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Effects of organic and mineral matter on reservoir quality in a Middle Triassic mudstone in the Canadian Arctic

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ABSTRACT

This study examines the hydrocarbon potential of the Middle Triassic Murray Harbour Formation (Sverdrup Basin, Arctic Canada) as a self-sourced reservoir. The Murray Harbour Formation consists of organic-rich mudstone and siltstone which has contributed oil and gas to the majority of known hydrocarbon fields in the basin. Organic matter (OM) and mineral fractions of the interval are investigated to characterize the effect that each fraction has on reservoir quality. The interval of interest is within the oil generation window, with a T_{max} of 443 °C and total organic carbon (TOC) value of 3.20 wt.% (median, n = 51). A modified method of Rock-Eval analysis, referred to as the extended slow heating (ESH) cycle, where heating occurs at a slower rate of 10 °C per minute up to 650 °C, was utilized to better resolve different fractions of OM. In conjunction with organic petrology, this allowed correct identification of the components of TOC and the effects each has on reservoir quality and hydrocarbon potential for the unit.

Three main OM fractions are identified: i) light free hydrocarbons, ii) medium to heavy fluid-like hydrocarbon residue (FHR), and iii) kerogen and solid bitumen. The kerogen (allo- and autochthonous) and solid bitumen fraction, which is dominated by solid bitumen, occurs in two petrographically observable forms: matrix and lump solid bitumen. Matrix bitumen is primarily disseminated within the clay-rich matrix and fills smaller pores, whereas lump solid bitumen fills larger pores. TOC has a negative correlation with porosity indicating that it occupies pore space, with a detrimental effect on hydrocarbon storage and flow at the present level of thermal maturity. However, thermally overmature areas of the Murray Harbour Formation may have increased microporosity within the solid bitumen network which could provide additional adsorption sites for generated gas within the reservoir. Macro- and micro-scopic phosphate nodules (likely high-density apatite mineral) appear throughout the interval, and under fluorescence microscopy, are observed to retain light free hydrocarbons and FHR. A strong positive correlation between porosity and grain density suggests that these nodules contribute to porosity and provide capacity for hydrocarbon storage within the rock. This important observation can be applied to other phosphate-rich mudrock plays, including the coeval Doig Formation Phosphate Zone in the established Alberta Basin, to potentially identify and exploit prolific zones.

1. Introduction

Mudrocks are typically homogeneous at the macroscopic scale, but are notoriously heterogeneous at the microscopic scale. Previously, limitations in technology have made these rocks difficult to study and even with current advances, their analysis remains challenging. However, depletion of resources in many accessible conventional hydrocarbon reservoirs is imposing the need for greater understanding of unconventional resources in fine-grained rocks. Small-scale variations in mineralogy (both allo- and authigenic) and organic matter (OM) can have large impacts on the quality of self-sourced hydrocarbon reservoirs. Therefore, it is important to attempt to identify the causes of these variations and the effects they can have in order to predict the best targets for hydrocarbon production. Because OM fractions can affect porosity both negatively (e.g., Sanei et al., 2015) and positively (e.g., Jarvie et al., 2007), each self-sourced reservoir must be studied individually with regard to the role OM plays in their quality.

The Sverdrup Basin is the location of many conventional hydrocarbon fields which have not been exploited due to economic and infrastructure constraints (Chen et al., 2000). Due to these limitations, as

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well as the remote location, harsh climate, and fragile ecosystems of the Canadian Arctic, the tight and shale oil and gas potential of the basin has yet to be investigated in detail.

This study integrates a variety of techniques to analyse core samples from the Middle Triassic Murray Harbour Formation to determine the effect that various fractions of organic and mineral matter have on reservoir quality. The unconventional hydrocarbon potential of the Murray Harbour Formation is not only important for the future development of Canada's northern resources, but also in the advancement of understanding self-sourced reservoirs in other basins globally.

2. Study area

The organic-rich mudstone and siltstone of the Murray Harbour Formation was deposited during the Middle Triassic in the Sverdrup Basin, located in the Canadian Arctic Archipelago. The Sverdrup Basin is a 1300 km-long rift basin containing strata from Mississippian to Neogene in age (Balkwill, 1978). During the Middle Triassic, the basin experienced two major transgressive–regressive cycles (Embry, 1991). The first of these transgressions occurred at the beginning of the Anisian, and the second, at the beginning of the Ladinian. During the regressive phases, overall sedimentation to the basin remained low resulting in minimal progradation of shelf sands from the southwest (Embry, 1991). Basinward, abundant organic carbon was deposited in marine shelf and deep basin settings with the mud and silt of the Murray Harbour Formation (Embry, 2011). The Murray Harbour Formation extends over most of the Sverdrup Basin, with the exception of northeastern Ellesmere Island and along the southern basin margins, where it is replaced by the equivalent sandstone-dominated Roche Point Formation (Embry, 1984, 1991). The Murray Harbour Formation consists of the Anisian informally named "lower member" and the Ladinian Cape Caledonia Member (Embry, 1984) and has an estimated maximum thickness of 300 m (Embry and Beauchamp, 2008). Previous studies of the Murray Harbour Formation have focused on source-rock potential and regional thermal maturity rather than localized self-sourced reservoir potential (e.g., Gentzis and Goodarzi, 1991, 1993; Brooks et al., 1992; Gentzis et al., 1996; Mukhopadhyay et al., 1997; Dewing and Obermajer, 2011).

