ERCB/AGS Open File Report 2012-18

Grosmont Formation Outcrops (T108-R6W5) at Vermilion Chutes, Peace River, North-Central Alberta (NTS 84J/07)

Energy Resources Conservation Board

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Abstract

This report describes outcrops of the Mikkwa and Grosmont formations that are exposed at Vermilion Chutes on the Peace River. The outcrop of the Mikkwa Formation exposed at the lower Vermilion Chutes is considered equivalent to the Grosmont Formation based on (1) similar lithology and paleontology to the Grosmont Formation in the subsurface, (2) the lack of a mappable Mikkwa Formation unit in the subsurface (e.g., Switzer et al., 1994), and (3) prior correlation of the Mikkwa Formation with the Grosmont Formation by Cutler (1983).

The lower Vermilion Chutes outcrop is mostly undolomitized and contains both reef (stromatoporoid and coral) and non-reef, *Thalassinoides*-burrowed facies, representing shallow-water patch reef and lagoonal paleoenvironments within the Grosmont carbonate platform.

At the upper Vermilion Chutes, the Grosmont Formation outcrop is bitumen stained and pervasively dolomitized, containing vugs originating from moulds of corals and stromatoporoids. Downstream from the Vermilion Chutes, at a locality called ‘Grosmont Flat,’ is a flat-lying outcrop similar in lithology to that of the upper Vermilion Chutes, but it contains circular, dish-shaped erosional structures up to 10 m in diameter.

1 Introduction

Belyea (1952) named the Grosmont Formation for the limestone and dolostone overlying shale of the Ireton Formation in the subsurface of north-central Alberta. Outcrops now known to be part of the Grosmont Formation occur along the Peace River and were first mentioned by Macoun (1877) and McConnell (1893). Norris (1963) published the first detailed description of the outcrops exposed along the Peace River. He differentiated a dolomitic Grosmont Formation exposed at the upper Vermilion Chutes from a dominantly limestone Mikkwa Formation, exposed downstream at the lower Vermilion Chutes and at the confluence of the Mikkwa and Peace rivers.

Norris (1963) used the term “Mikkwa Formation” for limestone exposed at the lower Vermilion Chutes on the Peace River and at the mouth of the Mikkwa River. Green et al. (1970) extended the Mikkwa Formation to include outcrops exposed along Harper and Lambert creeks, located to the southeast of the Peace River outcrops.

Norris (1963) and Green et al. (1970) placed the stratigraphic position of the Mikkwa Formation between the underlying (older) Ireton Formation and the overlying (younger) Grosmont Formation. Norris (1963) described the Mikkwa Formation from the Hudson’s Bay Fort Vermilion no. 1 well at L.S. 15, Sec. 32, Twp. 104, Rge. 8, W 5th Mer. (abbreviated 15-32-104-8W5) (Figure 1), of which the critical interval was not available for observation at the time of writing of this report. Cutler (1983) included the outcrop at Vermilion Chutes within the Mikkwa Formation, but correlated the Mikkwa Formation outcrop with the Grosmont Formation in the subsurface.

The Grosmont Formation outcrops on the Peace River at both the upper and lower Vermilion Chutes (Figure 2), the mouth of Mikkwa Creek, and at a locality 11 km downstream of the lower Vermilion Chutes locality, as a flat surface exposed only during low river levels. In this report, we describe the outcrops at the upper and lower Chutes and at the downstream exposure, which we call Grosmont Flat.

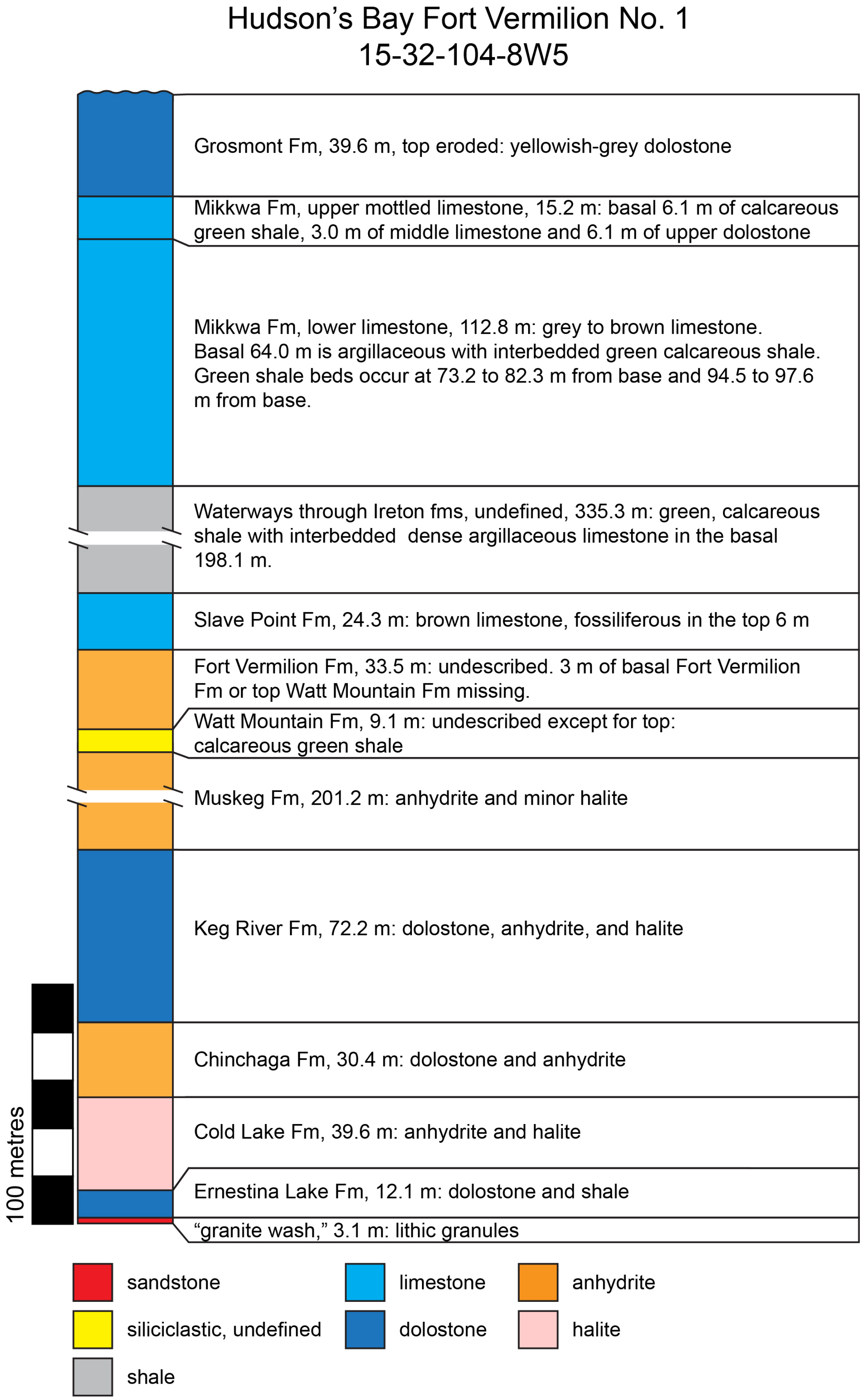
2 Background

2.1 Lower Vermilion Chutes

Macoun (1877) was the first to mention limestone exposed at the lower Vermilion Chutes. He described the rocks exposed in the falls of the lower Chutes as bedded “bluish limestone.” At the limestone cliffs below the falls, Macoun noted fossils but did not provide further information.

