ERCB/AGS Open File Report 2012-19

Geology of the Upper Devonian Moberly Member (Waterways Formation, Beaverhill Lake Group) Outcrops in Fort McMurray, Alberta (NTS 74D/11)

Energy Resources Conservation Board

Alberta Geological Survey

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Abstract

The Upper Devonian Moberly Member (Waterways Formation, Beaverhill Lake Group) is described herein from outcrops along the Athabasca and Clearwater rivers. Major lithologies of the Moberly Member include bedded to nodular argillaceous limestones, *Thalassinoides*-burrowed limestone, and a stromatoporoid and brachiopod limestone. Lithostratigraphic correlation indicates that the oldest strata outcrop at the water treatment plant locality, and the youngest strata outcrop at the downstream-most location on MacDonald Island. Structural observations suggest that the investigated outcrops occur on the southern limb of a single 5+ km syncline or dome. Two smaller scales of parasitic folds occur at the Athabasca River and water treatment plant outcrops.

1 Introduction

The lower Frasnian Moberly Member of the Waterways Formation outcrops within the town limits of Fort McMurray along the banks of the Athabasca and Clearwater rivers. In this report, we describe outcrops south of the Athabasca River Bridge, near the water treatment plant, and from a cliff along MacDonald Island (Figure 1). Other outcrops on the Athabasca River are located upstream from the mouth of the Horse River, on the west bank of the Athabasca River opposite MacDonald Island, and along the confluence of the Clearwater and Athabasca rivers. These outcrops were not examined because of their stratigraphic similarity to visited outcrops or because of inaccessibility during the 2010 and 2011 field seasons due to water levels.

The Moberly Member outcrop near the water treatment plant is one of the most accessible Devonian outcrops of the Waterways Formation in northeastern Alberta. This outcrop is a good example of the lower Moberly Member and contains a biostromal unit that is widespread in Moberly Member outcrops along the Athabasca River. At this locality, the biostromal unit contains fragmentary and toppled, massive stromatoporoids in a brachiopod-rich limestone. Across the river, south of the Athabasca River Bridge and north of the Horse River mouth, the same unit outcrops near water level, but the stromatoporoids are intact and in growth position.

Like all Waterways Formation outcrops in northeastern Alberta, the Moberly Member is deformed due to the dissolution of halite and anhydrite of the Prairie Evaporite Formation at depth and the ensuing subsidence or collapse of overlying strata. As a result, the Moberly Member outcrops near the water treatment plant and the Athabasca River Bridge contain low-amplitude folds of 50 to 200 m and, to a lesser extent, faults with minor offset (Figure 2).

2 Previous Work

Warren (1933) named the Waterways Formation based on outcrops exposed at the confluence of the Clearwater and Athabasca rivers near the town of Waterways. Crickmay (1957) later divided the Waterways Formation into five members based on core from Bear Biltmore no. 1 well at L.S. 7, Sec. 11, Twp. 87, Rge. 17, W 4th Mer. (abbreviated 7-11-87-17W4). The outcrops observed by Warren (1933) and those described herein fall within the Moberly Member of the Waterways Formation (Norris, 1963).

Norris (1963) measured the outcrops along MacDonald Island (Norris stations 6 and 6a) and south of the Athabasca River Bridge (Norris localities 4 and 5), but never visited the outcrop near the water treatment plant. Norris (1963) reported three of his informally numbered units of the Moberly Member (38, 39, 40) from the MacDonald Island outcrop and two from south of the Athabasca River Bridge (39, 40). From base to top, Norris described the average thickness and lithology of these units throughout the region as follows:

Unit 40: 235 cm, recessive to resistant, light olive green, interbedded argillaceous limestone and calcareous shale, containing bivalves and brachiopods.
Unit 39: 94 cm, resistant, light brown, massive, sparsely fossiliferous limestone.
Unit 38: 88 cm, recessive, light olive green, rubbly, thin-bedded argillaceous limestone and calcareous shale, highly fossiliferous.

Buschkuehle (2003) described a consolidated section of the Moberly Member from various localities along the Athabasca River. She described four units, from base to top:

1) 100 cm: interbedded marlstone and limestone with brachiopods and crinoids. This unit contains tempestite beds.
2) 200 to 250 cm: stromatoporoid reef with tempestite beds and hardgrounds.

3) 40 cm: brachiopod and crinoid bank interbedded with shale.
4) 100 cm: 6 to 7 shallowing-upward cycles of shale and/or argillaceous carbonate grading up to resistant fossiliferous limestone.

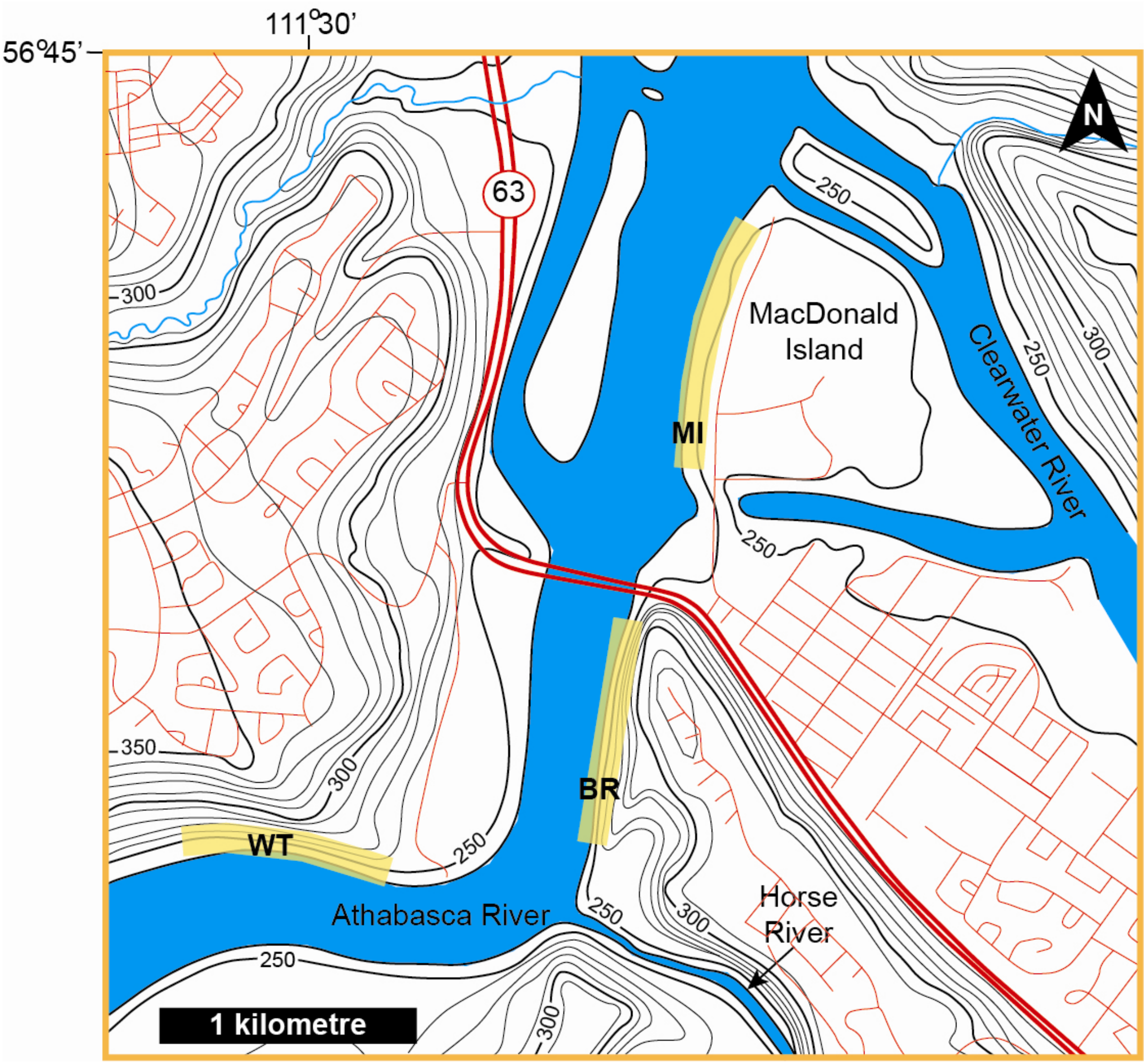

Figure 1. Location map of Moberly Member outcrops (highlighted in yellow) described in this report. WT = water treatment plant outcrop, BR = outcrop south of the Athabasca River Bridge, and MI = MacDonald Island outcrop. Measurements from BR and MI were taken approximately where the label is placed on the outcrop. The entire WT outcrop was examined for this report. Topographic major interval = 50 m; minor interval = 10 m.

