# Isotopic Signatures of Mixed Carbonate-Siliciclastic Pennsylvanian-Permian Strata, Sverdrup Basin, Arctic Canada: Implications for Diagenetic Pathways and Reservoir Potential*

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## Abstract

Pennsylvanian to Lower Permian mixed carbonates and siliciclastics associated with shelf cyclothems can hold great interest as it is a unique depositional relationship that can yield good reservoirs. Porosity development in ancient shelf sediments is often attributed to meteoric diagenesis and subaerial exposure of coarse-grained carbonate and siliciclastic rocks associated with recurring drops in sea level. Excellent seals are brought on by reoccurring transgressions that deposit finer-grained material onto underlying coarser-grained material. Petrographic and isotope analysis of six stratigraphic sections measured in the Blind Fiord area of Ellesmere Island illustrate that there are dominant diagenetic features, associated with subaerial exposure and meteoric diagenesis, that are related to regressions and base level falls. It was found that these features associated with subaerial exposure and meteoric diagenesis have unique isotopic signatures that lend a better understanding to depositional history and environmental impacts during diagenesis.

## Introduction

The southwestern margin of the Sverdrup Basin, located in the Canadian Arctic, consists of Upper Carboniferous to Lower Permian near-shore to shallow sub-tidal sandstones that interfinger with shelf carbonates (Figure 1). Arranged in a series of decameter high-order sequences, these cycles or cyclothems reflect global glacial-eustatic fluctuations. Basin-fringing siliciclastics (mostly sandstones) and carbonates (mostly grainstones) associated with these cyclothems holds great interest as it represents a unique depositional relationship that can often yield good hydrocarbon reservoirs. As seen in the mid-continent of the United States, these sequences can have good reservoirs because of porous units being pinched out in between impermeable seals brought on by each transgressive event (Heckel, 2002). Porosity development is often attributed to meteoric diagenesis and subaerial exposure of grainstones and sandstones associated with episodic drops in sea level (regressions). Furthermore, excellent seals are produced by the recurring transgressions that deposit impermeable shales and mudrocks onto underlying grainstones and sandstones. Through the examination of grainstones and sandstones of the Canyon Fiord and Belcher Channel formations associated with transgressions and regressions, a better understanding of reservoir potential can be obtained.

Evidence for subaerial exposure and meteoric diagenesis is seen through petrographic features such as *Microcodium* and caliche features, preferential dissolution of aragonite and high-Mg bioclasts, occasional vadose cements and common equant-spar and some blocky cements. Furthermore, development of porosity, especially in Pennsylvanian – Lower Permian glacio-eustatic cycles is often associated with repeated episodes of subaerial exposure. Some carbonates exhibit porosity, but generally the mixed carbonate-siliciclastic zones are the most porous.

A first attempt to characterize the isotopic range of Carboniferous and Permian carbonates of the Sverdrup Basin was published by Beauchamp et al. (1987). Their study recognized that the Sverdrup Basin was enriched in $^{13}C$ because of several factors including oceanic stagnation and thermohaline stratification that caused large amounts of $^{12}C$-enriched organic matter to accumulate and residual dissolved carbonate species to become enriched in $^{13}C$. Furthermore, their study documented significant differences between normal marine and meteorically influenced carbonates. The primary focus of our study was to investigate these allegations with an in-depth review of observed petrographic features, related to subaerial exposure and meteoric diagenesis, as well as normal marine conditions to document if these observations could be linked to distinct isotopic signatures.

