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Alberta Energy Regulator

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Outcrops of the Upper Devonian Moberly Member (Waterways Formation) on the Athabasca River north of Fort McMurray, Alberta (NTS 74D/14, 74E/3, and 74E/4)

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Abstract

Joint fieldwork completed by Alberta Geological Survey geologists and University of Alberta paleontologists over the summers of 2010–2012 resulted in the description and correlation of Moberly Member (Waterways Formation, Devonian) outcrops along the Athabasca River. The outcrops visited fall within townships 91–93 along the north-flowing Athabasca River north of Fort McMurray. The Moberly Member along this stretch of the river consists of mainly nodular to bedded, argillaceous limestone interrupted by thinner resistant limestone beds. Most of the units described in this report are fossiliferous. A biostromal unit is the most correlatable unit observed as it is easily recognized for its abundant stromatoporoids and is the thickest resistant limestone unit along this stretch of the river. To the south, this biostromal unit changes from a rudstone (through a bindstone of diverse stromatoporoids and other fossils) into a framework of massive stromatoporoids surrounded by a *Radiatrypa*-brachiopod rudstone. Of all of the Athabasca River outcrops visited, this section of the river contains the youngest beds of the Moberly Member.

1 Introduction

During the summers of 2010–2012, carbonate geologists of the Alberta Geological Survey and paleontologists from the University of Alberta visited outcrops along the Athabasca River to describe the lithology and facies of the Upper Devonian Waterways Formation. This report describes Moberly Member outcrops along the banks of the Athabasca River in townships 91–93 (UTM Zone 12 from 463717E, 6331707N to 474339E, 6301115N [NAD83]) (Figure 1). Descriptions of Moberly Member outcrops within the city of Fort McMurray are presented in Schneider et al. (2013). Those of the Moberly Member along the Athabasca River just north of Ft. McMurray (township 90) are described in Schneider et al. (2015a). Another report (Schneider et al. 2015b) presents the descriptions of Moberly Member outcrops along the Athabasca River just west of Fort McMurray (township 88, ranges 10 and 11).

Devonian limestones outcrop intermittently along the river and are conspicuous in their light buff colour. Most Devonian outcrops along this stretch of the river terminate beneath a thin forest soil. Some outcrops contain evidence of the Devonian–Cretaceous contact in the red-orange iron staining of upper beds. The outcrops are often folded into low-amplitude anticlines; synclines are rare. Joints are common at all outcrops. Slickensides were encountered at some outcrops, but no fractures contained offsets.

The Moberly Member along this stretch of the river comprises a series of bedded to nodular units with interspersed resistant limestone units ranging in thickness from 0.5 to 3 m. Nodular limestones form either cliffs or eroded slopes of loose nodules and can only be correlated via the resistant limestone beds.

Of the resistant limestone units, three contain stromatoporoids: units 2, 6, and 12 (see section 3). Only unit 6 is truly biostromal given the quantity and morphologies of stromatoporoids and corals. This 2 to 3 m thick resistant limestone is easily recognized and correlated between outcrops, especially because

- where not covered, the biostromal unit is always underlain by an approximately 60 cm thick, recessive, nodular, argillaceous limestone (unit 5) and a 50 cm thick resistant limestone (unit 4), and
- the other stromatoporoid-bearing units are thinner, not as resistant, and inconsistent in stromatoporoid abundance.

Unit 6 in this report is equivalent to unit 4 described from Moberly Member outcrops in township 90 (Schneider et al., 2015a) and to unit 10 of Moberly Member outcrops along the Athabasca River west of Fort McMurray in township 88 (Schneider et al., 2015b).

Some of the outcrops described in this report contain the youngest Moberly Member strata of those along the Athabasca River's edge. Younger Moberly Member strata can be examined away from the Athabasca River, such as at Beaver Creek near highway 63 or at outcrops along the Muskeg River.

2 Background

In his account of the Coppermine Expedition of 1819–1822, Franklin (1824) described a pipe-making limestone from the Pipestone Cliffs near Pierre au Calumet as a "clayey limestone, impregnated with various shells." As Pierre au Calumet is south of the confluence of the McKay and Athabasca rivers, his description is likely of Moberly Member limestone.

Of the Athabasca River outcrops, Macoun (1877) wrote that "nearly all the strata show graceful curves, the folds never rising more than ten feet." Because his observations came from the north-flowing Athabasca River, he described the outcropping beds as dipping north and south, with the strike crossing the river.

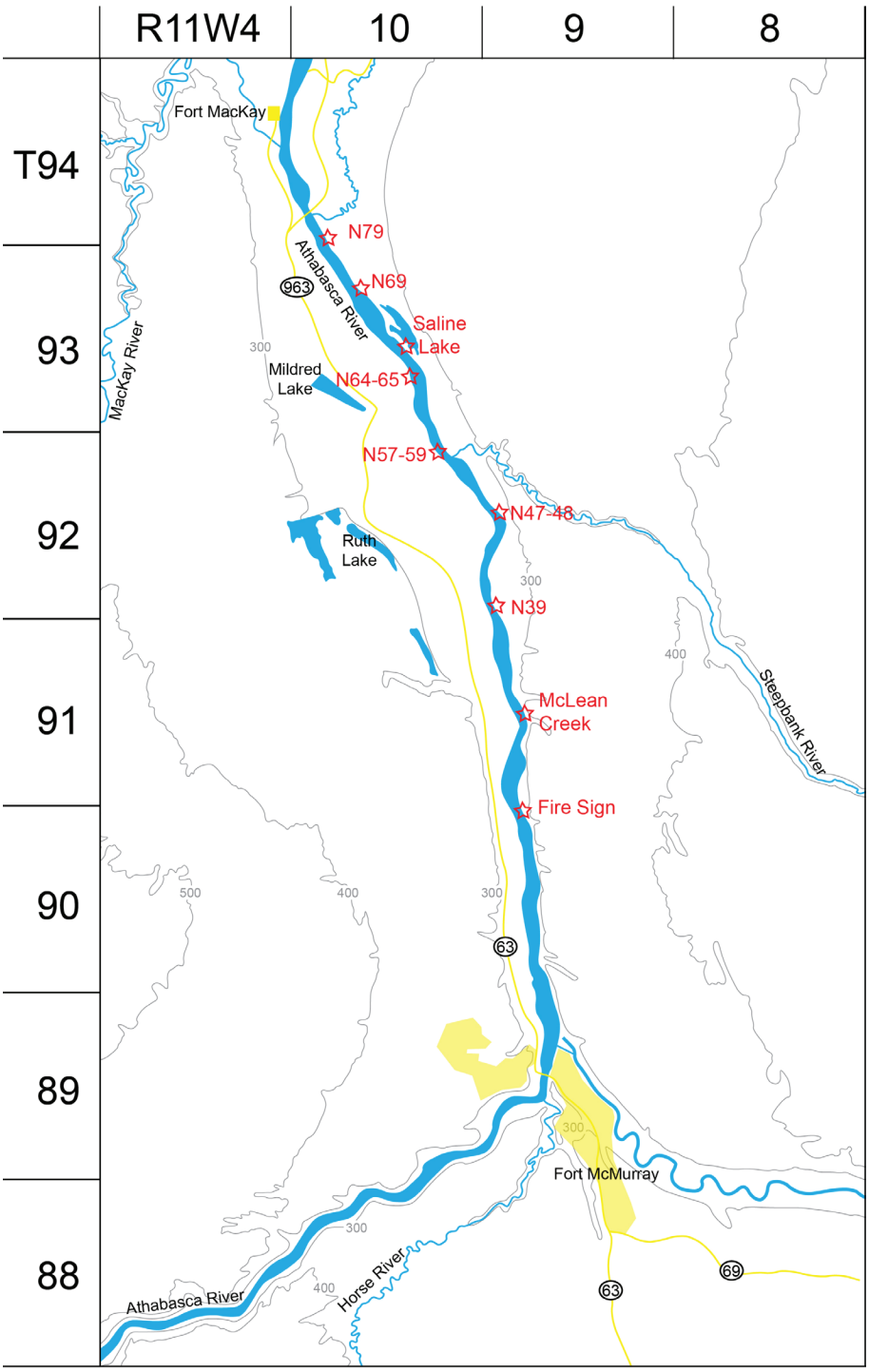

Figure 1. Map of the study area showing the locations of Devonian Moberly Member outcrops described in this report. Locations labelled "N" are named for the station numbers as reported in Norris (1963) (e.g., N57–59 = Norris stations 57 to 59).

Bell (1884) observed folded Waterways limestones below tar-bearing McMurray sandstone along the Athabasca River. In his words, the limestones "generally undulate slightly" and are "usually planed down to an even surface." He mentioned that the contact between the Devonian limestones and Cretaceous rock was sculpted by post-Devonian erosion but was frequently horizontal in nature. Bell was impressed at the parallel bedding of the two units, "not withstanding the great space in geological time which separates them." He also noticed that the McMurray sandstone, when heated under direct sun, often slumped or flowed "in large, viscid masses" over the limestone, a common phenomenon that often conceals the sub-Cretaceous unconformity.

McConnell (1893) observed the sub-Cretaceous unconformity along the Athabasca and Christina rivers. He found the oil sand to be conformable with the underlying Devonian strata—limestone and sandstone abutted without significant erosional features or angular contacts.

Norris (1963) visited most of the Moberly Member outcrops along the Athabasca River and completed the first comprehensive correlation for the region. He found that the outcrops on the Athabasca River are equivalent to the lower third of the Moberly Member and alternated between olive green, rubbly-bedded, argillaceous limestone to shale and light brown, resistant limestone. Most of the limestone units that he described are fossiliferous, but one bed in particular—his unit 37—is a cliff-forming stromatoporoid and atrypide brachiopod coquina. Norris also remarked that in the Moberly Member, limestone units tended to thin northward, increasing in shale content. For ease in describing the locality and when comparing previous work, Norris's station numbers are retained in this report.

Norris measured low-amplitude flexures in Waterways limestone along the Clearwater and Athabasca rivers, most of which dip less than 10 degrees; although a few dip up to 17 degrees. He further stated that these were minor folds in the limestone and unrelated to the overall westward dip of Devonian strata, but did not suggest a cause. Later, Norris (1973) redescribed the folding in the Waterways Formation as domes and basins with amplitudes up to 100 feet (30.4 m) and wavelengths up to 1 mile (1.6 km). He also suggested that some of the structures originated from solution of subsurface halite and subsequent differential subsidence.

Buschkuehle (2003) described the Moberly Member from several outcrops along the Athabasca River. In her descriptions, Moberly strata are light to medium grey, massive limestone or interbedded argillaceous fossiliferous limestone and calcareous shale. Locally, limestone is partially dolomitized. In her described composite section, the basal unit is 1 m of interbedded marl and limestone containing brachiopods, crinoids, and tempestite beds. A 2 to 2.5 m thick, light grey, massive stromatoporoid reef bank overlies the limestone and contains tempestite deposits, hardgrounds, and a bioturbated upper surface. Above the stromatoporoid biostrome, a 40 cm thick brachiopod and crinoid bank is interbedded with shale. Her outcrop series is capped by six or seven upward-shallowing cycles, each 1 m thick and with a basal marl grading up into resistant fossiliferous limestone. She interpreted the partial Moberly Member in an outcrop along the Athabasca River as a transitional zone between reef and fore-reef facies in an intermittently high-energy environment.

Near Fort McKay, exploration for high-quality, mineable carbonate resulted in the recognition of two distinct resistant units (the Upper Quarry Unit and Middle Quarry Unit) and two intervals of dominantly nodular, argillaceous limestone (Rowe, 1998; Dahrouge, 2004), which were described as follows:

1) The lowermost Moberly unit is an interbedded shale and nodular limestone containing occasional fossils and is separated from the underlying Christina Member by a thick, complex hardground.
2) The Middle Quarry Unit contains the three following laterally consistent lithofacies:

- a lower peloid marker unit of a peloidal wackestone to packstone with crinoid and brachiopod debris, often separated from underlying and overlying units by a hardground;
- a middle nodular unit of a nodular lime mudstone interbedded with green shale, often separated by hardgrounds from the underlying peloid marker bed and the overlying stromatoporoid biostrome; and
- a topmost stromatoporoid unit: massive to bedded, bulbous, tabular, and dendroid stromatoporoid floatstone to bindstone containing brachiopods in the matrix. This unit is capped by a hardground throughout the region.

3) The Middle Quarry Unit is separated from the Upper Quarry Unit by interbedded limestone and shale that contains brachiopods and often a basal fossiliferous limestone unit of a brachiopod-ooid-peloid-bearing packstone to grainstone in which most brachiopods are imbricated.
4) The Upper Quarry Unit underlies the sub-Cretaceous unconformity and is a massive, nodular lime mudstone to wackestone containing sparse brachiopods and crinoids.

Cotterill and Hamilton (1995) illustrated, but did not describe, several outcrops along the Athabasca River from the study area. Their illustrations depict fossiliferous limestone beds separated by thick sections of lime mudstone.

Dufresne et al. (1994) described folded Waterways limestones with dips up to 15 degrees and suggested that the gentle warping of carbonate strata originated from a gradual removal of subsurface halite. Nikols (1996) reconstructed a pattern of oval structures of troughs and domes, rather than simple folds, from bedding dips. Because joint frequency did not increase on the flanks between troughs and domes, Nikols suggested that deformation in Waterways strata was a slow process.