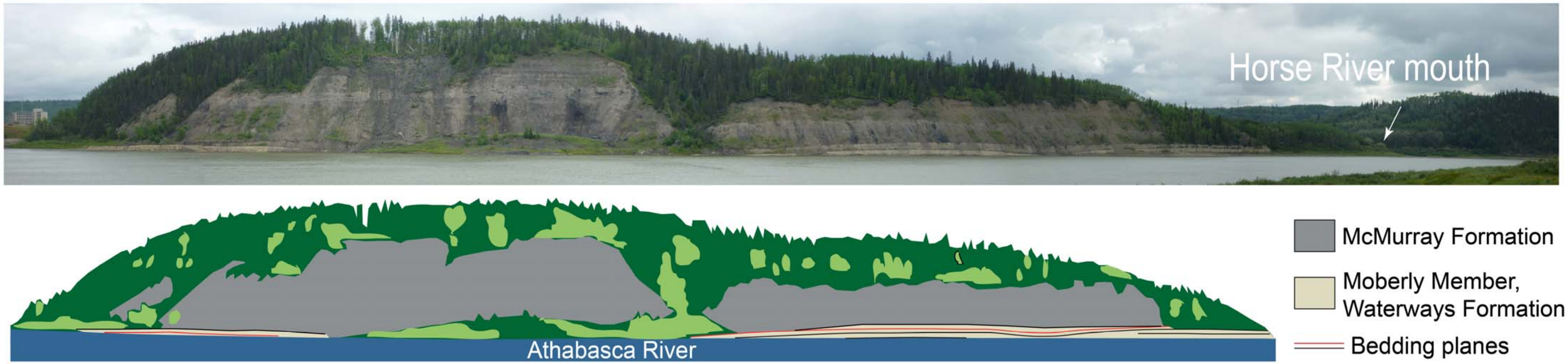

Figure 2. Moberly Member outcrop south of the Athabasca River Bridge in Fort McMurray on the east bank of the river.

3 Water Treatment Plant

3.1.1 Locality Description and Access

UTM Zone 12, 474769E, 6286353N (NAD83)

Drive along an unnamed access road to the water treatment plant. Continue past the plant on a small dirt road to the river bank. Park on the river bank and walk upstream to the outcrop.

If the river level is low, wade the river's edge along the rock wall to observe the western end of the outcrop. This portion of the outcrop is gently folded in five anticline-syncline pairs and is unconformably overlain by McMurray Formation oil sand or Pleistocene alluvium (Figures 3 and 4).

This outcrop contains typical Moberly Member fossiliferous limestone. Most beds contain brachiopods; a few are densely packed with brachiopod shells. One bed contains large pieces of stromatoporoids, all of which have been transported, given their fragmentation and random orientation. Most of the upper beds of the outcrop are bitumen stained, particularly along fractures.

The data presented herein were collected during two separate visits. Most of the outcrop was described in the first visit during the summer of 2010. Another visit to the outcrop in the summer of 2011 revealed the lowermost seven units, newly exposed during unusually high river levels earlier that summer. These lowermost beds were only visible behind a large boulder, where eddies presumably eroded the slumped talus of previous years.

The stratigraphic section starts from the lowermost exposed bed observed in 2011 and extends up to the sub-Cretaceous unconformity, where Devonian limestone is overlain by McMurray Formation oil sand or, where the oil sand has been eroded, Pleistocene alluvium. The outcrop was described at several localities along its length because folding, erosion, and slump resulted in intermittent accessibility of the upper- and lowermost beds. Most beds could be traced along the outcrop.

3.1.2 Stratigraphy

Measurements were taken at three spots along the outcrop. The base of unit 14 is easily traced throughout the outcrop and facilitated moving to new accessible locations.

From base to top, the outcrop contains the following units:

1) Approx. 30 cm, exposed with trenching: recessive, green, calcareous shale. The base of the shale is lost in talus (Figure 5).
2) 50 cm: recessive, light grey weathering, medium grey, 1 to 4 cm tabular to nodular-bedded, brachiopod rudstone in a lime mudstone to wackestone matrix. Fractures are bitumen stained (Figure 5).
3) 6 cm, three thin beds varying laterally in thickness: medium grey (weathering and fresh colour), crinoid and brachiopod rudstone in a wackestone matrix. Each bed contains a wavy, bioturbated, argillaceous lime mudstone crust up to 0.5 cm thick.
4) 45 cm: resistant, medium grey weathering, dark blue-grey, 1 to 2 cm tabular-bedded, nodular weathering, lime mudstone. Bedding surfaces contain *Planolites* burrows. A 2 to 3 cm thick, brachiopod and crinoid rudstone in a wackestone matrix occurs at 15 cm above the base. Another 4 cm brachiopod and crinoid rudstone, including long pleuricolumnals, occurs at 30 cm above the base (Figures 5 and 6).
5) 37 cm: recessive, light grey weathering and fresh, nodular weathering, *Thalassinoides* bioturbated, lime mudstone. Slightly resistant hardgrounds occur at 10 cm above the base and at the top of the unit (Figures 5 and 6).

6) 9 to 15 cm: recessive, light grey weathering, medium grey, centimetre-scale tabular to slightly wavy-bedded lime mudstone with millimetre-scale, green-grey, argillaceous partings. Fractures are bitumen stained. Pockets of crinoid columnals occur in the argillaceous partings (Figures 5 and 6).
7) 1 to 4 cm: resistant, medium grey weathering and fresh, sparry, crinoid rudstone in a grainstone matrix. A green, argillaceous, *Planolites*-burrowed crust occurs at the top of the unit. The entire unit is a three-dimensionally preserved, symmetrical ripple (Figures 5 and 6).
8) 14 to 27 cm: recessive, beige weathering, medium-grey, 1 to 3 cm tabular-bedded, nodular weathering, lime mudstone with greenish argillaceous partings. Fractures are bitumen stained. Unit and bed thicknesses vary laterally (Figures 5 and 6).
9) 1 to 9 cm: resistant, medium grey weathering and fresh, crinoid and brachiopod rudstone in a wackestone to packstone matrix. Fractures are bitumen stained. The weathered surface of the unit is hematite stained (Figures 5 and 6).
10) 38 cm: recessive, light grey weathering, medium grey, 1 to 2 cm tabular to nodular-bedded, lime mudstone with up to 0.5 cm argillaceous partings (Figures 5 and 6).
11) 6 to 9 cm: resistant, yellow-weathering, brown, brachiopod, gastropod and crinoid floatstone in a wackestone to packstone matrix (Figure 7). The lower and upper surfaces are uneven and wavy. This bed is highly variable in thickness along the outcrop (Figures 5, 6, and 7).
12) 14 to 30 cm: resistant, yellow-green-grey weathering, dark grey, brachiopod rudstone (coquina). Disarticulated atrypide and spiriferide brachiopods are concave-down (Figures 5 and 6).
13) 43 cm: recessive, green-grey-beige weathering, green-grey, interbedded 3 to 5 mm beds of brachiopod floatstone to rudstone in a wackestone matrix and 2 to 3 mm beds of calcareous shale. Some limestone beds are more resistant than others (Figures 5 and 6).

The section continues 100 m downstream:

14) Massive, resistant, beige-weathering, brown to beige-grey unit consisting of 3 sub-units (Figures 5, 6, and 8):
    a) 58 cm: brachiopod floatstone in a crinoid packstone to grainstone matrix. This sub-unit locally develops into a *Radiatrypa* rudstone, especially near the top. Single atrypide brachiopod shells are randomly oriented.
    b) 30 to 35 cm: stromatoporoid floatstone in a *Radiatrypa* rudstone matrix. Bulbous and domal stromatoporoids (15–30 cm in diameter) are toppled, fragmented, and randomly oriented. The majority of single brachiopod valves are oriented concave-down (Figures 9 and 10).
    c) 160 cm: brachiopod floatstone to rudstone in a wackestone to packstone matrix. Ten per cent of brachiopods are moldic and 25 per cent are articulated. Brachiopods are mostly *Radiatrypa* with sparse spriferides and rhynchonellides. The unit is sporadically bitumen stained.

