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Research paper

Influence of refractory organic matter on source rock hydrocarbon potential: A case study from the Second White Specks and Belle Fourche formations, Alberta, Canada

Dane P. Synnott [a, *], Keith Dewing [b], Hamed Sanei [a, b], Per Kent Pedersen [a], Omid H. Ardakani [b]

[a] Department of Geoscience, University of Calgary, 2500 University Drive NW, Calgary, T2N 1N4, AB, Canada
[b] Geological Survey of Canada, Calgary, 3303, 33rd St. NW, Calgary, T2L 2A7, AB, Canada

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ABSTRACT

Dilution by inert, refractory organic carbon can have a significant impact on the hydrocarbon potential of source rocks. In this study, a correction of total organic carbon, based on petrographic observations, is proposed to give a better indication of hydrocarbon generation potential. This correction shows that although the Second White Specks Formation is an excellent hydrocarbon source rock, hydrogen index and total organic carbon are influenced by dilution from refractory organic carbon of various sources. The results show that a higher degree of dilution occurs within the Belle Fourche Formation than the Second White Specks Formation. This dilution can have a significant impact on the hydrocarbon potential of the rock.

Volumetric calculation of the inert carbon fraction using organic petrographic methods provides a semi quantitative method to correct total organic carbon values for the refractory organic carbon dilution effect. Incorporation of the dilution corrected organic carbon value in hydrogen index calculations allows a greater understanding of source rock hydrocarbon potential. This method provides better differentiation of the small scale variation between micro-facies and formation, as observed in the Second White Specks and Belle Fourche formations, than traditional bulk geochemical methodologies and previously proposed correction methodologies. Degree of dilution, either through transport of recycled allochthonous or autochthonous reworking of organic matter *in-situ* is highly variable and represents a significant challenge in the characterization of heterogeneous source rocks.

This study investigates the organic petrology and geochemistry of a sediment core from the thermally immature area of the Upper Cretaceous Second White Specks Formation and Belle Fourche Formation. Reflectance and relative abundance of three maceral groups (bituminite, alginite, and refractory organic carbon macerals) showed significant organic matter compositional differences between micro-facies in the Second White Specks Formation. A change is also observed in organic matter composition from the upper part of the Belle Fourche Formation to the Second White Specks Formation. These compositional changes represent shifts in sediment source, sea floor oxygen levels, and depositional energy levels. These changes can be episodic, as observed between micro-facies, or longer time scale trends, as observed between the studied formations.

1. Introduction

The examination and assessment of source rock properties often begins with geochemical screening using methods such as Rock-Eval pyrolysis (Lafargue et al., 1998; Jarvie, 2012). This geochemical screening has the goal of assessing the quantity, quality, and thermal maturity of the dispersed sedimentary organic matter (OM) of the sample to better understand its hydrocarbon generation, retention, and expulsion properties (Peters and Cassa, 1994; Carvajal-Ortiz and Gentzis, 2015). Although these geochemical methodologies are useful in an initial screening, the limitations of

* Corresponding author.
E-mail address: dpsynnot@ucalgary.ca (D.P. Synnott).

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bulk geochemical analysis in recognizing distinct OM populations may result in overestimation or underestimation of resource density or misidentification of OM type (Peters and Cassa, 1994; Carvajal-Ortiz and Gentzis, 2015).

Total organic carbon (TOC) as measured through Rock-Eval Pyrolysis includes two main fractions, free hydrocarbons, and kerogen (Lafargue et al., 1998). In thermally immature rocks, the contribution of free hydrocarbons to TOC is negligible. Kerogen consists of two main fractions, the pyrolizable fraction (labile OM), and the residual fraction (residual carbon) (Lafargue et al., 1998), the residual fraction is the fraction of kerogen that remains following the thermal cracking induced through pyrolysis as well as inert, non-reactive organic carbon. Hydrogen index (HI) gives an indication of the hydrocarbon potential of the rock and is calculated by dividing the S2 value (S2 being the amount of hydrocarbons generated through thermal cracking) by the measured TOC (Lafargue et al., 1998). It has been previously recognized that interpretation of HI can be complicated by in-situ transformation of OM and original OM type (Dembicki, 2009; Devine, 2014; Jarvie, 2012; Carvajal-Ortiz and Gentzis, 2015). TOC that is elevated through high levels of non-reactive, refractory organic carbon (ROC) could resulting in misleading interpretation of hydrocarbon potential of the assessed source rock. Elevation of TOC by ROC would then result in a suppression of HI and would not provide an accurate indication of the hydrocarbon potential of the labile fraction of OM within the rock. Examination of the kerogen using organic petrology allows the kerogen types to be assessed directly with the aim of quantifying a simplified dilution factor and better understanding the labile fraction.

