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Measured Outcrop Sections T79-R17W4-01 (Stony Rapids) and T81-R17W4-01 (Pelican Cliffs) of the Pelican, Westgate, Fish Scales and Belle Fourche Formations near Stony Rapids, Athabasca River, Northeastern Alberta (NTS 83P/15 and NTS 84A/02)

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Acknowledgments

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Abstract

Two outcrop sections, T79-R17W4-01 (Stony Rapids) and T81-R17W4-01 (Pelican Cliffs), were measured on the Athabasca River in northeastern Alberta and a natural gamma-ray log was recorded for the Stony Rapids section. Combined, the measured sections traverse the stratigraphy of the Pelican, Westgate, Fish Scales and Belle Fourche formations. The lower part of the Pelican Formation exposure consists of interbedded sandstone and mudstone. A thick, cliff-forming, siderite-cemented sandstone bed, showing swaley and hummocky cross-stratification, dominates the upper part. The Pelican Formation is overlain by sulphur-stained, dark grey shale of the Westgate Formation. A prominent, indurated bioclastic bed with very high gamma-ray counts occurs at the bottom of the Fish Scales Formation. We observed two 1–2 cm thick bentonite units in the otherwise shale-dominated Fish Scales Formation. The contact between the Fish Scales and Belle Fourche formations is not exposed, and, based on comparisons with nearby downhole geophysical well logs, lies within a covered interval situated above the bentonite units. The exposed lower part of the Belle Fourche Formation is shale-dominated with silty lenses, coarsening upwards to siltstone with sandy siltstone lenses towards the top. Based on the observations presented in this report, we conclude that the lithostratigraphic divisions of the Colorado Group defined in the subsurface of southern Alberta can be applied to the Colorado Group exposed in northeastern Alberta.

1 Introduction

In this report, we present data on bedrock units measured at two locations, T79-R17W4-01 (Stony Rapids) and T81-R17W4-01 (Pelican Cliffs), both located along the Athabasca River, northeastern Alberta (Figure 1). Graphic logs of both measured sections are presented and stratigraphic context is given, where appropriate. Detailed lithofacies interpretation has been avoided. We used a handheld spectrometer (model RS-230) to record a log of the natural radiation of the bedrock at the Stony Rapids section. This work contributes to an Alberta Geological Survey (AGS) effort to update the 1:1 000 000-scale bedrock geology map of Alberta.

The measured sections provide data on units of the Colorado Group, a shale-dominated succession of Albian to Santonian age (Leckie et al., 1994, and references therein). Outcrop exposure of the Colorado Group in the Alberta Plains is largely limited to northeastern Alberta (with the exception of the Deer Creek outcrop on the Alberta-Montana border; Nielsen et al., 2003), where bedrock units above the Pelican Formation have commonly been assigned to the Labiche Formation (Wickenden, 1949; Green et al., 1970; Hamilton et al., 1998; Okulitch, 2006; Figure 1). However, in the subsurface of southern and east-central Alberta, strata equivalent to the lower part of the Labiche Formation are divided into the Westgate, Fish Scales and Belle Fourche formations based on drillcore observations and analysis of downhole geophysical well logs (Bloch et al., 1993; Stancliffe and McIntyre, 2001; Tu et al., 2007). These stratigraphic subdivisions were also identified, in this study, along the Athabasca River in northeastern Alberta, and therefore are used in place of the term Labiche Formation. This is consistent with the application of Westgate Formation and Fish Scales Formation terminology to the Birch Mountains of northeastern Alberta by Leckie et al. (2000).

Little has been published on outcrop sections of these units in the Athabasca area. Wickenden (1949) noted that Colorado Group strata were exposed along the Athabasca River and gave a brief description of the main units, and Keeler (1978) cited these exposures in his thesis on the Grand Rapids Formation. However, to our knowledge, this is the first detailed, published study on the sedimentology of Colorado Group outcrop sections in this area. The measured section at Stony Rapids includes the upper part of the Pelican Formation, a large part of the Westgate Formation, the Fish Scales Formation and portions of the Belle Fourche Formation. The measured section at Pelican Cliffs includes almost all of the Pelican Formation and the basal part of the Westgate Formation.

2 Location and Access

Both measured sections are located on the Athabasca River near 56˚N (Figure 2–4, Appendix 1) and are situated on south-facing slopes along bends in the generally northward-flowing river. The Stony Rapids section (T79-R17W4-01), located on the eastern side of the river, is 14 km south of the Pelican Cliffs section (T81-R17W4-01), which is on the western bank. The base and top of each section (Figure 5, Appendix 2) are at the level of the lowest and highest exposed bedrock at that location. Shale-dominated units have undergone extensive slumping in the surrounding area. We logged only in situ exposures, which required trenching to expose bedrock in places. The sites were accessed by helicopter in the summer of 2010. Appendix 1 provides the GPS location data.

