LIARD BASIN – MIDDLE DEVONIAN EXPLORATION

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ABSTRACT

The Liard Basin is a sub-basin of the Western Canada Sedimentary Basin (WCSB) system, straddling the Northwest and Yukon Territories boundary with the Province of British Columbia. The basin contains over 5 km of sedimentary strata of Cambrian through Upper Cretaceous age.

Exploration for Manetoe Dolomite reservoirs hosted within middle Devonian carbonates of the Dunedin and Nahanni formations began in the 1950's. Several pools have been found within the fold and thrust belt both in Northeastern British Columbia and the Yukon and Northwest Territories. Recent gas discoveries within the Devonian Nahanni Formation north of Fort Liard, NWT has renewed interest in this play. Resource assessments for the middle Devonian play in the Liard Basin estimates between 2.8 and 6.6 Tcf undiscovered gas, with approximately 2.5 Tcf estimated to be located within Northeastern British Columbia.

The British Columbia Ministry of Energy and Mines (BC MEM) is currently working with the University of Regina and the Geological Survey of Canada (GSC) to expand our knowledge and understanding of the Liard Basin. Through a contribution agreement, the BC MEM, in conjunction with Dr. Osman Salad Hersi of the University of Regina, is supporting graduate level studies on the sedimentology, stratigraphy and diagenesis of Middle Devonian, shallow-marine carbonates of the Dunedin Formation of subsurface Liard Basin, with application to petroleum exploration. The BC MEM also continues their relationship with the GSC, who has recently published a reinterpretation of the Bovie Structure which included the identification of new conceptual plays within the Liard Basin.

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INTRODUCTION

The Liard Basin is a sub-basin of the extensive Western Canada Sedimentary Basin (WCSB) system, straddling the Northwest and Yukon Territories boundary with the Province of British Columbia. The basin covers a total area of approximately 2.5 million hectares with up to 5000 m of Paleozoic and Mesozoic sedimentary fill. The Liard Basin is a frontier basin whose hydrocarbon potential is only just beginning to be appreciated.

The eastern boundary of the Liard basin is delineated by the Bovie Fault System, which also marks the approximate eastern limit of Mississippian through Upper Cretaceous strata (Monahan, 2000). Recent work by the Geological Survey of Canada (GSC), supported by the British Columbia Ministry of Energy and Mines (BC MEM) has reinterpreted the nature and history of the Bovie Structure (MacLean, 2002; MacLean and Morrow, 2004). MacLean and Morrow (2004) have reinterpreted the Bovie Fault as a two-stage compression; (i) a late-Carboniferous to Permian westward convergent steeply dipping thrust fault, which is cut by (ii) the Larimide aged Bovie Lake Thrust. This reinterpretation of the Bovie Structure has also identified several potential play types in Devonian, Carboniferous and Cretaceous strata associated with the Bovie Fault (MacLean and Morrow, 2004).

The western side of the Liard Basin is referred to as the Liard Plateau or the Liard Fold and Thrust Belt, a northward continuation of the fold and thrust belt of the Rocky Mountain foothills. Within this area, several hydrocarbon pools have been discovered within carbonates of the middle Devonian and several gas shows have been found at Mississippian through Permian intervals. The middle Devonian carbonate play type has upwards of 2.35 Tcf of remaining undiscovered gas in place within Northeastern British Columbia (NEB, 2000). The stratigraphy, sedimentology and diagenetic history of the middle Devonian Dunedin Formation of British Columbia is the focus of a multi-year collaboration between the University of Regina and the BC MEM.

A geological map of the Liard Basin has been created and is now available to aid exploration. The 1:250 000 scale map is a compilation of geology maps separately issued by the Geological Survey of Canada and has been updated with infrastructure, land tenure and petroleum and natural gas wells for the entire Liard Basin. Production data and Drill Stem Test results and interpretation for the middle Devonian have also been summarized.

GEOLOGIC SETTING, PALEOGEOGRAPHY, AND STRATIGRAPHY

Dunedin Formation

In the Devonian Period, NE BC and nearby regions of Alberta, Yukon and Northwest Territories were cut by several rifting events that produced deep depressions and uplifted shoulders that later became shallow marine shelf areas (Cecile *et al.* 1997, Pyle *et al.* 2003). The Macdonald-Mackenzie shelf was the most prominent in northeastern British Columbia and nearby regions, allowing deposition of thick carbonate successions that include the largest carbonate reservoirs in the region (Moore, 1989, Pyle *et al.* 2003).

