Biogenic Permeability in the Bakken Formation

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Abstract

The Late Devonian-Early Carboniferous Bakken Formation, a prolific producer of oil from low-permeability reservoir in the Williston Basin, is assessed for the potential of secondary production from bioturbated levels into fractures. For this purpose, core from various fields in Southern Saskatchewan were assessed. Methods of analysis include detailed ichnological description, minipermeametry, thin-section petrography and microCT from samples deemed characteristic of reoccurring ichnofabrics.

Three recurrent ichnofabrics were recognized: highly burrowed (BI = 5) a regularly laminated sandstone-mudstone unit dominated by small Planolites and Phycosiphon; a Nereites missouriensis-ichnofabric with subordinate Phycosiphon and Planolites; and a cross-stratified, locally cryptically bioturbated sandstone.

The Planolites/Phycosiphon ichnofabric shows permeability to air (Ka) that range between 0.01 and 0.50 mD. The highest K are associated with sandstone laminae and sand-filled burrows. Mudstone beds are typically admixed with some sand and many sand-filled burrows penetrate the mudstone beds. As such, the permeability is more isotropic and homogeneous than comparable laminated fabrics.

The Nereites missouriensis ichnofabric has similar permeability ranges, wherein Ka ranges from 0.01 to 0.20 mD. The highest permeabilities are associated with unburrowed matrix and silty haloes associated with Nereites missouriensis represent the mode of permeabilities, which is near 0.1 mD. The silty haloes represent biogenically reworked zones that extend as far as 4 mm from the causative burrow. These coalesce and as with the Planolites/Phycosiphon examples, the bioturbated texture presents an isotropic and homogeneous medium compared to laminated examples.

X-Bedded sandstones range in permeability from 0.05 to 0.70 mD. Levels characterized by cryptic bioturbation tend to occur in the upper part of this range, typically between 0.20 and 0.70 mD. Cryptically bioturbated levels present more homogenous permeability distributions compared to zones where the cross lamination is well preserved.
From these observations, it is ascertained that bioturbated levels within the Bakken Formation do not reduce the reservoir quality, but in fact enhance certain parameters such as isotropy and homogeneity. These characteristics suggest that bioturbated levels stand to contribute to fracture permeability.

Reference Cited

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A University of Saskatchewan and University of Alberta Collaborative Effort
RESEARCH

• The Bakken Formation is commonly a tight oil play.
• Our focus was to consider the way that biogenic permeability might contribute to oil production.
• Assessment of the bioturbate texture indicates that biogenic sedimentary structures likely contribute to enhanced fracture production.
Presenter’s notes: The study area is located in southeast Saskatchewan and it covers 29,900 square kilometers. 64 well cores have been slabbed and described in detail.
Presenter’s notes: The Bakken Formation is Late Devonian – Early Mississippian in age according to conodonts biostratigraphy and it has been subdivided into three Members: a Lower, a Middle and an Upper Member. The Lower and the Upper Member are monotonous and homogeneous and they consists of only one black shale facies. The Middle Member, in contrast, is much more heterogeneous and variable, both laterally and vertically and it has been subdivided into different units and subunits and comprise many sedimentary facies.
A. HIGHSTAND SYSTEMS TRACT

B. EARLY TRANSGRESSIVE SYSTEMS TRACT

C. LATE TRANSGRESSIVE SYSTEMS TRACT
Presenter’s notes: Based on the ichnology, two ichnofacies have been defined: distal Cruziana and impoverished Cruziana. The distal Cruziana is characterized by a high bioturbation index and relatively high ichnodiversity and reflects fully marine conditions. The impoverished Cruziana, in contrast, is characterized by a low bioturbation index and low ichnodiversity and reflects stressful conditions for the organism under brackish conditions.
FACIES DISTRIBUTION

BRACKISH-MARGINAL MARINE FACIES

- FACIES 6
- SUBFACIES 8C
- SUBFACIES 8B
- SUBFACIES 8A
- FACIES 7
- FACIES 9
- FACIES 10

Wave-Dominated Tidal Flats
Distal Bay
Barrier Bar
CONCEPTUAL FRAMEWORK

- Shelfal
- Bioturbated Transgressive Lower Shoreface
- Carbonate Ramp or Platform
- TSE
- Super K
- Sedimentary Media With Storage from Interbeds

Fractures:
1) typically <1% volume of media;
2) locally super K;
3) extreme dual perm / dual porosity.
CONCEPTUAL FRAMEWORK

Proportion of media burrowed.
We evaluated 4 sedimentary facies, primarily using micropermeametry.

1. Offshore *Nereites* Ichnofabric.
4. Shoreface associated cryptic bioturbated (?) sandstone.
Nereites ichnofabric

K (bulk) ~ 0.1 mD

trend of matrix permeability
trend of trace-fossil halo perm
The *Nereites* ichnofabric Ka ranges from 0.01 to 0.4 mD.

The highest permeabilities are associated with v.f. sand haloes associated with *Nereites missouriensis*.

The bioturbate texture presents an isotropic but heterogeneous (at a local scale) media.
Asterosoma ichnofabric A

Ch
Pl
As
Ph
As
Th
As?
Asterosoma ichnofabric A

K (bulk) \(
\sim 1 \text{ mD}
\)

trend of matrix permeability

trend of trace-fossil perm
Asterosoma ichnofabric B

K (bulk) \( \sim 0.2 \text{ mD} \)

trend of matrix permeability

trend of trace-fossil perm
• Permeability is provided from zones where sand is sequestered in burrow-associated packages.
• Nominally, the biogenic permeability is 10 times greater than that of the matrix.
• Some examples of this fabric provide bulk permeability in the mD levels. Good enough for unstimulated production locally.

*Asterosoma ichnofabric A*
Planolites ichnofabric
Planolites ichnofabric

$K (\text{bulk}) \approx 0.7 \text{ mD}$

Miniperm points that measure sand and matrix.

trend of shale permeability

trend of trace fossil and laminae perm
The *Planolites/Phycosiphon* ichnofabric shows permeability to air (Ka) that range between 0.05 and 1 mD. Possibly enough for unstimulated production locally.

- The highest K are associated with sandstone laminae and sand-filled burrows.
- Mudstone beds are typically admixed with some sand and many sand-filled burrows penetrate the mudstone beds.
Laminated to Cryptic Bioturbated Sandstone
Laminated to Cryptic Bioturbated Sandstone
- Laminated sandstones range in permeability from 0.05 to 1 mD.
- Levels characterized by cryptic bioturbation tend to occur in the upper part of this range.
The importance of highly bioturbated flow media:

- Highly bioturbated flow media is extremely important because it provides flow paths that contribute to natural and artificial fracture permeability.
- These flow paths have much higher surface-area contact to the matrix than do the fractures.
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CONCLUSION

1. Biogenic sedimentary structures in the Middle Bakken commonly have higher permeability than unburrowed matrix.

2. This is owing to redistribution of sand into discrete units.

3. Particularly the offshore units are thick and bioturbation increases the isotropy of the permeability field (i.e. $K_v \sim K_x$). However, the biogenic flow units are morphologically complex and increase the local heterogeneity / tortuosity.

4. Because the burrows are generally less than 10 mm diameter, and the degree of bioturbation is high, the surface area that is in contact with the matrix is much higher than with fracture permeability.