3 Composite Section, Athabasca River

Outcrops along the Athabasca River in townships 91 through 93 comprise an interval of the lower Moberly Member approximately 24 m thick (Figure 2). The rock is generally beige weathering, with minor variations due to iron staining. Three stromatoporoid-bearing units are easily traced between outcrops, allowing them to be easily correlated in the field. These three units were the basis for establishing a composite section.

From base to top, the composite section includes the following units:

- Unit 1 (maximum 330 cm exposed): recessive, grey, wavy- to tabular-bedded (4–10 cm), nodular-weathering, *Thalassinoides*-bioturbated, argillaceous, brachiopod-, crinoid-, and gastropod-bearing floatstone in a mudstone to packstone matrix. The topmost metre is centimetre-bedded.
- Unit 2 (115–136 cm): resistant, grey to brown-grey, variably tabular-bedded, nodular-weathering, bioturbated, argillaceous, brachiopod, crinoid, gastropod, and bulbous and branching stromatoporoid rudstone in a wackestone to packstone and, locally, grainstone matrix. Grainstones contain primarily carbonate sand. Hardgrounds were observed at two locations, but are not correlatable.
- Unit 3 (163–190 cm): recessive, grey, tabular- to nodular-bedded (1–5 cm), nodular-weathering, bioturbated, argillaceous, brachiopod and crinoid floatstone to local rudstone in a mudstone to wackestone matrix. Centimetre-scale rudstone beds are sporadic throughout the unit.
- Unit 4 (45–55 cm): resistant, light grey, unbedded, brachiopod-crinoid floatstone in a variable wackestone to grainstone matrix. The grainstone is derived from a carbonate sand of skeletal debris, peloids, and locally-derived intraclasts.
- Unit 5 (55–60 cm): recessive, light beige-grey, nodular-bedded (3–4 cm), bioturbated, argillaceous, brachiopod, crinoid, and gastropod floatstone in a lime mudstone to wackestone matrix. In some locations, the unit can contain rudstone stringers.

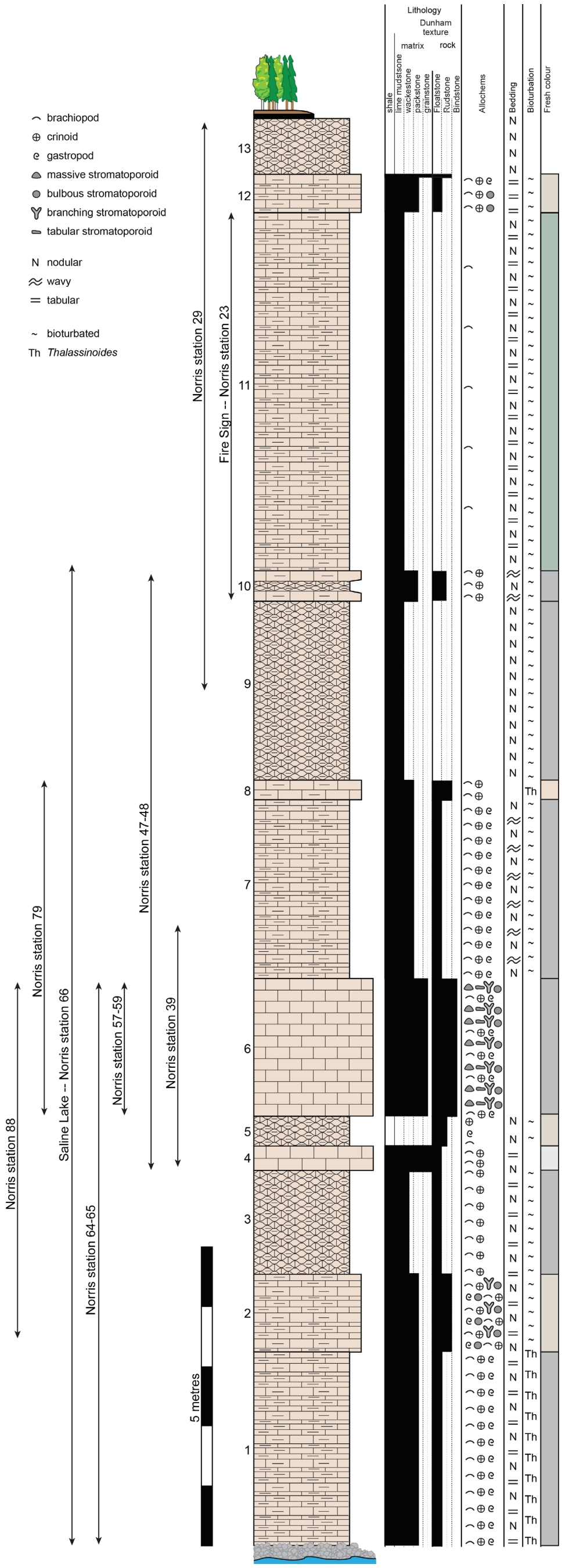

Figure 2. Composite section for the Moberly Member outcrops described in this report.

- Unit 6 (215–304 cm): resistant, light grey, massive, brachiopod, crinoid, gastropod, and stromatoporoid rudstone in a packstone to grainstone matrix. The dominant stromatoporoid morphology changes from north to south. Northern outcrops contain branching, bulbous, tabular, and lamellar stromatoporoids. Massive stromatoporoids increase in abundance southward. The southernmost outcrops contain massive stromatoporoids up to 0.5 m in height within a *Radiatrypa* rudstone. The top of the unit becomes recessive southward, which affects the accuracy of measurements and the separation between this unit and the overlying unit at the measured locations.
- Unit 7 (~300 cm): recessive, light grey to brown, wavy-bedded (5–10 cm), nodular-weathering, bioturbated, argillaceous, brachiopod, crinoid, and gastropod floatstone to rudstone in a mudstone to wackestone matrix. This unit was often slumped and was not easily measured.
- Unit 8 (~32 cm: resistant, beige, *Thalassinoides*-bioturbated, argillaceous, brachiopod and crinoid floatstone to rudstone in a wackestone matrix.
- Unit 9 (~300 cm: recessive, grey, centimetre-scale nodular-bedded, bioturbated, argillaceous, lime mudstone.
- Unit 10 (43–70 cm): two resistant beds separated by a middle recessive bed. Resistant beds vary between 7 and 27 cm and are tabular- to wavy-bedded, bioturbated, argillaceous, brachiopod and crinoid floatstone to rudstone in a wackestone to packstone matrix. The middle recessive bed is 12 to 23 cm and is a centimetre-scale nodular-bedded, bioturbated, argillaceous, brachiopod and crinoid floatstone to rudstone in a wackestone to packstone matrix.
- Unit 11 (~400 cm): recessive, grey to green-grey, tabular-bedded (0.5–5 cm), nodular-weathering, bioturbated, argillaceous, lime mudstone with occasional brachiopods.
- Unit 12 (65 cm): resistant, beige-grey, tabular-bedded (1–8 cm), bioturbated, argillaceous, brachiopod, crinoid, and gastropod, and bulbous stromatoporoid floatstone in a wackestone to packstone matrix grading up to a rudstone in a grainstone matrix.
- Unit 13 (>100 cm): recessive, nodular-weathering, argillaceous limestone. This unit could only be observed from a distance.

4 Norris Station 79

4.1 Locality Description and Access

UTM Zone 12, 463717E, 6331707N (NAD83)

This outcrop is a gentle anticline in which the resistant biostromal limestone of unit 6 (see section 3, composite stratigraphic section) forms a prominent bed on both limbs of the anticline and is partly eroded over the axis of the anticline (Figure 3). The outcrop was measured on the north end of the anticline.

This outcrop is easily accessed by boat.

4.2 Stratigraphy

From base to top, this outcrop contains the following (Figure 4):

- Unit 6 (204 cm): resistant and massive becoming benched in the lower 125 cm; recessive and wavy-bedded (10–20 cm) in the upper 75 cm; beige-weathering, beige-grey fresh, bioturbated, *Thamnopora*, stromatoporoid, crinoid, and brachiopod rudstone to bindstone and framestone. Stromatoporoids include branching, tabular, and massive forms. *Thamnopora* and massive stromatoporoids (up to 20 cm in diameter) occur within the upper bedded portion of the unit. The fauna is more diverse in the lower, massive portion of the unit.

Figure 3. Photomontage of the downstream end of the Norris station 79 Moberly Member outcrop, Athabasca River (downstream is to the left). The resistant limestone bed forms a gentle anticline and is just over 2 m thick. The recessive, beige wall of slumped limestone nodules above the resistant limestone is approximately 7 m high.

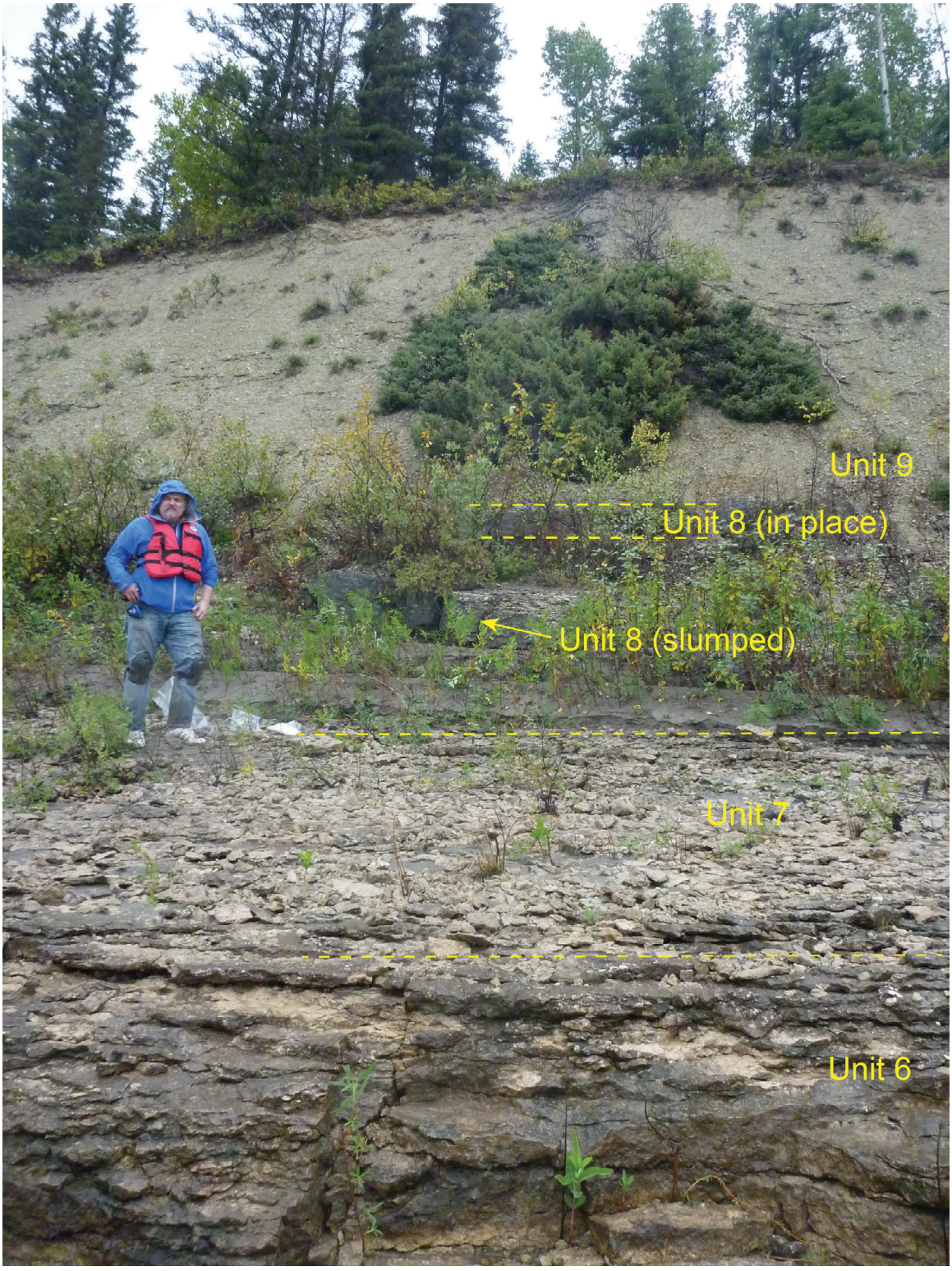

Figure 4. Units at the Norris station 79 outcrop of the Moberly Member on the Athabasca River. The perspective from which the photograph was taken causes units in the foreground to appear thicker than those further in the back.

- Uppermost unit 6 or lowermost unit 7 (50 cm): benched, recessive, beige-weathering, brown, wavy-bedded (10 cm), bioturbated, crinoid and brachiopod rudstone in a wackestone matrix. This unit contains abundant complete specimens of *Radiatrypa*.
- Unit 7 (235 cm): Covered by vegetation or slumped material.
- Unit 8 (52 cm): resistant becoming recessive (in the upper 20 cm), mottled beige and orange changing in the upper 20 cm to green-grey (weathering and fresh), *Thalassinoides*-burrowed, argillaceous, crinoid and brachiopod rudstone in a wackestone matrix.
- Unit 9+ (~700 cm): green-grey, calcareous shale containing argillaceous lime mudstone nodules. Some nodules are beige-weathering. One *Radiatrypa clarkei* specimen collected from float. *Planolites* burrows occur on float surfaces. Some float surfaces contain crinoids and small brachiopods.

4.3 Sub-Cretaceous Unconformity

The sub-Cretaceous unconformity was eroded and the top of the nodular unit is covered by soil.

