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Sedimentology and Stratigraphy of Middle and Upper Devonian Carbonates in Northern Alberta: A Contribution to the Carbonate-Hosted Pb-Zn (MVT) Targeted Geoscience Initiative

Alberta Energy and Utilities Board

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B. E. Buschkuehle

Alberta Geological Survey

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Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca

Web site: www.ags.gov.ab.ca

Cover photo: Limestone bank (resistant) and off-bank (recessive) facies of the Middle Devonian Moberly Member, Waterways Formation, Athabasca River near Fort McKay, northeast Alberta

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Acknowledgements

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Abstract

Outcrops of Middle and Upper Devonian carbonates in northern Alberta were examined as part of the Mississippi-Valley-Type ore deposit Targeted Geoscience Initiative (MVT-TGI) that was jointly supported in Alberta by the Alberta Geological Survey and the Geological Survey of Canada between April 1, 2001 and March 31, 2003. The Middle Devonian Methy Formation which is exposed along the Clearwater river consists of fossiliferous dolomitic limestone to dolostone, that was deposited in a moderate to high-energy fore-reef to reef environment. Faulting and minor amounts of saddle dolomite occur close to a reported galena occurrence at Whitemud Falls on the Clearwater River. The Middle Devonian Waterways Formation is best exposed along the Clearwater and north Athabasca Rivers and their tributaries. The basal Firebag Member consists of interbedded fossiliferous limestones and shales that were deposited in an open marine, low to moderate energy setting. The overlying Calumet Member contains interstratified shale and fossiliferous limestone banks, which were deposited in a basinal to fore-reef, moderately agitated, setting. The Christina Member consists of marlstone and limestone with fossiliferous banks, that represent occasional storm events in a below wave base depositional setting. The stratigraphically highest Member, the Moberly, contains fossiliferous limestones with calcareous shales and is partially dolomitized. It displays storm units and represents a high energy setting transitional between bank/reef and bank margin/fore reef environments. Late diagenetic features are rare to absent in the Waterways Formation. The Upper Devonian Mikkwa and Grosmont Formations were examined at Vermilion Chutes on the Peace River. The Mikkwa Formation changes upward from basal limestones and mud-wackestones to bank and reefal dolostones. The overlying Grosmont Formation changes upward from a dolomitic bank to a reefal dolostone. Minor calcite and saddle dolomite cements are present.

1 Introduction and Stratigraphic Overview

A sedimentological and stratigraphic study of Upper and Middle Devonian carbonates in northern Alberta was done at the AEUB/AGS as part of the Mississippi-Valley-Type Targeted Geoscience Initiative (MVT TGI) that was jointly supported in Alberta by the Alberta Geological Survey and the Geological Survey of Canada between April 1, 2001 and March 31, 2003.

The Upper and Middle Devonian carbonate successions (Table 1) in northern Alberta form a west dipping wedge, which crops out onto the Canadian shield about 150 km east of Fort McMurray as well as along the Athabasca, Clearwater, Peace River and other smaller river valleys. The rocks in the area have been described by MacDonald (1955), Crickmay (1957), Norris (1963), Cutler (1983), as well as numerous other authors. The Middle Devonian and Upper Devonian are comprised of three Groups in northern Alberta. Two of these Groups crop out in the Ft. McMurray region. One is the Elk Point Group, which represents the initial open-marine inundation of the Alberta Basin (Campbell, 1992a). The maximum thickness of the Elk Point Group in the Alberta Basin is about 500 to 600 m. The Elk Point Group can be further subdivided into the salt-bearing Prairie Formation and the dolomitic Methy Formation, which is equivalent to the Keg River/Winnepegosis reefal carbonates in other parts of the Alberta Basin.

Table 1. Generalized stratigraphy for northern Alberta (modified after Norris, 1963 and Hamilton, 1971).

<table>
<tr><th>System</th><th>Group</th><th colspan="2">Formation</th><th>Member</th></tr>
<tr><td rowspan="3">Upper
Devonian</td><td rowspan="3">Woodbend</td><td colspan="2">Grosmont</td><td>Hondo</td></tr>
<tr><td>Mikkwa</td><td>Ireton</td><td rowspan="2"></td></tr>
<tr><td>Cooking Lake</td><td>Hay River</td></tr>
<tr><td rowspan="8">Middle
Devonian</td><td rowspan="5">Beaverhill Lake</td><td colspan="2" rowspan="4">Waterways</td><td>Mildred</td></tr>
<tr><td>Moberly</td></tr>
<tr><td>Christina</td></tr>
<tr><td>Calumet</td></tr>
<tr><td colspan="2">Slave Point</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Ft. Vermilion</td></tr>
<tr><td rowspan="3">Upper Elk point</td><td colspan="2">Prairie</td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Methy</td><td>Keg River</td></tr>
<tr><td>Winnepegosis</td></tr>
</table>

The carbonates of the Methy Formation were deposited in a shallow marine environment with a tropical climate. An increased evaporation rate lead to the deposition of the Prairie evaporites and terminated reef growths of the Methy Formation. The Methy Formation crops out along the Clearwater River about 75 km east of Fort McMurray. Prairie Formation evaporites do not crop out and therefore are not included in the description. The Upper Elk Point Group is overlain by the Beaverhill Lake Group, which constitutes the uppermost stratigraphic unit in the Fort McMurray region. This group includes the Ft. Vermilion, Slave Point and Waterways Formations, and may reach a total thickness of 220 m in the Alberta Basin. The Slave Point and Ft. Vermillion carbonates do not crop out in the Ft. McMurray region, and hence are not discussed further. The Waterways Formation crops out along the Athabasca, Clearwater, MacKay and Firebag rivers, and has been the focus of field work for this project. The

Waterways Formation can be further subdivided into five Members: the Firebag, Calumet, Christina, Moberly and Mildred Members. Each Member contains slightly different amounts of carbonate and shale, which is due to the intercalation of platform carbonates and deeper water facies along a leeward platform margin (Campbell, 1992b).