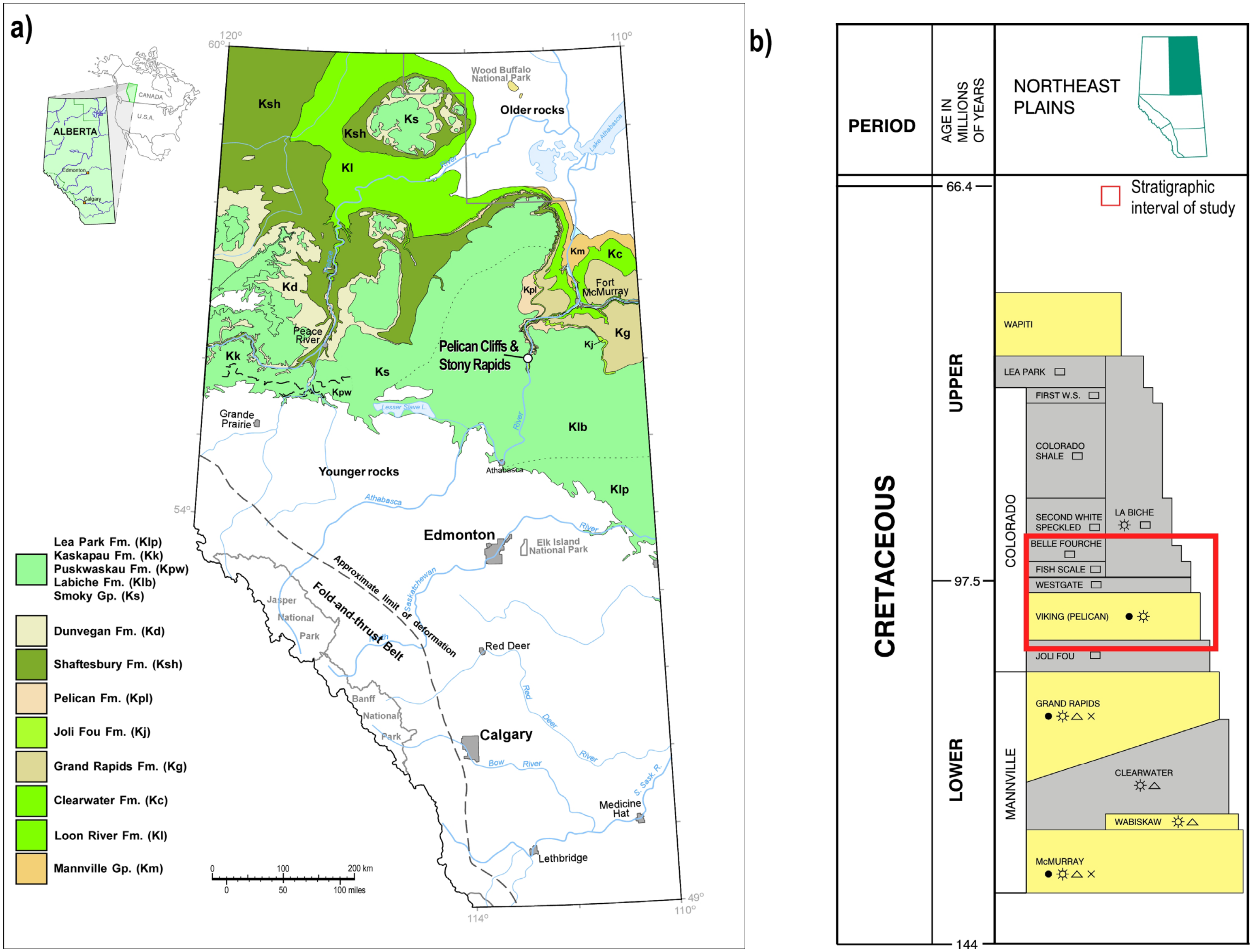

Figure 1. a) Simplified geological map (modified from Hamilton et al., 1998) of selected Cretaceous rocks in northern Alberta and the locations of measured sections T79-R17W4-01 (Stony Rapids) and T81-R17W4-01 (Pelican Cliffs). b) ERCB Table of Formations (2009) for the Cretaceous of northeastern Alberta.

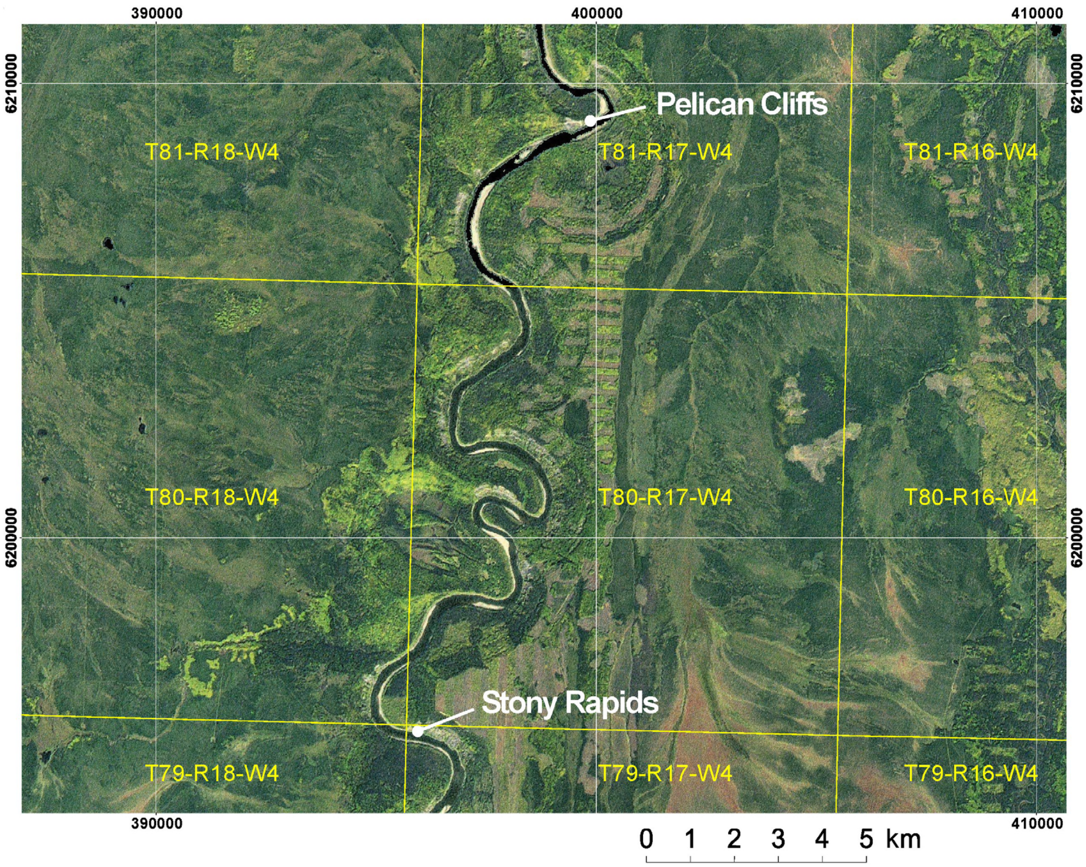

Figure 2. Location of measured sections on satellite image (UTM Zone 12, NAD83).