Core samples (n = 51) were taken at approximately 20 cm intervals between the depths of 2520.0 and 2530.69 m from core extracted from the Skybattle Bay M-11 well (Fig. 1) located on the southern tip of Lougheed Island in the west-central part of the Sverdrup Basin. The samples are from the Cape Caledonia Member of the Murray Harbour Formation, in an interval which corresponds to the base of the Ladinian 3rd-order stratigraphic sequence, deposited at the beginning of the second regressive phase in the Middle Triassic (Embry and Podruski, 1988). The studied interval preserves sediments which are interpreted to be deposited in a mid to outer marine shelf setting (Embry and Podruski, 1988) and redox-sensitive trace elements suggest anoxic bottom water conditions (Kondla et al., 2015). The core consists of calcareous, black mudstone interlaminated with grey-brown siltstone (Fig. 2). Beige, subround to round phosphatic nodules (up to several centimetres in diameter) occur at various intervals, along with pelecypod fragments aligned parallel to bedding. Grain size ranges from clay (8–13 μm) to very fine-grained sand (62–125 μm) with phosphate and mudstone intraclasts up to very large pebble (32–64 mm).

3. Methods

3.1. Organic petrology

Ten samples were selected for organic petrology based on parameters from standard Rock-Eval analysis. Samples were selected to evaluate the complete spectrum of variation in TOC, S2 and HI values for the interval. Whole-rock samples were coarsely crushed and made into polished pellets of randomly-oriented rock set in an epoxy-resin mixture. Each pellet was studied under oil immersion (n = 1.518 at 23 °C), in both incident and ultraviolet (UV) light (G 365 nm excitation,

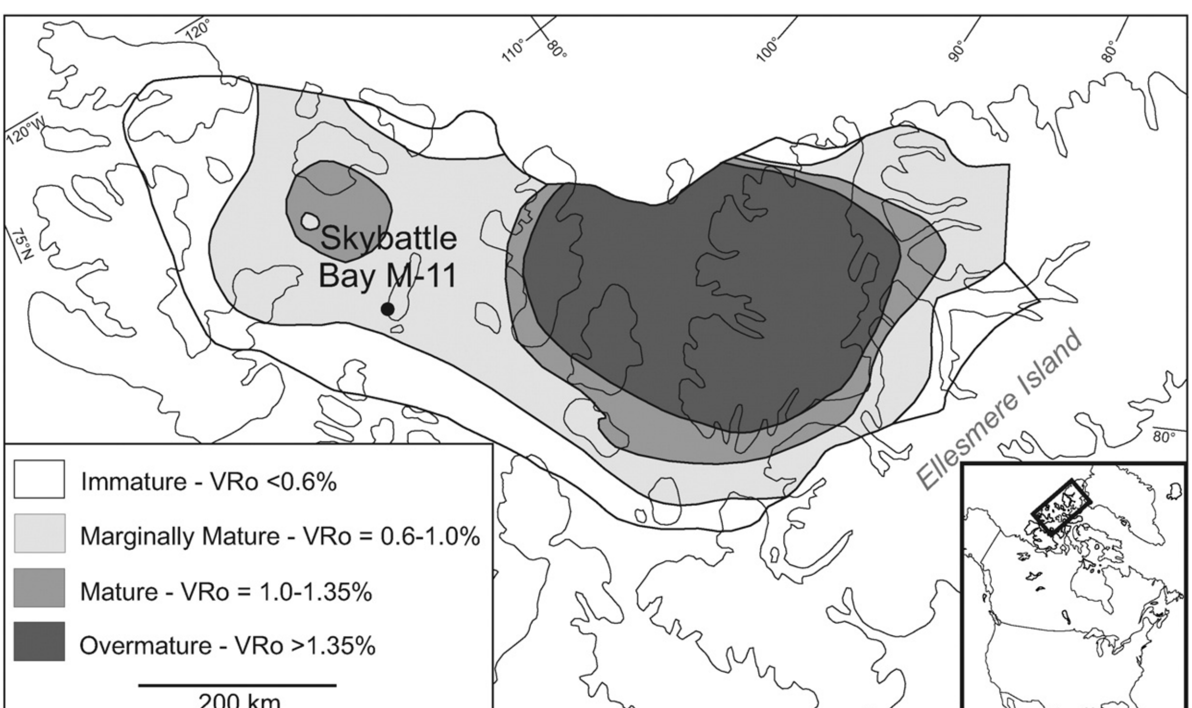

Fig. 1. Map showing the regional thermal maturity of Middle Triassic strata in the Sverdrup Basin (after Dewing and Obermajer, 2011; Embry, 2011). Black dot shows location of the studied core from well Skybattle Bay M-11. Inset shows location of study area within North America.