The Beaverhill Lake Group is overlain by the Upper Devonian carbonates of the Woodbend Group, which can be usually subdivided into Grosmont, Cooking Lake, Mikkwa, Hay River and Ireton Formations, and may be up to 700 m thick in central parts of the Alberta Basin. In the study area only the Grosmont and the Mikkwa Formations crop out along the Peace River at Vermillion Chutes (Cutler, 1983). The Grosmont and the Mikkwa represent shallow marine carbonates, with isolated reef growths, similar to the Middle Devonian Methy succession. The difference between the two reefal environments is that the evaporation state during Woodbend time did not reach saturation with respect to halite precipitation; hence in this case reef growth was terminated by the input of clastic material as opposed to evaporite deposition.

2 Lithology and Sedimentology

The lithological legend for the lithostratigraphic columns contained in this report is given in Figure 1.

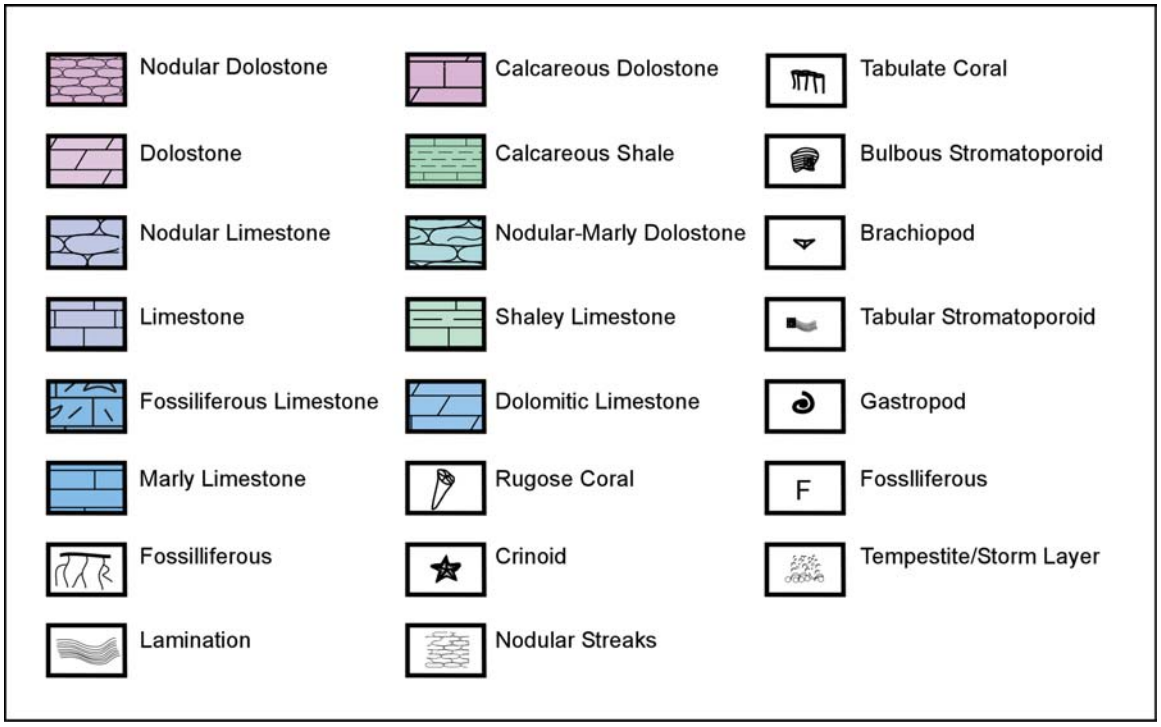

Figure 1. Legend for figures 3, 5, 6, 7, 8, 10.

2.1 Methy Formation (Upper Elk point Subgroup/Middle Devonian)

Station: BB018 Location: N 56.68987 / W 110.06390

The Methy Formation crops out along the Clearwater River. It is particularly well exposed at Whitemud Falls (Figure 2) where a maximum thickness of ~10 to ~12 m comprising four units can be described (Figure 3). The first unit is a light gray, dolomitic, fossiliferous limestone bank, which is medium grained and very resistant. It is overlain by an up to 200 cm thick, yellow-gray, calcareous dolostone, with crinoid

beds at the bottom and a range of bulbous to tabular stromatoporoids from bottom to top. This unit gradually changes into a very porous, pervasively dolomitized reefal bank of up to 350 cm thickness. Floating bulbous stromatoporoids and karst features are also observed. A 100 to 200 cm thick, grainy-sucrosic, dolomitic limestone with some occurrences of crinoids forms the top of the formation.

The Methy Formation represents the forereef-to-reef depositional environment, with moderately to highly agitated water on a carbonate platform. Porosity types range from interparticle to moldic and vuggy porosity and may average up to 25%. Some minor amount of saddle dolomites and calcite cement occur in vugs and fractures of the rocks

Figure 2. The Middle Devonian Methy Formation, Whitemud Falls, Clearwater River. Plate 1a - d, Methy Formation outcrop, Whitemud Falls, Clearwater River. The formation is a fossiliferous (crinoids, stromatoporoids) dolomitic limestone to dolostone representing a forereef to reef depositional environment with up to ca. 25% porosity. It is locally faulted, oxide altered (hematite) and with minor saddle dolomite. Carrigy (1959) reports a nearby galena occurrence associated with organic matter.

