AER/AGS Open File Report 2015-03

Alberta Energy Regulator

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Outcrops of the Upper Devonian Moberly Member (Waterways Formation) on the Athabasca River near Fort McMurray, Alberta (NTS 74D/14)

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July 2015

ISBN 978-1-4601-0140-7

Schneider, C.L., Leighton, L.R., Forcino, F.L. and Grobe, M. (2015): Outcrops of the Upper Devonian Moberly Member (Waterways Formation) on the Athabasca River near Fort McMurray, Alberta (NTS 74D/14); Alberta Energy Regulator, AER/AGS Open File Report 2015-03, 37 p.

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Published July 2015 by:
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Acknowledgements

We thank Steve Russell for the jet boat transportation and for being guided to outcrops with interesting features. Tyler Hauck reviewed the draft report and provided helpful comments. We also thank Tyla Willet and Aaron Dalton for the editing and proofreading of this report.

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. This report describes four outcrops of the lower Moberly Member along the Athabasca River in township 90 north of Fort McMurray. A resistant, biostromal unit of massive stromatoporoids in a brachiopod rudstone matrix is correlatable between the outcrops. Beds above this biostromal unit form low limestone cliffs along the river; beds below this unit outcrop intermittently. The Moberly Member beds described in this report were deformed into gentle folds.

1 Introduction

During the summers of 2010, 2011, and 2012, carbonate geologists of the Alberta Geological Survey and paleontologists from the University of Alberta visited outcrops along the Athabasca River to describe lithology and facies of the Upper Devonian Waterways Formation. This report describes the Moberly Member outcrops along the banks of the Athabasca River in township 90 (UTM Zone 12 from 475788E, 6292458N to 475178E, 6295668N [NAD83]) (Figure 1). Descriptions of Moberly Member outcrops within the Town of Fort McMurray are presented in Schneider et al. (2013); those of outcrops further north within townships 91–93 are given 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, but some subcrop beneath the McMurray Formation oil sand. Some outcrops contain evidence of the Devonian-Cretaceous contact in the red-orange iron staining of upper beds. The outcrops often exhibit low-amplitude anticlines; synclines are rarely exposed. Joints are common at all outcrops.

Outcrops of the Moberly Member along this stretch of the river are easily correlated because of the presence of a 2–3 m thick resistant limestone unit (unit 4) that contains massive stromatoporoids in a *Radiatrypa*-rudstone matrix. This unit is equivalent to unit 6 described from Moberly Member outcrops within townships 91-93 (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).

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.

Macoun (1877) wrote of Athabasca River outcrops, “nearly all the strata show graceful curves, the folds never rising more than ten feet.” Because his observations came from the northward-flowing Athabasca River, he described the dips as north and south, with the strike crossing the river.

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. He was impressed by 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

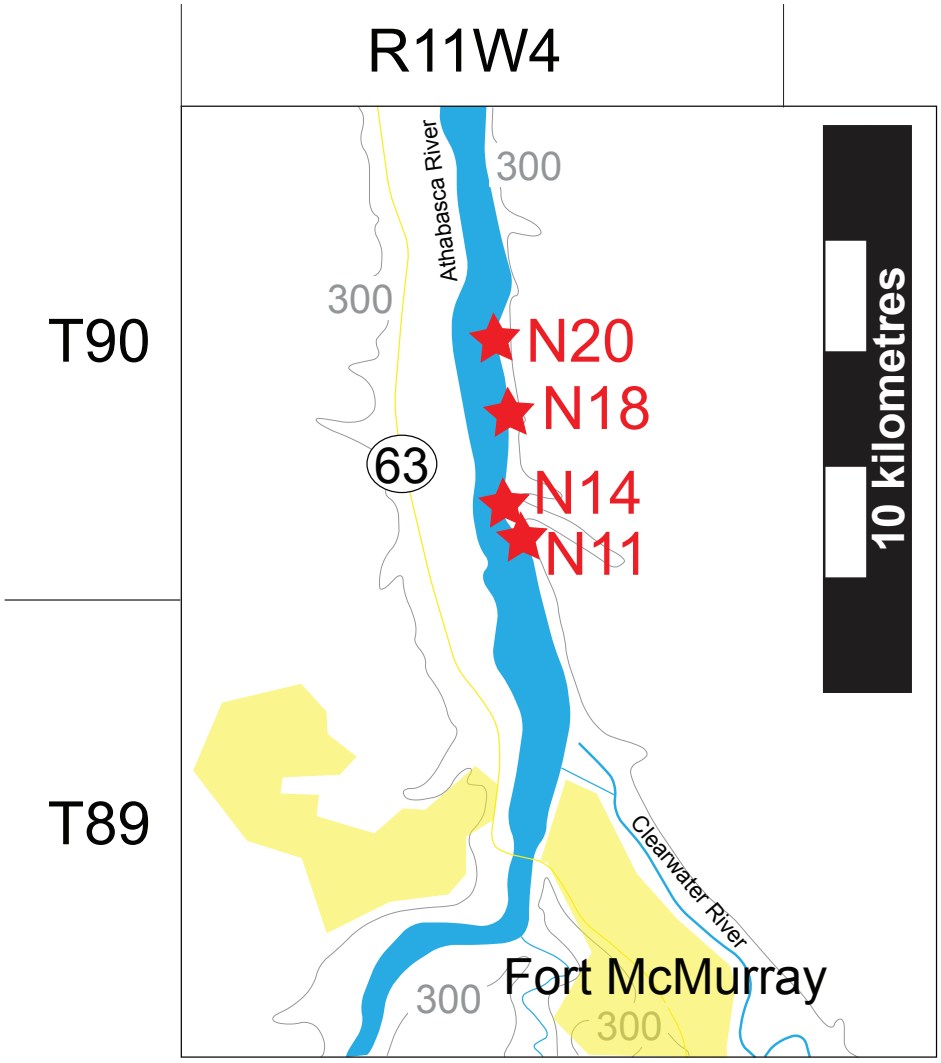

Figure 1. Map of the study area showing the locations of Devonian Moberly Member outcrops visited along the Athabasca River. Outcrops are named for the station numbers as reported in Norris (1963) (e.g., N11 = Norris station 11).

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, atrypide, brachiopod coquina. He also remarked that limestone units tended to thin northward with an increase in shale content in the Moberly Member. 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, with most dipping less than 10 degrees; although a few dip up to 17 degrees. He further stated that these flexures were minor folds in the limestone, 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). Norris (1973) 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 description of her 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 shallowing-upward cycles, each 1 m thick and with a basal marl grading up into resistant, fossiliferous limestone. Based on an Athabasca River outcrop, she interpreted the partial Moberly Member in outcrop as a transitional zone between reef and fore-reef facies in an intermittently high-energy environment.

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 the 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 of the Study Area

Outcrops along the Athabasca River north of Fort McMurray in township 90 comprise an approximately 12 m thick interval of the lower Moberly Member (Figure 2). The rock is generally beige weathering. Unit 4, which contains massive stromatoporoids, is easily traced between outcrops and is used for correlation in the field.

Although portions of the interval were covered, beds from unit 1 were lumped into a single nodular limestone unit. Field correlations to outcrops outside of the study area were the basis for combining these beds into a single unit.

From base to top, a composite section of the study area includes the following units:

- Unit 1 (280 cm): green-grey shale and grey argillaceous nodular lime mudstone to wackestone with fossiliferous rudstone beds. From 30 cm to 180 cm above the base of the unit, the rock is covered by slumped talus. Based on the nature of the talus, the rock is assumed to be similar to that in the beds above and below for the covered interval.

