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THE POTENTIAL FOR HORIZONTALLY DRILLING THE MIDDLE MEMBER OF THE BAKKEN FORMATION, NORTH DAKOTA

Julie A. LeFever
North Dakota Geological Survey, Grand Forks, North Dakota 58202

There have been multiple attempts over the history of the Williston basin to produce oil from the Bakken Formation. Since its discovery in 1953 several plays have focused on the Bakken. Early exploration was conventional in nature with notable development of the Bakken along the Antelope anticline and the Bakken fairway. As technology progressed, another phase of drilling into the Bakken occurred in the late 1980s-early 1990s. This horizontal play in the upper Bakken shale resulted in the drilling of a large number of wells and a significant increase amount of production from the formation. However, the decrease in the price of oil, drilling problems and spacing issues, as well as the need to encounter major regional fractures for significant production led to the end of the play. Now, the Bakken is once again the center of activity. Long considered to be an important source rock in the Williston basin, it has become the target for a major resource-based play. Current players with the help of newer technology hope to relieve the Bakken of its oil.

The current play in the Bakken Formation began in Richland County, Montana in 2001. Initial activity was slow with the drilling of only a few wells over the next couple of years. However, interest in the play increased as the production from these wells was made public leading to major lease plays in both Montana and North Dakota. The impact on Richland County is notable. Oil production for the county has doubled for 2003 and 2004. Now, as the play moves across the state line, it is important to look at the potential in the Bakken in North Dakota.

Stratigraphy and Structure

The overall stratigraphy of the play is relatively simple. The Three Forks Formation (Devonian) underlies the Bakken Formation (Mississippian-Devonian). It is overlain in an onlapping relationship by the Bakken with each successively higher member having a greater areal extent. This sequence is overlain by the thick carbonate sequence of the Lodgepole Formation (Mississippian). The following is a brief review of the geology of the Bakken Formation.

Three Forks Formation (Devonian)

The Three Forks Formation consists of an interbedded sequence of greenish grey and reddish brown shales, light brown to yellow grey dolostones, grey to brown siltstones, and quartzose sandstones with minor amounts of anhydrite. Local accumulations of a heavily burrowed coarse-grained siltstone to fine-grained quartz sandstone occur at the top of the Three

Forks. These local accumulations are informally known as the "Sanish Sand" and may be highly productive.

The Three Forks Formation conformably underlies the Bakken in the central portion of the basin; an angular unconformity exists between the two formations along the margins of the basin. The Three Forks Formation reaches a maximum thickness of 250 ft. Five lithofacies have been identified within the formation representing environments from subtidal to supratidal (Dumonceaux, 1984). The "Sanish sand" is thought to represent a beach or nearshore marine environment.

Bakken Formation (Mississippian-Devonian)

The Bakken is present in the subsurface Williston basin and extends over roughly two-thirds of the state of North Dakota. It attains a maximum thickness of 145 ft and has a well-defined depocenter just east of the Nesson Anticline.

Lower Shale Member

The shale is a dark brown to black, fissile, non-calcareous, organic-rich shale. Small amounts of siltstone, limestone, and sandstone are present towards the base of the shale. It is finely laminated to massive. Where present, fractures are smooth and conchoidal, but can be irregular or blocky. Fractures that are sub parallel to bedding are heavily oil stained. It is generally less organic than the upper shale. The organic matter appears to be distributed evenly throughout the member. Quartz is the dominant mineral with minor amounts of muscovite, illite and other clays. Pyrite is present in lenses, laminations, or is finely disseminated throughout. Fossils within the shale member include conodonts, algal spores, brachiopods, fish teeth, bones and scales.

Localized changes in lithology include the development of siltstone or limestone beds near the base of the formation. Also, a well developed lag deposit is present in some of the cores of the lower shale emphasizing the irregular contact. Where present, the lag deposits consists of conodonts, pyritized clasts, phosphatic particles, fish bones, subangular quartz sand and silt, carbonate debris, and rounded pebbles. Other cores show a sharp to gradational contact with the underlying Three Forks Formation.