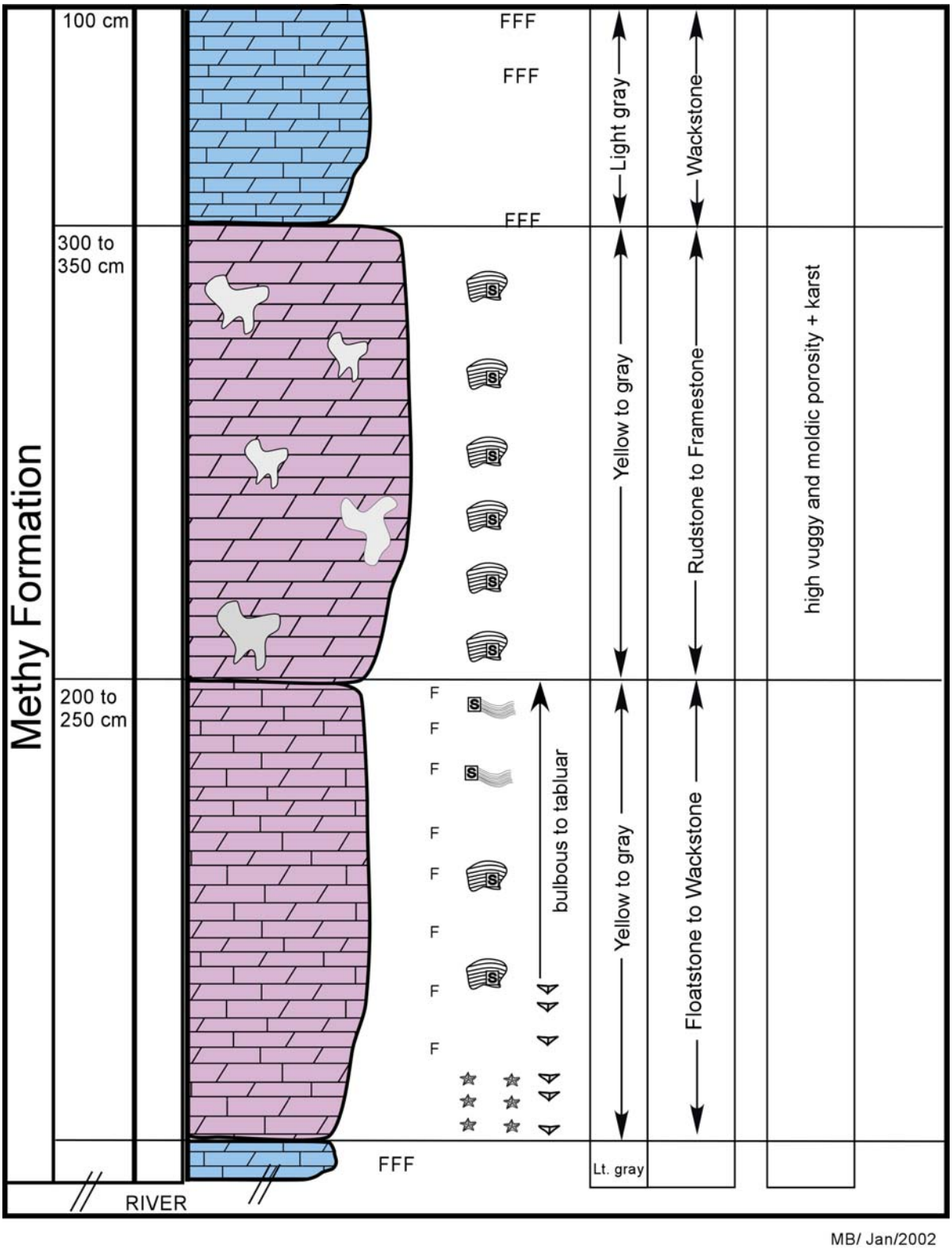

Figure 3. Lithostratigraphy of the Middle Devonian Methy Formation.

2.2 Firebag Member (Waterways Formation/Beaverhill Lake Group/Middle Devonian)

Station: BB019 Location: N 56.75479 / W 110.50479

The Firebag Member was examined on High Hill River, a smaller northern tributary to the Clearwater River (Figure 4). The Firebag Member consists of three units with a total thickness of ~ 500 cm in the outcrop (Figure 5). The bottom unit #1 consists of dark grey to greenish, muddy to marly interlayers (1 to 4 cm) of limestone and shale, with an average thickness of 200 cm. Large brachiopods of Atrypa sp. are abundant.

Figure 4. The Middle Devonian Waterways Formation, Clearwater, High Hill and Athabasca Rivers. Plate 2a - d. Waterways Formation: a) Firebag Member - interlayered fossiliferous limestone and shale, High Hill River, representing a moderately agitated open marine setting b) Calumet Member - shale and fossiliferous limestone (bank), Clearwater River, representing a fore-reef to basinal setting in a moderately agitated open marine environment c) Christina Member - marlstone to limestone, Athabasca River near Ft. MacKay, representing a below wave base intermittently agitated marine environment with fossiliferous limestone banks constituting of occasional storm events d) Moberly Member - locally partially dolomitized fossiliferous limestone, marly limestone and calcareous shale, Athabasca River, containing storm layers, fossil banks and bioturbated hardgrounds. The environment is transitional between bank/reef and bank margin/fore-reef areas in an intermittently agitated high energy setting.