The section continues 100 m downstream:

15) 20 cm: slightly recessive, grey weathering and orange stained, light grey lime mudstone with rare crinoid fragments. This unit varies in thickness laterally; it reaches a maximum thickness at the measured locality and thins to 10 cm elsewhere in the outcrop (Figures 5, 6, and 8).
16) 40 cm: recessive, brown weathering, medium grey, 1 cm bedded, nodular weathering, lime mudstone with fragmental brachiopods and millimetre-scale shale partings. This unit varies in thickness laterally, up to 70 cm thick elsewhere in the outcrop (Figures 5, 6, and 8).
17) 29 cm: resistant, beige weathering, light grey, bioturbated, brachiopod floatstone in a fragmentary brachiopod and crinoid wackestone matrix. Brachiopods become more abundant near the top of the unit. Brachiopods are disarticulated and commonly concave-down. Burrows are vertical, <1 cm in diameter, with striated sides (Figures 5, 6, and 8).
18) 165 cm: recessive, beige weathering, medium grey, 1 to 2 cm bedded, nodular weathering, crinoid-bearing lime mudstone with millimetre-scale shale partings. Nodule boundaries and fractures are bitumen stained (Figures 5, 6, and 8).

19) 95 cm: resistant, beige weathering, light grey and mottled, massive, *Thalassinoides* burrowed, brachiopod, crinoid, gastropod, and bivalve floatstone in a lime mudstone to wackestone matrix. The fauna contains several species of bivalves and gastropods. Burrows are light brown and, where burrow networks terminate at horizontal surfaces, form partings in the rock. The basal and top 35 cm are more heavily burrowed than the middle of the unit (Figures 5 and 8).
20) 37 cm: recessive, light grey weathering, medium grey, 1 cm nodular-bedded lime mudstone. Nodule boundaries are bitumen stained. The top of the unit is eroded (Figures 5 and 11).

3.2 Paleoenvironmental Interpretation

The base of the outcrop is a calcareous shale. Because the majority of the overlying beds are fossiliferous and/or heavily bioturbated limestone, this basal unit represents the deepest facies within the outcrop. This basal unit formed under quiet water conditions and in deeper water than overlying units.

The limestone units at this outcrop accumulated on the shallow shelf below fair-weather wave base and above storm wave base. Overall, shelly and trace fossils are typical of shallow water and muddy substrates. Common to abundant gastropods in units 11 and 19 suggests very shallow water. The remaining fauna in these units indicates that the paleoenvironment was sublittoral.

The disarticulation and degree of fragmentation of fossils suggests low sedimentation rates with high energy events. The fracturing and abrasion of fossils, the vertical distribution of allochems, and the pattern of brachiopod orientation in several beds suggests storm activity; units 3, 7, and 12 and several beds in unit 13 may be tempestites.

Most brachiopods are disarticulated, indicating significant postmortem time spent on the ocean floor before burial. Furthermore, a large proportion of brachiopod shells are concave-down in a hydrodynamically stable position. Thus, brachiopod taphonomy supports a low sedimentation rate and a high degree of disturbance of the ocean floor by mobile benthic organisms, infauna, water currents, or storm events which would facilitate the flipping of shells to their most stable position.

Unit 14, which contains stromatoporoids, is interpreted as a reef debris deposit. Abundant atrypide brachiopods suggest an off-reef environment; the presence of large stromatoporoid fragments indicates a location near a stromatoporoid bioherm or biostrome.

3.3 Structure

The outcrop contains five distinct but gentle, roughly north-south trending anticlines. Measuring from the west end of the outcrop, anticline axes occur at 44 m, 172 m, 221 m, 268 m, and 376 m.

Vertical joints are common in the outcrop. The limestone is also pervasively fractured in a fine-scale network of seemingly randomly oriented fractures, many of which are bitumen stained.

At the downstream end of the outcrop, a fault with a decimetre-scale offset and slickensides was found approximately 2 m above water level during the 2010 field season.

3.4 Post-Devonian Erosion

In some places, a siderite horizon several centimetres thick separates the Waterways Formation from the Cretaceous McMurray Formation oil sand. The siderite horizon lies at the base of the McMurray Formation or, at one locality, 2 cm above the contact into the oil sand (Figure 12). The Moberly limestone is often stained with siderite or hematite near the contact.

Brachiopods beneath this siderite horizon are usually white and recrystallized. Some fossils have a chalky texture; others retain morphological details even though recrystallization was pervasive. The limestone matrix beneath the siderite horizon is locally partially decalcified.

Where Quaternary alluvium overlies the Moberly Member, the siderite rind and uppermost Devonian beds were lost to post-Cretaceous erosion, and the limestone is essentially unaltered.

On a large scale, the contact between the Moberly Member and the overlying Cretaceous or Pleistocene strata is undulose and crosscuts the folded Moberly beds (Figures 2, 3, and 13).

Figure 3. Photomontage of the west end of the Moberly Member outcrop near the Fort McMurray water treatment plant.

Figure 4. Photomontage of the east end of the Moberly Member outcrop near the Fort McMurray water treatment plant, upstream of the rapids. The black vertical bar replaces an area that was not successfully photographed.

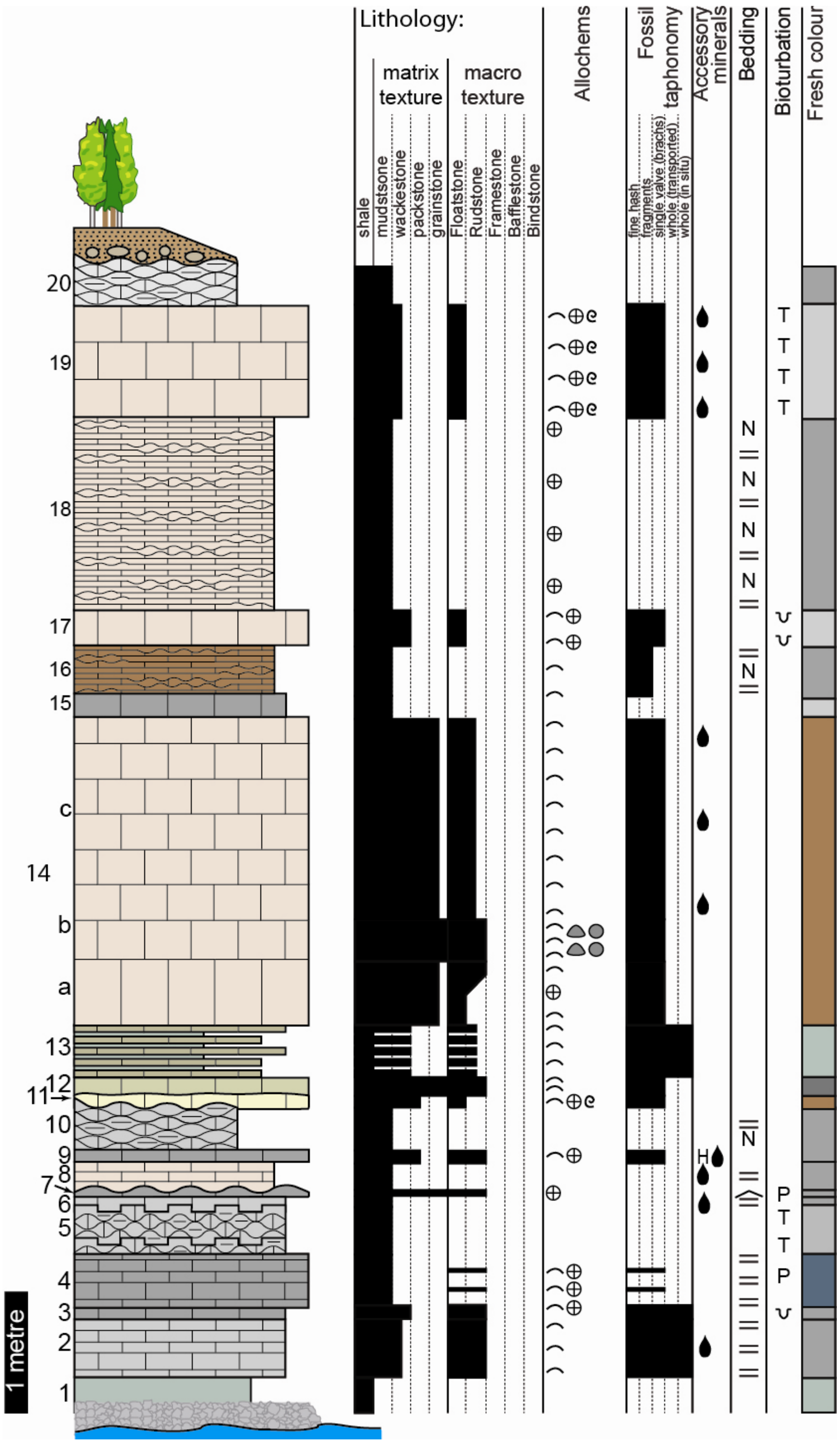

Figure 5. Stratigraphic section of the Fort McMurray water treatment plant outcrop along the north bank of the Athabasca River. The section is compiled from three measured localities.

