Sedimentology and Organic Petrology of the Middle Devonian Keg River Formation, Rainbow Sub-basin, Northwestern Alberta: Implications for Source Rock Accumulation and Reef Growth

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ABSTRACT

Organic-rich laminites within the Middle Devonian Keg River Formation are source rocks in the Rainbow Sub-basin. An integrated approach incorporating both sedimentology and organic petrology was used to determine the paleoenvironment and paleoecology of these source rocks. In addition, the primary control on organic matter accumulation in the Keg River was evaluated in the context of the controversy between "productivity vs. preservation". This research provides insight into the relationship between elevated nutrient levels, high phytoplanktonic productivity, and Devonian reef growth.

PRODUCTIVITY vs. PRESERVATION CONTROVERSY

Bottom-water anoxia has been regarded as the primary control responsible for accumulation and preservation of organic matter (Demaison and Moore, 1980; Tyson, 1987; Tyson and Pearson, 1991). Anoxic conditions can develop when the water column exhibits stratification due to development of a thermocline or halocline, due to runoff from terrestrial sources, or when limited wave fetch and inefficient vertical mixing are combined with the lack of a deep, cold, thermohaline current (Fig. 1). This stratification can produce an anoxic bottom layer in which activity of benthic scavengers and bioturbating organisms is restricted or eliminated. Such conditions are conducive to the accumulation and preservation of organic matter in fine-grained sediments.

Based on recent oceanographic studies, elevated primary productivity in surface waters has been proposed as an alternative to bottom-water anoxia as the primary control on organic matter accumulation (Parrish, 1982; Pederson and Calvert, 1990; Tribovillard *et al.*, 1994). Increased phytoplanktonic productivity can be triggered by a number of factors including upwelling currents that carry nutrients up into the photic zone, elevated salinity, and influx of terrestrial nutrients. Enhanced productivity results in increased flux of organic matter to the seafloor (Fig. 2). Aerobic bacteria attack settling organic matter and deplete oxygen levels in the surrounding water creating an oxygen minimum zone.

Anoxic-bottom waters occur where this oxygen minimum zone impinges on the continental margin. These mechanisms favour accumulation and preservation of organic matter.

