SEDIMENTOLOGY, ORGANIC PETROLOGY, ORGANIC GEOCHEMISTRY, AND PETROLEUM POTENTIAL OF THE MIDDLE DEVONIAN WINNIPEGOSIS FORMATION IN SOUTHWESTERN MANITOBA, CANADA

By

David McDonald

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Submitted to the Faculty of Graduate Studies
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ABSTRACT

The Middle Devonian Winnipegosis, Elm Point, and Ratner formations are parts of the Elk Point Group, which is a cyclical succession of carbonate and evaporite rocks that were deposited within the Hume-Dawson sequence in the Western Canada Sedimentary Basin. In Manitoba, these formations occur in the subsurface in the southwestern part of the province and are partly exposed in the Devonian outcrop belt along the eastern erosional margin of the Elk Point Basin. The lower and upper members of the Winnipegosis Formation are composed of ramp and isolated reef/platform units respectively. Within the study area, the western platform margin is approximately coincident with the Birdtail-Waskada Axis, which reflects the Precambrian Superior Boundary Zone, and the northern margin is approximately coincident with the contact between the Precambrian Uchi and English River domains, which raise the issue of tectonically controlled basin differentiation. At the end of Winnipegosis time, the Elk Point Basin became restricted and the basin was filled by interlaminated carbonate and anhydrite of the Ratner Formation followed by the deposition of anhydrite, halite, and bittern salts (Muskeg and Prairie Evaporite formations) as a result of evaporative drawdown.

Based on detailed core examination, fifteen lithofacies have been recognized in the Winnipegosis, Elm Point, and Ratner formations in the study area: A) non-fossiliferous mudstone, B) mottled-nodular skeletal wackestone-mudstone, C) nodular-patterned mudstone, D) bituminous laminite, E) interlaminated mudstone-anhydrite, F) massive-

mottled mudstone, G) septarian-type nodular skeletal packstone, H) bedded-mottled peloidal packstone, I) intraclast floatstone, J) bituminous skeletal wackestone-floatstone, K) peloidal-udoteacean packstone, L) stromatoporoid floatstone, M) coral-stromatoporoid rudstone-framestone, N) laminated mudstone-peloidal packstone, and O) microbial bindstone. These lithofacies have been grouped into five lithofacies associations: ramp, platform interior, platform slope, isolated reef, and basinal salina. The ramp association (lithofacies A, B, C, D) comprises the Lower Winnipegosis Member/Elm Point Formation and includes deposits of inner to mid-ramp settings as well as off-shore tidal flat islands. The platform interior association (lithofacies D, H, I, O) and platform slope association (lithofacies D, F, G, H, I, M, N, O) comprise the Upper Winnipegosis Member and include deposits of open to slightly restricted lagoonal and lower to upper slope settings respectively. The isolated reef association (lithofacies I, J, K, L, M, N, O) occurs in the Upper Winnipegosis Member isolated reef deposits and includes proto-reef, lagoonal, fore-reef, reef-crest, and reef flat deposits. The basinal salina association (lithofacies D, E) comprises the Ratner Formation.

Bituminous laminites (lithofacies D) occur in the ramp-to-platform and ramp-to-basin transitions, platform interior and platform slope successions, and in basinal successions. Based on examination of representative samples of these bituminous laminites using white and ultra-violet incident light microscopy, organic facies indicative of either normal or elevated phytoplankton productivity (blooms) were interpreted based on the maceral assemblages present. Bituminous laminites in the study area were deposited primarily as a result of elevated phytoplankton productivity; three bloom facies were identified: BL1, cyanophyte blooms; BL2, cyanophyte and Prasinophyte blooms; and

BL3, calcisphere-producing phytoplankton blooms. They are best developed in stratigraphic intervals associated with changes in depositional regime including the transition from ramp-to-platform/basin and from an open to restricted basin at the end of Winnipegosis time.

Organic geochemical analyses were also conducted to evaluate the kerogen type, extent of thermal maturation, and the petroleum generative potential of the bituminous laminites. Data from Rock Eval pyrolysis analyses, which were plotted on modified van Krevelen diagrams, indicate that bituminous laminites within the study area are geochemically varied, but most samples plot between Type II and Type III kerogen fields. Additionally, all analyzed bituminous laminites are thermally immature with respect to hydrocarbon generation; however, one laminite in the Lower Winnipegosis Member, which is the most southwestern and deepest one in the study area, has approached the onset of catagenesis.

The Winnipegosis Formation is best known for its isolated reef petroleum plays in Saskatchewan; however at least three other plays exist: platform margin, platform interior, and basin laminites (Ratner Formation). In the study area, previously documented and newly found oil shows from cores and cuttings indicate that an unknown quantity of petroleum has migrated through parts of the study area. However, there has been no petroleum production from the Winnipegosis Formation in Manitoba to date.