The lower shale is conformable with the Three Forks Formation in the central portion of the basin, but unconformably overlies the formation along the margins of the basin. It reaches a maximum thickness of 50 ft with a well defined depocenter to the east of the Nesson anticline (Figure 1). Other abrupt changes in thickness occurring in north-central and McKenzie County North Dakota are probably related to dissolution of the Devonian Prairie Salt.

Middle Member

Vertically variable, the middle member consists of five different lithofacies that can be traced laterally throughout the Williston basin. A brief description of the lithofacies follows.

Lithofacies 1 consists of light grey, greenish-grey, or brownish-grey argillaceous siltstone. It is generally massive, cemented with calcite, and has scattered pyrite nodules and fossils (crinoids and brachiopods). Locally the unit is burrowed. Porosity is intergranular.

Lithofacies 2 consists of greenish-grey to brownish-grey, argillaceous siltstone or sandy siltstone to brownish-grey, very fine grained sandstone. Small scale clay drapes are present, as well as burrows. The upper portion of this unit is the producing zone in Richland County, Montana. This unit is also productive in North Dakota.

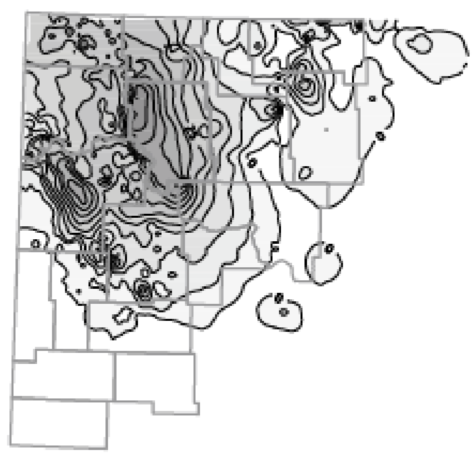


Figure 1. Isopachous map of the Lower Bakken Shale, North Dakota. (C.I. = 5 ft.)

There are three parts to *Lithofacies 3*. The upper and lower third consists of wavy to flaser-bedded, light to medium grey, argillaceous to sandy siltstones and brownish-grey, very fine-grained sandstones with local claystones. The middle third consists of a medium grey, dark grey, or greyish-tan, fine- to medium-grained sandstone that may be massive, cross-bedded, or thinly laminated. This unit is also productive in the northern portion of North Dakota.

Lithofacies 4 consists of alternating medium grey argillaceous siltstones, light to medium grey very fine-grained sandstones and dark grey shale. The unit is thinly laminated, display planar and cross-ripple laminations, moderately bioturbated in places, and locally cemented.

Lithofacies 5 is a medium to light grey, massive to wispy laminated siltstone that is generally well cemented. It varies from a calcareous siltstone to sandstone that is comprised predominantly of quartz with minor amounts of feldspar, to a dolostone, silty limestone, and occasionally an oolitic limestone.

All of the rock types are well cemented with calcite, silica, or dolomite; however, the middle sandstone lithofacies provides enough reservoir qualities to be locally productive. The limestones are rich in quartz sand and silt. The siltstones and sandstones are massive to coarse-bedded with occasional trough or planar cross-bedding. There is some local soft sediment deformation and bioturbation. Fossils include brachiopods, pelmatozoan fragments, gastropods, and trace fossils. Mineral composition is variable across the basin, although quartz increases in a northward direction.

The middle member is thought to have been deposited in aerobic marine to marginal marine conditions with moderate current activity. The light color, cross-bedding, trace fossils and abundant benthic fauna substantiate this hypothesis. It is conformable with the underlying and overlying shales in the central portion of the basin. Towards the margin, the middle member lies unconformably over the Three Forks Formation. It also has a well defined depocenter just to the east of the Nesson anticline (Figure 2).