McConnell (1893) described low limestone cliffs lining the shore of the Peace River extending from the upper Vermilion Chutes to the mouth of the Mikkwa River, then known as the Red River. He described the rock forming the lower Vermilion Chutes as approximately 60 feet of bitumen-free, light grey or cream-coloured, thickly bedded limestone alternating with recessive, reddish or greenish argillaceous beds. McConnell attributed the formation of the falls at the lower chutes to erosion of argillaceous beds. Based on the corals, stromatoporoids, brachiopods, and bivalves collected at the lower Vermilion Chutes, McConnell correlated the lower Vermilion Chutes limestone with limestone exposed along on the Athabasca River (now known to belong to the Waterways Formation).

Norris (1963) first described the “Mikkwa Formation” from outcrops exposed along the Peace River. He divided the Mikkwa Formation into two informal units: a lower limestone member, which outcrops near the mouth of the Mikkwa River and which unconformably underlies the upper “mottled limestone” member, which outcrops along the northern bank of the lower Vermilion Chutes. Norris’s (1963) composite section for the “mottled limestone” member of the Mikkwa Formation exposed at the lower Vermilion Chutes on the Peace River, from base to top, is as follows:



Hudson's Bay Fort Vermilion No. 1
15-32-104-8W5

Grosmont Fm, 39.6 m, top eroded: yellowish-grey dolostone

Mikkwa Fm, upper mottled limestone, 15.2 m: basal 6.1 m of calcareous green shale, 3.0 m of middle limestone and 6.1 m of upper dolostone

Mikkwa Fm, lower limestone, 112.8 m: grey to brown limestone. Basal 64.0 m is argillaceous with interbedded green calcareous shale. Green shale beds occur at 73.2 to 82.3 m from base and 94.5 to 97.6 m from base.

Waterways through Ireton fms, undefined, 335.3 m: green, calcareous shale with interbedded dense argillaceous limestone in the basal 198.1 m.

Slave Point Fm, 24.3 m: brown limestone, fossiliferous in the top 6 m

Fort Vermilion Fm, 33.5 m: undescribed. 3 m of basal Fort Vermilion Fm or top Watt Mountain Fm missing.

Watt Mountain Fm, 9.1 m: undescribed except for top: calcareous green shale

Muskeg Fm, 201.2 m: anhydrite and minor halite

Keg River Fm, 72.2 m: dolostone, anhydrite, and halite

Chinchaga Fm, 30.4 m: dolostone and anhydrite

Cold Lake Fm, 39.6 m: anhydrite and halite

Ernestina Lake Fm, 12.1 m: dolostone and shale

"granite wash," 3.1 m: lithic granules

Figure 1. Core from Hudson's Bay Fort Vermilion no. 1 well (15-32-104-8W5). Measurements are based on those of Crockford in Norris (1963) and updated to Table of Formations (ERCB, 2009) nomenclature, except for the Mikkwa and Grosmont formations, which were taken from Norris (1963). Most of the Mikkwa-Grosmont formations' cored interval was not available at the time of writing.

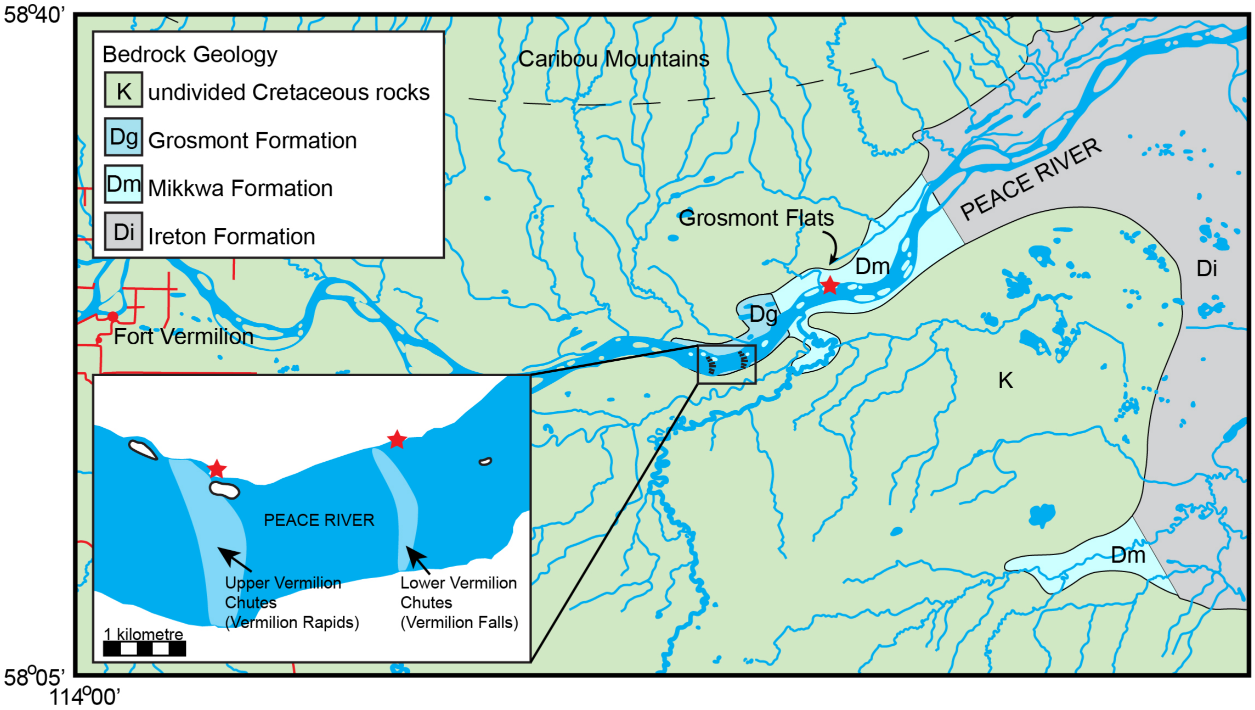


Figure 2. Map of the Vermilion Chutes area. Described outcrop sections are labelled with red stars in the inset map.

