AER/AGS Open File Report 2014-08

Alberta Energy Regulator

Outcrops of the Lower Waterways Formation (Firebag and Calumet Members) on the Clearwater, Athabasca, and Firebag Rivers, Alberta (NTS 74D, E)

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Outcrops of the Lower Waterways Formation (Firebag and Calumet Members) on the Clearwater, Athabasca, and Firebag Rivers, Alberta (NTS 74D, E)

C.L. Schneider[3], M. Grobe[1], L.R. Leighton[2], F. Hein[1], and F.L. Forcino[2]

[1] Alberta Energy Regulator
Alberta Geological Survey
[2] Department of Earth and Atmospheric Sciences, University of Alberta
[3] Formerly of Alberta Energy Regulator/Alberta Geological Survey (see page ii for current address)

September 2014

ISBN 978-1-4601-0134-6

Schneider, C.L., Grobe, M., Leighton, L.R., Hein, F. and Forcino, F.L. (2014): Outcrops of the Lower Waterways Formation (Firebag and Calumet members) on the Clearwater, Athabasca, and Firebag rivers, Alberta (NTS 74D, E); Alberta Energy Regulator, AER/AGS Open File Report 2014-08, 34 p.

Author addresses:
C.L. Schneider
Department of Earth & Atmospheric Sciences
University of Alberta
Edmonton, AB T6G 2E3
Canada
780-628-4384
E-mail: clschnei@ualberta.ca

L.R. Leighton and F. Forcino
Department of Earth & Atmospheric Sciences
University of Alberta
Edmonton, AB T6G 2E3
Canada
780-492-3983
E-mail: lleighto@ualberta.ca, forcino@ualberta.ca

Published September 2014 by:
Alberta Energy Regulator
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Fax: 780.422.1459
E-mail: AGS-Info@aer.ca
Website: www.ags.gov.ab.ca

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Acknowledgements

We thank Steve Russell for boat transportation to outcrops on the Athabasca and Clearwater rivers. We also thank Phoenix Heli-Flight for transportation to outcrops on the Firebag and Athabasca rivers. We are grateful to Jill Weiss for field support and assistance. Tyler Hauck provided helpful comments on an earlier draft of this report. Aaron Dalton edited and produced the final version of the report.

Abstract

Alberta Geological Survey geologists and University of Alberta paleontologists visited several Waterways Formation outcrops on the Clearwater, Athabasca, and Firebag rivers during the summer field seasons of 2010 and 2011. Outcrops described include Firebag Member outcrops on the Athabasca and Firebag rivers, Calumet Member outcrops on the Clearwater River, and an outcrop containing the upper Calumet and the Christina members on the Athabasca River. The outcrop on the Firebag River had previously been attributed to the Slave Point Formation but, based on lithology, is more properly assigned to the Firebag Member of the Waterways Formation.

1 Introduction and Background

Outcrops of the Waterways Formation along the Clearwater and Athabasca rivers have attracted the notice of explorers and geologists for over a century. Early travellers on the river recorded in their journals simple descriptions of the light coloured, gently folded limestones that underlie dark oil sand. Fossils collected from the shores of the rivers indicated faunas similar to those known from Devonian formations in the United States.

Warren (1933) named the Waterways Formation for the limestone outcrops along the confluence of the Athabasca and Clearwater rivers. Crickmay (1957) divided the Waterways Formation into five members within the Bear Biltmore no. 1 (07-11-087-17W4) core (Figure 1). From base to top, these members are Firebag, Calumet (Calmut), Christina, Moberly and Mildred. Warren's (1933) Fort McMurray–area outcrops fall within the Moberly Member; the Firebag, Calumet, and Christina members outcrop further downstream on the Athabasca River and upstream on the Clearwater River to almost the Alberta-Saskatchewan border.

Norris (1963) produced a detailed correlation of the Waterways Formation outcrops in northeast Alberta. Over several years, Norris and others described most of the outcrops along the Clearwater and Athabasca rivers and their tributaries east and north of Fort McMurray. Norris (1963) recognized that the Moberly Member outcrops along the Clearwater River near Fort McMurray and along much of the Athabasca River in the Devonian outcrop zone. Older members outcropped upstream along the Clearwater River and at the distal end of the Devonian outcrop zone on the Athabasca River, reflecting the northeastwards subcropping of progressively older, westward-dipping, and eroded Devonian strata.

Buschkuehle (2003) described several outcrops of the Waterways Formation members, including one each of the Firebag, Calumet, and Christina members. She described an outcrop of the Christina Member downstream of the Athabasca River barge dock near Fort McKay and outcrops of the Firebag and Calumet members along the High Hill and Clearwater rivers, respectively. The Clearwater River Calumet Member outcrop is among those redescribed herein.

Most of the outcrops described in this report are best accessed by boat out of Fort McMurray (Figure 2). A boat operator who is experienced on these rivers is recommended; both rivers are very shallow and have frequently shifting sandbars and submerged obstacles. Most outcrops are at river level and are easily observed along the shore. Some Waterways Formation outcrops are accessible by helicopter, but many outcrops often terminate at the river's edge and lack landing space for aircraft. A few outcrops may be accessed by car and a short hike.

2 Athabasca River

2.1 Locality description and access

UTM Zone 12, 467785E, 6374446N (NAD83) (locality '1', Figure 2)

This is the northernmost known Devonian outcrop along the Athabasca River. Here, the Firebag Member outcrops as a series of low-angle, dipping beds that have been eroded to near water level and have weathered into loose slabs (Figure 3). Beds dip to the west-southwest on the upstream end of the outcrop and to the north-northwest on the downstream end of the outcrop, suggesting a low-amplitude anticline. Bedding planes frequently bear conspicuous, large brachiopods, mainly of the atrypide *Variatrypa clarkei*. Brachiopods also weather out of a small area of exposed shale at the downstream end of the outcrop.

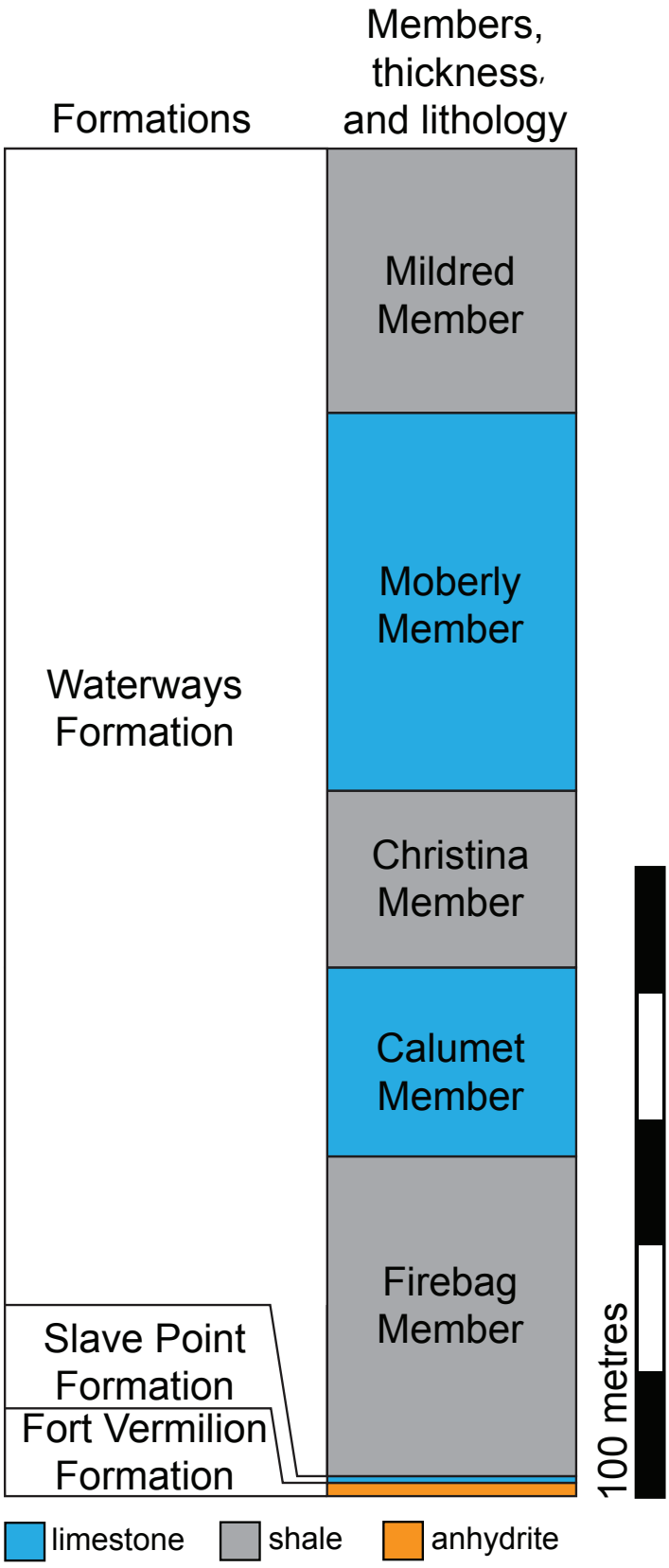

Figure 1. Beaverhill Lake Group stratigraphic nomenclature and dominant lithologies in the Bear Biltmore no. 1 (07-11-087-17W4) core as described by Crickmay (1957).