4.4 Structure

The entire outcrop forms a low-amplitude anticline. Fractures through the limestone are vertical except on the northern limb of the anticline, where fractures dip approximately 45 degrees to the south (Figure 5). The transition from vertical to south-dipping fractures is laterally abrupt rather than gradual.

5 Norris Station 69

5.1 Locality Description and Access

UTM Zone 12, 466403E, 6327701N (NAD83)

This outcrop forms a gentle, low, anticlinal cliff along the riverbank (Figure 6). Upper beds are accessible on the downstream end of the outcrop. A brief stop at this outcrop confirmed that unit 6 formed the prominent resistant bed seen in the anticline.

This outcrop is easily accessed by boat.

5.2 Stratigraphy

From base to top, the outcrop contains the following units (Figure 7):

- Unit 3 (~300 cm): tabular- to wavy-bedded, nodular-weathering, argillaceous limestone; recessive in the upper 100 cm.
- Unit 4 (~50 cm): resistant, massive limestone.
- Unit 5 (~50 cm): recessive, nodular-weathering, argillaceous limestone.
- Unit 6 (~250 cm): resistant, massive limestone. Branching, tabular, bulbous, and massive stromatoporoids are abundant. Stromatoporoids are commonly bitumen stained (Figures 8 and 9).

Brachiopods collected at this outcrop include productides, *Variatrypa*, *Radiatrypa*, and *Eleutherokomma*.

5.3 Sub-Cretaceous Unconformity

The outcrop is capped by a regolith of limestone nodules from unit 7 which grades up into a thin soil. The sub-Cretaceous unconformity has been eroded.

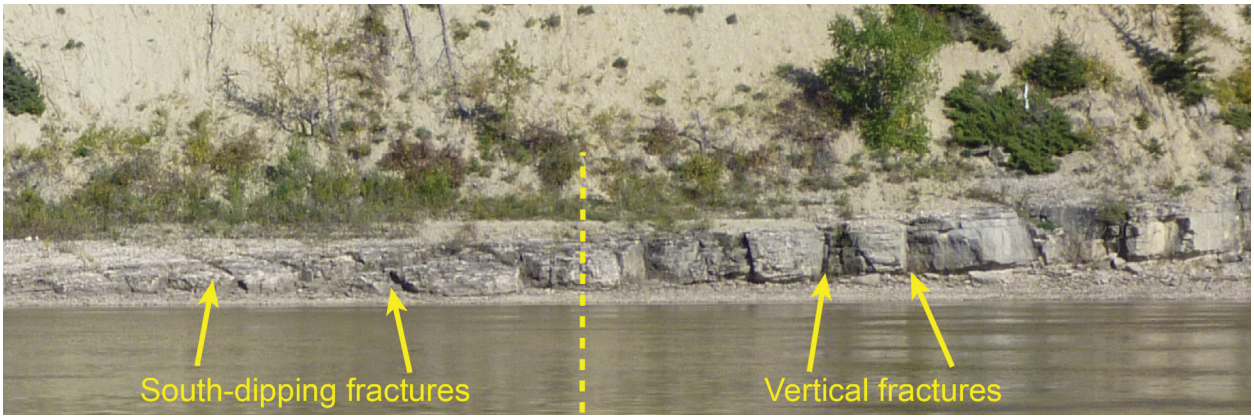

Figure 5. Fractures in the Norris station 79 outcrop of the Moberly Member on the Athabasca River. Downstream (left), fractures are south-dipping and approximately 45 degrees from horizontal. Upstream (right), fractures are vertical to subvertical.

Figure 6. Photomontage of the Norris station 69 Moberly Member outcrop on the Athabasca River. The view is upstream and to the southeast.

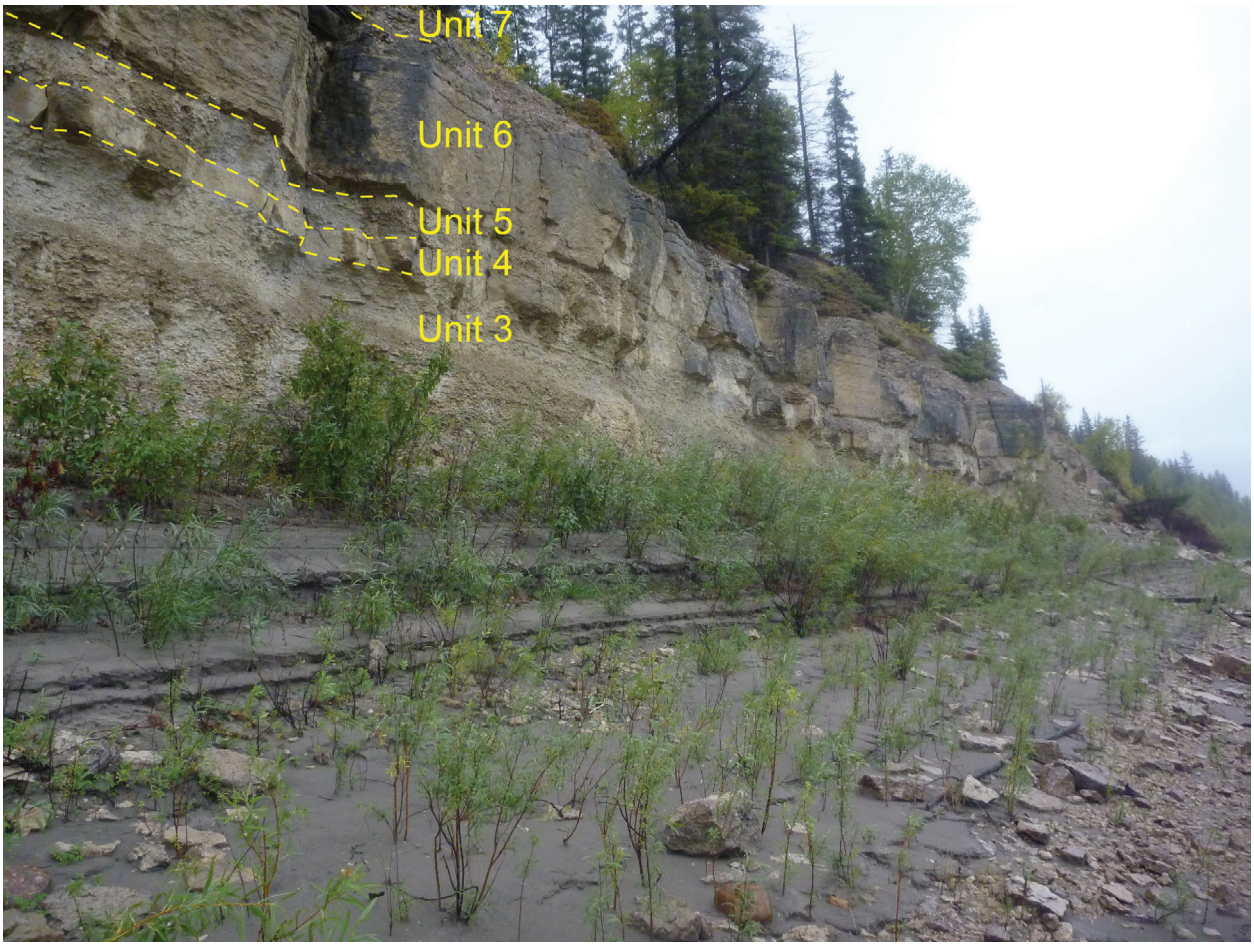

Figure 7. Units 3 through 7 at the Norris station 69 Moberly Member outcrop on the Athabasca River.

Figure 8. Bitumen fill within the galleries (pore spaces) of a stromatoporoid.

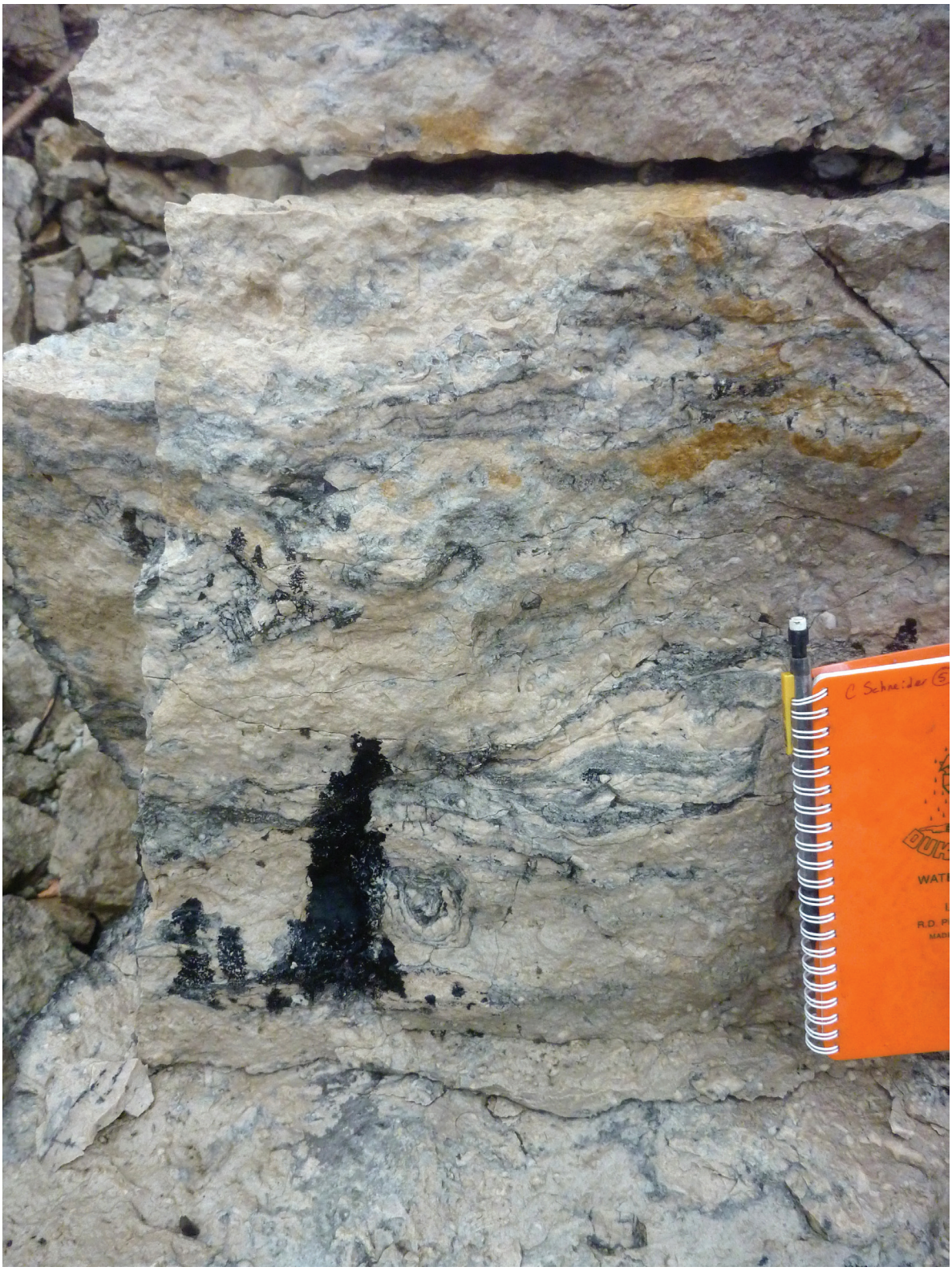

Figure 9. Bitumen flow from biostromal unit 6 at the Norris station 69 Moberly Member outcrop on the Athabasca River. Dark grey patches in the rock are the bitumen staining and fill within the galleries of stromatoporoids.

5.4 Structure

This outcrop is a low-amplitude anticline, particularly evident in the resistant beds of units 4 and 8 (Figure 6).

6 Norris Station 66 (Saline Lake)

6.1 Locality Description and Access

UTM Zone 12, 468377E, 6325169N (NAD83)

The outcrop is an approximately 15 m high cliff in which limestone beds dip gently towards the north (Figure 10). Resistant limestone beds are interspersed among thick units of nodular-weathering limestone. The biostromal unit 6 forms the thickest resistant unit at the outcrop. Most beds from the upper portions of the cliff are inaccessible and can only be observed in slumped blocks.

This outcrop can be accessed by boat or, when the water level is low, by helicopter. Saline Lake is a short hike along a narrow path through the woods to the north of the outcrop.

6.2 Stratigraphy

The accessible beds of the outcrop, from base to top, include the following units (Figure 11):

- Unit 1 (at least 330 cm): recessive, tabular-bedded (3–8 cm), *Thalassinoides*-bioturbated, argillaceous, brachiopod, and crinoid floatstone in a lime mudstone to wackestone matrix (Figure 12), weathering into mottled orange and beige nodules. The upper 90 cm is more recessive and centimetre-scale bedded. Some beds in this unit are a brachiopod, gastropod, and crinoid rudstone of varying thicknesses (Figure 13). Brachiopods include *Radiatrypa*, small specimens of *Schizophoria*, productides, and *Eleutherokomma*.
- Unit 2 (136 cm): resistant, beige-weathering, beige-grey, variably tabular-bedded, bioturbated, argillaceous, brachiopod, crinoid, gastropod, and stromatoporoid floatstone to rudstone in a packstone matrix. This unit varies laterally between two resistant units separated by a recessive, nodular middle unit and a single contiguous unit. Stromatoporoids include bulbous and branching forms in the upper portion of the unit. Brachiopods include *Radiatrypa* and *Spinatrypa*. A hardground occurs at the top of the unit and a 2 cm thick brachiopod coquina overlies the hardground (Figure 14).
- Unit 3 (190 cm): recessive, beige-weathering, grey, nodular-bedded (2–3 cm), brachiopod floatstone in a lime mudstone to wackestone matrix.

