SPE 13

A Comprehensive Field Guide for Facies Characterization of the Athabasca Oil Sands, Northeast Alberta

Alberta Energy and Utilities Board

Alberta Geological Survey

Special Report 13

A Comprehensive Field Guide for Facies Characterization of the Athabasca Oil Sands, Northeast Alberta

(with maps, air photos, and detailed descriptions of seventy-eight outcrop sections)

Frances J. Hein, C. Willem Langenberg, Campbell Kidston,
Habtemicael Berhane, and Tim Berezniuk
Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 - 98th Avenue
Edmonton, Alberta
Canada T6B 2X3

Darrell K. Cotterill, Parallax Resources Limited, Spruce Grove, Alberta

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Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 - 98th Avenue
Edmonton, Alberta
Canada T6B 2X3

Telephone: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca

Website: www.ags.gov.ab.ca

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Contents

Overview

The present study was initiated May 1, 1997, and was designed to do regional facies work on the Athabasca oil sands deposit of northeast Alberta, focusing on outcrops as well as selected subsurface core studies of the McMurray Formation. The aim of this project was to characterize the oil sands of the Athabasca deposit at a facies scale-of-resolution that would be used as a basis for ongoing regional assessment of the oil sands deposit. This study was very successful in combining detailed outcrop and subsurface results that lead to the development of three facies models for the McMurray succession, and represents an important step forward in our understanding of the Athabasca oil sands deposit.

This report is intended to be a comprehensive catalogue of selected major outcrops that were measured during regional facies work on the McMurray Formation, and serves as a compilation of the fieldwork over four seasons (1997-2000) in the Athabasca River drainage area. Emphasis of the present study was on the geologic setting, sedimentology and facies analysis of the oil sands deposits, and included detailed work on 78 outcrop sections, about 150 cores, and over 6000 regional geophysical well-log picks. All of the outcrop sections occur along the Athabasca-Clearwater river drainage networks. In conjunction with this regional facies work, detailed palynological and biostratigraphic analyses were completed, mainly in the Steepbank River area and along the southern margin of the Bitumount Basin (Dolby, 1998, 2000, 2001). Other in-depth work included outcrop-geophysical log correlation and synthetic seismic modeling of outcrops in the Steepbank River, with comparisons with subsurface seismic results in the Clarke Creek area (Hein *et al*., 2001; Langenberg *et al*., 1999, 2001).

The present special report compliments two earth science reports. The first earth science report contains an overview of the exploration and historical development of the Fort McMurray area, with emphasis on development of the oil sands industry in Alberta (Hein, 2000a). The second earth science report, an atlas of lithofacies of the McMurray Formation, includes a comprehensive facies classification that incorporates both outcrop and subsurface examples (Hein *et al*., 2000). We hope that these publications will aid other workers dealing with the complex issues concerning development of the vast Athabasca oil sands deposits, and will serve as valuable sources of information for government, industry and general public stakeholders.

1.0 Introduction

Four major oil sands deposits occur in northern Alberta – the Athabasca, Wabasca, Cold Lake and Peace River (Figure 1). These deposits account for 40% of the world's resources of bitumen, with total reserves of bitumen estimated at more than 1.7 trillion barrels (Masson and Remillard, 1995). In 1995, 1996 and 1997 drilling and production from the oil sands reached record levels for bitumen and synthetic crude oil in Alberta (AEUB, 1998). In 1999 synthetic crude oil production from crude bitumen production in the surface mineable area of the Athabasca deposit was 18.8 million cubic metres, including 13.1 million cubic metres from the Syncrude mine and 5.7 million cubic metres from the Suncor project (AEUB, 2000).

Figure 1: Location map of the Athabasca, Cold Lake, Peace River and Wabasca oil sands deposits.

In 2000, the EUB estimated the ultimate volume of crude bitumen in place in Alberta to be about 400 billion cubic metres, of which about 24 billion cubic metres may be recoverable by surface mining. The remainder of the ultimate volume of crude bitumen in place occurs in areas with thick overburden; and these deposits would have to be extracted by in situ thermal recovery or underground mining. New calculations by the EUB are thought to more realistically reflect the ultimate recovery potential of crude bitumen. This new estimate results in the total initial ultimate potential amount of crude bitumen recoverable at about 49 billion cubic metres, for both surface mineable and non-mineable areas (AEUB, 2000).

Oil sand development (and other non-conventional energy resources, such as coal bed methane, CBM, solar- or wind-energy) is expected to grow in the next century. Synthetic crude oil production from the oil sands has filled the gap left by the declining conventional oil reserves. For example, by comparison, in 1998 total conventional oil and natural gas liquids that was produced in Alberta was about 119 million cubic metres, with natural gas production at 137 billion cubic metres. By the year 2005 it is estimated that about half of Canadian crude oil production (including both bitumen and synthetic crude oil products) would be from the oil sands (Oil Sands Developers of Alberta, 1988). As of December 2000, there are 20 announced projects by industry in the oil sands of northeast Alberta, the bulk of which (9 projects) are in the Athabasca deposit (Stringham, 2000). Since 1998, industry has invested $9 billion Canadian in the oil sands of northeast Alberta, with another $34 billion Canadian announced in new or expanded oil sands projects (Williamson and Lee, 2000). Of these new or expanded projects, in situ bitumen recovery projects proposed or under construction account for >$4.5 billion Canadian (Brunka, 2000).

Such rapid expansion of non-conventional fuel exploration in the oil sands area has not been without problems. Since 1978 (Mellon, 1978), bitumen rights have been separated from other mineral rights, such as shallow gas in overlying reservoirs, and there have been disputes between the bitumen-rights owners and the gas producers in the same development/lease area. These technical problems regarding co-production of Steam Assisted Gravity Drainage (SAGD) processes for in situ bitumen extraction in the same areas as gas production from reservoirs in the McMurray/Wabiskaw interval relate, in general, to engineering, hydrogeological and environmental issues (Alberta Energy and Utilities Board, 2000; Barson et al., 2001; Bachu and Stein, 1996). In the EUB 2000-22 decision report, dealing with shut-in of gas in the Surmont area, part of the Board’s assessment relied on possible influences of interbedded mudstone (as lateral accretion cross-beds, intraclast breccias, or mud-plug vertical accretion abandonment fills) on SAGD processes. To date, there has been little “ground truthing” of such subsurface facies in the Athabasca oil sands that can be tied directly to observed sedimentary features in outcrop (cf. Hein et al., 2000, among others). Part of the rationale for the present report is to get detailed descriptions of measured outcrops of the Athabasca deposit into the public domain, so that industry, government and the general public can use this information in their assessment of present and future technologies in the development of the vast Athabasca oil sands deposit.

2.0 Previous Work

An historical overview of the discovery and development of the Athabasca Oil Sands is given in Carrigy and Kramers (1973). Updates are presented in Strom (1986), Houlihan and Evans (1988), Wightman *et al.* (1992), Mink and Houlihan (1995), Polikar *et al.* (1998), Sadler and Houlihan (1998), with a summary given in Hein (2000a). A number of field guides have been written about the geology of the Fort McMurray area, with emphasis on the oil sands (Carrigy, 1959; Carrigy and Kramers, 1973; Kramers, 1973; Hein 2000b; Mossop *et al.*, 1982; Stewart and MacCallum, 1978; Wightman and Pemberton, 1997; Wightman *et al*., 1992). Selected applications of outcrop analogues to detailed subsurface reservoir characterization have been done at the Dover River Project (UTF-site) by Strobl *et al.* (1997a, b) and in the Steepbank area by Flach (1977, 1984) and Langenberg *et al.* (1999, 2001a). The present work represents an updated field guide to the oil sands of the Fort McMurray area that incorporates a unified lithofacies scheme (Appendix 2) and a revised stratigraphy of the McMurray Formation (Hein *et al.*, 2000).

3.0 Stratigraphy

The stratigraphic section preserved in outcrop in the Fort McMurray area includes the uppermost portions of the Devonian Christina and Moberly Members of the Waterways Formation (Beaverhill Lake Group) and the overlying Lower Cretaceous McMurray Formation and Wabiskaw Member of the Clearwater Formation (Mannville Group) (Figure 2).

