Maceral variations and Maceral Assemblages within the Upper and Lower Members of the Bakken Formation, Williston Basin, Saskatchewan, Canada.

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Summary

From the application of organic petrology, the Upper and Lower Members of the Bakken Formation are found to have considerable variation in organic matter type and assemblages both along depth and across a given transect. Two variations of the maceral Bituminite (amorphous organic matter) were found and a trend exists such that the two replace on another across a given transect. Four organic facies are defined from the maceral assemblages present, and sub-divisions are also defined based on the dominant maceral, or micro-fossils present. The Bakken Formation black shales were likely deposited under anoxic conditions, where changes in water chemistry and the availability of light were the primary mechanisms responsible for the variations in the type and amount of organic matter deposited.

Introduction

Argillaceous rocks are most often considered to be homogeneous entities, because at the macroscopic scale they appear to be so. The Bakken Formation within southern Saskatchewan contains two black shale Members, the Upper and Lower Bakken. This study has examined the organic matter within the Upper and Lower Members of the Bakken Formation using fluorescence light microscopy on samples taken from core, at closely-spaced intervals across southern Saskatchewan.

The organic constituents, or macerals, in the Upper and Lower Members of the Bakken Formation vary significantly along depth within a given borehole (ie. temporally) and also across a given section (ie. spatially). The macerals present in the Bakken Formation black shales include: amorphous organic matter (identified as the maceral Bituminite), with minor amounts of Alginite and 'Degraded Alginite'. Bituminite is the dominant maceral and forms the groundmass of the Bakken Formation black shales. Bituminite was unequivocally distinguished from clay or other inorganic material by prolonged exposure to ultraviolet/blue light for a designated time period, using the 'alteration effect' of liptinites.

Two sub-macerals of Bituminite were distinguished, identified as Bituminite A and Bituminite C. These two sub-macerals 'substitute' for one another across a given east-west transect, (see Figure 1) such that: the sub-maceral Bituminite A is the dominant maceral within the centre of the study area, whereas Bituminite C occurs as the groundmass along the peripheral area of the sub-crop preceded by a transitional area where there is a mixture of both Bituminite A and Bituminite C.

The considerable variation in maceral assemblages, both with depth and along a given section, have implications towards hydrocarbon generative potential of these source rocks. In order to comprehend the variation in organic matter, maceral assemblages were grouped into organic facies. Four groups of organic facies were identified and defined (see Table 1), each with their own respective sub-division based upon the type of groundmass (ie. either Bituminite C or Bituminite A) and both the amount or type of microfossils present.

A number of differing depositional environments for each organic facies are proposed using the presence or absence and type of microfossils present (ie. algae, acritarchs and spores) within each organic facies (and organic facies sub-division). The Bakken Formation black shales are interpreted to have been deposited under anoxic conditions, where changes in water chemistry and the availability of light were the primary mechanisms responsible for the variations in the type and amount of organic matter deposited.

Theory and/or Method

A suite of 15 vertical boreholes across the Canadian portion of the Williston Basin were selected for a high resolution source rock characterization study of the Bakken formation. Cores were initially logged and samples were taken at regular, closely spaced intervals within the organic-rich strata of interest (Upper and Lower Bakken) based upon the high gamma response on a petrophysical wireline log.

Two sub-samples were derived from each core sample. Sub-sample 1 was crushed to 2-4mm in size and sub-sample 2 was cut perpendicular to bedding. Then, both were mounted in low-fluorescing, two-stage epoxy in petroleum jelly lubricated teflon moulds. Samples were then polished using a modified version of the procedure outlined in Mackowsky (1982) and examined using a Leitz Orthoplan research microscope calibrated for auto-fluorescent reflected light. A x50 air objective was used with x10 oculars, for an overall magnification of x500. The identification and characterization of petrographic constituents was obtained in light using a Leitz Orthoplan microscope set for epifluorescence using a 4-Lambda PLOEMOPAK and filter block "G" (BP 250 to 460nm, RKP 510 nm, LP 520 nm), with a 100w mercury-arc discharge lamp. Point count analysis was conducted using a Swift point counter with an inter-point and inter-line distance of 50µm. Five hundred counts (ie analyses) per sample were conducted according to published guidelines (ICCP, 1971), in order to keep the analytical error below 1% and to create an acceptable, statistical representation of the sample. Organic matter was described using the maceral concept (Stopes, 1935) following the guidelines and standards set by the International Committee of Coal and Organically Petrology (1963, 1971, 1974).

Examples (see below)

Table 1: Definitions for each of the Organic Facies and their sub-divisions proposed here for the Upper and Lower Members of the Bakken Formation.

