Lynn D. Helms, Director, Department of Mineral Resources
Edward C. Murphy, State Geologist
North Dakota Geological Survey
2007

Bakken Formation Middle Member Lithofacies 1

Julie A. LeFever

Geological Investigations No. 45-1

LITHOFACIES 1

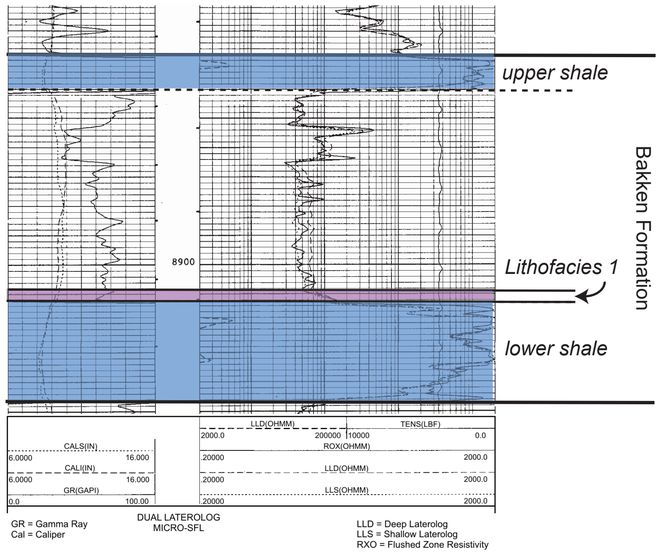
Lithofacies 1 is a transitional facies from the anoxic deposition of the lower Bakken black shale into the normal marine setting. Subtle variations of components and shale content determine the distribution of the various environments present. Core coverage for the facies is limited to the basin margin and southern portion of the Nesson anticline. Two cores along the margin consist of medium brown, shaly- to silty-limestone. The remaining cores consist of light-grey, greenish-grey, or brownish-grey argillaceous siltstone with the argillaceous content increasing basinward.

The shaly- to silty-limestone that is present within this facies contains a mixture of bioclastic material consisting of crinoid, brachiopod, and a few bryozoan fragments. One of the wells also contained glauconite grains. Where a contact was present in the core, it was erosional. The remaining portion of the sequence consists of a massive- to burrowed argillaceous siltstone and an interbedded argillaceous siltstone-claystone sequence. Crinoid fragments and burrowing with an occasional gastropod are present along the margins. The lithofacies becomes more massive with a few scattered brachiopods towards the basin center. Where present, the porosity is interparticle with calcite and pyrite acting as the predominant cement. As the contact with the underlying Bakken shale is approached, there is a noticeable increase in the amount of pyrite present in the rock. Bioclastic material is commonly coated or replaced with pyrite. Where the lower shale is absent a lag deposit has developed at the contact, consisting of bitumen-coated fossil fragments, brachiopods and brachiopod spines, sand and pyrite grains. Contacts between Lithofacies 1 and the lower Bakken shale vary from erosional and unconformable along the margin to a gradational contact in the central basin.

Lithofacies 1 ranges in thickness from 1.5 to 6 ft, averaging 3 ft. Maximum thickness for this lithofacies is in the area of the main depocenter for the middle member. Thickness remains constant over the rest of its extent with the exception of one locality in Billings County. At that location the abnormal thickness is probably related to the dissolution of the Prairie Salt. The recognition of the facies on wireline logs is dependent on the presence of the lower shale. The wireline log character for Lithofacies 1 is a small response in the gamma-ray signature (see wireline log) that is sometimes difficult on the older logs where the shale signature is less defined.

Lithofacies 1 represents upper to lower shoreface environments of deposition. Contacts are conformable in the central portion of the basin becoming sharp and unconformable to the southwest. Sediment source was from the northeast and restriction of transport by the Nesson anticline was not significant at this time. The marine connection was relatively narrow to the west of the Nesson, and in a predominantly north-south direction.

SENW Sec. 11, T.160N., R.95W
Conoco, Inc.
#17 Watterud "A"