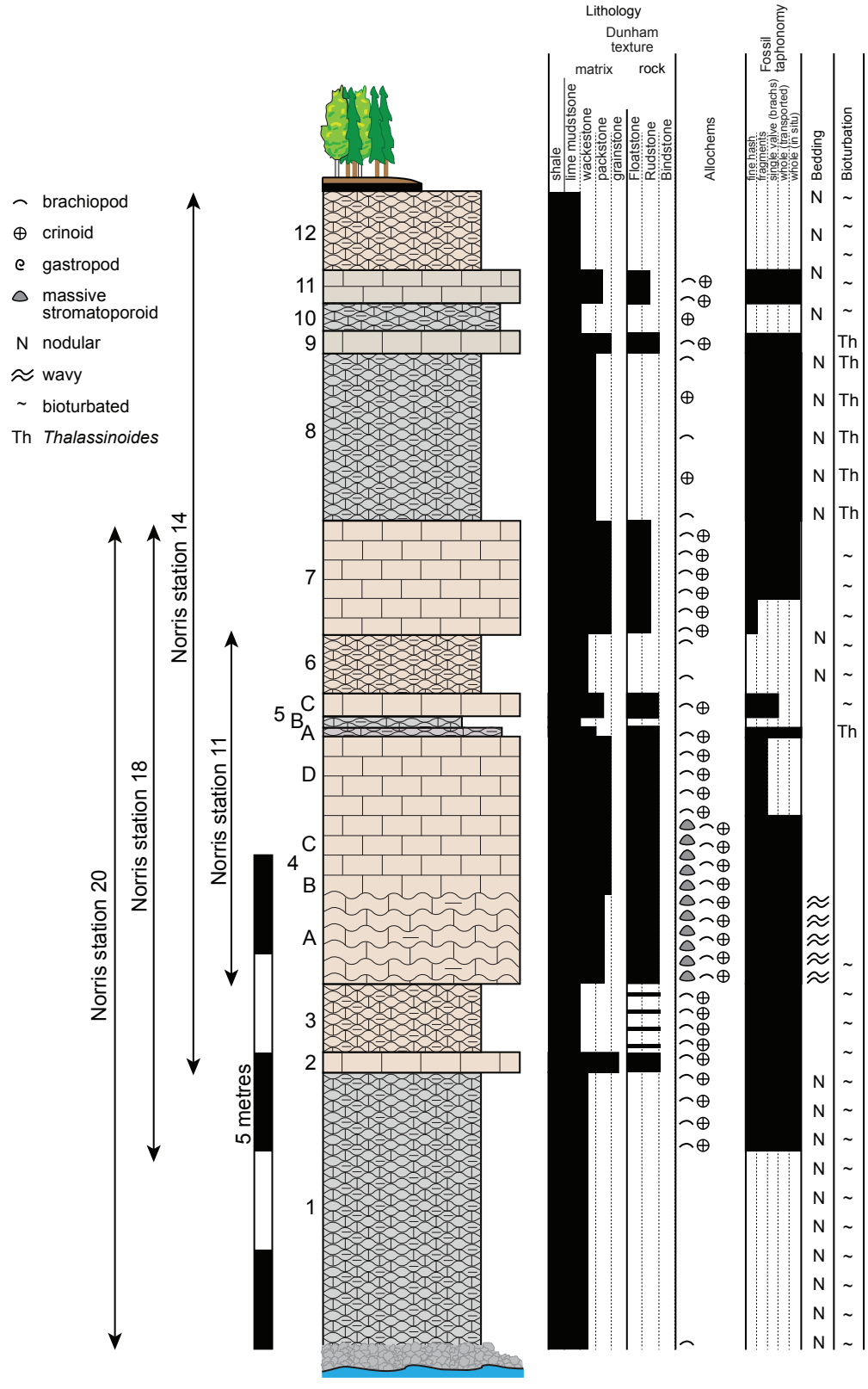

Figure 2. Composite section for the Moberly Member outcrops described in this report.

- Unit 2 (13–15 cm): grey weathering and fresh, unbedded, bioturbated, brachiopod and crinoid rudstone in a packstone matrix.
- Unit 3 (65–70 cm): recessive, beige to grey weathering, nodular-bedded, bioturbated, argillaceous lime mudstone to wackestone with rudstone beds containing variable abundances of brachiopods, crinoids, and intraclasts in a packstone to grainstone matrix.
- Unit 4 (243–347 cm): resistant, beige rudstone that contains the following subunits (from base to top):
  - subunit 4a (92 cm): wavy to nodular, bioturbated, slightly argillaceous, massive stromatoporoid and brachiopod rudstone in a wackestone to packstone matrix.
  - subunit 4b (35 cm): massive stromatoporoid and brachiopod rudstone.
  - subunit 4c (20–50 cm): slightly recessive, wavy-bedded, massive stromatoporoid, brachiopod, and crinoid rudstone.
  - subunit 4d (76–85 cm): brachiopod and crinoid rudstone in a packstone matrix. Brachiopods are fragmental.
- Unit 5 (32–53 cm): recessive, nodular limestone that contains the following subunits (from base to top):
  - subunit 5a (7–15 cm): pink-grey weathering and fresh, nodular-bedded, *Thalassinoides*-bioturbated, argillaceous, brachiopod and crinoid rudstone in a wackestone matrix.
  - subunit 5b (5–15 cm): grey weathering, argillaceous lime mudstone nodules floating in green-grey shale.
  - subunit 5c (20–31 cm): beige, unbedded, bioturbated, brachiopod and crinoid rudstone in a wackestone to packstone matrix.
- Unit 6 (50–70 cm): grey weathering and fresh, nodular-weathering, bioturbated, argillaceous lime mudstone to wackestone with occasional brachiopods. The basal 15 cm are more resistant.
- Unit 7 (168 cm): resistant, beige weathering and fresh, bioturbated, argillaceous, brachiopod and crinoid floatstone to rudstone in a packstone matrix. The basal 34 cm is a grainstone of skeletal sand. The top of the unit is a hardground. At places, this unit can exhibit good *Thalassinoides* burrow networks in mottled red-brown and grey colouring and nodular texture.
- Unit 8 (265 cm): recessive, grey, calcareous shale with orange-red and grey weathering, grey, bioturbated, argillaceous, lime mudstone nodules (1 to 2 cm diameter). The shale contains crinoid columnals.
- Unit 9 (17 cm): resistant, orange-grey weathering, pink-grey, *Thalassinoides*-bioturbated, brachiopod and crinoid rudstone in a packstone matrix.
- Unit 10 (30 cm): recessive, grey, calcareous shale with orange-red and grey weathering, grey fresh, bioturbated, argillaceous, lime mudstone nodules (1 to 2 cm diameter). The shale contains crinoid columnals.
- Unit 11 (35 cm): resistant, grey and beige weathering, pinkish-beige fresh, wavy- to nodular-bedded, bioturbated, argillaceous, brachiopod, crinoid, and gastropod floatstone to rudstone in a wackestone to packstone matrix.
- Unit 12 (77 cm exposed): recessive, grey, calcareous shale with orange-red and grey weathering, grey fresh, bioturbated, argillaceous, lime mudstone nodules (1 to 2 cm diameter). The shale contains crinoid columnals.

Outcrops were described and measured with varying amounts of detail. Some units at outcrops could be broken into subunits based on lithological variation without apparent partings or differences in recessiveness or resistance to weathering, or into beds if the unit was observed to have distinct and separate beds. Time constraints and, more often, inaccessible beds led to observations that were only able to identify the unit and estimate bed thickness from a distance. The following sections are an account of observations from each outcrop visited. Outcrops are named for the stations listed by Norris (1963) from his extensive report of Athabasca River outcrops.

4 Norris Station 11

4.1 Locality Description and Access

UTM Zone 12, 475788E, 6292458N (NAD83)

This outcrop is a low limestone wall beneath wooded, slumped McMurray Formation oil sand. Unit 4 is the most prominent bed at the outcrop. Upper beds are recessed into the slope in the woods. Upstream of this outcrop, a brecciated, orange-red and beige mottled and orange knoll of limestone protrudes from the surrounding oil sand (Figure 3).

This outcrop is best accessed by boat. The knoll is a good spot to anchor a boat.

4.2 Stratigraphy

- Unit 4 (243 cm): resistant, beige-grey weathering, beige, limestone that contains the following four subunits at this station (from base to top; Figure 4):
  - subunit 4a (92 cm): approximately 10 cm wavy- to nodular-bedded, bioturbated, slightly argillaceous, massive stromatoporoid and brachiopod rudstone in a wackestone matrix. Stromatoporoids are rare and are slightly lighter in colour than the surrounding matrix. Brachiopods include atrypides and *Eleutherokomma*.
  - subunit 4b (35 cm): massive stromatoporoid and brachiopod rudstone. Stromatoporoids are up to 50 cm in diameter or height and most were toppled (Figure 5). Tabular stromatoporoids are present but rare. Brachiopods are mainly atrypides and are randomly oriented.
  - subunit 4c (40 cm): slightly recessive, laterally varying between massive to 1 to 3 cm wavy-bedded, massive and columnar stromatoporoid, brachiopod, and crinoid rudstone (Figure 5). Stromatoporoids are both in situ and toppled. The brachiopod *Radiatrypa* is highly abundant. Single valves are shingled and whole specimens are closely packed. The shingling of brachiopods can give this subunit a wavy-bedded to nodular appearance. This unit increases laterally to a thickness of 100 cm at the expense of subunits 4a and 4b.
  - subunit 4d (76 cm): wavy-bedded, brachiopod and crinoid rudstone in a packstone matrix (Figure 6). Brachiopods are fragmental. This unit contains rare massive stromatoporoids. A parting occurs 58 cm from the top of the unit.
- Unit 5 (53 cm): recessive, nodular-weathering, argillaceous limestone that contains the following four subunits (from base to top; Figure 7):
  - subunit 5a (15 cm): pink-grey weathering and fresh, nodular-bedded (1–4 cm), argillaceous, *Thalassinoides*-bioturbated, crinoid, and brachiopod rudstone in a wackestone matrix (Figure 8). Nodule boundaries are stained with siderite and bitumen.
  - subunit 5b (15 cm): very recessive, high (up to 1 cm), green-grey-beige, argillaceous, lime mudstone nodules in green-grey calcareous shale.
  - subunit 5c, lower bed (15 cm): pink-grey weathering and fresh, nodular-bedded (1–4 cm), argillaceous, *Thalassinoides*-bioturbated, crinoid, and brachiopod rudstone in a wackestone matrix. Nodule boundaries are stained with siderite and bitumen.
  - subunit 5c, upper bed (16 cm): resistant, buff-beige weathering, pink-beige, brachiopod and crinoid rudstone in a packstone matrix (Figure 9). Brachiopods include *Desquamatia*.
- Unit 6 (56 cm): recessive, green-grey, argillaceous, lime mudstone nodules up to 1 cm in diameter in green-grey calcareous shale (Figures 7 and 10).