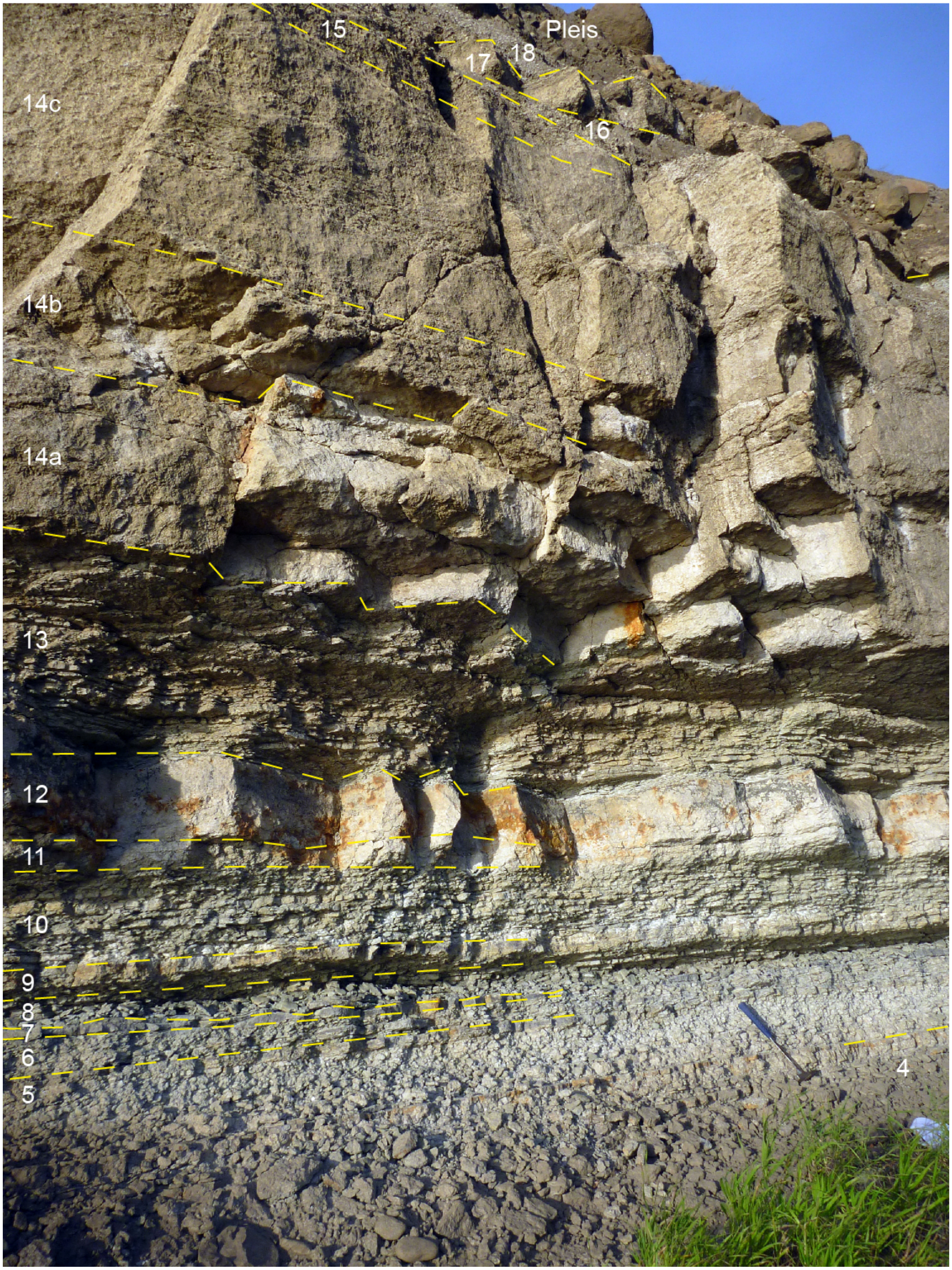

Figure 6. Stratigraphic units in Moberly Member from the Fort McMurray water treatment plant outcrop. View is of the south-facing cliff at the eastern end of the outcrop.

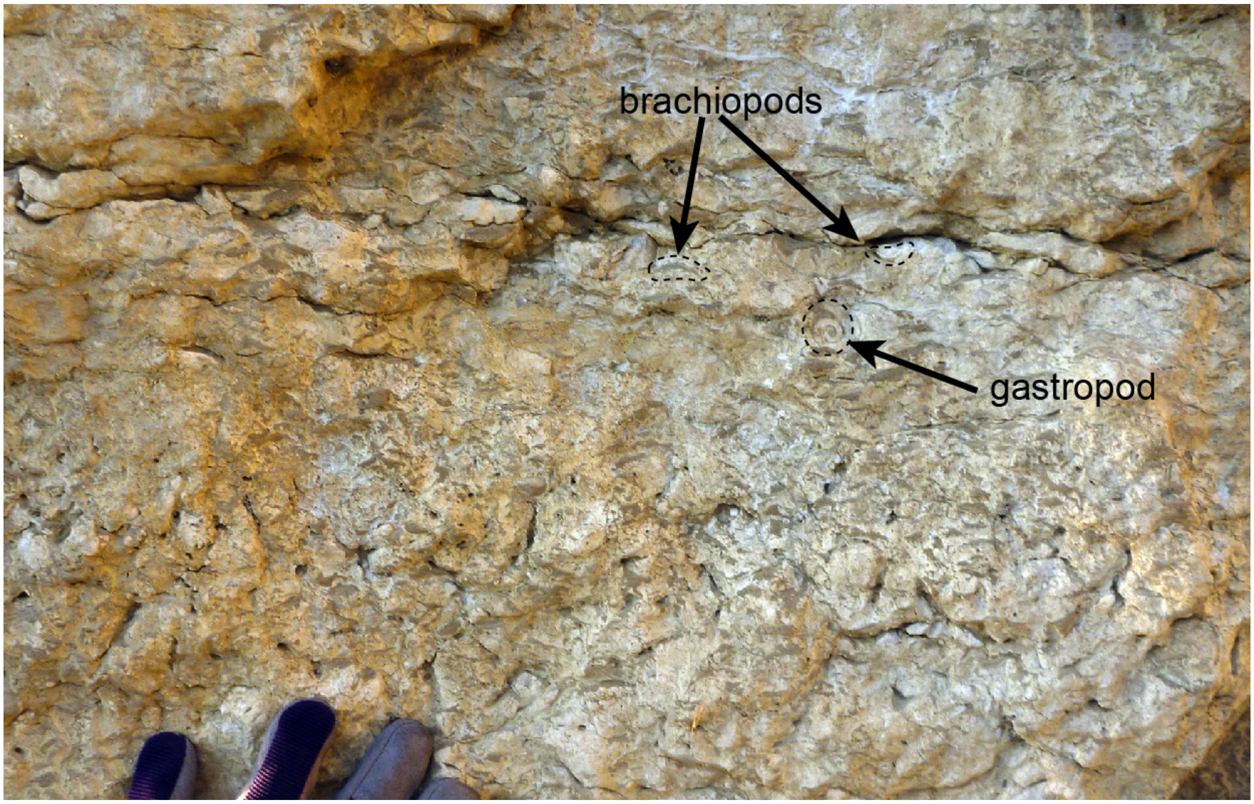

Figure 7. Close-up of the vertical weathered surface of unit 11 from the Moberly Member outcrop near the Fort McMurray water treatment plant. Fossils (concave-down brachiopod valves and gastropods) are best seen just below the parting near the top of the photograph.

Figure 8. Units in the Moberly Member outcrop near the Fort McMurray water treatment plant. An incised Pleistocene channel truncates the McMurray Formation and the uppermost outcropping beds of the Moberly Member at this locality.

