

Regional Stratigraphic Study of the Exshaw/Bakken Formations: Insights from Sedimentology and Ichnology

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Summary

The Exshaw and Bakken formations comprise a relatively thin and widespread, Late Devonian to Early Mississippian sedimentary unit in southern Alberta and Saskatchewan. It is informally divided into three members: a lower black shale, a highly variable middle member consisting of siltstone, sandstone and limestone facies, and an upper black shale that is lithologically similar to the lower shale. This study provides a regional sedimentological and stratigraphic analysis of the Exshaw/Bakken interval, with emphasis on the ichnology of the middle member.

Eleven facies and four facies associations were identified along a regional trend extending from the type section of the Exshaw Formation at Jura Creek in western Alberta, to the Exshaw/Bakken transition at the Alberta/Saskatchewan border, to the Bakken Formation in southeast Saskatchewan (Township 2, Range 19W2). Stratigraphic and sedimentological analysis reveals that paleodepositional environments at the time of Exshaw/Bakken deposition included a brackish embayment east of the Sweetgrass Arch and a barrier island west of the Arch. Both systems lie marginal to an offshore/shelf system, which is more commonly recognized as representative of the Exshaw/Bakken interval.

Ichnological data support the interpretation of widespread, environmentally stressed conditions at the time of Exshaw/Bakken deposition. Low diversity assemblages of *Nereites missouriensis*, *Helminthopsis* and *Phycosiphon*, in moderate abundance, represent opportunistic behaviour commonly associated with restricted environments.

Introduction

The Exshaw/Bakken interval, which is typically no thicker than 35 to 40 metres, extends from the front ranges of the Rocky Mountains, into the Western Canada Sedimentary Basin (WCSB) and the Williston Basin. It includes organic-rich, black shale that is considered to be an important source of oil contained in

many of the reservoirs in the Western Canada and Williston basins (Creaney and Allen, 1990; LeFever *et al.* 1991). The regional stratigraphy of the Exshaw/Bakken interval has been studied extensively (Christopher 1961; Smith and Bustin, 1996; 2000), and is usually represented in a fairly simplistic way from basic lithological or micro-paleontological evidence. Only recently have ichnological characteristics been considered; Angulo *et al.* (2008) and Angulo and Buatois (2009) incorporated ichnology into their localized southern Saskatchewan study of the Bakken Formation. This study aims to put the Exshaw/Bakken formations into a regional lithostratigraphic framework utilizing sedimentology and ichnology to enhance the interpretation of depositional environments. The primary objective is to describe and correlate the facies and facies associations of the Exshaw/Bakken interval from the type section at Jura Creek, Alberta through the WCSB to the Alberta/Saskatchewan border, into the Williston Basin to the southeastern corner of Saskatchewan (Figure 1). The secondary objective is to perform a detailed ichnological analysis of the Exshaw/Bakken interval in order to determine the paleoecological and paleoenvironmental significance of the observed bioturbate textures.

Facies and Facies Associations

Detailed core analysis resulted in the identification of eleven facies, encompassing shale, siltstone, mudstone, sandstone and bioclastic grainstone lithologies, which were then grouped into four facies associations (FA). The characteristic facies for each facies association are shown in Figure 2. Each association has a definable lateral extent and is interpreted to represent a unique depositional setting. FA1, interpreted as offshore/shelf deposits, is the most laterally extensive as it spans across Alberta and Saskatchewan. The brackish embayment deposits of FA2 are largely confined to southern Saskatchewan. FA3 and FA4, representing deposition of sandstone in a barrier island complex, are located along the Alberta/Saskatchewan border in the vicinity of the Sweetgrass Arch. The lithostratigraphic relationship between the facies associations and their distribution across southern Alberta and Saskatchewan is shown in Figure 3.