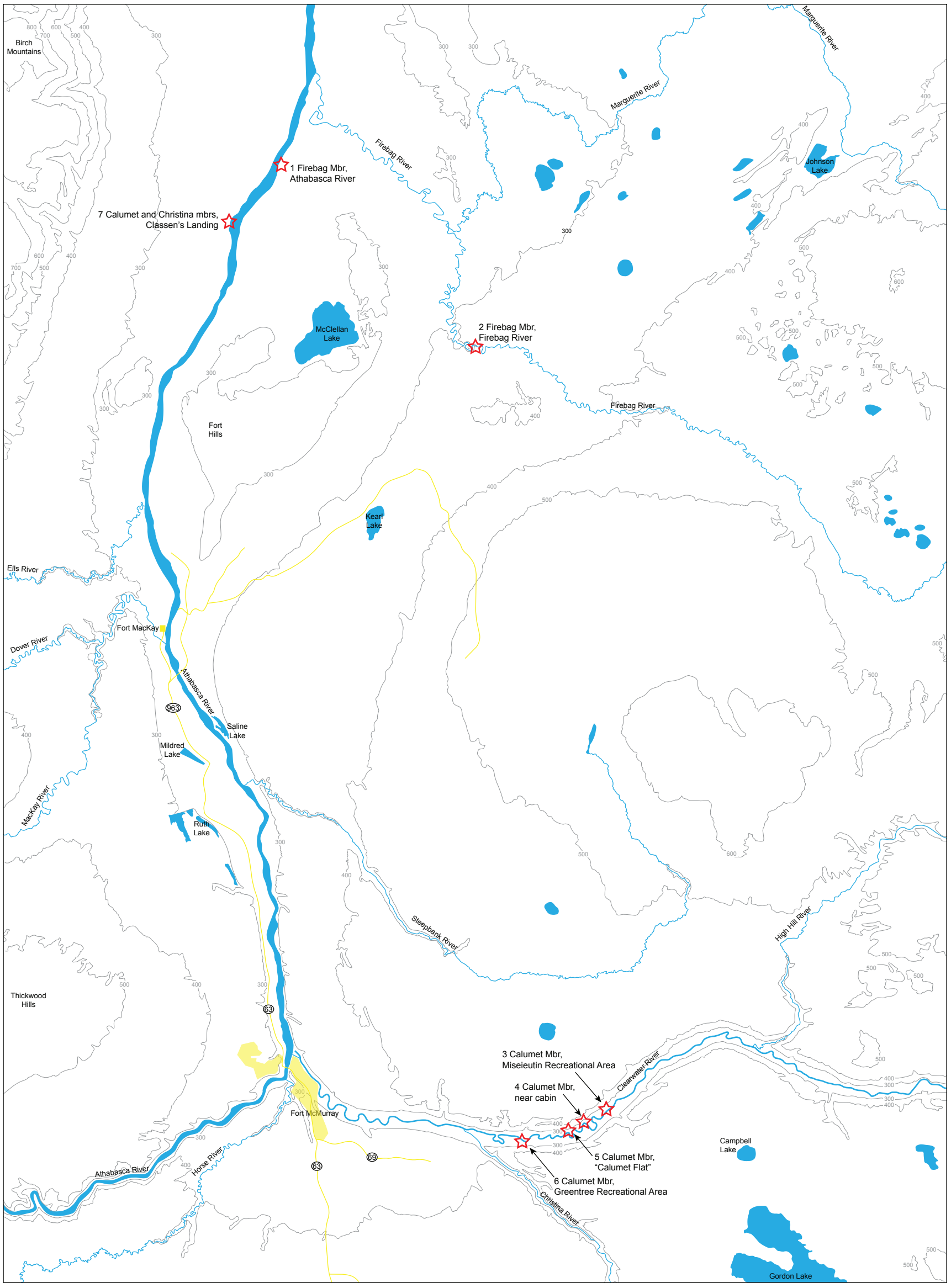

Figure 2. Map of outcrops described in this report.

Figure 3. Outcrop of the Firebag Member, Waterways Formation, on the Athabasca River. According to Norris (1963), this outcrop is the northernmost Devonian exposure along the Athabasca River. Outcropping limestone beds are weathered to the level of the slope and benched upslope and downstream. Loose slabs weather from these benched beds. Shale with loosely weathering brachiopods is exposed at the upstream end of the outcrop and can be exposed with trenching at the downstream end of the outcrop (not in the photograph).

A light grey Mesozoic sandstone is exposed a short walk downstream near the water level.

This outcrop is accessible by boat or, when the river level is sufficiently low, helicopter to the river bank.

This outcrop is equivalent to that of Norris's (1963) stations 103 and 104.

2.2 Stratigraphy

The Firebag Member is mostly shale except for a regionally extensive argillaceous limestone in the middle of the unit. This outcrop contains some of the beds from the middle limestone (Figure 4).

Beds from this outcrop dip gently to the northwest and are truncated by fluvial erosion to the level of the bank. Thickness measurements were calculated from the average dip and the measured length of horizontal exposure of each unit. From base to top, the outcrop contains the following units:

1) 20 cm: resistant, blue-grey weathering, grey, nodular-bedded, argillaceous atrypide brachiopod rudstone in a mudstone matrix interbedded with up to 1 cm thick partings of blue-grey shale.

2) 100 cm: recessive, grey weathering, green-grey, millimetre-scale laminated calcareous shale with argillaceous lime mudstone nodules up to 5 cm in diameter and large atrypide brachiopods. Brachiopods are common in the lower 40 cm and become rare in the upper 60 cm. The top 10 cm contains five beds of medium grey, argillaceous lime mudstone, each 1 cm thick, interbedded with shale.
3) 230 cm: resistant, grey-beige weathering, medium grey, 2 to 5 cm tabular to wavy-bedded, argillaceous lime mudstone. Beds are separated by 1 to 2 cm thick, brown-grey weathering, green-grey calcareous shale interbeds. Rare brachiopods occur in the shale beds.
4) Recessive, green-grey, calcareous shale overlies the limestone. Brachiopods weather loose from this shale or from the top bed of unit 3.

2.3 Paleoenvironmental Interpretation

The argillaceous limestone beds at this outcrop formed during a decrease of terrigenous mud influx into the basin or during a regression that allowed calcareous organisms to establish and produce sufficient carbonate. Argillaceous carbonate mud accumulated in a low-energy paleoenvironment below fair-

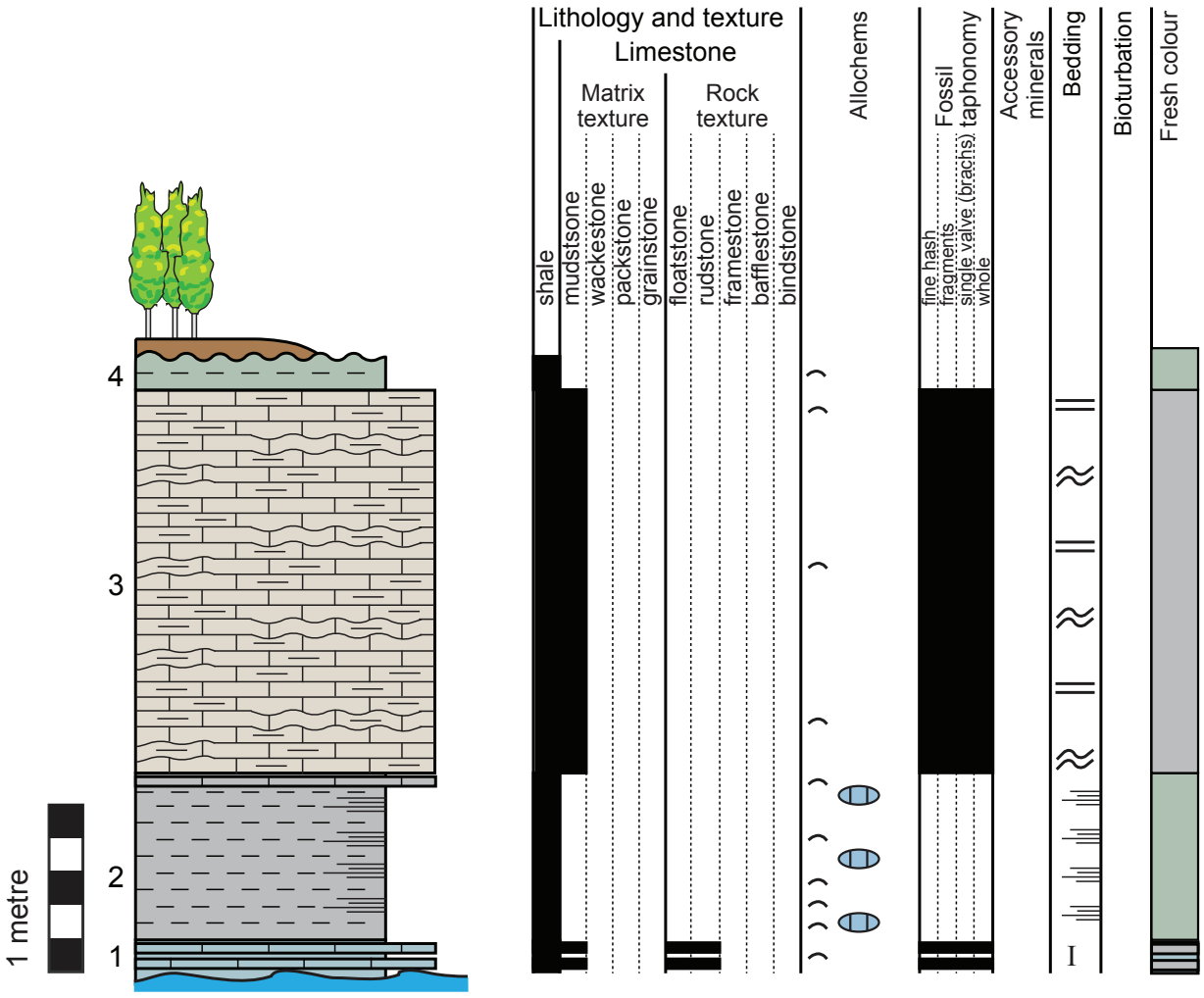

Figure 4. Reconstructed measured section of the Firebag Member on the Athabasca River. The outcrop is weathered to the level of the river bank and is benched recessively upslope.

weather wave base but above storm wave base. A brachiopod-dominated paleocommunity that contained abundant Variatrypa clarkei thrived for the duration of lime mud accumulation.

2.4 Structure

Resistant beds dip 10 degrees to the northwest and strike 71 degrees on the downstream end of the outcrop and 170 degrees at the upstream end of the outcrop. The outcrop is eroded to nearly ground level in multiple benches of individual beds. The stratigraphic top of the section is upslope from the river, with older beds terraced towards the river level.

2.5 Post-Devonian Erosion

The outcrop is eroded to the level of the low-sloping river bank and, in the upslope portion of the outcrop, is overlain by river sediment and soil. The sub-Cretaceous unconformity in the Firebag Member outcrop has been lost to erosion.

3 Firebag River

3.1 Locality description and access

UTM Zone 12, 496964E, 6369975N (NAD83) (locality '2', Figure 2)

This 50 m long, 1 m high outcrop lines the western bank on a meander in the Firebag River. This exposure contains tabular-bedded, argillaceous limestone of the Firebag Member 'middle limestone' (Figure 5).