Figure 3. Line of section and outcrop exposure at the Pelican Cliffs section. Photograph taken from helicopter facing north.

Figure 4. Line of section and outcrop exposure at the Stony Rapids section. Photograph taken from helicopter facing north.

3 Lithological Description

3.1 Pelican Formation

The Pelican Formation is defined based on outcrop at the mouth of the Pelican River in Twp. 79, Rge. 17, W. 4th Mer. (abbreviated T79-R17W4), located 7 km south of the Stony Rapids section, in northeastern Alberta (Glass, 1990). McConnell (1893) was the first to use the term "Pelican," referring to the main sandstone body as the "Pelican sand" and used "Pelican shale" to describe the underlying mudstone. These units were later elevated to formation status as the Pelican Formation and the Joli Fou Formation, respectively (Wickenden, 1949). Exposure of the Pelican Formation is limited to northeastern Alberta, where it outcrops along both sides of the Athabasca River valley and around the eastern and northern margins of the Birch Mountains (Hamilton et al., 1998). The Pelican Formation interval on the Athabasca River is of Albian age and is thought to correlate with the Viking Formation present in the subsurface of central and southern Alberta (e.g., Reinson et al., 1994). Industry generally uses the term "Viking Formation" due to the formation's economic importance in the subsurface. As a result, it is more commonly used than Pelican Formation (Reinson et al., 1994).

The Viking Formation is defined in the subsurface of central Alberta (e.g., Reinson et al., 1994) and can be temporally correlated to the upper part of the Bow Island Formation in southern Alberta (Reinson et al., 1994; Pedersen and Schröder-Adams, 2002). In north-central Alberta, the Viking Formation has been correlated to the diachronous Paddy Member of the Peace River Formation (Reinson et al., 1994; Stelck et al., 2000). From hereon, when discussing this stratigraphic interval in the area of the measured sections, we refer to the Pelican Formation. We use the term Viking Formation when referring to subsurface occurrences farther south, where this term is in common usage.

The base of the Pelican Formation is not exposed in either of the two measured sections. The heavily vegetated and poorly exposed interval directly beneath the lowermost part of the exposed Pelican Formation is likely to represent the mudstone of the underlying Joli Fou Formation (Figure 3). The contact between the Joli Fou and Pelican Formations is generally thought to be gradational (Reinson et al., 1994).

The lower part of the Pelican Formation (0–10.5 m in the Pelican Cliffs section and 0–0.6 m in the Stony Rapids section; Figure 5 and Appendix 2) is characterized by a visually striking interbedding of dark grey mudstone with lenses or continuous beds of white, very fine to fine-grained sandstone (Figures 5 and 6, Appendix 2). Mudstone units typically have sulphur staining and interbedded sandstone units have iron-stained margins where in contact with mudstone. Interbedding between mudstone and sandstone lenses is particularly fine scaled (2 cm partings) in this basal interval (Figures 5 and 6). Sandstone units are thicker (up to 50 cm) in the upper part of the interval. Although these thicker sandstone beds commonly appear to be structureless (possibly due to weathering), bioturbation and ripple cross-lamination with flaser bedding (both simple and bifurcated) were observed in some units. At the Pelican Cliffs section, two coarsening and thickening-upwards cycles were noted.

We observed a pebble lag consisting of varicoloured, extraformational chert and intraformational sideritic clasts at 1.6 m in the Pelican Cliffs section. Sideritic concretions are absent or diffuse and poorly formed in the basal part of the Pelican Cliffs section but become more common and better defined in the sandstone beds upsection. Siderite-cemented horizons are common in the upper part of the Pelican Formation sandstone packages in both measured sections (8 m and 16.1–17.5 m at Pelican Cliffs; 5.7 m, 6.6 m and 7.8 m at Stony Rapids).

In both measured sections, the lower, interbedded mudstone and sandstone interval is overlain by a thick sandstone body (10.5–17.5 m at Pelican Cliffs; 0.6–8.35 m at Stony Rapids). At Pelican Cliffs, this thick sandstone is a well-exposed, cliff-forming unit (Figure 7). Throughout this unit, sedimentary structures are generally poorly defined due to weathering. The unit has a sharp and erosional undulose base and the lower part exhibits swaley cross-stratification (SCS), with sets up to 30 cm thick, and occasional wave ripples. Between rare, discontinuous siltstone-mudstone intervals, the sandstone (12.0–13.0 m) is bioturbated. Poorly defined SCS and hummocky cross-stratification (HCS) were observed in the upper half of the main sandstone, which grades into low-angle inclined bedding (although this may also be the inclined end of large-scale, low-angle SCS or HCS). Faint bitumen staining was observed on some surfaces, as was sulphur staining, which gives the unit a light yellowish weathering colour.

The main sandstone interval at Pelican Cliffs fines upwards and is overlain by a distinctive chocolate-coloured and siderite-cemented coarse to granular-grained sandstone unit (16.1 m; Figure 8). The sharp base of this unit is undulose and wave rippled, with pebbles (up to 3 cm across) of quartz, extraformational chert, and intraformational siderite randomly distributed throughout the lowermost 10 cm. Rock fragments are abundant throughout this cemented horizon. Concretions that appear more iron rich than the siderite cement have also formed in the upper part of this unit.