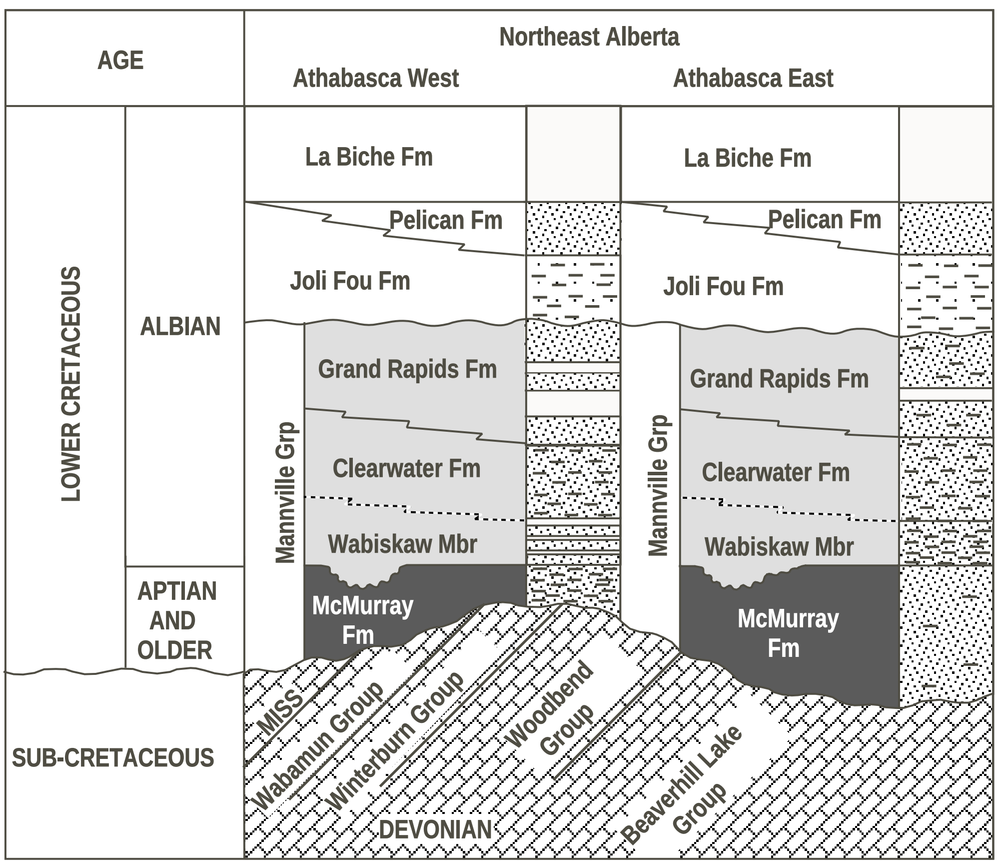


Figure 2. Schematic cross section, Fort McMurray area (modified from Wightman, et. al., 1995 and 1997).

Selected outcrop sections included in this study lie along the Athabasca River valley and its associated tributaries, mainly to the west and north of Fort McMurray (Figure 3). The unconformable contact between the Devonian and Cretaceous successions locally has significant relief (from 5 m to >130 m) (Figures 4 to 7), a result of profound differential weathering of the variably argillaceous carbonate units, combined with tectonic collapse caused by dissolution of underlying Devonian Elk Point Group evaporates. In the Fort McMurray area, positive structural elements along the sub-Cretaceous unconformity surface include the Grosmont High and the Beaverhill Lake High. Negative structural elements are the Bitumont Basin and the associated regional linear depression, called the Prairie Salt Scarp, that trends roughly parallel to the strike of the sub-cropping Devonian units and slightly oblique to the present-day valley of the Athabasca River (Figures 3, 4). Collapse of the carbonate units, after regional dissolution of the underlying salts, resulted in small-scale folding and faulting in areas proximal to the dissolution front. Karstification along the sub-Cretaceous unconformity created numerous sinkholes and other paleokarst features. The highly variable structural and erosional relief on the sub-Cretaceous unconformity greatly influenced sediment dispersal patterns and facies architecture of the overlying McMurray Formation and the Wabiskaw Member of the Clearwater Formation (Figures 4 to 9).

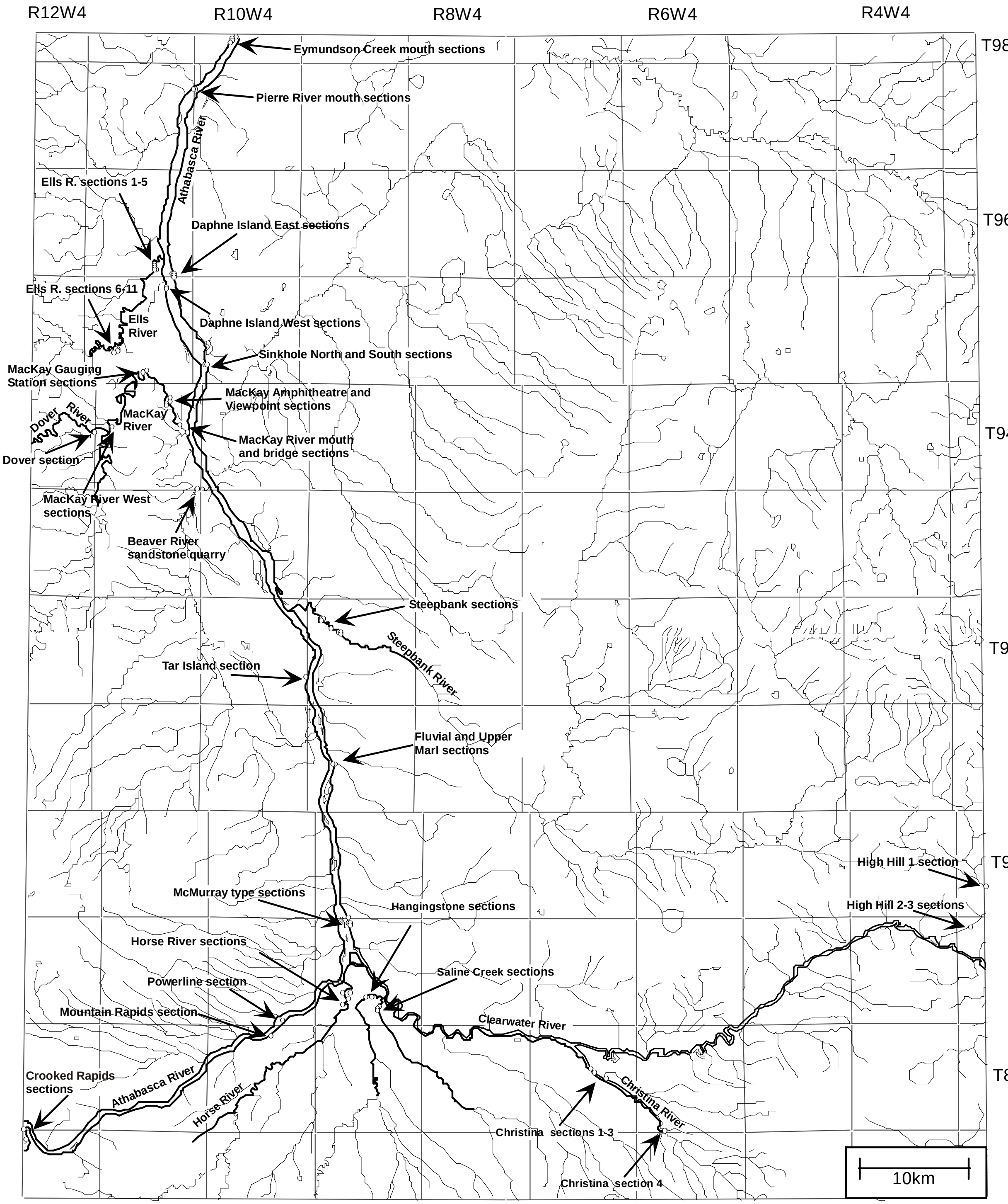


Figure 3. Map showing distribution of major outcrop sections of the McMurray Formation along the drainage system of the Athabasca and Clearwater rivers, from Township 87 - 98 and Range 3 West of the 4th Meridian to Range 12 West of the 4th Meridian. Horizontal scale bar is 10 km.