The Upper Cretaceous Second White Specks Formation is an important source rock for hydrocarbons in units such as the Cardium and Viking formations (Creaney and Allan, 1990) and has been increasingly evaluated as a potential unconventional hydrocarbon play (Clarkson and Pedersen, 2011). The industrial interest in the Second White Specks Formation has spurred research into its organic matter (OM) composition, and the impact of OM on the source rock and reservoir properties of the formation (Caldwell et al., 1978; Goodarzi and Stasiuk, 1987; Stasiuk and Goodarzi, 1988; Schröder-Adams et al., 1996; Bloch et al., 1999; Furmann et al., 2014; Synnott et al., 2016). Previously recognized bacterial degradation of in-situ OM (Stasiuk and Goodarzi, 1988; Synnott et al., 2016) and deposition of inert transported OM (Stasiuk and Goodarzi, 1988; Bloch et al., 1999; Furmann et al., 2014) make it an ideal formation to study the impact of dilution on hydrocarbon potential. This study aims to build on the previous, sometimes contradictory, research by integrating multiple data sets to describe the OM constituents of the Second White Specks and upper part of the Belle Fourche formations, investigating the compositional differences between micro-facies of the Second White Specks Formation, and comparing the two studied formations.

2. Geological setting

The Second White Specks Formation of the Upper Cretaceous Colorado Group in south-central Alberta (Fig. 1; Creaney and Allan, 1990) was deposited during the transgressive phase of the Greenhorn Cycle in late Albian to early Turonian time. It is primarily composed of calcareous, organic-rich mudstone (Slingerland et al., 1996; Schröder-Adams et al., 1996). During the time of deposition, warm Tethyan waters from the south extended into the northern part of the Western Interior Seaway (WIS) allowing northward colonization by planktonic foraminifera and coccoliths (Bloch et al., 1999). Oceanic productivity has been interpreted to have been high and the sea floor is inferred, due to high TOC, lack of benthic foraminifera and visible bioturbation to have been anoxic during the Greenhorn Cycle (Caldwell et al., 1978; Schröder-Adams et al., 1996; Bloch et al., 1999). This resulted in excellent preservation of OM (Caldwell et al., 1978; Schröder-Adams et al., 1996; Bloch et al., 1999).

The underlying Belle Fourche Formation is a westward-thickening wedge of non-calcareous to slightly calcareous mudstone and siltstone conformably overlying the Fish Scales Formation (Fig. 1; Bloch et al., 1999; Yang and Miall, 2008). During the time of deposition of the lower Belle Fourche Formation, a large delta in northeast British Columbia prograded southward depositing the Dunvegan Formation, and much of the interbedded sand and siltstone of the Belle Fourche is a distal expression of the Dunvegan delta (Bloch et al., 1999; Plint, 2013). This progradation infilled accommodation space which is likely the primary cause of relatively shallower water depth interpreted throughout Belle Fourche (Bloch et al., 1999; Plint, 2013). In contrast to the overlying Second White Specks, the WIS during the deposition of the Belle Fourche was dominated by cold, low salinity, boreal waters and bottom water oxygen levels have been interpreted to be dysoxic but highly variable, allowing some colonization by benthic organisms, limited OM productivity, high dilution by terrestrial OM, and relatively limited OM preservation (Leckie et al., 1992; Bloch et al., 1999).

The OM of the Second White Specks Formation has been described and characterized from south-western Saskatchewan eastward to Manitoba with the goal of assessing its potential as an oil shale resource (Paterson, 1982; Macauley, 1984a, 1984b; Macauley et al., 1985). The OM of the Second White Specks is typically described as a mixture of type II and III kerogen containing abundant liptinitic OM including bituminite, originally described as "unfigured bitumen" and commonly occurring in conjunction with intact fluorescing alginite including *Tasmanites* (Stasiuk and Goodarzi, 1988; Goodarzi and Stasiuk, 1987). It has been previously suggested that there is an insignificant difference in organic matter composition between the underlying upper part of the Belle Fourche Formation and the Second White Specks Formation in western Alberta (Furmann et al., 2014). It has, however, also been suggested that further east a distinct boundary in OM composition can be observed between these formations (Bloch et al., 1999). The thermal maturity of the Second White Specks Formation ranges from immature in the east up to the oil window in west-central Alberta and into the gas window in western Alberta, proximal to the deformation front (Fig. 1; Creaney and Allan, 1990).

3. Methodology

3.1. Sampling

Twelve samples were collected from a core of the Second White Specks Formation and upper part of the Belle Fourche Formation at a depth interval of 647.9 m–691.5 m in well 100/07-29-042-12W4/00 located at 52° 38.6′ N, 111° 41.6′W in south-central Alberta (Fig. 1). Of these samples, 5 are from the Belle Fourche Formation and 7 are from the Second White Specks Formation.

Studies by Zajac (2016) recognized five micro-facies on a millimeter scale within the Second White Specks Formation. Each of these five micro-facies represents different depositional processes and sediment source (Zajac, 2016). For the purposes of this study, two of these micro-facies, (micro-facies 1 and 4) representing endpoints in depositional processes, were examined to compare their organic matter composition. Two samples were taken from micro-facies 4 and the remainder were taken from micro-facies 1 (Zajac, 2016).