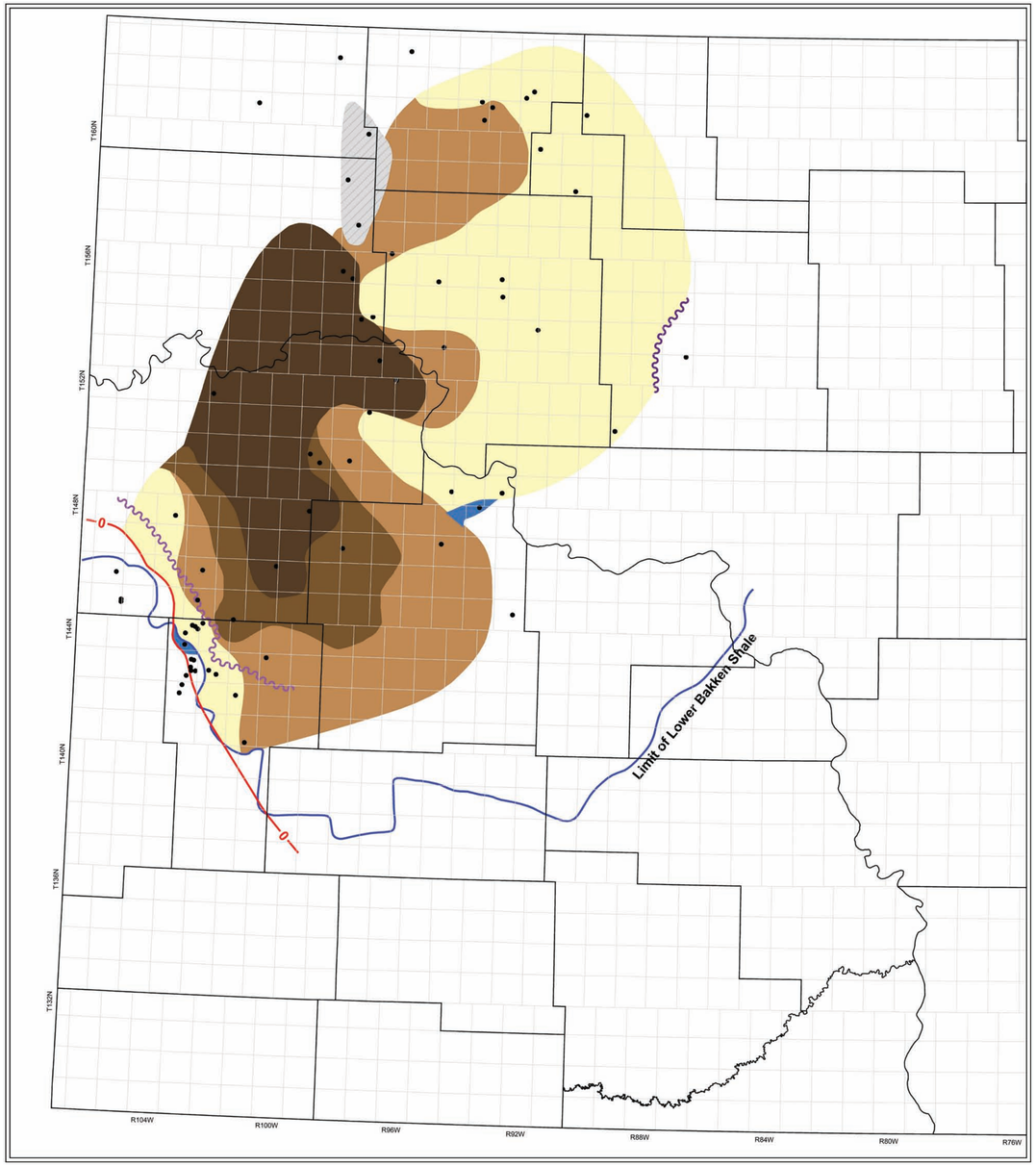


GR = Gamma Ray
Cal = Caliper

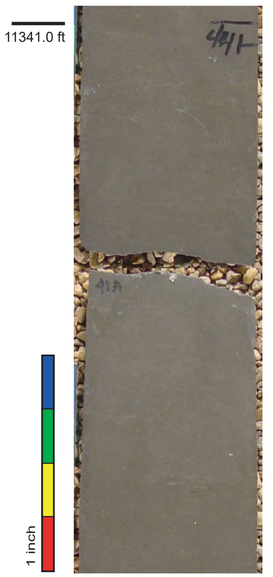
DUAL LATEROLOG
MICRO-SFL

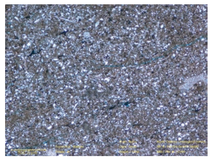
LLD = Deep Laterolog
LLS = Shallow Laterolog
RXO = Flushed Zone Resistivity

NDIC File No: 13318

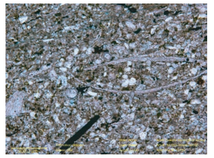


NENW Sec. 19, T.147N., .96W.
Maxus Exploration Co.
#21-19 Carus Fee
KB = 2547

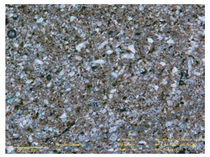




Dolomitization has occurred along the micro-fractures present in the calcareous siltstone. Scattered fossil fragments are also present.



Brachiopod shells and spines within a calcareous siltstone. Locally calcite cement has been replaced with dolomite. Fossil fragments are commonly replaced with pyrite.



Microfractures and interparticle porosity within calcareous siltstone.

Lithofacies 1

- -0- Limit L1 Facies
- Unconformity - L1 - Lower Unit
- Limit of Lower Bakken Shale
- Siltstone - Upper Shoreface
- Siltstone - Middle Shoreface
- Siltstone - Lower Shoreface
- Siltstone - Mudstone - Distal
- Limestone
- Not Cored
- Bakken Core Locations

Lynn D. Helms, Director, Department of Mineral Resources
Edward C. Murphy, State Geologist
North Dakota Geological Survey
2007

Bakken Formation Middle Member Lithofacies 2

Julie A. LeFever

Geological Investigations No. 45-2

LITHOFACIES 2

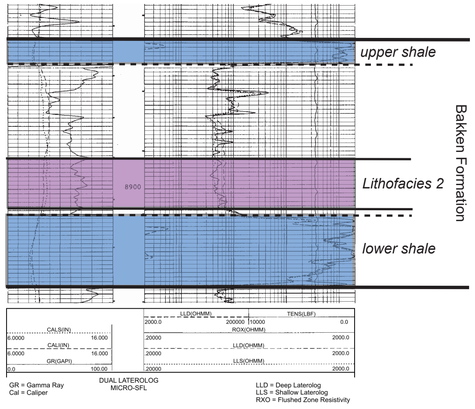
Lithofacies 2 varies from a greenish-grey argillaceous siltstone to brownish grey very fine-grained sandstone. Sandstone accumulations are areally restricted on localized highs. There is an abrupt change in lithologies that is represented by a narrow band from a more gradual portion of the shelf to the deeper sediment starved portion of the basin with an abrupt edge along the western Nesson anticline.

The sandstone portion of the facies is medium grey to dark grey and very fine-grained with brachiopods, burrows, and localized crinoid fragments. Rip-up clasts were observed along the southwestern limit of the sandstone. Calcite is the common cement and cementing is complete in areas of coarser grain size. Local dolomitization of the calcite cement enhances the porosity. The sandstone gradually changes in to a medium brown siltstone with brachiopods and burrows with localized dolomite cement. As the central portion of the basin is approached the siltstone becomes a medium-dark grey shaly siltstone. The facies is characterized by clay draping and or Helminthopsis burrows. These are concentrated in the lower portion of the section. Extensive burrowing has homogenized the upper section. Porosity is also enhanced by burrowing. Fossils are commonly replaced by pyrite. Pyrite nodules are occasionally present.

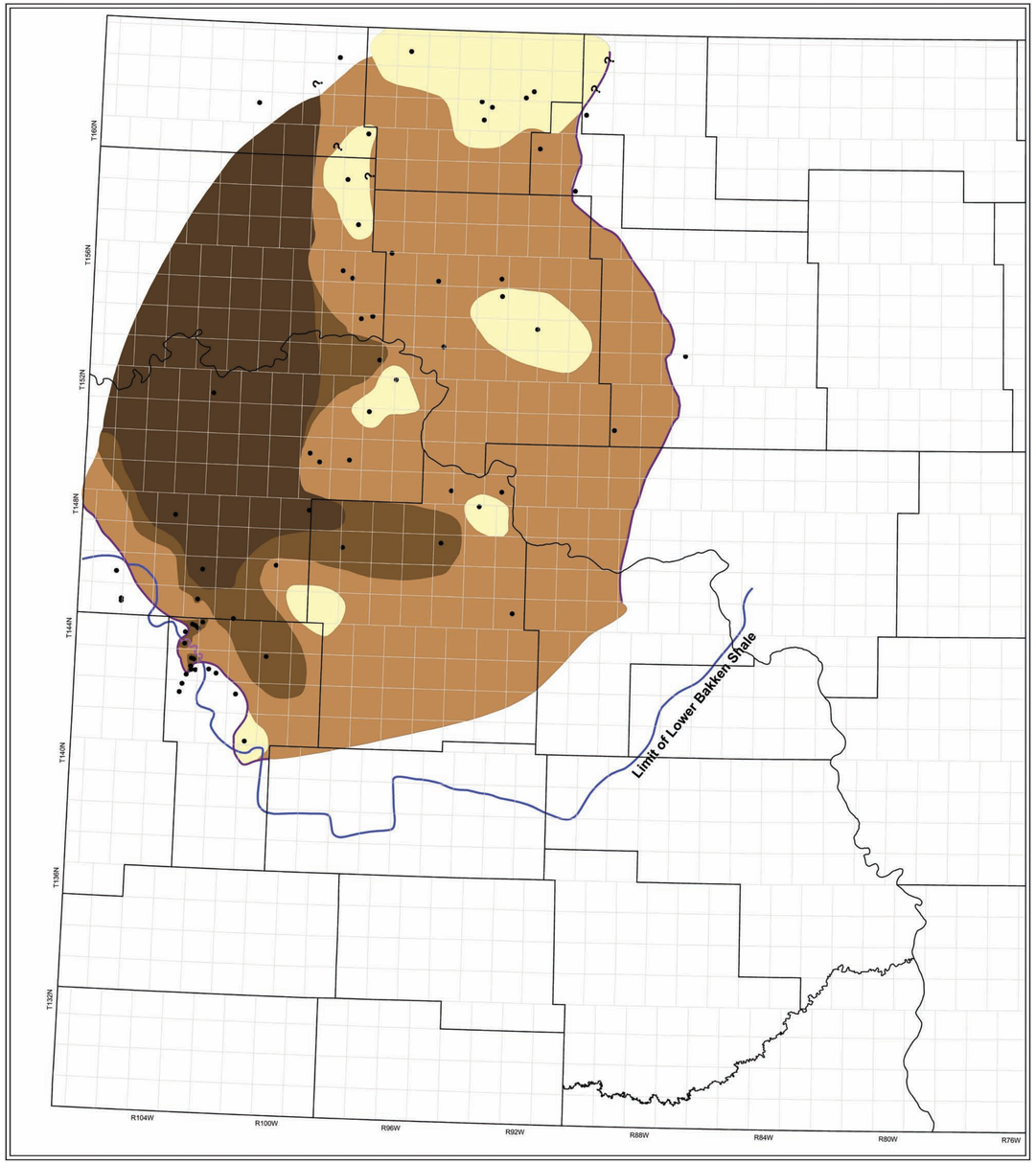
Lithofacies 2 reaches a maximum thickness of 40 ft, averaging 14 ft. The facies gradually thins towards the margin. Abrupt thickness variations occur in areas of uplift or salt collapse. The facies has the greatest areal extent and is easily recognized throughout the Williston basin by its distinctive burrows and clay drapes. The interval is mappable on wireline logs. The lower section deflects the gamma-ray curve to the right (increasingly shaly) with the upper section having a noticeably cleaner gamma-ray curve representing the highly burrowed portion of the facies (see wireline log). Log porosities for this interval commonly range from 6 to 12% and appear to indicate dolomitization. This section is the stratigraphic equivalent to the producing zone in the Elm Coulee Field, Montana. Mapping with wireline logs should reference the available core control whenever possible.