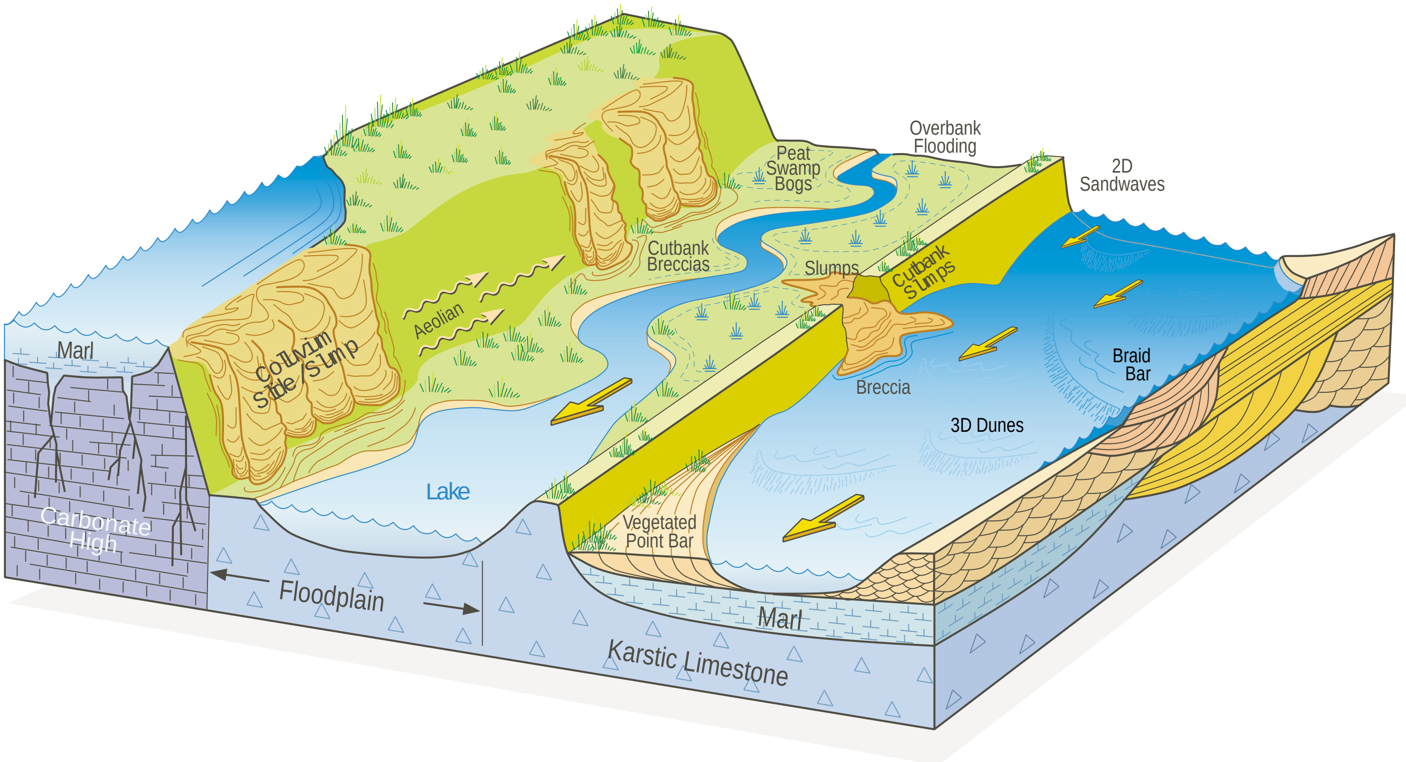


Figure 4. Schematic facies model for the Lower McMurray Formation, Athabasca deposit, northeast Alberta (modified from Hein et al., 2000).

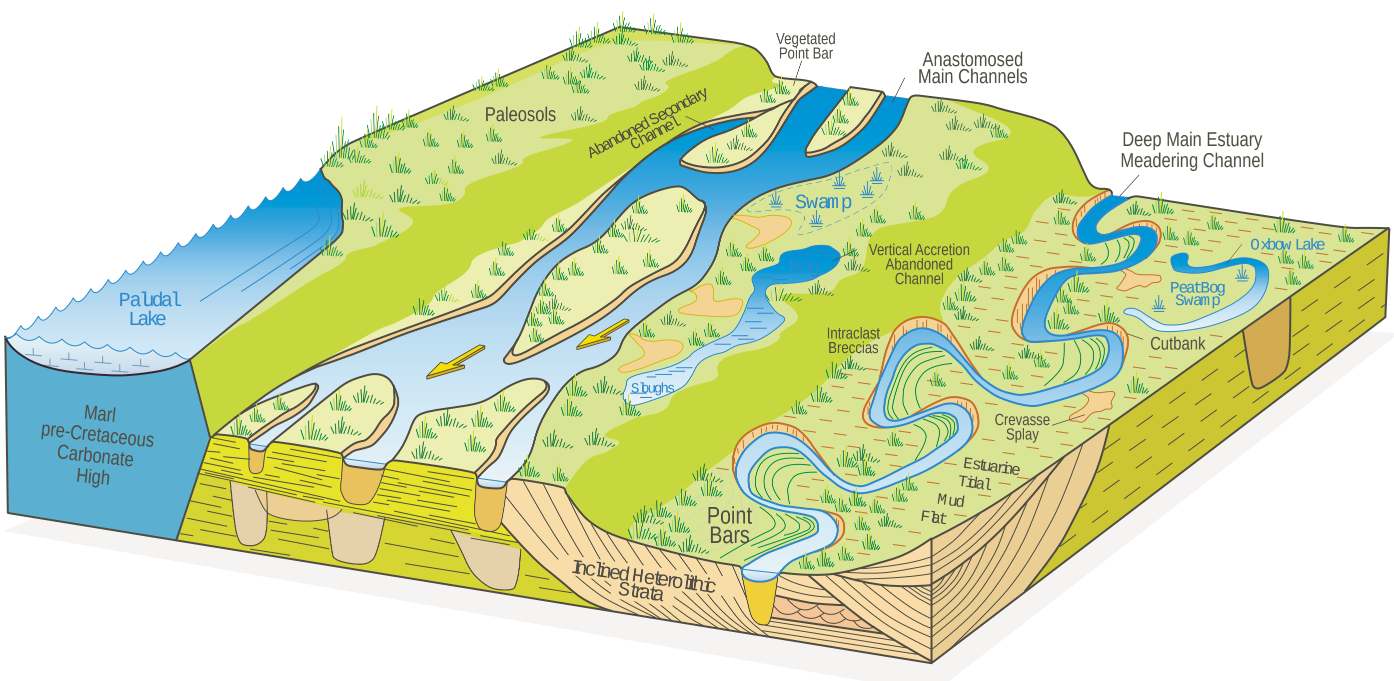


Figure 5. Schematic facies model for the lower part of the Upper McMurray Formation, Athabasca deposit, northeast Alberta (modified from Hein et al., 2000).