Figure 2. Isopachous Map of the Bakken Middle Member, North Dakota. (C.I.=5 ft.)

Upper Shale Member

The shale is similar to the lower shale. It is laminated to massive with poorly-sorted beds of silt-sized material. The upper shale has a higher organic content with lesser amounts of clay, silt, and dolomitic grains. It also lacks the crystalline limestone and siltstone of the lower shale. A lag sandstone rich in conodonts, fish bones, teeth and phosphatic particles may occur at the basal contact of the member.

It represents the maximum extent of the Bakken Formation in the basin (Figure 3). As with the others, the upper shale appears conformable with the middle member in the central portion of the basin, although there is a faunal break between the two members. The break is thought to represent a disconformity or paraconformity that may coincide with a regionally extensive unconformity. It forms an angular unconformity with the Three Forks Formation along the margin of the basin and is conformably overlain by the Lodgepole Formation. The upper shale attains a maximum thickness of 23 ft with a broader, less-defined depocenter.

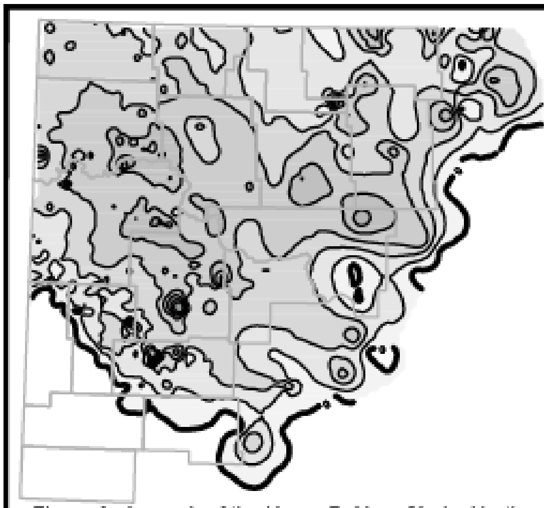


Figure 3. Isopach of the Upper Bakken Shale, North Dakota (C.I.= 5 ft.)

Lodgepole Formation

The Lodgepole Formation consists of a dense, dark grey to brownish grey limestone and calcareous shale with minor amounts of chert and anhydrite. A thin, black shale and black organic-rich limestone is present along the margin of the basin. This zone is informally known as the “False Bakken”, and is readily apparent on wireline logs. It is separated from the Bakken by a thin, dense, medium grey pelmatozoan-rich limestone.

The Lodgepole Formation conformably overlies the Bakken and reaches a maximum thickness of 900 ft. It represents a marine transgression that restored normal circulation to the basin. Five major facies are represented by these rocks: a dark grey, irregularly laminated, crinoidal mudstone-wackestone, the central basin facies; a medium to light grey argillaceous crinoid brachiopod wackestone to packstone of the basin slope; a light colored, cherty skeletal wackestone to packstone of the open shelf; a crinoidal mudstone from at or near the shelf break; and a grey shale from a restricted environment (Heck, 1979). These facies continued to onlap toward the basin margin throughout lower Lodgepole deposition.

Horizontal Drilling of the Bakken Middle Member – North Dakota

Production from the middle member of the Bakken Formation is not new to North Dakota. There have been a few wells, primarily along the northern Nesson anticline that have been perforated in and produced from the Bakken middle member. The Bakken in these wells was not the primary target; that was deeper usually the Devonian Winnipegosis. It was generally considered to be a bailout zone, perforated because the wells were reaching their economic limit or had no other production. Production from these wells was limited.

Two distinct plays areas are developing in the North Dakota portion of the Williston basin. The play in lower portion of the state involves the lithofacies that can be mapped over from Montana (Lithofacies 2). The upper half of the state involves the lithofacies that can be traced into Canadian Provinces and are highly productive in several fields across the border (Lithofacies 3). Both of these lithofacies have had some vertical production in the past and have a large potential for future production.