## Methods

Benoit Beauchamp collected samples from stratigraphic sections located near Blind Fiord during the 1985, 1989 and 1997 field seasons and have been added to samples collected by Victoria Walker during 2010 field season. The stratigraphic sections observed ranged from 200 to 1,300 metres thick and consist of dozens of sandstone-grainstone cycles, individually ranging from five to 20 metres in thickness, belonging to the Canyon Fiord, Belcher Channel, Nansen and Raanes formations. Thin sections were prepared from collected samples and were then examined for petrography, micropaleontology, microfacies, and evidence of subaerial exposure, meteoric diagenesis and normal marine conditions. Overall, 122 samples were selected for $\delta^{13}C$ and $\delta^{18}O$ isotope analyses. Samples were largely selected based on the extent of subaerial exposure and meteoric diagenetic features. Normal marine samples were also chosen for the sake of comparisons. Prepared samples were submitted for isotope analysis at the Isotope Science Lab, University of Calgary. For isotope analysis, approximately 15 mg from each powdered sample was digested with anhydrous phosphoric acid in a Y tube reaction vessel at 25°C. The reaction to the acid caused the release of $CO_{2(g)}$. The product gas was then collected and cryogenically distilled from the reaction vessel and put into a small Pyrex tube and flame sealed. The $CO_2$ gas was then used as the inlet to the ion source of a VG 903 Stable Isotope Mass Spectrometer and analyzed for its $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios. Isotope ratios were calibrated and expressed as δ-values relative to the PDB standard.

## Results

Examination of isotopic signatures reveals notable trends between normal marine rocks and rocks that have undergone either meteoric diagenesis or subaerial exposure (denoted by the presence of *Microcodium*). This study has also revealed some interesting chemical signatures of samples from deep-water carbonates containing dolomite, microbial carbonates and carbonate samples from an Ordovician interval that was unconformably underlying Pennsylvanian strata within the west-central portion of the study area. However, the primary focus of this study is on whether a distinction can be made in isotopic signatures in rocks that have undergone some portion of diagenesis compared to samples that exhibit normal marine conditions. Isotopic analysis conveys that there are four primary trends within this study and distinctions can be observed between grainstones and mud-bearing carbonates, such as mudstones, wackestones and packstones, as well as between rocks containing evidence of meteoric diagenesis and *Microcodium*. Similar patterns observed by Beauchamp et al. (1987) are also observed within this study. It was revealed that "normal marine" rocks within the Sverdrup Basin have relatively heavier $\delta^{13}C$-values typically ranging from +4 to +7‰ and $\delta^{18}O$-values ranging from -2.5 to -11‰ (Beauchamp et al., 1987). Similar trends are observed here (Figure 2) with normal marine samples ranging from -0.6 to +6.8‰ ($\delta^{13}C$) and -2.4 to -8.0‰ ($\delta^{18}O$). Moreover, it was found that these isotopic signatures could be further differentiated by rock type and that mud-bearing carbonate rocks such as mudstones, wackestones and packstones tend to be slightly enriched in heavier oxygen and carbon isotopes. The cause of this differentiation is still under investigation.

In general, rocks that have undergone meteoric diagenesis and subaerial exposure show depletions in $^{13}C$ and $^{18}O$, as a result of interactions with fresh water and biological (land plants and microbes) activity (such as *Microcodium*) (Cerling, 1984; Beauchamp et al., 1987, Clark and Fritz, 1997; Poage and Chamberlain, 2001, Robinson et al., 2002; Kabanov et al., 2008). Samples exhibiting evidence of meteoric diagenesis range in $\delta^{13}C$-values of +5.8 to +1.1‰ and in $\delta^{18}O$-values from -4.2 to -9.8‰. These variations are likely a result of the degree of meteoric diagenesis and interaction with meteoric water as well as reflecting the composition of the original rock type (grainstone vs. wackestone, etc.) as well as later burial cements. Samples containing significant amounts of *Microcodium* varied in $\delta^{13}C$-values from +4.6 to -4.3‰ and in $\delta^{18}O$-values from +2.7 to -8.8‰.

## Conclusions

The primary objective of this study was to assess whether or not carbon and oxygen stable isotopes can provide supplementary evidence for subaerial exposure and meteoric diagenesis within the Sverdrup Basin. In combining petrographic and isotopic analyses, distinctive trends enable us to decipher between carbonates that were variably influenced by meteoric diagenesis and contrast them with normal marine carbonates. The isotopic analysis thus provides us with a reliable tool to determine the origin of porosity in cyclic shelf sediments. Furthermore, these findings should shed light on the depositional history of the basin during the Pennsylvanian and Lower Permian as well as provide insights into understanding stratigraphic controls on porosity and hydrocarbon potential.