Figure 5. Outcrop of the Firebag Member on the Firebag River, facing west (downstream), showing the tabular-bedded, argillaceous mudstone in the thickest portion of the outcrop.

The outcrop was folded into one low-amplitude anticline. At high water level, part of or the entire outcrop may be submerged.

Dahrouge (2006) described this outcrop as the Slave Point Formation, which Okulitch (2006) included in his bedrock map of the Lake Athabasca region. This outcrop is a better fit with the middle limestone unit of the Firebag Member rather than the Slave Point Formation because of its argillaceous nature, bedding, and green-grey colour. In core, the Slave Point Formation is beige to brown and not argillaceous except for local dark brown, wispy argillaceous partings. Both the middle limestone unit of the Firebag Member (Waterways Formation) and the Slave Point Formation can be fossiliferous, so the lack of fossils in this outcrop is not an indicator of either formation. Dahrouge (2006) described a rugose coral and brachiopods from the outcrop, which were not found during this visit; however, rugose corals are extremely rare in either unit.

To access by helicopter, land on the point bar at 496727E 6369881N and walk along the river level upstream. The outcrop is around the bend from the point bar and approximately 300 m upstream from the point bar.

3.2 Stratigraphy

Like the Athabasca River locality, this outcrop contains the middle limestone of the Firebag Member. However, this locality is unfossiliferous. Brachiopods and crinoids were found in float slabs, but the bed from which these slabs originated was not located in the outcrop.

The entire outcrop is 136 cm of resistant, green-grey and beige-grey weathering, grey, 1 to 5 cm tabular-bedded, argillaceous lime mudstone. Fractures are bitumen-stained. The top 24 cm is reddish stained and green-grey weathering, up to 1cm tabular-bedded and contains *Planolites* and other unidentified burrows on the top surfaces of the beds (Figures 6, 7, and 8).

Figure 6. Upper, centimetre-scale, reddish-stained beds of the Firebag Member outcrop on the Firebag River.

Figure 7. *Planolites* trace fossils (without burrow fill) on the upper surface of a bed in the middle of the Firebag Member outcrop on the Firebag River.

Figure 8. *Planolites* trace fossils from the surface of a bed from the middle of the outcrop.

3.3 Paleoenvironmental Interpretation

The lime mud formed in quiet water conditions. The lack of fossils and the presence of one burrow type (Planolites) on the top of some beds suggest that stressed environmental conditions prohibited most large organisms from colonizing the locality.

3.4 Structure

The outcrop contains one anticline. The axis of the anticline occurs 39 m from the eastern, upstream end of the outcrop and 13 m from the western, downstream end of the outcrop. The eastern limb dips 2 to 3 degrees to the southeast, and the western limb dips 5 to 6 degrees to the west.

At the axis of the anticline, joints range from a strike of 115 degrees with an 85 degree dip to a strike of 195 degrees and a vertical dip. Joints occur every 30 to 150 cm.

3.5 Post-Devonian Erosion

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

4 Miseieutin Recreation Area, Clearwater River

4.1 Locality Description and Access

UTM Zone 12, 512176E, 6282461N (NAD83) (locality '3', Figure 2)

At the Miseieutin Recreation Area, nodular and massive limestones outcrop intermittently along the Clearwater River. Two thin shale beds occur at this outcrop: one near the base and the other at the top of the outcrop, the latter altered by pedogenic processes; the soil on top of the uppermost limestone contains traces of the original shale and loose brachiopods.

Brachiopods weather from the outcrop and litter the river bank. *Schizophoria* sp. and stropheodonts are the most common brachiopods at the outcrop. Other fossils collected at this outcrop include spiriferide and atrypide brachiopods, planispiral gastropods, solitary rugose corals, crinoid columnals, and nautiloid segments.

The best access is by boat to the Miseieutin Recreation Area. Dock the boat at the recreation area sign and walk upstream along the shore to the outcrop. Thin beds may be exposed along the river bank if the water level is low and erosion has exposed the beds. Massive limestones outcrop in the brush and tree roots upslope of the river bank (Figures 9 and 10).

This outcrop is equivalent to that of Norris's (1963) stations 172 and 173.

4.2 Stratigraphy

The base of the outcrop is separated from the river by approximately 60 cm of river sediment and limestone talus containing abundant, loose *Schizophoria* and *Douvellina* brachiopods. From base to top, the outcrop contains the following units:

1) 5 cm: resistant but friable, beige weathering, medium grey, 1 to 2 cm bedded, brachiopod rudstone in a wackestone to packstone matrix (Figure 11). Large, dark grey *Schizophoria* brachiopods are abundant.

2) 33 cm: recessive, green-grey, calcareous shale. Whole brachiopods, including abundant *Schizophoria*, weather out of the shale near the top and base of the unit.
3) 40 cm: resistant, beige weathering, brown-grey, massive, bioturbated, brachiopod and crinoid floatstone in a wackestone matrix.
4) 175 cm: cover.
5) 80 cm: resistant, beige weathering, brown-grey, massive, bioturbated, fragmental brachiopod floatstone in a wackestone matrix. The massive bed is broken by two partings at 45 cm and 67 cm above the base of the unit.
6) 123 cm: cover.
7) 45 cm: resistant, white-brown weathering, light grey, 1 to 4 cm wavy to nodular-bedded, bioturbated, argillaceous, brachiopod floatstone in a lime mudstone to wackestone matrix (Figure 12). Some brachiopods occur in the shale partings between the nodular beds and weather free from the rock.

4.3 Paleoenvironmental Interpretation

The Calumet Member limestone at this outcrop was deposited in a sublittoral paleoenvironment under low to moderate energy conditions. The presence of gastropods suggests deposition in shallow water. The richness of the fauna combined with the abundance of organisms encrusted on the brachiopod shells (bryozoans, *Microconchus* sp., *Hederella* spp.) indicates a mature and thriving paleoecosystem.

4.4 Structure

Limestone beds above the river bank dip 13 degrees to the southwest. The uppermost beds may have a localized steeper dip because of upheaval from tree roots.

Figure 9. Outcrop of Calumet Member limestone at Miseieutin Recreation Area along the Clearwater River.

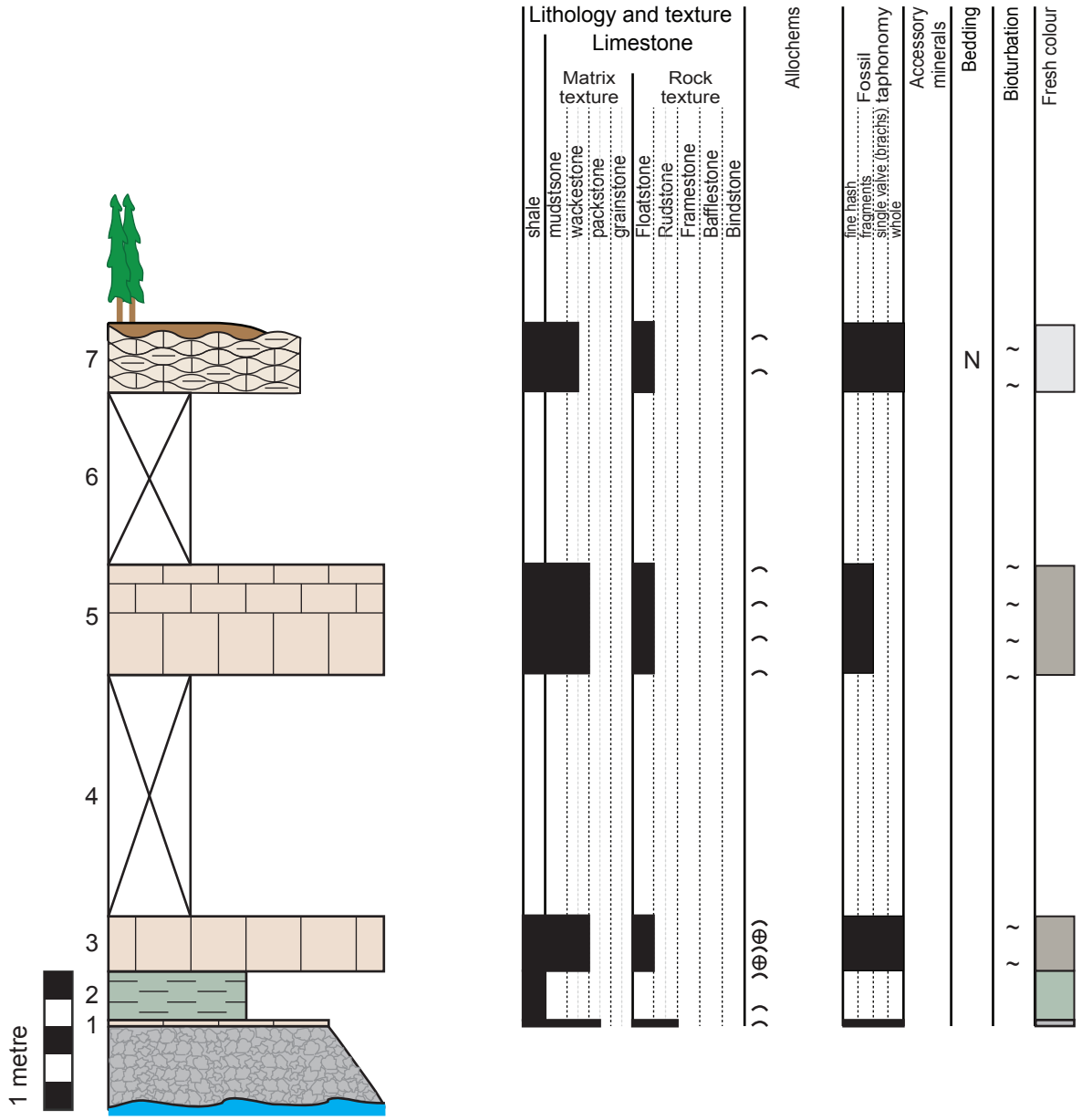

Figure 10. Measured section of the Calumet Member outcrop from Miseieutin Recreation Area, Clearwater River.

Figure 11. The riverbank at the Calumet Member outcrop at Miseieutin Recreation Area on the Clearwater River. The yellow arrow points to the lowermost bed discovered in the outcrop. Shale outcrops above the yellow arrow.

