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Stratigraphy, permeability, and bioturbation in the Deadwood and Winnipeg Formations (Williston Basin, Saskatchewan, Canada): insights for CCS

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Summary

The Cambro-Ordovician Deadwood and Winnipeg Formations have emerged as targets for CO_2 storage in recent years. Since hydrocarbons are not present in the Deadwood and Winnipeg Formations in southern Saskatchewan, wells penetrating the Cambro-Ordovician section are few and far apart. The consequent scarcity of data makes regional stratigraphic interpretations difficult.

In this study, we completed a comprehensive description of the first full-length core drilled through the Deadwood and Winnipeg Formations in south Saskatchewan, near Estevan at the DEEP Torquay well. A total of 19 facies were identified and grouped into 8 facies associations that correspond to a range of marine depositional environments. Porosity and permeability analyses were used to estimate reservoir quality in the different facies and determine facies with the best reservoir properties. Generally, the reservoir quality is better in the Winnipeg Formation. The highest porosity and permeability values were observed in upper shoreface sandstones in both the Deadwood and Winnipeg Formations, particularly sections characterized by abundant vertical trace-fossils (*Skolithos*); and in the lower shoreface bioturbated sandstones of the Winnipeg Formation.

Permeability for selected reservoir facies was measured using a minipermeameter on a centimeter-scale grid spanning the full width of slabbed core sections. The data were then compiled into high-resolution permeability grids (Figure 1), which served as the basis for numerical modeling in MODFLOW. These models enabled the estimation of bulk permeability, both vertically and horizontally, at the core scale. Our results indicate that bioturbation is associated with improved permeability in the Deadwood and Winnipeg Formations. The intensity of bioturbation and grain size were determined to be the main controls on the flow rate. The bioturbated *Skolithos*-bearing sandstones appear to be the best reservoir overall, capable of supporting the highest flow rates (Table 1).

Methods

A total of 191.8 m of available core was examined and described. The core includes the Deadwood Formation, the Black Island Member of the Winnipeg Formation, and a few meters of the Icebox Member of the Winnipeg Formation. Core description accounted for lithology, grain size and sorting, physical sedimentary structures, mud content, and ichnological data

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(ichnogenera and Bioturbation Index). Helium porosimetry was conducted on 113 core plug samples. Prior to cutting the plugs, pressure decay permeability to nitrogen was measured on the slabbed core at the same locations where the plugs were later extracted. In addition, seven slabbed core sections were selected from facies exhibiting the best reservoir properties for detailed permeability analysis and flow studies. Permeability was measured on 1.0x1.0 cm^2 grids using a Core Laboratories Pressure-Decay Profile Permeameter (Figure 1). The resulting data was used to model the flow pathways in each sample using MODFLOW (Harbaugh 2005; Harbaugh et al., 2017).

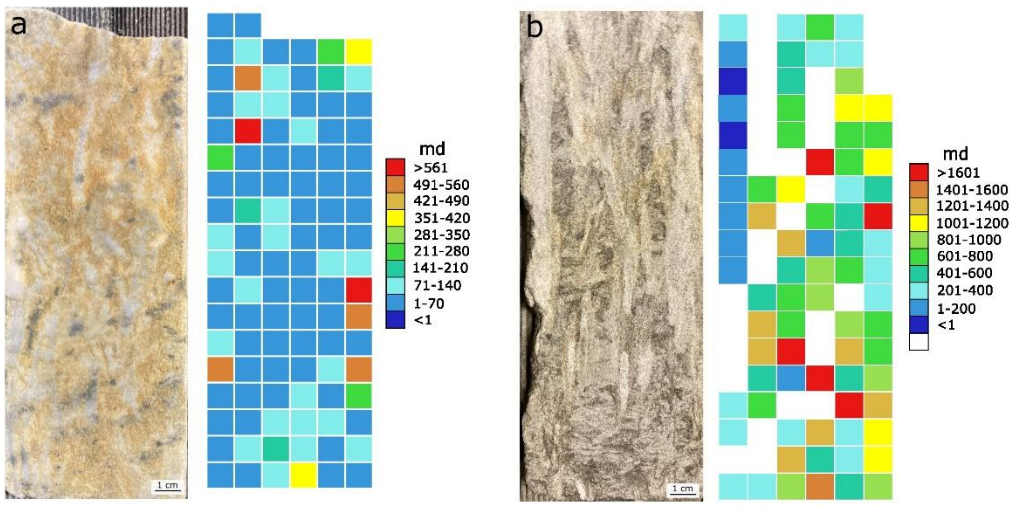

Figure 1: Sandstone samples with their corresponding permeability grid; (a) lower shoreface sandstone and (b) pipe rock sandstone from the Winnipeg Formation.

Results and conclusion

A total of 19 facies were identified and grouped into 8 different facies associations, ranging from shoreface to proximal offshore settings. The highest porosity and permeability values were observed in the bioturbated sandstones of the Winnipeg Formation. These high-quality sandstones, deposited in a lower shoreface environment, are promising targets for CO_2 storage. Good reservoir quality is also seen in the upper shoreface sandstones of the Deadwood and Winnipeg Formations. However, some of the samples from these facies are heavily cemented (quartz, hematite, dolomite, or anhydrite), which significantly reduces porosity and permeability, and therefore reservoir quality. Our analysis shows that the bioturbation index and grain size are the primary controls on permeability and flow rates.

Table 1: Reservoir facies description and their corresponding flow rate modeled in MODFLOW

Facies name	Photo	Grain size and sorting	Ichnology	Depositional environment	Vertical flow rate (cm3/s)
White clean sandstone		• very fine sand • good sorting	• uncommon bioturbation (BI:1-2) • *Planolites, Thalassinoides, Arenicolites, Skolithos*	Upper shoreface	9.30E-06
Bioturbated siltstone		• silt to very fine sand • good sorting	• common to complete bioturbation (BI: 4-6) • *Planolites, Thalassinoides, Arenicolites, Skolithos*	Proximal offshore	3.06E-06
Bioclastic sandstone		• very fine to fine sand • moderate sorting	• cryptic bioturbation (BI: 5)	Lower shoreface	3.06E-06
Glauconitic cross-bedded sandstone		• very fine sand • good sorting	• cryptic bioturbation (BI: 5) • rare Skoholitos and Arenicolites	Upper shoreface	3.06E-06
Bioturbated sandstone		• fine to medium sand • moderate sorting	• abundant to complete bioturbation (BI: 5-6) • Skolithos, Arenicolites, Paleophycus, Planolites • occasional Thalassinoides and Psilonichnus	Lower shoreface	1.15E-04
Skolithos sandstone		• fine to medium sand • moderate sorting	• complete bioturbation (BI: 6) • abundant vertical cylindrical burrows up to 10 cm long of Skolithos	Upper shoreface	1.49E-03

References

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