The Dunedin Formation consists of Middle Devonian (Eifelian) carbonate strata that were deposited on the MacDonald Shelf. The shelf continued across the B.C.'s border with the Yukon and Northwest territories where equivalent strata, the Landry-Nahanni formations, were deposited. Southward (i.e., Southern NE BC and NW Alberta), the Dunedin Formation merges with the prolific Keg River Formation (Nadjiwon, 2001). These middle Devonian carbonates contain hydrothermally dolomitized facies (Manetoe dolomite facies and equivalents; see below) with potentially good reservoir quality.

The Dunedin Formation is a transgressive unit dominated by peritidal and subtidal shallow marine carbonates and, due to southward facies retrogradation, the Besa River Formation oversteps the Dunedin Formation in the southeastern (Morrow, 1978, Nadjiwon, 2001). Broad subdivision of the Dunedin Formation documents that the formation consists of a lower lithofacies characterized by a bioclastic dolomitic wackestone and an upper lithofacies of a bioclastic grainstone to wackestone units (Morrow, 1978, Nadjiwon, 2001). Further south, where the formation passes to the reefal Keg River Formation, intercalations of coral and stromatoporoid reef facies are common. Due to the reefal "tongues", the thickness of the Dunedin Formation varies significantly (e.g., from 108 m to over 300 m within a distance of 11 km, Nadjiwon *et al.*, 2000), however, causes of this abrupt thickness change are not clear. Possibilities may include synsedimentary faulting and/or establishment of reefal margin defined by differential reef growth responses to sea level fluctuations (cf. transgression-instigated catch-up situation of Jones and Desrochers, 1992). The Dunedin Formation continues across the northern provincial-territorial borders where it is equivalent with the gas-producing Landry-Nahanni Formation in the Yukon and Northwest territories.

The Manetoe Dolomite Facies

Dolomites associated with subsurface middle Devonian carbonates of southeast Yukon Territory, southwest Northwest Territories and NE BC host one of the world's largest Mississippi Valley-type (MVT) deposits (Rhodes *et al.* 1984, Qing, 1998). These dolomites are also important gas reservoirs (Collins and Lake, 1989, Morrow and Davies, 2001). The dolomitized strata are known as the Manetoe Dolomite Facies (Manetoe) in the Northwest and Yukon territories (Morrow and Potter, 1998; Morrow *et al.* 1986, 1990); they form good reservoir intervals in many gas-producing fields in the region (e.g., Pointed Mountain, Kotaneelee, Fort Liard, Beaver River and Crow River gas fields). The Manetoe is characterized by a fractured and brecciated white sparry dolomite (Morrow *et al.* 1990; Morrow and Potter, 1998). Although the Manetoe dolomite facies that occur within the Dunedin and Nahanni-Landry successions of Yukon and NWT, respectively are fairly well documented (Morrow and Potter, 1998; Morrow and Davies, 2001, Morrow *et al.* 1986, 1990), knowledge is lacking in NE BC, as the equivalent dolomites of the Dunedin Formation are relatively less understood. Understanding the origin, fabric, porosity, reservoir potential and vertical and lateral distributions of this dolomite facies is essential for gas exploration activities within this prospective frontier basin.

MIDDLE DEVONIAN HYDROCARBON POTENTIAL

Fold and Thrust Belt

Exploration to date for middle Devonian Manetoe Dolomite within the Dunedin and Nahanni formations has been focused within the Liard Fold and Thrust Belt. The Liard fold and thrust belt of BC covers an area of approximately 1.25 million hectares. Exploration has resulted in the discovery of two fields, Beaver River and Crow River. Outside of these two fields, only 6 exploration wells have been drilled targeting the middle Devonian, all drilled prior to 1974. Within the Yukon and NWT, a total of 5 middle Devonian fields have been discovered with less than 10 exploration wells outside of proven fields.

Exploration within the Liard basin began in the 1950's with the first well drilled in the Liard Fold belt at the Toad River Anticline (Joint Venture No. 1 c-10-E/94-N-7; rig released in 1954). Amoco Canada Petroleum Co. Ltd. made the first discovery at the Beaver River Field in 1958. Further drilling delineating the Beaver River pool and subsequent discoveries were made in the 1960's at Pointed Mountain in the North West Territories and Kotaneelee, Yukon Territory. Originally over 1.4 Tcf of reserves were associated with the Beaver River pool alone, however, high water to gas ratios resulting from the highly fractured reservoir and active water drive led to lower than expected recoveries from these fields, which were subsequently shut-in during the mid-1970's (see Davidson and Snowdon, 1978). Recent exploration has resulted in new pools being discovered in the Fort Liard region, NWT. Beyond this however, there has been only limited exploration for Devonian aged reservoirs within the Liard Basin.