Overlying units were observed from the river bank. The thicknesses given below are estimates.

- Unit 4 (~50 cm): resistant, beige-weathering limestone.
- Unit 5 (~30 cm): recessive, beige-weathering, nodular-bedded, argillaceous limestone.
- Unit 6 (~120 cm): resistant, beige-weathering, limestone. A float block of this unit found on the river bank is a stromatoporoid- and *Thamnopora* rudstone to bindstone in a grainstone matrix (Figure 15). It contains massive, branching, bulbous, and tabular stromatoporoids. The grainstone matrix was formed from carbonate sand of fossil debris. Tabular stromatoporoids give the rock a bedded appearance by binding rudstone layers of *Thamnopora* and branching stromatoporoids. Stromatoporoids and corals are bitumen stained.
- Unit 7 (~300 cm): recessive, tabular- to wavy-bedded (5–10 cm), argillaceous limestone, weathering into beige nodules.
- Unit 8 (~25 cm): resistant, beige-weathering limestone.

Figure 10. The outcrop of the Moberly Member at the Saline Lake (Norris station 66) location, Athabasca River. The view is downstream and slightly east.

Figure 11. Units of the Moberly Member at the Saline Lake outcrop, Athabasca River.

Figure 12. Tabular-bedded and nodular-weathering limestone of unit 1 of the Moberly Member at the Saline Lake outcrop, Athabasca River. Note the orange mottling on the grey limestone beds from the preferential oxidization of *Thalassinoides*-burrow networks.

Figure 13. Brachiopod, gastropod, and crinoid rudstone in unit 1 of the Moberly Member at the Saline Lake outcrop, Athabasca River. Note the ripple shape of the rudstone bed. A mechanical pencil for scale is sticking out of a crack above the bed at the top of the photo near the crest of the ripple.

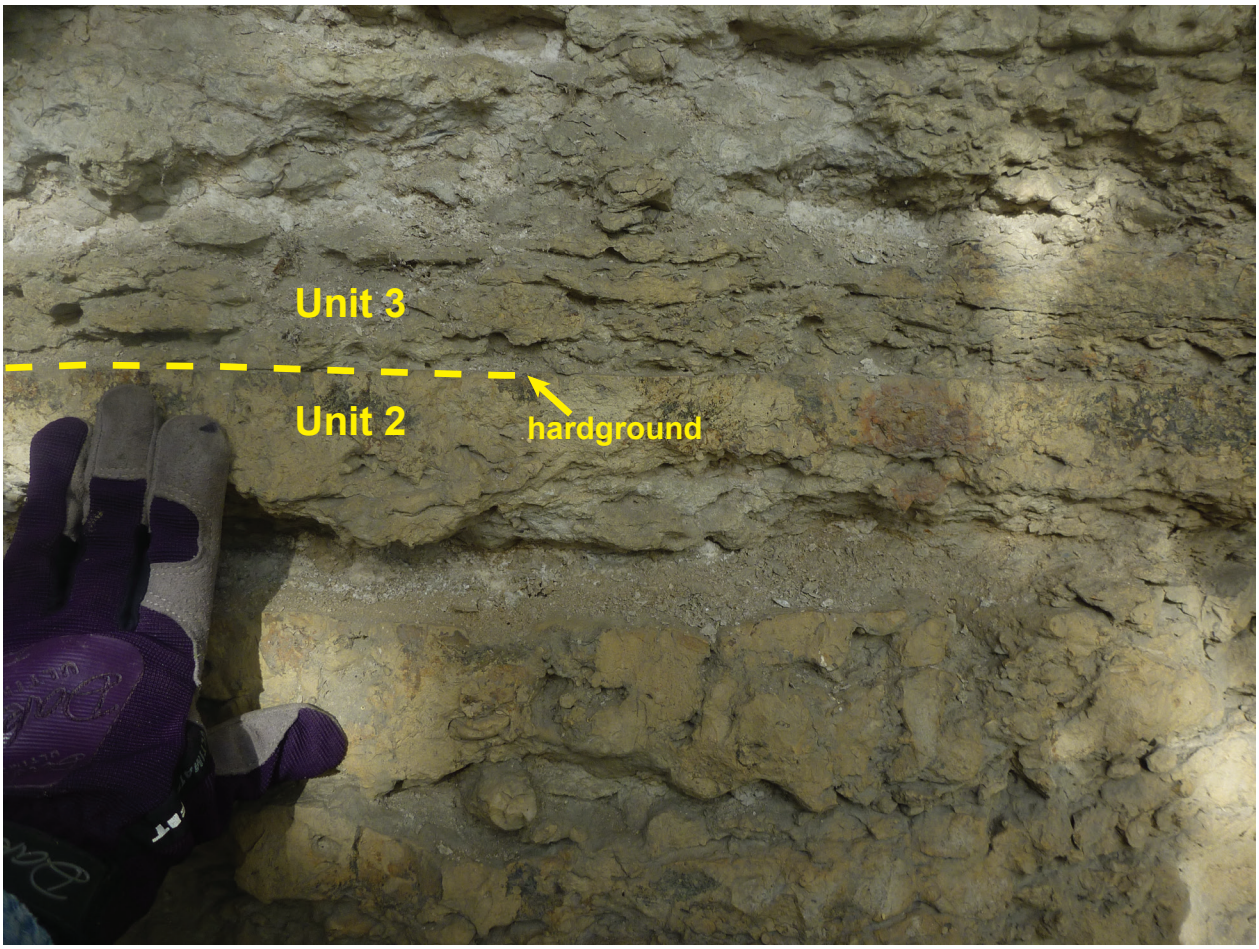

Figure 14. A hand marks the resistant beds at the top of unit 2 of the Moberly Member at the Saline Lake outcrop, Athabasca River. A hardground caps unit 2; the sharp, flat-lying surface can be traced just above the fingers.

Figure 15. Branching stromatoporoids and *Thamnopora* from a float block derived from unit 6 of the Moberly Member at the Saline Lake outcrop, Athabasca River. Bitumen (dark grey) stains the matrix and some of the stromatoporoids.

- Unit 9 (~300 cm): recessive, beige-weathering, thinly nodular-bedded, argillaceous limestone.
- Unit 10 (~50 cm): resistant, reddish-weathering limestone. The reddish staining likely originated from the proximity of the unit to the sub-Cretaceous unconformity.
- Unit 11 (~20–30 cm): recessive, reddish-weathering, thinly nodular-bedded, argillaceous limestone. Reddish staining likely originated from the proximity of the unit to the sub-Cretaceous unconformity.

6.3 Sub-Cretaceous Unconformity

The sub-Cretaceous unconformity has been eroded, and the outcrop is capped by a thin soil.

6.4 Structure

Beds at this location lie essentially flat. Near-vertical joints are present in the outcrop.

7 Norris Stations 64–65

7.1 Locality Description and Access

UTM Zone 12, 468509E, 6324319N (NAD83)

This outcrop forms a long, 120 m wide cliff above a steep but narrow river bank (Figure 16). A gentle syncline warps the beds in the upstream end of the outcrop, but beds on the downstream end of the outcrop appear to lie flat. This outcrop is best accessed by boat.

This outcrop is similar to that at the Saline Lake location. Beds from the Saline Lake location are easily recognized by their proportions and stratigraphic associations. In lower beds, they are recognized by their fauna. Units 4 and 5, which were not accessible at Saline Lake, can be examined at this outcrop.

7.2 Stratigraphy

From base to top, the outcrop includes the following units (Figure 17):

- Unit 1 (>243 cm): recessive, mottled grey and orange (weathering and fresh), wavy- to nodular-bedded (5–10 cm), *Thalassinoides*-bioturbated, argillaceous, brachiopod, crinoid, and gastropod floatstone in a variable lime mudstone to packstone matrix (Figures 18 and 19). Rudstone beds (1–4 cm) of brachiopods, crinoids, and gastropods occur sporadically throughout the unit (Figures 19, 20, and 21). The uppermost metre is centimetre-scale nodular-bedded and becomes increasingly recessive upward. Vertical fractures are stained burnt orange with siderite and can be pyrite filled (Figure 22). *Eleutherokomma* noted.
- Unit 2 (115 cm): resistant, beige-weathering, beige-grey fresh, laterally variable bedded to massive brachiopod, crinoid, gastropod, and stromatoporoid floatstone to rudstone in a wackestone to grainstone matrix. Subunits discernible and unique to unit 2 at this location, based on vertical lithological variation in the unit, include the following, from base to top (Figure 18):
  - Subunit 2a (1–4 cm): brachiopod coquina; *Radiatrypa* and *Eleutherokomma* identified.
  - Subunit 2b (15 cm): fossil fragment carbonate sand packstone to grainstone.
  - Subunit 2c (30 cm): brachiopod and branching, bulbous stromatoporoid rudstone in a packstone matrix. Bulbous stromatoporoids become more common upward. *Radiatrypa* identified. Two hardgrounds occur at the top and 5 cm below the top of this subunit (Figures 18 and 23). The upper hardground is bitumen stained along part of its surface (Figure 23).
  - Subunit 2d (5 cm): grainstone of skeletal carbonate sand, capped by a hardground.

Figure 16. Syncline on the upstream end of the Moberly Member outcrop at the Norris stations 64–65 location, Athabasca River. To the right in the distance is the Saline Lake outcrop. The view is downstream.

Figure 17. Informal units of the Moberly Member as described in this report at the Norris stations 64–65 location on the Athabasca River.

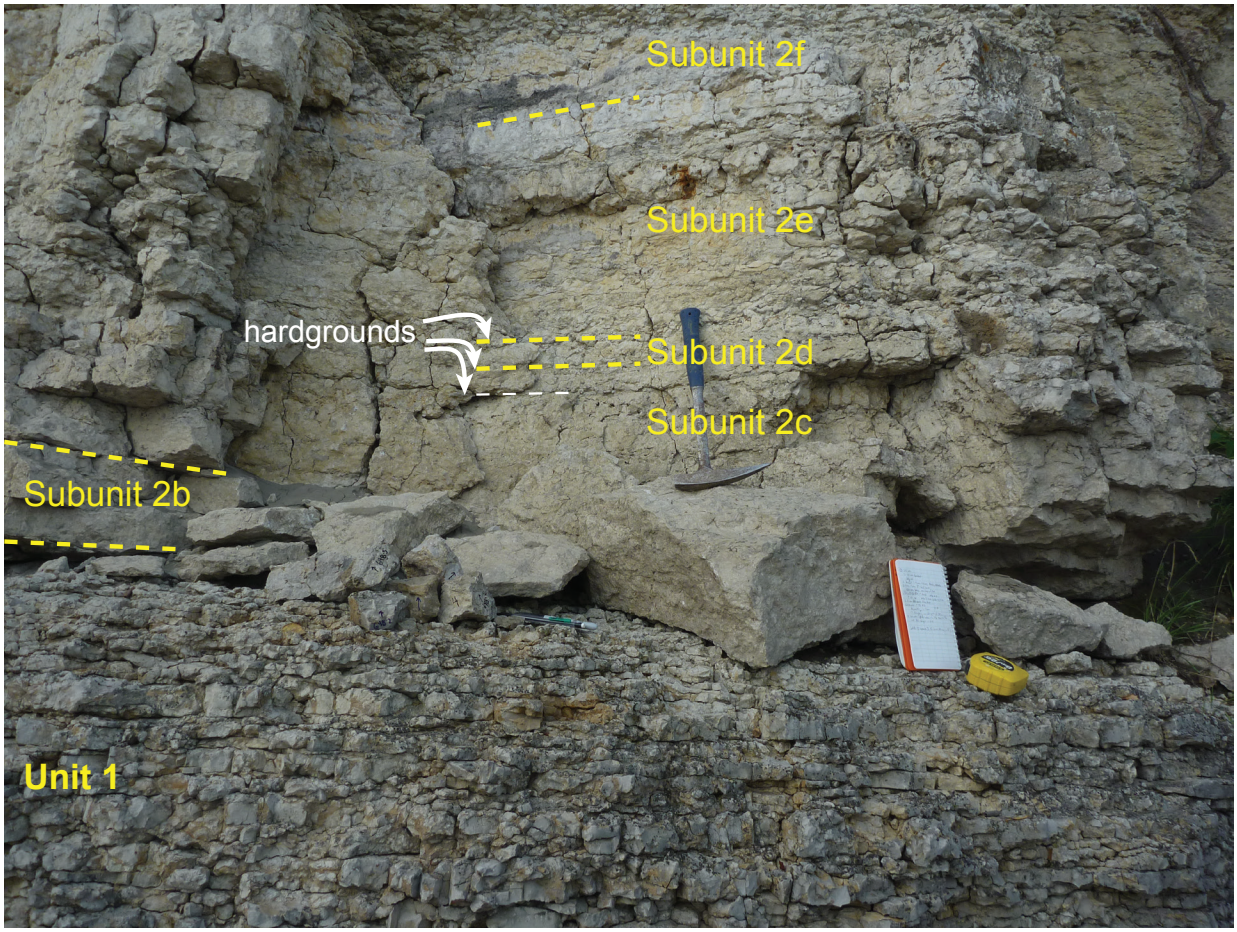

Figure 18. Units 1 and 2 of the Moberly Member from the Norris stations 64–65 location on the Athabasca River. Subunit 2a cannot be seen in this photograph. Hardgrounds occur at the tops of subunits 2c and 2d (see the dashed yellow lines separating the subunits) and 5 cm below the top of subunit 2c (white dashed line).