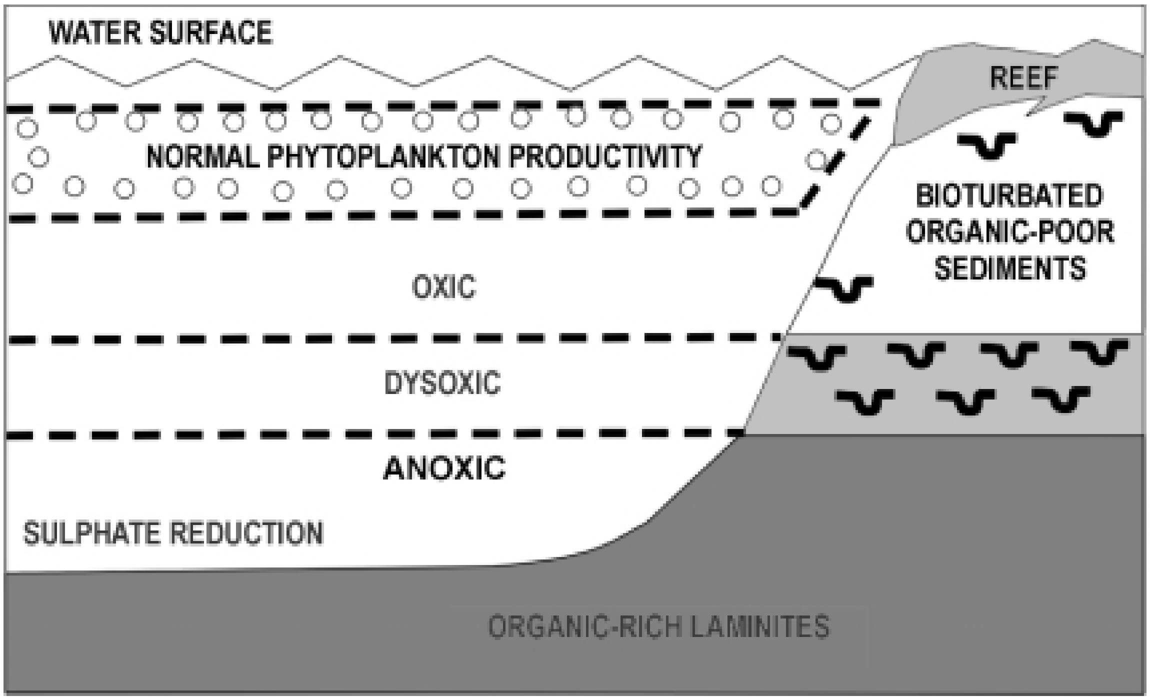

Fig. 1. *Preservation is the primary control on organic matter accumulation when anoxic bottom waters inhibit or eliminate benthic scavenging and bioturbation (modified from Stasiuk et al., 1995).*

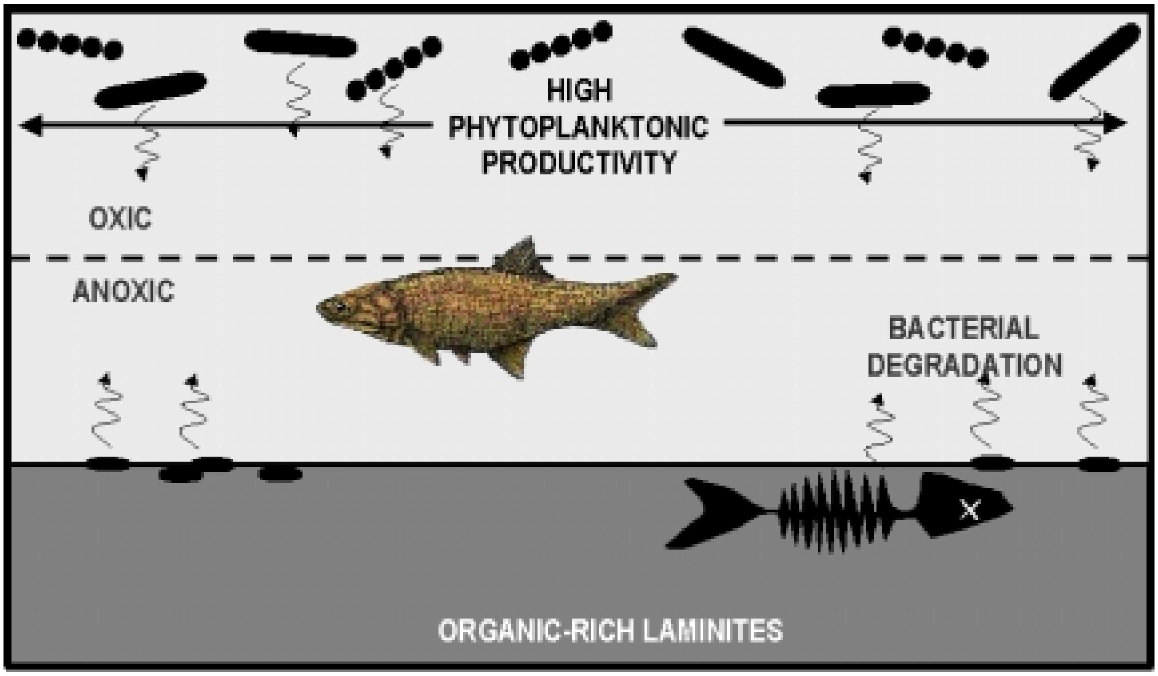

Fig. 2. *Productivity is the primary control on organic matter accumulation when phytoplanktonic productivity in surface waters is elevated (modified from Stasiuk et al., 1995).*

OBJECTIVES and METHODOLOGY

An integrated approach utilizing both sedimentology and organic petrology was used to determine the primary control on organic matter accumulation within organic-rich laminites of the Middle Devonian Keg River Formation in the Rainbow Sub-basin. Such determinations also have far-reaching implications for the study of Devonian reefs and understanding the effects of elevated nutrient levels (i.e. eutrophication) on reef growth and demise.