Figure 3. Norris station 11 on the Athabasca River showing the erosional knob of the Moberly Member in the foreground. The white arrows point to unit 4 of the outcrop described in section 3.1.1.

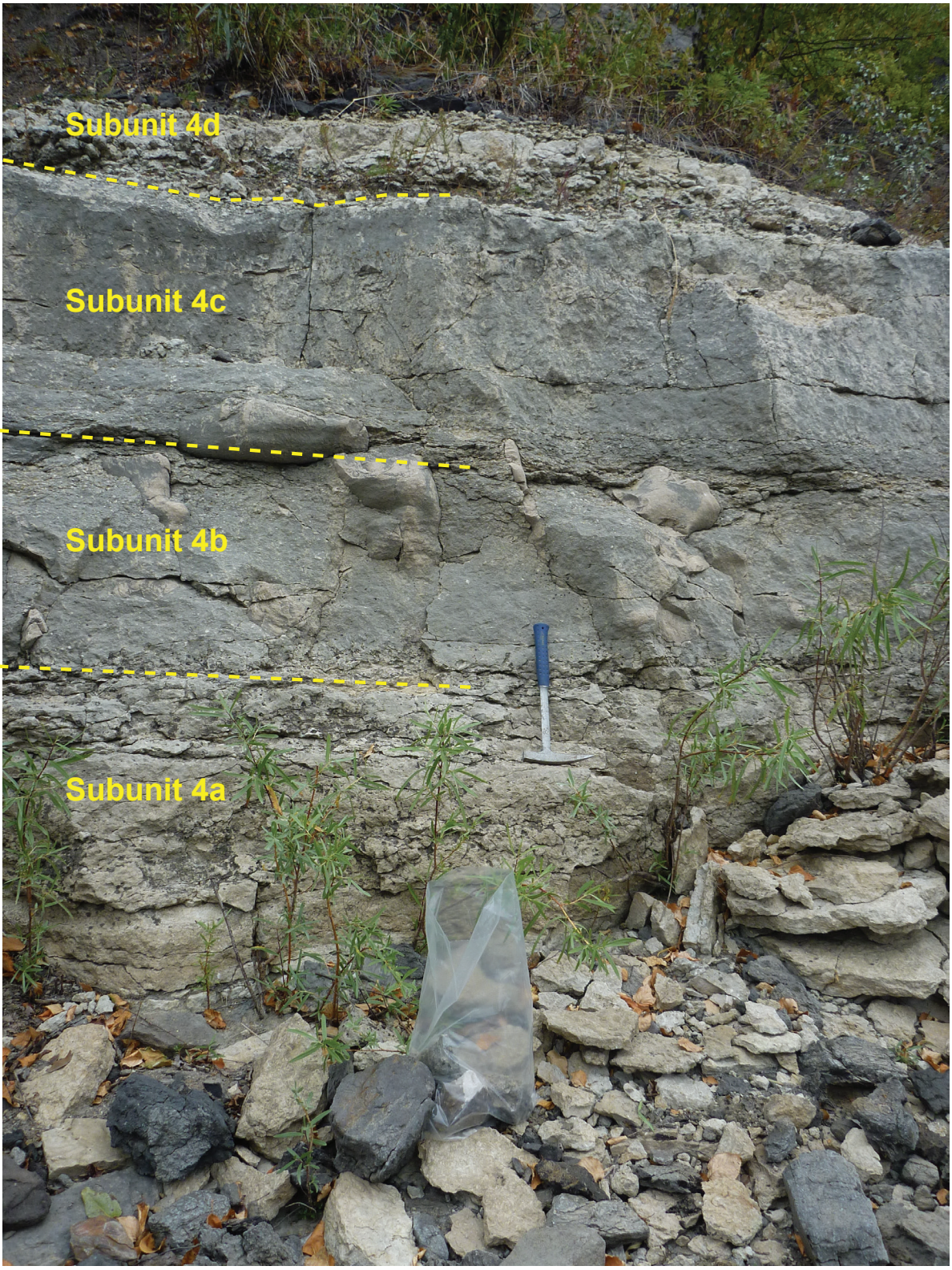

Figure 4. Subunits of unit 4 (a, b, c, d) of the Moberly Member at Norris station 11 on the Athabasca River.

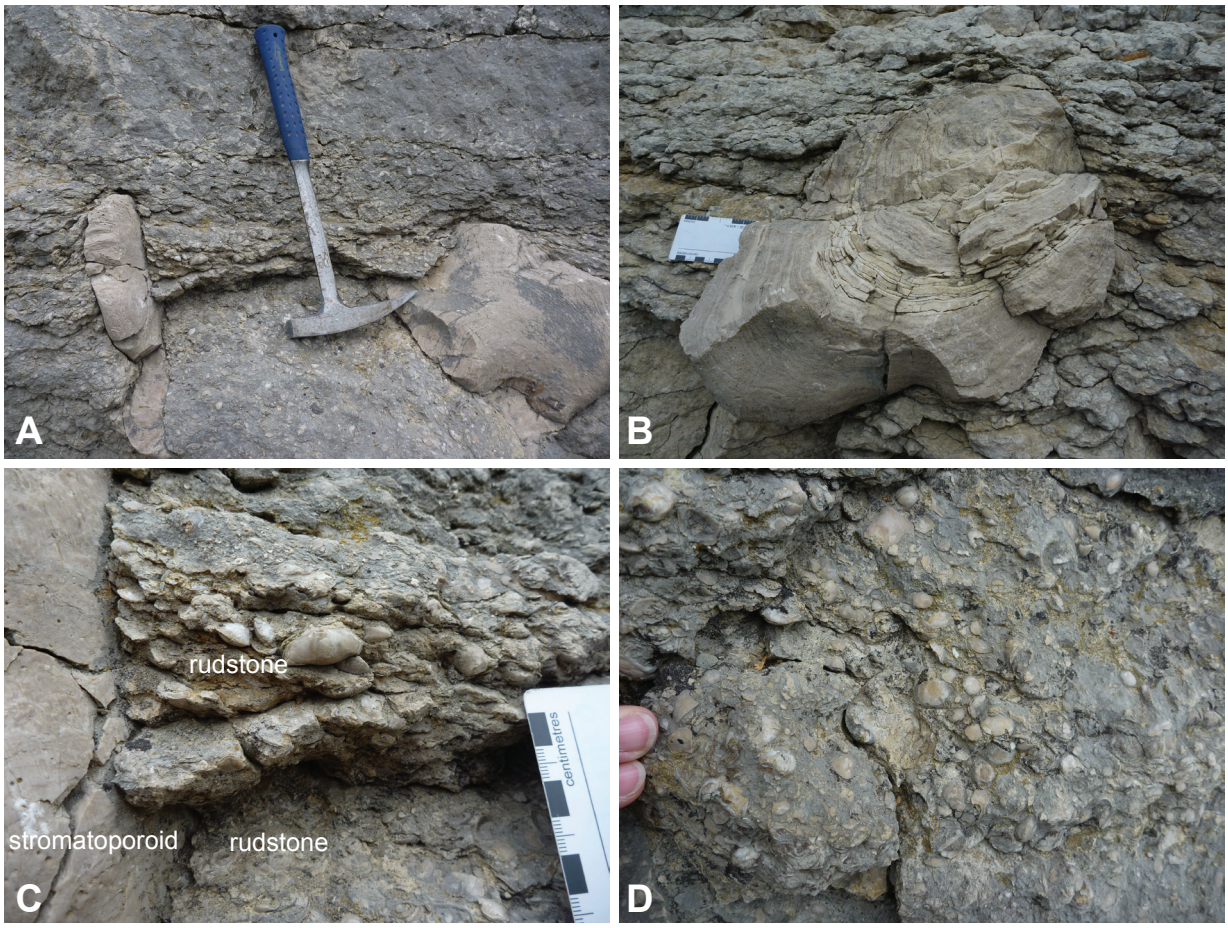

Figure 5. Four close-ups of unit 4 of the Moberly Member at Norris station 11 on the Athabasca River: (A) massive stromatoporoids surrounded by brachiopod rudstone in subunit 4b (hammer for scale); (B) massive stromatoporoid surrounded by a brachiopod rudstone in subunit 4c; (C and D) close-ups of the brachiopod rudstone texture in subunit 4c. Most brachiopods are *Radiatrypa*.