Organic Facies	Description	Sub-OF	Description
1	**Bituminite A groundmass with very little alginite and many acritarchs in field of view.**	A	Bituminite A is the primary maceral with abundance well over 90% of the total organic matter. Trace microalginite, abundance is under 5% of the total organic matter. As many as 50 acritarchs could be seen in the field of view. Fragmented or underdeveloped *Leiosphaeridia* alginite may or may not be present.
		As	Very similar to 1A but contains spores in the field of view. Tasmanite is likely to be present, but underdeveloped.
2	**Either Bituminite A or C groundmass with relatively abundant, large bodied alginite (*Leiosphaeridia* and *Tasmanite*).**	2 A	Bituminite A is the primary maceral with an average abundance of 89%. Alginite is present (*Leiosphaeridia* is nearly always more abundant than *Tasmanite*), abundances over 10% could be indicative an algal bloom. *Leiosphaeridia* have a maximum size of 370µm but may be as small as 111 µm. *Tasmanites r*ange from 111 to 278 µm. Bituminite B is likely to be present but only in trace amounts. Bituminite C and DA may or may not be present, but only in abundances under 15% (combined) of the total organic matter.
		2 C	Bituminite C is the primary maceral with an average abundance of 86% of the total organic matter. Bituminite C groundmass with fine liptodentrinite (algae detritus) within the groundmass. *Leiosphaeridia* has maximum sizes ranges from 111 to 370 µm. *Tasmanite* has maximum sizes ranging from 148 to 333µm. Bituminite B may or not be present and if so, it would under 5% of the total organic matter. Degraded Alginite may or may not be present and if so it would beunder 15% of the total organic matter.
3	**Bit A and Bit C interlaminated with degraded alginite.**	3 A	A mixture of Bituminite A, Bituminite C and +/-DA. Bituminite A is the dominant maceral, by having abundance over 50%. Bituminite B and Alginite (*Leiosphaeridia* and *Tasmanite*) are likely to be present but under 15% (combined) of the total organic matter. Acritarchs and (rarely) spores may be present in the field of view.
		3 A C	A mixture of Bituminite A, Bituminite C and DA. None of the three main macerals are dominant; the abundances of these three are near one third-one third-one third. Bituminite B and Alginite (Leios and Tasmanite) are likely to be present but under 10% (combined) of the total organic matter. Acritarchs and (rarely) spores may be present in the field of view.
		3 C	A mixture of Bituminite A, Bituminite C and DA. Bituminite C is the dominant maceral, by having abundance over 50%. Bituminite B and Alginite (*Leiosphaeridia* and *Tasmanite*) are likely to be present but under 10% (combined) of the total organic matter. Acritarchs and (rarely) spores may be present in the field of view.
4	**Bituminite A or C with degraded alginite lenses and mineral matter**	4 A	Bituminite A groundmass with lenses of Degraded Alginite and a fairly high mineral matter content. Bituminite C may or may not be present, but if so abundance would be under 10%. Bituminite B and Alginite is likely to be present, but under 10% (combined) of the total organic matter. Acritarchs and (rarely) spores are likely to be in the field of view.
		4 C	Bituminite C groundmass with lenses of Degraded Alginite and a fairly high mineral matter content. Bituminite A may or may not be present, but if so abundance would be under 10%. Bituminite B and Alginite is likely to be present, but under 10% (combined) of the total organic matter. Acritarchs and (rarely) spores are likely to be in the field of view.