1) 1.8 m of medium brownish-grey, thin to medium-bedded, brachiopod and coral-rich limestone containing red argillaceous partings near the top.
2) 1.5 m covered interval.
3) 1.4 m of medium brown and purplish-red mottled, irregularly thin and nodular-bedded, sparsely fossiliferous limestone.
4) 1.0 m of medium brown and purplish-red mottled, irregularly thin-bedded (5 to 30 cm thick), richly fossiliferous limestone.
5) 1.2 m of medium brownish-grey and purplish-red mottled, rubbly thin-bedded, slightly argillaceous, fossiliferous limestone.
6) 1.8 m of medium brownish-grey and purplish-red mottled, massive, brachiopod and *Thamnopora*-bearing limestone.
7) 1.6 m of recessive, medium brownish-grey and dark purplish-red mottled, rubbly thin-bedded limestone.
8) 3.8 m of medium brownish-grey, massive, fossiliferous limestone becoming dolomitic and coral-rich towards the top.
9) 1.2 m of medium brownish-grey to light olive-grey with red to purple mottling, irregularly thin-bedded, argillaceous limestone containing abundant corals and brachiopods.

Above the “mottled limestone” member exposed at the lower Vermilion Chutes, Norris (1963) also described the lowermost Grosmont Formation as 2.7 m of medium to dark brownish-grey, fine-grained, irregularly thin-bedded becoming thicker-bedded towards the top, vuggy dolostone. Norris (1963) reported a few poorly preserved corals and *Spinatrypa* brachiopods.

Green et al. (1970) briefly described the Mikkwa Formation as a 122.0 m thick succession of limestone and dolomitic limestone with minor shale.

Cutler (1983) correlated the Mikkwa Formation outcrop at the lower Vermilion Chutes with the Grosmont Formation in the subsurface. Within the exposed Mikkwa Formation limestone, Cutler (1983) recognized several shallowing-upward, 1 to 4 m thick cycles, each containing hardgrounds at the top. Cutler’s (1983) section of the Mikkwa Formation exposed at Vermilion Chutes, from base to top, includes the following:

Unit A: brachiopod and crinoid wackestone.

Unit B: nodular, argillaceous, brachiopod and crinoid wackestone with a green, calcareous shale at the base.

Unit C: brachiopod wackestone.

Unit D: nodular, crinoid- and brachiopod-bearing, calcareous shale.

Unit E: nodular, argillaceous brachiopod and coral wackestone with pyritized hardground surfaces.

Unit F: coral-stromatoporoid floatstone.

More recently, Buschkuehle (2003) investigated the Mikkwa Formation outcrops at the lower Vermilion Chutes along the Peace River. From base to top, Buschkuehle (2003) described it as follows:

1) A basal light grey to reddish dolomitic limestone containing fossil debris.
2) 1.0 m of red and red-grey, fossiliferous limestone containing abundant brachiopods.

3) 0.4 m of red-grey, nodular limestone.
4) 1.1 m of variegated red and grey, nodular, lime mudstone to wackestone;
5) 1.0 m of a yellowish-grey "brachiopod bank."
6) 2.0 m of yellow, massive, coral-rich dolostone that is highly porous from coral dissolution and contains bitumen staining, calcite and dolomite in the coral moulds.

Buschkuehle (2003) did not recognize the Grosmont Formation at the upper Vermilion Chutes, but instead assigned the uppermost beds exposed at the lower Chutes (units 6 and 7 in the present study) to the Grosmont Formation. She recognized three units in the Grosmont Formation which, from base to top, are as follows:

1) A basal framestone colonial coral bank containing *Alveolites*, *Halysites*, and other corals in growth position.
2) A yellow to grey, finely nodular dolostone that grades into the overlying unit.
3) A fabric-selective dolostone with wavy bedding, containing abundant crinoids, corals, and stromatoporoids.

2.2 Upper Vermilion Chutes

From his exploration of the Lower Peace River, Macoun (1877) reported a thickly bedded dolostone full of "small holes" at the upper Vermilion Chutes that dipped slightly upriver. Macoun also mentioned an oil seep immediately downstream of the dolostone outcrop.

Norris (1963) described the Grosmont Formation from the upper Vermilion Chutes as a coarsely vuggy, petroliferous, reefal dolostone. From base to top, Norris (1963) described a composite section as follows:

1) 0.6 m of recessive, pale orange-brown and red mottled, argillaceous limestone.
2) 1.2 m of pale brownish-grey, irregularly thick-bedded, fine-grained, vuggy dolostone with poorly preserved stromatoporoids and corals.
3) 3.7 m of a light brownish-grey, fine-grained, massive, lightly vuggy, petroliferous dolostone with poorly preserved corals and brachiopods and occasional vugs filled with bitumen.
4) 4 m covered interval.
5) 1 m of mottled light pinkish-grey and brownish-grey, massive, fine-grained, slightly petroliferous dolostone that is coarsely pitted and forms the capping rock of the upper Chutes.
6) 1 m of light bluish-grey to dark grey, massive, coarsely vuggy dolostone.

Cutler (1983) described the upper Vermilion Chutes outcrop as 4 m of pervasively dolomitized Grosmont Formation. In etched samples, he found brachiopods, crinoids, and stromatoporoids.

3 Lower Vermilion Chutes

3.1 Locality

Location: UTM Zone 11, 624377E, 6472679N (NAD83)

Access: By helicopter; land on the limestone bench beside the falls and walk downstream to a small collapse in the limestone wall. Carefully scramble down this collapse to access the lower portion of the outcrop. Alternatively, go by boat to the upper falls then hike downstream along the north bank to the lower chutes.

The Grosmont Formation at the lower Vermilion Chutes forms the obstruction in the Peace River that creates the waterfall. Near the southern shore of the river, several islands of Grosmont limestone split the falls and trap debris during flood stages. Outcrops along the north bank are small cliffs or are benched.

Note: Water levels on the Peace River greatly influence how much of the outcrop is observable. In this report, water levels were higher than those of any previous published visit, so the lowermost beds of Norris (1963), Cutler (1983), and Buschkuehle (2003) were not observed during this visit to the outcrop.

3.2 Stratigraphy

The reef facies of the Grosmont Formation outcrop forms a broad bench at the top of the falls (Figure 3). Here, moldic, ghosted, and recrystallized corals and stromatoporoids are abundant but are heavily weathered (Figure 4). Above this bench, a short section (1.5 m) of more recessive outcrop occurs at the forest edge (Figure 5). Below the falls, the lower beds form a cliff that stretches downstream and around the bend in the river before pinching out against the river's edge (Figure 6).

The base of the outcrop forms several shallow benches of resistant, *Thalassinoides*-burrowed floatstone and rudstone (Figure 6). The most striking aspect about these beds and those of the cliff above is the brilliant reddish mottling formed by the exposed burrows. Similarly, many brachiopod shells are stained red, while branching stromatoporoids form long, meandering beige shapes and small crinoid columnals are bright white against the grey rock.

Only three hardgrounds were noted in the cliff during this visit. Because of the pervasive red staining in the *Thalassinoides* burrows and burrow network termination surfaces, and because hardgrounds are also red stained, hardgrounds are not easily identified. At this outcrop, hardgrounds are best recognized by first locating red-stained termination surfaces of *Thalassinoides* burrow networks and then closely observing those surfaces for evidence of an omission event, such as boring of the surface, early cementation, and phosphatization (Figure 7). Thus, other hardgrounds in the outcrop likely exist, but only those that could be identified with certainty are included in this report. Most *Thalassinoides* termination surfaces were firmgrounds, lacking the mineralization and borings seen on true hardgrounds.