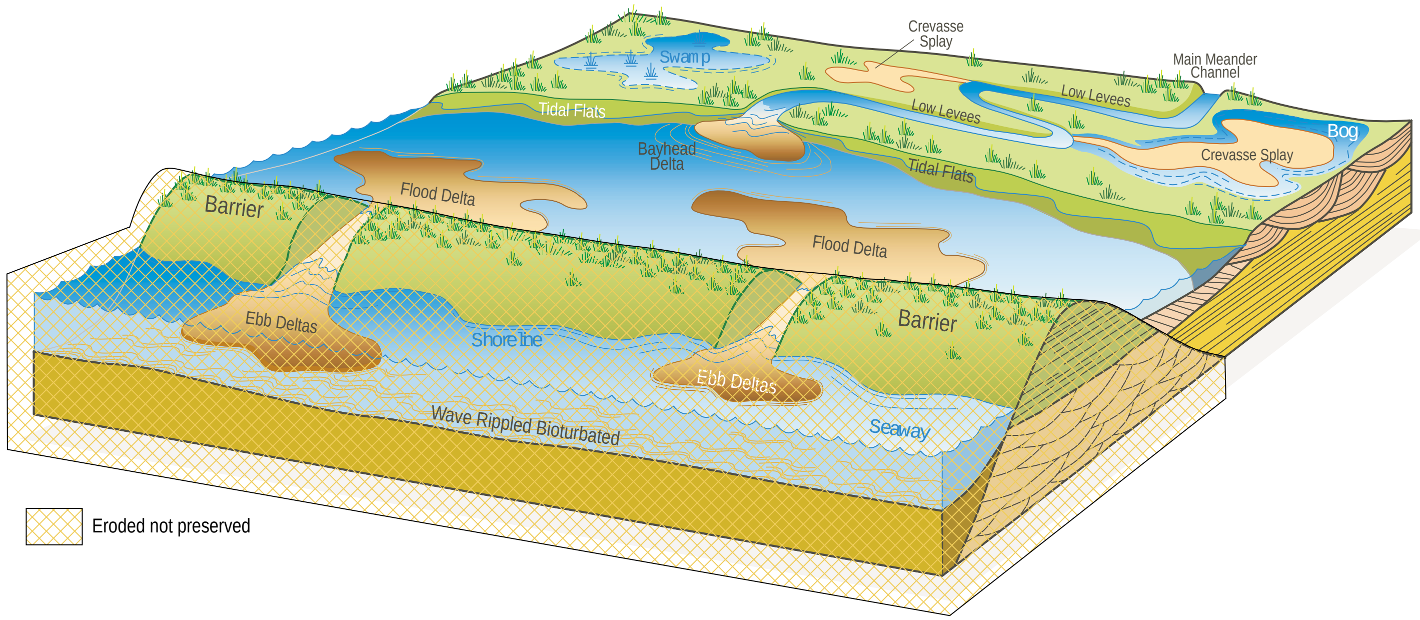


Figure 6. Schematic facies model for the upper part of the Upper McMurray Formation, Athabasca deposit, northeast Alberta (modified from Hein et al., 2000).

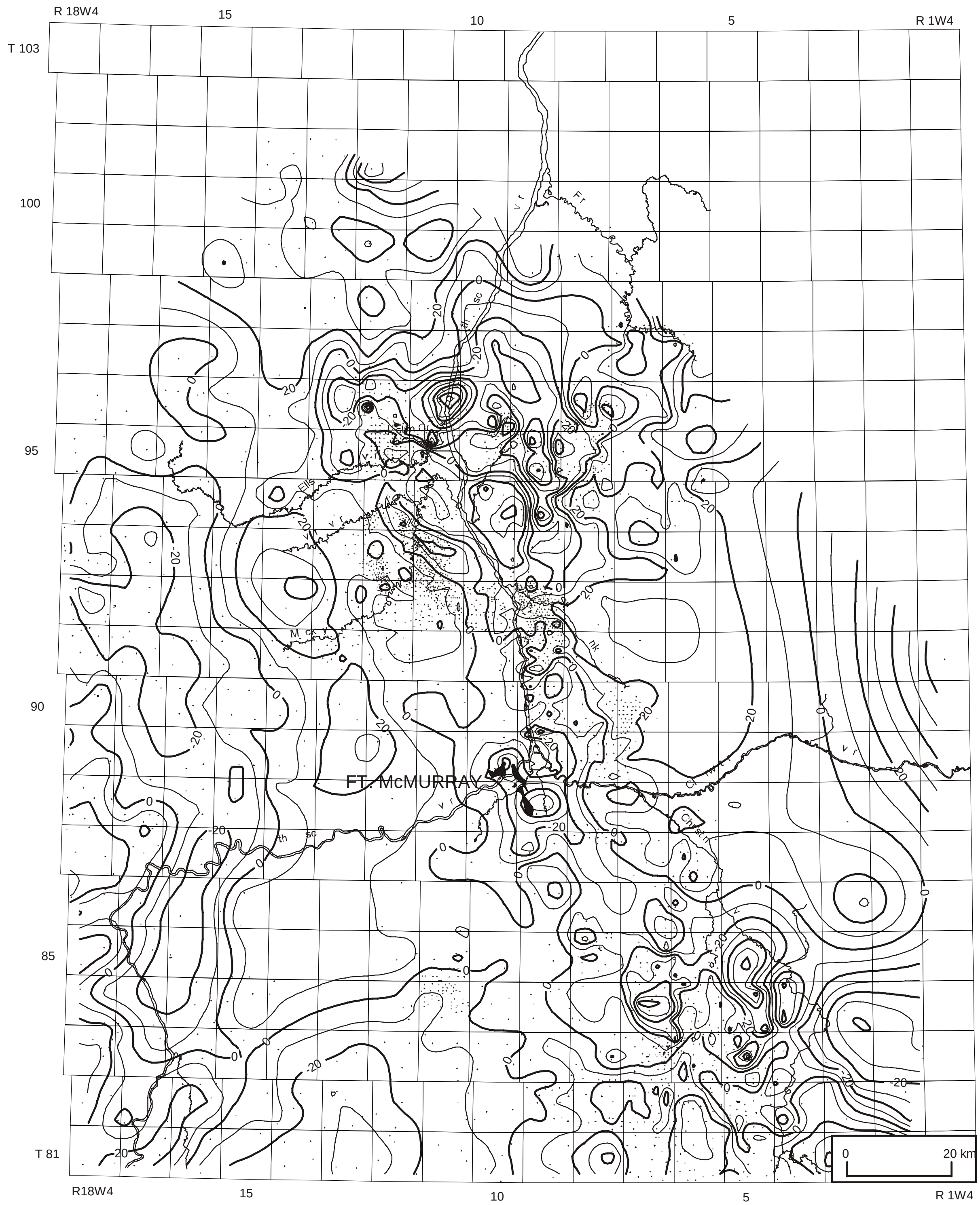


Figure 7. Topography of the sub-Cretaceous unconformity as shown by a third-order residual map on the unconformity surface from Township 81-103 and Range 1 West of the 4th Meridian to Range 18 West of the 4th Meridian. Horizontal scale bar is 20 kilometres. (modified from Hein et al., 2000).