Figure 19. Wavy-bedded limestone of unit 1 of the Moberly Member at the Norris stations 64–65 location on the Athabasca River. Note the orange mottling on grey limestone beds, which originated from the oxidization of *Thalassinoides*-burrow networks. The field notebook rests on top of the rudstone pictured in Figure 21.

Figure 20. Two rudstone beds containing brachiopods, crinoids, and gastropods within unit 1 of the Moberly Member at the Norris stations 64–65 location on the Athabasca River.

Figure 21. Close-up of a brachiopod, gastropod, and crinoid rudstone bed in unit 1 of the Moberly Member at the Norris stations 64–65 location on the Athabasca River.

Figure 22. Pyrite-filled, near-vertical fracture (to the right of the hand) in unit 1 of the Moberly Member at Norris stations 64–65 location on the Athabasca River.

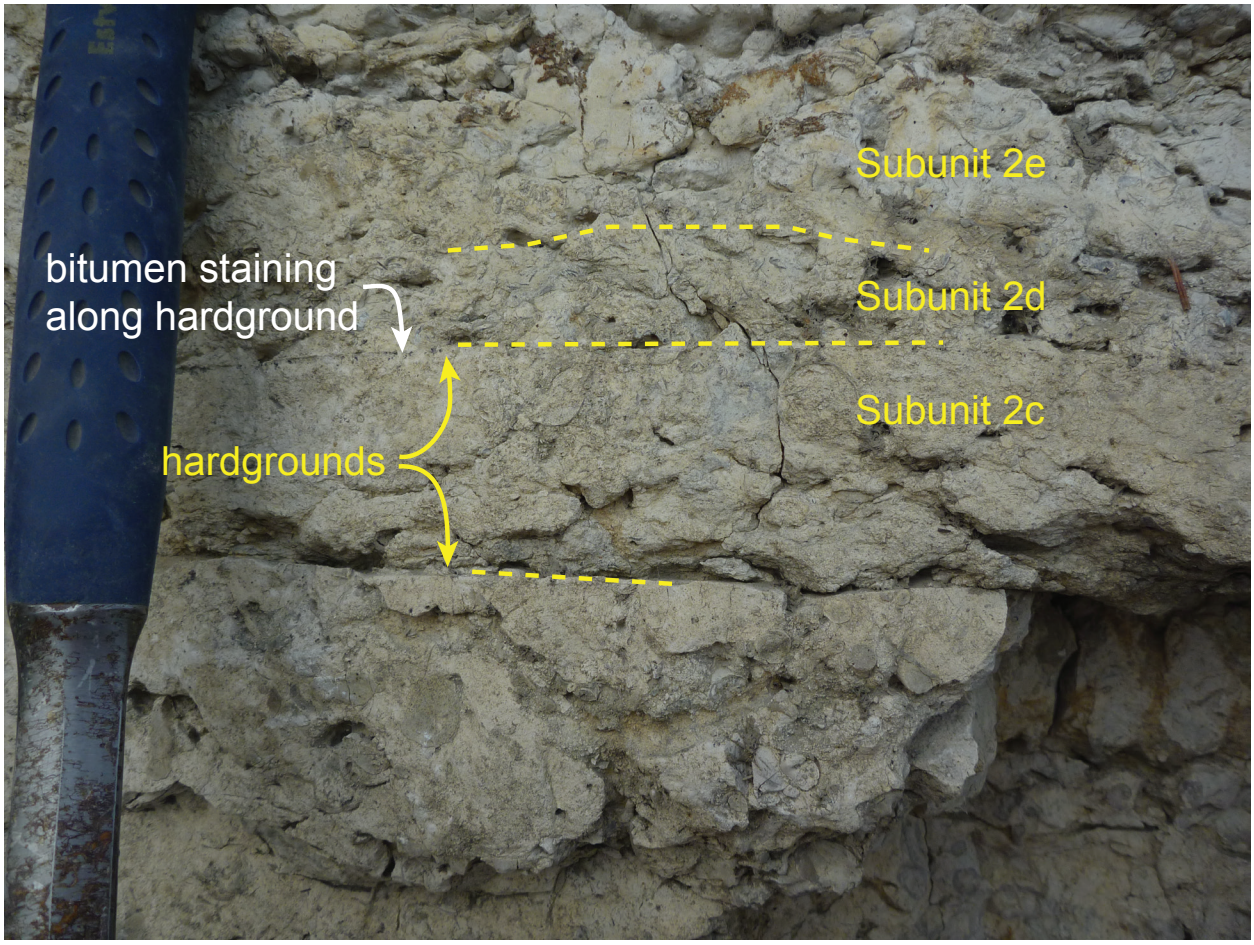

Figure 23. A close-up of subunits 2c and 2e of the Moberly Member at the Norris stations 64–65 location on the Athabasca River. Hardgrounds occur along each of the dashed lines. The hardground at the boundary between subunits 2c and 2d is intermittently bitumen stained; black to dark grey stains along the hardground near the white arrow are bitumen.

- Subunit 2e (53 cm): nodular-weathering (1–5 cm), brachiopod, crinoid, and gastropod floatstone to rudstone in a wackestone to packstone matrix. Single brachiopod valves occur in rudstone stringers intermittently throughout the unit.
- Subunit 2f (20 cm): light beige- and nodular-weathering, *Thalassinoides*-bioturbated, brachiopod floatstone with brachiopod rudstone stringers in the middle of the unit.

- Unit 3 (163 cm): recessive, beige-weathering, beige-grey fresh, centimetre-scale tabular- to nodular-bedded, bioturbated, argillaceous, brachiopod and crinoid floatstone to rudstone in a wackestone matrix. Brachiopods are fragmental to whole and include *Eleutherokomma* and *Arcuaminites*. Thin, starved-ripple coquinas occur at 15 cm, 35 cm, 40 cm, and 60 cm below the top of the unit.
- Unit 4 (43–47 cm): resistant, orange-beige-weathering, light grey, brachiopod and crinoid floatstone in a peloidal-skeletal grainstone matrix.
- Unit 5 (60 cm): beige-weathering, light beige-grey fresh, recessive, nodular-bedded (up to 3 cm), lime mudstone to wackestone with occasional brachiopod or gastropod fossils and rudstone stringers.
- Unit 6 (~120 cm, truncated by erosion): resistant and massive, orange-beige- weathering, stromatoporoid and brachiopod rudstone (observed in float block on the river bank). Stromatoporoids include *Amphipora* and branching, domal, and massive stromatoporoids.

7.3 Sub-Cretaceous Unconformity

The sub-Cretaceous unconformity has been eroded. This outcrop is overlain by a thin soil.

7.4 Structure

Beds in this outcrop lie flat except for the upstream end, which contains a gentle syncline (Figure 16). Vertical fractures are common.

8 Norris Stations 57–59

8.1 Locality Description and Access

UTM Zone 12, 469510E, 6320957N (NAD83)

This outcrop has been heavily disturbed by construction in the area above and behind the cliff. Debris from construction on the river terrace surface was pushed over the edge of the cliff, thus most of the outcrop is covered in debris and coated in mud. The only observable units were parts of unit 6 and several rudstone beds near the water level (Figure 24).

This outcrop is easily accessed by boat.

8.2 Stratigraphy

The top of the outcrop contains units 6 and 7. Unit 7 was not observed closely because the uppermost strata were inaccessible. At this location, unit 6 is broken into three distinct beds separated by 1 to 2 cm argillaceous partings (Figure 25). From base to top, these beds are as follows:

- Bed 1 (100 cm): grey-beige, brachiopod, crinoid, gastropod, and massive and bulbous stromatoporoid floatstone to rudstone in a packstone to grainstone matrix. A rubbly-textured breccia capped by a hardground or scour surface caps the top of this bed (Figure 26).

Figure 24. The Moberly Member outcrop at the Norris stations 57–59 location on the Athabasca River.

Figure 25. Unit 6 and one of the three stratigraphically lower beds of unit 3 observed in the Moberly Member at the Norris stations 57–59 location on the Athabasca River. At this outcrop, unit 6 can be separated into three distinct beds based on the presence of argillaceous partings. The white arrow points to a brachiopod and crinoid floatstone to rudstone bed approximately 180 cm below the base of unit 6. This bed is one of three thin floatstone to rudstone beds of unit 3, that were discovered upstream of this location.

Figure 26. Beds 1 and 2 of unit 6 of the Moberly Member at the Norris stations 57–59 location on the Athabasca River. Note the sharp contrast between the light grey limestone of bed 1 and the darker grey limestone of bed 2. A hardground or scour surface caps the top of bed 1 and overlies a rubbly-textured breccia that is up to 10 cm thick at the top of unit 1.

- Bed 2 (30 cm): beige to light brown, brachiopod, crinoid, gastropod, and massive and bulbous stromatoporoid rudstone in a grainstone matrix (Figure 26). The top 2 cm is a beige to tan lime mudstone bed that overlies a hardground and scour surface.
- Bed 3 (85 cm): inaccessible for close observation.

Talus on the slope below unit 6 originated from the constructed terrace above the outcrop. Nodular, argillaceous limestone from units 7 and higher was pushed over the edge of the outcrop when the terrace was mechanically smoothed.

At the upstream end of the outcrop near water level and at the middle of the outcrop approximately 180 cm below the base of unit 6 (Figure 25), from base to top, are the following three 1 to 2 cm thick beds:

- a fragmental brachiopod and crinoid rudstone in a packstone matrix,
- a brachiopod and crinoid floatstone to rudstone in a packstone to grainstone matrix that contains *Planolites* burrows on its top surface, and
- a mytilid bivalve rudstone in a lime mudstone to wackestone matrix.

8.3 Sub-Cretaceous Unconformity

The sub-Cretaceous unconformity has been eroded or was removed by construction activity.

8.4 Structure

The outcrop forms a limb of a gentle anticline, with the beds dipping upstream. Slickensides were observed on some float blocks (Figure 27).

9 Norris Stations 47–48

9.1 Locality Description and Access

UTM Zone 12, 472898E, 6316979N to 472990E, 6316294N (NAD83)

This outcrop measures 150 m in length along the river (Figure 28). A steep slope of limestone nodules outcrops above the resistant bed of unit 6 (Figure 29). The biostromal unit 6 is accessible at the downstream end; the overlying beds are accessible on the upstream end, where the limb of the anticline dips towards the river.

This outcrop is best accessed by boat.

9.2 Stratigraphy

From base to top, the outcrop contains the following (Figure 29):

- Unit 4 (at least 50 cm; unit continues below water level): resistant, beige-grey-weathering limestone.
- Unit 5 (55 cm): recessive, grey- and nodular-weathering, argillaceous limestone.
- Unit 6 (158 cm): resistant, beige-grey-weathering, grey, massive stromatoporoids in a brachiopod and crinoid rudstone in a wackestone to packstone matrix. Unit 6 can be split into four subunits at this location based on lithological variation within the brachiopod and crinoid rudstone (Figure 30). From base to top, these subunits are as follows:

Figure 27. Slickensides on a fracture in unit 3 of the Moberly Member at the Norris stations 57–59 location, Waterways Formation.

Figure 28. The Norris stations 47–48 location of the Moberly Member on the Athabasca River. The downstream direction of the river is to the left in the photomontage.

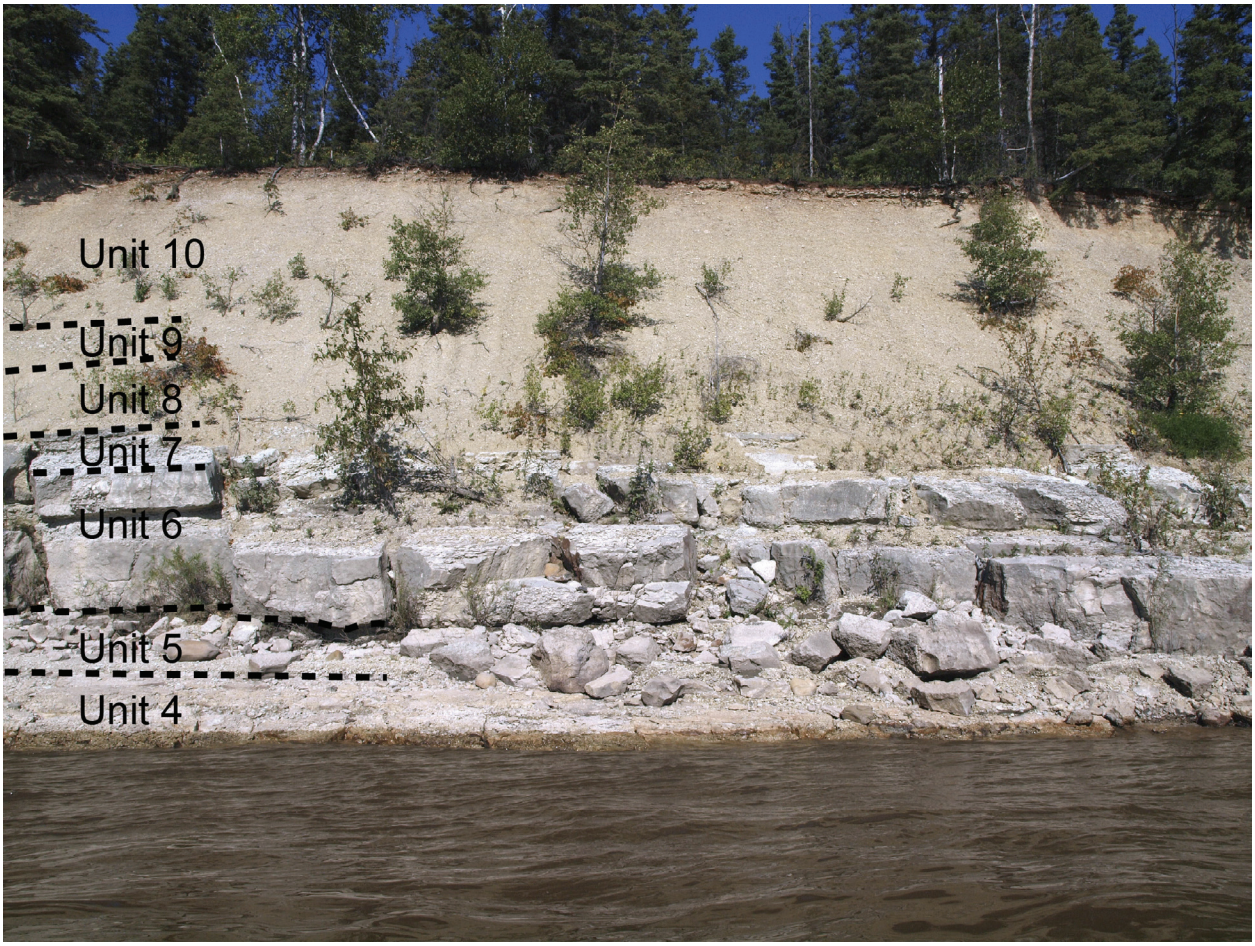

Figure 29. Units of the Moberly Member at the Norris station 47–48 location on the Athabasca River. The top of unit 4 formed a resistant, horizontal bench at the time of this photo; it therefore appears thicker than described in this report. The majority of unit 4 is below water level. Unit 10 has slumped over and is obscuring a good view of units 7 through 9.