The sediments of Lithofacies 2 represent upper to lower shoreface. Although Helminthopsis is thought to represent deep water facies, in this case it is indicative of a facies not an environment. Sediment source is from the northeast with transport restricted to the eastern side of the Nesson anticline. It is readily apparent that the marine channel has become broader with the transgression of the Bakken seas. It is also apparent that uplift on the Nesson is confined to the northern and southern portion of the structure.

SENW Sec. 11, T.160N., R.95W
Conoco, Inc.
#17 Watterud "A"

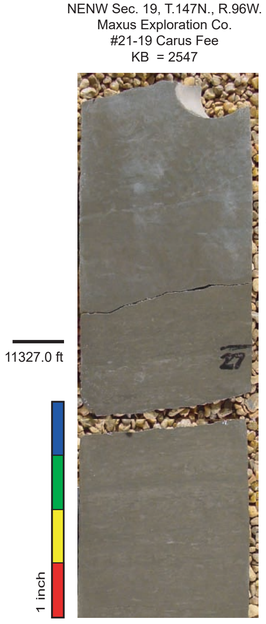


NDIC File No: 13318



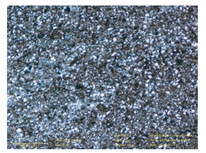
Upper

NENW Sec. 19, T.147N., R.96W.
Maxus Exploration Co.
#21-19 Carus Fee
KB = 2547



Interparticle and microfracture porosity are prevalent in the very fine-grained sandstone to siltstone interbeds.

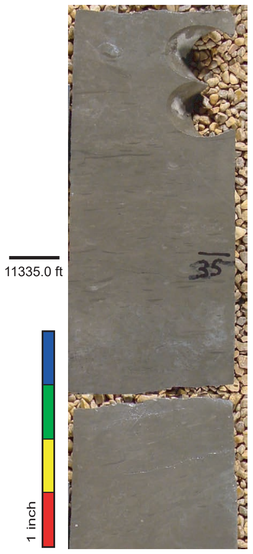
Pervasive interparticle porosity within thin dolomitic limestone beds.

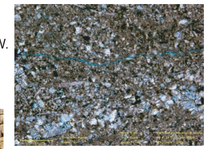


Interbedded dolomitic limestone with a very fine-grained sandstone-siltstone. Heavily burrowed with interparticle porosity.

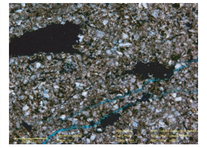
Lower

NENW Sec. 19, T.147N., R.96W.
Maxus Exploration Co.
#21-19 Carus Fee
KB = 2547

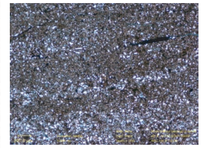




Dolomitization has occured along small lenses or thin laminae of calcite. Interparticle-intercrystalline and micro-fracture porosity are prevalent.



Open and pyrite cemented microfractures within clay draped sandstone-siltstone sequence. Some of the calcite cement exhibits dolomitization.



Very fine-grained sandstone-siltstone laminae over-lain by clay drapes with pervasive interparticle and microfracture porosity.

Lithofacies 2

- Limit of L2 Lithofacies
- Unconformity - L2 - Underlying Unit
- Limit of Lower Bakken Shale
- Upper Shoreface
- Sandstone Siltstone - Middle Shoreface
- Siltstone - Lower Shoreface
- Siltstone - Mudstone - Distal
- Bakken Core Locations

Lynn D. Helms, Director, Department of Mineral Resources
Edward C. Murphy, State Geologist
North Dakota Geological Survey
2007

Bakken Formation Middle Member Lithofacies 3

Julie A. LeFever

Geological Investigations No. 45-3

LITHOFACIES 3

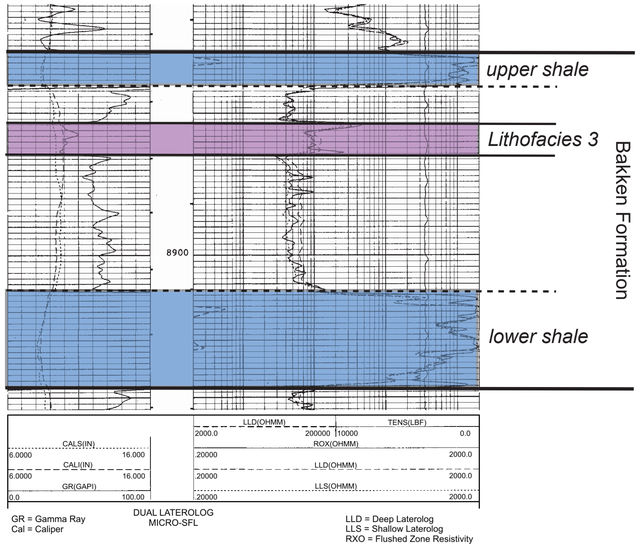
Lithofacies 3 varies from a medium grey to dark grey to greyish-tan, very fine- to fine-grained sandstone to a medium grey limestone. Localized accumulations of coarser material exist in the northeastern portion of the map (Burke County). Limestone forms a series of bands along the southwestern extent of the Bakken. Towards the basin margin the limestone changes from a sand-algal packstone, to a sand-ooid packstone, ooid packstone, to an ooid-crinoid packstone-grainstone.