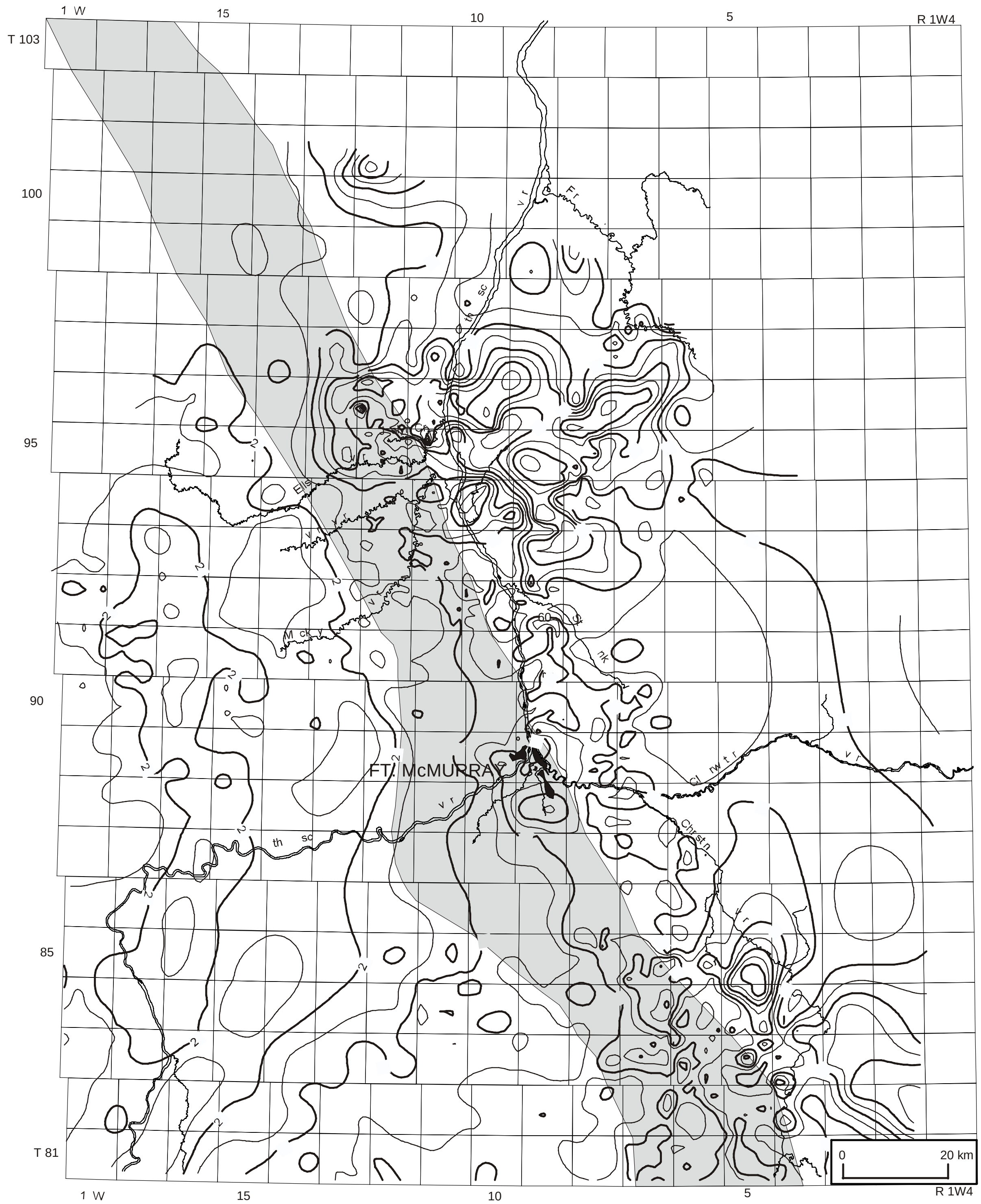


Figure 8. Isopach map of the McMurray Formation with the salt scarp shown in shaded area, from Township 81-103 and Range 1 West of the 4th Meridian to Range 18 West of the 4th Meridian. Contour interval is 10 m. Horizontal scale bar is 20 km. (modified from Hein et al., 2000).

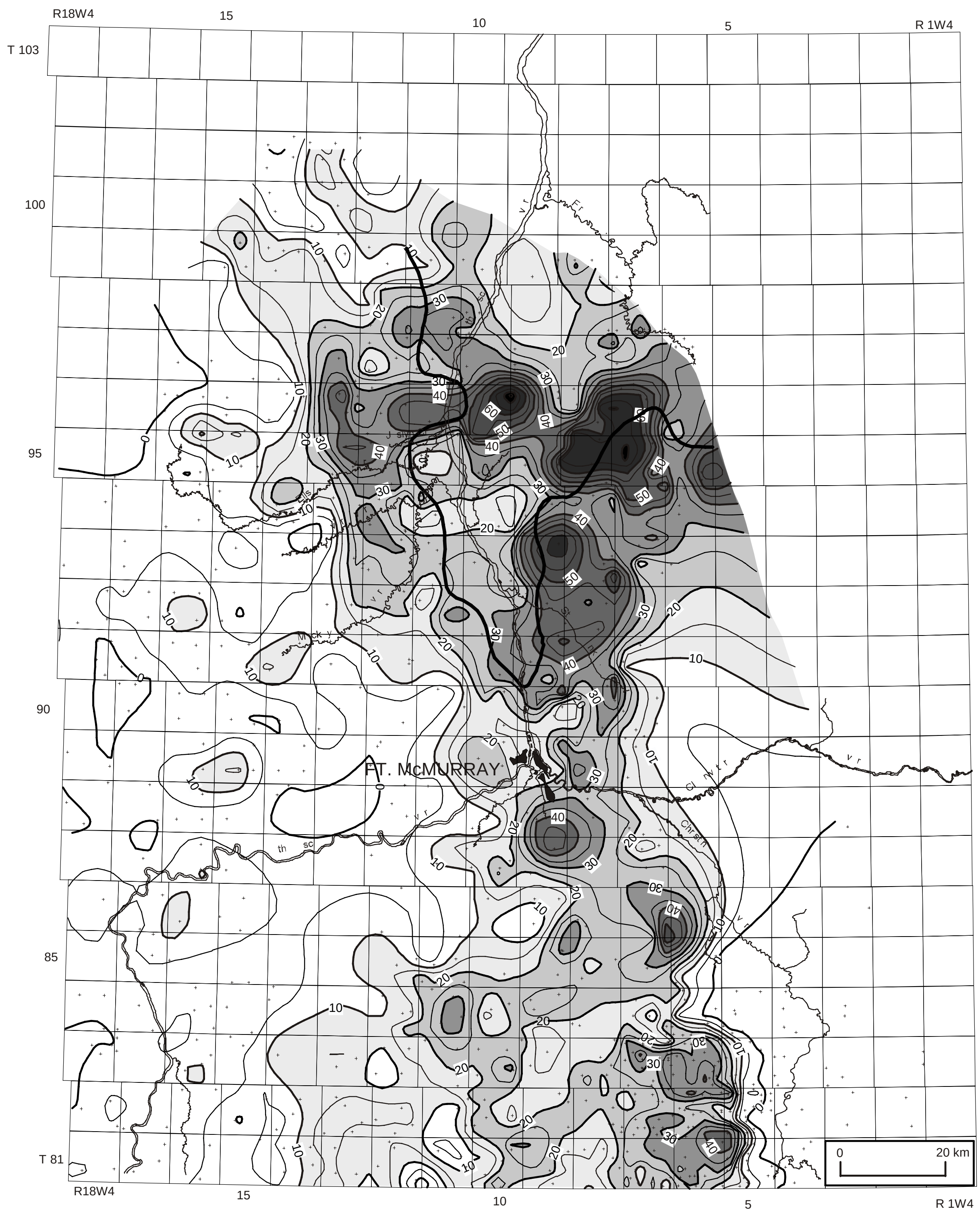


Figure 9. Isopach of the McMurray Formation with shading indicating areas with greater than six mass percent bitumen, from Township 81-103, Range 1 West of the 4th Meridian to Range 18 West of the 4th Meridian. Contour interval is 5 m. Horizontal scale bar is 20 km. Pleistocene erosional edge shown by the bold line in the upper right corner of the map. (modified from Hein et al., 2000).

4.0 McMurray Formation and Reservoirs

The McMurray Formation is the lowermost siliciclastic unit within the Lower Cretaceous Mannville Group in northeast Alberta (Cant and Abrahamson, 1996). The succession is bounded unconformably at the base and the top, and has internal disconformities, locally disrupting the McMurray succession. The basal sub-Cretaceous unconformity, as previously mentioned, has significant relief, and had a profound effect on sediment distribution and depositional facies patterns within the McMurray Formation. The top of the McMurray Formation has been removed by post-Cretaceous erosion. The youngest of these valley incision events occurred during the Quaternary Period, with some meltwater channels incising over 100 m into the underlying Cretaceous bedrock (Andriashek, 2000).

The McMurray Formation was deposited on an exposed karstic landscape of ridges and valleys and varies in thickness from being absent over Devonian highs to over 130 m thick in the Bitumont Basin. There is an increase in complexity of facies associations as assigned to the Lower and Upper McMurray Formation, concomitant with an increase in facies heterogeneity and interpreted lack of stability in the location of facies tracts. Bitumen-sand reservoirs accumulated as incised paleovalley-fills cut within the karstic pre-Cretaceous landscape and are within the Lower McMurray fluvial-dominated lowstand deposits (Figure 4). Reservoirs occur mainly within braided channel-and-bar sands. Local water sands occur in paleolows along the basal sub-Cretaceous unconformity, and may pose problems for in situ thermal production of the oil sands (The most common, at present, being used in pilot schemes is Steam-Assisted Gravity Drainage, or ‘ SAGD.’).