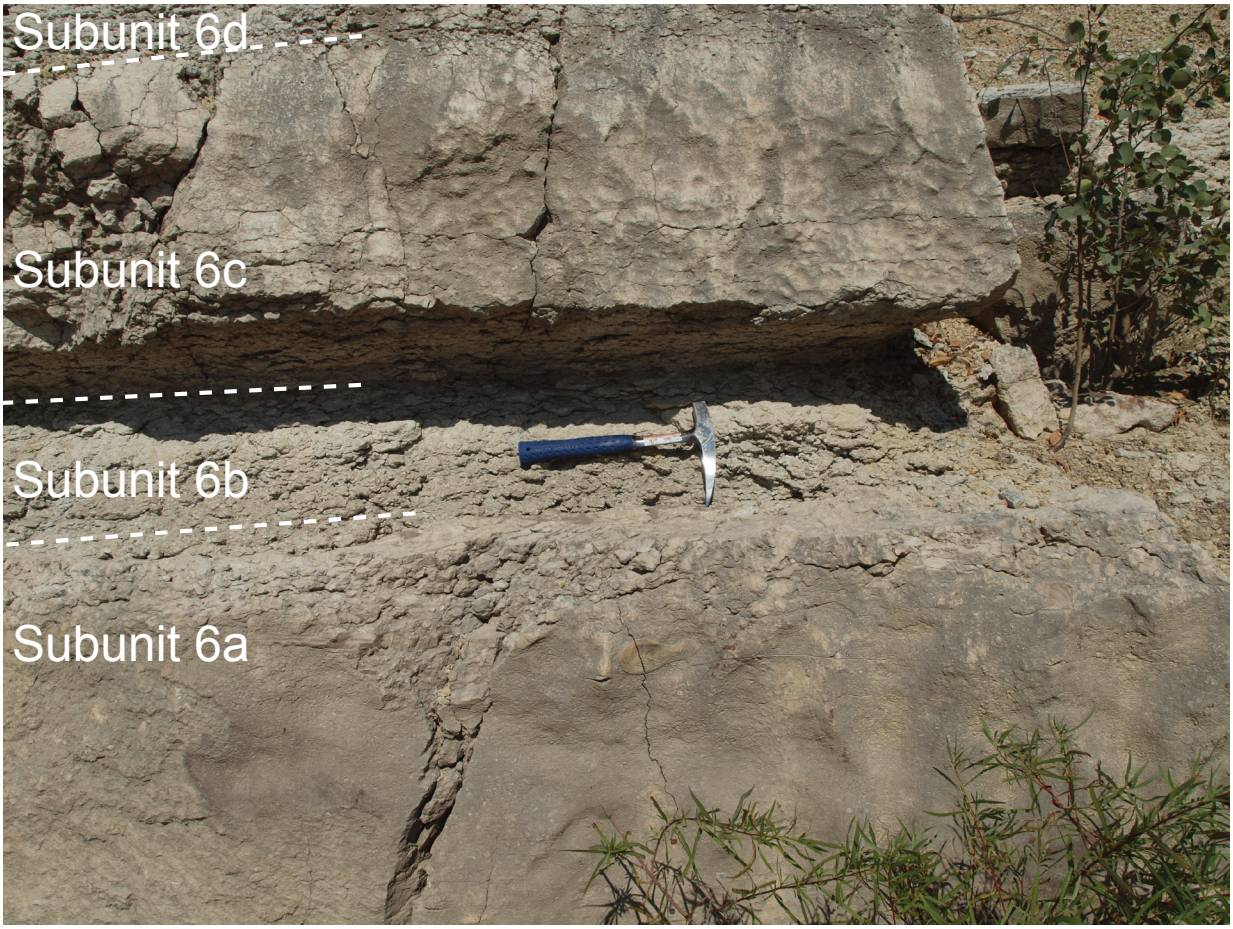

Figure 30. Subunits of unit 6 (a, b, c, d) of the Moberly Member at the Norris stations 47–48 location on the Athabasca River.

- Subunit 6a (58 cm): massive stromatoporoids in a brachiopod and crinoid rudstone with a packstone matrix (Figures 31 and 32). A hardground or scour surface occurs 5 cm below the top of this subunit.
- Subunit 6b (10–15 cm): very recessive, nodular-weathering, argillaceous, brachiopod floatstone to rudstone.
- Subunit 6c (31 cm): stromatoporoids in a nodular-weathering, intraclastic, brachiopod, crinoid, and gastropod grainstone that was originally a carbonate sand.
- Subunit 6d (65 cm): recessive, benched, brachiopod and crinoid floatstone to rudstone; lacks stromatoporoids. This bed is locally covered by slumped unit 7 nodules.

• Unit 7 (~50 cm; measurement approximated because of slump material from unit 10): increasingly recessive upward, grey weathering and fresh, wavy-bedded, bioturbated, brachiopod floatstone in a wackestone to packstone matrix (Figure 29).
• Units 8 and 9 (~70 cm): beige- and nodular-weathering (nodules up to 5 cm), grey fresh, bioturbated, argillaceous lime mudstone. Some brachiopods can be found in the slightly more resistant nodular beds of upper unit 9. The top of unit 9 can be seen as a resistant protuberance in the slump of nodules originating from unit 10. The thickness of unit 9 cannot be determined because of slump, so the measurements are for units 8 and 9 combined (Figure 29).
• Unit 10 (~300 cm): beige- and nodular-weathering (centimetre-scale), grey fresh, bioturbated, argillaceous lime mudstone. Unit 10 slumps over units 7 through 9, resulting in approximated measurements of all four units (Figures 29 and 33).
• Unit 11 (43 cm): contains the following three beds from base to top (Figure 34):
  - Bed 1 (7 cm): slightly resistant, beige-grey- and nodular-weathering, light grey fresh, bioturbated, argillaceous brachiopod and crinoid floatstone in a wackestone to packstone matrix. Brachiopods include rhynchonellides, atrypides, and spiriferides and are whole or are single valves.
  - Bed 2 (12 cm): recessive, beige-grey- and nodular-weathering, light grey fresh, bioturbated, argillaceous, brachiopod and crinoid floatstone in a wackestone matrix. Brachiopods are whole and include rhynchonellides.
  - Bed 3 (24 cm): resistant, beige-grey-weathering, light grey fresh, wavy-bedded, bioturbated, argillaceous, brachiopod and crinoid floatstone in a wackestone to packstone matrix. Brachiopods are single valves.
• Unit 12 (~ 200 cm): recessive, beige- and nodular-weathering, grey fresh, centimetre-scale, bioturbated, argillaceous, lime mudstone (Figure 33).

9.3 Sub-Cretaceous Unconformity

The sub-Cretaceous unconformity has been eroded, and the outcrop is covered by a thin soil.

9.4 Structure

This outcrop contains the axis and southeastern limb of an anticline. Near the downstream end of the outcrop, the lower units lie nearly flat. The upstream end of the outcrop arcs gently into the water, where upper beds are accessible (Figure 28).

Vertical fractures are common at this outcrop. Some fractures throughout unit 6 contain yellowish, translucent calcite crystals up to 1 cm in diameter (Figure 35). Slickensides were observed on unit 6 near the downstream end of the outcrop (Figure 36).

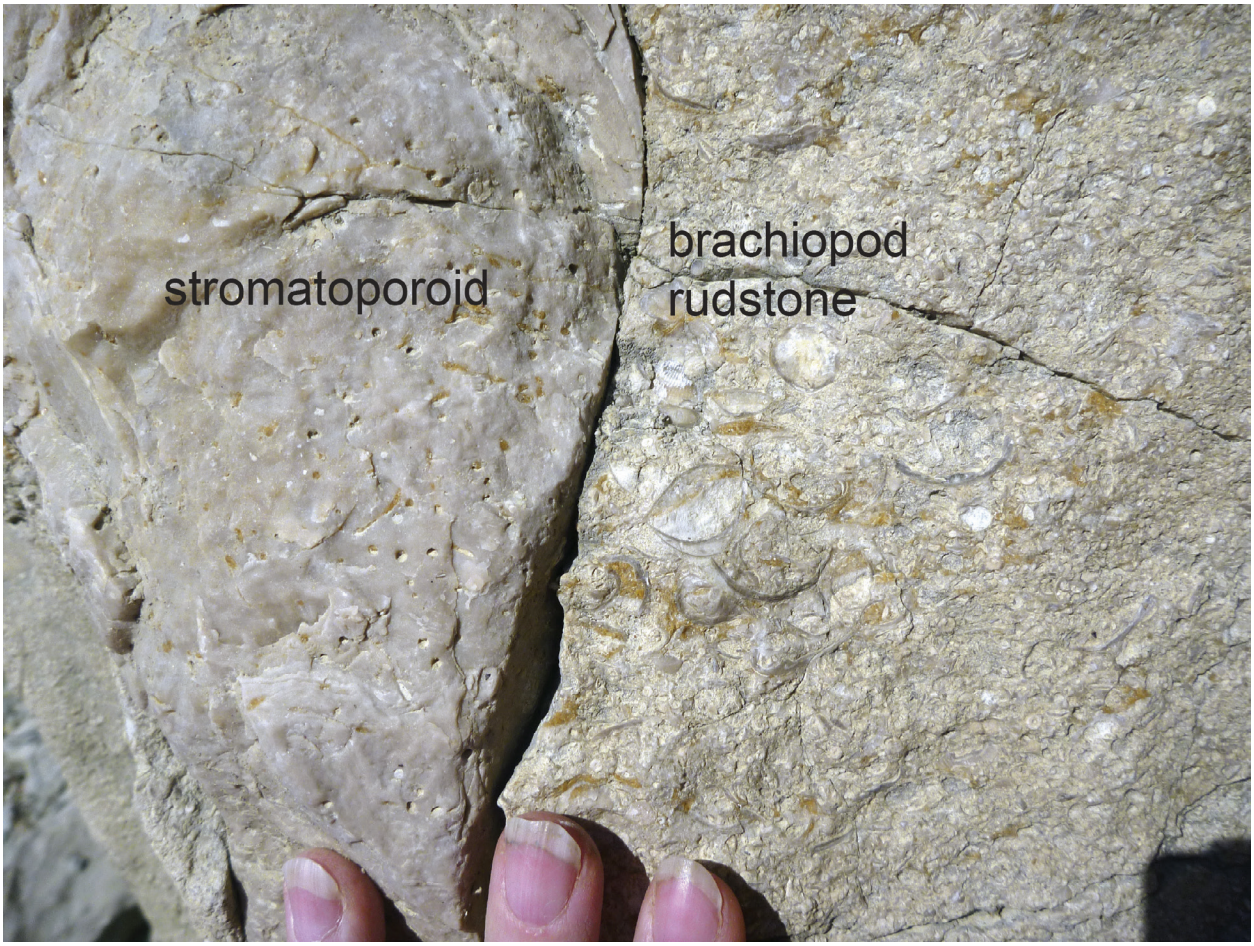

Figure 31. Massive stromatoporoid within a brachiopod rudstone in subunit 6a of the Moberly Member at the Norris stations 47–48 location on the Athabasca River. Brachiopods in the rudstone are mostly *Radiatrypa*. Small holes on the surface of the stromatoporoid are borings that were produced by an unidentified boring organism while the stromatoporoid was alive or before the stromatoporoid became buried by younger sediments.

Figure 32. Close-up of the brachiopod rudstone at the top of subunit 6a of the Moberly Member at the Norris stations 47–48 location on the Athabasca River. Note the close packing of the brachiopod shells.