Detailed core descriptions of over 300 m of drill core and well logs from six wells in the Rainbow Sub-basin were used to identify genetic successions within the Lower Keg River Member. Over 100 thin-sections were examined using transmitted light microscopy to determine fossil content, matrix composition, fine-scale sedimentary structures, and primary textures obscured by dolomitization.

Seventy-six samples were selected for organic petrology and Rock-Eval analysis. Care was taken to sample the most potentially organic-rich intervals present in each core. Samples were analyzed using white and ultra-violet incident light microscopy in order to identify macerals (structured particles of organic matter) and determine organic facies (OF). Rock-Eval pyrolysis was utilized to quantify the amount and type of organic matter in these samples including total organic carbon (TOC).

SEDIMENTOLOGY

The Keg River Formation is subdivided into the Lower Keg River Member and the Upper Keg River Member (Fig. 3). The Lower Keg River Member represents a carbonate ramp succession consisting of two shallowing-upward cycles of lime mudstone to crinoid wackestone to floatstone. An organic-rich laminated lime mudstone (herein referred to as the Lower Keg River laminite), 1-3 m thick, occurs at the base of the second shallowing-up cycle. The Lower Keg River laminite consists of organic-rich laminae interlaminated with argillaceous lime mudstone. Another organic-rich laminite (herein referred to as the Upper Keg River laminite) occurs at the base of the Upper Keg River Member. The Upper Keg River laminite forms relatively thick successions in basinal areas between reefs, possibly up to 9 m thick based on cuttings from well 4-30-110-9W6. Only sparse, very thin, organic-rich laminae occur interbedded with peloidal-skeletal grainstones of the allochthonous reef foreslope; only 20 cm total thickness of organic-rich laminae were measured in 30 m of foreslope sediment in well 12-33-109-8W6.