Bitumen-rich reservoirs formed within estuarine valleys stacked above the Lower McMurray channel sands and are assigned to the Upper McMurray Formation. These bitumen-sand reservoirs occur mainly within stacked estuarine-tidal channel-and-point bar complexes (Figure 5). Local water-sands occur in the lower parts of the Upper McMurray, whereas in the upper parts somewhat more continuous gas and water reservoirs are relatively common. Bitumen-, water- and gas-reservoirs formed within an estuarine complex and associated prograding coastal plain (Figures 5, 6). Sediments of the coastal plain proper in off-channel sites generally do not form thick enough accumulation of porous sands for significant hydrocarbon reservoirs; however, in off-channel sites such as splays, thicker and more porous sands may serve as local gas reservoirs.

The McMurray Formation is notorious for having very complex sedimentary facies relationships that change both laterally and vertically over very short distances. This marked facies heterogeneity within the McMurray Formation is partly a reflection of multiple transgressive-regressive cycles of erosion and deposition that left a fragmentary preserved stratigraphy, particularly in areas to the south where there was little accommodation space during sedimentation. The highly variable topography on the basal unconformity combined, to a lesser degree, with the upper erosional surface (Wabiskaw/McMurray contact) greatly influences the thickness of bitumen sands within the McMurray Formation (Figures 7-10). A north-south thickening trend in the McMurray Formation correlates with location of a salt dissolution zone running generally north-northwest from Ranges 1W4 Meridian to 8W4 Meridian, Townships 72 to 90 (Figures 8, 9). North of Fort MacKay the thickening of the McMurray succession also has an added east-west component from Range 7W4 Meridian to 13W4 Meridian, within Townships 94 to 96. This trend corresponds to an axial trend of the Bitumont Basin (Figures 7, 10).

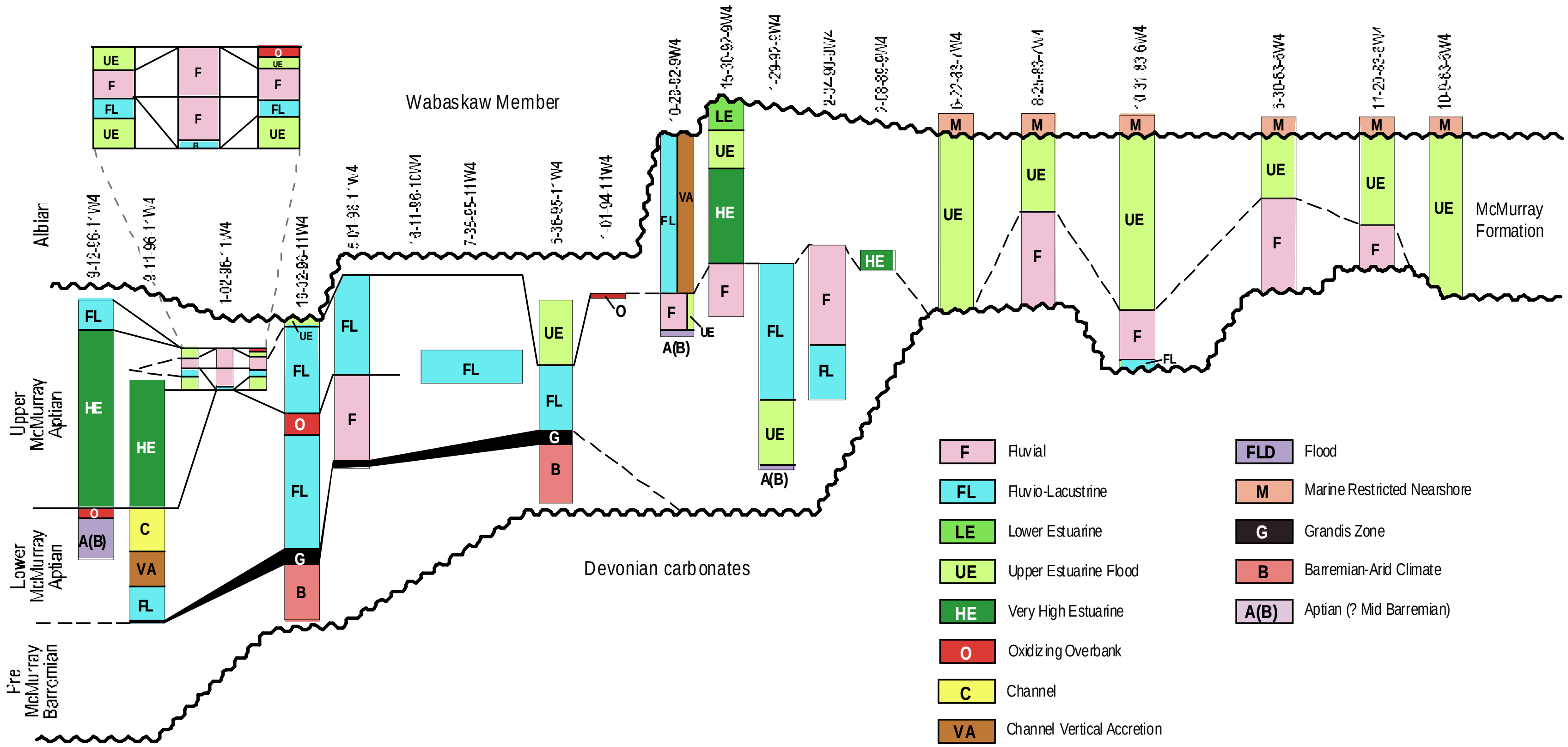


Figure 10. Schematic regional north-south section of the McMurray formation showing rapid thinning of the Formation, concomitant with a rapid reduction in accomodation space.

5.0 Methodology

In the present study detailed sedimentological and stratigraphic analysis was done on 78 outcrops of the McMurray Formation in the Athabasca River drainage near Fort McMurray (Appendix 1). In selecting appropriate outcrops to study, attention was given to accessibility, the condition of the outcrop exposure (i.e. largely slumped or covered or well-exposed and intact), and regional spacing with respect to observed facies trends. A unified facies classification was used to describe units on a bed-by-bed basis. This facies scheme is given in Hein *et al*. (2000) (Appendix 2). After logging the sections in the field, detailed results of the outcrop analysis were input into the Applecore graphics and database program, compatible with the MacIntosh PC system (v. 0.7.3e, copyright M. Ranger, Chestermere Lake, AB) (Appendix 3). More general results of the logging phases were then input into Canvas for Windows (IBM PC system), and used as one-page text figures in the following report. Due to difficulties in exporting detailed Applecore logs as raster images into Canvas, some of the detail becomes abbreviated on the raster images. Consequently, full printouts of the detailed Applecore logs are given in Appendix 3.

In terms of organization of the field guide, site descriptions are grouped according to general access and location, where sites with road access around Fort MacKay and Fort McMurray are described separately from those sections that can be only accessed by helicopter, zodiac, canoe or jetboat. Sections are described for the following separate areas: Fort MacKay (6.0), Ells River (7.0), Fort McMurray area (8.0), Athabasca River (9.0), Steepbank River (10.0), Christina River (11.0), Dover River (12.0), and High Hill River (13.0). Each major grouping of outcrops can be considered a separate and complete entity. In some areas the measured sections are similar to one another, and are described under one heading (for example the Saline Creek Sections in 8.1). In other areas there is significant variation between outcrops such that more detailed section measuring was required to capture the facies variation. Consequently, in these cases, sections are described separately (for example the Horse River Sections in 8.3.1 to 8.3.4).