Figure 6. A close-up of subunit 4d of the Moberly Member at Norris station 11 on the Athabasca River.

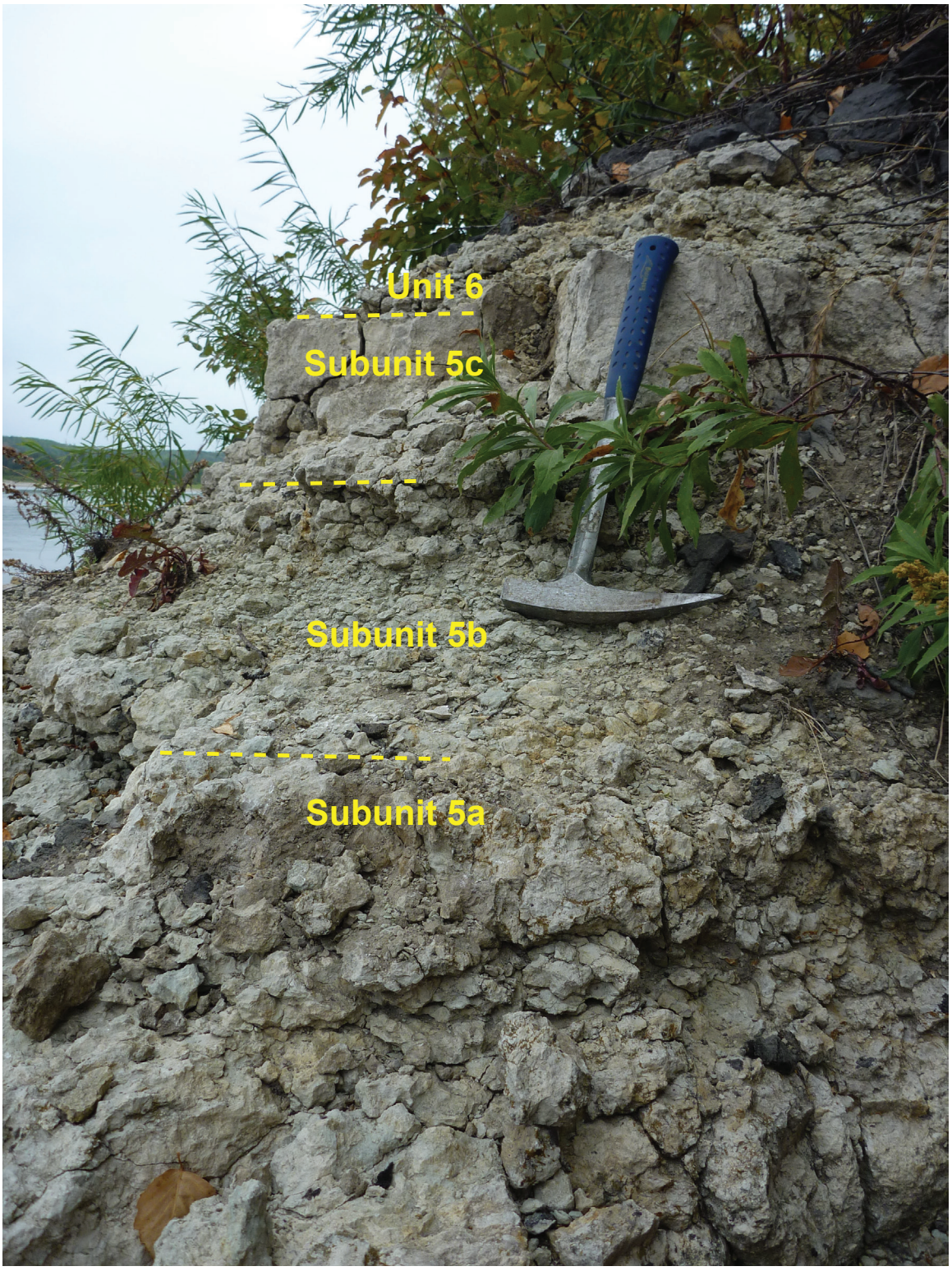

Figure 7. Subunits 5a, b, and c and the base of unit 6 in the Moberly Member at Norris station 11 on the Athabasca River.

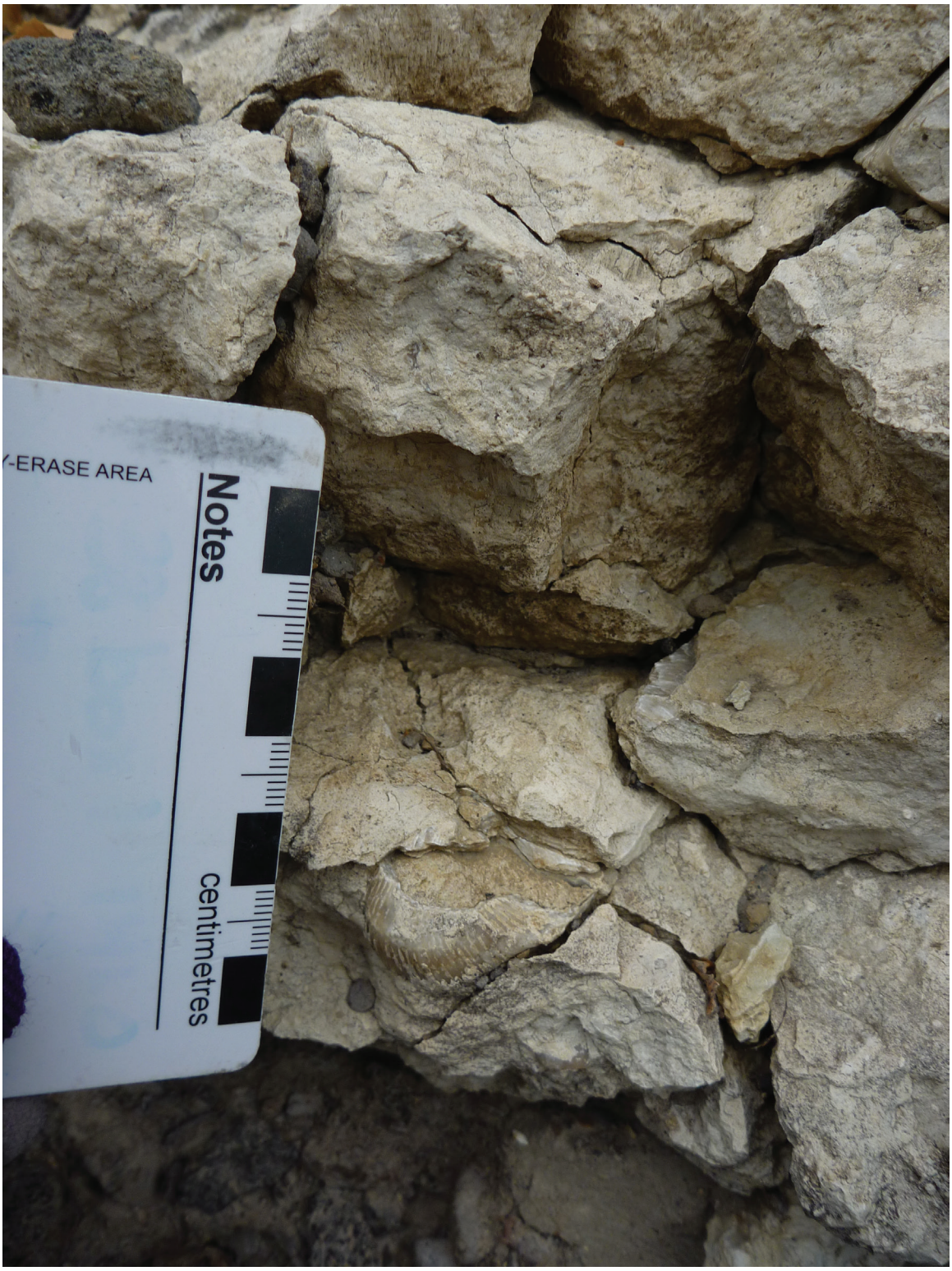

Figure 8. A close-up of subunit 5a of the Moberly Member at Norris station 11 on the Athabasca River.