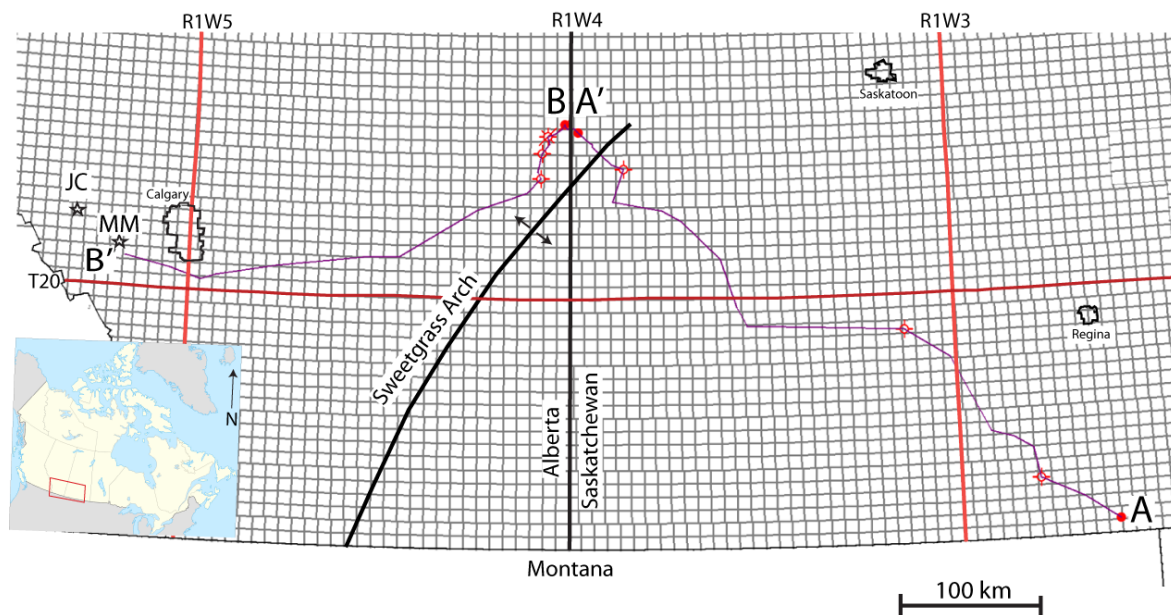


Figure 1: Study Area

Map of study area showing regional cross-section lines. Well symbols in red represent location of cored intervals. A-A' and B-B' are shown in Figure 3. JC=Jura Creek type section; MM=Moose Mountain. Position of Sweetgrass Arch from Richards, 1989.

