

PS Sedimentary Facies, Depositional Environment and Sequence Stratigraphy of the Upper Devonian-Lower Carboniferous Bakken Formation in the Southeastern Corner of Saskatchewan*

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Abstract

The Upper Devonian-Lower Carboniferous Bakken Formation is deposited in the subsurface of the Williston Basin in northeastern Montana, North Dakota, southwestern Manitoba and southeastern Saskatchewan. Now it is one of the most important oil-producing units in Saskatchewan. In the southeastern corner of Saskatchewan, the Bakken Formation unconformably overlies either the Upper Devonian Big Valley Formation or the Torquay Formation, and is conformably overlain by the Lower Carboniferous Souris Valley (Lodgepole) Formation. The research area includes Townships 1 through 17, Ranges 30 of the First Meridian to Ranges 1 of the Second Meridian, which is just west of the border between Saskatchewan and Manitoba. The lower black shale member is essentially absent in this area, except for the Rocanville Oil Field area.

The Bakken succession typically consists of the middle sandy to silty member and the upper black shale member. According to detailed core analysis, the Bakken Formation is divided into eight facies and two subfacies: facies 1 (flaser-bedded very fine-grained sandstone); facies 2 (wavy-bedded very fine-grained sandstone); facies 3 (parallel-laminated very fine-grained sandstone and siltstone); facies 4 (sandy siltstone with rip-up clasts); facies 5 (Interbedded highly bioturbated very fine-grained sandstone and siltstone); facies 6 (interbedded highly bioturbated sandy siltstone to silty very fine-grained sandstone and sparsely bioturbated micro-hummocky cross-stratified very fine-grained sandstone); facies 7 (highly bioturbated siltstone); and

facies 8 (black shale). Our integrated sedimentologic, ichnologic, and sequence-stratigraphic study suggests that the deposition of Bakken Formation occurred in two different paleoenvironmental settings: open marine (facies 4 to 8), and brackish-water marginal-marine (facies 1 to 3). The base of the marginal-marine interval is represented by a sequence boundary (coplanar surface or amalgamated sequence boundary and transgressive surface). This surface has been identified in previous studies west-southwest of our study area, therefore assisting in high-resolution correlation of Bakken strata.

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Abstract

The Upper Devonian-Lower Carboniferous Bakken Formation occurs in the subsurface of the Williston Basin in northeastern Montana, North Dakota, southwestern Manitoba and southern Saskatchewan. The Bakken Formation is one of the most important oil-producing units in Saskatchewan, and represents the largest light oil pool discovered in Western Canada. In the southeastern corner of Saskatchewan, the Bakken Formation unconformably overlies either the Upper Devonian Big Valley Formation or the Torquay Formation, and is conformably overlain by the Lower Carboniferous Souris Valley (Lodgepole) Formation. The lower black shale member is essentially absent in this study area, except in the Rocanville oil field. The Bakken succession typically consists of the middle sandy to silty member and the upper black shale member. According to detailed core analysis, the Bakken Formation is divided into eight facies and two subfacies: facies 1 (flaser-bedded very fine-grained sandstone); facies 2 (wavy-bedded very fine-grained sandstone); facies 3 (parallel-laminated very fine-grained sandstone and siltstone); facies 4 (sandy siltstone); facies 5 (interbedded very fine-grained sandstone and siltstone); facies 6 (interbedded highly bioturbated sandy siltstone and micro-hummocky cross-stratified very fine-grained sandstone); facies 7 (highly bioturbated siltstone); and facies 8 (black shale). Our integrated sedimentologic, ichnologic, and sequence-stratigraphic study suggests that deposition of the Bakken occurred in two different paleoenvironmental settings: open marine (facies 4 to 8) and brackish-water marginal marine (facies 1 to 3). The base of the marginal-marine interval is represented by a sequence boundary (coplanar surface or amalgamated sequence boundary and transgressive surface). This surface has been identified in previous studies west-southwest of our study area, therefore assisting in high-resolution correlation of Bakken strata.