Figure 9. A close-up of the rudstone texture in subunit 5c of the Moberly Member at Norris station 11 on the Athabasca River.

Figure 10. The contact between unit 6 of the Moberly Member and McMurray Formation oil sand at Norris station 11 on the Athabasca River.

4.3 Sub-Cretaceous Unconformity

The contact between unit 6 and the McMurray Formation oil sand is sharp. The limestone does not appear to be decalcified or karsted. The basal oil sand at the contact lacks limestone intraclasts.

Upstream of the measured section, unit 4 forms a knob that protrudes from slumped oil sand. The limestone forming this brecciated knob is slightly decalcified and capped by a siderite rind several centimetres thick (Figure 11). This siderite rind incorporates limestone from the top of the Moberly Member and oil sand from the base of the McMurray Formation.

4.4 Structure

Limestone beds are nearly flat lying, although the location of the limestone knob relative to the rest of the Devonian outcrop suggests dipping of Devonian strata at this locality to the north.

5 Norris Station 14

5.1 Locality Description and Access

UTM Zone 12, 475382E, 6293102N (NAD83)

On the upstream side of the bend in the river, this outcrop forms a low limestone cliff that extends into the river (Figures 12 and 13). A gentle syncline warps the beds along a portion of the outcrop (Figure 13) and at the bend in the river, beds dip towards the water (Figure 14).

Beds are accessible downstream and proximal to the bend in the river. Unit 4 dips into the water at this point, providing a resistant ledge on which to stand and examine the outcrop. Overlying beds also dip towards the river and downstream (north). The uppermost beds can be accessed in the treed berm above the river bank.

Beds above unit 4 are eroded from the axis and downstream end of a syncline that extends from the bend in the river to the downstream end of the outcrop. Beds above unit 4 are present only on the upstream limb of the syncline. At the axis, we noticed a small oil seep in the talus of the river bank. On the downstream end of the syncline, units 2 through 4 reappear with bed 4 creating a prominent resistant limestone ledge above comparably recessive units 2 and 3 (Figures 15 and 16).

This outcrop is best accessed by boat.

5.2 Stratigraphy

At coordinates 475290E, 6293337N, the beds measured include the following units (from base to top):

- Unit 2 (13 cm; exposed): resistant, beige weathering and fresh, brachiopod and crinoid rudstone in a packstone to grainstone matrix.
- Unit 3 (65 cm): recessive, beige-orange and grey mottled weathering and fresh, centimetre-scale nodular-bedded, bioturbated, argillaceous lime mudstone to wackestone. *Planolites* burrows are preserved along some horizons. The unit contains 2 to 3 cm thick beds of brachiopod, crinoid, and intraclast rudstone in a packstone to grainstone matrix (Figures 16 and 17).

At coordinates 475397E, 6293039N, the beds measured include the following units and subunits (from base to top; Figures 14 and 18):

Figure 11. Altered edge of a Moberly Member knoll at Norris station 11 on the Athabasca River, upstream of where the outcrop was described.

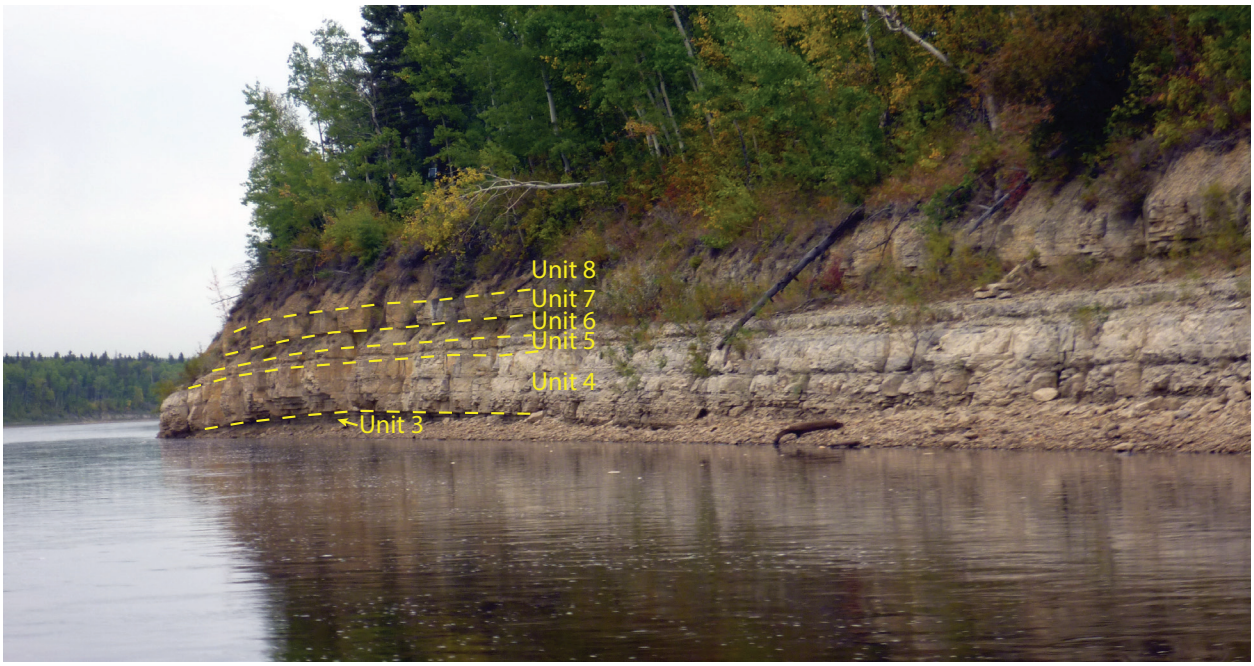

Figure 12. Units of the Moberly Member upstream of the bend in the river at Norris station 14 on the Athabasca River.

Figure 13. A photograph of the same area as that in Figure 12 showing a gentle syncline in the beds of the Moberly Member on the Athabasca River upstream of Norris station 14.

Figure 14. Units and subunits of the Moberly Member at Norris station 14 on the Athabasca River. View is downstream (to the north). Since the beds dip towards the north, the distal end of the outcrop (the base of unit 8) appears lower than the top of unit 4 at the proximal end of the outcrop.

Figure 15. Unit 4 of the Moberly Member outcrops downstream of Norris station 14 on the Athabasca River.

Figure 16. Units 3 and 4 of the Moberly Member downstream of Norris station 14 on the Athabasca River. Unit 3 is recessed beneath the resistant biostromal rudstone of unit 4.

Figure 17. A close-up of the nodular texture of unit 3 of the Moberly Member downstream of Norris station 14 on the Athabasca River.