The main sandstone body in the Stony Rapids section (0.6–6.3 m) has a sharp, planar, horizontal base and is characterized by at least two well-defined, coarsening-upwards cycles. Flaser bedding is common throughout the sandstone (flasers are simple and 5–10 cm long). Occasional SCS (at the base of the sandstone body at 3.3 m) and asymmetrical wave ripples were observed. Intervals of bituminous and sulphur-stained shale up to 30 cm thick are intercalated with the main sandstone units at 3.0, 6.3 and 6.95 m. The top of the main sandstone body is siderite cemented. In contrast to the Pelican Cliffs section, the upper part of the Pelican Formation (6.25–8.35 m) in the Stony Rapids section consists largely of thinly interbedded (or lenticular) silty, very fine to fine-grained sandstone and dark laminated mudstone. This interval, which varies from sandstone to mudstone dominated, is overlain by a 70 cm thick unit of medium- to coarse-grained, siderite-cemented sandstone at the top of the Pelican Formation that shows flaser bedding commonly and SCS occasionally and contains sideritic concretions.

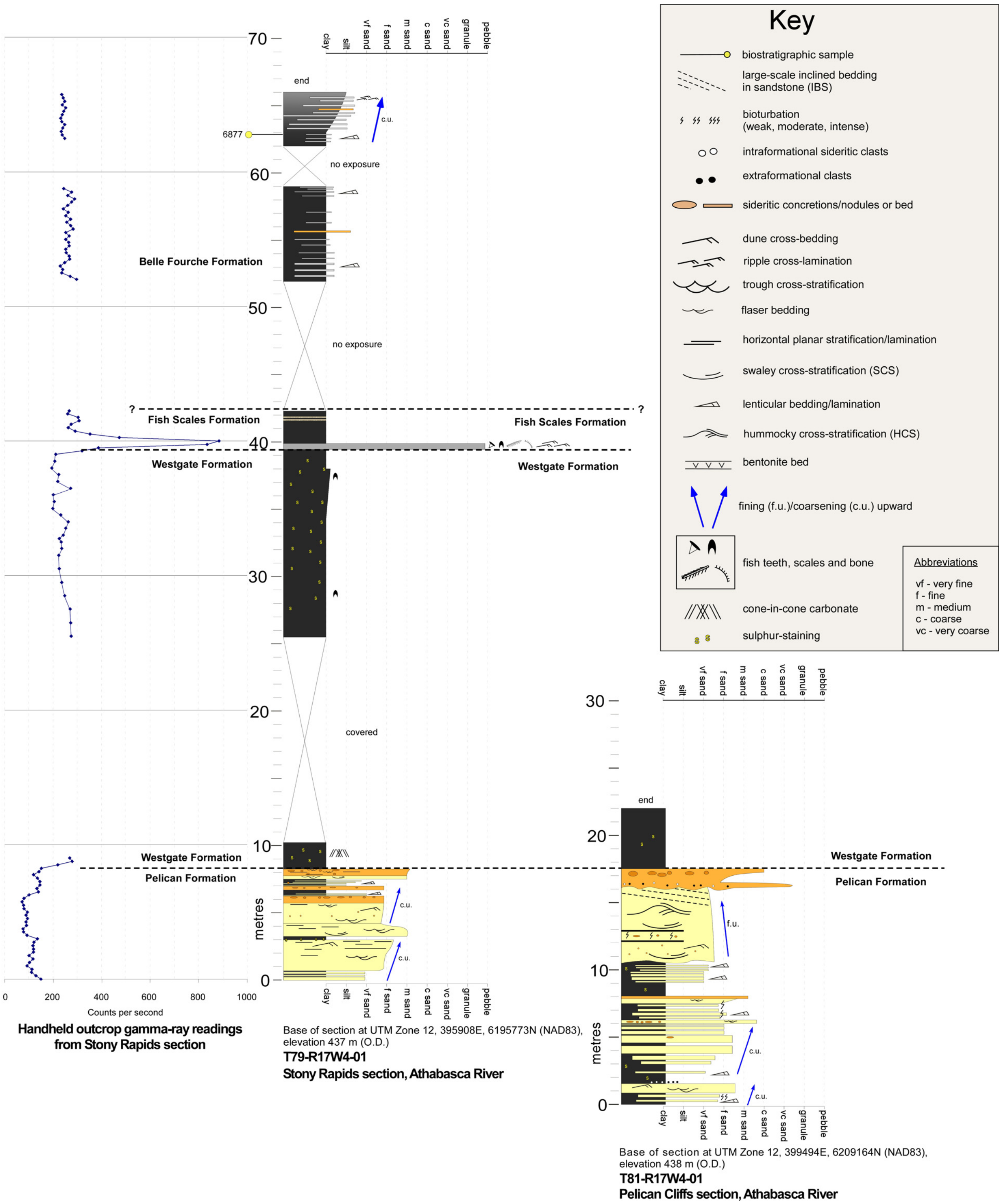

Figure 5. Graphic logs of measured sections at Stony Rapids and Pelican Cliffs with outcrop gamma-ray log for the Stony Rapids section. We measured the sections using an Abney level attached to a 1.6 m Jacob staff. See large-format version of logs in Appendix 2 for detailed unit descriptions.

Figure 6. Centimetre-scale interbedding of sandstone and shale within the basal part of the Pelican Formation at 3.8 m in the Pelican Cliffs section.

3.2 Westgate Formation

Bloch et al. (1993) formally defined the upper Albian Westgate Formation in southern Alberta, where it is thought to lie conformably on the Viking Formation (Caldwell and North, 1984; Caldwell et al., 1993). The Westgate Formation records a major transgression in the Western Canada Sedimentary Basin, which resulted in the flooding of the Mowry seaway (Stritch and Schröder-Adams, 1999).

The Westgate Formation (8.35–39.2 m in the Stony Rapids section; 17.5 m to the top of the section at Pelican Cliffs) overlies the Pelican Formation with a horizontal, planar, and sharp contact. It consists of dark grey to black, organic-rich, non-calcareous, finely laminated mudstone that has a blocky fracture on weathered surfaces. The lower part of the Westgate Formation (10.1–26.2 m) is not exposed at Stony Rapids, and from 26.2 to 32.7 m the unit is poorly exposed due to slumping. Sulphur staining is common, particularly along fractures, and becomes more pronounced upsection at Stony Rapids. Cone-in-cone calcite structures were also observed. Fish scales are rare but present. A subtle siltier-upwards cycle is noted in the Stony Rapids section from 34.25 to 38.1 m.