Figure 12. View from above unit 7 of the Calumet Member outcrop from Miseieutin Recreation Area on the Clearwater River.

The topmost limestone bed, unit 7, is brecciated by tree roots and other weathering processes. The limestone is white and chalky in appearance and may be partially decalcified.

4.5 Post-Devonian Erosion

The sub-Cretaceous unconformity is missing because of erosion, and the outcrop is overlain by a thin soil.

5 Calumet Member Outcrop, Clearwater River

5.1 Locality description and Access

UTM Zone 12, 509762E 6281257N to 509508E 6281048N (NAD83) (locality '4', Figure 2)

This locality intermittently outcrops along a 254 m long stretch of the north bank of the Clearwater River. The eastern, upstream end of the outcrop series is a succession of low-lying, horizontal to slightly dipping beds separated by intervals of shale that outcrop near the top of the river bank (Figure 13). The westernmost, downstream outcrop is a low knoll of gently dipping to undulose limestone beds that rises above the river bank (Figure 14). During high river levels, most of the outcrop would be underwater, leaving only the limestone knoll at the western end of the outcrop exposed.

This outcrop is accessible by boat. A large grassland at the eastern end of the outcrop may seem like a good landing pad for a helicopter, but the ground is gently sloped towards the river and may be marshy in the spring and early summer. Note that residents occupy the cabin upslope from the outcrop.

This outcrop is equivalent to that of Norris's (1963) station 178. The downstream limestone knoll and underlying shale was previously described by Buschkuehle (2003).

5.2 Stratigraphy

Intermittent outcrops start in unit 3 at the eastern end of the outcrop series (Figure 15). Unit 1 outcrops slightly downstream of the eastern end of the outcrop and is exposed in the core of a syncline (Figure 16). Beds from the anticline between the outcrop of units 1 and 3 are missing. Another outcrop occurs at the western end, but because of deformation and cover, its relationship to the eastern outcrops is unknown. At the eastern end of the outcrop, correlation between individual beds based on faunal content reveals that limestone beds undulate through a series of gentle folds, appearing and disappearing into the bank talus.

The limestone at the eastern end of the outcrop is rich in atrypide brachiopods (Figure 17). A composite of the beds from the eastern end of the outcrop series contains the following units (Figure 18):

1) >50 cm: recessive becoming resistant, blue-grey to green-grey shale grading up through a brachiopod-rich calcareous shale into 20 cm of a more resistant, green-grey weathering and fresh, up to 10 cm nodular weathering, argillaceous crinoid and brachiopod rudstone in a packstone matrix (Figure 16).
2) 60 cm: resistant, green-grey weathering, blue grey, 2 to 8 cm tabular to wavy-bedded, occasionally nodular weathering, bioturbated, argillaceous, crinoid and brachiopod rudstone in a wackestone to grainstone matrix. Beds are separated by calcareous shale partings. Several beds contain a capping argillaceous, burrowed or bored, lime mudstone firmground to hardground crust. Fractures are stained bright orange and contain pyrite (Figure 16).
3) 20 cm: Grey to green-grey weathering and fresh, nodular weathering (up to 10 cm in diameter), very argillaceous brachiopod and crinoid rudstone in a packstone matrix. Upstream this unit thickens to 40 cm and transitions into calcareous shale containing brachiopods, which weather loose.

Downstream the unit is 30 cm thick and becomes a nodular brachiopod and crinoid rudstone in a wackestone to packstone matrix (Figure 15).

A knoll of tabular limestone beds occurs at the western end of the outcrop (Figures 14, 19, and 20). Because of folding throughout the entire series of intermittent outcrops, it is unknown whether these beds occur above or below the limestone and shale at the eastern end of the outcrop series. The limestone at the western end of the outcrop series is described as follows:

4) 60 cm: resistant, green-grey weathering, fresh dark grey, up to 2 cm tabular-bedded, bioturbated, argillaceous lime mudstone. Thin shale partings separate the beds. The tops of the beds contain trace fossils (Figures 21 and 22). One bed, seen in float near this outcrop, contains symmetrical, low-amplitude ripples (Figure 22). Fractures in individual beds are stained orange and are filled with pyrite (Figures 21, 22, and 23).

5.3 Paleoenvironmental Interpretation

The eastern end of the outcrop series formed within a shallow marine environment below fair-weather wave base and above storm wave base. In these fossiliferous beds, most of the brachiopods are whole and display no key evidence of tempestites such as shingling of single brachiopod shells or taphonomic indicators such as abrasion or breakage. These brachiopods likely lived gregariously in dense patches rather than accumulating from storm events. Only one bed within unit 3 is a thin grainstone of crinoid and brachiopod fragments, suggesting a coquina arising from a storm event or other high-energy setting.

The western end of the outcrop series contains limestone of a very different nature reminiscent of upper Christina Member interbedded limestone and shale, except for abundant *Planolites* and other burrows. Abundant *Planolites* burrows combined with the lack of benthic sessile fossils suggests a stressed paleoenvironment. Symmetrical ripples preserved in one bed suggest at least short-term shallowing into the littoral zone.

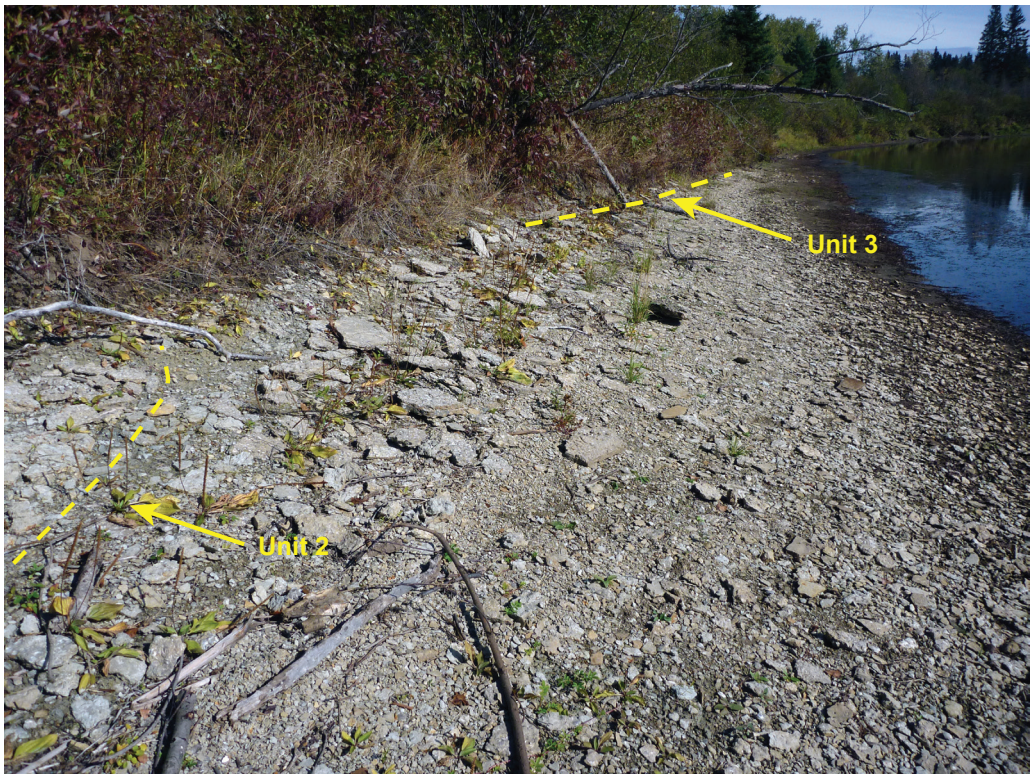

Figure 13. Outcropping and weathered limestone beds on the upstream, east end of the Calumet Member outcrops at locality 4 on the Clearwater River.

Figure 14. Downstream, west end of the Calumet Member outcrop at locality 4 on the Clearwater River. A hammer for scale is outlined in yellow and rests against in situ beds of units 2 and 3.

Figure 15. The upstream-most outcrop of the Calumet Member at locality 4 on the Clearwater River. The hammer rests against the topmost exposed bed of unit 3.

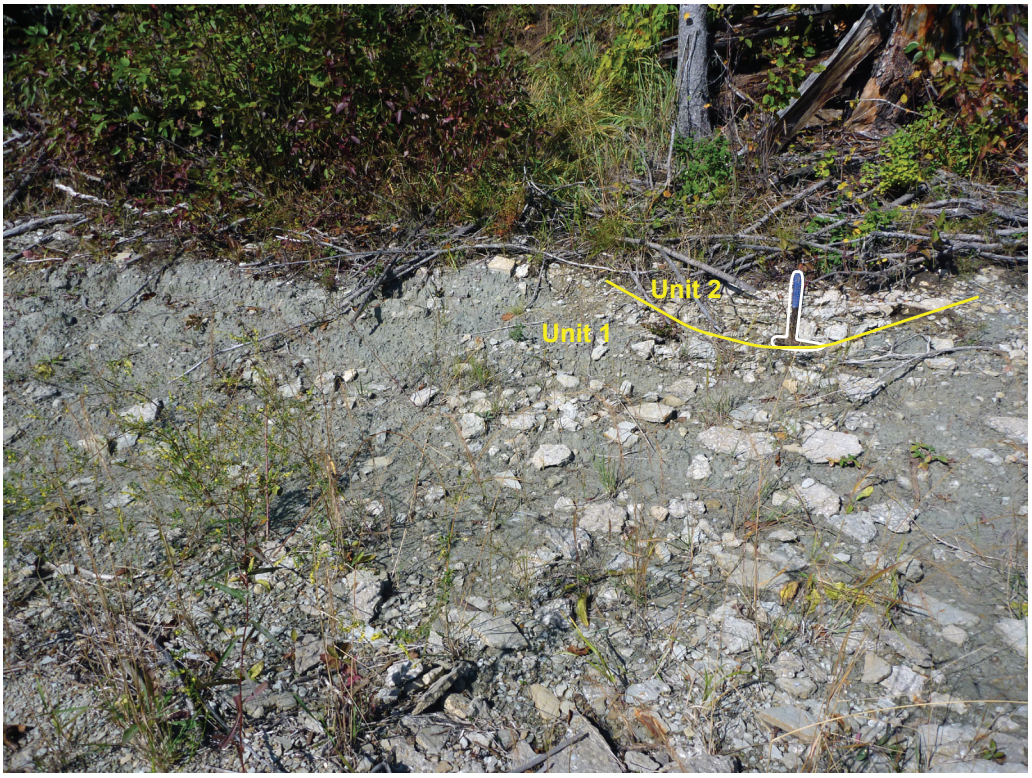

Figure 16. Units 1 and 2 of the Calumet Member outcropping at locality 4 on the Clearwater River.

