibbey	6,444	125
Rock Layer	Madison	6,569	222
Rock Layer	Charles Ratcliffe	6,791	172
Rock Layer	Mission Canyon FA	6,963	451
Rock Layer	Lodgepole	7,414	702
Rock Layer	Bakken	8,116	7
Rock Layer	Three Forks	8,123	178
Rock Layer	Birdbear	8,301	77
Rock Layer	Duperow	8,378	286
Rock Layer	Souris River	8,664	186
Rock Layer	Dawson Bay	8,850	210
Rock Layer	Interlake	9,060	668
Rock Layer	Gunton	9,728	42
Rock Layer	Stoughton	9,770	90
Rock Layer	Red River	9,860	636
Rock Layer	Roughlock	10,496	44
Rock Layer	Icebox	10,540	135
Rock Layer	Black Island	10,675	41
Unconformity			
Rock Layer	Deadwood F	10,716	43
Rock Layer	Deadwood E	10,759	152
Rock Layer	Deadwood D	10,911	62
Rock Layer	Deadwood C	10,973	192
Rock Layer	Deadwood B	11,165	130
Unconformity			
Rock Layer	Deadwood A	11,295	46
Unconformity			
Rock Layer	Precambrian	11,341	

Porosity for NDGS #7340		
Lithology	Depth (ft)	Porosity (fractional)
Sandstone	10,685	0.17
Sandstone	10,690	0.17
Sandstone	10,695	0.13
Sandstone	10,700	0.13
Sandstone	10,705	0.11
Sandstone	10,710	0.10
Sandstone	10,715	0.17
Sandstone	10,720	0.15
Sandstone	10,725	0.09
Sandstone	10,730	0.13
Sandstone	10,735	0.25
Sandstone	10,740	0.23
Sandstone	10,745	0.19
Sandstone	10,750	0.24
Sandstone	10,755	0.19
Sandstone	10,760	0.12
Sandstone	10,765	0.15
Sandstone	10,770	0.13
Sandstone	10,775	0.13
Sandstone	10,780	0.11
Sandstone	10,785	0.13
Sandstone	10,790	0.09
Sandstone	10,795	0.11
Sandstone	10,800	0.10
Sandstone	10,805	0.13
Sandstone	10,810	0.14
Sandstone	10,815	0.14
Sandstone	10,820	0.02
Sandstone	10,825	0.04
Sandstone	10,830	0.08
Sandstone	10,835	0.13
Sandstone	10,840	0.13
Sandstone	10,845	0.17
Sandstone	10,850	0.16
Sandstone	10,855	0.16
Sandstone	10,860	0.16
Sandstone	10,865	0.10
Sandstone	10,870	0.14
Sandstone	10,875	0.17
Sandstone	10,880	0.18
Sandstone	10,885	0.19

Porosity for NDGS #7340		
Lithology	Depth (ft)	Porosity (fractional)
Sandstone	10,890	0.18
Sandstone	10,895	0.16
Sandstone	10,900	0.18
Sandstone	10,905	0.17
Sandstone	10,910	0.11
Sandstone	10,915	0.04
Sandstone	10,920	0.08
Sandstone	10,925	0.04
Sandstone	10,930	0.06
Sandstone	10,935	0.08
Sandstone	10,940	0.06
Sandstone	10,945	0.08
Sandstone	10,950	0.14
Sandstone	10,955	0.03
Sandstone	10,960	0.11
Sandstone	10,965	0.10
Sandstone	10,970	0.16
Sandstone	10,975	0.10
Sandstone	10,980	0.08
Sandstone	10,985	0.07
Sandstone	10,990	0.06
Sandstone	10,995	0.11
Sandstone	11,000	0.06
Sandstone	11,005	0.05
Sandstone	11,010	0.10
Sandstone	11,015	0.11
Sandstone	11,020	0.05
Sandstone	11,025	0.06
Sandstone	11,030	0.03
Sandstone	11,035	0.03
Sandstone	11,040	0.02
Sandstone	11,045	0.02
Sandstone	11,050	0.02
Sandstone	11,055	0.03
Sandstone	11,060	0.02
Sandstone	11,065	0.02
Sandstone	11,070	0.02
Sandstone	11,075	0.03
Sandstone	11,080	0.02
Sandstone	11,085	0.02
Sandstone	11,090	0.02