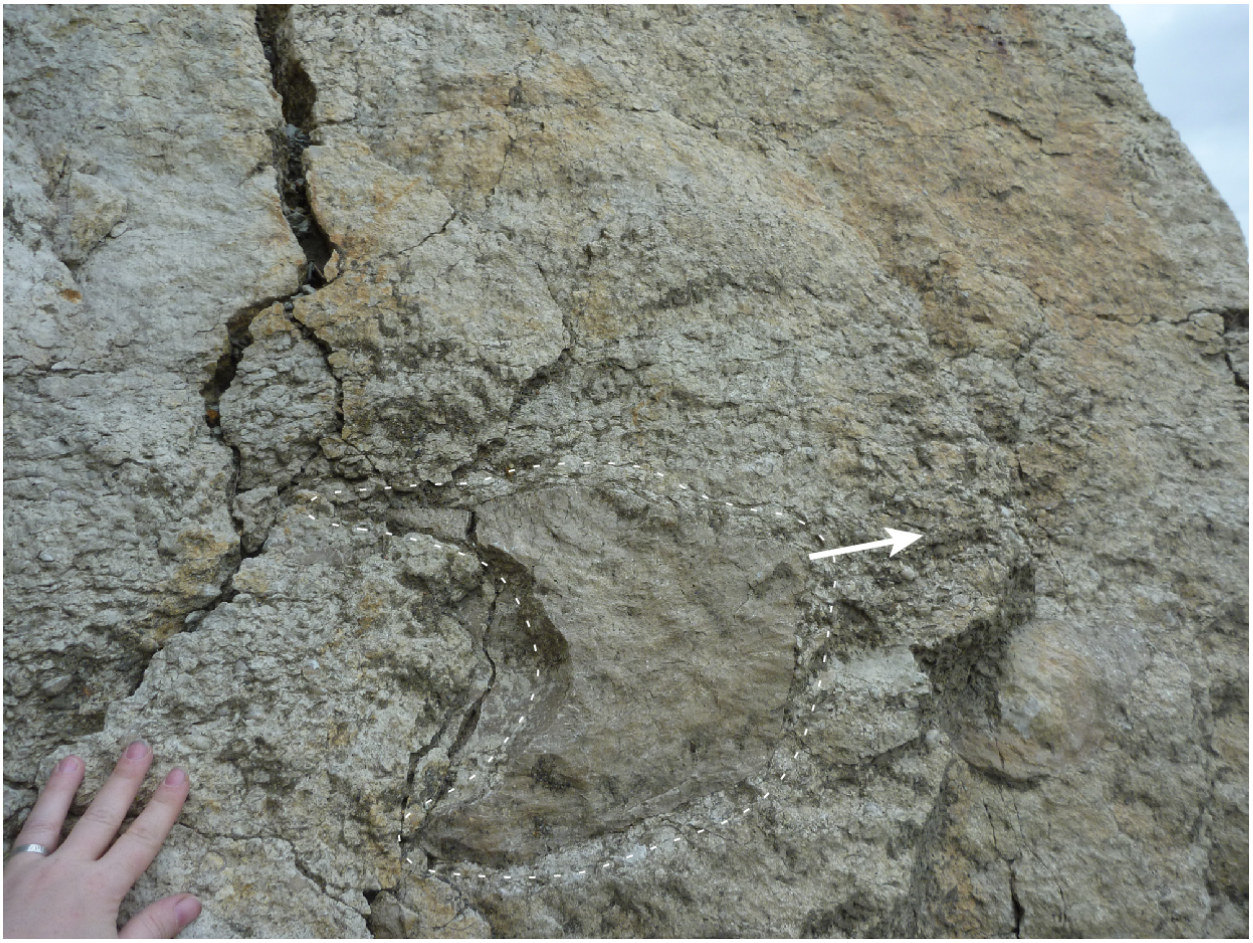

Figure 9. The vertical face of unit 14b from the Moberly Member outcrop near the Fort McMurray water treatment plant. A topped and transported stromatoporoid is oriented with its top surface facing right and is embedded in an atrypide brachiopod coquina. The abundant *Variatrypa clarkei* brachiopods cause the rough surface texture of the rock surrounding the stromatoporoid.

Figure 10. Close-up of unit 14b from the Moberly Member outcrop near the Fort McMurray water treatment plant. The rough surface in the rock face is caused by shells and whole specimens of the brachiopod *Variatrypa clarkei*; a few brachiopods are circled in white dashed lines. The stromatoporoid on the right side of the photo contains abundant borings, some of which are seen in the photo as small black dots.

Figure 11. East end of the Moberly Member outcrop near the Fort McMurray water treatment plant outcrop showing the uppermost unit 20, which can be observed only in this end of the outcrop. The photo was taken from a boat in the rapids. The limestone outcrop is approximately 3m high.

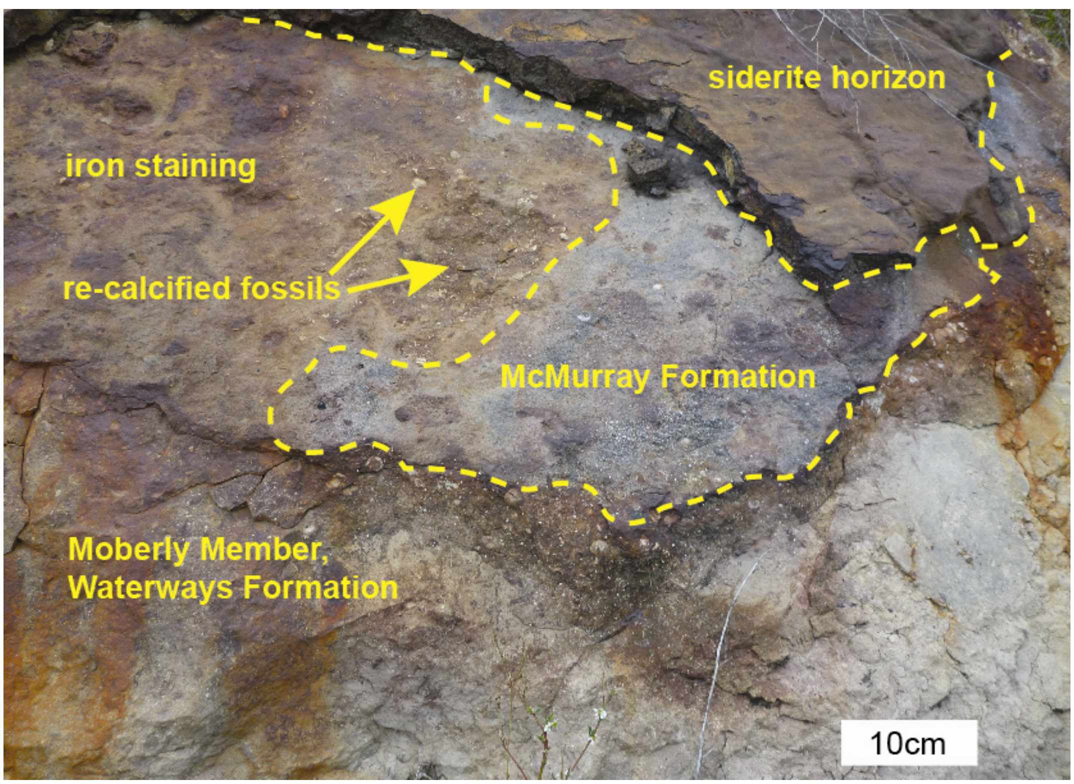

Figure 12. Bedding plane view of the siderite horizon between Devonian and Cretaceous strata at the Fort McMurray water treatment plant outcrop. The siderite horizon is present only where the base of the McMurray Formation has not been eroded. At this locality, a thin lamina of McMurray oil sand sits between the Devonian limestone and the siderite horizon.

Figure 13. View from the upstream, west end of the Fort McMurray water treatment plant outcrop. Notice the erosional truncation of the Moberly Member limestone beds beneath the McMurray Formation oil sand.

4 Athabasca River Bridge

4.1 Locality Description and Access

UTM Zone 12, 475646E, 6286454N (NAD83)

This outcrop is best accessed by boat. Otherwise, a wandering traverse through the park above the river followed by a steep path leads down to the outcrop.

This outcrop contains the typical Moberly nodular limestones and the biostromal unit (which may not be exposed if the river level is high). The outcrop gently undulates through two parasitic anticlines separated by a syncline, which are superimposed on a larger anticline that spans the length of the outcrop. At this locality, the upper beds of the Devonian limestone and the McMurray Formation oil sand form a steep cliff (Figure 4).