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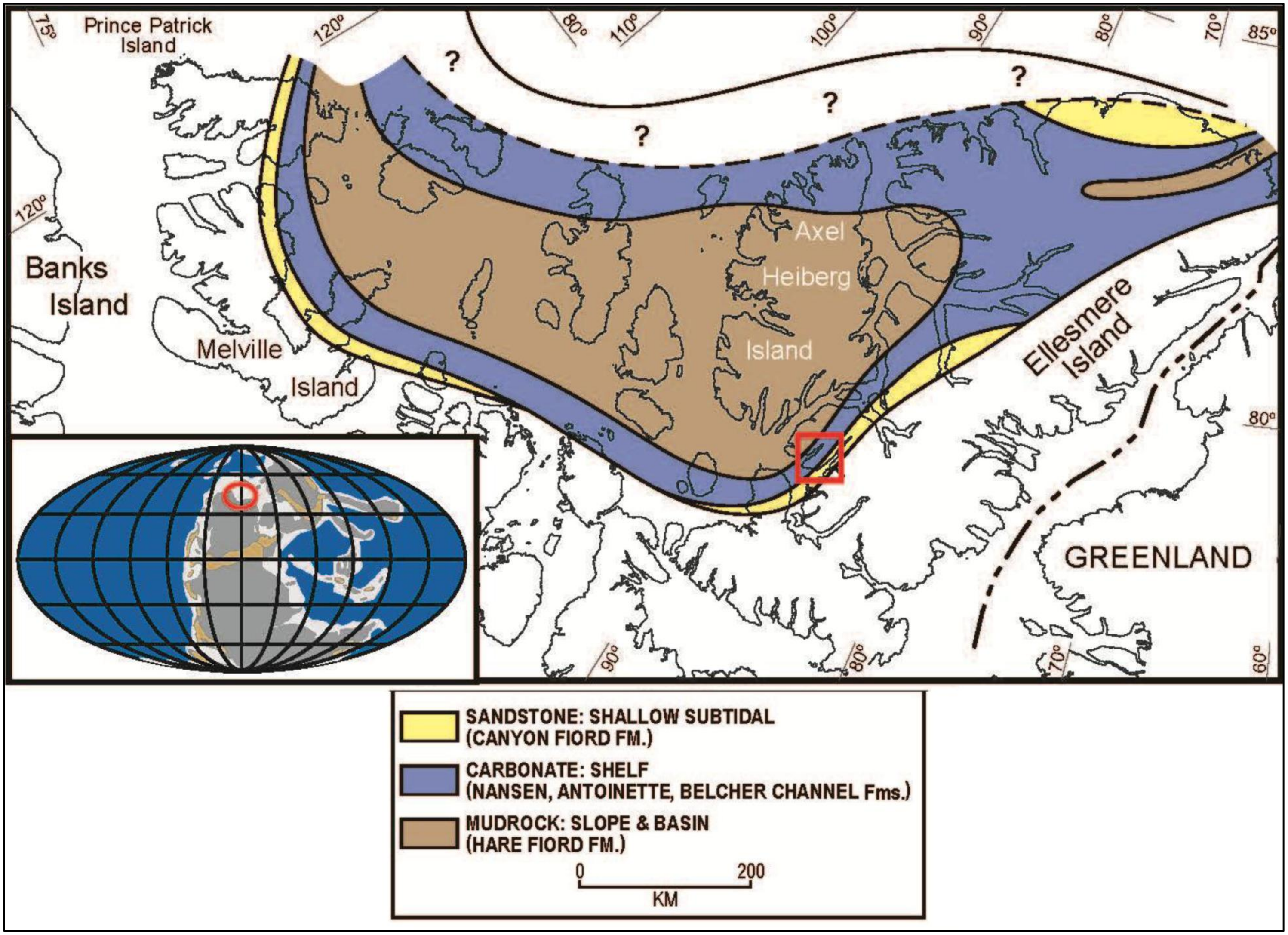


Figure 1. Distribution of the key stratigraphic units - Canyon Fiord and Belcher Channel formations, within the Sverdrup Basin. Red box outlines the location of the study area. The global map in the bottom left corner illustrates the paleogeography of the Sverdrup Basin during the Late Carboniferous. Modified from Embry and Beauchamp (2008).