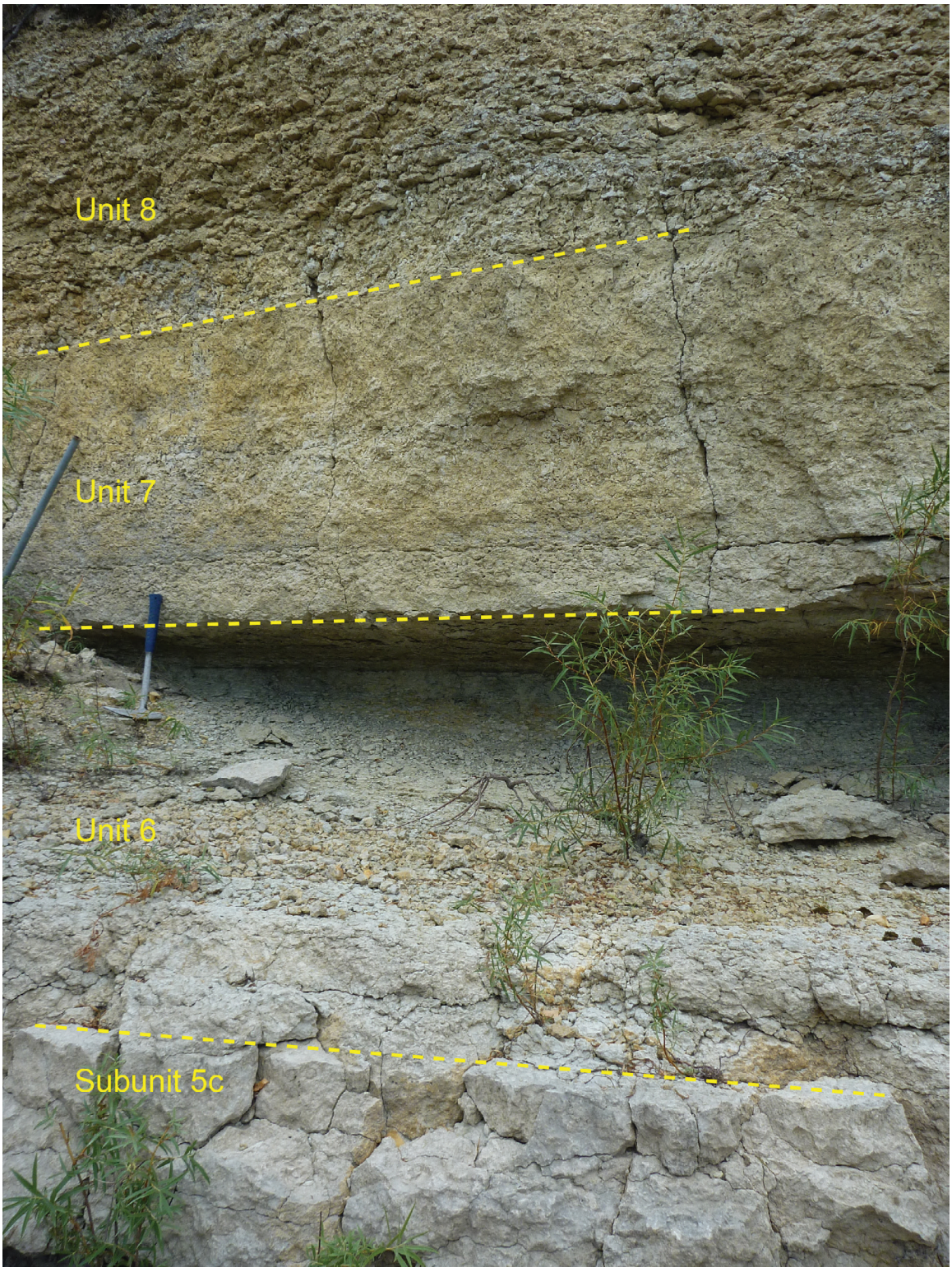

Figure 18. Subunit 5c and units 6 to 8 of the Moberly Member at Norris station 14 on the Athabasca River. The benched surface of the basal, slightly resistant limestone of unit 6 combined with the recessive upper portion of unit 6 causes the unit to appear thicker in this photograph than reported.

- Unit 4 (only partially exposed above water level), subunit descriptions do not differ from those of the composite section:
  - subunit 4c (20 cm)
  - subunit 4d (85 cm)
- Unit 5, subunit descriptions do not differ from those of the composite section:
  - subunit 5a (15 cm)
  - subunit 5b (10 cm)
  - subunit 5c (24 cm)

At coordinates 475387E, 6293049N (Figure 18):

- Unit 6 (70 cm): recessive, mottled reddish and grey, nodular-bedded, bioturbated, argillaceous lime mudstone. The basal 16 cm are green-grey, nodular-weathering, argillaceous, *Thalassinoides*-bioturbated, gastropod, brachiopod, and crinoid floatstone in a wackestone to packstone matrix.
- Unit 7 (112 cm exposed): recessive, beige weathering, argillaceous brachiopod and crinoid floatstone to local rudstone in a wackestone to packstone matrix (Figure 19). The basal 34 cm are a brachiopod rudstone in a grainstone matrix of skeletal fragments (Figure 20). The uppermost 10 cm are a packstone to grainstone. This unit is complete at coordinates 475386E, 6293080N, where it is 168 cm thick, with a capping hardground in place. At this spot, *Thalassinoides* bioturbation is evident in the weathered pattern of mottled colours and nodular textures.

At coordinates 475361E, 6293135N:

- Unit 8 (265 cm): recessive, grey, calcareous shale with orange-red and grey weathering, grey, bioturbated, argillaceous, lime mudstone nodules (1 to 2 cm diameter). The shale contains crinoid columnals.

At coordinates 475357E, 6293156N:

- Unit 9 (17 cm): resistant, red-orange-grey weathering, pink-grey, *Thalassinoides*-bioturbated, brachiopod and crinoid rudstone in a packstone matrix.
- Unit 10 (30 cm): recessive, grey, calcareous shale with orange-red and grey weathering, grey fresh, bioturbated, argillaceous, lime mudstone nodules (1 to 2 cm diameter). The shale contains crinoid columnals.
- Unit 11 (35 cm): resistant, grey and beige weathering, pink-beige fresh, wavy- to nodular-weathering, bioturbated, argillaceous, gastropod, brachiopod, and crinoid floatstone to rudstone in a wackestone to packstone matrix.

At coordinates 475358E, 6293164N:

- Unit 12 (77 cm): recessive, grey, calcareous shale with orange-red and grey weathering, grey fresh, bioturbated, argillaceous, lime mudstone nodules (1 to 2 cm diameter). The shale contains crinoid columnals.

5.3 Sub-Cretaceous Unconformity

The McMurray Formation has been eroded from the outcrop and the Devonian-Cretaceous contact has not been preserved. The outcrop is overlain by a thin soil. Glacial striae were observed on the top of unit 11 at coordinates 475357E, 6293156N.

Figure 19. A close-up of unit 8 of the Moberly Member at Norris I station 14 on the Athabasca River.

Figure 20. A close-up of the brachiopod rudstone in a grainstone matrix at the base of unit 8 of the Moberly Member at Norris station 14 on the Athabasca River. The white dashed lines circle *Desquamatia* brachiopods.

5.4 Structure

The outcrop contains a syncline along the accessible portion of the outcrop and an anticline around the bend in the river in the upstream, inaccessible cliff. At coordinates 475397E, 6293039N, the top of subunit 4c is at water level. Downstream, at 475300E, 6293292N, the top of subunit 4c is approximately 230 cm above water level.

The orientation (dip and dip direction) of individual beds was measured at the following locations:

Easting	Northing	Dip (degrees)	Dip direction
475396	6293039	6	NNW
475387	6293049	2	NNW
475386	6293080	3	NNW
475374	6293100	7	NNW
475370	6293122	4	NNW
475361	6293134	6	NNW
475362	6293135	7	NNW
475358	6293164	6	NNW
475353	6293169	7	NNW
475343	6293178	11	N
475300	6293292	6	SSE
475293	6293346	5	SE
475290	6293314	5	SE

6 Norris Station 18

6.1 Locality Description and Access

UTM Zone 12, 475316E, 6294464N (NAD83)

This outcrop forms a long, nearly unbroken cliff along the river bank above the talus slope (Figure 21). Beds are mostly flat lying along this stretch of outcrop with occasional minor, gentle folds. A talus slope at the location allows access to the upper portion of unit 4.

This outcrop is best accessed by boat as there is no space for a helicopter to land.

6.2 Stratigraphy

From base to top, the outcrop includes the following units (Figure 22):

- Unit 1 (100 cm), which can be broken into several subunits at Norris station 18:
  - subunit 1 (5 cm): resistant, green-grey, brachiopod, crinoid, and intraclast rudstone. An argillaceous parting separates this bed from the overlying bed.
  - subunit 2 (3 cm): resistant, bioturbated, grey, brachiopod and crinoid rudstone with lime mudstone filling *Planolites* burrows and load casts.
  - subunit 3 (10 cm): recessive, green-grey, calcareous shale.
  - subunit 4: two beds (10 cm thick in total): resistant, beige, brachiopod, crinoid, and intraclast rudstone in a packstone matrix (Figure 23). These beds are good markers for discerning this unit in outcrops along the Athabasca River from other units with similar lithology and texture because

Figure 21. The stretch of Moberly Member outcrop that includes Norris station 18 on the Athabasca River. View is looking north (downstream) of the location.

Figure 22. Units 3 to 7 of the Moberly Member at Norris station 18 on the Athabasca River. The asterisk and dashed lines in unit 3 mark a prominent, 15 cm thick rudstone bed. The arrow points to the orange field notebook resting on the exposed portion of unit 2.