Figure 17. Float slab with atrypide brachiopods from unit 3. The slab is from the upstream end of the Calumet Member outcrop at locality 4 on the Clearwater River.

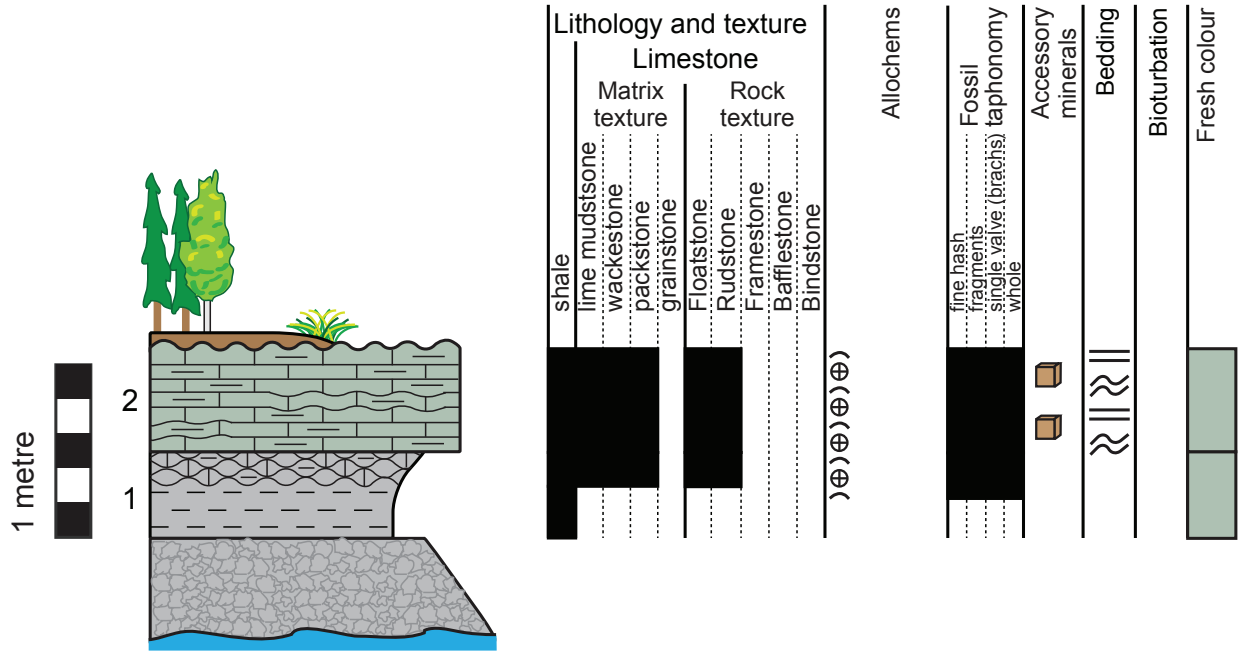

Figure 18. Measured section of the shale and limestone beds exposed at the upstream, east end of the Calumet Member at locality 4 on the Clearwater River.

Figure 19. Close-up of dipping beds from the downstream, west end of the Calumet Member outcrop at locality 4 on the Clearwater River.

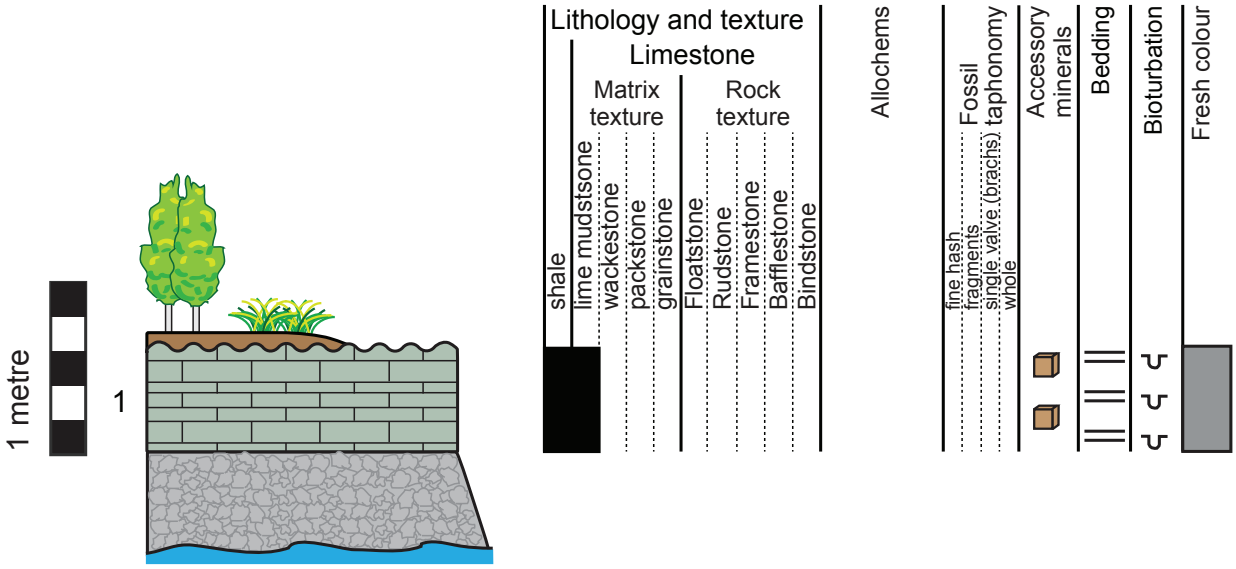

Figure 20. Measured section of the limestone knoll exposed at the downstream, west end of the Calumet Member outcrop at locality 4 on the Clearwater River.

Figure 21. *Planolites* trace fossils in a fractured slab from the downstream, west end of the Calumet Member outcrop at locality 4 on the Clearwater River. Burrows are hollows in the surface of the rock. Fractures are filled with pyrite.

Figure 22. Fractured slab from the Calumet Member outcrop at locality 4 along the Clearwater River. The fractures in the right side and along the top of the slab are pyrite filled. Planolites burrows exhibit concave epirelief and form small vugs in the top surface of the slab. The wavelength between the crests of the symmetrical ripples is approximately 6 cm.

Figure 23. Fractures in a slab of the Calumet Member from an outcrop at locality 4 along the Clearwater River. The fractures are filled with pyrite.

5.4 Structure

All beds are folded. Correlation of the intermittent beds at the eastern end of the outcrop series indicates the existence two or more gentle synclines and anticlines, but weathering and extensive cover makes structural observations difficult. At the eastern end of the outcrop, beds of unit 3 dip very gently upstream. Unit 2, downstream of unit 3, either dips upstream or is horizontal; the nature of this nodular unit makes the structural interpretation of this bed uncertain.

At the western end of the outcrop, thin tabular beds of unit 4 dip downstream, 10 degrees to the west.

5.5 Post-Devonian Erosion

Soil overlies the shale and eroded limestone beds, so the sub-Cretaceous unconformity has been lost to erosion.

6 Calumet Flat, Clearwater River

6.1 Locality Description and Access

UTM Zone 12, 507875E, 6280212N (NAD83) (locality '5', Figure 2)

Compared to other outcrops described in this report, the limestone beds in this outcrop dip steeply (20 to 24 degrees) to the east. The outcrop has been eroded to a low-sloping bank, forming a flattened bar of exposed limestone on the bend in the river, hence the name 'Calumet Flat' (Figure 24). Bedding planes are benched upslope and eastward.

Most of the beds are an argillaceous brachiopod floatstone, which weathers and fractures into small slabs or nodules. The large *Schizophoria* and strophomenide brachiopods that are common to other Calumet Member outcrops along the Clearwater River are also abundant here and weather easily from the argillaceous limestone surfaces.

The outcrop is easily accessible by boat. When the river level is high, the remaining exposed slope may be too steep for helicopter landing, but at low water levels, a small helicopter may be able to land on the downstream, slightly flatter end of the outcrop.

This outcrop is equivalent to that of Norris's (1963) station 179.

6.2 Stratigraphy

The outcrop was described in four sections: the downstream end, containing intact dipping beds (units 1 through 4); a nodular-weathered unit (unit 5), for which dip could not be measured; a small limestone knoll at the upslope, eastern end of the outcrop (units 6 through 8); and the eastward dipping beds beyond the limestone knoll on the upstream end of the outcrop (unit 9). A composite measured section was reconstructed from these localities within the outcrop (Figure 25). Where necessary, unit thicknesses were calculated from the dip data and the exposed length of each unit.