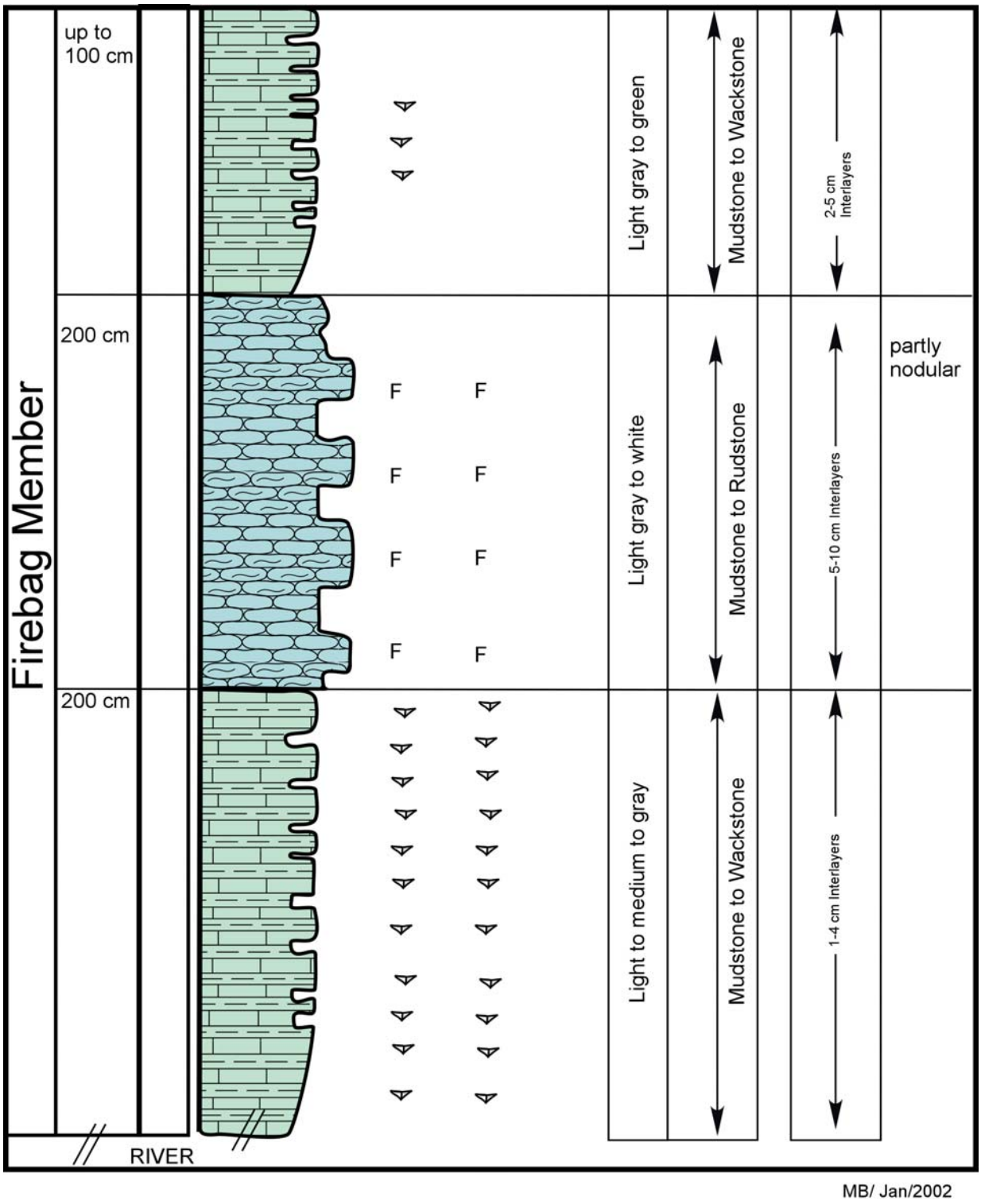

Figure 5. Lithostratigraphy of the Middle Devonian Firebag Member, Waterways Formation.

The overlying unit #2 is a light gray-to-medium-gray interlayering of limestones and marls that is ~200 cm thick. It contains less brachiopods and shale than unit #1, however a general higher amount of fossils exists, which makes this unit more resistant than the overlying and underlying units. The layers are in

the size range of 5 to 10 cm and the rocks are mudstones to rudstones.

Unit #3 is again an interlayering of gray to green limestones and shales and displays a wavy-nodular texture. The mudstone and wackestone contain various amounts of brachiopods and high amounts of shale. The Firebag Member has been deposited in an open marine, slightly to moderately agitated environment. The main pore types are interparticle and shelter voids with an average porosity not exceeding 5%. The main fossil assemblage consists of brachiopods. No late diagenetic products were observed.

2.3 Calumet Member (Waterways Formation/Beaverhill Lake Group/Middle Devonian)

Station: BB020 Location: N 56.67365 / W 110.84453

The Calumet Member was examined on the Clearwater River (Figure 4). It consists of two units with an average thickness of 50 to 100 cm in outcrop (Figure 6). The two units represent a single shallowing-upward cycle of 4th to 5th order. Unit #1 is a medium gray, shaly limestone to shale, which is only a few cm thick. The mudstones are fossil-free and very fine-grained. The overlying unit #2 consists of a resistant, light gray limestone bank with abundant brachiopods and crinoids, which may contain shaly/muddy interlayers.