Lithofacies 2 Play

The play in the lower half of the state concerns the lower portion of the middle member (Lithofacies 2). This activity is a continuation of the Richland County play and involves mapping the well-defined porosity zone into North Dakota (Figure 4)

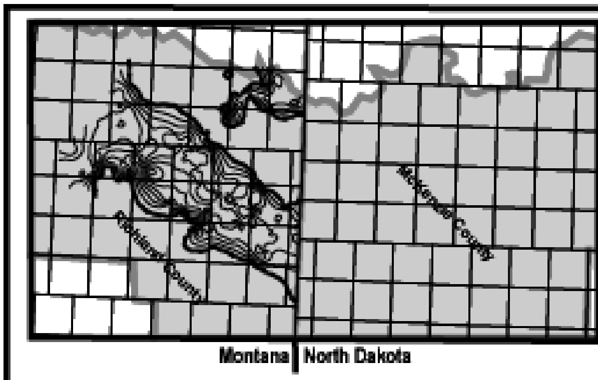


Figure 4. Richland County, Montana porosity trend as mapped to the North Dakota state line.

This activity covers the portion of North Dakota known as the Bakken fairway where the majority of the horizontal upper Bakken shale wells were drilled in the late 80s-early 90s. Wells in this area are not limited to Bakken production. Most of the fields have multiple pays that are associated with structural features such as folds, faults, or both. These features contribute to the fracturing of the Bakken and may enhance the quality of the reservoir.

The members are thin over this area of North Dakota and are more likely to be influenced by the structural features present. Thin beds fracture readily. The regional scale natural fractures present are related to folding or faulting or salt tectonics and are important to reservoir enhancement and production.

Another important fracture network that is present throughout this area is related to the generation of hydrocarbons. This area is over the most thermally mature portion of the Bakken shales. High total organic carbon contents in conjunction the appropriate temperatures and pressures have resulted in the generation of extreme amounts of hydrocarbons. The presence of highly impermeable rocks above and below the Bakken have retarded or stopped vertical migration. Subsequent lateral migration of this oil has resulted in the flushing of water from the system leaving an oil-wet system over the entire Bakken in the deeper portion of the state. Migration may or may not have completely removed the water towards the immature areas. In addition, oil generation is responsible for the overpressuring of the formation throughout the southern area. Associated with that overpressuring is an additional storage in the form of microscopic fractures. These have been described in cores of the shales as bedding plane fractures that have noticeable oil halos when wet. These microfractures are also readily apparent in thin sections from the middle member. The presence of the microfractures provides an additional amount of storage capacity and enhanced permeability.

In addition to natural fractures, additional storage is added by matrix porosity within the rock. This porosity is primarily intergranular with some intercrystalline. Fluid movement within the system along fracture networks has locally enhanced the porosity by the dolomitization of calcite cement.

Early in Bakken history, successful Bakken wells were those that encountered natural fractures. Less than successful wells, those not encountering natural fractures, needed a stimulation treatment. In the case of the vertical wells this treatment consisted of producing the well, collecting the produce oil and using it as part of a sand/oil fracture stimulation treatment; diesel was commonly substituted for produced oil. Approximately 78% of the wells drilled in this area were stimulated with some kind of fracture treatment. This treatment was necessary for economic reserves. Horizontal wells in the upper shale were unable to fracture stimulate the well if regional fractures were not encountered. Today horizontal wells drilled into the middle member can apply the necessary treatments.

Lithofacies 3 Play

Lithofacies 3 is a sandstone-siltstone bed that occurs in the middle of the member throughout the northern portion of North Dakota and into Saskatchewan and Manitoba (Figure 5). It is highly productive in Saskatchewan with a long production history from Rocanville and Roncott fields. In North Dakota, production from vertical wells in this facies is marginal and found in 9 fields along the northern Nesson anticline including Temple, Stoneview and North Tioga. It also has an easily mappable log characteristic throughout North Dakota with a notably cleaner response on the gamma-ray curve.