Figure 33. Units 10 to 12 of the Moberly Member at the Norris stations 47–48 location on the Athabasca River. View is downstream.

Figure 34. Beds 1 through 3 of unit 11 of the Moberly Member at the Norris stations 47–48 location on the Athabasca River.

Figure 35. Calcite crystals on a fracture surface covering a stromatoporoid (left of the crystals) and the brachiopod rudstone of subunit 6a of the Moberly Member at the Norris stations 47–48 location on the Athabasca River.

Figure 36. Slickensides at the top of subunit 6a of the Moberly Member at the Norris stations 47–48 location on the Athabasca River. The white dashed line outlines the subvertical slickensides.

10 Norris Station 39

10.1 Locality Description and Access

UTM Zone 12, 473164E, 6311461N and 473090E, 6311575N (NAD83)

The location measured is one limb and the axis of a low-amplitude anticline (Figure 37). The undescribed limb is downstream and contains the same units. Unit 6 is the resistant bed that forms the distal portions of the exposed limbs of the anticline but is eroded over the axis of the anticline. Lower units are exposed near water level in the centre of the anticline. Units 4 through 6 were briefly observed at the upstream end of the anticline, and units 2 and 3 were described near the axis of the anticline.

This location is easily accessed by boat.

10.2 Stratigraphy

The following units were described from the axis of the anticline:

- Unit 2 (113 cm): this unit can be broken into two beds separated by a 1 to 2 cm, bitumen-stained, argillaceous, wackestone parting. From bottom to top, these beds are as follows:
  - Bed 1 (89 cm): Light grey-beige (weathering and fresh), wavy-bedded (5–8 cm), *Thamnopora* and bulbous stromatoporoid rudstone in a wackestone matrix. *Thamnopora* are abundant.
  - Bed 2 (24 cm): light grey-beige-weathering, light grey fresh, wavy-bedded (5–7 cm), brachiopod, crinoid, *Thamnopora*, and massive and bulbous stromatoporoid rudstone in a wackestone matrix. Fossils are bitumen stained. The top is a hardground with truncated, toppled stromatoporoids. The surface also contains *Planolites* burrows up to 1 cm in diameter (Figure 38).
- Unit 3 (unmeasured): recessive, light beige-grey weathering, light grey, nodular (5–10 cm), brachiopod, crinoid, and gastropod floatstone in a wackestone matrix. Gastropods are common and several taxa are present. Brachiopods include atrypides, strophomenides, and a large productide.

Units 4 through 6 were observed briefly at the upstream end of the anticline (Figure 39):

- Unit 4 (55 cm): resistant, light beige-grey- and nodular-weathering, light grey fresh, approximately 4 cm wavy-bedded), bioturbated, brachiopod and crinoid rudstone in a wackestone matrix. Brachiopods are fragmented. The top 3 to 4 cm is a dark-grey-weathering, brachiopod, crinoid, gastropod, and intraclast rudstone in a wackestone to packstone matrix. The unit is capped by a dark grey lime mudstone crust containing *Planolites* burrows.
- Unit 5 (60 cm): nodular limestone. Nodules are centimetre-scaled.
- Unit 6 (>104 cm): resistant, beige-grey weathering, massive, stromatoporoid framestone in a brachiopod and crinoid rudstone matrix with a packstone-grainstone matrix. Stromatoporoids bear millimetre-scale and larger circular borings. One stromatoporoid was observed toppled and erosionally truncated (Figure 40).

The overlying recessive, benched limestone above was not observed.

10.3 Sub-Cretaceous Unconformity

The sub-Cretaceous unconformity has been eroded and the outcrop is overlain by a thin soil.

Figure 37. The Moberly Member at the Norris station 39 location on the Athabasca River. View is downstream. The distal and proximal ends of the anticline are capped by the thick, resistant limestone of unit 6, which was eroded over the axis of the anticline.

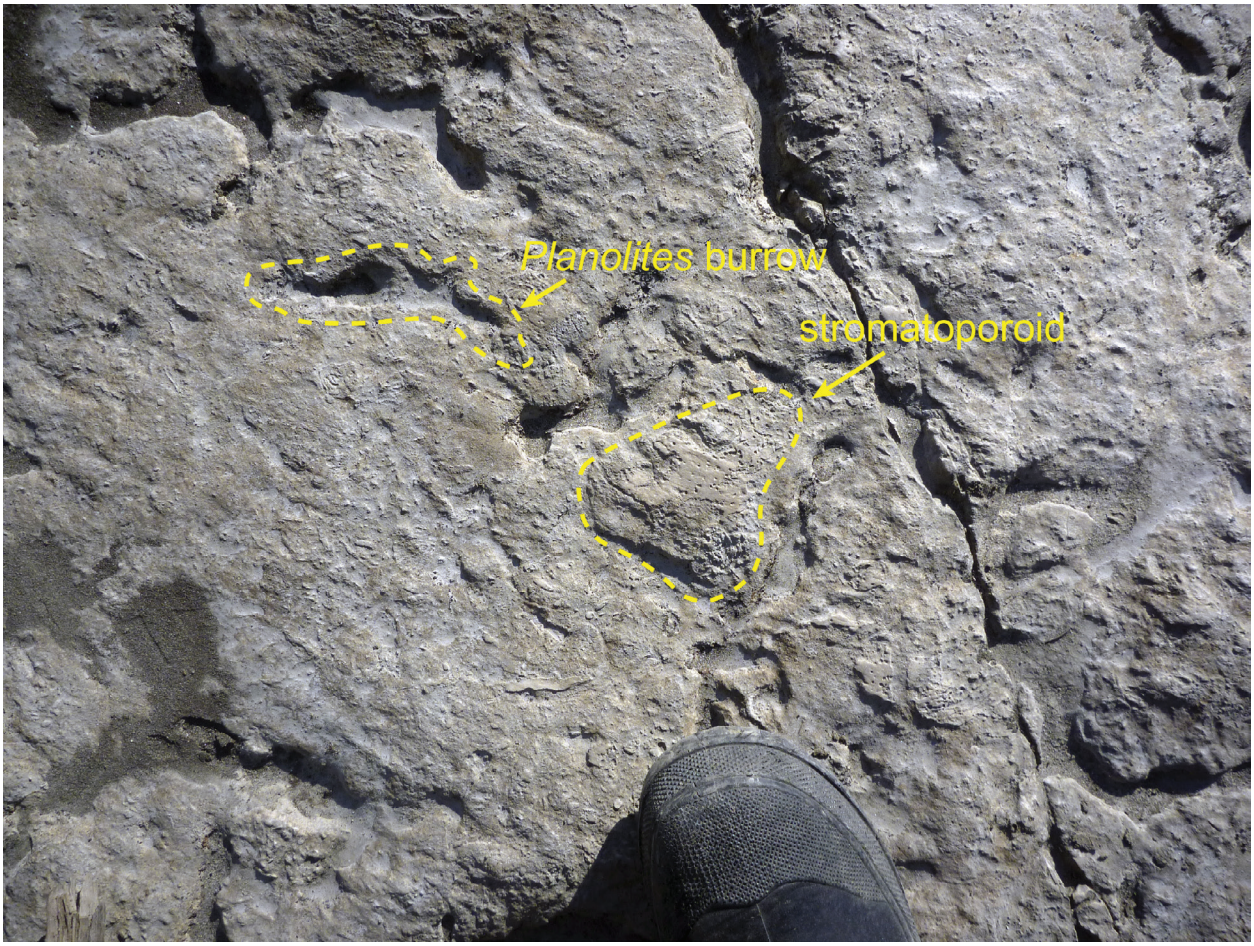

Figure 38. The top surface of unit 2 exposed at the axis of the anticline at the Norris station 39 location on the Athabasca River. The surface is a hardground that contains *Planolites* burrows and toppled and erosionally truncated branching and bulbous stromatoporoids.

Figure 39. The upstream end of the Norris station 39 outcrop on the Athabasca River. In the photograph, the exposed flat bedding-plane surface of the top of unit 4 creates the illusion of some non-existent vertical thickness between units 4 and 5.

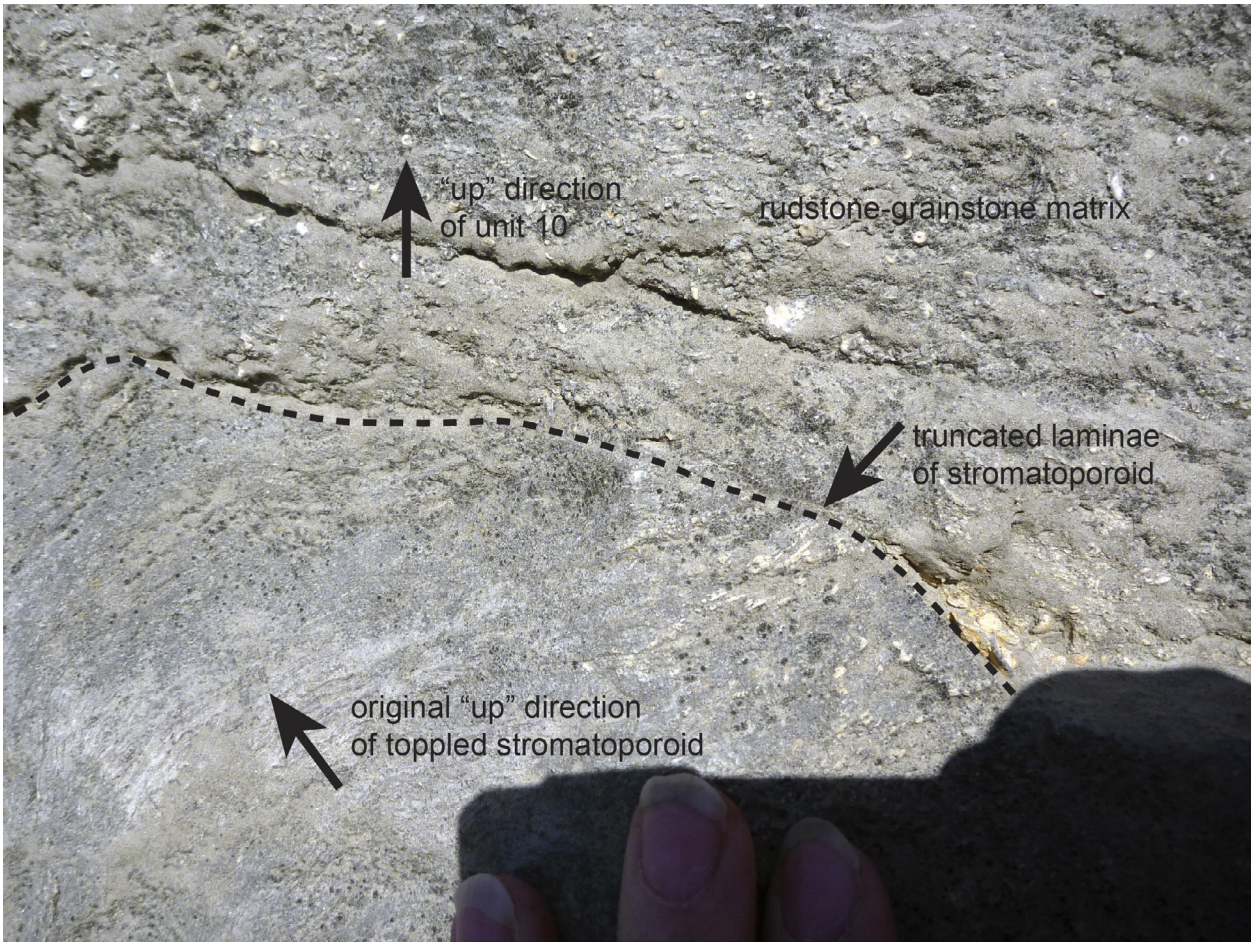

Figure 40. Close-up of a toppled and truncated massive stromatoporoid within the brachiopod rudstone of unit 6 of the Moberly Member at the Norris station 39 outcrop on the Athabasca River.

10.4 Structure

This location is on the upstream end of a gentle anticline. The unit 6 resistant limestone dips southward into the water at this outcrop. Another outcrop downstream is the other limb of the anticline. Unit 6 limestone was eroded over the axis of the anticline.

11 McLean Creek Outcrop

11.1 Locality Description and Access

UTM Zone 12, 474693E, 6305797N (NAD83)

This outcrop was not visited by Norris (1963). This location is approximately 80 m south of the confluence of McLean Creek with the Athabasca River and on the opposite bank of the Athabasca River from Norris' station 28.

This outcrop forms a steep slope of limestone nodules with two resistant beds beneath a tree-covered slope (Figures 41 and 42). The goal was to examine the upper resistant bed (unit 12) for this outcrop. Units 9, 10, and 11 below the upper resistant bed were not closely examined. Unit 13 was observed from below.

Access is easiest by boat. Scaling the steep slope of limestone nodules is difficult. The best access to the upper Moberly Member beds is along slightly less-steep gullies in the side of the cliff.

11.2 Stratigraphy

From bottom to top, the outcrop contains the following:

- Unit 9 (~200 cm exposed): recessive, beige-grey and nodular-weathering (1–3 cm), argillaceous limestone.
- Unit 10 (~25 cm): resistant, beige-grey-weathering, argillaceous limestone.
- Unit 11 (~400 cm): recessive, beige-grey- and nodular-weathering (1–3 cm), argillaceous lime mudstone (Figure 43).
- Unit 12 (65 cm): resistant, beige-weathering, beige-grey fresh, tabular-bedded (3–8 cm), brachiopod, crinoid, and bulbous stromatoporoid floatstone in a crystalline wackestone to packstone matrix. Bulbous stromatoporoids are 2 cm in diameter. The top 5 to 7 cm is a brachiopod, crinoid, and gastropod rudstone in a grainstone matrix (Figure 43).
- Unit 13 (~100 cm): recessive, beige-grey- and nodular-weathering (1–2 cm), argillaceous limestone.