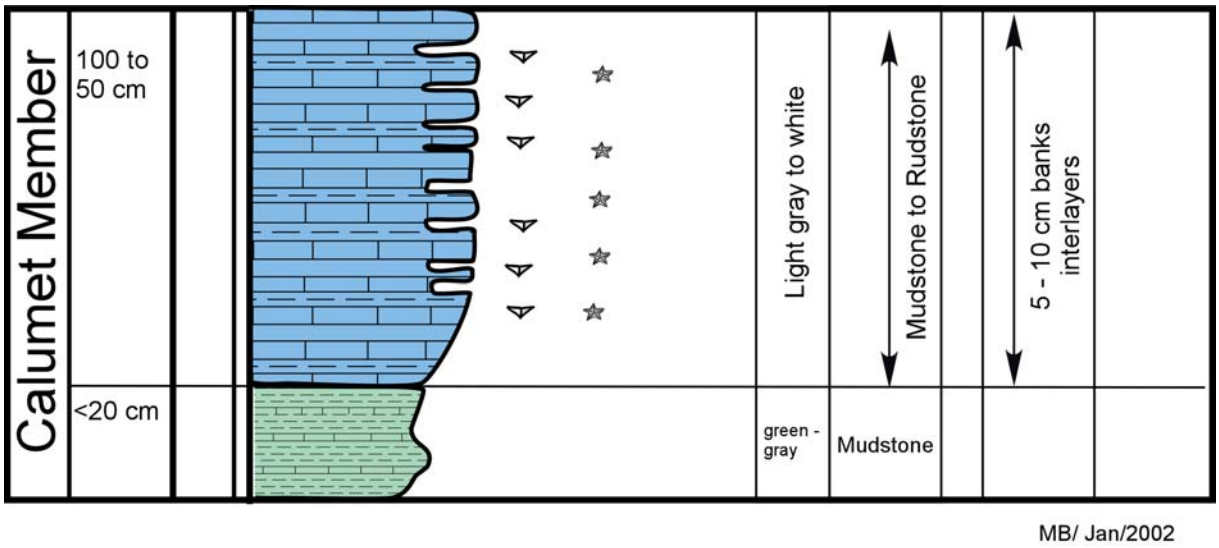

Figure 6. Lithostratigraphy of the Middle Devonian Calumet Member, Waterways Formation.

This unit has been deposited in an open marine, slightly to moderately agitated environment. The main facies types are rudstones to mudstones. The main pore types are interparticle and shelter voids with an average porosity not exceeding 5%. The main fossil assemblages are brachiopods and crinoids, indicating a quiet fore-reef to basinal environment. No late diagenetic products were observed.

2.4 Christina Member (Waterways Formation/ Beaverhill Lake Group/ Middle Devonian)

Station: BB016 Location: N 57.18859 / W 111.62738

This exposure of the Christina Member lies on the west bank of the Athabasca River just north of the community of Fort MacKay (Figure 4). The Christina Member consists of a light to medium gray limestone/marlstone unit that is about 7 m thick in the outcrop (Figure 7). The member starts with a

200 cm thick interbedding (10 cm scale) of nodular limestones and fossiliferous banks (mudstone/wackestones). A less resistant, crumbly mudstone unit of 60 cm thickness, which contains only small fossil debris, overlies it. A massive brachiopod floatstone bank of 25 cm thickness follows this unit that is in turn overlain by 50 cm of nodular-crumbly limestone with gastropods. Another resistant brachiopod bank of 60 cm thickness follows and the top of the outcrop is formed by a nodular limestone/marlstone unit of about 200 cm thickness.