Figure 5 - Isopachous map of Lithofacies 3,North Dakota. (C.I. = 2 ft.)

All of these wells in North Dakota in this zone with the exception of one were completed as a bailout zone. This facies is generally coarser grained and cleaner than the rest of the middle member and usually contains a greater amount of cementation. Thickness of the pay zone is 12 ft with porosities ranging from 7-12%.

Vertical well completions generally consisted of acidization and a gelled water-sand fracture treatment. It is interesting to note that the best producer in Stoneview underwent the least amount of acid treatment suggesting that acidization probably detrimental to the well releasing precipitating iron hydroxide and producing fines that plug porosity and permeability.

It is also interesting to note that where these wells produce the Bakken shales are not mature. The fact that these wells and the fields in Canada produce demonstrates that the 45 degree oil is capable of migrating throughout the middle member.

Drilling and Completion Methods within the Bakken Formation

Horizontal drilling of the middle Bakken member may profit from examining drilling practices that were performed on vertical Bakken wells. Several observations may be made when examining the drilling records of the past.

Vertical Wells

Early wells were drilled with salt-based mud systems. This practice was changed over to oil-based mud systems in an effort to prevent dissolution and resulting casing collapse of the overlying Madison salt section. The typical completion method for a vertical well then consisted of perforating the well followed by a sand-oil fracture stimulation treatment.

Acidizing the Bakken wells also created problems, the treatment reacted with the pyrite present in the shales forming an iron hydroxide precipitate and plugged available porosity and permeability. Vertical wells that were later stimulated with acid, declined dramatically and most were plugged and abandoned.

Water and the Bakken do not mix. The Bakken is an oil-wet reservoir and wells that had water introduced to the system had difficulty unloading the water. Introduction of water into the system could be through drilling fluids, acidizing, or fracture stimulation methods.

Early on it was established that the wells with significant vertical production were draining fractured reservoirs. Problems encountered in the completions of vertical wells could be factored into the completion methods of the horizontal wells. Wells properly completed showed decline curves with that characteristically had a rapid drop in production over the first year, followed by steady production with years of virtually no decline.

Horizontal Wells

The first horizontal drilling play in the upper Bakken shale had its own problems and resulting in a long learning curve. Drilling long distances in the less competent shale created problems. It was common to be stuck in the hole with time as the key factor to freedom. It appear a certain amount of circulation time was required to break up the rock material into small enough chips to send it up the wellbore. Adding material to the hole did not decrease that time and may have damaged the formation.

Fractures in the shales were also sensitive to drawdowns either through drill stem or production testing. Once fractures were closed production dropped off. Additionally, were there were no natural fractures, there was no production. There was no ability to stimulate the wellbore as was previously done in vertical holes. Also, the wellbore still had the same sensitivity factors to fluids that were encountered in the vertical holes.

Table 1. Reservoir properties for the Bakken Middle Member (pers. comm. L. Helms)

Formation Type	Fractured Silty Dolomite
Vertical Thickness	8 – 10 ft.
TVD	11,000 ft.
Porosity	8 – 10 %
Water Saturation	25%
Permeability	<0.1 mD
Initial Pressure	5000-7000+ psig
OOIP	2.0 – 2.5 MMSTB/sec
One Fracture Log	21' avg spacing (3' - 148')
Spacing	640-1280 acre
1-2 Laterals	4500-11,000 ft of pay
Frac @ 70 + BPM	Gelled water + 400,000 to 1,000,000 lbs sand
125-325 Propped Fractures	8'-35' half length & 35' average spacing

Additional problems resulted from fracture communication. Interference between wellbores was documented to extend over large areas. Horizontal wellbores were found to have an effect on a vertical wellbore 2500 to 3000 ft away. The large scale regional fractures are highly interconnected, causing pressure and fluid communication to extend over several sections. This interference would not show up immediately, but would generally become apparent after a month of continuous production.