The facies is predominantly sandstone and is moderately well-sorted to well-sorted and may be poorly-sorted locally. Clasts consist predominantly of quartz with some feldspar and heavy minerals. The grains are rounded to well-rounded; the finer grained material is sub- rounded to sub-angular. Cement is generally calcite, and in some cases pyrite. Pyrite is disseminated throughout the interval. The lower portion of the interval is locally reverse graded. The middle portion of the section consists of an alternating sequence of massive to cross-bedded to thinly laminated beds. These beds are generally coarser grained than the under and overlying lithologies. Overlying these beds is a series of multiple fining upward sequences. Other structures that have been noted in the core are rip-up clasts, load or channel structures, usually into the finer grained material, and calcite-filled fractures. Locally, soft-sediment deformation destroys the entire fabric. Oil staining may be present in the very fine-grained, laminated, predominantly quartz sandstone portion of the core. It appears that as the grain size increases in this lithofacies so does its ability to undergo cementation.

The thickness of Lithofacies 3 reaches a maximum of 17.5 ft, averaging 8 ft in the North Dakota portion of the Williston basin. This lithofacies is generally limited to the northern half of the state and thickens in a northward direction. Distribution of this facies from wireline logs is difficult to determine as the edge is approached. It has a prominent, consistent, and easily mappable gamma-ray log response over the majority of its extent (see wireline log). However, as its depositional edge is approached, it is difficult to determine its log characteristic with any certainty. At least one well appears to have penetrated a channel sand.

The sediments of Lithofacies 3 represent middle to lower shoreface environments of deposition. Contacts are conformable, but unconformities occur in localized areas along the Nesson anticline, along the southwestern margin, and along the Canadian border. The presence of an unconformity surface, soft-sediment deformation and the increase thickness in the area of Divide County suggests dissolution activity in the underlying Devonian Prairie salt by extending the Hummingbird trough into North Dakota. Available cores indicate that the northern and southern portion of the Nesson anticline was a positive feature throughout the deposition of this unit with a probable bypass channel through the lower central portion of the anticline. The structure is probably responsible for the distribution of clastics in this interval. Sand, sourced from the north, was routed around the eastern side of the Nesson anticline leading to the development of carbonates along the southwestern edge. It also starved the western side of the state of coarse clastics, producing a finer-grained facies.

SENW Sec. 11, T.160N., R.95W
Conoco, Inc.
#17 Watterud "A"

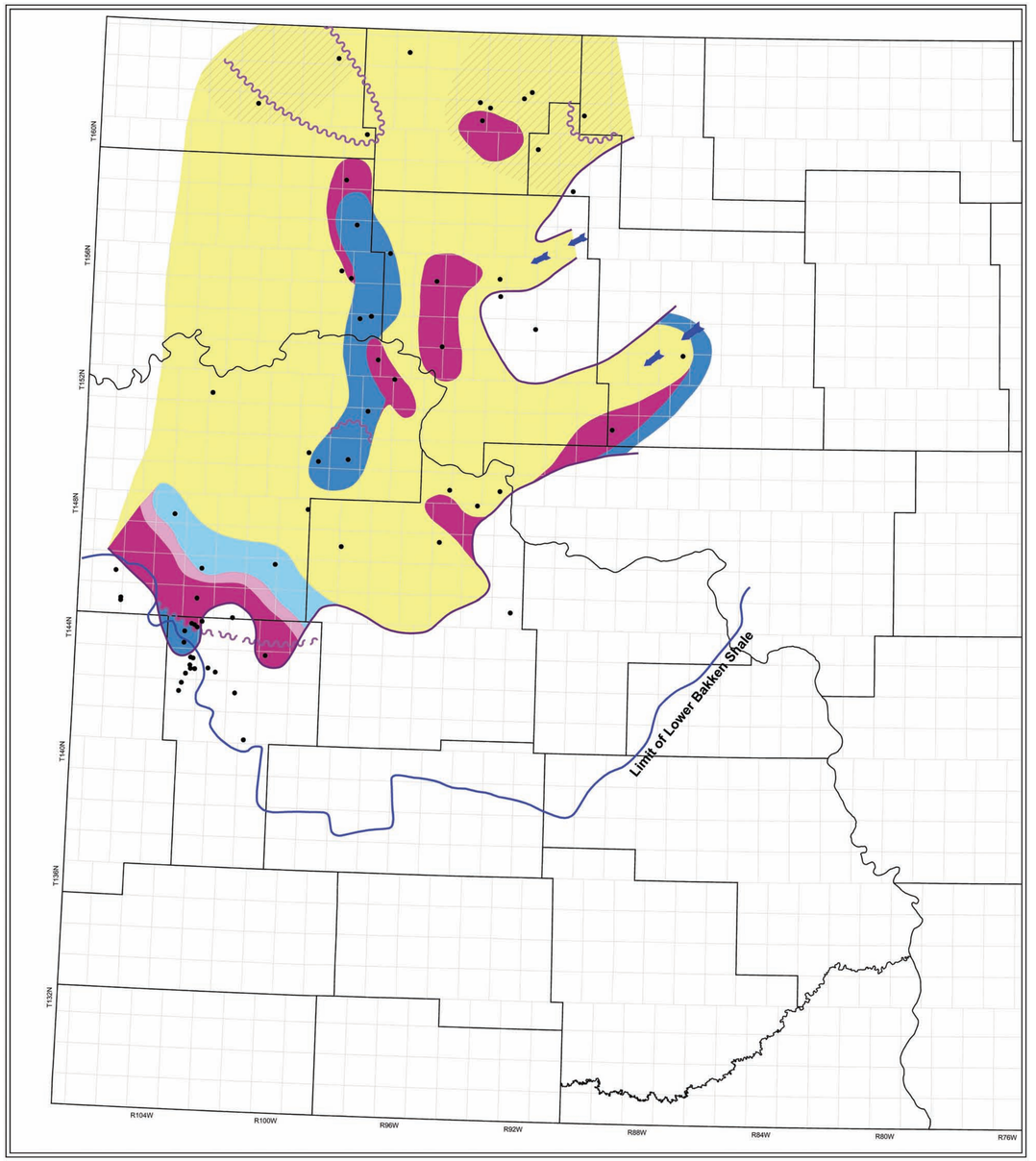


GR = Gamma Ray
Cal = Caliper

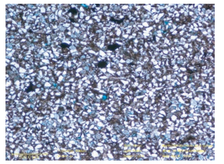
DUAL LATEROLOG
MICRO-SFL

LLD = Deep Laterolog
LLS = Shallow Laterolog
RXO = Flushed Zone Resistivity

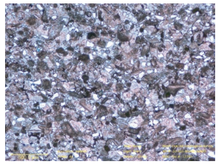
NDIC File No: 13318



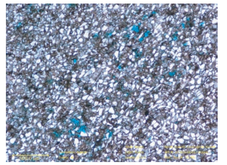
NENW Sec. 19, T.147N., R.96W.
Maxus Exploration Co.
#21-19 Carus Fee
KB = 2547



Very fine-grained sandstone to siltstone with well developed interparticle porosity. Microfractures are also present.