Porosity for NDGS #7340		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	11,095	0.02
Sandstone	11,100	0.04
Sandstone	11,105	0.06
Sandstone	11,110	0.07
Sandstone	11,115	0.05
Sandstone	11,120	0.11
Sandstone	11,125	0.07
Sandstone	11,130	0.09
Sandstone	11,135	0.07
Sandstone	11,140	0.07
Sandstone	11,145	0.04
Sandstone	11,150	0.04
Sandstone	11,155	0.05
Sandstone	11,160	0.02
Sandstone	11,165	0.06
Sandstone	11,170	0.05
Sandstone	11,175	0.06
Sandstone	11,180	0.06
Sandstone	11,185	0.11
Sandstone	11,190	0.20
Sandstone	11,195	0.09
Sandstone	11,200	0.07
Sandstone	11,205	0.07
Sandstone	11,210	0.07
Sandstone	11,215	0.06
Sandstone	11,220	0.07
Sandstone	11,225	0.06
Sandstone	11,230	0.07
Sandstone	11,235	0.10
Sandstone	11,240	0.17
Sandstone	11,245	0.15
Sandstone	11,250	0.09
Sandstone	11,255	0.15
Sandstone	11,260	0.05
Sandstone	11,265	0.12
Sandstone	11,270	0.11
Sandstone	11,275	0.13
Sandstone	11,280	0.14
Sandstone	11,285	0.15
Sandstone	11,290	0.13
Sandstone	11,295	0.15

Porosity for NDGS #7340		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	11,300	0.12
Sandstone	11,305	0.13
Sandstone	11,310	0.20
Sandstone	11,315	0.17
Sandstone	11,320	0.20
Sandstone	11,325	0.09
Sandstone	11,330	0.14
Sandstone	11,335	0.12
Sandstone	11,340	0.10

General Well Information for NDGS #8169	
Latitude	46.759015 North
Longitude	102.298513 West
Present-Day Onshore Ground Elevation	2,350 feet
Total Depth	12,218 feet
Kelly Bushing Elevation	2,372 feet

Temperature for NDGS #8169		
Measured Depth (ft)	**Log Temperature (°F)**	**TSC (hrs)**
12,141	201	15.5

Stratigraphy for NDGS #8169			
Type	**Name of Layer**	**Top MD (ft)**	**Thickness (ft)**
Rock Layer	Cenozoic	0	4,310
Rock Layer	Mowry	4,310	318
Rock Layer	Inyan Kara	4,628	394
Rock Layer	Swift	5,022	442
Rock Layer	Rierdon	5,464	384
Rock Layer	Spearfish	5,848	146
Rock Layer	Minnekahta	5,994	43
Rock Layer	Opeche	6,037	98
Rock Layer	Broom Creek	6,135	981
Rock Layer	Kibbey	7,116	118
Rock Layer	Madison	7,234	236
Rock Layer	Charles Ratcliffe	7,470	196
Rock Layer	Mission Canyon FA	7,666	447
Rock Layer	Lodgepole	8,113	721
Rock Layer	Bakken	8,834	8
Rock Layer	Three Forks	8,842	167
Rock Layer	Birdbear	9,009	71
Rock Layer	Duperow	9,080	254
Rock Layer	Souris River	9,334	121
Rock Layer	Dawson Bay	9,455	278
Rock Layer	Interlake	9,733	697
Rock Layer	Gunton	10,430	50
Rock Layer	Stoughton	10,480	91
Rock Layer	Red River	10,571	633
Rock Layer	Roughlock	11,204	44
Rock Layer	Icebox	11,248	109
Rock Layer	Black Island	11,357	27
Unconformity			
Rock Layer	Deadwood F	11,384	12
Rock Layer	Deadwood E	11,396	172
Rock Layer	Deadwood D	11,568	82
Rock Layer	Deadwood C	11,650	222
Rock Layer	Deadwood B	11,872	190
Unconformity			
Rock Layer	Deadwood A	12,062	79
Unconformity			
Rock Layer	Precambrian	12,141	

Porosity for NDGS #8169		
Lithology	Depth (ft)	Porosity (fractional)
Sandstone	11,385	0.25
Sandstone	11,390	0.18
Sandstone	11,395	0.17
Sandstone	11,400	0.14
Sandstone	11,405	0.13
Sandstone	11,410	0.09
Sandstone	11,415	0.07
Sandstone	11,420	0.09
Sandstone	11,425	0.09
Sandstone	11,430	0.05
Sandstone	11,435	0.05
Sandstone	11,440	0.04
Sandstone	11,445	0.03
Sandstone	11,450	0.02
Sandstone	11,455	0.04
Sandstone	11,460	0.03
Sandstone	11,465	0.05
Sandstone	11,470	0.03
Sandstone	11,475	0.02
Sandstone	11,480	0.04
Sandstone	11,485	0.03
Sandstone	11,490	0.02
Sandstone	11,495	0.07
Sandstone	11,500	0.06
Sandstone	11,505	0.07
Sandstone	11,510	0.04
Sandstone	11,515	0.04
Sandstone	11,520	0.06
Sandstone	11,525	0.07
Sandstone	11,530	0.08
Sandstone	11,535	0.10
Sandstone	11,540	0.11
Sandstone	11,545	0.12
Sandstone	11,550	0.14
Sandstone	11,555	0.03
Sandstone	11,560	0.05
Sandstone	11,565	0.03
Sandstone	11,570	0.06
Sandstone	11,575	0.08
Sandstone	11,580	0.08
Sandstone	11,585	0.12

