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Depositional environment and hydrocarbon potential of the Middle Triassic strata of the Sverdrup Basin, Canada

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A B S T R A C T

This study summarizes the results of petrographic and geochemical analysis of Middle Triassic strata from the Sverdrup Basin in the Canadian Arctic. In this work, we investigate the distribution and depositional conditions of dispersed organic matter (OM) as a preliminary step towards understanding the potential of this stratigraphic interval as an unconventional reservoir. Closely-spaced samples from three Middle Triassic cores (southern margin, basin centre, northern margin) are analyzed using Rock-Eval analysis, inductively coupled plasma-mass spectrometry (ICP-MS), and organic petrology. Total organic carbon (TOC) ranges between 0 and 4.8 wt.%, with the most organic-rich interval having a median TOC value of 3.2 wt.%. Kerogen type varies from Type II to Type III throughout the sampled intervals. Samples from near the top of the regressive systems tract of the Anisian 3rd order sequence (basin centre) and near the middle of the Ladinian 3rd order sequence (southern margin) contain predominantly reworked, highly oxidized macerals and abundant coarser clastic material. Results support oxic to suboxic depositional conditions for these intervals. By contrast, samples from near the base of regressive systems tracts of both sequences (basin centre and northern margin) have the highest amounts of TOC (i.e., median = 3.2 wt.% and 1.4 wt.%), containing retained migrabitumen and abundant labile primary kerogen, respectively. The base of the Ladinian regressive systems tract near the basin axis was deposited under anoxic conditions and can be considered a prospective shale oil interval. Small-scale cyclic clastic influx episodes along the northern margin of the basin show changes from oxic to suboxic bottom waters. These cycles may be considered evidence for northerly-derived sediment from Crockerland during the Middle Triassic. The results and interpretations of this study can be applied to analogous fine-grained successions in other basins to better understand their unconventional reservoir potential.

1. Introduction

Many Canadian basins have been evaluated for unconventional hydrocarbon potential, with the exception of the frontier basins including those in the Canadian Arctic. As global energy demands continue to increase, hydrocarbon exploration and development will be driven towards these remote basins. Improvements to technology have made exploitation of shale-hosted and tight reservoirs economical, unlocking new resources and generating new interest in units formerly viewed only as source rocks. Middle Triassic, organic-rich shale and siltstone units occur in the Sverdrup Basin in the Canadian Arctic Archipelago (Fig. 1) and are included in the Murray Harbour Formation. Between 1969 and 1986, 119 drilled wells, mainly in the western part of the Sverdrup Basin, led to the discovery of 8 oil and 25 gas pools (Chen et al., 2000). The Murray Harbour Formation has already been identified as one of the major source rocks for many of these hydrocarbon pools (Brooks et al., 1992).

Previous studies of Triassic-aged dispersed organic matter (OM) tend to regard Middle and Upper Triassic strata as a single source rock unit. Rock-Eval analysis, vitrinite reflectance and biomarkers have been used to establish the regional thermal maturity of the Schei Point and Blaa Mountain groups (e.g., Dewing and Obermajer, 2011; Goodarzi et al., 1989). These studies found increasing thermal maturity from the edges of the Sverdrup Basin to the axis, likely the result of increasing burial depth. More localized studies (e.g., Gentzis and Goodarzi, 1991, 1993; Gentzis et al., 1996) reveal variations in thermal maturity at a smaller scale within the Schei Point Group. These variations are attributed to differential uplift and subsidence rates, as well as increased heat flow from igneous intrusions and salt diapirs. Characterization of the Schei Point Group OM in these studies as well as by Mukhopadhyay et al. (1997) show mainly Type I and Type II marine kerogen with oil generation potential and thermal maturities ranging from immature to mature. Hydrocarbons within the Schei Point Group show excellent correlation with discovered oils in the basin, indicating the

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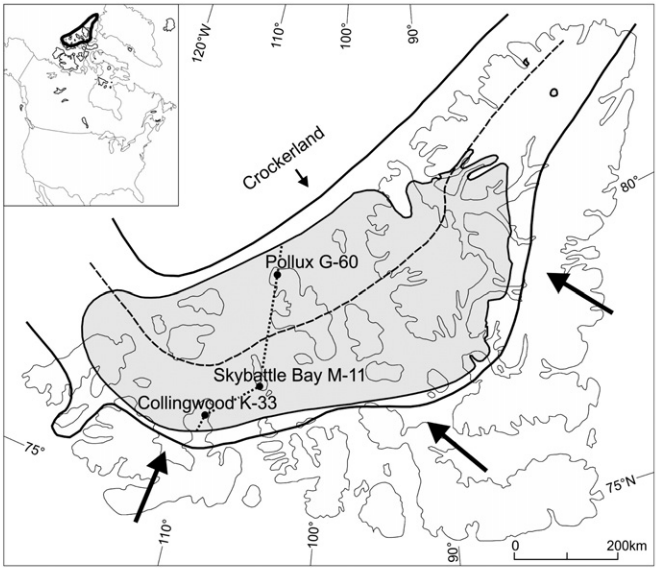

Fig. 1. Map of the Sverdrup Basin showing basin outline (heavy solid lines) and axis (dashed line) as well as the paleogeographic location of Crockerland. Locations of the studied wells are marked with black circles. Large black arrows along the southern margin indicate the predominant sediment source to the basin; small black arrow along the northern margin indicates a minor sediment source to the basin (Crockerland) (after Embry and Beauchamp, 2008). Shaded area indicates extent of Middle Triassic strata both in the subsurface and as outcrop (after Embry, 1991). Line of section for Fig. 2 is indicated by dotted line.