In the past, resource assessments have been conducted with the aim to identify the resource potential of the Liard Basin. The National Energy Board (NEB) assessed the resource potential for the NE BC portion of

the play to be 2.5 Tcf of ultimate resource total, with 2.35 Tcf remaining undiscovered. A 2001 assessment of the Manetoe Facies reservoirs in the Yukon assigned an IGIP of 3.4 Tcf. This is a total ultimate resource potential of 5.9 Tcf, though it does not include the NWT. For the entire fold and thrust belt, the natural gas potential in Canada was assessed in 2001 by the Canadian Gas Potential Committee (CGPC) as a total IGIP of 5.6 Tcf (CGPC, 2001), with 2.8 Tcf remaining undiscovered, mainly in middle Devonian reservoirs.

Basin Center / Bovie Fault Zone

The center of the basin between the western foothills and the Bovie Fault zone covers approximately 1.0 million hectares. Within this immense area only two wells, Amoco *et al.* La Biche (a-67-D/94-O-13 RR: 1974-08-28) and Burlington Chevron Patry (c-86-B/94-O-5/02 RR: 2000-01-25), have penetrated middle Devonian carbonates. Subsea depth to the middle Devonian carbonate in these wells is -4635m (15,207') and -3696m (12,126') respectively. Burlington Chevron Patry found dolomite at a depth of -3846 m (subsea). However, of these wells, only Amoco *et al.* La Biche was tested. Two drill stem tests were run over the middle Devonian carbonate, with an inhibited water cushion of 2590m. No blow was recorded during the flow and recoveries were not recorded, as the tool became stuck in the hole following the second test, however, a sample bomb did recover gas (97% C1) from the second DST. These wells indicate that both dolomite and gas are present within the middle Devonian carbonates of the Liard Basin center.

To date, no resource assessment has been made for the middle Devonian within the Liard Basin center. However, conceptual plays along the western margin of the Bovie Structure were identified by MacLean and Morrow, 2004.

FUTURE WORK

The sedimentologic, stratigraphic and diagenetic attributes of the Dunedin Formation and its basin-fill architecture of the Middle Devonian Dunedin Formation (NE BC) are not well understood despite the high potential of hydrocarbon content. In order to attract industry interest to this frontier basin, a clear understanding of these attributes and reservoir qualities of the Dunedin Formation is crucial. The Ministry of Energy and Mines is working with Dr. Osman Hersi of the University of Regina through a contribution agreement supporting graduate level studies on the sedimentology, stratigraphy and diagenesis of Middle Devonian Dunedin Formation shallow water carbonates of subsurface Liard Basin, with application to petroleum exploration. The objective of the proposed study is essentially two-folded: 1) to study the microfacies, lithostratigraphic and biostratigraphic attributes of the formation, its vertical and lateral lithofacies variations and correlations and a model for its depositional setting; and 2) to decipher the diagensis, origin, areal and vertical distributions and reservoir characteristics of the dolomite facies associated with the formation (i.e., Manetoe-equivalent dolomite facies). These goals are achievable by performing and integrating detailed sedimentological, lithostratigraphic, biostratigrpahic analyses, 3-D lithofacies mapping of the formation (integrating subsurface data with interpretation of seismic profiles) and detailed diagenetic studies, porosity evolution and reservoir characterization of the formation. Integration of these data interpreted in the light of sequence stratigraphic approach will also better constrain the 3-D evolution of the depositional systems through time and space. This will eventually enhance our understanding of the lateral and vertical distributions of the reservoirs. The overall scope of the proposed research is the enhancement of our knowledge with respect to the nature and internal architecture of this formation, diagenesis and subsurface distribution of the dolomite facies associated with the formation and reservoir characterization of both dolomitized and undolomitized intervals of the formation.

The Ministry of Energy and Mines continues their relationship with the Geological Survey of Canada (GSC) through support for their ongoing work on the Liard Basin. The Geological Survey of Canada is continuing interdisciplinary studies incorporating seismic, stratigraphy and source rock studies (see Morrow *et al.* 2002; Morrow and Shinduke, 2003; Potter *et al.*, 2003; Maclean and Morrow, 2004).

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