Organofacies and Source Potential of the Middle Ordovician Winnipeg Formation within Southern Saskatchewan

Christopher Seibel and Stephen Bend

Department of Geology, The University of Regina,
Regina, Saskatchewan

INTRODUCTION

Since the mid 1960's gas has been produced from the Middle Ordovician Winnipeg Formation in North Dakota and since the 1990's condensate has been produced from the Winnipeg Formation in Saskatchewan. The analysis of Winnipeg core derived from wells drilled in southeastern Saskatchewan has also indicated the presence of a light oil (i.e. API^{o} ~50). However, like the oils of the Deadwood Formation, the source of these hydrocarbons has remained unresolved and has not been the focus of a systematic study to date. This study, which is part of an ongoing larger regional evaluation of Lr. Palaeozoic oils and potential source rocks, focuses upon the source rock potential of the Saskatchewan portion of the Middle Ordovician Winnipeg Formation. The Winnipeg Formation is comprised of three members, the Black Island Member (predominantly quartz sandstone), the Icebox Member (predominantly shale) and the Roughlock Member (calcareous shale). The Roughlock Member is restricted to the extreme southeastern part of Saskatchewan. This study focusses upon the Black Island and Icebox Member shales

Organofacies

The concept of *organofacies* used in this study is that of Conford *et al* (1979) modified to incorporate the concept of mappable units proposed by Jones and Demaison (1982). We therefore define an organofacie as *a mappable subdivision of a designated stratigraphic unit, distinguished from adjacent subdivisions by a unique association (or assemblage) of organic petrographic and geochemical characteristics*. The use of organofacies in petroleum geochemistry/petrology may appear descriptive, however the primary goal of organofacies is the prediction of the likely occurrence of hydrocarbon source rocks elsewhere in a given basin, this study perhaps illustrates that goal.

DISCUSSION

Black Island Member

The geochemical (i.e. RockEval and Total Organic Carbon and extract g.c.-m.s.) and petrographic analysis of Winnipeg Formation shales show significant spatial and temporal variation. Shale units of the Black Island Member (BIM) typically yield Total Organic Carbon (TOC) values less than 2.0 wt% and S2 values that range from 7 to 10 mg/g. The relatively organic lean shales of the BIM contain Type I/II kerogen, which is dominated by small thin-walled Prasinophyte alginite and a weakly autofluorescing amorphous matrix. Studies elsewhere have shown

that the presence of Prasinophyte alginite is strongly correlated with the occurrence of marine sediments deposited under dysoxic to anoxic conditions.

Icebox Member

The basal shales of the Icebox Member have been interpreted as a 'flooding surface' (e.g. Dow, 1974) and these shales appear to have the greatest source potential of any Cambrian to Middle Ordovician lithological unit analysed to date; although the geochemical analysis of the Icebox Member shales indicates a wide variation in source rock potential across Southern Saskatchewan.

The systematic analysis of core and drill cuttings yield TOC values that range from 1.0 to 11.0 wt %, S2 values that range from 2 to 85 mg/g and hydrogen indices that range from 300 to 800, associated with the presence of Type I and Type I/II kerogen. Petrographic analysis indicates the presence of an alginite rich kerogen dominated by variable amounts of *Gloecapsomorpha prisca*, Prasinophyte alginite, amorphous kerogen and acanthomorphic acritarchs. Maturation indices (T_{max} and autofluorescence) indicate an overall increase in thermal maturity from 425^{o}C (e.g. 1-4-20-32W2) up to 451^{o}C towards the Nesson Anticline.

Organofacies 1

The spatial distribution of TOC values, variation in S2 yield and occurrence of petrographic type within the Icebox is not random, but follows a mappable pattern in which geochemical and petrographic characteristics define four organofacies. *Organofacies 1,* which is dominated by a highly laminated alginite comprised of *Gloecapsomorpha prisca*, has the highest TOC values (> 11 wt%), greater S2 values (> 96 mg/g) and highest hydrogen indices (750 to 924). This organofacies may be similar to that of the *'layered G. prisca'* organofacies of Stasiuk and Osadetz (1990) as described in the Yeoman Formation. Organofacies 1 occurs on the eastern side of Saskatchewan (e.g. 1-4-20-32W2) where the Winnipeg Formation unconformably overlies the Precambrian. Organofacies 1 possibly represents a 'platformal facies' layed down within a shallow environment of deposition.

Organofacies 2

Organofacies 2 is comprised of lesser amounts of *G. prisca,* which appears in a disseminated form along with an increasing amount of amorphous kerogen. The TOC values for Organofacies 2 range from 1 to 7 wt%, the S2 yields range from 3 to 60 and the hydrogen indices range from 300 to 800. The host lithology locally appears silty with the suggestion that bodies of disseminated *G. prisca* may have been subject to syndepositional incipient oxidation. Organofacies 2 is proximal to Organofacies 1.

Organofacies 3

Organofacies 3 is considered 'transitional' and is characterized by the presence of acanthomorphic acritarchs such as *Veryhacium* and *Micrystrichium,* small remnants of *G. prisca,* an increase in small, thin-walled, Prasinophyte alginite

(e.g. *Leiospheridia, Tasminities*) and amorphous alginite. Organofacies 3 is the leanest organofacies typically yielding TOC values of 1.5 to 2.5 wt%, S2 values ranging from 4 to 13 mg/g and hydrogen indices that range from 370 to 600.

Organofacies 4

Organofacies 4 is associated with TOC and S2 values that range from 1 to 6 wt% and 3 to 39 mg/g respectively and hydrogen indices that range from 300 to 600. Organofacies 4 is characterized by the presence of thin-walled Prasinophyte alginite, the absence of *G. prisca* and the absence of acanthomorphic acritarchs such as *Veryhacium* and *Micrystrichium*. This organofacies occurs towards the southwestern and northern erosional edge of the Winnipeg Formation and towards the Nesson Anticline. This Organofacies is considered to be the most basinal facies.

SUMMARY AND FUTURE WORK

The source rock potential of the Middle Ordovician Winnipeg Formation within Saskatchewan has been identified and described within an Organofacies framework. The generation potential of the Icebox shales is unequivocally linked to the type and abundance of kerogen with the Icebox; that is the greatest generative potential (i.e. highest TOC's and greatest S2) typifies *Organofacies 1, which* is associated with the dominance of the alginite *G.prisca*. The distribution of source rock potential (i.e. 'richness') is also linked to depositional setting, *viz* 'platformal' versus 'basinal' in which the greatest potential is linked to the 'platformal' depositional setting, although no controls have been identified as yet. The next phase of this work will be to place this potential source rock within the 'oil / source 'familial association' of Osadetz *et al*. (1992) We also wish to characterize the type of hydrocarbons that could be expected from the mature / post mature Icebox equivalents. We are keen to identify the control(s) that govern the distribution of the four organofacies outlined above. If the depositional controls are understood, it maybe possible to predict the location of other occurrences of Organofacies 1 & 2 in North Dakota and define 'Winnipeg Formation petroleum fairways'.

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