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CHAPTER 1: INTRODUCTION

1.1 Prologue

The occurrence of Devonian reefs in the subsurface of the Western Canadian Sedimentary Basin has been of paramount significance to the economy of western Canada as the Devonian System historically has been the most prolific conventional oil-producing interval in Western Canada (e.g., Wendte, 1992).

The impetus for hydrocarbon exploration in reefs in the Middle Devonian Winnipegosis Formation of southern Saskatchewan and North Dakota was the reef discoveries in the Keg River Formation of the Rainbow-Zama trend in northwestern Alberta (Precht, 1986). The Keg River reefs are coeval with the Winnipegosis reefs. According to early estimates, these Keg River reefs had total hydrocarbon reserves greater than $159x10^6$ m^3 with per well recoverable reserves often in excess of $159x10^3$ m^3 (Barss et al., 1970). After many dry wells, discoveries during the 1980's in southeastern Saskatchewan included the Hitchcock area isolated reefs, as well as the Tableland isolated reef, which had estimated recoverable hydrocarbon reserves of $2.5x10^5$ m^3, and the Temple Field in the western platform margin of North Dakota, which had defined recoverable hydrocarbon reserves of $1.03x10^6$ m^3 (Ehrets and Kissling, 1987; Martindale and MacDonald, 1989).

In comparison to the Winnipegosis Formation in Saskatchewan, North Dakota, and the equivalent Keg River Formation in Alberta, the Winnipegosis Formation and other Devonian strata in Manitoba have received little study and their full economic potential is

poorly known. This study focuses on the sedimentology, organic petrology and organic geochemistry of the Winnipegosis Formation and associated Elm Point and Ratner formations at the eastern margin of the Elk Point Basin in the southwest corner of Manitoba.

1.2 Geologic Setting

Devonian strata of the Western Canadian Sedimentary Basin (WCSB) occur in a widespread belt extending from the Arctic Ocean and the Alaska-Yukon border to southwestern Manitoba, and continue into the north-central United States (e.g., Perrin, 1987; Wendte, 1992). These strata include a diverse variety of depositional facies with recurring lateral and vertical relationships (e.g., Wendte, 1992). Rudimentary facies belts include platform carbonates and evaporites, reefal carbonates, and basin-filling shales, limestones and evaporites.

Generally, Devonian deposition in the WCSB is interpreted to be characterized by steady transgression interrupted by brief regressive pulses (e.g., Moore, 1988). Consequently, Devonian strata are divided by discontinuities into five sequences: (1) Delorme sequence, (2) Bear Rock sequence, (3) Hume-Dawson sequence, (4) Beaverhill-Saskatchewan sequence, and (5) Palliser sequence. Each sequence began with an influx of siliciclastics, followed by deposition of platform carbonates and mound building; reef-building was only attained during the third and fourth sequences.

The Hume-Dawson sequence was deposited during the Middle Eifelian to Middle Givetian (e.g., Moore, 1988). During this time, the northern region of western Canada had deepened to form an open platform and the Keg River Barrier (Presqu'ile Barrier) had built across the area northeastward of the Peace River Arch. The elongated, intracratonic Elk Point Basin formed behind the barrier where sub-basins had coalesced and extended from northeastern British Columbia and the District of Mackenzie southeastward into the Williston Basin of southern Saskatchewan and Manitoba, and northern North Dakota and Montana (e.g., Norris et al., 1982; Moore, 1988; Meier-Drees, 1994) (Fig. 1.1). Carbonate rocks in the Hume-Dawson sequence deposited in this basin are assigned to the Keg River Formation in Alberta and the Winnipegosis Formation in Saskatchewan, North Dakota, and Montana, and to the Winnipegosis and Elm Point formations in Manitoba (e.g., Norris et al., 1982; Perrin, 1987; Moore, 1988).

As the sea transgressed to its maximum extent, the Elk Point Basin differentiated into two regions: a shallow fringing carbonate platform and a bathymetrically deeper basin (Perrin, 1982). In Manitoba, this differentiation appears to be at least partially tectonically controlled as the platform margin lies coincident with the Birdtail-Waskada Axis, which is a trend manifested as structural and isopach anomalies in Phanerozoic strata that overlie the Precambrian Superior Boundary Zone (e.g., McCabe, 1971) (Fig. 1.2). Swarms of isolated reefs grew up to 200 m high in response to deepening sub-tropical to tropical waters (e.g., Moore, 1988; 1989a). At the end of Winnipegosis time, the Elk Point Basin became restricted and the basin was filled by laminated/ interlaminated carbonate and anhydrite (Ratner Formation) followed by the deposition of