Wells also required periodic workovers to remove the accumulated salt and fines from the wellbore. However, when the wells were successful they were capable of producing high volumes of oil.

Technology has finally caught up to the Bakken Formation. The current play drills the more competent middle member Bakken (Table 1). The ability to fracture stimulate these horizontal wells is what makes this play work. Whereas, in the late 1980s-early 1990s wells had to rely on encountering natural fractures to supply the oil; the wells in this play create their own fractures like the earlier vertical wells.

Wells generally consist of two 4000 to 5000 ft laterals drilled on a 1280-acre spacing unit. They are drilled with saturated brine instead of an inverted mud system. The zone generally has between 7 to 12% porosity, a permeability of .01 to .02 mD, and 70 to 80% oil saturation. Once drilled, the well is then treated with a 650,000 to 1 million pounds gelled water-sand fracture stimulation treatment. Due to high gas content, it is common for the wells to flow for quite a while before having to be put on pump.

Conclusions

It can be demonstrated that the same facies that produce in Montana are present and potentially productive in North Dakota. Changes in composition occur when moving away from the original play area in Montana. Locally the rocks may be slightly more silty or sandy or have an increase in clay content. These lithology changes may require slightly different completion techniques. Additional changes in completion techniques can be related to the hydrocarbon kitchen. In areas of intense hydrocarbon generation, fractures occurring within the shale change from horizontal bedding plane fractures to conchoidal fractures. This may change how the shales would react to a fracture treatment.

North Dakota has additional productive section. Lithofacies are thicker by proximity to the depositional center. The middle member has proven production from both Lithofacies 2 and 3. Also, production and additional potential exists locally at the base of the Bakken Formation, in the Sanish sand. This is a significant producer at Antelope field and occurs throughout the Bakken fairway. This highly burrowed sandstone/siltstone facies is probably related to salt collapse. Also, the lower Lodgepole limestone between the upper Bakken shale and the false Bakken may be another potential target. Detailed mapping of all of these zones will be required to determine the best location to tap into the Bakken resources.

There are large areas where salt collapse has played an important role on Bakken deposition and fracturing. The salt does not have to be completely removed to affect the overlying sequence of rock. It may be responsible for additional fractures and an increase in pay section. A detailed examination of dissolution areas could turn out to be quite profitable.

Finally, technology has created the ability to stimulate horizontal wells. Past history shows that the Bakken doesn’t like to give up its oil easily. In the early 1990s it required a natural fracture system. Now, that fracture system that can be artificially generated to open the Bakken up to production. The drilling of these wells with 1 or 2 long horizontal legs and stimulating them with a large fracture treatment is expensive, but can lead to a very profitable well.

References Cited

Dumonceaux, G.M., 1984, Stratigraphy and depositional environments of the Three Forks Formation (Upper Devonian), Williston Basin, North Dakota, Master's Thesis, University of North Dakota, Grand Forks, North Dakota, 189 p.

Heck, T., 1979, Depositional environments and diagenesis of the Bottineau interval (Lodgepole) in North Dakota, Master's Thesis, University of North Dakota, Grand Forks, North Dakota, 227 p.

A.

B.

C.

D.