4.2 Stratigraphy

The stratigraphic section starts at river level and extends to the sub-Cretaceous unconformity (Figure 14). All measurements were taken along the southernmost edge of the outcrop, where a steep path allows access to all of the units.

The lower units are benched on the river bank from river level to the cliff. Exposure of lowermost units 1 through 7 depends on the river level at the time of the visit. From base to top, the benched Moberly Member units south of the Athabasca Bridge are as follows (Figure 14):

1) 17 cm (from river level; base of unit not observed): resistant, grey weathering, pink-grey, wavy-bedded (separated into three beds of approximately equal thickness), brachiopod-bearing wackestone. In a short walk upstream along the river bank, this unit contains bulbous to domal stromatoporoids 10 to 20 cm in diameter.
2) 15 cm: resistant, grey weathering, light brown, brachiopod-bearing wackestone.
3) 25 cm: beige weathering, light brown, 4 to 5 cm wavy-bedded, brachiopod-bearing wackestone. The upper 15 cm is a mottled brachiopod floatstone in a mudstone matrix with an uneven, wavy top.
4) Four sub-units in a massive, somewhat resistant unit:
   a) 9–15 cm: grey-beige weathering, beige, crinoid and peloid grainstone. This unit fills the undulating top surface of unit 3.
   b) 10–15 cm: grey-beige weathering, beige brachiopod rudstone in a wackestone matrix.
   c) 7 cm: mottled dark to light grey-beige weathering, beige-brown, brachiopod-bearing wackestone containing thin-shelled brachiopods.
   d) 13 cm: grey-beige weathering, beige, nodular-bedded, rubbly weathering lime mudstone to wackestone.
5) 56 cm: slumped, rubbly limestone debris.
6) 20 cm: resistant, beige-orange weathering, grey, massive, brachiopod and crinoid rudstone in a packstone matrix.

The upper units were described from the limestone cliff face (Figure 15). Unit 7 forms the transition from the river bank into the base of the cliff. The topmost units were accessed from a steep path on the south end of the outcrop:

7) 140 cm: slumped, rubbly limestone debris (Figures 14 and 15).
8) 102 cm: resistant, mottled beige-orange weathering, mottled beige-grey and reddish-brown, massive, *Thalassinoides*-bioturbated, brachiopod floatstone in a lime mudstone to packstone matrix. Burrows are 0.5 cm in diameter, up to 5 cm in length, and filled with crinoid fragments and intraclasts. At the top of the unit, burrows are reddish-brown argillaceous wackestone between light beige-grey lime

mudstone to wackestone nodules (Figures 16 and 17). Differential weathering of softer, reddish burrows and harder limestone nodules creates a brecciated appearance in the rock. Fracture surfaces are bitumen stained (Figures 14, 15, 16, and 17).

9) 225 cm: resistant, beige weathering, grey-brown, bioturbated, 1 to 2 cm nodular-bedded, fragmental brachiopod wackestone (Figure 16). The uppermost 25 cm are more resistant (Figures 14, 15, and 16).
10) 161 cm: recessive, beige weathering and fresh, 0.5 cm nodular-bedded, rubbly weathering, highly argillaceous lime mudstone. The topmost 30 cm are a slightly more resistant, pink, *Thalassinoides*-burrowed, brachiopod floatstone in a wackestone matrix. *Thalassinoides* burrows are rusty in colour and are filled with lime mudstone to wackestone (Figures 14 and 15).
11) 88 cm: This unit is partially covered by centimetre-scale limestone nodules (Figures 14 and 15). Only three beds were visible and described as follows:
    a) 44 cm above base: 8 cm thick, beige-orange weathering, grey, crinoid wackestone, weathers with a powdery texture.
    b) 65 cm above base: 3 cm thick, beige-orange weathering, grey, crinoid-bearing wackestone to packstone.
    c) 73 cm, top of unit eroded: 15 cm thick, beige-orange weathering, grey, brachiopod floatstone in a lime mudstone to packstone matrix. Large, whole atrypide brachiopods are likely *Variatrypa clarkei*.

4.3 Paleoenvironmental Interpretation

Like the outcrop at the water treatment plant locality, the outcrop at the Athabasca River Bridge locality represents a shallow-water, sublittoral paleoenvironment. Intense bioturbation in unit 8 suggests that the water depth in this unit was the most shallow of those at this outcrop, but still remained below fair-weather wave base.

Stromatoporoids in the basal unit likely formed a localized bioherm, in which individual stromatoporoids formed on the ocean floor but never amassed into a well-defined reef. Stromatoporoids at this outcrop may have contributed to the reef-proximal bioclasts in stratigraphically equivalent unit 14b of the water treatment plant locality.

4.4 Structure

On a large scale, the entire outcrop is a gentle, roughly east-west trending anticline, as the north end of the outcrop dips below river level and the south end dips towards a low outcrop on the opposite bank of the Horse River mouth (Figures 1 and 4).

Within the large-scale anticline, both ends of the outcrop are folded into low-amplitude, parasitic anticlines separated by a low-amplitude syncline (Figure 4). The saddle formed by the syncline is partially covered by slumped McMurray Formation oil sand.

4.5 Post-Devonian Erosion

A thin siderite horizon separates the McMurray Formation from the Moberly Member. The erosional surface is undulose and incises into the upper units of this locality.

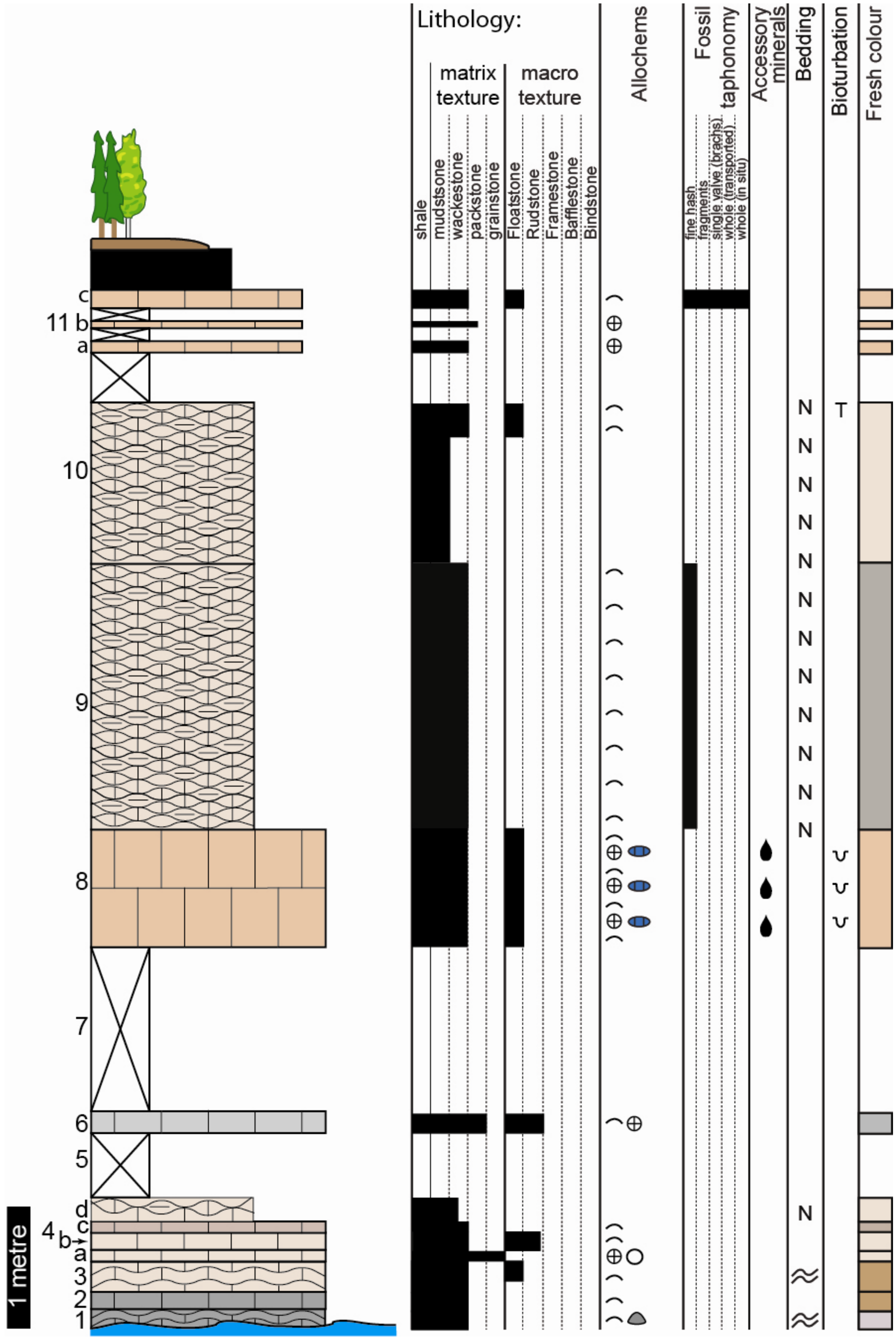

Figure 14. Stratigraphic section of the Moberly Member outcrop south of the Athabasca River Bridge in Fort McMurray. Units 1 through the lower portion of 7 are benched into the riverbank; upper unit 7 through the top of the Devonian limestone form the base of the cliff on the east side of the river.

