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Middle to Late Permian Sedimentation in the Sverdrup Basin, Canadian Arctic: A 40-Year Old Stratigraphic Problem Resolved

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Summary

Contrary to a long-held belief, Upper Permian strata are present in the Sverdrup Basin of Arctic Canada, and a nearly continuous conformable record with the overlying Blind Fiord Formation occurs in the basin central area. These strata are dominated by spiculitic chert that forms an entirely separate unconformity-bounded transgressive-regressive sequence. The Wuchiapingian Sequence is one of four sequences that encompass the Middle Permian to Lower Triassic interval. Two new stratigraphic units have been formally erected for the first time to better account for Upper Permian strata in the Sverdrup Basin. The Lindström Formation is a unit of white to pale grey spiculitic chert that represents sedimentation on a shallow, open marine, wave- and storm-dominated ramp. The Black Stripe Formation, which is in part correlative with the Lindström Formation, comprises black to dark grey spiculitic chert associated with siliceous shale and siltstone of slope to basinal origin. The upper part of the Black Stripe Formation comprises a deepening-upward succession of black cherty siltstone and siliceous shale that recorded Changhsingian sedimentation. The basal Blind Fiord contact which coincides with the Latest Permian Extinction event in the Sverdrup Basin is marked by an unusual abundance of pyrite, a hallmark of the extinction horizon around the world. A seemingly-rapid, yet progressive carbon isotopic shift across the Black Stripe-Blind Fiord contact in distal settings suggests a continuous stratigraphic record, even though a hiatus associated with maximum flooding and condensation does exist. The Late Permian age of the Lindström and Black Stripe formations is substantiated by conodont biostratigraphy and carbon isotope chemostratigraphy. Late Changhsingian conodonts were recovered from the base of the Blind Fiord Formation, while *Hindeodus parvus*, the species that marks the base of the Triassic at the GSSP in China, and associated conodont assemblages, occurs a few tens of metres above the base of the Blind Fiord Formation. Black shale in the Lindström and correlative Black Stripe Formation may have a genuine source potential as shown by high TOC values and preliminary RockEval analysis.

Introduction

For more than 40 years, it was widely believed that a widespread unconformity occurs beneath Triassic strata throughout the Sverdrup Basin (Canadian Arctic) and that all of the Late Permian record, and a substantial part of the Middle Permian record as well, had been eroded or was never deposited prior to the onset of earliest Triassic sedimentation. A number of recent regional studies on the Permian and Triassic succession of the Sverdrup Basin have since suggested that while a major sub-Triassic unconformity does exist at the basin margin, a conformable and apparently uninterrupted succession occurs across the P-T transition in the axial, deeper part of the basin. Late Permian sedimentation did take place in the Sverdrup Basin, and while much of this record is eroded at the basin margin, it is represented by lithologicaly distinct mappable units of mostly spiculitic chert in more distal areas.

Methods

This study combines surface and subsurface litho-, bio-, chemo- and sequence stratigraphy. Thirty surface and subsurface localities were examined in details and mapped around the southern and northern areas of the Sverdrup Basin.

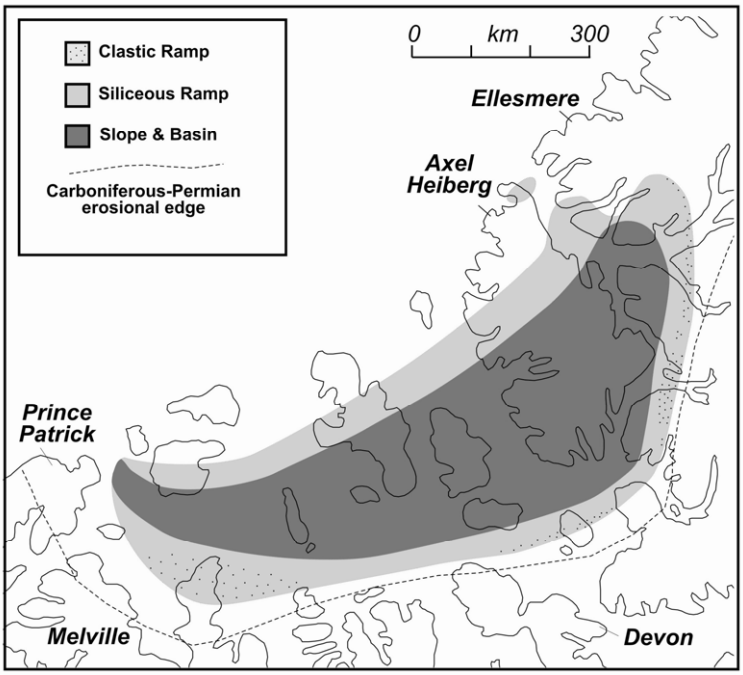

Figure 1: Late Permian paleogeography of Sverdrup Basin.