For each general area, there is a topographic map and aerial photograph, with minor text describing general location and access. Site locations are designated by easting and northing using the Universal Transverse Mercator (UTM) system, where all coordinates are located in Zone 12 (Appendix 1). In cases where the outcrops are more widely dispersed, individual UTM designations are given for the individual sections, under the section descriptions. General area descriptions are under headings 6.0 through 13.0, with topographic maps given first (Figures 6.0.1 to 13.0.1), followed by annotated aerial photographs (Figures 6.0.2 to 13.0.2). Next each measured section is described with keynote things to see, followed by a detailed description and interpretation. Next is a summarized, one-page, stratigraphic log (Figures 6.1.1 to 13.1.1) and representative outcrop photos (Figures 6.1.2 to 13.1.2a, b, c, etc.) The reason for this type of organization and numbering is that each section is internally consistent and can be used separately in the field, depending upon where one wants to go. The present guide, as such, is much too bulky for fieldwork, and is meant to be a compendium that can be abstracted for site-specific use.

Note: Of local interest, there are a series of ATV- and cross-country trail maps available from the public information gate at the southern entrance to Fort McMurray (i.e. just north of the turnoff to the Oil Sands Interpretive Centre).

6.0 Fort MacKay Outcrops

Map Coordinates: 74 E/4 Fort MacKay, UTM 459900E, 6338820N (for the MacKay Amphitheatre Section #2, about midway location for the MacKay River outcrops that were measured).

General Location and Outcrop Selection: Along the MacKay River air photo interpretation identified 68 cutbank sections that have exposed outcrops. However, most of these sections are not easily accessible except those at the downstream end of the river near Fort MacKay. The others have to be accessed by 4x4 ATV's along dirt trails into the MacKay River valley from the Dover River Project (Alberta Oil Sands Technology and Research Authority Underground Test Facility, AOSTRA - UTF) site, or by boat upstream from the settlement of Fort MacKay, depending upon river level. Access to the outcrops around Fort MacKay is via roadways, trails and creek/river courses.

Eleven outcrop sections in the Fort MacKay area are described, including the: MacKay River Amphitheatre #1 and #2 sections, MacKay River Viewpoint Section, MacKay River Gauging Station #1 and #2 sections, MacKay River Karst-Fill #1 to #3 sections, MacKay River West Section, the Beaver River Sandstone Quarry Section, MacKay River near Bridge Section, and the MacKay River Upstream of Mouth Section (Figures 6.0.1 and 6.0.2).

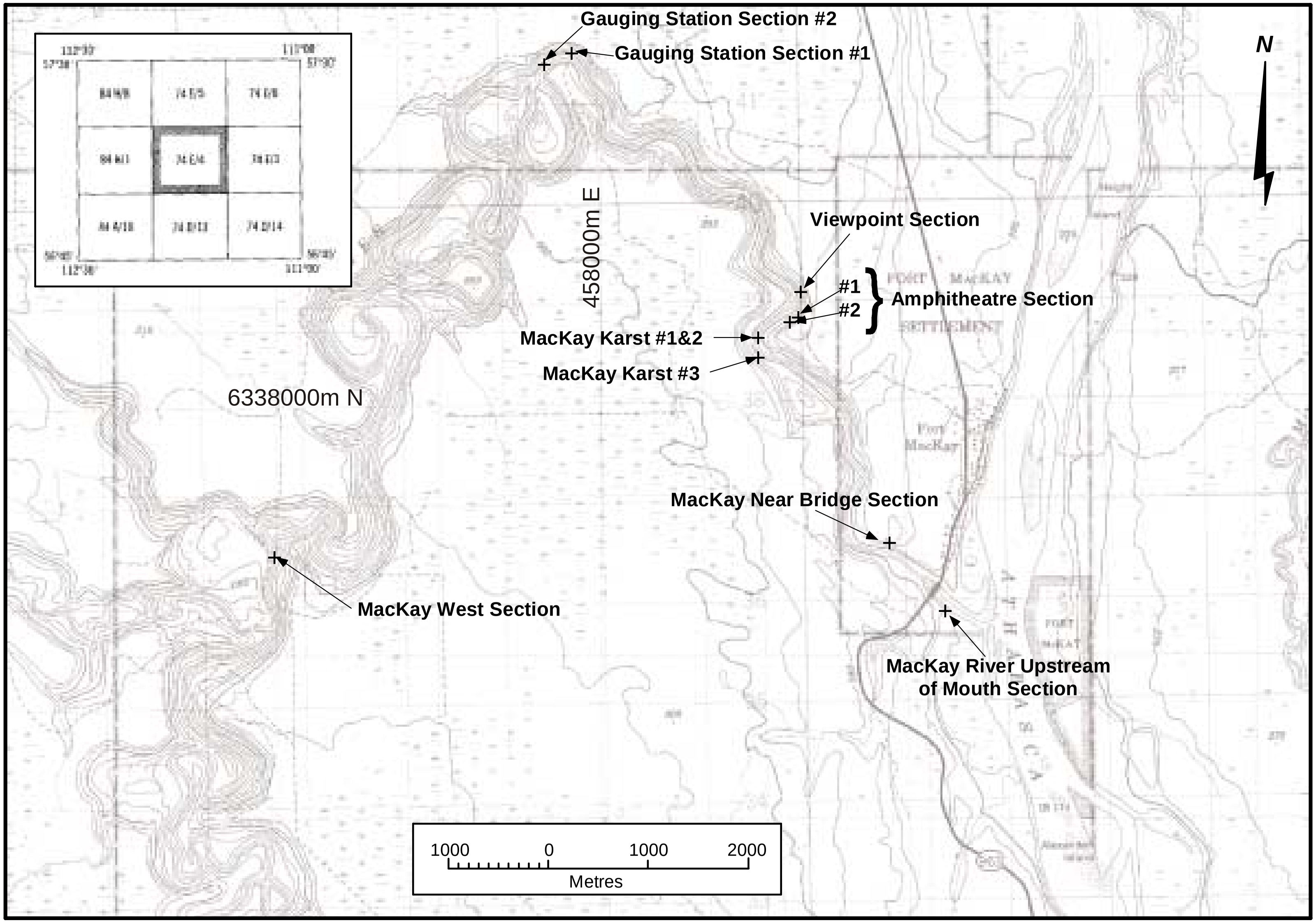


Figure 6.0.1. Map showing access to the MacKay River outcrops near the Fort MacKay First Nations Settlement.