Figure 23. The rock hammer rests on the *Eleutherokomma* beds of unit 1 of the Moberly Member at Norris station 18 on the Athabasca River.

the beds contain abundant *Eleutherokomma* brachiopods. However, the presence of several *Eleutherokomma* beds in unit 1 makes correlating individual beds difficult.
    - subunit 5 (30 cm): cover or slump, argillaceous lime mudstone nodules and talus.
    - subunit 6 (42 cm): recessive, beige-grey, tabular-bedded (1 to 2 cm) and nodular-weathering, bioturbated, argillaceous wackestone with occasional brachiopods and crinoids. Two rudstone layers of brachiopods, crinoids, and gastropods occur 15 cm and 42 cm, respectively, from the top of the unit.
- Unit 2 (at least 15 cm; base covered with talus): resistant, grey weathering and fresh, unbedded, bioturbated, brachiopod and crinoid rudstone in a packstone matrix.
- Unit 3 (70 cm): recessive, mottled beige-orange and grey, centimetre-scale nodular-bedded, bioturbated, argillaceous lime mudstone. The unit contains 2 to 3 cm thick beds of brachiopod rudstone (Figure 24).
- Unit 4 (347 cm): resistant, beige weathering and fresh, massive stromatoporoid and brachiopod rudstone. The basal 127 cm is wavy bedded. Partings occur approximately 280 cm and 320 cm above the base of the unit. Brachiopod taxa include atrypides and *Eleutherokomma*.
- Unit 5 (~50 cm): recessive, beige-grey weathering, nodular, argillaceous limestone that weathers into three beds (from base to top): 1) 10 cm slightly resistant, 2) 20 cm slightly recessive, and 3) 35 cm slightly resistant.
- Unit 6 (~50 cm): recessive, beige-grey and nodular-weathering, argillaceous limestone.
- Unit 7 (~100 cm): resistant, grey-weathering, massive limestone. Two partings occur in the unit that split the limestone into three beds, which are, from base to top, 20, 50, and 30 cm thick.

6.3 Sub-Cretaceous Unconformity

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

6.4 Structure

The long stretch of outcrop that includes Norris station 18 contains very gentle anticlines and synclines. The northern end of the outcrop dips towards the river.

7 Norris Station 20

7.1 Locality Description and Access

UTM Zone 12, 475178E, 6295668N (NAD83)

This outcrop is a continuation of the lengthy but occasionally intermittent stretch of limestone cliff that includes the Norris station 18 (Figure 21). The limestone cliff sits above a large pile of talus. A green shale bed was seen near the river level in the talus slope.

This outcrop is best accessed by boat as there is no place for a helicopter to land.

7.2 Stratigraphy

At the base of the talus slope near the river level and approximately 5 m below the base of the outcrop cliff is a 30 cm thick green-grey, calcareous shale with thin, argillaceous lime mudstone beds. Bivalves and *Eleutherokomma* were noted in some beds, likely from unit 1.

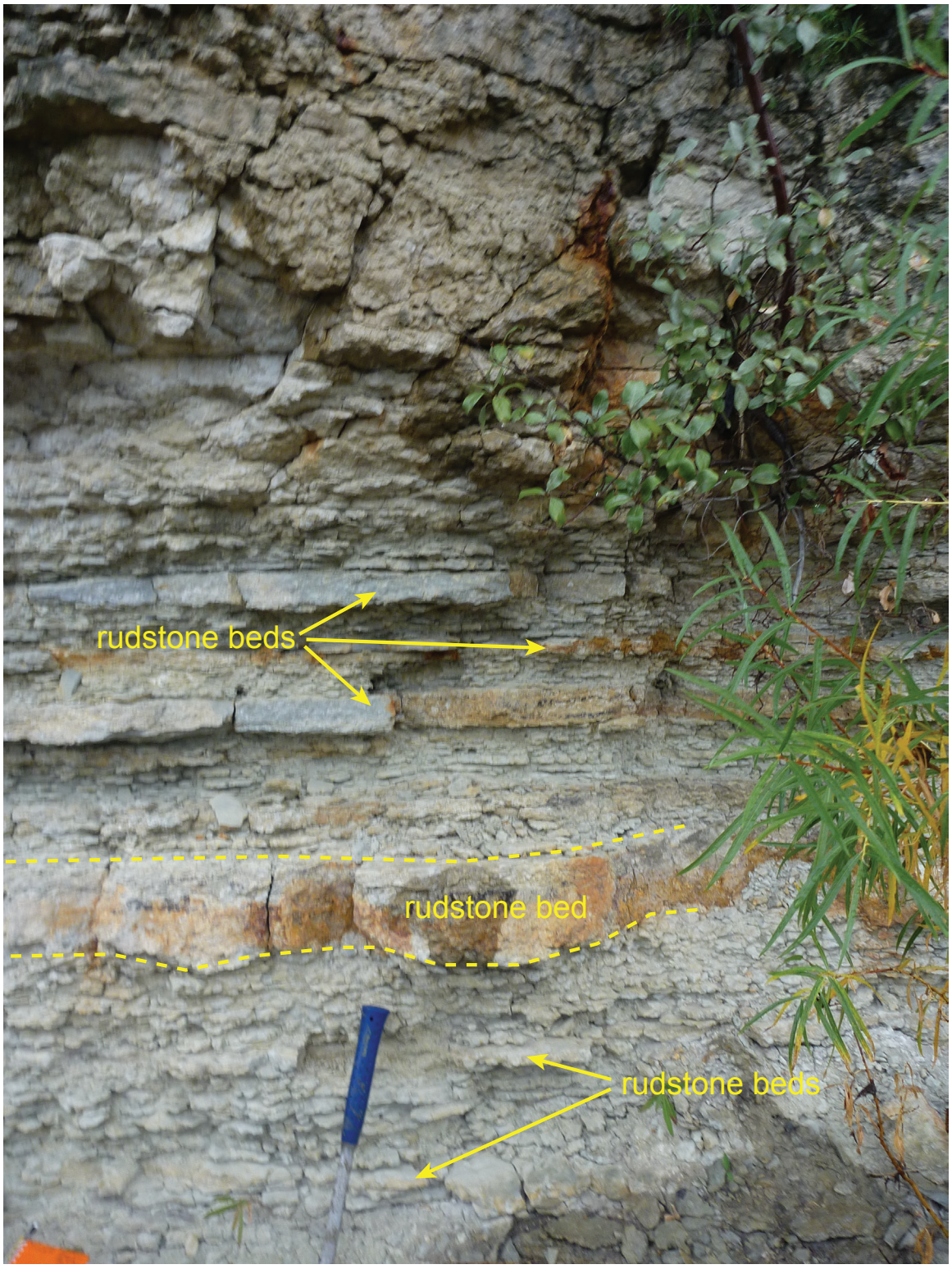

Figure 24. A close-up of unit 3 beds of the Moberly Member at Norris station 18 on the Athabasca River.

This bed is separated from the next highest exposed bed by an approximately 5 m high talus slope of limestone blocks that have weathered from the cliff and argillaceous lime mudstone nodules.

At the top of the talus slope below the cliff along the bank of the river (Figure 25) are the following units:

- Unit 4:
  - subunit 4c (~ 50 cm; exposed): resistant, beige-grey weathering and fresh, brachiopod rudstone containing in situ massive stromatoporoids. The matrix of the rudstone is a skeletal packstone to grainstone. The top of the subunit becomes slightly recessive (Figure 26).
  - subunit 4d (80 cm): resistant, beige weathering, beige-grey, brachiopod and crinoid rudstone in a packstone matrix. Brachiopods are fragmental (Figure 27).
- Unit 5 (Figure 27):
  - subunit 5a (7 cm): slightly recessive, beige and nodular weathering, beige fresh, *Thalassinoides*-bioturbated, argillaceous, brachiopod and crinoid rudstone in a wackestone to packstone matrix.
  - subunit 5b (5 cm): recessive, green-grey calcareous shale with beige-grey weathering, grey and green-grey-beige fresh, argillaceous, lime mudstone nodules (up to 1 cm diameter). The base of this unit contains a dense concentration of brachiopods.
  - subunit 5c (20 cm): resistant, beige weathering and fresh, unbedded, bioturbated, brachiopod and crinoid rudstone in a packstone matrix.
- Unit 6 (54 cm):, green-grey calcareous shale with green-grey, argillaceous, lime mudstone nodules (up to 1 cm diameter). The basal 15 cm is gradational with the underlying subunit 5c and less argillaceous than the remainder of unit 5 (Figure 27).
- Unit 7 (~ 60 cm; top eroded): resistant, beige-grey weathering, unbedded, limestone.

7.3 Sub-Cretaceous Unconformity

Siderite-stained nodules eroded from unit 7 are overlain by a regolith of McMurray Formation oil sand. Up to 10 cm of the basal oil sand contains floating, orange and beige limestone nodules.

7.4 Structure

The beds at this station along the stretch of limestone outcrop are flat lying.

8 Conclusion

The four outcrops described are easily correlated in the field because of the presence of the resistant biostromal unit 4. This unit contains large (up to 0.5 m in diameter or height), stromatoporoids of domal to columnar shapes that ‘float’ in a brachiopod rudstone matrix. Most brachiopod specimens in this rudstone are of the genus *Radiatrypa*. Stromatoporoids are not dense enough in the rock to form a framestone.