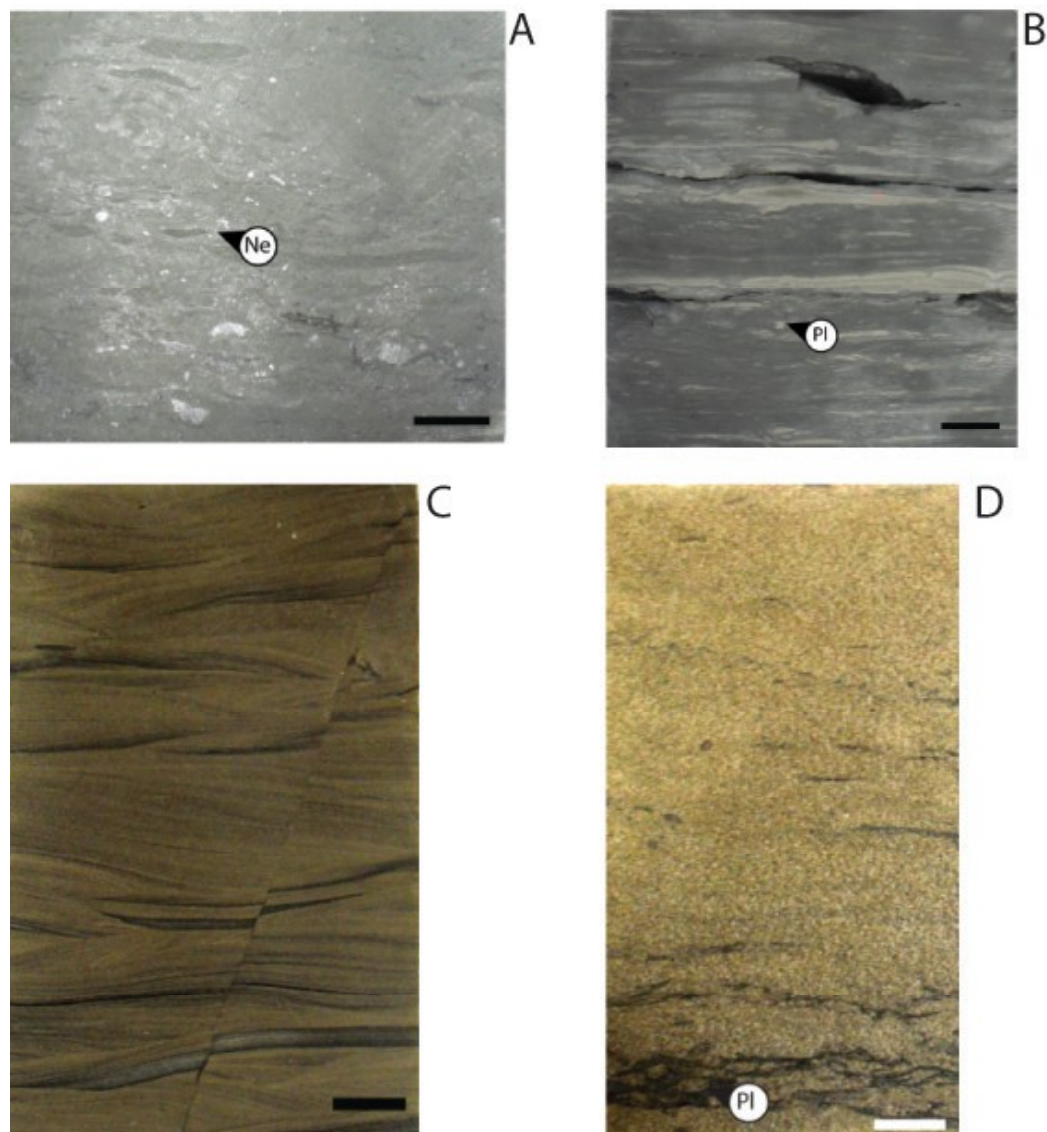


Figure 2: Characteristics Facies for Each Facies Association

A) Bioturbated siltstone with bioclasts (FA1); Ne=*Nereites missouriensis*. (11-34-029-25W3; 864.30m depth). B) Lenticular-bedded sandy mudstone (FA2); Pl=*Planolites*. (6-20-005-24W2; 1824.10m depth). C) Ripple cross-laminated sandstone with syn-sedimentary fault (FA3). (07-17-032-02W4; 788.26m depth). D) Flaser-bedded sandstone with burrow-mottled mud laminae (FA4); Pl=*Planolites*. (07-17-032-02W4; 785.25m depth). Each scale bar is 1 cm long.