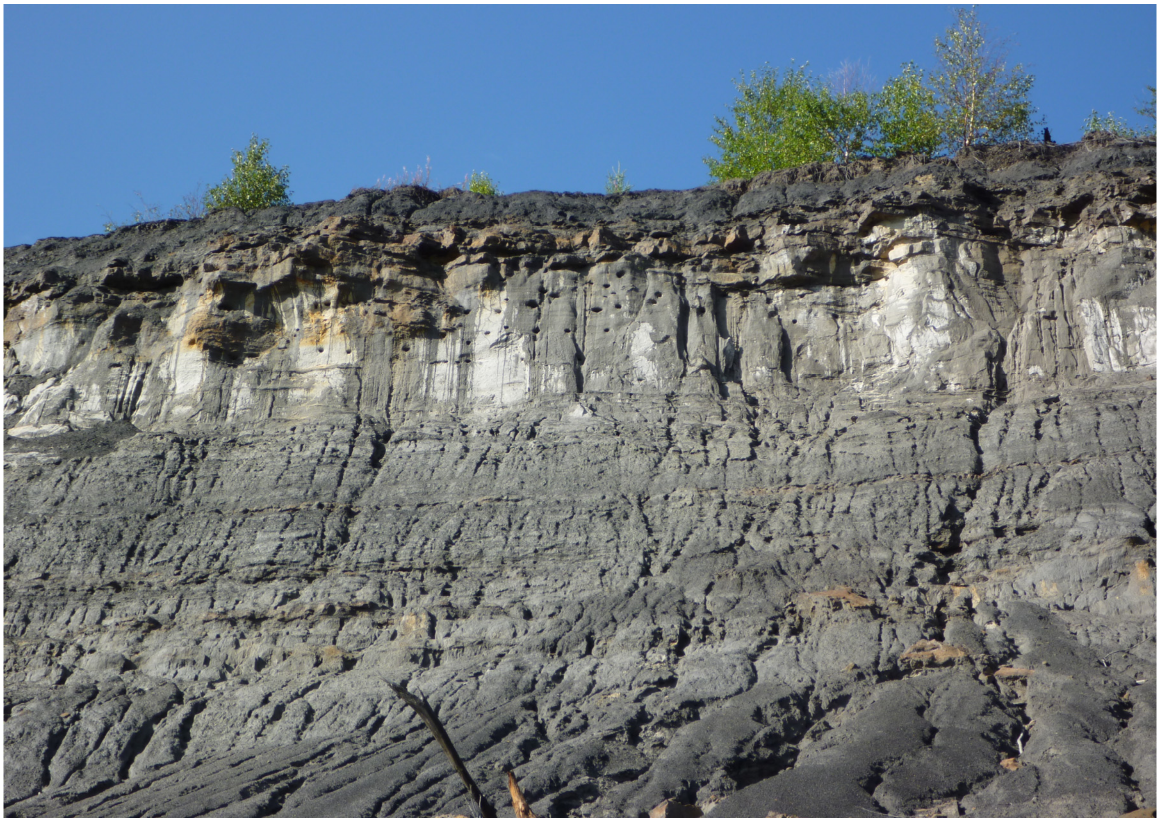

Figure 7. Cliff-forming main sandstone body of the Pelican Formation, Pelican Cliffs. Above the main pale sandstone is an iron-stained, siderite-cemented conglomerate overlain by dark shale of the Westgate Formation. Photo taken looking north from UTM 399557E, 6209187N, Zone 12, NAD83. Base to top of cliff is approximately 20 m.

Figure 8. Chocolate-coloured and iron-stained siderite-cemented gravel above the main Pelican Formation sandstone body at 16.1 m in the Pelican Cliffs section. Arrows point to flattened and elongated black chert pebbles up to 3 cm long randomly oriented throughout the gravel.

3.3 Fish Scales Formation

The Fish Scales zone (and the Base of Fish Scales radioactive marker) has long been recognized in the mid-Cretaceous shales of the Western Canada Sedimentary Basin (e.g., Reinson et al., 1994). This interval was assigned formation status within the Colorado Group by Bloch et al. (1993). The Fish Scales Formation is stratigraphically equivalent to strata in the middle part of the Shaftesbury Formation of the Fort St. John Group in northwestern Alberta (e.g., Stelck, 1958; Roca et al., 2008) and to the Barons Sandstone in southern Alberta (Chetin, 1960; Putnam and Oliver, 1984; Leckie et al., 2000). The base of the Fish Scales Formation is thought to mark the Albian–Cenomanian boundary (Stelck, 1958; Leckie et al., 1992; Leckie et al., 2000). An unconformity may exist between the Westgate and Fish Scales formations (Stelck, 1958; Caldwell et al., 1978; Leckie et al., 1992; Leckie et al., 2000; Roca et al., 2008).

At 39.4 m in the Stony Rapids section, the base of the Fish Scales Formation is marked by a sharp-based, light grey weathering, indurated and cemented 10–12 cm thick bed of fragmented fish teeth, bones, and scales with 10% shaly siltstone laminae that define faint dune cross-bedding (Figure 9). This bioclastic bed is a striking and important marker in the outcrop (Figure 10) for dividing the shales of the lower Colorado Group. Furthermore, its geophysical response is a regionally significant marker in the subsurface across Alberta (e.g., Leckie et al., 1992; Bloch et al., 1993; Leckie et al., 1994; Walker, 1995). However, we note that the base of the Fish Scales Formation is not always marked by a bone bed. For example, the base of the Fish Scales Formation in the section measured by Leckie et al. (1992) near Peace River (see also Leckie et al., 2000) is marked by “30 cm of wave-rippled, coarse-grained sandstone overlain by an 8 cm thick bone bed.”