The outcrop is abundantly fossiliferous. Brachiopods, crinoids, and branching stromatoporoids rarely weather out of the rock and are best seen on the planar surfaces of benched *Thalassinoides*-burrowed floatstone and rudstone. Tabular and massive stromatoporoids and colonial rugose corals erode from some units and are collectable in the talus at the base of the outcrop.

This outcrop lacks the dolomitization, bitumen saturation, and karst that are common to the Grosmont Formation in subsurface. The outcrop is mainly limestone, with only very localized dolomitization or bitumen staining.

The outcrop forms a gentle anticline, with the north-trending axis of the anticline occurring adjacent to the bottom of the falls. Fractures are relatively infrequent.

The top of the outcrop is either exposed or covered by vegetation. The lowermost exposed bed in the outcrop continues into the river. Stratigraphy for this outcrop is illustrated in Figures 6, 8, and 9 and is described, from base to top, as follows:

1) 275 cm, limestone: resistant, becoming recessive upward, dark grey mottled with red, green-grey, and beige weathering, medium grey with red mottling, 5 to 20 cm tabular-bedded, heavily bioturbated, *Thalassinoides*-burrowed, brachiopod floatstone to rudstone in a wackestone to packstone matrix. When exposed, lower beds form benches from the water level up to the cliff base; the upper 130 cm becomes nodular, argillaceous, and recessive, forming the lower portion of the cliff. In this upper 130 cm, 2 to 3 cm diameter *Thalassinoides* burrows are more resistant to weathering and form a

nodular weathering texture. Some beds contain small crinoid columnals and branching stromatoporoids, such as *Stachyodes*. Atrypide, spiriferide, stropheodontoid, and terebratulide brachiopods are scattered across benched surfaces, including the genera *Strophomena* and *Variatrypa*. One very fossiliferous surface at 160 cm from the top is a crinoid, brachiopod, and branching stromatoporoid rudstone in which the brachiopods are stained red, the tiny crinoid columnals are bright white, and the 1 cm diameter branching stromatoporoids are preserved as long (up to and exceeding 10 cm) beige segments. In this fossiliferous bed, the allochems are calcitic, but the matrix has undergone partial dolomitization. Fossils in this bed comprise up to 50% of the rock. Another crinoid, brachiopod, and branching stromatoporoid floatstone occurs at 145 cm below the top of the unit, with fossils similar in colour and preservation as the bed at 160 cm from the top. Allochems in this bed comprise only 20% of the rock in this upper bed (Figures 6, 8, and 10);

2) 2 cm, limestone: recessive, green-grey weathering, brown-grey and red, laminated lime mudstone. Laminated calcitic shale occurs in the 0.2 cm above and below the bed. The top surface of the lime mudstone is wavy (<0.5 cm relief) and is an argillaceous ‘crust’ containing *Planolites* burrows. This thin bed forms a good marker for the outcrop (Figures 10 and 11);

3) 107 cm, limestone: resistant, cliff-forming, mottled beige, grey and red (weathered and fresh), massive, heavily bioturbated, *Thalassinoides*-burrowed, brachiopod and crinoid rudstone in a wackestone to packstone matrix. An argillaceous parting occurs 18 cm below the top and is traceable throughout the outcrop. The top of the unit is a hardground marked by pervasive and slightly brighter red-staining, phosphatization, and the termination of a *Thalassinoides* burrow network (Figures 7, 8, 10, and 11);

4) 136 cm, limestone: resistant, cliff-forming, mottled beige, grey and red (weathered and fresh), 5 to 15 cm wavy to nodular bedded, crinoid, and brachiopod rudstone in a wackestone to packstone matrix at the base increasing upward to a crinoid, brachiopod, *Amphipora*, bulbous, and tabular stromatoporoid rudstone to bindstone in a packstone to locally grainstone matrix. Bindstones are formed by closely stacked tabular stromatoporoids. Hardgrounds similar to that at the top of unit 3 occur at 23, 40, and 70 cm above the base of the unit, respectively (Figures 7 and 12); and

5) 145 cm, limestone: resistant, becoming recessive and argillaceous in the upper 75 to 80 cm, mottled beige, grey and red (weathered and fresh), massive becoming nodular weathering in the upper 75 to 80 cm, brachiopod, crinoid, tabular, branching, and massive stromatoporoid rudstone to bindstone in a packstone to locally grainstone matrix. The bindstone is formed by closely stacked tabular stromatoporoids. One large, solitary rugose coral was found in the upper surface of the unit at the top of the cliff.

This last unit both underlies and, in the upper beds, grades laterally into the dark grey dolostone that forms the benched platform beside the falls of lower Chutes. Up to this level, most brachiopods are red stained, stromatoporoids are beige, and crinoids are bright white in the rock. Approximately 100 cm of cover separates this unit from the upper portion of the outcrop (Figure 8):

6) 60 cm, limestone: recessive, mottled grey, green-grey and red weathering, grey and red mottled, 2 to 10 cm wavy bedded, nodular weathering, argillaceous, bioturbated, branching, and massive stromatoporoid, colonial rugose coral, crinoid and brachiopod rudstone to locally framestone in a wackestone to grainstone matrix;

7) 125 cm, limestone and dolostone: increasingly resistant, mottled grey and red (weathering and fresh), 5 to 15 cm wavy bedded, bioturbated, crinoid, and brachiopod rudstone in a wackestone to packstone matrix, transitioning through 40 to 60 cm above the base into a dolomitized rudstone in the top 65 cm.

Figure 3. The reef bench at the top of the lower Vermilion Chutes. The log-covered island near the edge of the falls appears behind the helicopter.

Figure 4. A large stromatoporoid on the reef bench at the top of the upper Vermilion Chutes. Note the footprints in the centre of the stromatoporoid and the toe of a boot at the bottom centre of the photograph for scale.

Figure 5. Uppermost outcrop at the lower Vermilion Chutes containing units 6 and 7. Photo from Buschkuehle (2003).

Figure 6. The outcrop below the falls at the lower Vermilion Chutes, downstream view. Note the benched beds of unit 1 between the cliff and the river. J. Weiss for scale.

Figure 7. Hardground at the top of unit 3 at the lower Vermilion Chutes locality. Note the increased red staining of *Thalassinoides* burrows at, and just below, the hardground.