Silty limestone with bioclastic material. Porosity is minimal to non-existent.



Calcareous siltstone to very fine-grained sandstone with abundant interparticle porosity.

Lithofacies 3

- Limit of Lithofacies 3
- Unconformity - L3 - Underlying Unit
- Limit of Lower Bakken Shale
- Limestone - Ooids & Crinoids
- Limestone - Ooids
- Limestone - Ooids & Sand
- Algal Mats with Ooids & Sand
- Fine-Grained Sandstone
- Fine- to Coarse-Grained Sandstone
- Channel Direction
- Bakken Core Locations

Lynn D. Helms, Director, Department of Mineral Resources
Edward C. Murphy, State Geologist
North Dakota Geological Survey
2007

Bakken Formation Middle Member Lithofacies 4

Julie A. LeFever

Geological Investigations No. 45-4

LITHOFACIES 4

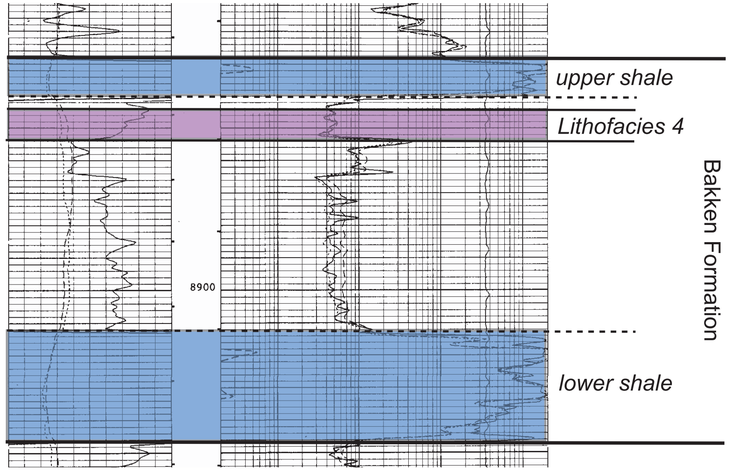
Lithofacies 4 is represented by two distinct parts. The lower portion consists of an alternating sequence of medium grey, argillaceous siltstone to light to medium grey, very fine-grained sandstone with dark grey shale laminae. The upper portion consists of an alternating sequence of medium to light grey siltstones, dark grey claystones to brown-black shales, and tan to light brownish grey, very fine-grained sandstones.

The lower siltstone to sandstone portion of the sequence shows thin parallel or slightly undulatory laminations. Laminations that are thicker are usually coarser grained. Locally, the rock is cemented with dolomite. Soft-sediment deformation is present locally. The basal beds to the upper sequence are thinly laminated, very fine-grained sandstones and siltstones with abundant burrows. Overlying sediments contain interbeds of thinly laminated to cross-bedded siltstones and very fine-grained sandstones. The sandstones occur also as discontinuous beds or lenses due to burrowing. Distribution of the argillaceous content within the interval varies locally, but generally increases towards the western side of the basin. Other features exhibited in core include dewatering structures and thin beds locally rich in organics. Cement, where present, is generally dolomite.

Lithofacies 4 ranges in thickness from 4 to 14 ft. The lower and upper portions of the facies reach a maximum thickness of 4 and 10 ft respectively. Distribution of cores for this facies is limited. The lower contact of the facies is easily recognized on logs since it overlies the prominent clean gamma-ray bench created by lithofacies 3 (see wireline log). Its upper contact with the overlying lithofacies 5 is easier to recognize on newer logs.

The sediments of Lithofacies 4 represent lower through upper shoreface environments. The upper contact is generally gradational with the overlying lithofacies. The lower contact is conformable in the northern portion of the basin and unconformable in the southern portion of the basin. Environments change quickly in response to salt collapse. Sandy beds are still concentrated to the east of the Nesson anticline similar to the underlying lithofacies.

SENW Sec. 11, T.160N., R.95W
Conoco, Inc.
#17 Watterud "A"