Figure 9. Bioclastic bed (resistant unit above scale card) that marks the base of the Fish Scales Formation. View north from 396007E, 6195848N, UTM Zone 12, NAD83.

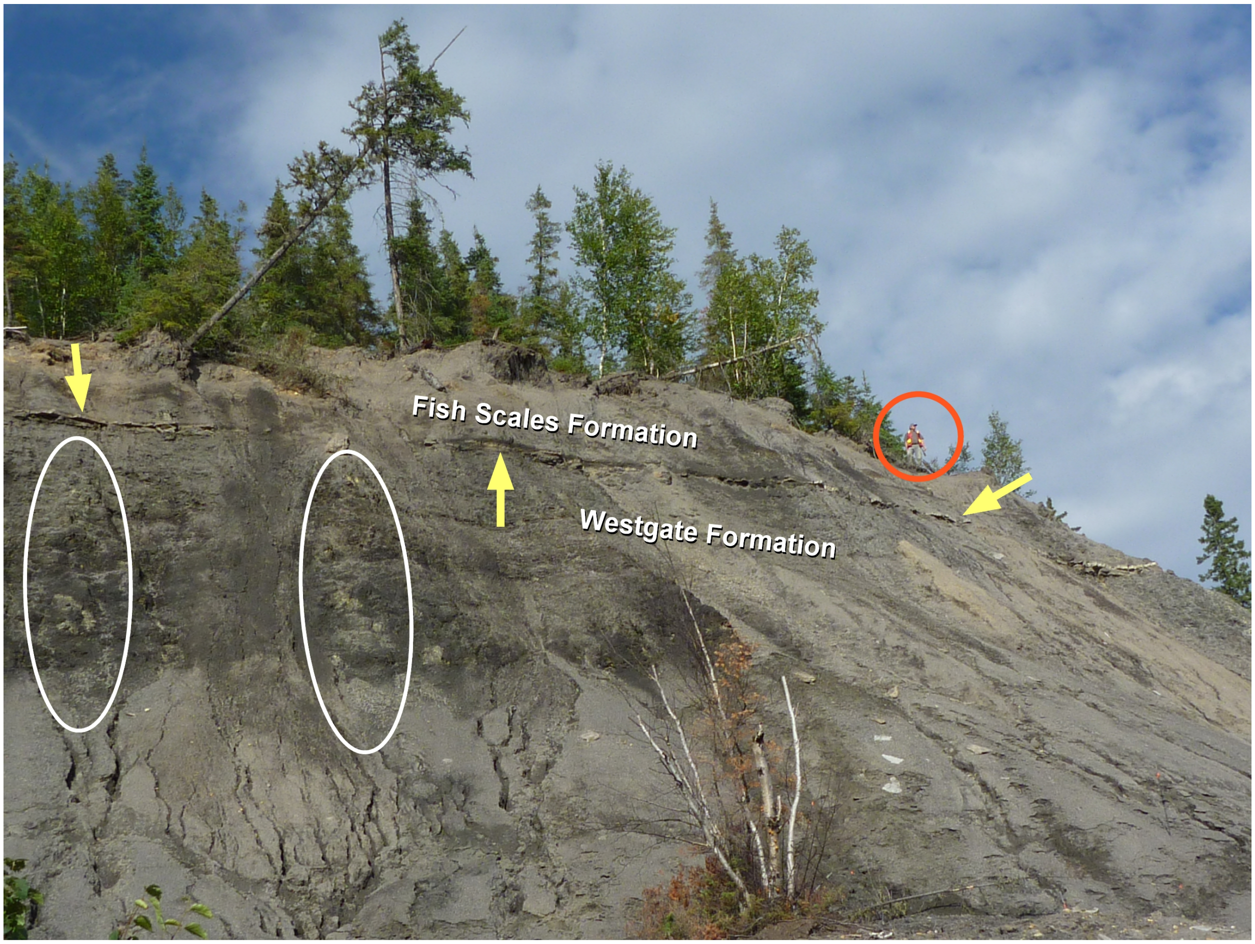

Figure 10. View of the sulphur-stained (white circles) Westgate Formation and the 10 cm thick prominent bioclastic bone bed (yellow arrows) that marks the base of the Fish Scales Formation. Red circle shows person for scale. View north from 395908E, 6195773N, UTM Zone 12, NAD83.

Two 1–2 cm thick, pale cream bentonite units with iron staining are present within the Fish Scales Formation (at 41.6 and 41.9 m at Stony Rapids). The mudstone immediately above the bioclastic bed is similar to that of the underlying Westgate Formation, with a blocky weathering fracture pattern, but generally lacks sulphur staining. Other than the very rare fish scales and bones observed just beneath the bentonite units, fish debris is absent from the mudstone of the Fish Scales Formation. Above the lowermost bentonite in the Fish Scales Formation, the mudstone matrix is slightly to moderately bentonitic.

See Section 4.3 for discussion on where we place the contact between the Belle Fourche and Fish Scales formations.

3.4 Belle Fourche Formation

The Belle Fourche Formation is conformable with the underlying Fish Scales Formation in southern and central Alberta (Schröder-Adams et al., 1996) and has a gradational lower contact in northern Alberta (Leckie et al., 1992; Leckie et al., 2000).

In the measured section at Stony Rapids, the lowermost significant (defined as >50 cm thick) exposure of the Belle Fourche Formation is at 52.0 m. It consists of dark grey shale, with thin, discontinuous, light grey siltstone lenses, ranging from 1 to 5 mm thick, which show internal planar lamination. Some thicker siltstone intervals are normally graded. The siltstones become thicker, coarser and more continuous through the upper part of the Stony Rapids section (63.05 m to top). Some ripple cross-lamination was also observed in the uppermost siltstone. Sample 6877, which we collected for biostratigraphic analysis (Appendix 3 – Biostratigraphy), confirms that this interval is part of the Belle Fourche Formation.