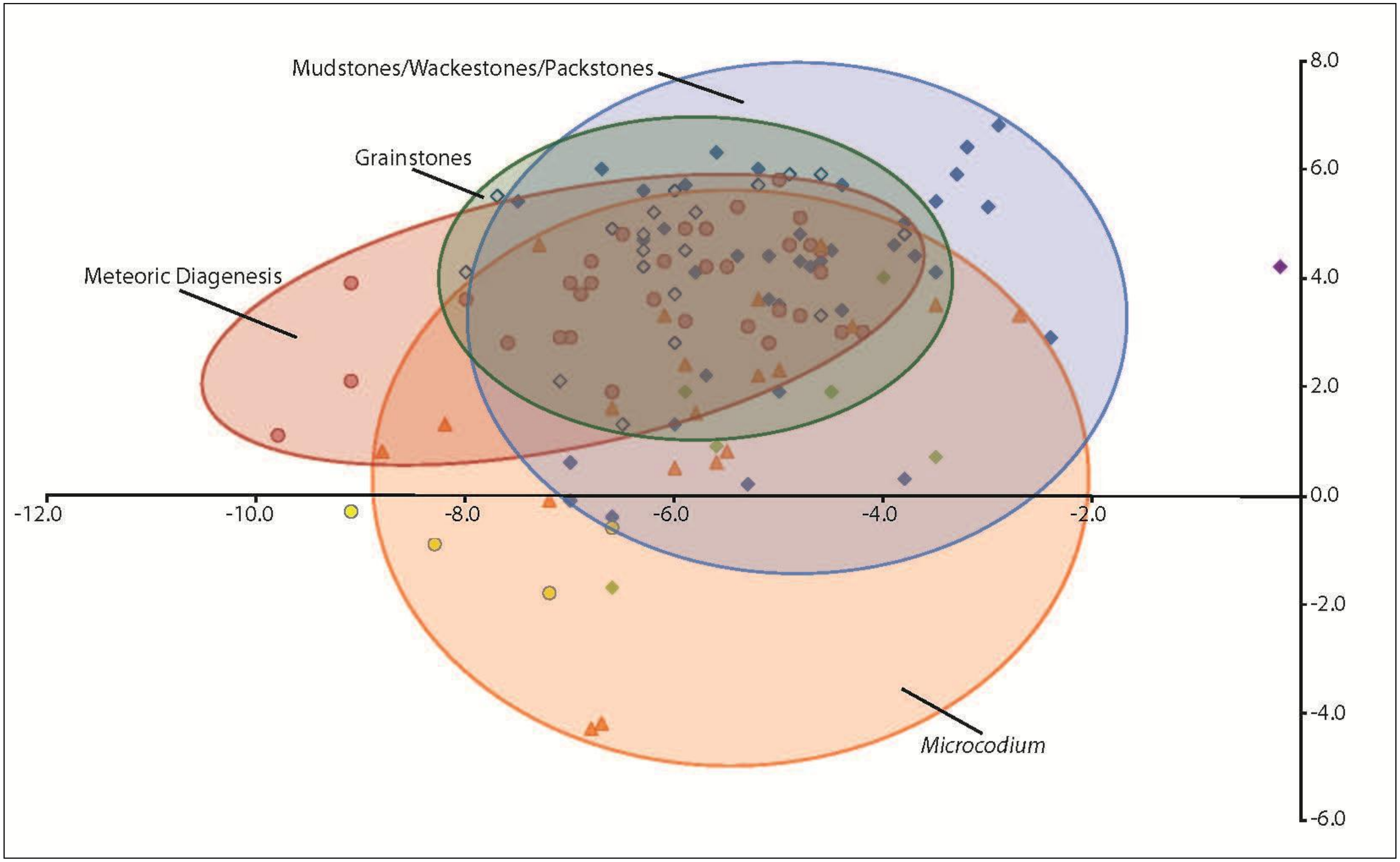


Figure 2. Distribution of carbon and oxygen stable isotope analysis of rock samples that exhibited evidence for subaerial exposure, meteoric diagenesis or have characteristics of normal marine environments. $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios were calibrated and expressed as δ-values relative to the NBS-19 (PDB) standard. Precision and accuracy as 1 sigma of (n=10) lab standards are 0.2 for both $\delta^{13}C$ and $\delta^{18}O$ values.