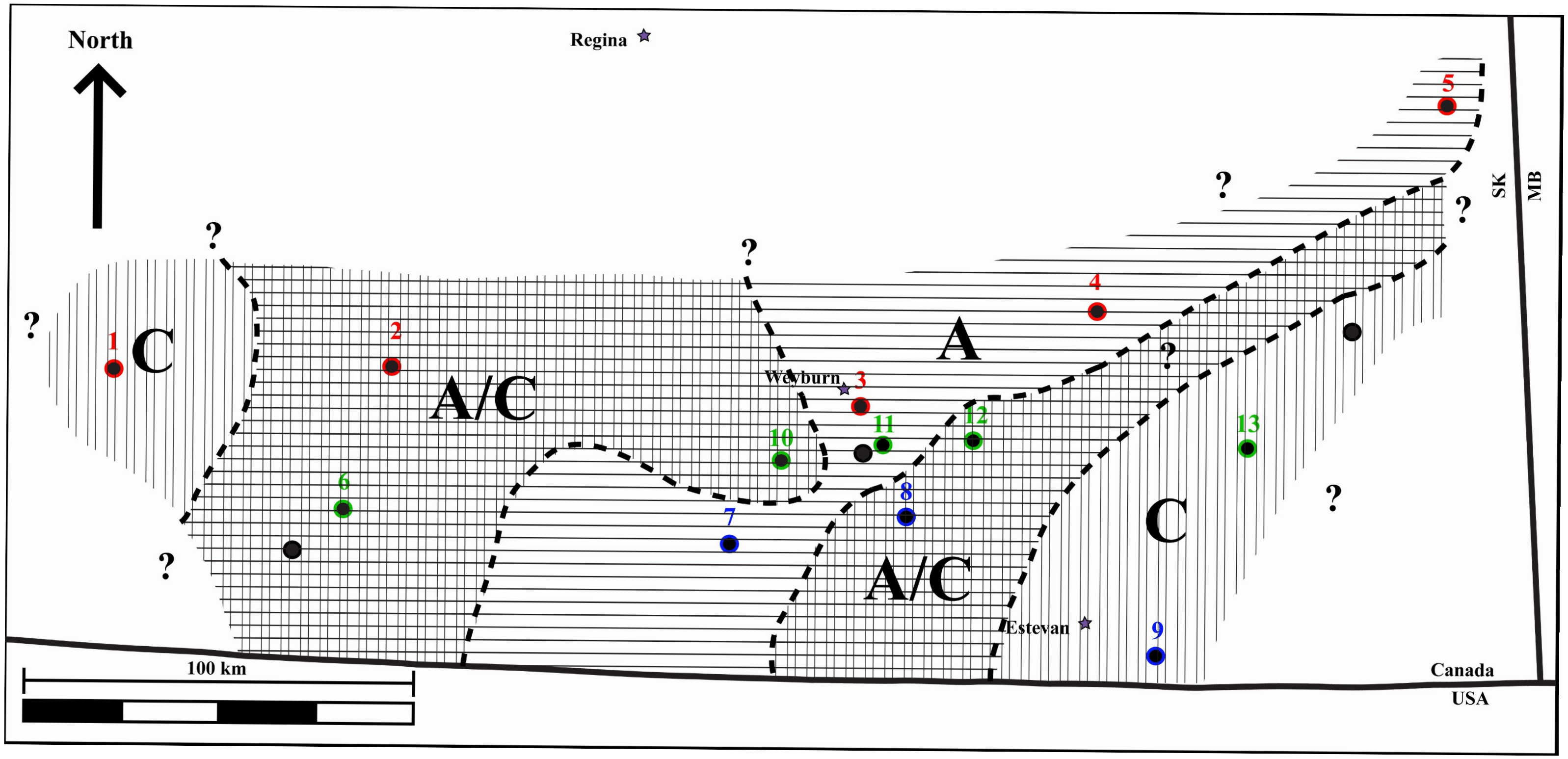

Figure 1: South-eastern Saskatchewan Bakken Formation divided into areas where: ‘C’ Bituminite C is the dominate maceral; ‘A’ Bituminite A is the dominant maceral; and ‘A/C’ a transitional zone of intermixing Bituminite A and Bituminite C groundmass.

Conclusions

1. The most abundant maceral within the Bakken Formation black shales is Bituminite. Occurring as two sub-macerals herein called Bituminite A and Bituminite C. Alginite is a minor maceral, occurring primarily in amounts under 10% of the total organic matter.
2. The Bakken Formation shales are not homogeneous spatially nor temporally, and that the Upper and Lower Member shales are petrographically distinct from one another. Using a closely-spaced sampling protocol on core, petrographic characteristics of the Upper and Lower Bakken have been shown to vary significantly along a given section and within a single well profile.
3. One of the most significant observed variance is the progressive change in groundmass material moving from the central portion of the data set (Bituminite A), towards the sub-crop periphery (Bituminite C). Other changes in organic matter content include: the maceral Alginite is most abundant in the central portion of the basin; Sporinite and Microaglinite are most likely to be found in the eastern part of the basin within the Upper Bakken; with an increase in fragmentation (?) degradation(?) of Alginite towards the west.
4. A previously unrecognized maceral herein named 'Degraded Alginite' has been found throughout the Bakken Formation shales. Recognizable by the presence of interval wavy lensoid-like texture with a very dull, chocolate brown fluorescence and internal reflections.
5. The use of prolonged exposure (liptinite alteration) to ultra-violet/blue light as a specific test for the distinguishing of organic matter from mineral matter within a sample has not previously been used. Photo-oxidation has been traditionally been used as gage for the maturity of the organic matter present. However, due to the dull fluorescence intensity of the majority of the organic matter the prolonged exposure test was an exceptionally useful tool for differentiating organic matter from mineral matter and as a means of verification that the groundmass was indeed organic material.
6. The groundmass of the Bakken Formation has been determined to be the maceral Bituminite. Two sub-macerals of Bituminite, Bituminite A and Bituminite C, were recognized. These sub-macerals 'substitute' for one another across a given east to west transect such that: Bituminite A is dominant in the centre of the data set, whereas Bituminite C is found along the peripheries, with transitional zones composed of a mixture of Bituminite A and C occurring in between these two areas.
7. This study has been able to define four organic facies categories, each with their own subdivisions based on a groundmass of Bituminite A or Bituminite C. Each organic facies have been plotted on east to west cross-sections which demonstrate the vast variations in organic matter within the Bakken Formation black shales.
8. Each of the defined organic facies are likely due to a slight changes the in paleo-depositional setting. Using a model proposed by Butterfield and Chandler (1992), depositional environments are interpreted for the Bakken Formation black shales based upon the microfossils present within each of the defined organic facies. This suggests that the Bakken Formation black shales represent the formation and accumulation of organic matter in a series of discrete successive zones ranging from near-shore to an increasingly distal depositional environment.

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