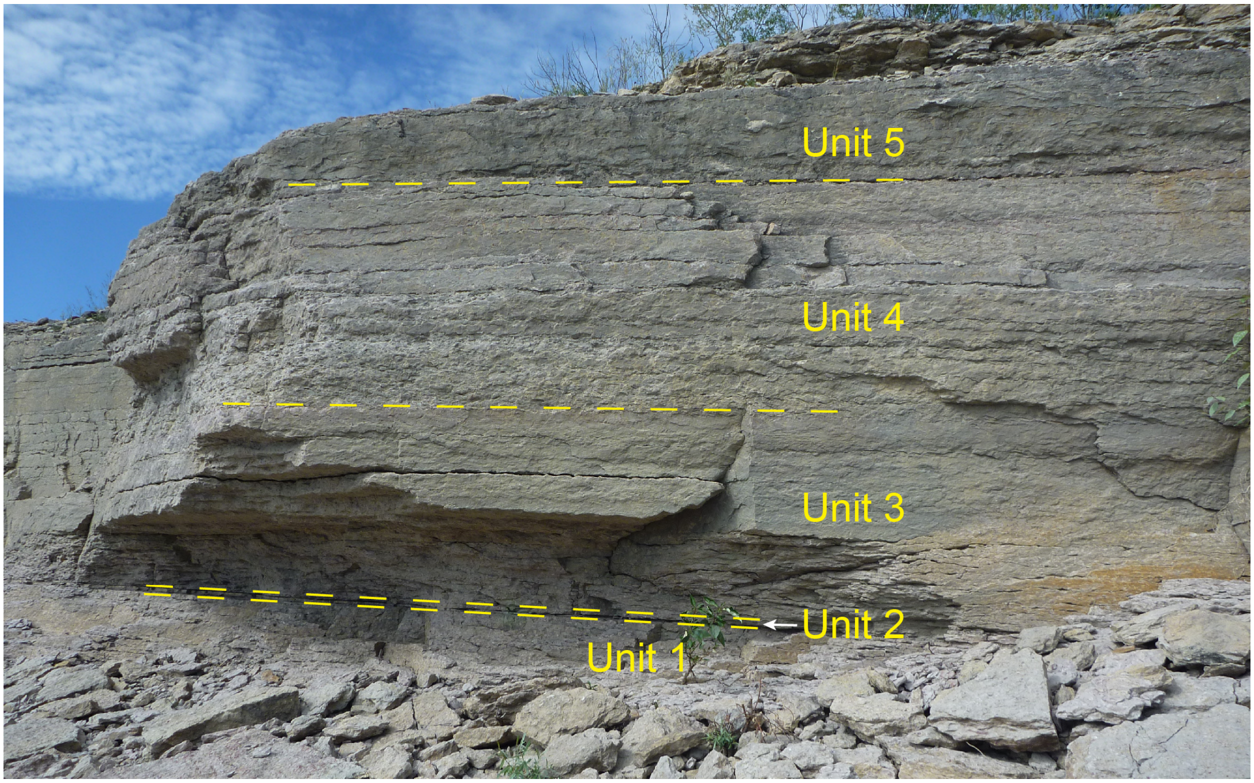


Figure 8. Cliff below the falls at the lower Vermilion Chutes with units labelled.

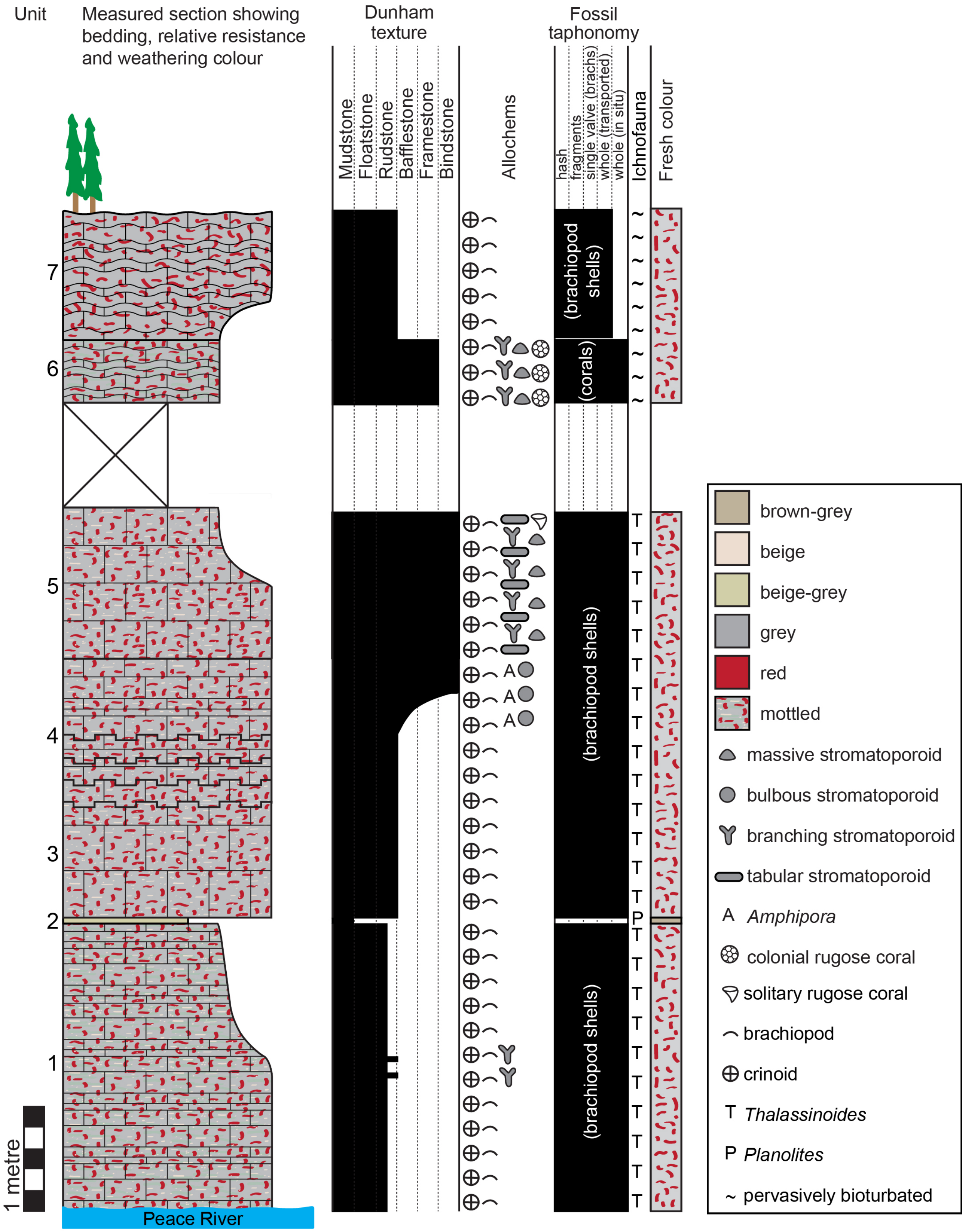


Figure 9. Stratigraphic section of the outcrop at the lower Vermilion Chutes.