Study Area and Stratigraphic Chart

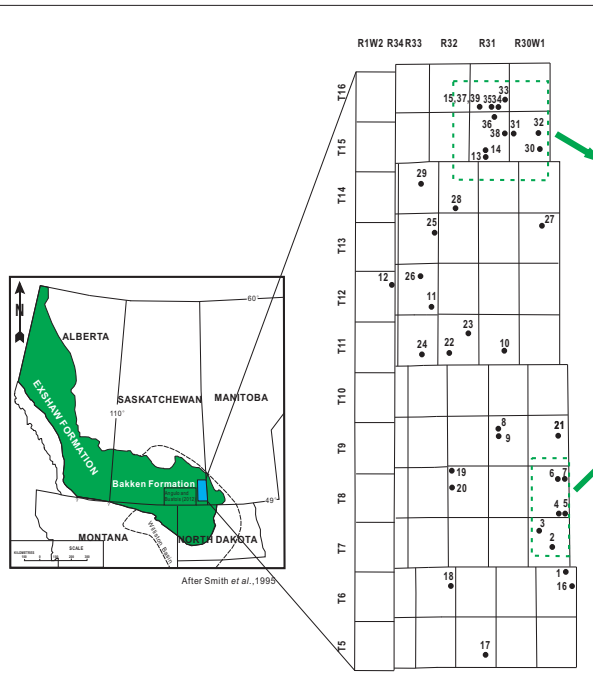


Figure 1- Study area in the southeastern corner of Saskatchewan and well locations of described Bakken cores.

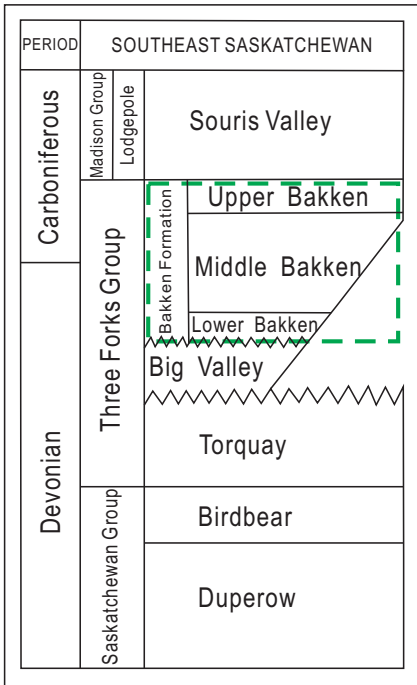


Figure 2- Stratigraphic Chart (modified from Christopher, 1961)

Reference:
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Sedimentary Facies and Environment