Geological Setting

The rapidly-subsiding Sverdrup Basin of the Canadian Arctic Archipelago (Fig. 1) recorded apparently uninterrupted Late Carboniferous to Early Cretaceous deep-water marine sedimentation within a peri-cratonic basin-axial trough that remained connected to the world oceans via a western seaway. Subsidence of the Sverdrup Basin was initiated during Early and Late Carboniferous time through a series of extensional rifting pulses along previously compressional Ellesmerian structures. By Middle Permian time, the basin was undergoing passive regional subsidence, with little or no fault involvement.

The Sverdrup Basin is now a 1200 km long, 400 km wide and 13 km thick Carboniferous to Tertiary depocentre that underlies Canada's northernmost Arctic islands (Fig. 1). In addition to its spectacular Permian and Triassic outcrops, the combined results of significant Tertiary uplift (Eurekan Orogeny) and absence of vegetation, the Sverdrup Basin is a proven oil- and gas-rich province that has been the focus of

intense industry activity from the late 1960s to the mid 1980s. The P-T transition has been penetrated by thirty-five wells and imaged through thousands of kilometres of industry-acquired seismic data.

Stratigraphic relationships

A significant sub-Triassic unconformity does occur at the basin margin and it cuts into much older Permian rocks near the basin's erosional edge. For a long time, the Degerböls Formation (Fig. 2) was considered the youngest Permian unit beneath the Blind Fiord Formation. Age-diagnostic fossils from the carbonate- and chert-dominated Degerböls Formation included a handful of brachiopods interpreted as Guadalupian (Middle Permian) in age. In addition, a single specimen of the ammonoid *Neogeoceras macnairi*, indicative of a Wordian age, was found in a basin margin location within the green glauconitic sandstone of the Trold Fiord Formation, which is correlative with the Degerböls Formation.

The Degerböls Formation, however, is not the youngest unit beneath the Blind Fiord Formation (Fig. 2). This is obvious on seismic profiles on Melville Island, where a basinward-dipping wedge of shale, siltstone and chert that thickens up to nearly 1 km in a basinward direction lies between the most basinward prograding tongue of Degerböls carbonate and the base of the Blind Fiord Formation. A similar succession can be observed in the west Blind Ford area of SW Ellesmere Island, where a wedge of nearly 400 m of shale, siltstone, chert and minor carbonate rests between the last prominent prograding carbonate tongue of the Degerböls Formation and the Blind Fiord Formation. Chert-dominated strata lying stratigraphically above Degerböls carbonates belong to a number of stratigraphic sequences unrecognized by previous workers.

Earlier workers were evidently unaware of the existence of this succession. In fact, Thorsteinsson (1974), based on limited biostratigraphic information, envisioned the Degerböls Formation as having no equivalent in the basin axial area, where he believed the Blind Fiord Formation was lying directly upon Roadian sediments, hence suggesting a 20 million year stratigraphic gap. While recognizing that evidence of sub-Triassic erosion was lacking, Thorsteinsson (1974) nevertheless proposed that a major basin-axial uplift and accompanying erosion were responsible for the interpreted unconformity. The idea of a sub-Triassic basin-wide unconformity and that the Roadian or the Wordian were the youngest Permian stage in the Sverdrup Basin persisted for a long time.

New findings

Since then, both seismic profiles and field observations have shown that the Sverdrup Basin was, from the Middle Permian onward, a depression that underwent passive regional subsidence. Progressively younger reflectors and strata dip basinward, while progressively older units are truncated landward beneath younger unconformities. Furthermore, sedimentologic evidence shows that the basin axial area was, from the Moscovian onward, a deep-water trough fully connected with Panthalassa to the west, with a bathymetry in the hundreds of metres, and at times between 2 to 3 kilometre deep. Sedimentation was not interrupted by subaerial exposure and erosion, although condensation and variably long hiatuses could have occurred in such a deep water setting. In the basin-axial areas, such as on eastern Axel Heiberg Island, deep-water non-siliceous greenish-grey weathering shale of the Blind Fiord Formation lies upon deep-water black siliceous shale. The basal Blind Fiord contact in the distal areas is a conformable lithostratigraphic boundary, accompanied below and above by an unusually-high concentration of pyrite, a hallmark of the Latest Permian Extinction (LPE) event around the world.