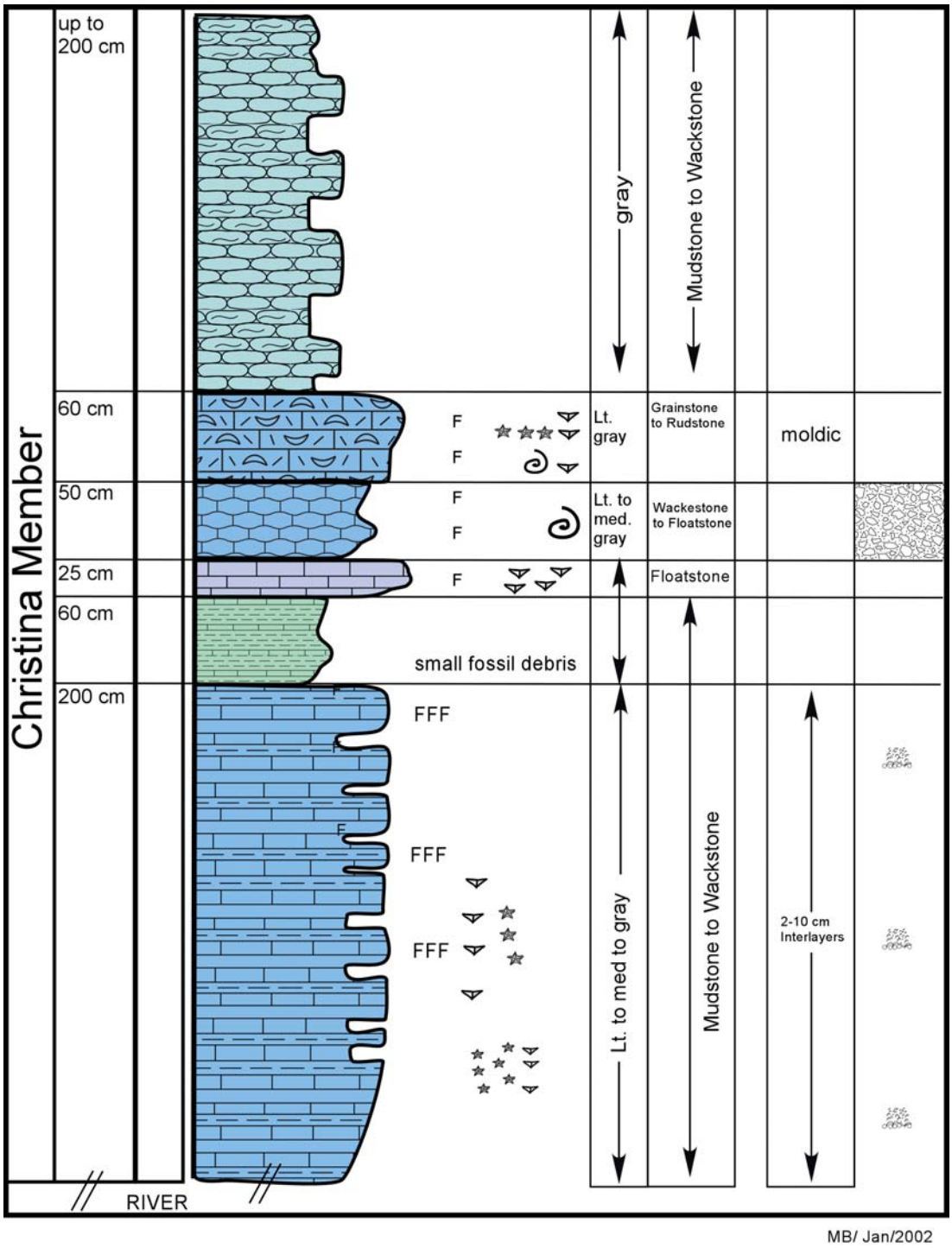

Figure 7. Lithostratigraphy of the Middle Devonian Christina Member, Waterways Formation.

The Christina Member represents a below wave base intermittently agitated marine environment. The generally quiet environment was interrupted by occasional storm events that caused the accumulation of relatively resistant fossiliferous banks. The porosity types are inter- and intraparticle and the porosity is rather low (<3%) due to high contents of micrite. The nodular texture of the limestones is synsedimentary to early diagenetic, and was formed in water saturated limestone/shale layers as a result of density inversions. No late diagenetic products were observed.

2.5 Moberly Member (Waterways Formation/Beaverhill Lake Group/Middle Devonian)

Station: various locations along the banks of the Athabasca river

The Moberly Member is well exposed along the Athabasca River north of Fort McMurray (Figure 4). It is comprised of light to medium gray, massive limestone units, fossiliferous marly limestones and interbedded calcareous shales, and can be partially dolomitized (Figure 8). The maximum thickness of the Member recorded during this study is about 12 m, however, Norris (1963) reports a thickness of up to 61 m. The bottom unit of the Moberly Member consists of about 100 cm of interlayered marlstone and limestone with various amounts of brachiopods and crinoids, which can be interrupted by tempestites. Wackestones to packstones are dominant with varying shale content. A 200 to 250 cm thick light gray stromatoporoid reef bank tops this unit. It is very massive, contains storm layers and several hardgrounds with bioturbated upper surfaces. The next unit is a 40 cm thick brachiopod/crinoid bank with a moderate amount of interbedded shale. A series of 6 to 7, 100 cm scale, shallowing upward cycles exists with a shaly marly bottom unit that grades into resistant fossiliferous limestone banks.
The Moberly Member represents the transition zone between the bank/reef and bank margin/fore-reef areas in an intermittently agitated high energy environment. Although small shallowing upward cycles (4^{th} to 5^{th} order) occur within the Upper Moberly, it generally represents a single higher order transgressive cycle.

Major porosity types range from moldic to interparticle porosity and the average porosity values may reach up to 25 % in the reefal areas, however it is usually not higher than 10 %. Main fossil constituents are brachiopods, crinoids and stromatoporoids. No late diagenetic products were observed.

2.6 Mikkwa Formation (Upper Devonian)

Station: BB023 Location: N 58.37720 / W 114.87341

The Mikkwa Formation crops out on the Peace River at Vermilion Chutes (Figure 9) and along Harper Creek with a maximum thickness of about 600 cm. The outcrop can be subdivided into six units with a basal light gray to reddish dolomitic limestone that contains small fossil debris (Figure 10). The second unit is a 100 cm thick, red/red-gray, fossiliferous limestone with large amounts of brachiopod shells. This unit is overlain by 40 cm of red-gray nodular limestone. A 110 cm thick, variegated red-gray nodular, less resistant, mud- to wackestone unit follows. Towards the top of the outcrop the limestones gradually change into fossiliferous dolostones, beginning with a 100 cm thick, yellowish -gray brachiopod bank, followed by a massive, up to 200 cm thick, yellow, reefal dolostone. The dolostone contains abundant rugose and colonial corals, as well as a few crinoids and were deposited on the reef bank. The rocks are highly porous (moldic) due to coral dissolution. The molds are often hydrocarbon stained and contain calcite and/or dolomite cements.