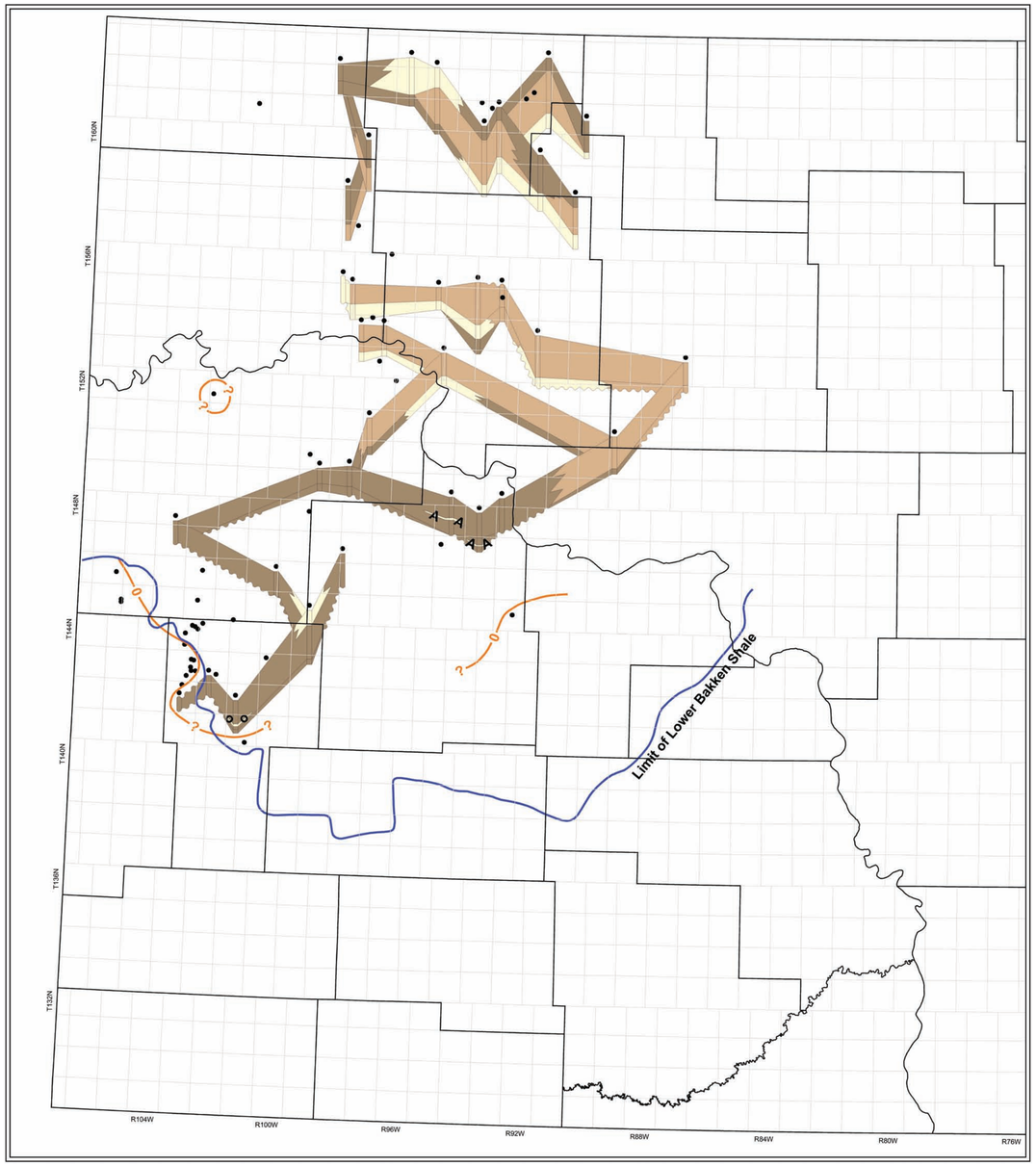


DUAL LATEROLOG
MICRO-SFL

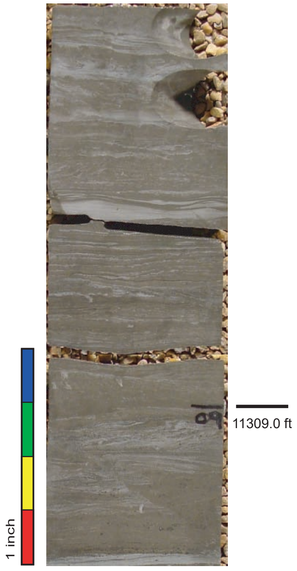
GR = Gamma Ray
Cal = Caliper

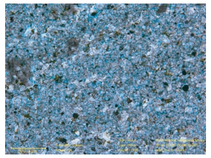
LLD = Deep Laterolog
LLS = Shallow Laterolog
RXO = Flushed Zone Resistivity

NDIC File No: 13318

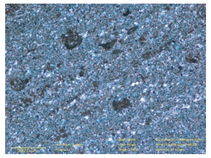


NENW Sec. 19, T.147N., R.96W.
Maxus Exploration Co.
#21-19 Carus Fee
KB = 2547

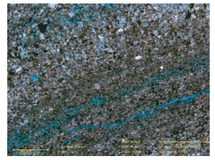




Dolostone bed with abundant interparticle porosity.



Silty dolomitic limestone with pervasive interparticle porosity.



Calcareous siltstone to very fine-grained sandstone interbedded with thin dolomitic limestone beds. Microfracturing is prominent in siltstone-sandstone layers and with interparticle porosity in the carbonates.

Lithofacies 4

- Unconformity
- -0- Limit of Lithofacies 4
- Limit of Lower Bakken Shale
- -o- Oolite Bed
- -A- Algal Layer
- Upper to Middle Shoreface
- Middle Shoreface
- Lower Shoreface
- Bakken Core Locations

Lynn D. Helms, Director, Department of Mineral Resources
Edward C. Murphy, State Geologist
North Dakota Geological Survey
2007

Bakken Formation Middle Member Lithofacies 5

Julie A. LeFever

Geological Investigations No. 45-5

LITHOFACIES 5

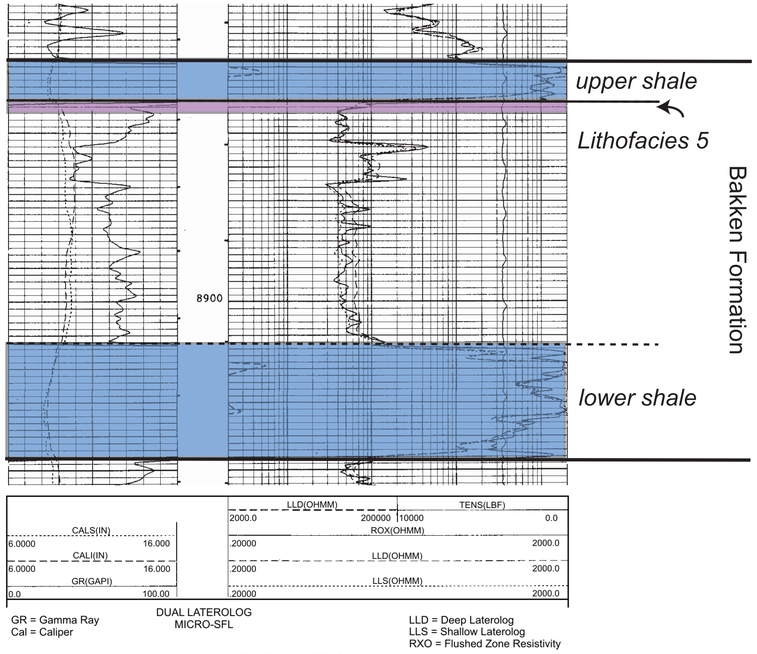
Lithofacies 5 is a transitional facies that underlies the upper Bakken shale and consists of a medium to light grey or greenish-grey, massive to wispy laminated siltstone to a greenish grey massive carbonate.

Thin beds of very fine-grained sandstone occur toward the bottom of the interval. These beds are tan to light grey and commonly have cross-ripple laminations. One fine-grained layer is underlain by an argillaceous layer rich in brachiopods. This brachiopod-rich layer is present in several of the wells. Brachiopods are present throughout the entire interval. In addition to the brachiopods, bryozoan and crinoid fragments are present in wells associated with localized highs, such as the southern Nesson anticline and Burke County areas. In the shoaling areas the cement is commonly dolomite. The change from limestone to dolomite also occurs on the southern Nesson anticline as the localized zero edge is approached. Many of the fossils are completely or partially replaced with pyrite. Pyrite is disseminated through out the section increasing in concentration towards upper shale contact. The interval is massive immediately below the contact with the shale.

Thickness of the interval ranges from 2 to 6 ft, averaging 4.7 ft. The contact with the overlying Bakken shale may be gradational or abrupt depending on the location of the well in the basin. There is usually a well developed lag deposit of fossil fragments, bitumen grains, and pyrite, immediately overlying the contact where it is erosional. It is represented as a small clean spike on the newer gamma-ray logs (see wireline logs). However, it is commonly overshadowed by the high radioactivity of the overlying shale requiring close core control.

The majority of the lithofacies is middle to lower shoreface reflecting the transgression of the upper Bakken Sea. Areas of shoaling are limited to localized highs. Along the southwestern corner of the map, Lithofacies 5 unconformably overlies the middle member, the lower Bakken shale, and the Devonian Three Forks Formation.