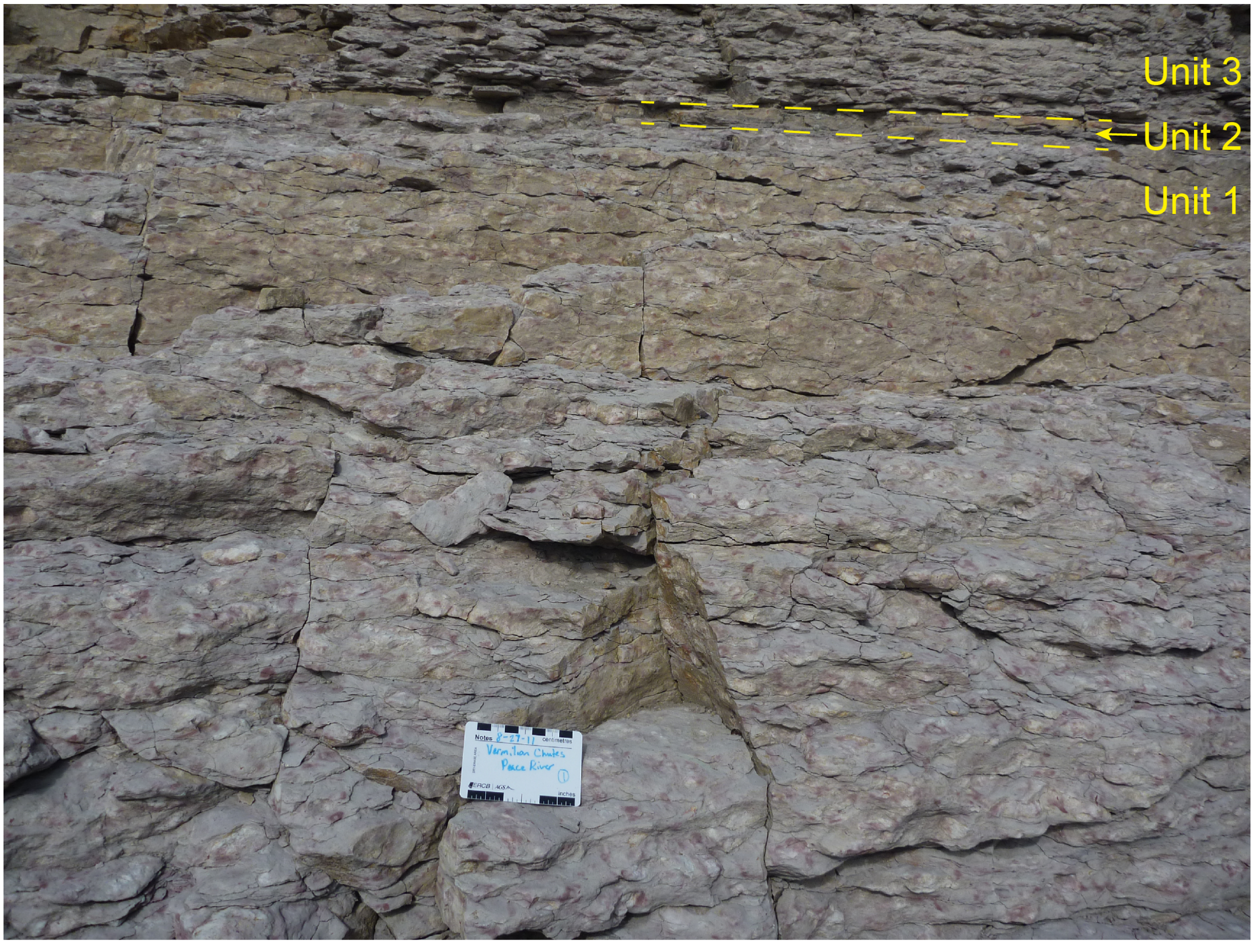


Figure 10. Upper beds of unit 1, unit 2, and lowermost unit 3 at the lower Vermilion Chutes locality. Note the nodular-textured beds of upper unit 1. Upper bar on scale card is in centimetres.

Figure 11. Close-up of unit 2 at the lower Vermilion Chutes locality. The thin shales above and below the lime mudstone bed of unit 2 appear thicker in this photograph because of weathering at the photographed spot; units 1 and 3 are slightly more recessive than the lime mudstone of unit 2, which protrudes slightly from the outcrop relative to beds above and below.

Figure 12. Close-up of upper unit 4 at lower Vermilion Chutes locality. Note the in situ tabular stromatoporoids and other fossils in the cliff face.

3.3 Biofacies

We recognized four distinct biofacies in the lower Vermilion Chutes outcrop:

1) *Thalassinoides*-burrowed, crinoid and brachiopod biofacies (units 1 and 3)
   Thalassinoides burrow networks are pervasive in this biofacies. Most bedding planes contain brachiopods, crinoids, and locally branching stromatoporoids up to 1 cm diameter. Crinoids are disarticulated, but brachiopods are whole and frequently are clustered, suggesting the remains of in situ aggregations. Pervasive *Thalassinoides* bioturbation and the presence of abundant brachiopods and crinoids suggest deposition on the low- to moderate-energy shallow shelf below fair-weather wave base.
2) Diverse, bioturbated, brachiopod, crinoid, coral, and stromatoporoid biofacies (unit 4)
   The fauna in this biofacies is a mixture of the brachiopods and crinoids of the *Thalassinoides*-burrowed biofacies and the coral and stromatoporoid bioherm (see below). This biofacies was either a patch reef-proximal ecosystem or a successional stage between the *Thalassinoides*-burrowed biofacies and the bioherm, when corals and stromatoporoids sporadically colonized the shelly remnants of brachiopods and crinoids. Like the *Thalassinoides*-burrowed biofacies, this biofacies is pervasively bioturbated. Tabular stromatoporoids may locally bind skeletal debris and sediment. This biofacies formed on the shallow platform below fair-weather wave base and under moderate- to high-energy conditions.
3) Coral and stromatoporoid bioherm (units 5 and 6)
   Corals and stromatoporoids were sufficiently common to form a framework within this biofacies, with tabular stromatoporoids occasionally binding the framework organisms. Colonial rugose corals and massive stromatoporoids are common; tabular, branching, and bulbous stromatoporoids are less abundant. Corals and stromatoporoids built sufficient positive topography to cause a localized regression. This biofacies formed in a patch reef on the shallow platform under moderate- to high-energy conditions and below fair-weather wave base.
4) Abiotic argillaceous lime mudstone facies (unit 2)
   This facies, which exists only in unit 2 at this outcrop, is mostly devoid of life except for the *Planolites* traces left by burrowing organisms in a single horizon. The argillaceous lime mudstone facies is laminated. Deposition occurred under low energy conditions mostly devoid of epifauna and sediment-churning infauna.

3.4 Paleoenvironmental Interpretation

According to Machel and Hunter (1994), bulbous and massive stromatoporoids were most common behind the wave-washed reef crest. Similar facies occurred on the crests of patch reefs. Branching stromatoporoids lived proximal to the reef core, both in the back- and fore-reef environments.

Kershaw's (1998) interpretation of paleoenvironmental parameters controlling the distribution of stromatoporoid growth forms is similar to that of Machel and Hunter (1994). Bulbous and massive stromatoporoids formed the reef core but become secondary to tabular stromatoporoids in the high-energy reef-crest environment. Branching stromatoporoids such as *Stachyodes* and *Amphipora* thrived in the back-reef environment. *Stachyodes* had a reef-proximal distribution, whereas *Amphipora* was distributed throughout the lagoon.