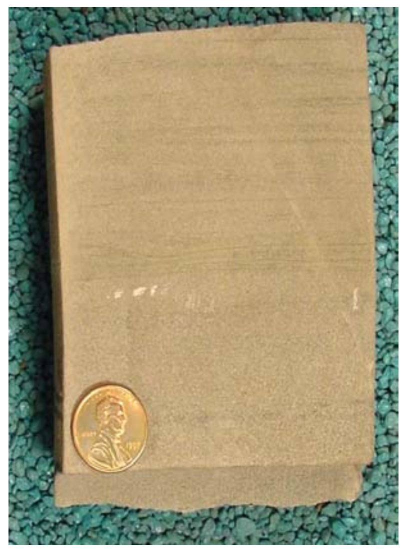
Core photos from the Shell Oil Company - #32-4 Young Bear (SWNE Sec. 4, T.148N., R.92W.) A. Photograph shows the nature of the gradational contact between the lower Bakken shale and the overlying Lithofacies 1. The rock immediately above the contact consists of a silty, lime mudstone with small crinoid fragments. This grades upward into a massive calcareous siltstone. (Depth - 10469 ft) B. Slightly further away from the contact, the core becomes more typical of the lithofacies. It is generally massive, may have an occasional brachiopod or crinoid fragment. (Depth - 10468 ft) .) C. This photograph shows the characteristic clay draping associated with Lithofacies 2. Also displayed is the change from an argillaceous siltstone to a sandy siltstone to very fine-grained sandstone. Burrowing is present but not as abundant as in the adjacent photograph. (Depth – 10458.6 ft) D. This sample is from the upper portion of the interval. Burrowing is pervasive and has destroyed any pre-existing fabric. Clay drapes are present but rare. The lithofacies is locally dolomitized. (Depth – 10453.6 ft)

A.

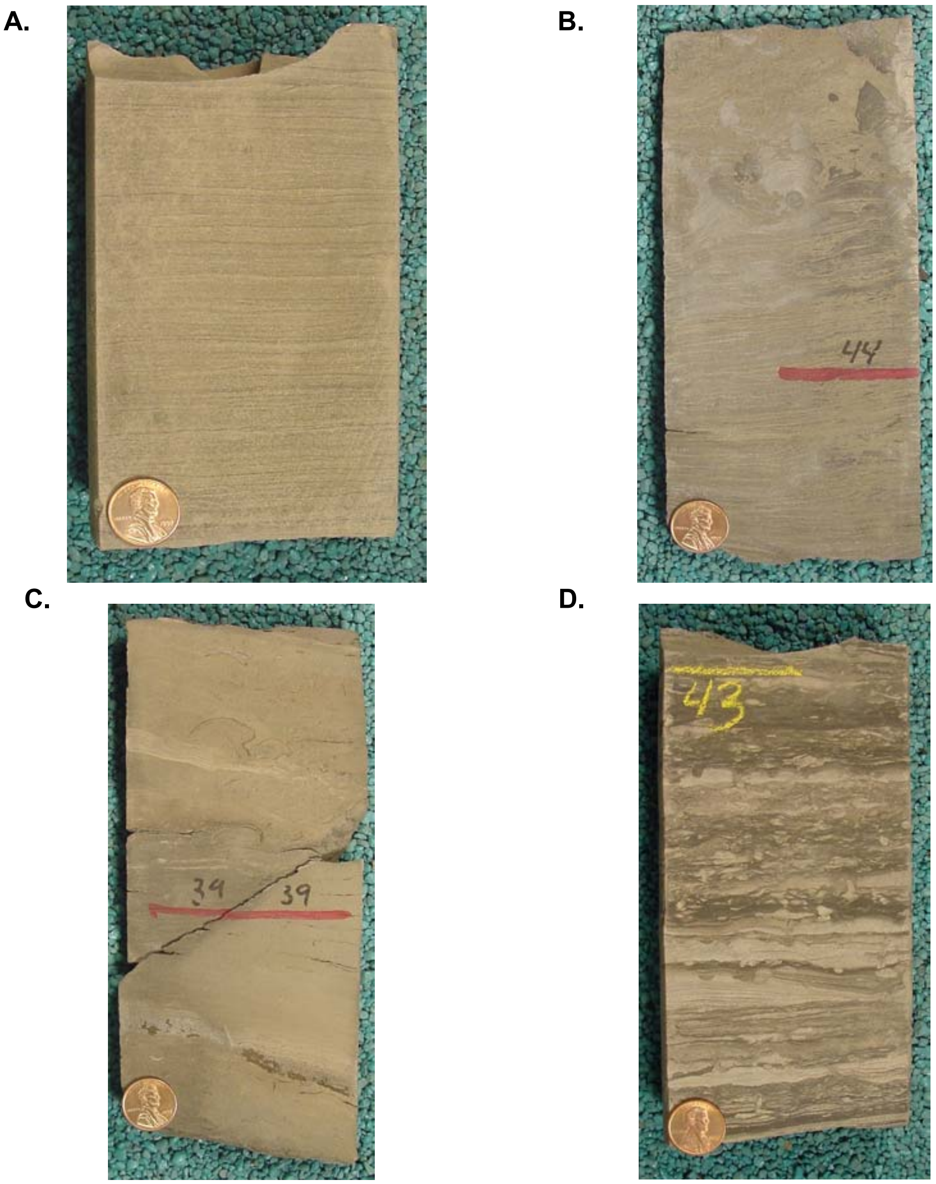
B.