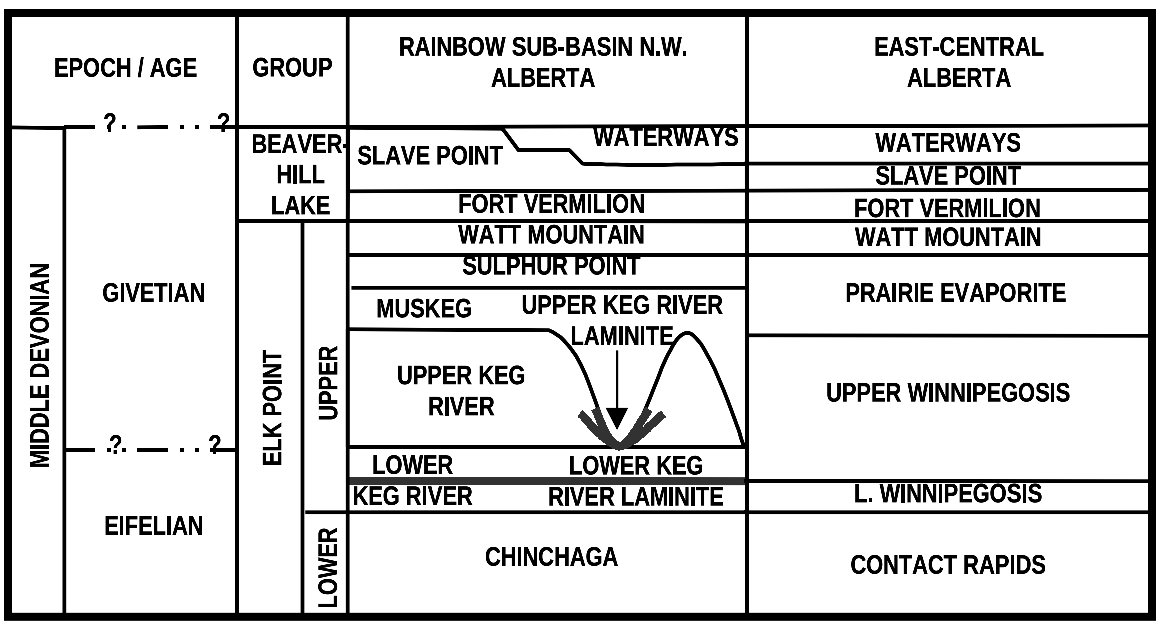

Fig. 3. *Middle Devonian stratigraphy of the Rainbow Sub-basin, and East-Central Alberta (modified from Chow et al.¸1995).*

ORGANIC PETROLOGY

The concept of organic facies is central to organic petrology. Organic facies (OF) are based on the distribution and relative abundance of alginites (unicellular and multicellular algae), acritarchs, and sporinites (terrestrial spores and pollen) (Fig. 4). OF A, representing paleoenvironments distal from shore, is characterized by abundant large, thick-walled Prasinophyte alginites and small, thin-walled Prasninophyte alginites (P). OF C is characterized by sporinites (Sp), multicellular coccoidal alginites (C), *Veryachium* acritarchs (V), and abundant small, thin-walled Prasinophyte alginites. OF C represents proximal to shore settings. OF B, representing an intermediate setting, is recognized by the presence of a variety of acanthomorphic (spinose) acritarchs (H, M, V) and small, thin-walled Prasinophytes.