Figure 15. The south end of the Moberly Member outcrop south of the Athabasca River Bridge in Fort McMurray. Units 2 through 6 are not visible in this photograph and are covered by vegetation. The outcrop is approximately 5 m high.

Figure 16. View of the vertical face of unit 8 and the lower portion of unit 9 from the Moberly Member outcrop south of the Athabasca River Bridge in Fort McMurray.

Figure 17. Close-up of the top of unit 8 from the Moberly Member outcrop south of the Athabasca River Bridge in Fort McMurray. Differential weathering of the softer, reddish-brown *Thalassinoides* burrows caused the limestone nodules to appear brecciated.

5 MacDonald Island

5.1 Locality Description and Access

UTM Zone12, 476022E, 6287945N (NAD83)

Drive to the golf course on MacDonald Island and, with permission, park as close as possible to the west side of the island (Figure 1). Walk south along a dirt road on the top of the island-margin cliff along the Athabasca River until it ends at a rugged, narrow path. Follow this foot path through the grass and then scramble carefully down tumbled limestone blocks at the south end of the island to river level.

5.2 Stratigraphy

This outcrop contains only three units and is overlain by Quaternary alluvium and soil (Figure 18). All three units are easily traced along the island margin and are essentially unchanged in lithology or thickness. The outcrop starts above a low bank of talus and is covered by a thin soil.

From base to top, the three units are as follows:

1) From water level, 100 cm or more: recessive, beige weathering, medium grey, thinly bedded (1 to 2 cm), crinoid-bearing lime mudstone with millimetre-scale shale partings; weathers into centimetre-scale nodules. The base of the unit is lost in river bank talus (Figures 18 and 19).
2) 96 cm: resistant, mottled beige and brown weathering, light grey, massive, *Thalassinoides*-burrowed, brachiopod, crinoid, and gastropod floatstone in a lime mudstone to wackestone matrix. Burrows are light brown and, where burrow networks terminate at horizontal surfaces, form partings in the rock (Figures 18, 19, and 20).
3) 165 cm: slightly recessive, light grey weathering, mottled medium and dark grey, nodular-bedded, *Thalassinoides*-burrowed, lime mudstone. Nodules are bitumen stained. The top of the unit is slightly undulose and covered by soil (Figures 18 and 19).

5.3 Paleoenvironmental Interpretation

This outcrop accumulated on a shallow-water platform below fair-weather wave base. Abundant *Thalassinoides* burrows and gastropods in units 2 and 3 suggest a very shallow, sublittoral, moderately quiet paleoenvironment.

5.4 Structure

This outcrop is essentially flat-lying at the measured south end of the island. A very subtle, east-west-trending anticline runs the entire length of the outcrop, with the axis near the south end of the island.

Vertical joints and vertical to near-vertical fractures are common in the cliff face. Bitumen flowed from occasional vugs to form surface stains on the outcrop (Figure 21).

5.5 Post-Devonian Erosion

The sub-Cretaceous unconformity is not preserved at this outcrop. The topmost unit is overlain by Quaternary alluvium, so the sub-Cretaceous unconformity has been eroded.

6 Correlation and Structure

The three outcrops measured in Fort McMurray are correlatable (Figure 22). The resistant, *Thalassinoides*-burrowed, fossiliferous floatstone can be correlated between the three outcrops (unit 12, water treatment plant; unit 8, Athabasca River Bridge; unit 2, MacDonald Island). At the water treatment plant and MacDonald Island localities, this unit contains distinctive, planispiral gastropods.

Another unit, the stromatoporoid biostrome, was correlatable between the water treatment plant (unit 14b) and the Athabasca River Bridge (unit 1) outcrops. At the Athabasca River Bridge locality, stromatoporoids occur in situ. Stromatoporoids at the water treatment plant locality are broken and toppled, suggesting transport from a nearby source. Thus, the Athabasca River Bridge locality contains the in situ biostrome, and the contemporaneous strata at the water treatment plant locality represent the biostrome-proximal sediments containing broken and transported stromatoporoids in a brachiopod coquina.

The three outcrops display structure expected for this area, given the dissolution of Prairie Evaporite Formation halite and anhydrite in the subsurface. Comparisons of measurements taken at the three outcrops indicate that Devonian strata in the studied area dip to the northeast approximately 6 m over 2.5 km distance.

Like all Waterways Formation outcrops in northeastern Alberta, the Moberly Member is structurally deformed in response to Prairie Evaporite Formation dissolution at depth and the collapse of overlying strata. The oldest strata in the outcrops described in this report are located upstream at the water treatment plant outcrop; the youngest strata outcrop downstream at MacDonald Island. In contrast to the gently folded strata at the Athabasca River Bridge and water treatment plant outcrops, the outcrop along the west bank of MacDonald Island is nearly flat lying. These outcrops are evidence of a large-scale fold in the area. At the Athabasca River Bridge and water treatment plant outcrops, and approximately 5.2 km downstream at Norris's (1963) station 11, the biostromal unit was exposed at or above water level during the 2010 field season. At MacDonald Island, younger beds form the cliff face; the biostromal unit is in the subsurface. Thus, the area may represent a 5+ km wavelength syncline, in which the MacDonald island outcrop is situated at or near the axis of the syncline.

The outcrops described in the present study occur on the axis (MacDonald Island) and limb (Athabasca River Bridge, water treatment plant) of the 5+ km syncline. Outcrops occurring on the limb of the syncline contain two scales of smaller, parasitic folds and rare small faults. The outcrop near the water treatment plant undulates gently through five north-south-trending folds with a wavelength of about 100 m and contains at least one decimetre-scale fault (Figures 2 and 3). The outcrop south of the Athabasca River Bridge also is gently folded, but contains a single, outcrop-long, east-west-trending anticline as well as smaller east-west-trending parasitic folds on each limb (Figure 4). Because the outcrop face of the water treatment plant and that of the Athabasca River Bridge are oriented perpendicular to one another, the combination of the north-south axis trends at the water treatment plant locality and the east-west axis trends at the nearby Athabasca River Bridge locality indicate that the overall geometry of deformation in the area is a series of domes and saddles rather than anticlines and synclines.

7 Summary

The outcrops of the Devonian Waterways Formation in Fort McMurray include beds from the lower Moberly Member. Strata include fossiliferous and argillaceous limestones and a stromatoporoid and brachiopod rudstone. Outcrops at the Water Treatment Plant, the Athabasca River bridge, and MacDonald Island were correlated based on a *Thalassinoides*-bioturbated floatstone.