Porosity for NDGS #8169		
Lithology	Depth (ft)	Porosity (fractional)
Sandstone	11,590	0.12
Sandstone	11,595	0.07
Sandstone	11,600	0.06
Sandstone	11,605	0.08
Sandstone	11,610	0.09
Sandstone	11,615	0.08
Sandstone	11,620	0.10
Sandstone	11,625	0.06
Sandstone	11,630	0.10
Sandstone	11,635	0.08
Sandstone	11,640	0.12
Sandstone	11,645	0.14
Sandstone	11,650	0.12
Sandstone	11,655	0.05
Sandstone	11,660	0.09
Sandstone	11,665	0.07
Sandstone	11,670	0.08
Sandstone	11,675	0.05
Sandstone	11,680	0.09
Sandstone	11,685	0.05
Sandstone	11,690	0.07
Sandstone	11,695	0.06
Sandstone	11,700	0.08
Sandstone	11,705	0.09
Sandstone	11,710	0.07
Sandstone	11,715	0.04
Sandstone	11,720	0.02
Sandstone	11,725	0.03
Sandstone	11,730	0.03
Sandstone	11,735	0.02
Sandstone	11,740	0.07
Sandstone	11,745	0.04
Sandstone	11,750	0.05
Sandstone	11,755	0.03
Sandstone	11,760	0.02
Sandstone	11,765	0.02
Sandstone	11,770	0.02
Sandstone	11,775	0.02
Sandstone	11,780	0.04
Sandstone	11,785	0.02
Sandstone	11,790	0.03

Porosity for NDGS #8169		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	11,795	0.02
Sandstone	11,800	0.04
Sandstone	11,805	0.02
Sandstone	11,810	0.03
Sandstone	11,815	0.03
Sandstone	11,820	0.03
Sandstone	11,825	0.03
Sandstone	11,830	0.06
Sandstone	11,835	0.04
Sandstone	11,840	0.05
Sandstone	11,845	0.05
Sandstone	11,850	0.06
Sandstone	11,855	0.07
Sandstone	11,860	0.04
Sandstone	11,865	0.07
Sandstone	11,870	0.06
Sandstone	11,875	0.08
Sandstone	11,880	0.08
Sandstone	11,885	0.07
Sandstone	11,890	0.13
Sandstone	11,895	0.14
Sandstone	11,900	0.17
Sandstone	11,905	0.06
Sandstone	11,910	0.07
Sandstone	11,915	0.09
Sandstone	11,920	0.09
Sandstone	11,925	0.09
Sandstone	11,930	0.07
Sandstone	11,935	0.11
Sandstone	11,940	0.14
Sandstone	11,945	0.08
Sandstone	11,950	0.08
Sandstone	11,955	0.80
Sandstone	11,960	0.17
Sandstone	11,965	0.14
Sandstone	11,970	0.13
Sandstone	11,975	0.11
Sandstone	11,980	0.15
Sandstone	11,985	0.13
Sandstone	11,990	0.14
Sandstone	11,995	0.10

Porosity for NDGS #8169		
Lithology	**Depth (ft)**	**Porosity (fractional)**
Sandstone	12,000	0.09
Sandstone	12,005	0.12
Sandstone	12,010	0.13
Sandstone	12,015	0.15
Sandstone	12,020	0.14
Sandstone	12,025	0.14
Sandstone	12,030	0.13
Sandstone	12,035	0.13
Sandstone	12,040	0.07
Sandstone	12,045	0.09
Sandstone	12,050	0.13
Sandstone	12,055	0.10
Sandstone	12,060	0.13
Sandstone	12,065	0.10
Sandstone	12,070	0.09
Sandstone	12,075	0.09
Sandstone	12,080	0.07
Sandstone	12,085	0.07
Sandstone	12,090	0.09
Sandstone	12,095	0.10
Sandstone	12,100	0.07
Sandstone	12,105	0.11
Sandstone	12,110	0.07
Sandstone	12,115	0.08
Sandstone	12,120	0.05
Sandstone	12,125	0.09
Sandstone	12,130	0.10
Sandstone	12,135	0.09
Sandstone	12,140	0.07

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