In the outcrop described here, tabular stromatoporoids are commonly associated with a diverse fauna, rather than the low diversity typical of reef crests. At the lower Vermilion Chutes outcrop, thin tabular stromatoporoids bound sediment composed of stromatoporoid fragments, brachiopods, and crinoid columnals. Likely these organisms thrived in the reef-proximal environment, where the skeletal remains of organisms formed abundant debris and tabular stromatoporoids expanded over the coarse sediment.

Pervasive *Thalassinoides* bioturbation throughout most of the outcrop suggests the formation of many strata on the well-oxygenated, moderate-energy, shallow shelf, well within the photic zone and below fair-weather wave base. Where units are more fossiliferous and grain supported, such as in units 4 and 5, water energy was higher and transported fine sediments from the local environment, allowing corals and stromatoporoids to encrust the shelly debris.

Patch reefs in units 5 and 6 formed within the shallowest environment. Corals and stromatoporoids built sufficient positive topography to elevate the local paleoenvironment into higher-energy, perhaps wave-agitated, water.

A preliminary interpretation of the paleoenvironmental history of the outcrop follows, with a general interpretation of depositional paleoenvironments illustrated in Figure 13:

1) The base of the outcrop formed in the low- to moderate-energy environment of the shallow lagoon on the Grosmont Platform (unit 1). *Thalassinoides* burrow networks were continually maintained by infaunal organisms. A brachiopod and crinoid fauna, occasionally including branching stromatoporoids, thrived on the surface.
2) Transgression and an influx of terrigenous mud did not greatly affect the *Thalassinoides* burrowers but caused a decline in epifauna (upper unit 1).
3) Almost all biotic activity ceased during a highstand. Terrigenous mud sedimentation dominated the quiet, somewhat deeper lagoon (unit 2). *Planolites* burrowers invaded the quiet, abiotic environment for a brief time.
4) Regression led to a return of *Thalassinoides* burrowers and the epifaunal crinoid-brachiopod community in slightly agitated water (unit 3 and lower unit 4).
5) The accumulation of shells combined with further regression and moderate water energy facilitated the colonization of bulbous stromatoporoids and *Amphipora* (upper unit 4). With an increase in skeletal debris, massive stromatoporoids and tabular stromatoporoids appeared, locally binding sediment (unit 5).
6) Proximal to the present-day lower Vermilion Chutes, massive and tabular stromatoporoids were joined by colonial rugose corals to form a patch reef. At the measured locality, the near-reef environment continued to support abundant stromatoporoids, including sediment-binding tabular stromatoporoids (upper unit 5). Water energy was moderate to high.
7) (The covered interval occurs here.)
8) Abundant colonial rugose corals and massive stromatoporoids formed the framework of a patch reef. Tabular stromatoporoids bound the reef, whereas brachiopods and crinoids were secondary organisms existing in and around the bioherm (unit 6). Water energy was high, and the patch reef may have extended up into the agitated wave zone.
9) The water deepened and the patch reef ceased. A return to the quiet to slightly agitated regime of the shallow shelf environment allowed for a thriving network of *Thalassinoides* burrowers and a rich brachiopod and crinoid epifauna (unit 7).

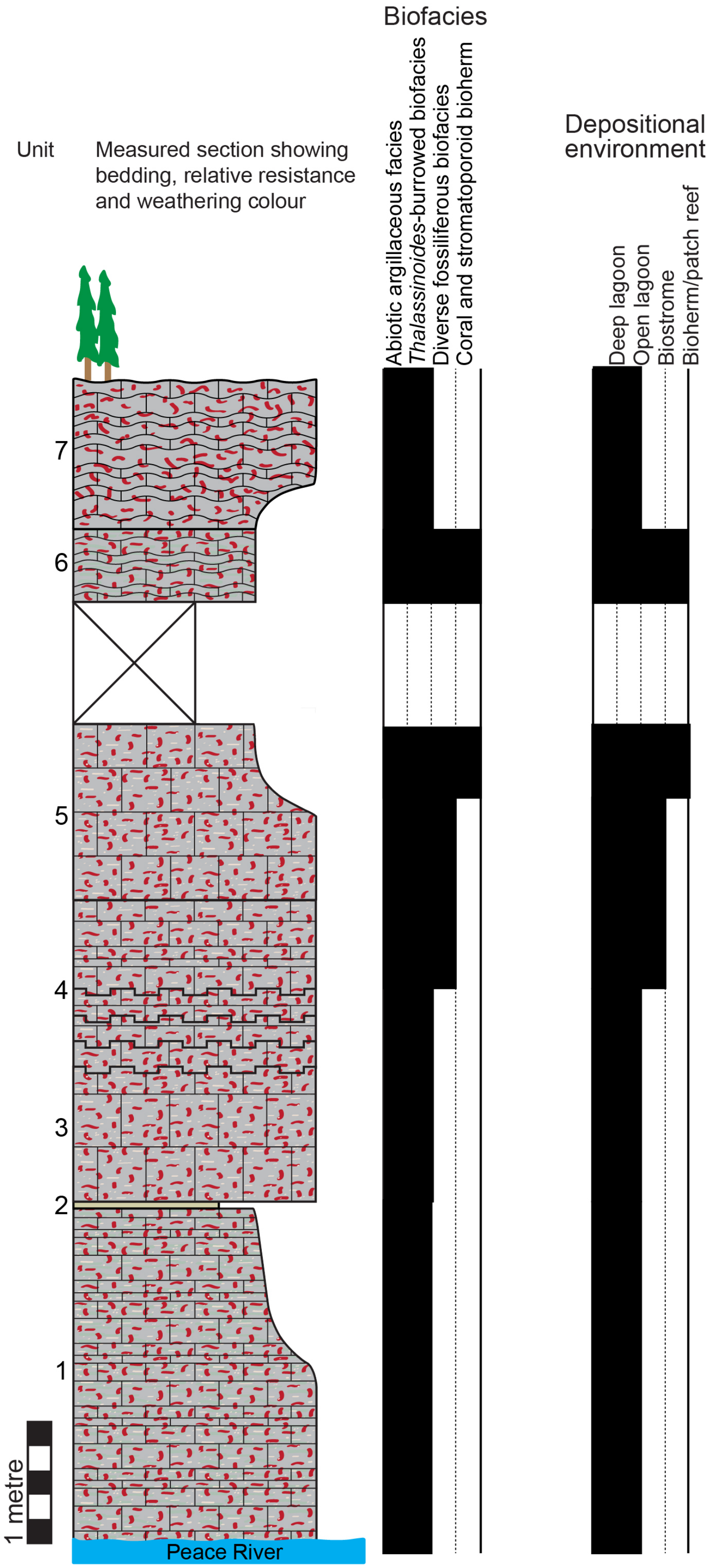


Figure 13. Interpreted sea level and biofacies in the lower Vermilion Chutes outcrop.

4 Upper Vermilion Chutes

4.1 Locality

Location: UTM Zone 11, 622003E, 6471994N (NAD83)

Access: By helicopter; land on the limestone bench on the north bank and walk upstream to the dolostone outcrops. Alternatively, by boat; park above the upper Vermilion Chutes and hike to the outcrop along the north bank of the river.