In the downstream end of the outcrop, eastward-dipping beds 'stair step' from the base located at the western end of the outcrop up to a small limestone knoll at the northeastern corner. Beds dip between 20 and 24 degrees to the east. From base to top, the outcrop contains the following units:

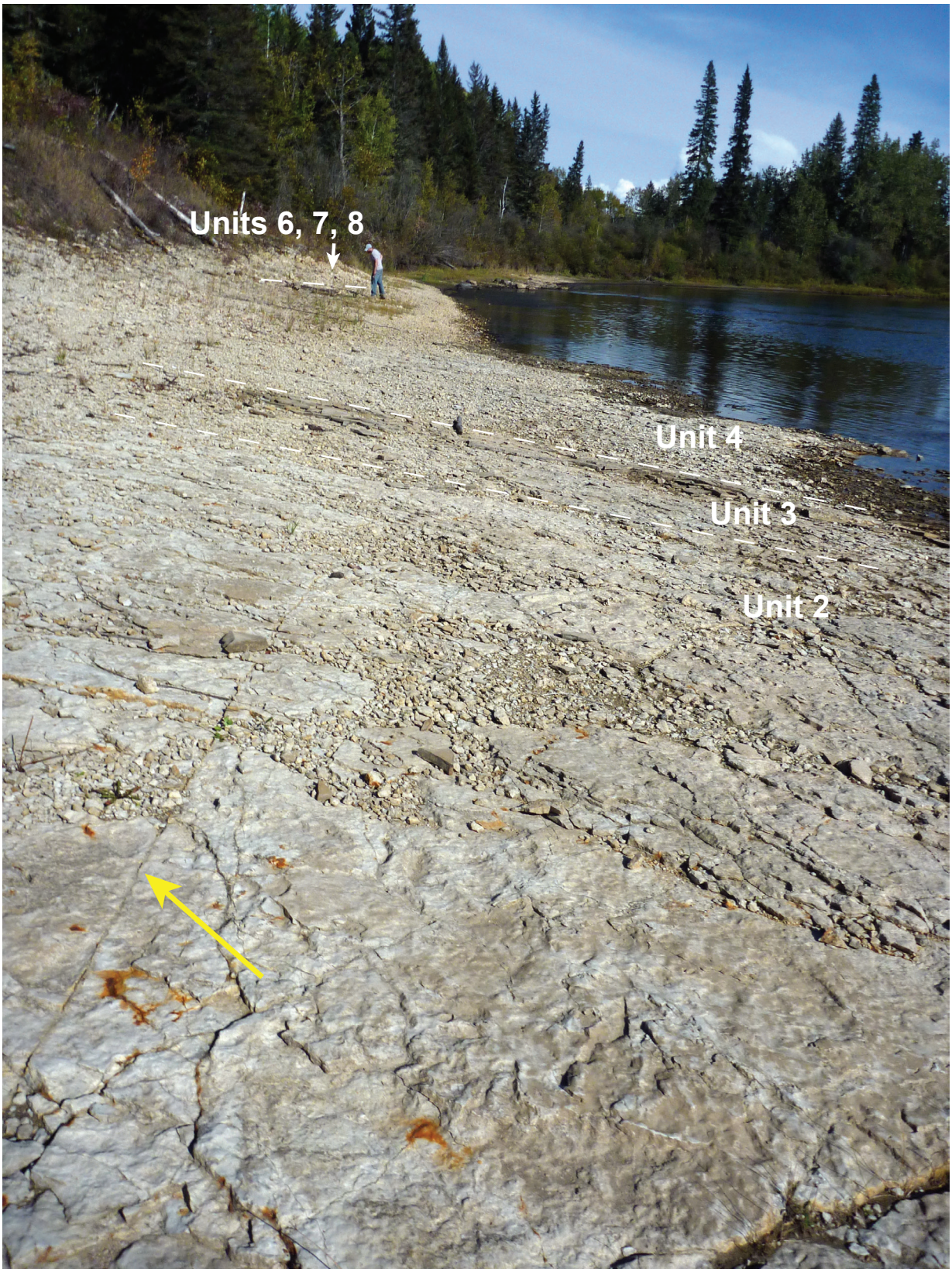

Figure 24. Outcrop of the Calumet Member at the 'Calumet Flat' locality on the Clearwater River. The photo was taken from the downstream end of the outcrop.

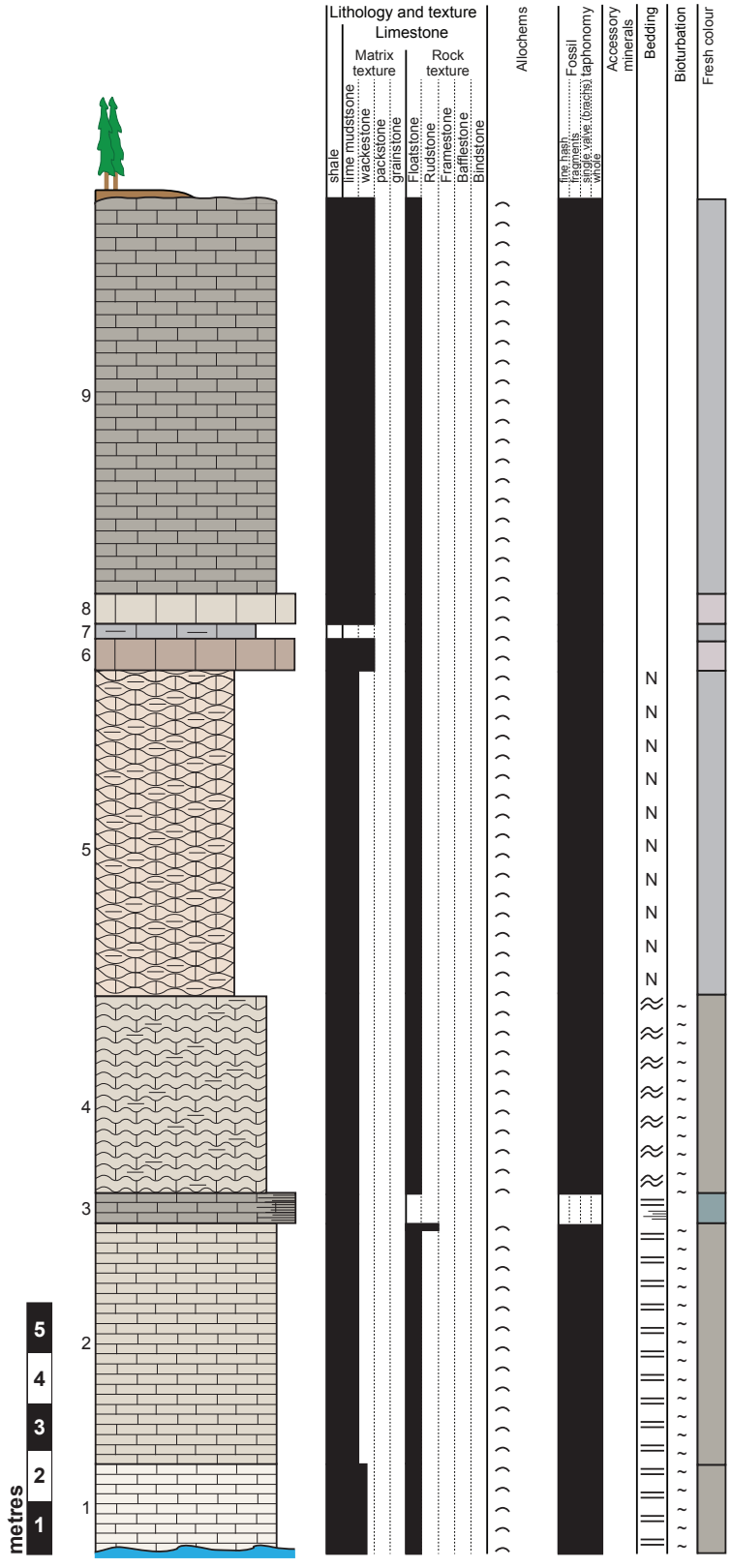

Figure 25. Measured section of the Calumet Member at the 'Calumet Flat' locality on the Clearwater River.

1) 176 cm: resistant, light beige-grey weathering, brown-grey to blue-grey, bioturbated, argillaceous brachiopod floatstone in a lime mudstone to wackestone matrix. *Schizophoria* is the most common brachiopod genus. Brachiopods weather dark grey.
2) 480 cm: resistant, beige-grey weathering, brown-grey, bioturbated, argillaceous, sparse brachiopod floatstone in lime mudstone matrix. The top surface of the unit is a brachiopod rudstone with white-weathering brachiopods, mainly *Schizophoria* and strophomenides.
3) 59 cm: resistant and hard, brown-beige-grey weathering, dark blue-grey, 2–3 cm flaggy-bedded, locally laminated lime mudstone. The top surface contains *Planolites* burrows. Slickensides are present (Figure 26).
4) 408 cm: resistant, beige-grey weathering, brown-grey, 1 to 2 cm wavy-bedded, nodular weathering, bioturbated, argillaceous, sparse brachiopod floatstone in a lime mudstone matrix. This unit contains brachiopod rudstone horizons. *Schizophoria* is the most common brachiopod genus.

The dip of unit 5 could not be measured because of the nodular weathering nature of the unit. A dip of 20 degrees was assumed, based on the dips of adjacent downstream units.

5) 738 cm: recessive, beige-weathering, grey, nodular weathering, brachiopod floatstone in a lime mudstone matrix. *Schizophoria* brachiopods are common.

The next three units form a small knoll on the eastern end of the outcrop. Here, the thickness of each unit could be directly measured. Like the rest of the outcrop, *Schizophoria* and stropheodont brachiopods are the most common fossils. The bottom and top beds of this knoll are the most resistant units of the outcrop.

6) 40 cm: resistant, beige-brown weathering, pink-grey, massive, brachiopod floatstone in a wackestone matrix.
7) 30 cm: recessive, argillaceous, brachiopod floatstone in a wackestone matrix. Brachiopods weather loosely from the outcrop.

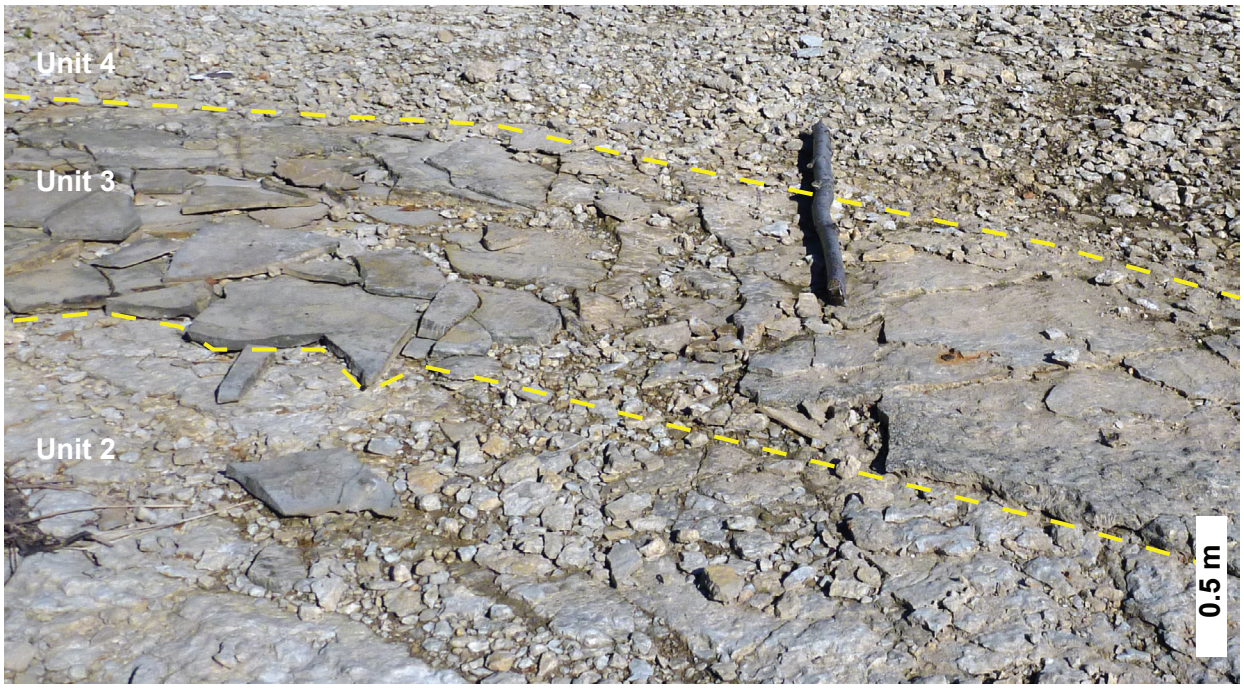

Figure 26. Some of the beds of unit 3 from the Calumet Member at the 'Calumet Flat' locality on the Clearwater River. Benching of unit 3 beds is not clear in the photo, but the characteristic colour and texture of these beds is representative of the unit.