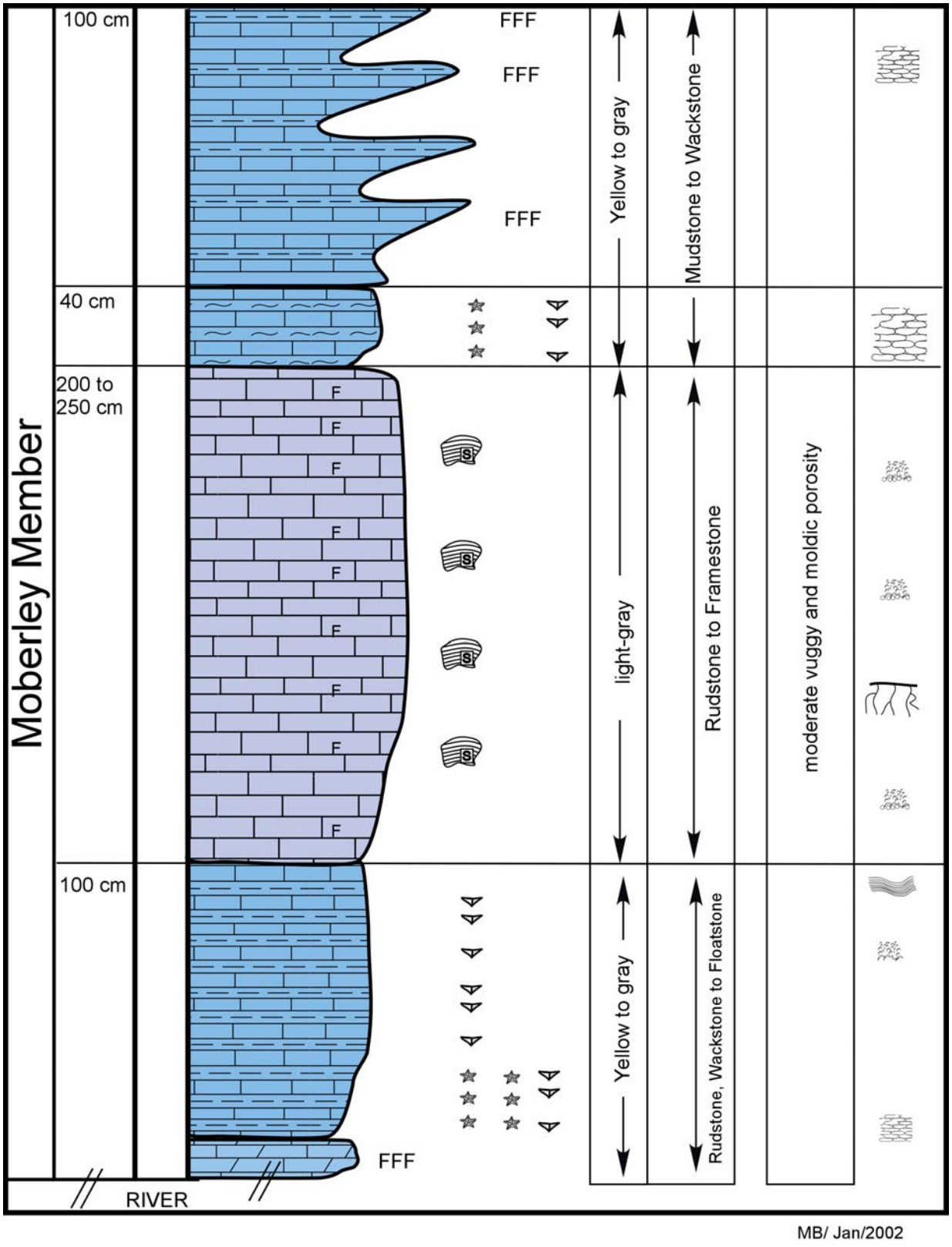

Figure 8. Lithostratigraphy of the Middle Devonian Moberley Member, Waterways Formation.

Figure 9. Upper Devonian Mikkwa and Grosmont Formations, Vermilion Chutes, Peace River. Plate 3a-d. Mikkwa and Grosmont Formations,Vermilion Chutes, Peace River: a, b) upper member Mikkwa Formation - this member is hematite stained throughout and changes from fossiliferous limestone with mud-wackestone to bank and reefal dolostones at the top as the transitional contact (top of outcrop in a.; level of helicopter in b.) with the overlying Grosmont Formation is approached. It represents a fore-reef to high energy reef-front environment. c, d) Grosmont Formation - this formation changes upward from a dolomitic coral bank to a fossiliferous, reefal, fabric-selective dolostone with moldic/vuggy porosity and hydrocarbon stain increasing downward toward the Mikkwa Formation. Green stain in a) and d) is zinc zap.