4 Gamma-Ray Data

Figure 5 and the following text summarize the gamma-ray data collected from the Stony Rapids section.

4.1 Pelican Formation

Overall, the main Pelican Formation sandstone intervals have a relatively low gamma-ray response. The stratigraphically lowest significant sandstone body (0–3 m) has slightly higher gamma-ray counts than the middle sandstone body (3–6 m). Gamma-ray counts for the middle sandstone reflect grain size distribution, and the curve has an overall box shape. Interbedded shale and sandstone units have a predictably higher gamma-ray count, and where thicker sandstone intervals are present, the gamma-ray count is lower.

4.2 Westgate Formation

The base of the Westgate Formation is marked by a pronounced increase in measured gamma radiation, which defines it in the subsurface on gamma-ray logs, and is mappable across much of Alberta (Bloch et al., 1993; Leckie et al., 1994). The outcrop gamma-ray curve suggests a subtle upwards grain size coarsening in the upper part of the Westgate Formation, starting near 27 m. We also observed a slight coarsening-upwards trend (to 38 m) during outcrop logging.

4.3 Fish Scales Formation

Very high gamma-ray counts correlate with the bioclastic unit at 39.5 m, which defines the base of the Fish Scales Formation. This highly radioactive unit is an important regional stratigraphic marker in the subsurface across much of Alberta (Bloch et al., 1993; Leckie et al., 1994). A modest increase in gamma-ray counts correlates with the bentonite beds near the top of the Fish Scales Formation. The Fish Scales Formation has many of the attributes of a condensed section, such as being relatively thin, containing multiple bentonites and having low sedimentation rates, as indicated by the bioclastic layer (Schröder-Adams et al., 1996; Leckie et al., 2000). Due to the condensed nature of the Fish Scales Formation, it is reasonable to consider that the two bentonite beds at Stony Rapids should be included within the Fish Scales Formation. In nearby geophysical downhole well logs (e.g., 00/09-02-081-18W4/0, 00/10-19-079-18W4/0), the Fish Scales Formation is characterized by a variable gamma-ray response, from an isolated high spike (correlating to the bioclastic bone bed) to multiple spikes. The gamma-ray spike at the base of the Fish Scales Formation also correlates with a modest increase in resistivity that gradually decreases upwards. In well logs, we pick the top of the Fish Scales Formation at the top of a series of gamma-ray spikes and where there is a subtle low notch in the resistivity log.

The subsurface thickness of the Fish Scales Formation in the surrounding area is approximately 2.5 m. Therefore, in outcrop, the boundary with the overlying Belle Fourche Formation can be placed either immediately above the bentonite beds, or slightly higher, within the unexposed part of the section.

4.4 Belle Fourche Formation

The exposed section of the Belle Fourche Formation, composed of mudstone, has a moderate to high gamma-ray count, similar to the Westgate Formation. There is a gradual upwards decrease in gamma-ray counts that correlates with the coarsening-upwards cycle observed near the top of the measured section.

5 Summary

This report extends the lithostratigraphic subdivisions of the Colorado Group used in southern and east-central Alberta, consisting of the Westgate, Fish Scales, and Belle Fourche formations (Bloch et al., 1993; Stancliffe and McIntyre, 2001; Tu et al., 2007), into the Athabasca River area of northeastern Alberta.

This report also provides, through the measured sections at Stony Rapids and Pelican Cliffs, tight constraints on geological contacts that contribute towards updating the 1:1 000 000-scale provincial bedrock geological map of Alberta.

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Appendix 1 – GPS Location Data

We obtained GPS location data for the Stony Rapids and Pelican Cliffs measured sections (NTS 83P/15 and NTS 84A/02) using Garmin® GPSMAP® 60CSx handheld units. The UTM coordinates are Zone 12, NAD83. The ± values indicate estimates of horizontal error generated by the GPS units.

Easting	Northing	Horizontal Error (±)	Elevation (m)	Comment
399494	6209164	3.8	438	Base of Pelican Cliffs section (0.0 m)
399557	6209187	3.4	460	Top of Pelican Cliffs section (22.0)
395908	6195773	1.0	437	Base of Stony Rapids section (0.0 m)
395908	6195773		447	10.0 m up Stony Rapids section (top of first subsection before lateral shift)
396007	6195848	4.0	466	32.0 m up Stony Rapids section (second subsection)
396007	6195848	1.4	476	41.6 m up Stony Rapids section (near top of second subsection before lateral shift)
395956	6195947	1.3	486	53.0 m up Stony Rapids section (1 m above base of third subsection)