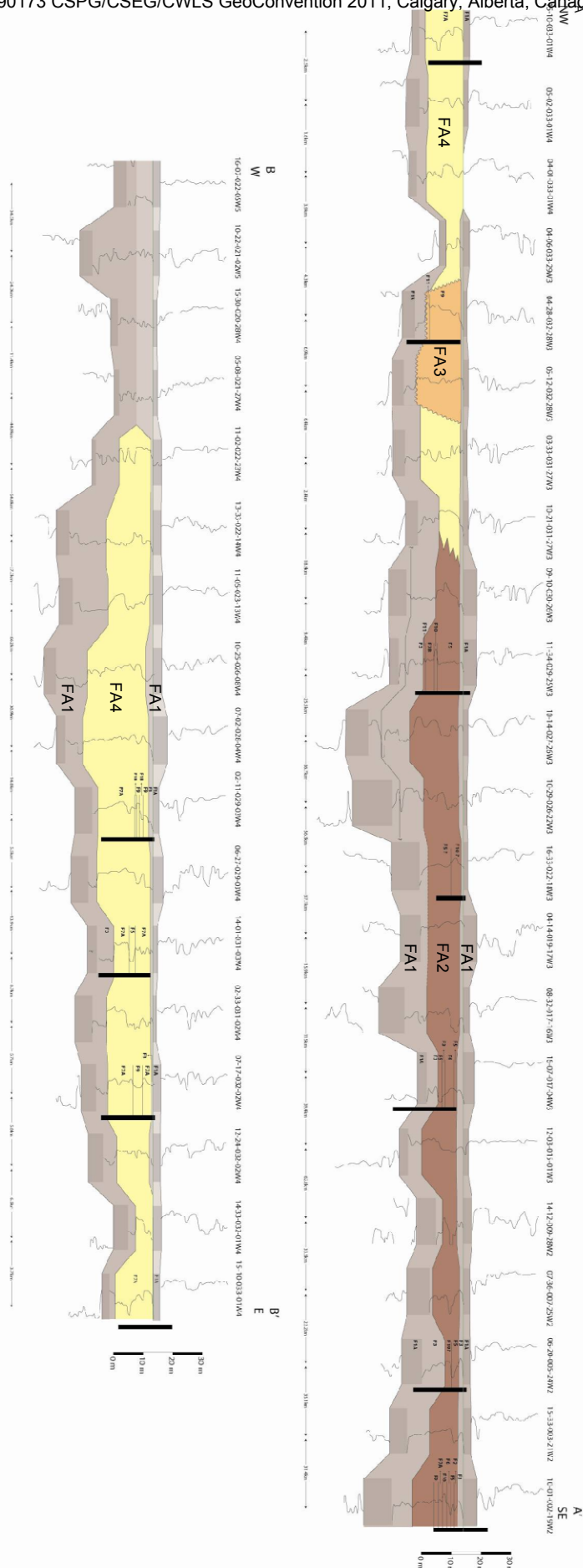


Figure 3: Regional Lithostratigraphic Cross-Sections A-A' and B-B'. These cross-sections show the distribution and relationships between Facies Associations 1-4. See Figure 1 for the locations of the sections. The well log traces are of the gamma ray log; black bars represent cored intervals; dark grey boxes represent the high API of the black shales. Light grey = FA1, brown = FA2, orange = FA3 and yellow = FA4.

Figure 3: Regional Lithostratigraphic Cross-sections A-A' and B-B'

These cross-sections show the distribution of and relationships between Facies Associations 1 – 4. See Figure 1 for the location of the sections. The well log traces are of the gamma ray log. Black bars represent cored intervals; dark grey boxes represent the high API of the black shale facies. Light grey = FA1, brown = FA2, orange = FA3 and yellow = FA4.

Ichnological Implications

Ichnology plays an important role in the analysis of facies and interpretation of facies associations in the Exshaw/Bakken interval. For example, the middle siltstone member contains a distinct and recurring bioturbate texture that can be tracked from the type section of the Exshaw Formation at Jura Creek across Alberta into Saskatchewan and Manitoba. It occurs within Facies Association 1 and always contains a low diversity trace fossil assemblage of *Phycosiphon*, *Helminthopsis* and *Nereites missouriensis* (Figure 4). This assemblage can be interpreted as an “opportunistic” suite of trace fossils, characterized by low diversity and moderate density, reflecting environmentally stressed conditions as a result of fluctuating environmental parameters such as salinity, temperature, turbidity, food supply, and oxygen level. This ichnological signature implies that much of the Exshaw/Bakken interval was deposited in a stressed marine basin that likely experienced low sedimentation rates, limited food supply and low oxygen levels as a result of limited circulation.

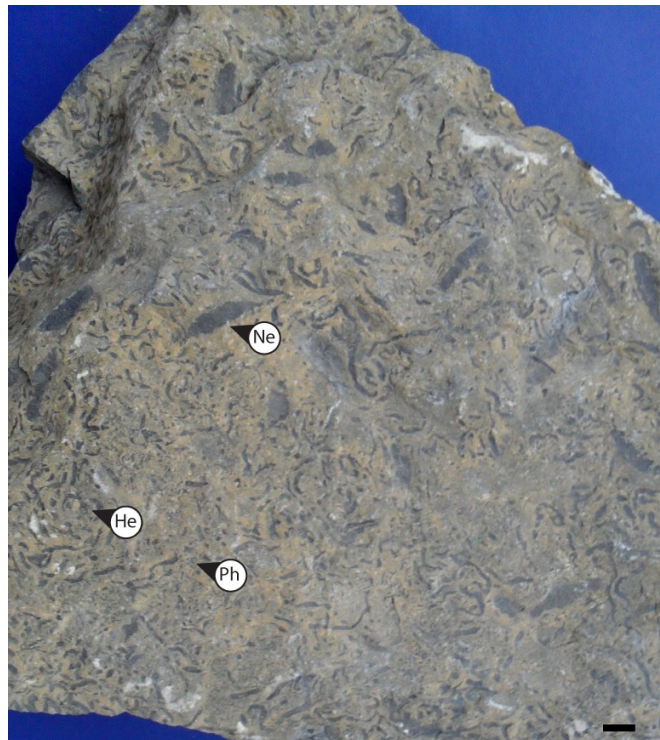


Figure 4: Characteristic Bioturbate Texture Found in FA1

Slab collected from the type section of the Exshaw Formation at Jura Creek, Alberta. *Helminthopsis* (He), *N. missouriensis* (Ne) and *Phycosiphon* (Ph). Scale bar is 1 cm long.

Conclusions

Two main conclusions resulted from this study. The interpretation of four unique facies associations representing a range of environments from offshore/shelf to brackish embayment suggests that the Exshaw/Bakken interval is positionally and stratigraphically more complex than previously thought. This is supported by the ichnological signature of a key facies, represented by a low diversity, moderate density, opportunistic assemblage that reflects a stressed, oxygen deficient marine basin.

Acknowledgements

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