The chert-dominated Permian units immediately beneath the Blind Fiord Formation are part of a distinctive sequence that can be traced all around the Sverdrup Basin (Fig. 2). Its shallow water end-member (Lindström Formation) and its deep-water correlative (Black Stripe Formation) are mappable units that have

distinctive lithologic characteristics. Owing to recent biostratigraphic and chemostratigraphic advances, a Late Permian age can be ascribed with confidence to these units.

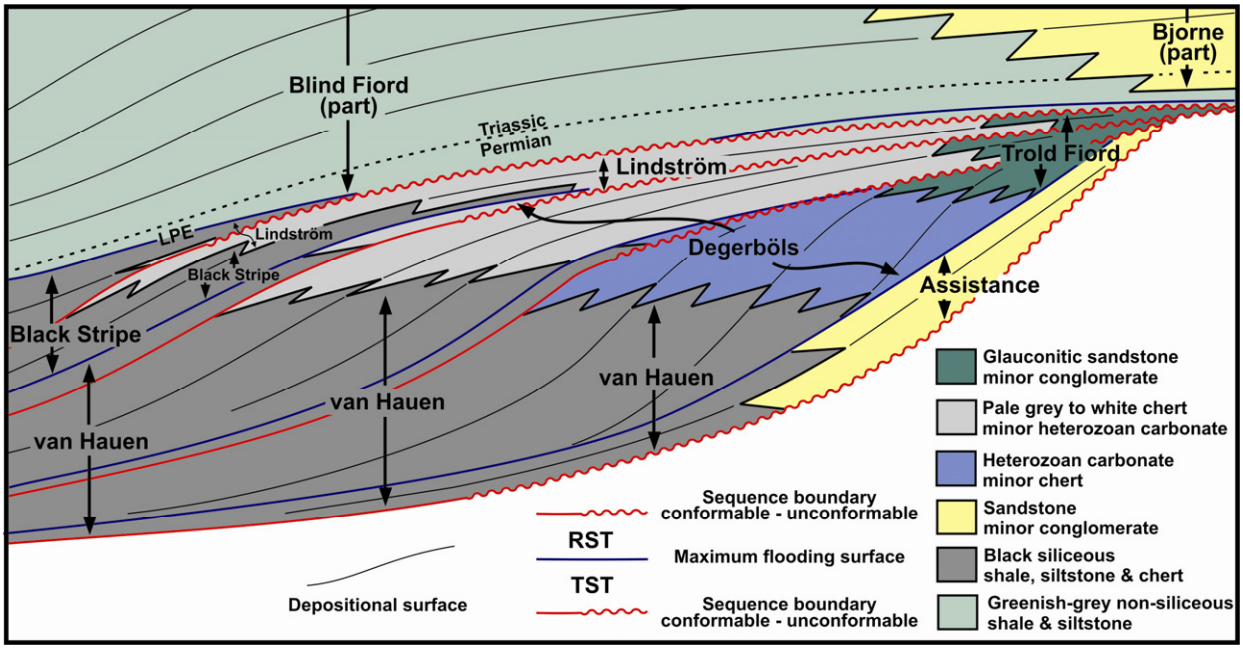

Figure 2: Middle Permian to Lower Triassic stratigraphy of Sverdrup Basin.

Conclusions

The application of seismic stratigraphy, sequence stratigraphy, biostratigraphy, chemostratigraphy and twenty-five years of sustained surface and subsurface sedimentological work has enabled us to clarify the Middle to Late Permian relationships in the Sverdrup Basin. We have demonstrated the presence of Late Permian strata in the Sverdrup Basin, as well as the existence of a major sub Blind Fiord unconformity at the basin margin, but one that does not carry across the basin axial area where a near continuous stratigraphic record across the Latest Permian Extinction is documented. In fact, differential growth of the peripheral shallow-water shelf area relative to the basin-centre deep-water area throughout the Carboniferous and Permian was such that by the end of the Permian the Sverdrup Basin floor lay at near-abyssal depth. It took the entire Triassic interval to fill in that hole.

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