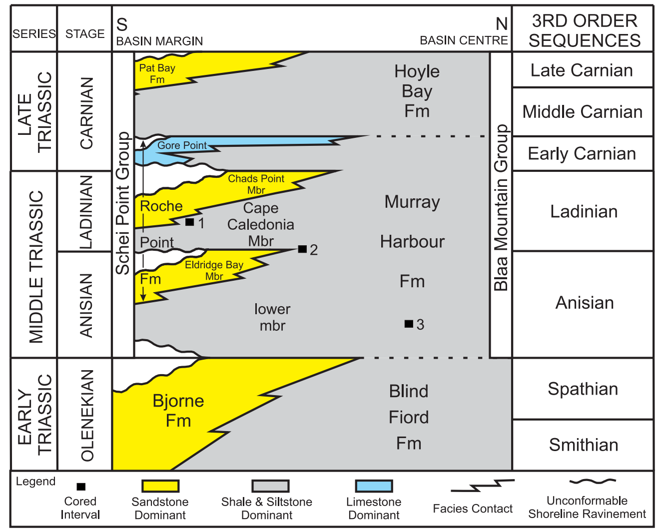

Fig. 2. Middle Triassic stratigraphy of the western Sverdrup Basin. Section line is shown in Fig. 1. 3rd order sequence boundaries are indicated along right edge (Embry, 1984a, 2011). Numbered core locations are indicated by black squares: 1) Collingwood K-33; 2) Skybattle Bay M-11; and 3) Pollux G-60.

Schei Point Group rocks are one of the main sources of hydrocarbons for these pools (Brooks et al., 1992).

This study investigates the distribution and type of dispersed OM in these Middle Triassic strata, as well as the associated depositional conditions. Results will give insight into how prospective these strata may be for unconventional hydrocarbon exploration as well as identify the most prospective areas. These insights can be applied to analogous fine-grained self-sourced reservoirs to better understand their heterogeneous nature.

2. Geological setting and study area

The Sverdrup Basin is a southwest-northeast trending rift basin located in the Canadian Arctic Archipelago (Balkwill, 1978). It is approximately 1300 km long and 350 km wide, covering a total area of 300 000 km^2 (Embry and Beauchamp, 2008). The formation of the basin began with rifting of the Ellesmerian Orogen during the early Carboniferous (Balkwill, 1978). Slow, passive subsidence of the newly formed basin was punctuated by periods of regional and local uplift resulting from changes to tectonically induced stresses acting on the basin (Embry and Beauchamp, 2008). Those authors note that periods of uplift combined with highly variable rates of sediment input, changed the extent and depth of the basin dramatically, from more than 2 km of water depth in the Early Triassic to nearly complete subaerial exposure at the end of the Late Triassic. Renewed rifting of the basin commenced in the Early Cretaceous and ended in the Late Cretaceous. Deposition in the Sverdrup Basin ended with deformation of the eastern part of the basin and regional uplift of the western portion as a result of compression during the Late Eocene Eurekan Orogeny. Throughout the evolution of the Sverdrup Basin, the major sediment source was siliciclastic Devonian strata along the southern and southeastern margins of the basin (Embry and Beauchamp, 2008; Patchett et al., 2004) (Fig. 1). A minor sediment source area (Crockerland) existed to the north of the basin from the Carboniferous to the Early Jurassic (Embry, 1993) (Fig. 1).

The focus of this study is the Middle Triassic succession (Fig. 2). It has been dated through ammonite and pelecypod fossils (Embry, 1984a, 1991; Tozer, 1961, 1963). Regional stratigraphic studies have resulted in a lithostratigraphic and sequence stratigraphic framework for the Middle Triassic strata throughout the Sverdrup Basin (Fig. 2) (Embry, 1984a,b, 1991, 2011; Embry and Beauchamp, 2008). Two formations comprise the Middle Triassic strata, the sandstone-dominant Roche Point Formation and the shale–siltstone-dominant Murray Harbour Formation. Both of these formations are part of the Middle-Upper Triassic Schei Point Group, along the southern margins of the basin (Embry, 1984a). The Murray Harbour Formation is also included in the Middle-Upper Triassic Blaa Mountain Group, which consists of equivalent deep-water strata within the central portion of the basin (Embry, 1984a). The Roche Point Formation is subdivided into four members, listed in ascending order: sandstone-dominant Eldridge Bay Member, shale–siltstone-dominant Cape Caledonia Member, sandstone-dominant Chads Point Member, and limestone-dominant Gore Point Member. The Murray Harbour Formation can be divided into two members, an informal “lower member” and the overlying Cape Caledonia Member (Fig. 2) (Embry, 1984b).

The Middle Triassic interval comprises one second order sequence and consists of two 3rd order sequences which are of Anisian and Ladinian age (Fig. 2). Each of these sequences is subdivided into a transgressive systems tract (TST) and overlying regressive systems tract (RST). The two 3rd order sequences of the Middle Triassic each contain a thin TST which is sandstone-dominant on the basin margins and becomes shale and siltstone dominant further basinward. Each sequence consists mainly of a RST which records a coarsening-upward (shallowing-upward) succession capped by an unconformity on the basin margins and by a conformable maximum regressive surface in the central portion of the basin. Used in conjunction with geochemical and organic geochemical methods, this sequence framework can be used to begin to establish the unconventional reservoir potential of the unit. This paper seeks to identify how OM accumulation and preservation relates to the paleogeographic location, depositional environment, and sequence stratigraphic position within the Middle Triassic succession.

Along the southern and eastern basin margins the Murray Harbour Formation was deposited in mid-outer shelf environments with the overlying Roche Point Formation strata representing shallow shelf to delta plain deposits. Basinward, the sandstones of the Roche Point Formation change facies to offshore shelf shale and siltstone which are part of the Murray Harbour Formation (Fig. 2). The Murray Harbour