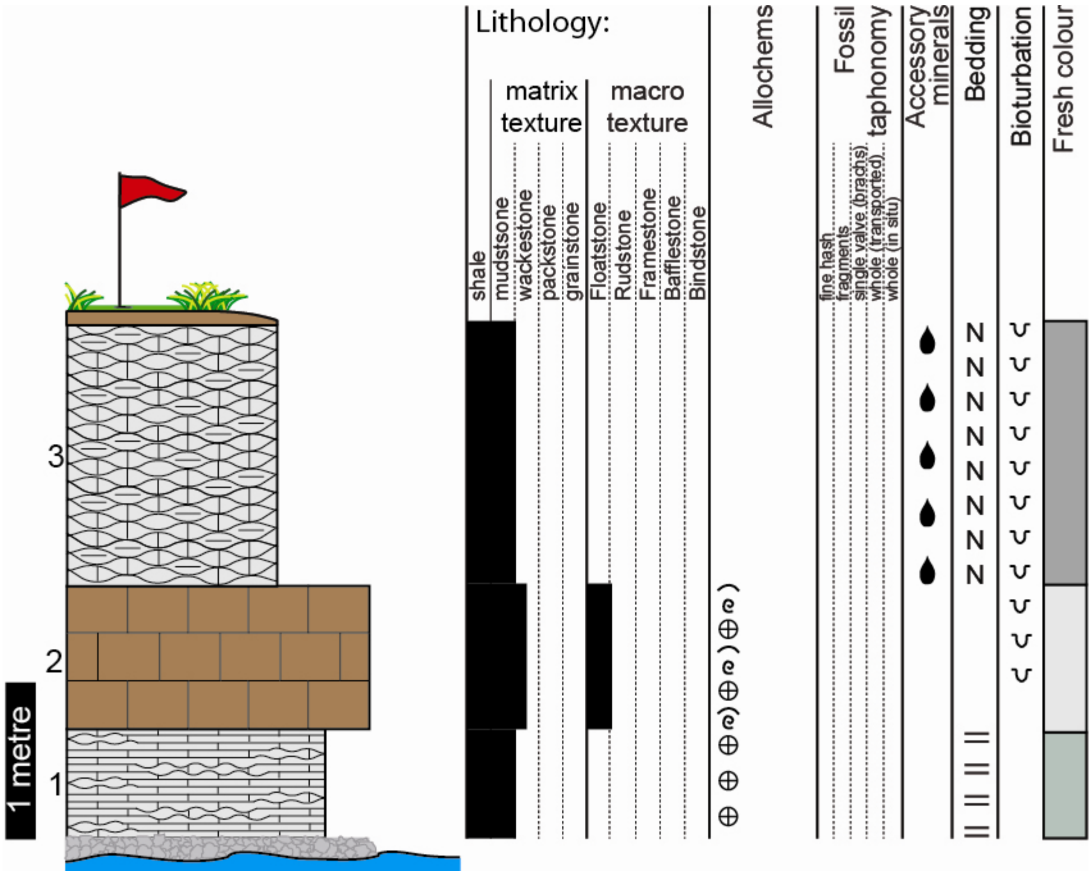

Figure 18. Stratigraphic section of the Moberly Member outcrop on the western margin of MacDonald Island in Fort McMurray.

Figure 19. Units in the Moberly Member outcrop along the western margin of MacDonald Island in Fort McMurray. The vug from which bitumen seeped is marked by a red rock hammer.

Figure 20. Close-up of the vertical face of *Thalassinoides* burrow networks in unit 2 of the Moberly Member outcrop on the western edge of MacDonald Island in Fort McMurray. The mottled beige and grey colour in the rock resulted from differential weathering of matrix and burrows.

Figure 21. Close-up of bitumen that leaked from a vug in unit 2 of the Moberly Member outcrop on the western edge of MacDonald Island in Fort McMurray.

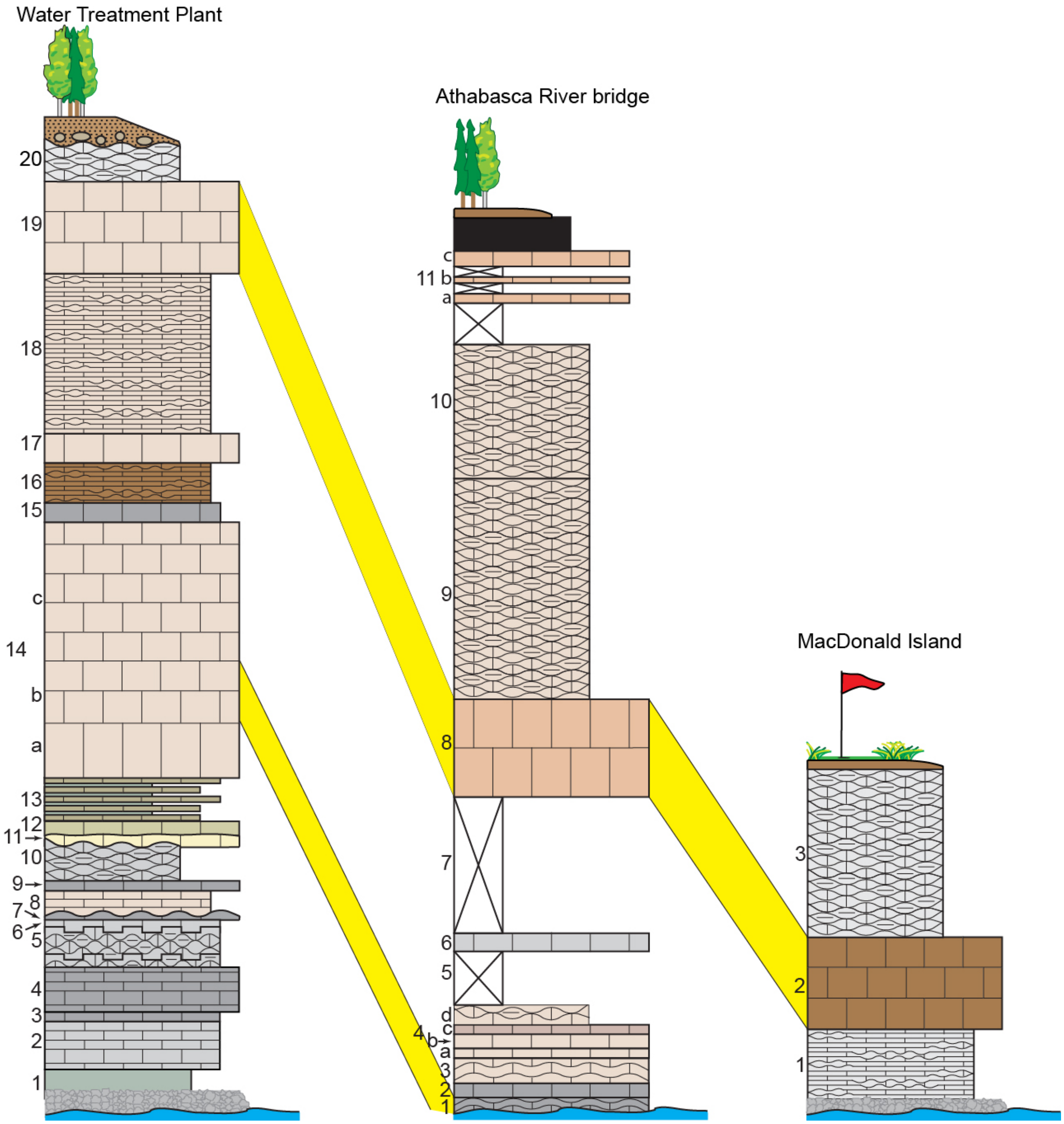

Figure 22. Correlation between the three Moberly Member outcrops described in this report. Correlation is based on a *Thalassinoides*-bioturbated limestone found at all three outcrops (unit 19, water treatment plant; unit 8, Athabasca River Bridge; unit 2, MacDonald Island; upper correlation) and a stromatoporoid-brachiopod rudstone found at the outcrops near the Fort McMurray water treatment plant (unit 14b) and the Athabasca River Bridge (unit 1; lower correlation).

8 References

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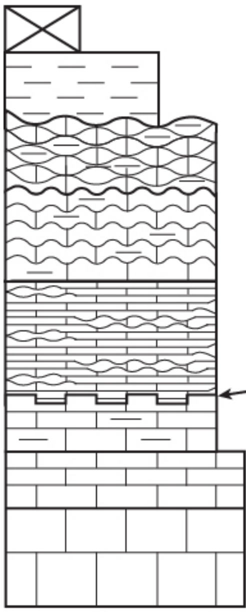
Appendix: Key to Stratigraphic Sections

Lithology:



covered/slumped; no section

shale

nodular argillaceous limestone

wavy bedded argillaceous limestone

tabular to nodular bedded limestone

hardground

tabular bedded argillaceous limestone

tabular bedded limestone

massive limestone

beige-orange

light brown

brown

beige-brown

beige

yellow

yellow-green-grey

green-grey

beige-green-grey

beige-grey

pink-grey

light grey

grey/medium grey

dark grey

dark blue-grey

Allochems:

massive stromatoporoid

bulbous stromatoporoid

gastropod

brachiopod

⊕ crinoid

intraclast

○ peloid

Accessory minerals:

bitumen

H hemetite

burrow

T Thalassinoides

P Planolites

N nodular

= tabular

wavy

symmetrical ripple