Appendix 2 – Large-Format Version of Figure 5 Graphic Logs with Descriptions


Key
biostratigraphic sample
large-scale inclined bedding in sandstone (IBS)
bioturbation (weak, moderate, intense)
intraformational sideritic clasts
extraformational clasts
sideritic concretions/nodules or bed
dune cross-bedding
ripple cross-lamination
trough cross-stratification
flaser bedding
horizontal planar stratification/lamination
swaley cross-stratification (SCS)
lenticular bedding/lamination
hummocky cross-stratification (HCS)
bentonite bed
fining (f.u.)/coarsening (c.u.) upward
fish teeth, scales and bone
cone-in-cone carbonate
sulphur-staining
Abbreviations
vf - very fine
f - fine
m - medium
c - coarse
vc - very coarse
clay
s lt
vf sand
f sand
m sand
c sand
vc sand
granule
pebble
end
mudstone becomes more silty upwards with more laterally persistent siltstone ribs that coarsen to silty v.f. sandstone up to 1-2 cm thick, 2-5 cm spacing
c.u.
6877
blocky, dark grey mudstone with siltstone ribs spaced 5 cm apart and typically 3-5 mm thick but exceptionally 10 mm; iron-stain weathering
no exposure
dark grey mudstone with light grey siltstone; siltstone typically 1-5 mm thick with planar lamination and occasional normal-graded bedding
Belle Fourche Formation
no exposure
?
?
Fish Scales Formation
1-2 cm thick pale cream bentonites with iron staining; shale above is slightly to moderately bentonitic
light grey, indurated, cemented 10-12 cm thick bioclastic band of fragmented fish debris; minor mudstone defines dune cross-lamination
Westgate Formation
dark grey, blocky, sulphur-stained finely laminated mudstone; occasional fish scales
covered
dark grey, organic-rich, blocky, sulphur-stained finely laminated mudstone
Westgate Formation
Pelican Formation
m. grained sandstone with flaser bedding, occasional SCS, distinct sulphur-staining; siderite cemented top with iron-rich siderite concretions <7 cm across
dark mudstone interbedded with silty, v.f. grained sandstone with parallel laminated bands 2-5cm thick and flattened lenses
siderite-cemented f. grained sandstone with Fe-rich sideritic concretions 5 cm across
occasional SCS with flasers and mudstone bands, that are increasingly common upward.
deformed mudstone clasts 10-15 cm across; 0.5-1 cm concretions and associated iron staining; rare wave cross-bedding
intervening bituminous- and sulphur-stained mudstone
blonde to white, v.f. to f. grained, poorly cemented sandstone with bifurcated and simple flasers and mudstone bands; sandstone is massive at base
very clay-rich dark grey mudstone with iron and sulphur staining and faint parallel lamination, interbedded with 5-20 cm thick, poorly cemented, pale to light grey, silty, v.f. grained sandstone beds.
metres
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
Counts per second
Handheld outcrop gamma-ray readings from Stony Rapids section
Base of section at UTM Zone 12, 395908E, 6195773N (NAD83), elevation 437 m (O.D.)
T79-R17W4-01
Stony Rapids section, Athabasca River
30
20
10
0
end
dark grey finely laminated mudstone with sulphur staining
Westgate Formation
Pelican Formation
indurated f. to c. grained sandstone with basal granular sandstone containing chert and sideritic pebbles up to 3 cm across and crude horizontal bedding
slight fining up into low-angle inclined bedding
SCS and HCS with sets up to 30 cm high and occasional mudstone drapes
cliff-forming v.f. to f. grained sandstone, pale to sulphur stained in colour
rare silty/mud intervals are weakly bioturbated
undulose base with 2 cm relief
f.u.
finely interbedded (2-5 cm spacing) sulphur-stained black mudstone with pale white sandstone lenses
siderite-cemented sandstone top weathers blonde to buff colour
black, organic-rich mudstone with sulphur staining interbedded with continuous pale white sand or isolated lenses that may exhibit weak bioturbation
c.u.
<3 cm wide intraformational sideritic and varicoloured extraformational chert pebble lag
poorly cemented blonde to pale v.f. to f.grained litharenite with well-rounded quartz grains moderately bioturbated lenticular sandstone into sharp-based sandstone with simple flasers bedding (5 cm long) and occasional assymetric dune cross-bedding (15 cm high).
metres
Base of section at UTM Zone 12, 399494E, 6209164N (NAD83), elevation 438 m (O.D.)
T81-R17W4-01
Pelican Cliffs section, Athabasca River

Appendix 3 – Biostratigraphy

Sample 6877 was collected from a mudstone at 62.8 m in the Stony Rapids section for biostratigraphic analysis. We sent splits from the sample to D. McNeil (Geological Survey of Canada, Calgary, Alberta) for foraminiferal analysis and to G. Dolby & Associates Ltd. (Calgary, Alberta) for palynological study. McNeil (2010) and Dolby (2010) provide details of sample preparation and analytical methodology used. Results are detailed below.

Palynology

Formation: Belle Fourche
Age: Cenomanian

Remarks: The dinocyst fraction is dominated by extremely abundant specimens of *Alterbidinium daveyi*. Although *Alterbidinium daveyi* can be a rare component of upper Westgate samples, such an abundance of specimens is characteristic of the Belle Fourche. There are rare specimens of *Chichaouadinium vestitum*, *Ginginodinium evittii* and *Luxadinium propatulum*, all of which extend into the lower part of the formation where they occur sporadically in very small numbers. Singh (1983) described *Leptodinium modicum* from the Upper Shaftesbury, but its extent has not been determined.
Significant species:
Alterbidinium daveyi (extremely abundant), *Ginginodinium evittii* (rare), *Luxadinium propatulum* (extremely rare), *Chichaouadinium vestitum* (rare), *Circulodinium vannophorum, Cribroperidinium exilicristatum, Leptodinium modicum, Wallodinium lunum, Odontochitina operculate, O. singhii*

Foraminifera

Age: indeterminate
Significant species:
Prasinophyta (algal cysts)
Lancettopsis sp. – 2; *Leiosphaeridia* sp. (small, thick walled) – 4; *Tasmanites* sp. – 1.

Appendix 4 – Outcrop Gamma-Ray Methodology

Gamma-ray values, in counts per second, were measured on the section at nominal vertical intervals of 0.25 m using a handheld RS-230 spectrometer. Total counts were measured over a counting time of five seconds. Commonly, three five-second readings were obtained, with a minimum of five seconds between readings, and the median used for plotting the gamma-ray curve. Each measurement was obtained by placing the face of the RS-230 (near the detector) directly against the outcrop at the measurement location. Measurement locations were chosen to be as planar as possible over areas of about 0.5 m in diameter. If necessary, loose material was scraped away to expose the outcrop before the gamma-ray data were collected.

RS-230 Specifications

Manufacturer: Radiation Solutions Inc. (Mississauga, Ontario)
Model: RS-230
Detector: bismuth germanate (BGO)
Detector Size: 103 cm^3 (6.3 cu inch) volume
Stabilization: internal (fully automatic)
Mode: survey (total count)
Count-Rate Measurement: counts per second
Energy Response: 30–3000 keV
Internal Sampling Rate: 20 per second
Sample Time: moving average of five readings of one second each
Channels: 1024