The Grosmont Formation at the upper Vermilion Chutes forms many round black islands in the rapids, a tree-covered island near the north bank, and a narrow band of outcrops along the north bank. Outcrops at the water level occasionally contain potholes formed by river water. The outcrop is stained black, not by bitumen but by a black rind, and is pitted from dissolved corals and stromatoporoids.

Note: Water levels on the Peace River greatly influence how much of the outcrop is observable. In this report, water levels were higher than those of any previously published visit.

4.2 Lithology

The upper Vermilion Chutes contains rocky islands in the middle of the rapids and a two-metre-high outcrop on the north bank (Figures 14, 15, and 16). At this locality, the Grosmont Formation is pervasively dolomitized, such that primary allochems are completely recrystallized. Only vague remnant structures of massive stromatoporoids and patterns of holes from colonial rugose corallites remain in the outcrop. The rock itself is massive, medium-crystalline, and weathers black. Texture appears to be mudstone, but given the presence of stromatoporoids and corals, dolomitization and recrystallization likely overprinted the original rudstone to bindstone and framestone texture.

The outcrop is unevenly pitted and contains vuggy porosity because of the dissolution of corals and stromatoporoids. On the rock bench just above the river surface, the outcrop is stained black by a mineral precipitate. This precipitate also covers large glacial erratics resting on the outcrop and in potholes (Figures 17 and 18). A similar precipitate was observed by M. Fenton coating joints developed in till in the region. At this time, the mineralogy and origin of the precipitate is unknown. Bitumen and calcite crystals were noted in some moulds.

In the middle of the rapids, the dolostone forms a series of blackened, circular islands (Figure 16). This differs from the blocky structure of the islands at the lower Chutes (Figure 19) and is reminiscent of dish-shaped erosional structures in an outcrop of the Grosmont Formation some distance downstream (Figure 20).

4.3 Biofacies

Only one biofacies occurs in the outcrops at Vermilion Chutes: a stromatoporoid-coral biostrome to bioherm. Corals and stromatoporoids formed a framework within this biofacies, but because of the pervasive dolomitization of the outcrop, the presence of binding organisms, such as tabular stromatoporoids, is unknown. Brachiopods and crinoids noted by Norris (1963) and Cutler (1983) were minor contributors to this biofacies.

4.4 Paleoenvironmental interpretation

At the upper Vermilion Chutes, dolostone of the Grosmont Formation was originally a well-developed reef. Circular structures formed by the eroded dolostone in the middle of the chutes are reminiscent of patch reefs in the shallow back-reef environment of modern barrier reefs. Cutler (1983) suggested that inter-reef sediments were eroded by the river, forming the more resistant, circular structures of Grosmont patch reefs in the middle of the chutes.

Figure 14. Pervasively dolomitized Grosmont Formation at the upper Vermilion Chutes on the north bank of the Peace River. In photo, from left to right: C. Schneider, H. Vigneault, J. Weiss.

Figure 15. Pervasively dolomitized outcrop on the north bank of the upper Vermilion Chutes. M. Fenton provides scale.

Figure 16. Round islands of Grosmont Formation dolostone in the Peace River at upper Vermilion Chutes. Photo by M. Fenton, August 2010, when river water level was lower than described in this report.

Figure 17. Outcrop surface of the Grosmont Formation on the north shore of the Peace River at the upper Vermilion Chutes. Black staining covers the entire outcrop. White to light grey colouration is from mud or evaporite minerals.

Figure 18. Grosmont Formation outcrop on the north shore of the Peace River at upper Vermilion Chutes. Three black, mineral-stained glacial erratics are nested in a pothole. View is oriented downstream.

Figure 19. Lower Vermilion Chutes. Note the blocky nature of the islands in the middle of the falls. Photo by M. Fenton, August 2010, when river water level was lower than as described in this report.

Figure 20. Circular structures on the outcrop surface of the Grosmont Formation downstream at Grosmont Flat on the north bank of the Peace River. Note the circular structure of the large puddles in the centre of the photo, which form in shallow, dish-shaped structures formed by the erosion of beds that dip towards the centre of the puddle. J. Pawlowicz provides scale. Photo by M. Fenton, August 2010, when river water level was lower than as described in this report.

5 Grosmont Flat

5.1 Locality

Location: UTM Zone 11, 632970E, 6479201N (NAD83)

Access: By helicopter; land on the flat expanse of black dolostone or on the sandy point bar of a nearby upstream island. This outcrop is in the river and is separated from the north bank by a narrow channel.

The outcrop is flat but undulose with round, shallow (<0.5 m deep), up to 10 m diameter, dish-shaped structures in the surface (Figure 20). Vague but frequent remnants of corals, stromatoporoids, gastropods, and brachiopods are scattered throughout the outcrop.

5.2 Lithology

This outcrop greatly resembles the upper Vermilion Chutes outcrop in texture and colour. Only one unit is present: a resistant, black (weathering and fresh), variably fine to coarsely crystalline dolostone. The texture appears to be that of mudstone, but given the presence of reefal organisms, dolomitization and recrystallization likely overprinted the original rudstone to bindstone and framestone texture.

The abundant vugs from dissolved stromatoporoids and corals seen in the upper Vermilion Chutes outcrop are not seen here. Instead, the surface is smoothed by fluvial erosion. The most striking features of this outcrop are circular, dish-shaped structures eroded into the outcrop. Lithology within and outside of these structures appear to be similar, but fossil remnants were most often observed around the edges of these structures. Rarely, beds exposed around the edges of the structures can be seen dipping towards the center of the dish.

5.3 Biofacies

This outcrop, like that of the upper Vermilion Chutes, contains only one biofacies: a coral-stromatoporoid bioherm. Likely this outcrop was originally a reef.

5.4 Paleoenvironmental Interpretation

Given the presence of coral heads and massive stromatoporoids, this outcrop was originally a reef on the shallow shelf. Water energy was high and, if the reef built sufficient structure, may have extended into wave-agitated surface water.

6 Conclusion

Given the distinct differences between the outcrops—mottled, bioturbated limestone of the lower Vermilion Chutes and black dolostone of the upper Chutes—Norris's (1963) reasoning for two different formation names is logical. However, the Grosmont Formation from subsurface contains a wide range of facies, from supratidal sediments to deep lagoon laminites and reefs (i.e., Cutler, 1983). The "Mikkwa Formation" of the lower Vermilion Chutes falls well within the range of lithologies and biofacies for the Grosmont Formation. Furthermore, Cutler's (1983) correlation between the lower Vermilion Chutes outcrop and the subsurface Grosmont Formation supports the inclusion of these outcrops into the Grosmont Formation.

The "Grosmont Flat" locality of a nearly flat-lying, river-level dolostone has not been described previously. In the absence of faulting or folding, and given the regional westward dip of Devonian strata, the rocks exposed at this outcrop may be older than either of the Vermilion Chutes localities. Based on the repetition of facies known from subsurface Grosmont Formation sequences (i.e., Cutler, 1983), we suggest that the biohermal facies seen at Grosmont Flats recurred in a younger cycle at the upper Vermilion Chutes locality.

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