Facies	Lithology	Sedimentary Structures	Bioturbation Index and Trace Fossils	Sedimentary Environment
1	Light grey, very fine-grained sandstone, with locally calcite-cemented intervals and common oil staining	Flaser bedding, with common combined ripples, and wave and current ripple cross-lamination. Climbing ripples and mudstone drapes are moderate to abundant. Low-angle planar cross-stratification and mudstone rip-up clasts are locally present.	Bioturbation is generally absent, with only sporadically <i>Planolites montanus</i> confined to mudstone drapes.	Wave-dominated tidal flat
2	Light grey, very fine-grained sandstone, with common pyrite and locally calcite-cemented blebs	Wavy bedding with common mudstone laminae. Wave and current ripple cross-lamination are locally present.	The bioturbation index is absent to rare, except for local presence of <i>Planolites montanus</i> .	Bay margin
3A	Dark grey, thinly interlaminated very fine-grained sandstone and siltstone	Parallel lamination with local mudstone drapes. Soft-sediment deformation structures (convolute bedding and load structure) are locally present.	Bioturbation index is only 0 to 1, and <i>Planolites montanus</i> is the only trace fossil identified.	Bay margin
3B	Interlaminated to locally interbedded light grey, very fine-grained sandstone and dark grey siltstone	Parallel lamination to locally bedding, with thinly dark laminae of organic debris. Syneresis cracks, sandstone beds with combined-flow ripples and soft-sediment deformation structures locally occur.	Bioturbation index is 2 to 3; the dominant ichnotaxa are <i>Planolites montanus</i> , and <i>Palaeophycus tubularis</i> , and the subordinate ones are <i>Rosselia</i> isp. and <i>Siphonichnus eccensis</i> . Escape trace fossils are present in the sandy beds.	Distal bay
4	Dark yellowish green, sandy siltstone, with mudstone rip-up clasts, granule to pebble conglomerate, and common shell fragments	Massive	Bioturbation index is 1 to 2. The ichnofauna consists of <i>Phycosiphon incertum</i> and <i>Chondrites</i> isp.	High-energy ravinement during drowning of the embayment
5	Interbedded, light grey, very fine-grained sandstone and siltstone	Bed boundaries are not clear.	Bioturbation index is 4 to 5; the dominant trace fossils are <i>Palaeophycus tubularis</i> and <i>Phycosiphon incertum</i> , and subordinate ones are <i>Asterosoma</i> isp., <i>Nereites missouriensis</i> and <i>Planolites montanus</i> .	Offshore transition
6	Interbedded medium to dark grey, highly bioturbated sandy siltstone and light grey, micro-hummocky cross-stratified very fine-grained sandstone	Microhummocky cross-stratification (HCS) occurs in the sandstones. Wave and combined-flow ripples are locally present on the top of HCS beds.	In the siltstone, the bioturbation index is 4 to 5; the dominant trace fossils are <i>Phycosiphon incertum</i> and <i>Nereites missouriensis</i> , subordinate ones are <i>Asterosoma</i> isp., <i>Teichichnus rectus</i> , <i>Planolites montanus</i> , and <i>Thalassinoides</i> isp. In the sandstone, the bioturbation index is 0 to 1; <i>Teichichnus rectus</i> and escape trace fossils are present.	Upper offshore
7	Greyish green, highly bioturbated siltstone with rarely sandstone lenses, common pyrite, and local shell fragments	Massive	Bioturbation index is 5 to 6, but identification of discrete ichnotaxa is difficult, except for <i>Phycosiphon incertum</i> and locally <i>Nereites missouriensis</i> .	Lower Offshore
8	Black shale, with pyrite and concretions, and locally conodont fragments	Massive to locally parallel-laminated. Fractures that are filled with pyrite and calcite locally occur.	Bioturbation is commonly absent.	Shelf

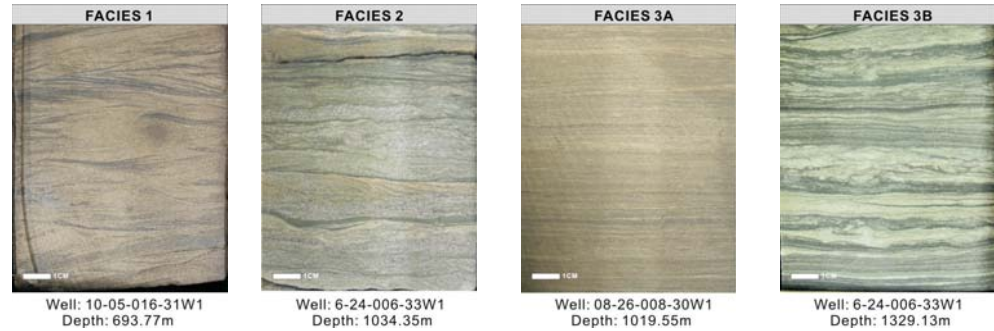


Figure 3- Core photographs showing the sedimentary facies for brackish-water marginal-marine facies association in the Bakken Formation in southeastern corner of Saskatchewan