SENW Sec. 11, T.160N., R.95W
Conoco, Inc.
#17 Watterud "A"

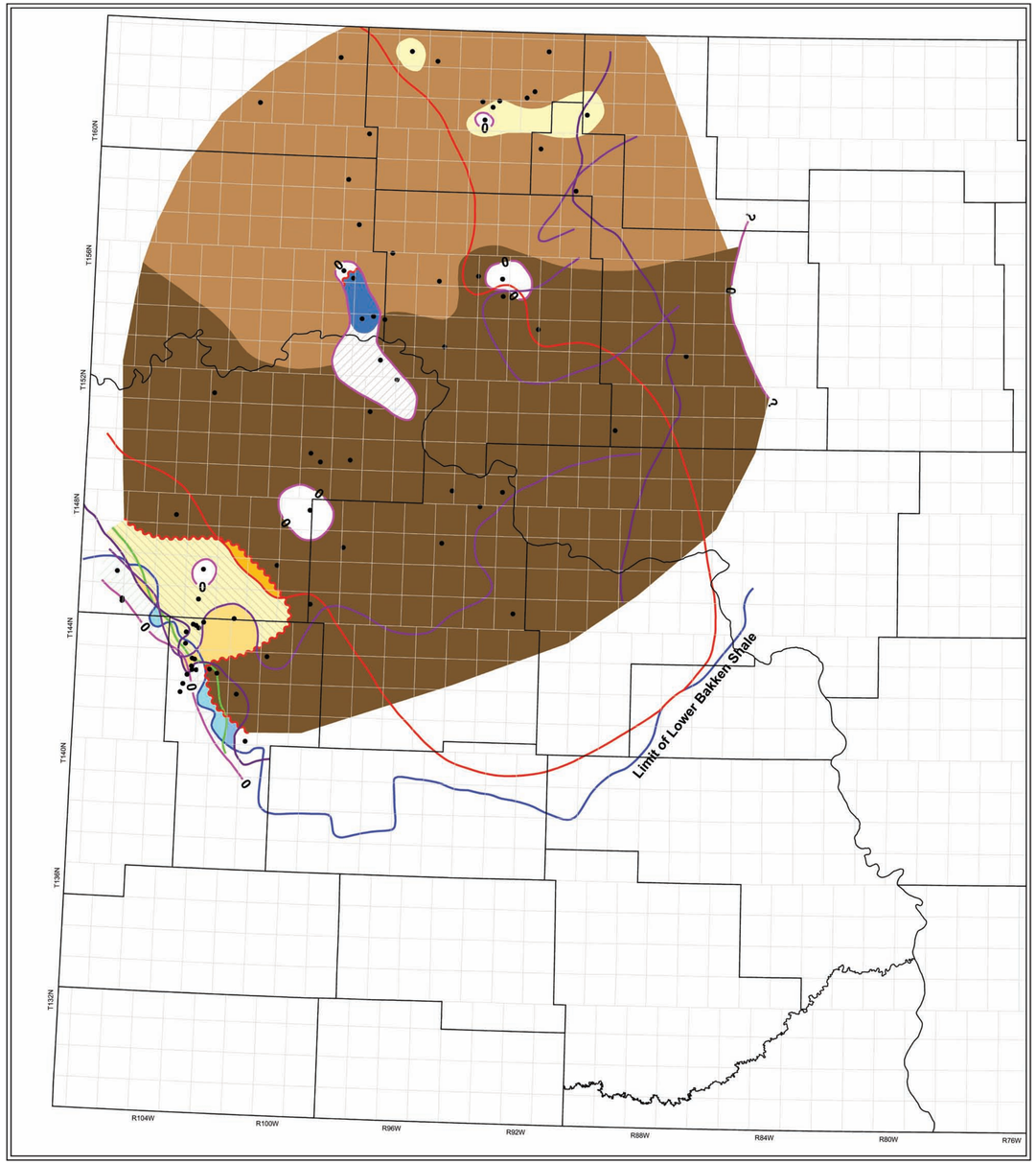


GR = Gamma Ray
Cal = Caliper

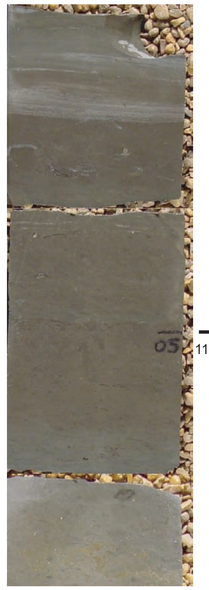
DUAL LATEROLOG
MICRO-SFL

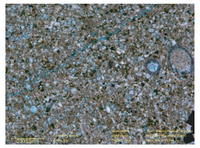
LLD = Deep Laterolog
LLS = Shallow Laterolog
RXO = Flushed Zone Resistivity

NDIC File No: 13318

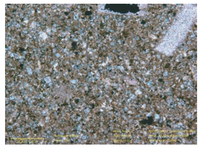


NENW Sec. 19, T.147N., R.96W.
Maxus Exploration Co.
#21-19 Carus Fee
KB = 2547

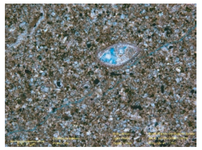




Dolostone with abundant interparticle porosity and some moldic and microfracture porosity.



Dolomitic limestone with pervasive interparticle porosity. Pyrite grains and replacement of fossil fragments by pyrite are common.



Silty dolomitic limestone with brachiopods and brachiopod fragments. Pyrite grains are also abundant through this lithofacies. This interval has abundant interparticle porosity and limited micro-fracture and moldic porosity.

Lithofacies 5

- 0 Limit of Lithofacies 5
- Limit of Lower Bakken Shale
- Limit of Lithofacies 1
- Limit of Lithofacies 2
- Limit of Lithofacies 3
- Limit of Central Basin Facies
- Unconformity
- No Core With Facies
- Carbonate - Limestone/Dolomite
- Upper Shoreface - Oolite - Sandstone Shoal
- Middle Shoreface
- Lower Shoreface
- Bakken Core Locations

L5 Uncomformities

- Central Basin Facies
- Lithofacies 3
- Lithofacies 2
- Lithofacies 1
- Lower Bakken Shale
- Three Forks Formation

Lynn D. Helms, Director, Department of Mineral Resources
Edward C. Murphy, State Geologist
North Dakota Geological Survey
2007

Bakken Formation Middle Member Lithofacies CBF

Julie A. LeFever

Geological Investigations No. 45-CBF

LITHOFACIES - CENTRAL BASIN FACIES

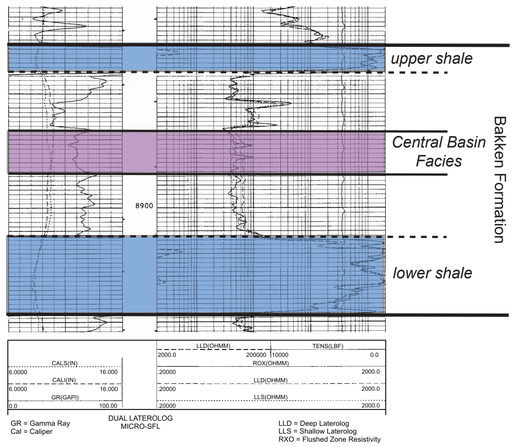
The central basin facies (cbf) consists of four distinctive lithologies that are limited to the central portion of the Williston basin. They are visible in core but are too small to be identified individually on wireline logs. As a group, the combined sequence on wireline logs with core control is mappable.

The basal 5 ft of this combined sequence consists of a laminated, slightly argillaceous sandy siltstone. There is a slight undulation to the laminations. This is overlain by 2 ft of medium brownish-grey massive siltstone. The third bed set consists of a 4.5 ft thick interbedded sequence of very fine-grained sandstones and wavy laminated claystones. The beds become lensoidal locally due to burrowing. A medium grayish-brown, laminated sequence of siltstones and very fine-grained sandstones completes the sequence. These laminations are very thin (< 5 cm) and uniform in thickness; thicker individual beds are massive to cross-bedded. Thicker individual beds are massive to cross-bedded. Although very fine-grained, cementation is limited to non-existent and the interval shows extensive oil staining.