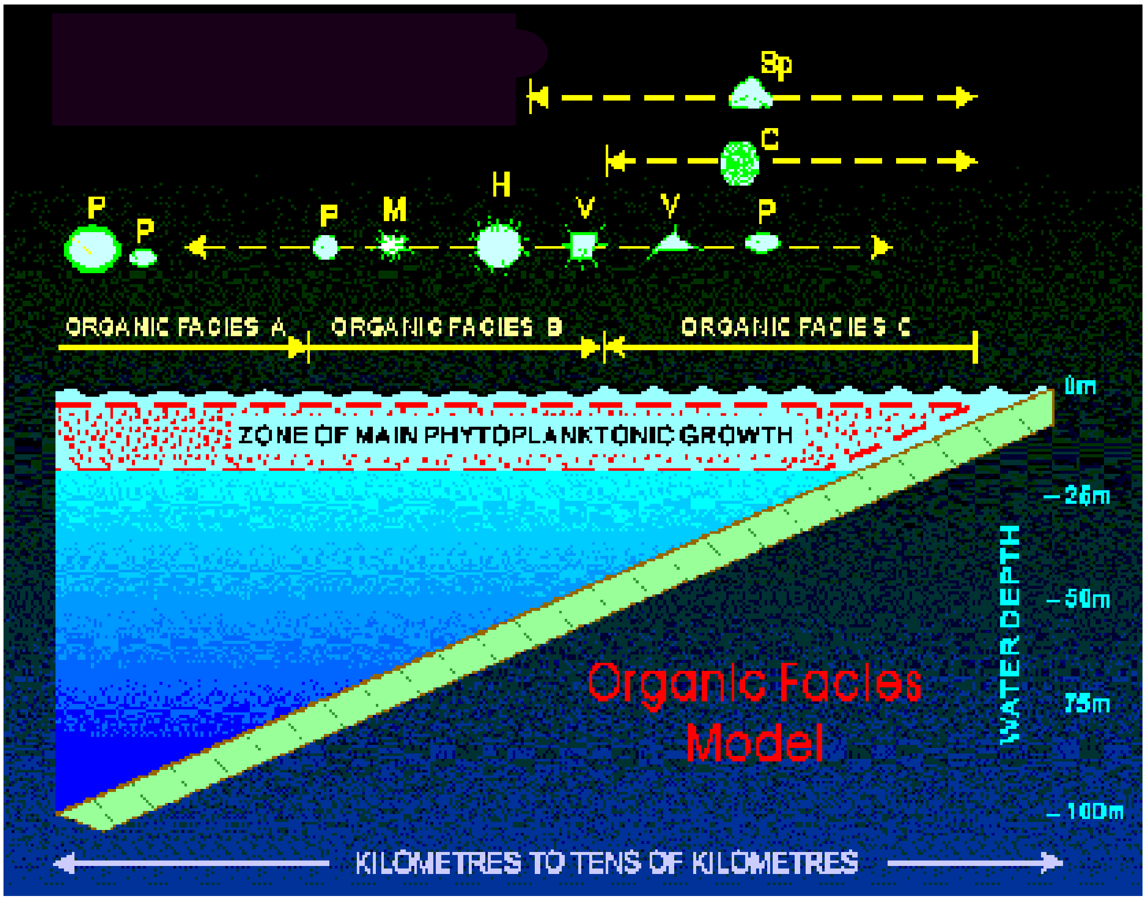

Fig. 4. *Maceral-based organic facies (OF) model for Devonian strata in the Western Canada Sedimentary Basin (modified from Stasiuk, 1999).*

During periods of elevated productivity, Prasinophyte alginites develop large, thick-walled forms in response to environmental stresses such as decreased light penetration due to increased phytoplankton population density, temperature and nutrient variation. These large, thick-walled Prasinophytes are deposited in all environments during algal bloom episodes. Algal akinete cells, specialized reproductive resting cells of filamentous algae, also form in response to unfavourable conditions. Therefore, the presence of large thick-walled Prasinophytes in association with algal akinete cells in organic-rich sediments indicates that elevated phytoplanktonic productivity was the primary control on organic matter accumulation. Maceral associations representative of algal blooms are classified as OF A in this study.

In the Rainbow Sub-basin, the Upper Keg River laminite in foreslope positions consists of OF A characterized by abundant large, thick-walled alginites and algal akinete cells. These macerals also make up a minor component of the Upper Keg River laminite in off-reef positions. Small, thin-walled alginites and spinose acritarchs dominate the Lower Keg River laminite, as well as the Upper Keg River laminite in offreef positions, indicating deposition in intermediate settings (OF B) during times of normal phytoplanktonic productivity.

SYNTHESIS

Based on sedimentology and organic petrology, the Lower Keg River laminite is interpreted to have accumulated under conditions of normal phytoplanktonic productivity and depth-related anoxia (Fig. 5). In contrast, the Upper Keg River laminites involved minor high productivity (algal bloom) episodes. These periods of elevated phytoplanktonic productivity were required to establish anoxia at relatively shallow water depths to allow very thin organic-rich laminae to accumulate on the reef foreslope. Macerals indicating these periodic blooms are also observed in off-reef positions of the Upper Keg River laminite. In these basinal settings, the minor influence of algal bloom macerals is overwhelmed by more abundant macerals that indicate that depth-related anoxia was the primary control on organic matter accumulation. Therefore, the Middle Devonian reefs within the Rainbow Sub-basin grew during predominantly low nutrient level conditions.