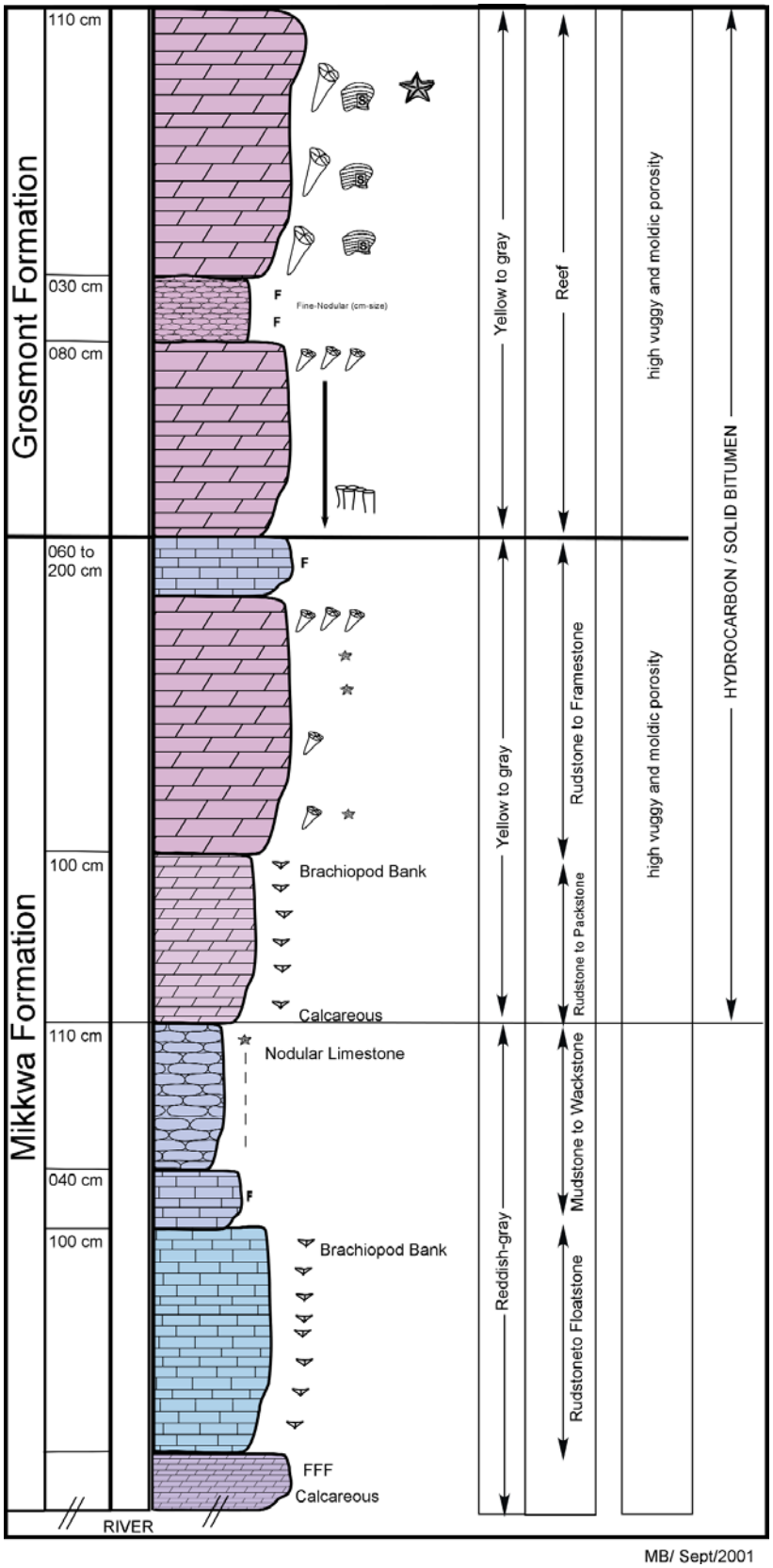

Figure 10. Lithostratigraphy of the Upper Devonian Mikkwa and Grosmont Formations.

2.7 Grosmont Formation (Upper Devonian)

Station: BB022 Location: N 58.37720 / W 114.87341

The Grosmont Formation is exposed on the Peace River at Vermillion Chutes and has an average thickness of 200 cm (Figure 9). It was examined at the same location as the underlying Upper Mikkwa Formation. It can be subdivided into three units (Figure 10) with a basal gray, 50 cm thick dolomitic (framestone) coral bank containing colonial (*Alveolites*/ *Halysites*) and rugose corals in growth position. It is followed by a finely nodular (cm-size), yellow to gray dolostone, which gradually changes into a fossiliferous, fabric-selective dolostone. This reefal unit displays laminar/wavy stratification and is highly fossiliferous containing crinoids, corals (*Thamnopora/Alveolites*) and stromatoporoids. Medium to high moldic/vuggy porosity exists and increases towards the underlying Mikkwa Formation. Hydrocarbon stain is moderate to rare, also increasing towards the underlying Mikkwa Formation. Previous industry exploration has returned 0.1% Zn from the Grosmont at this location but no visible Pb-Zn mineralization was observed during this study.

3 Conclusions

The Devonian sediments in the study area consist of dolostones, limestones, argillaceous limestones and shales. The faunal assemblage and facies diversity indicate a shallow marine depositional environment, with elevated temperature and evaporation rates during the Upper Elk Point Group, that led to the formation of the Upper Elk Point salt basin. Increased flooding during Beaverhill Lake time resulted in an interlayering of carbonate cycles, with each cycle representing shallowing up-ward sequences of third to fourth order. During the Upper Devonian the study area comprised an extensive carbonate platform with resulting reef growth. Carbonate deposition was eventually terminated by the input of terrigenous clastics during the end of the Frasnian.

The porosity varies between 0 % and 25%, with the highest porosities being in reefal carbonates. Calcite and saddle dolomite cements occur at least in the Middle Devonian Methy Formation and in the Upper Devonian Grosmont/Mikkwa Formation. These products, although minor in abundance, indicate a diagenetic pore fluid flow, which may have contributed to potential MVT ore deposits. The highest probability of finding MVT ore deposits will be in highly porous carbonates, since only these provide a sufficient accommodation space for fluids and mineral precipitates.

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