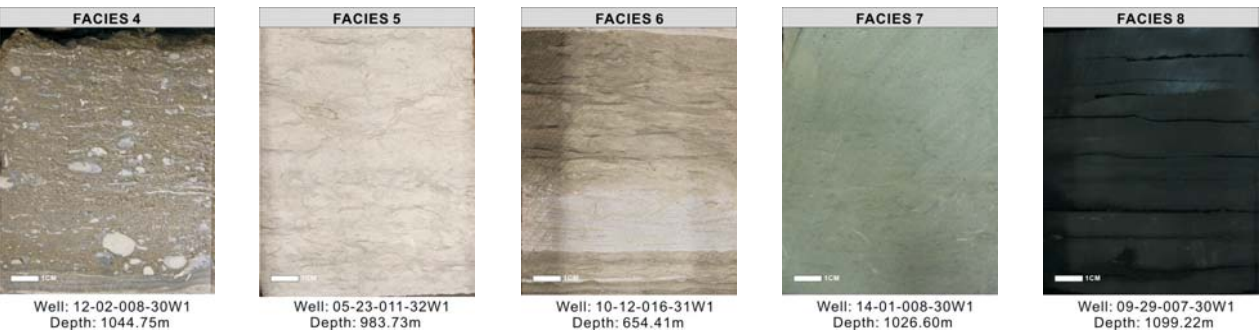


Figure 4- Core photographs showing the sedimentary facies for open-marine facies association in the Bakken Formation in southeastern corner of Saskatchewan

Sequence Stratigraphy

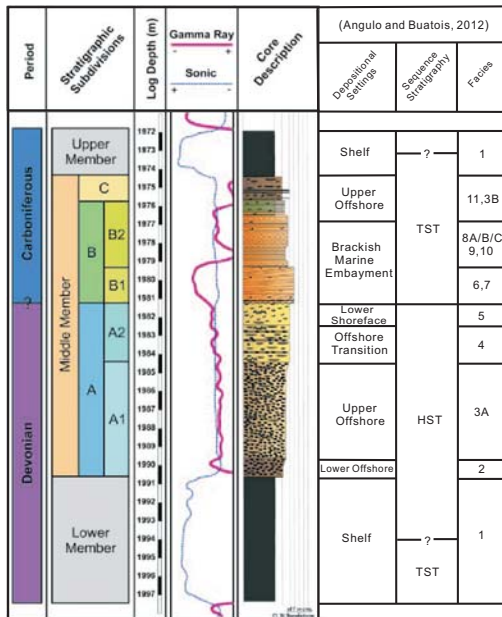


Figure 5- The idealized stratigraphic log of the Bakken Formation in southeastern Saskatchewan (Angulo and Buatois, 2012)

In the southeastern corner of Saskatchewan (this study area), which is in a more proximal location, most of the basal transgressive systems tract deposits (lower part of lower Bakken shale) and highstand systems tract deposits (upper part of lower Bakken shale and lower open-marine interval) have been eroded because of the subsequent drastic sea level fall. The brackish-water marginal-marine interval (Facies 1-3) was deposited during the early transgression. Then the open-marine environment (Facies 5-8) was re-established after deposition of a transgressive lag (Facies 4). In most of this study area, the whole Bakken succession records a transgressive systems tract. The base of the marginal-marine interval is represented by a coplanar surface or amalgamated sequence boundary and transgressive surface. According to Sandberg et al. (2002), there is a general sea-level fall across the Devonian-Carboniferous boundary due to the southern Hemisphere glaciation. Therefore, this coplanar surface may represent the Devonian-Carboniferous boundary (Angulo and Buatois, 2012).

However, in the Rocanville oil-field area, when the lower Bakken shale, which records deposition during the basal transgression, is preserved, it is unconformably overlain by the brackish-water marginal-marine and open-marine deposits during the upper transgression. The whole succession records two transgressive systems separated by a coplanar surface (Figure 6).

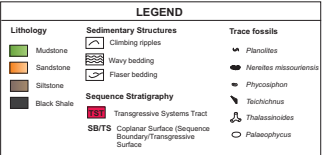


Figure 6- The most complete stratigraphic log of the Bakken Formation in southeastern corner of Saskatchewan



Base Well:12-02-008-30W1(showing most incomplete sequence)

Base Well:09-05-016-31W1, Rocanville Oil Field(showing most complete sequence)