11.3 Sub-Cretaceous Unconformity

The outcrop is overlain by dark grey McMurray Formation oil sand. The contact with the top of the Devonian limestone was slumped and the nature of the contact was not observed.

11.4 Structure

This outcrop dips gently to the north.

Figure 41. The McLean Creek outcrop on the Athabasca River. The Moberly Member underlies the McMurray Formation oil sand on the downstream end of the outcrop (left) and underlies soil on the upstream end of the outcrop (right).

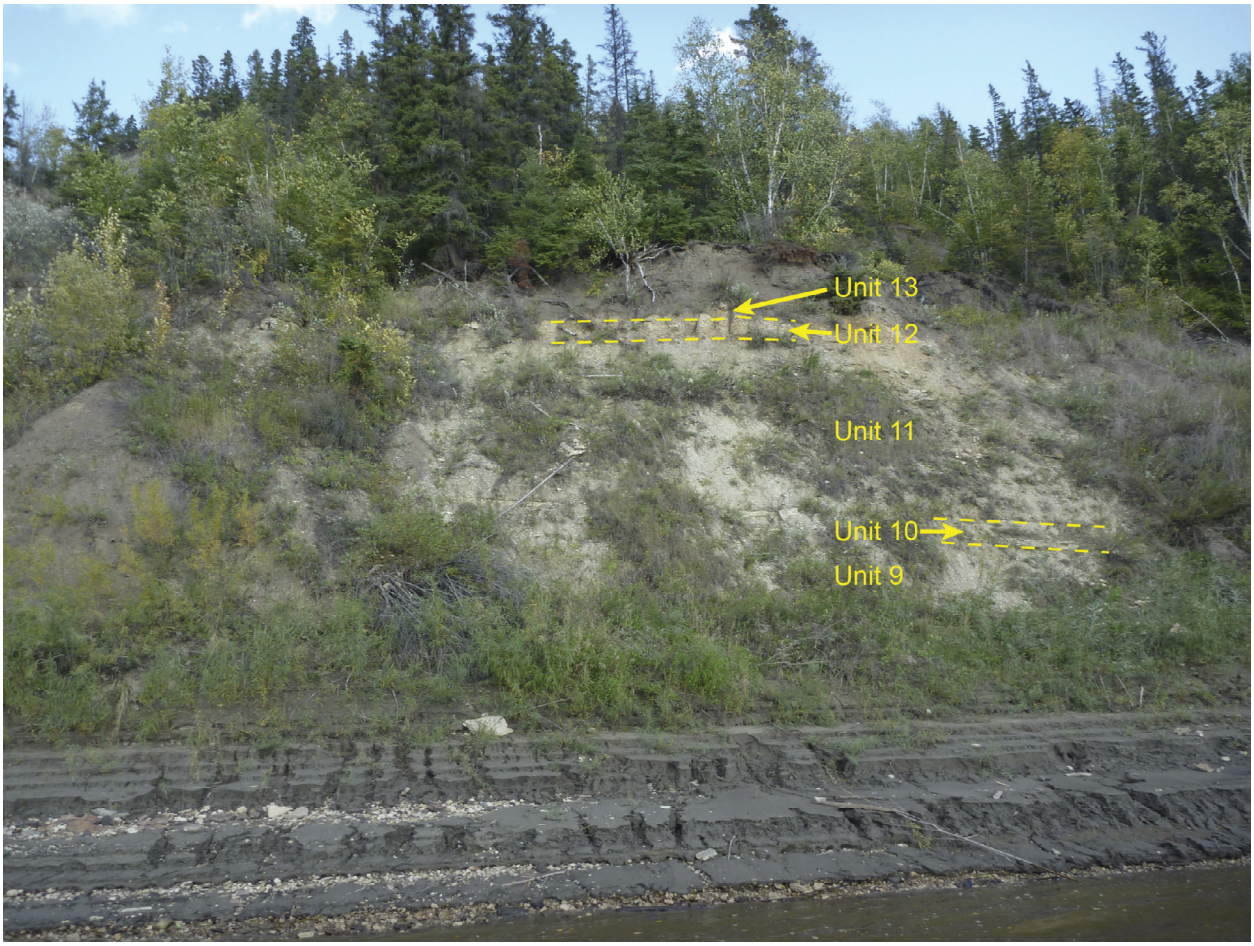

Figure 42. Units within the Moberly Member at the McLean Creek outcrop on the Athabasca River.

Figure 43. M. Grobe and T. Hauck investigating unit 12 of the Moberly Member at the McLean Creek outcrop on the Athabasca River.

12 Norris Station 23 (Fire Sign)

12.1 Locality Description and Access

UTM Zone 12, 474339E, 6301115N (NAD83)

This outcrop wraps around a meander. On the downstream end of this outcrop, a sign on the top of the cliff reads, “Help Prevent Forest Fires” (Figure 44). Downstream and around the meander from the sign, resistant unit 10 forms a wide bench (Figure 45). Unit 11 forms a short cliff or wall of nodules that is traceable along most of the outcrop and can be accessed from a narrow ledge along the edge of the cliff. Caution is advised as the ledge is narrow; weathered nodules can cause treacherous footing, and the water below is deep and swift.

The outcrop is easily accessed by boat. Docking is best on the downstream end of the outcrop where unit 10 forms a resistant ledge. When the water level is low, a very narrow bank of talus is exposed at the base of the upstream end of the outcrop.

12.2 Stratigraphy

From base to top, the strata in the resistant bench include the following units (Figure 45):

- Unit 9 (50 cm exposed): green-grey-weathering (grading upwards to brown), grey fresh, nodular-bedded (1–4 cm), bioturbated, argillaceous lime mudstone to wackestone.
- Unit 10 (54 cm): contains three beds, from base to top, as follows:
  - Bed 1 (12–14 cm): resistant, brown-weathering, fresh light brown, bioturbated, argillaceous, brachiopod rudstone in a wackestone to packstone matrix. The top 4 cm is a lime mudstone with a burrowed surface.
  - Bed 2 (23 cm): recessive, green-grey (weathering and fresh), centimetre-scale nodular-bedded, bioturbated, argillaceous, brachiopod and crinoid rudstone in a wackestone to packstone matrix.
  - Bed 3 (22 cm): two beds of resistant, brown-weathering, brown-grey, bioturbated, argillaceous, brachiopod floatstone to rudstone in a wackestone to packstone matrix. Brachiopods are fragmented.

Upstream, above the resistant bench, the nodular limestone wall includes the following (Figure 46):

- Unit 11 (383 cm): recessive, green-grey- and nodular-weathering, green-grey fresh, wavy-bedded (1–4 cm), argillaceous, lime mudstone to wackestone with a local brachiopod floatstone texture (Figure 47). Some nodules and beds are laminated. A prominent bed 175 cm from the base varies in thickness from 1 to 4 cm, and is a slightly resistant, fragmental brachiopod floatstone to rudstone in a wackestone matrix (Figure 48). A 10 cm thick bed is 200 cm from the base and is a brachiopod rudstone with a capping hardground. The upper 125 cm is a tabular-bedded (1–2 cm), very argillaceous, lime mudstone.

Observed from the boat, upstream of the fire sign, overlying unit 11 and underlying a thin soil is

- Unit 12 (~25 cm): orange- (from iron staining), otherwise white-weathering, resistant, unbedded limestone (Figure 49).

12.3 Sub-Cretaceous Unconformity

The outcrop is overlain by a thin soil. The upper 125 cm becomes increasingly orange upsection with iron staining. Unit 12, where it is preserved, is also orange stained.

Figure 44. The fire sign upstream of the measured section at the Fire Sign outcrop.

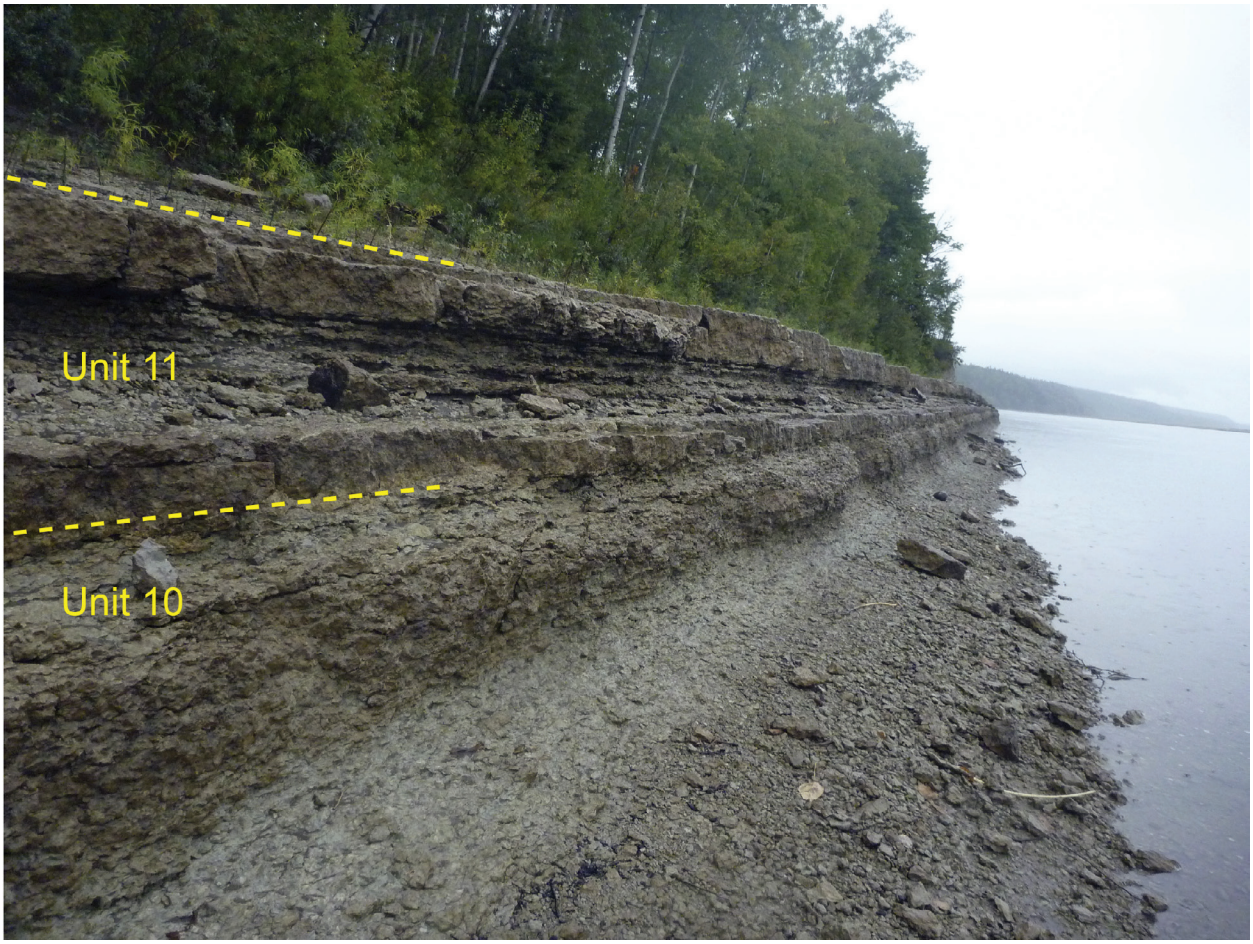

Figure 45. Downstream location at the Fire Sign outcrop, including units 8 and 10 of the Moberly Member. The top of unit 10 is partly eroded in this photo.

Figure 46. The wall of limestone nodules that is unit 12 of the Moberly Member at the Fire Sign outcrop on the Athabasca River. The ledge at the base of the wall of nodules is the top of resistant unit 10.

Figure 47. The wall of limestone nodules that is unit 12 of the Moberly Member at the Fire Sign outcrop on the Athabasca River. The ledge at the base of the wall of nodules is the top of resistant unit 10.

Figure 48. Resistant brachiopod floatstone to rudstone bed in unit 11 of the Moberly Member at the Fire Sign outcrop on the Athabasca River.

Figure 49. Location downstream of the fire sign and upstream of the measured location at the Fire Sign outcrop on the Athabasca River where unit 12 of the Moberly Member is preserved.

12.4 Structure

Where the outcrop was measured, limestone beds lie nearly flat.

13 Conclusion

Most of the Moberly Member at the outcrops described is a nodular, argillaceous limestone. Resistant units are dispersed throughout the nodular limestones. In general, nodular limestones become less fossiliferous above unit 6.

Resistant units can be easily correlated between outcrops, particularly the 200 to 300 cm thick biostromal unit (unit 6), which is a branching and tabular stromatoporoid rudstone to bindstone in the northern portion of the study area and a massive stromatoporoid framestone in a *Radiatrypa* rudstone matrix in the southern portion of the study area.

Two other units contain stromatoporoids (units 2 and 12) but are distinct from unit 6 in that they are thinner (0.5 to 1 m thick) and stromatoporoids are less abundant. A 0.5 m thick packstone to grainstone bed (unit 4), which often contains peloids or skeletal sand, is present 60 cm below the biostromal unit 6. and also helps with correlation.

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