The entire sequence reaches a maximum thickness of 24 ft. Additional core data is expanding the areal extent of this lithofacies. As with the other middle member lithofacies, the contacts with the overlying and underlying beds vary from unconformable to gradational. Disconformities are abrupt and common with this interval and appear to be in response to local tectonics (probably related to salt dissolution).

The combined facies is within the middle shoreface environment. Cores on the western side of the state show finer grained sediment similar to the other middle member facies. The northern and southern end of the Nesson is structurally high noted by the thinner interval and unconformable contacts with the overlying lithofacies.

SENW Sec. 11, T.160N., R.95W
Conoco, Inc.
#17 Watterud "A"

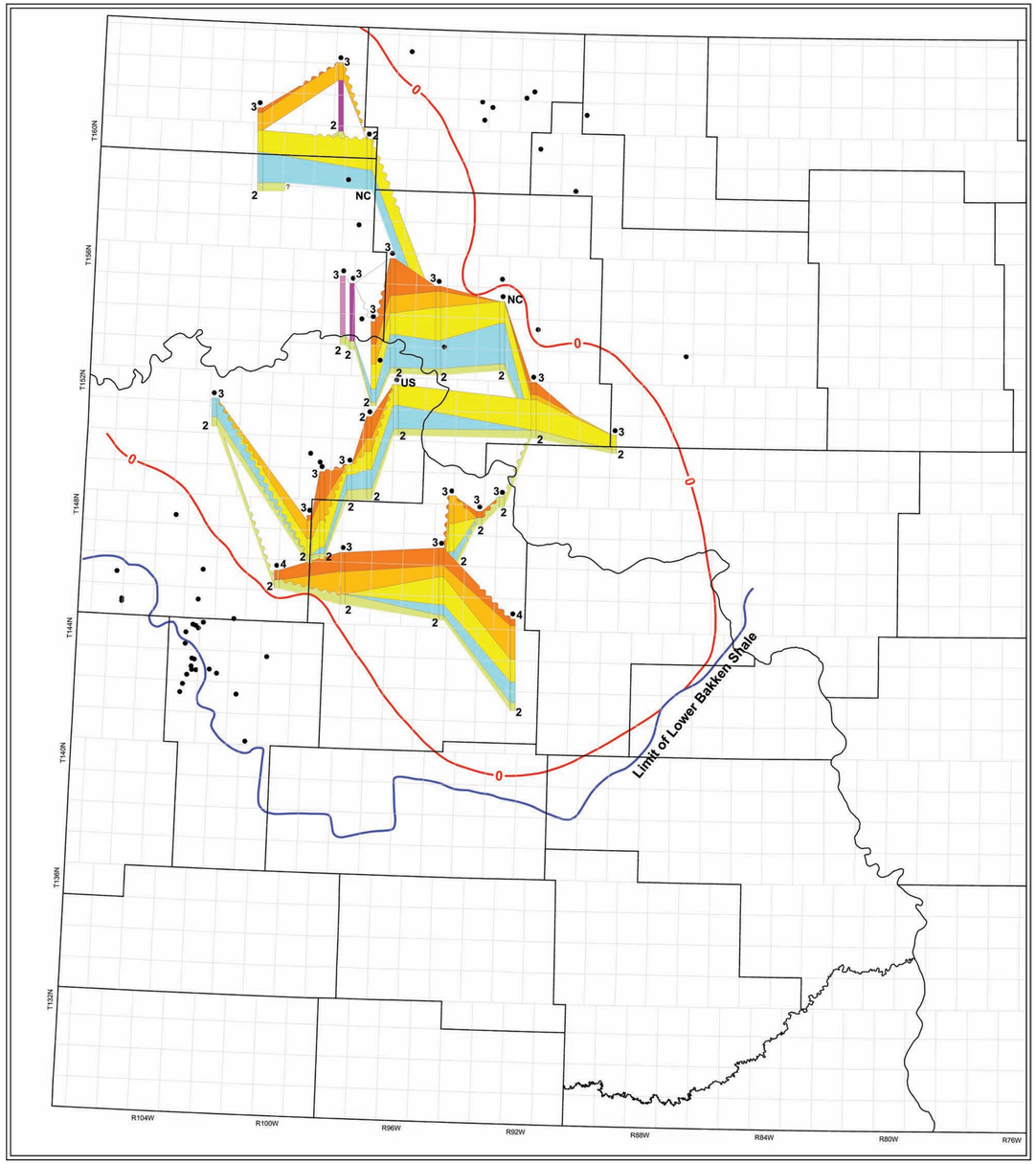


GR = Gamma Ray
Cal = Caliper

DUAL LATEROLOG
MICRO-SFL

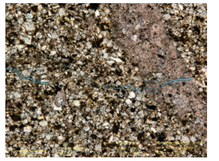
LLD = Deep Laterolog
LLS = Shallow Laterolog
RXO = Flushed Zone Resistivity

NDIC File No: 13318



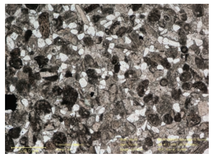
Top Unit

SWNE Sec. 4, T.148N., R.92W.
Shell Oil Co.
#22-4 Young Bear
KB = 2361



Very fine-grained quartz sandstone with a predominantly dolomitic cement. Abundant disseminated pyrite. Numerous open and healed microfractures and interparticle porosity.

Second Unit

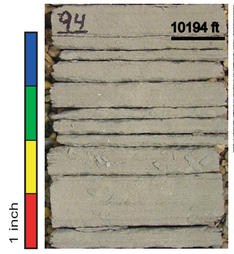


Wacke-packstone interbed with ooids, quartz brachiopods and brachiopod spines. No visible porosity.

Siltstone to very fine-grained sandstone with calcite cement. Minimal intercrystal and inter-particle porosity related to dolomitization of the cement.

Third Unit

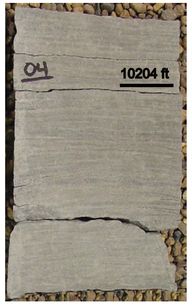
NENW Sec. 35, T.156N., R.93W.
Shell Oil Co.
#21-35 L. Texel
KB = 2409

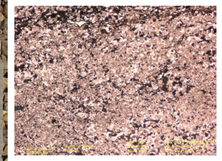


Interbedded siltstone and very fine-grained quartz sandstone sequence with calcite cement. Limited interparticle porosity due to dolomitization of the calcite cement.

Base Unit

SWSE Sec. 15, T.145N., R.91W.
Pan American Petroleum Corp.
#1 Jacob Huber
KB = 2212





Sandy limestone interbed with interparticle and fracture porosity. Locally abundant disseminated pyrite.

Central Basin Facies

- Laminated Siltstone/ Very Fine-Grained Sandstone
- Waxy bedded Very Fine-grained Sandstone-Claystone
- Massive Siltstone
- Laminated Sandy Siltstone
- L2 Porosity Zone
- 3 Overlying / Underlying Lithofacies / No Core
- Unconformity Surface
- -0- Limit of Central Basin Facies
- Limit of Lower Bakken Shale