Units below biostromal unit 4 do not outcrop well. Where they do outcrop, the best exposed beds are the recessive tabular to nodular beds of unit 3. The base of unit 3 is never exposed. The beds of unit 1 were only observed at Norris station 18.

Above the biostromal unit 4, units 5 through 8 form the short limestone cliffs from Norris stations 14 to 20. Unit 5 consistently thins northward at these stations.

As reported by Norris (1963) and others, outcrops contain gentle anticlines and synclines. The steepest dips measured in the study area were at Norris station 14 on the limb of an anticline along a bend in the Athabasca River.

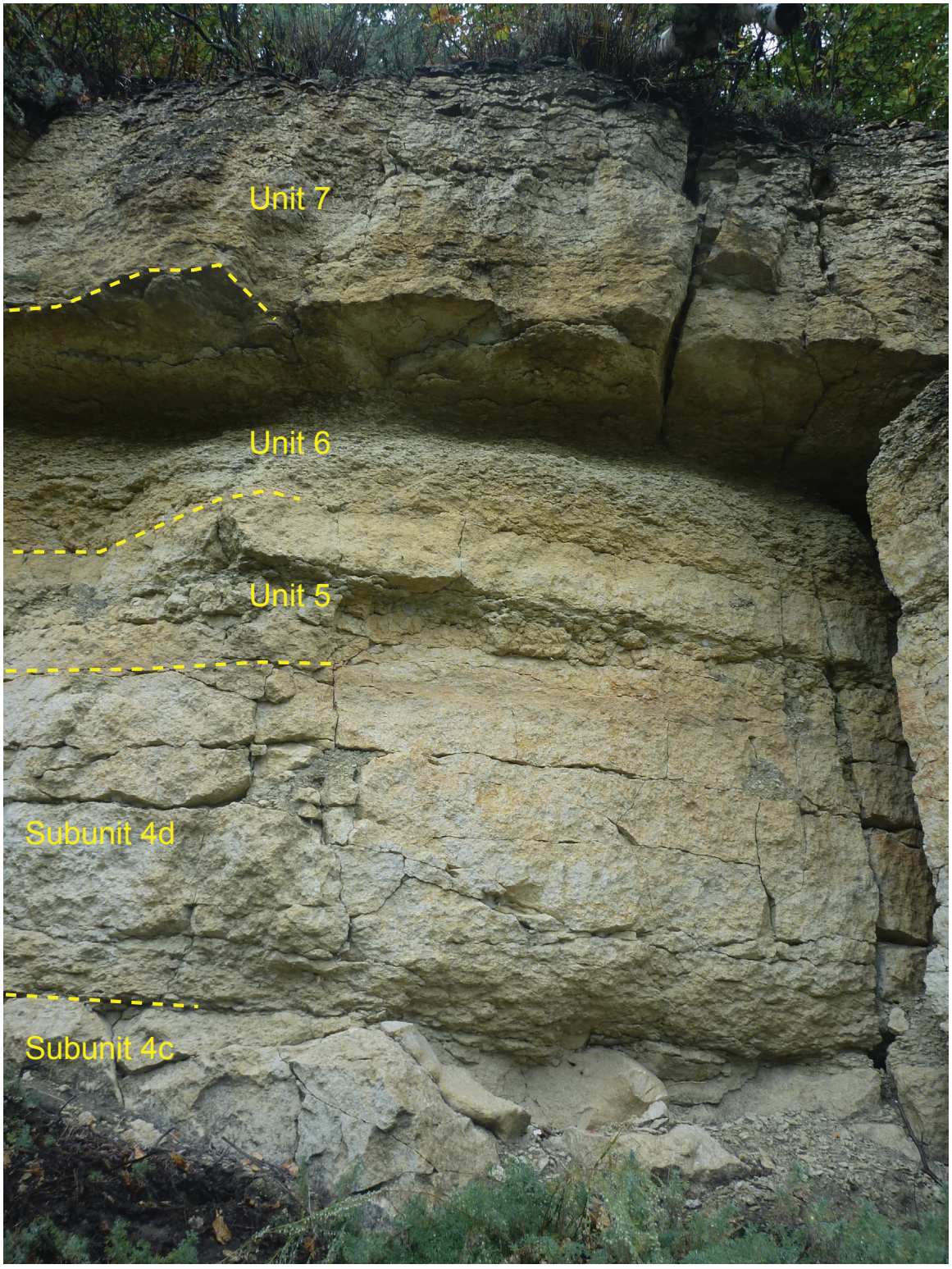

Figure 25. The stratigraphy of the Moberly Member at Norris station 20 on the Athabasca River.

Figure 26. Massive, columnar stromatoporoid in a brachiopod rudstone in subunit 4c of the Moberly Member at Norris station 20 on the Athabasca River.

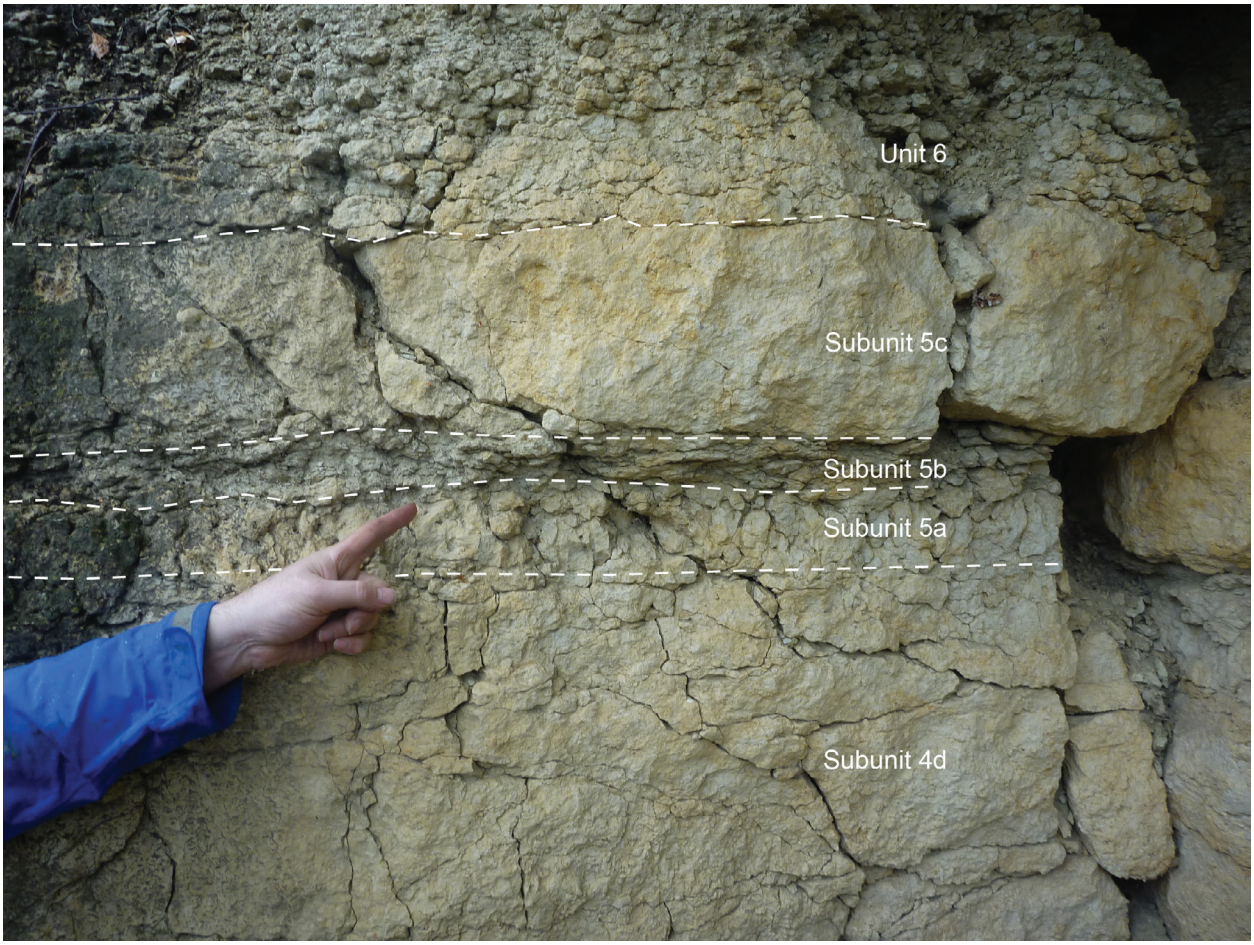

Figure 27. A close-up of subunits 4d to 5c and unit 6 of the Moberly Member at Norris station 20 on the Athabasca River. The finger points to a closely packed layer of brachiopods at the boundary between subunits 5a and 5b.

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