C.

D.



A series of core photographs that are representative of Lithofacies 3. A. Marathon Oil Company - #26-1 Laredo (SWNE Sec. 26, T.156N., R.91W.) Photograph shows an alternating sequence massive to thinly laminated fine-grained sandstone common to this interval. (Depth - 9284.8 ft) B. From the same well, beds in this photograph are inclined. It is interesting to note that the lithofacies in this well represents a channel. (Depth – 9294.4). C. Exeter Exploration Co. - #8-30 Schmitz (SENE Sec. 30, T.152N., R.85W.) This photograph shows very fine-grained sandstone with cross-ripple laminations. (Depth – 10849 ft) D. Conoco Oil Company - #17 Watterud “A” (SESW Sec. 4, T.148N., R.95W.) This core photograph is of a very fine-grained, finely laminated sandstone common to this interval. (Depth – 8857.6 ft)



Core photographs that are representative of Lithofacies 4. A. Conoco Oil Company - #17 Watterud "A" (SESW Sec. 11, T.160N., R.95W.) Photograph shows the thin, slight wavy bedded argillaceous siltstone of this interval. (Depth – 8171.6 ft) B. Shell Oil Company - #32-4 Young Bear (SWNE Sec. 4, T.148N., R.92W.) Photograph is an example of local variations encountered in some of these facies. Silty laminations are interbedded with algal mats. (Depth – 10443.5 ft) C. Shell Oil Company - #32-4 Young Bear (SWNE Sec. 4, T. 148N., R.92W.) well shows the interbedded sequence of argillaceous siltstones with cleaner, discontinuous very fine-grained sandstones. Burrowing and brachiopods are present. (Depth – 10438.6 ft) D. Conoco Oil Company - - #17 Watterud "A" (SESW Sec. 11, T.160N., R.95W.) well is more basinward than the previous photograph. This core slab has higher argillaceous content that emphasizes the discontinuous nature of the very fine-grained sandstone. The sequence is highly disrupted by burrowing. (Depth – 8843 ft)

A.

B.

Core photographs representative of Lithofacies 5. A. Shell Oil Company - #32-4 Young Bear (SWNE Sec. 4, T. 148N., R.92W.) well shows the massive nature of the lithofacies. A traceable brachiopod bed is present in this photograph. (Depth – 10437.4 ft) B. Meridian Oil Inc. - #44-27 MOI (SESE Sec. 27, T. 143N., R.102W.) This photograph shows the contact between Lithofacies 5 and the upper Bakken shale where it is unconformable. The contact is slightly irregular overlain by a well developed lag deposit consisting of fossil fragments, bitumen grains, and pyrite. (Depth – 10225.6 ft)

A.

B.

Core photographs representative of the "Sanish" sandstone from the Raymond T. Duncan. - #1 Rose (SENE Sec. 2, T.153N., R.94W.). A. Medium brown highly burrowed siltstone to very fine-grained sandstone characteristic of the "Sanish" (Depth – 10601.3 ft). B. Characteristic apple green and tan interbedded sequence of the Three Forks Formation. (Depth – 10605 ft)