8) 60 cm: resistant, grey-beige weathering, pink-grey, brachiopod floatstone in a wackestone matrix.

Past the small knoll of units 6 through 8 on the east end of the outcrop, beds dip approximately 23 degrees.

9) 780 cm: resistant, brown-grey weathering, grey, argillaceous, brachiopod floatstone in a wackestone matrix.

6.3 Paleoenvironmental Interpretation

This outcrop formed in the sublittoral environment above storm wave base and under low to moderate water energy. The presence of strophomenide brachiopods suggests that the substrate was soft, since these large, concavo-convex brachiopods specialized in 'snowshoeing' or 'floating' on soft mud. Most brachiopods bear calcified epibionts (bryozoans, *Microconchus* sp., *Hederella* sp.), organisms that encrusted the shell of the live brachiopod. The presence of epibionts suggests a sufficiently stable paleoenvironment to allow the development of a complex benthic ecosystem.

6.4 Structure

This outcrop has some of the steepest dipping beds of all the Waterways Formation outcrops. Dips range from an eastward 20 to 24 degree dip at the downstream end of the outcrop and a 23 degree dip in the upstream end of the outcrop.

The outcrop is pervasively fractured by joints that trend mainly west and southeast. Some fractures in unit 3 bear slickensides.

Most joints do not bear evidence of mineralization, but some smaller fractures are stained orange and are filled with pyrite.

6.5 Post-Devonian Erosion

The outcrop is truncated by fluvial erosion and, at the top of the river bank, covered by soil. Thus, the sub-Cretaceous unconformity has been eroded from this outcrop.

7 Greentree Recreation Area, Clearwater River

7.1 Locality Description and Access

UTM Zone 12, 502768E, 6279028N (NAD83) (locality '6', Figure 2)

This outcrop forms a small cliff at the base of the Greentree Recreation Area along the Clearwater River (Figure 27). During low water level, a bank of river sediment and limestone talus offers easy access to the outcrop.

This outcrop is best accessed by boat. A small helicopter may be able to land in the recreational area if it is not in use and if the picnic tables do not obstruct the landing.

This outcrop is equivalent to that of Norris's (1963) station 181.

Figure 27. Outcrop of the Calumet Member at the Greentree Recreation Area on the Clearwater River.

7.2 Stratigraphy

Fossils weather loose from this outcrop and are mostly *Schizophoria* and rare stropheodont brachiopods. From base to top, this outcrop contains the following units (Figure 28):

1) 70 cm: resistant, brown-grey weathering and fresh, 10 cm bedded, slightly argillaceous, brachiopod floatstone in a fragmental fossil wackestone matrix. This unit becomes increasingly argillaceous near the top.
2) 15 cm: recessive, brown-grey weathering and fresh, nodular to wavy-bedded, argillaceous brachiopod floatstone. Upward, this unit becomes increasingly argillaceous and recessive. Fossils from this unit include one small orthocone nautiloid cephalopod.
3) 50 cm: recessive, beige weathering and fresh, nodular-bedded, brachiopod floatstone in a wackestone matrix. Shale partings surround the nodules. *Schizophoria* brachiopods are common.
4) 115 cm: resistant, beige weathering, light beige-grey, 5 to 10 cm wavy-bedded, nodular weathering, crinoid and brachiopod floatstone in a wackestone matrix. Beds are thicker in the lower portion of the unit and thin upwards.

7.3 Paleoenvironmental Interpretation

This outcrop formed below fair-weather wave base and above storm wave base on the shallow shelf under low to moderate energy conditions. The brachiopod fauna, particularly the presence of concavo-convex stropheodonts, suggests a soft-sediment paleosubstrate.

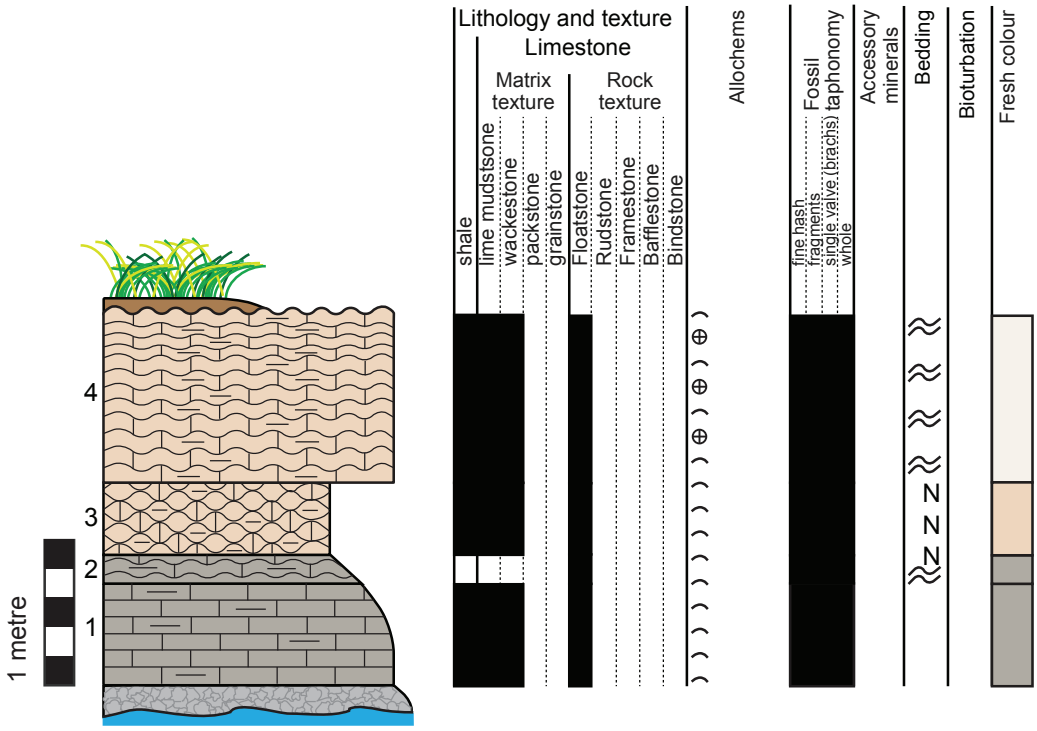

Figure 28. Measured section of the Calumet Member at the Greentree Recreation Area on the Calumet River.

7.4 Structure

Limestone beds dip 10 degrees to the southeast.

7.5 Post-Devonian Erosion

This outcrop is capped by soil, and the pre-Cretaceous unconformity has been lost to erosion.

8 Calumet and Christina Members, Waterways Formation, Classen's Landing, Athabasca River

8.1 Locality Description and Access

UTM Zone 12, 462599E 6367552N (NAD83) (locality '7', Figure 2)

This outcrop forms a large, distinctive white cliff along the Athabasca River at Classen's Landing (Figure 29). When the river level is sufficiently low, the lowermost unit is exposed as a wide limestone bench at the downstream end of the outcrop (Figure 30). The large white cliff can be accessed by a scramble over a talus slope (Figure 31).

At this outcrop, the Calumet Member forms the benched limestone of the upstream end of the outcrop (Figures 30 and 32), and the Christina Member includes the interbedded lime mudstone and shale of the more resistant, cliff-forming units (Figure 31). The contact between the two members was not encountered during this visit.

Figure 29. Outcrop of Calumet and Christina members at Classen's Landing on the Athabasca River. The limestone bank in the foreground at river level contains the top beds of the Calumet Member; the light grey to white cliff behind and upstream contains beds from the Christina Member. Photo was taken from the boat, looking upstream.

Figure 30. Downstream view of the limestone bench of the Calumet Member at Classen's Landing on the Athabasca River. Units 1 and 3 are in the Calumet Member; unit 7 is in the Christina Member.

Figure 31. Cliff of Christina Member shale and limestone at the upstream end of the Classen's Landing outcrop on the Athabasca River.

Figure 32. Close-up of unit 3 at or near the top of the Calumet Member at Classen's Landing on the Athabasca River. The hammer leans against the vertical face of the limestone bed.

In core, the contact between the Calumet and Christina members is placed at a hardground surface between a fossiliferous limestone below and the shale above. At the Classen's Landing outcrop, a hardground was not observed at the top of unit 3, the uppermost limestone bed of the downstream limestone benches. This limestone bed may be the top of the Calumet Member, but because of slumping of overlying sediment and soil, the placement of the boundary between the two members at this outcrop remains uncertain.

The outcrop is easily accessed by boat to the limestone surface at the downstream end of the outcrop or by helicopter to the river bank.

This outcrop is equivalent to that of Norris's (1963) stations 101 and 102.

8.2 Stratigraphy

The outcrop was measured at the benched limestone on the downstream end, at a small slumped block at the base of the cliff, and at the white limestone beds of the limestone cliff.