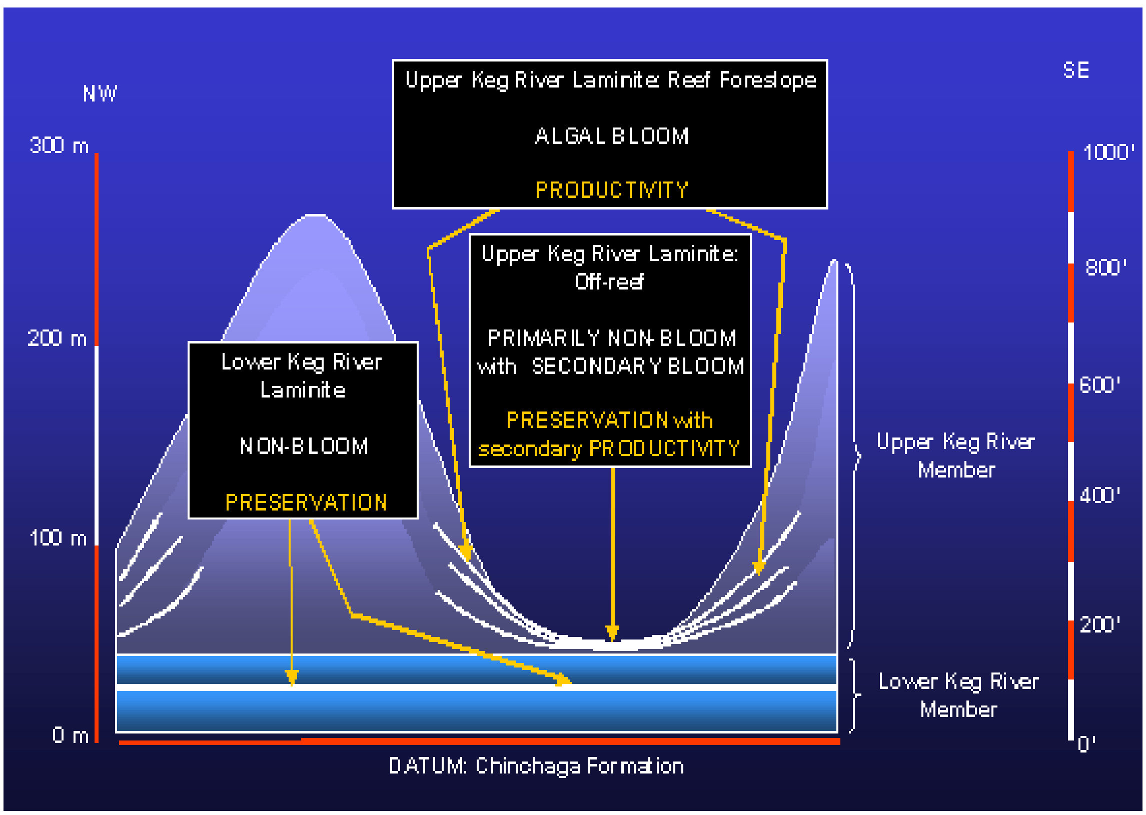

Fig. 5. *Schematic cross section indicating the primary controls on organic matter accumulation within source rocks deposited in the Keg River Formation of the Rainbow Sub-basin.*

IMPLICATIONS FOR REEF GROWTH

Increased nutrient levels accompanied by elevated phytoplanktonic productivity have typically been considered detrimental to reef growth. This is due to the increased abundance of "fouling organisms", such as fleshy algae and suspension feeders, as well as decreased water clarity and effective light penetration (James and Bourque, 1992). However, various studies have suggested that Devonian stromatoporoid reefs could tolerate higher nutrient levels than modern reefs (Hallock and Schlager, 1986, Wood, 1993, 1995, Kiessling *et al.*, 1999). This study presents evidence that Middle Devonian reefs in the Rainbow Sub-basin grew during prevailing conditions of low-nutrient influx punctuated by episodic eutrophic conditions characterized by elevated phytoplanktonic productivity. Therefore, no unequivocal evidence was found to support the theory that Devonian stromatoporoid reefs could tolerate extended periods of high nutrient concentrations. If high nutrient concentrations were detrimental to Devonian reef growth, this research suggests that the reefs in the Rainbow Sub-basin were relatively unaffected or had ample time to recover and thrive between episodes of short-lived eutrophic conditions.

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