At the downstream end of the outcrop containing the benched limestone beds, the outcrop contains the following units, from base to top (Figure 33):

1) 50 cm: resistant, beige-grey weathering, grey, 3 to 7 cm wavy-bedded, bioturbated, gastropod, crinoid and brachiopod floatstone in a lime mudstone matrix. Crinoid columnals are two different sizes: 1 and 5 mm diameter. Brachiopods include *Spinatrypa*, spiriferides, and strophomenides. The fauna also includes a 5 cm diameter planispiral gastropod, many of which occur in a bed 30 cm from the top of the unit (Figure 34). The unit contains abundant joints, with two major orientations striking 110 degrees and 3 degrees, respectively. Joints are variable in width along their length and can be up to 5 cm wide and filled with yellow calcite crystals up to 2 cm in length (Figure 35). This unit continues unbroken into the river (Figure 30).
2) 32 cm: cover.
3) 28 cm: resistant, beige weathering, grey, bioturbated, brachiopod floatstone in a wackestone matrix. Fractures are stained orange (Figure 32).
4) Approximately 175 cm: cover.

The following units are in the base of the cliff on the downstream end of the outcrop at a small slumped block. Because of slumping and displacement, the measurement of unit 5 is estimated.

5) Approximately 175 cm: recessive and slumped, white weathering, light grey, mixed nodular limestone and shale. Hardground slabs with a 2 mm thick phosphatic rind occur in the float and are encrusted with *Microconchus*. At the base of the unit, a fauna of loose fossils includes crinoid columnals and brachiopods, including douvalinids, *Desquamatia*, *Spinatrypa*, *Cyrtina*, and *Athyris*.
6) 135 cm: resistant, white weathering, light grey, 3 to 5 cm tabular-bedded lime mudstone interbedded with 1 to 3 cm beds of calcareous shale. This portion of the outcrop appears to be a tilted block, in which an aspen has fractured the block with roots. At this spot, this unit is overlain by Pleistocene sediment.

The following units were measured at the upstream end of the outcrop, approximately 2 m above the river level in the cliff face (Figure 32). Measurements were estimated using a hand level.

7) Approximately 500 cm: recessive, slumped, white weathering lime mudstone nodules and talus.
8) Approximately 450 cm: resistant, cliff-forming, white weathering, light grey, 3 to 5 cm tabular-bedded lime mudstone interbedded with 1 to 3 cm beds of calcareous shale (Figures 30 and 31).

8.3 Paleoenvironmental Interpretation

The beds of the Calumet Member accumulated in a shallow-water, sublittoral environment. The presence of large gastropods and the diverse brachiopod fauna supports the existence of a thriving ecosystem in shallow water. These beds were deposited in the sublittoral zone, well above storm wave base.

Shale and limestone beds of the Christina Member are barren of fossils and contain hardgrounds, especially in the nodular float of unit 5. The lack of fossils and the presence of hardgrounds suggest a paleoenvironment unsuitable for macro-organisms.

8.4 Structure

Limestone beds near the base of the cliff and the top of the talus slope dip approximately 2 degrees to the southeast.

Joints in the beds of unit 1 trend 3 degrees and 110 degrees and are filled with yellow calcite crystals.

8.5 Post-Devonian Erosion

The outcrop is overlain by thin soil, so the post-Cretaceous unconformity has been lost to erosion.

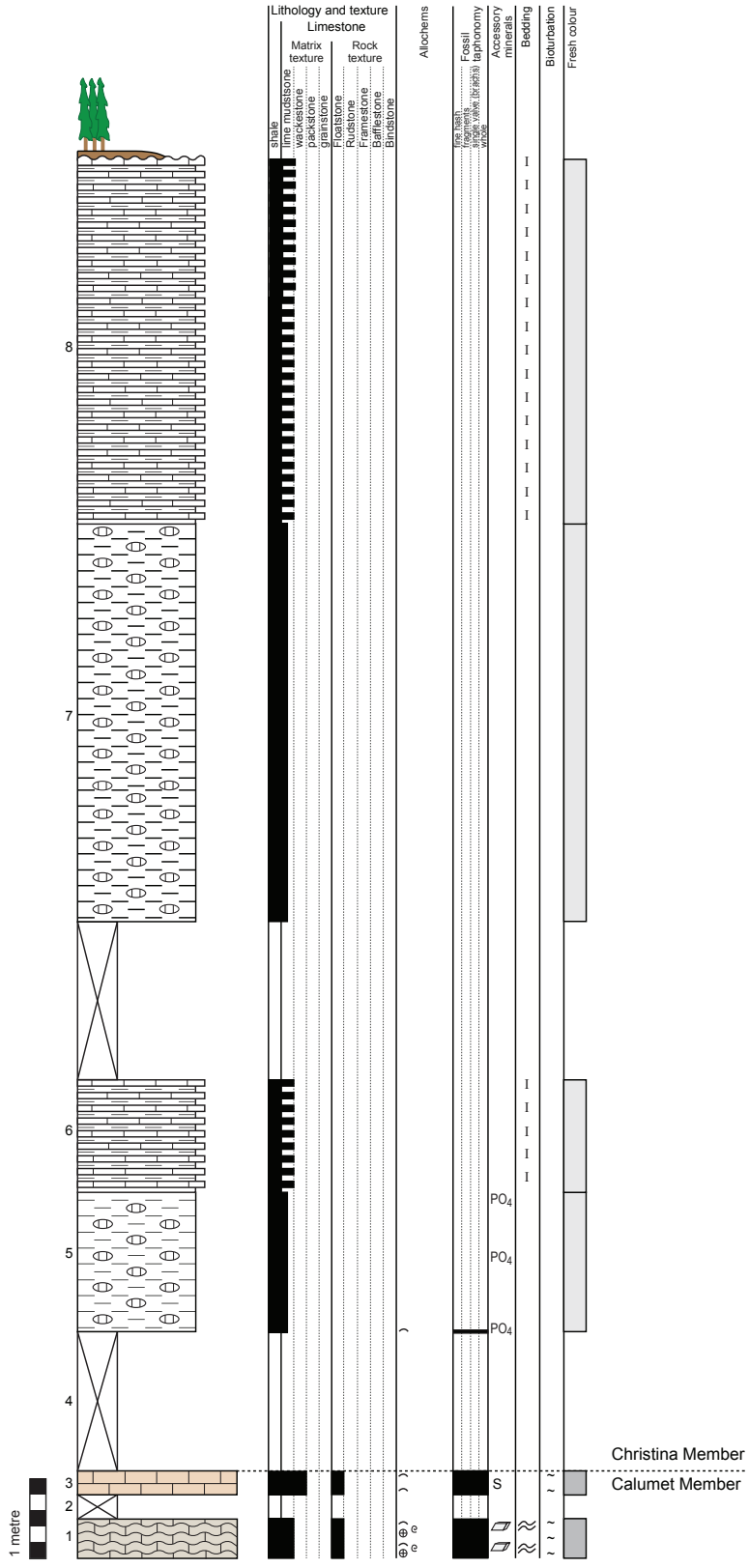

Figure 33. Measured section of the Calumet and Christina members at the Classen's Landing outcrop on the Athabasca River.

Figure 34. Two gastropods from unit 1 are outlined on the surface of a Calumet Member limestone bed at Classen's Landing on the Athabasca River. At the left of the photo, the pick end of a rock hammer provides scale.

Figure 35. Photo of a fracture and calcite crystals filling the fracture in unit 1 of the Calumet Member at Classen's Landing on the Athabasca River.

9 References

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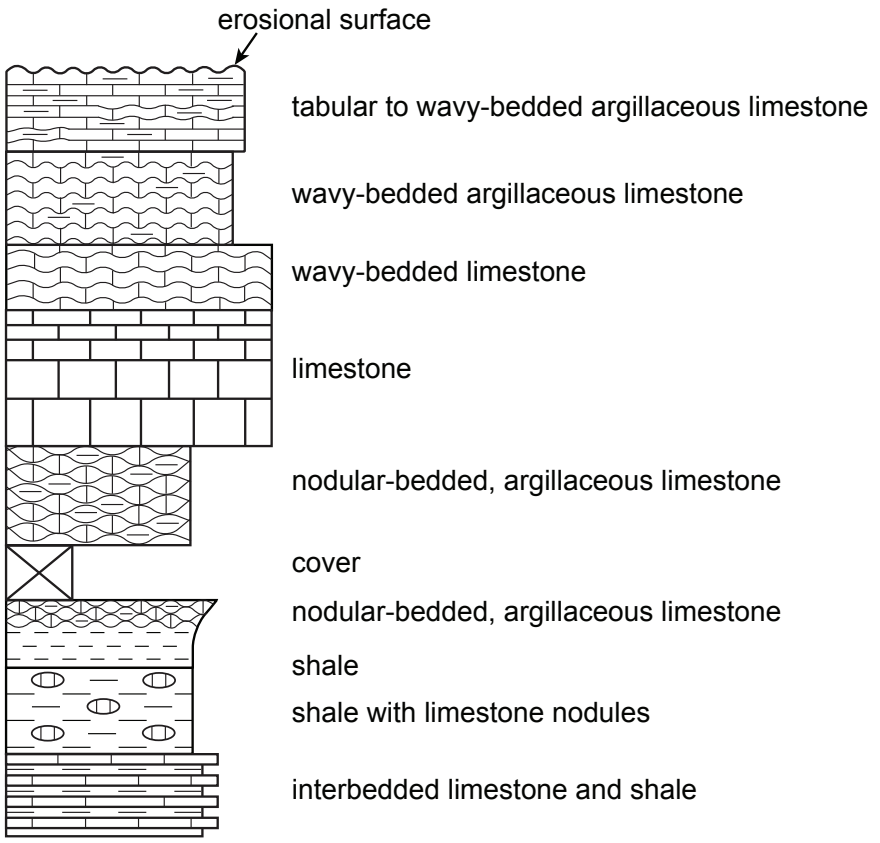
Appendix 1 – Key to Measured Sections



- white
- light grey
- grey
- beige-grey
- light beige-grey
- beige
- beige-brown
- brown-grey
- pink-grey
- green-grey
- dark blue-grey
- black

- brachiopod
- crinoid
- gastropod
- limestone nodule

- calcite
- pyrite
- PO_4 phosphate
- S sulfur

- burrow
- ~ bioturbated

- tabular
- wavy
- laminated
- N nodular
- I interbedded