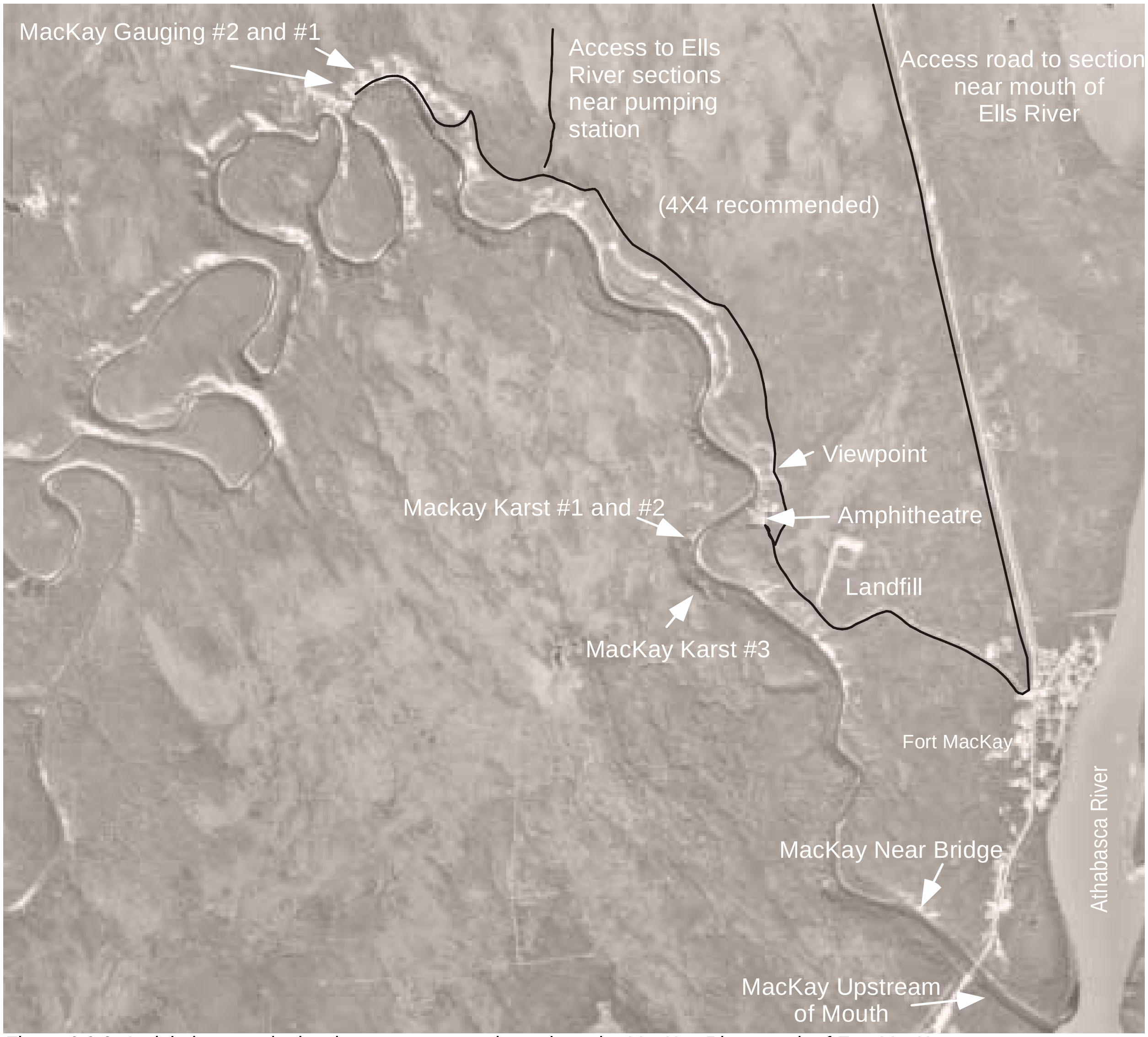


Figure 6.0.2. Aerial photograph showing access to sections along the MacKay River, north of Fort MacKay.

6.1 MacKay River Amphitheatre Sections

Map Coordinates: 74E/4 Fort MacKay, UTM 459900E, 6338820N (Section #2)

Location and Access: Drive north of Fort McMurray on Highway 63. Turn northwest (left) from Highway 63 onto the Fort MacKay access road (963 on Figure 6.0.1), marked by a road sign, just north of the highway bridge over the Beaver River. Continue on the access road to Fort MacKay, going through town to the north end where there is a fork in the road. Turn left and drive along the dirt road until you reach a fork (the right fork goes to the landfill dump). Take the left fork along the MacKay River. Stop approximately 0.5 – 0.75 km from the fork to the dump (Figures 6.0.1 and 6.0.2). Access trail to the west and walk for 2 minutes to the cutbank overview of the section at the end of the trail. Easier access down to the base of the outcrop is to the south (left) down a prominent spur that marks the downstream end of the main Amphitheatre outcrop. Note: only drive when roads are dry.

Keynote things to see:

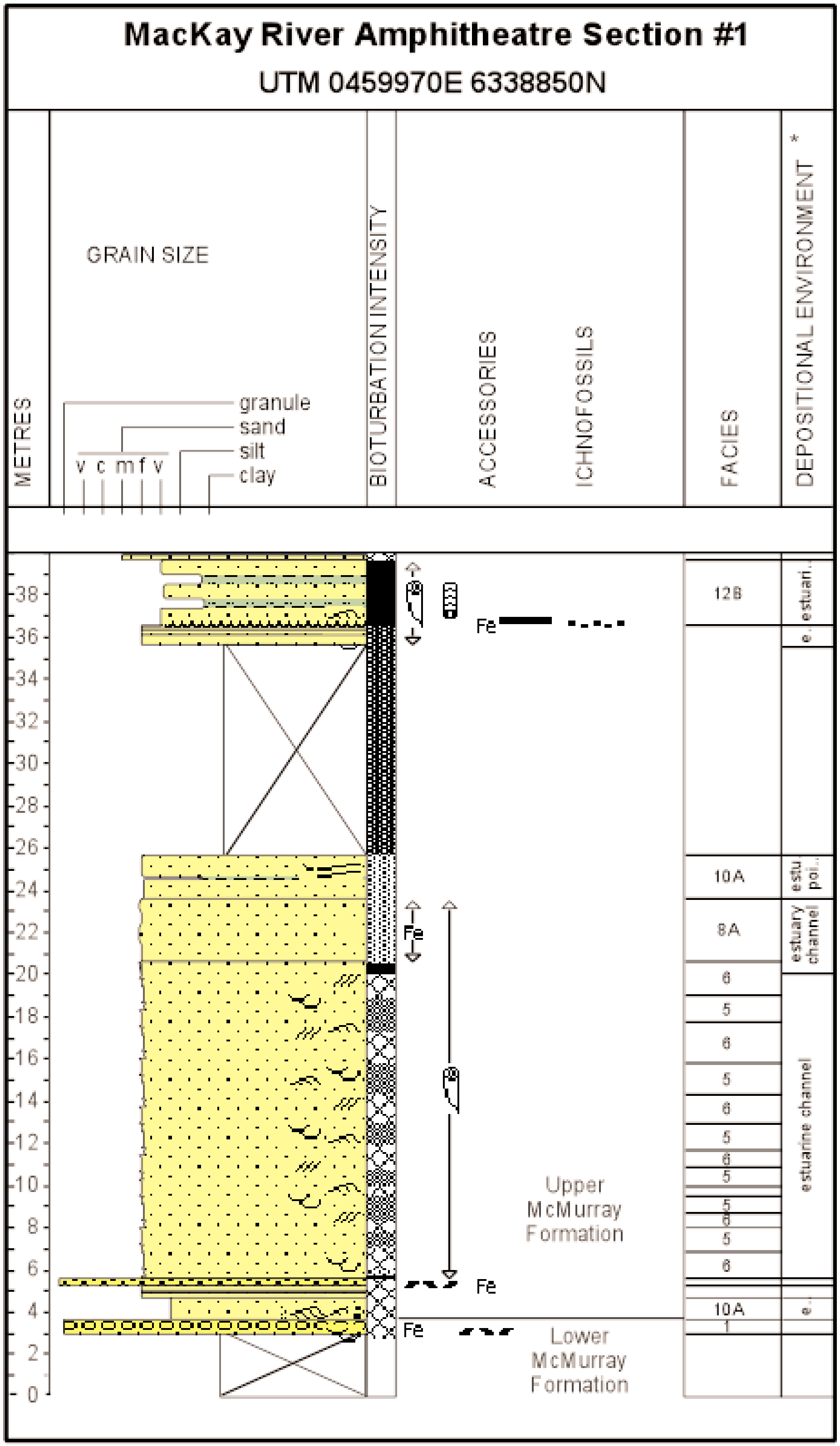
- Excellent burrow structures in the float;
- Thick, muddy, vertical accretion abandoned channel fill deposits;
- Tidal channel sediments;
- Glacial-scour and thrust contacts between the Quaternary and McMurray units.

Description: At the very base of the Amphitheatre section along the MacKay River is a thick succession of poorly exposed organic shaly siltstone and coaly siltstone/shale that occurs within a paleokarst low along the sub-Cretaceous unconformity (due to poor exposure this part of the outcrop was not measured in detail). The overlying contact with the more typical coarse-grained channel facies of the Lower McMurray Formation is covered. At the northernmost limit of the main Amphitheatre outcrop (Figures 6.1.1, 6.1.2b) is a thin, coarse-grained pebbly sandstone that shows trough cross-bedding, and represents the Lower McMurray succession (Figure 6.1.2c). This exposure is often covered, depending upon the degree of recent slumping. Most of this outcrop exposes dominantly fine-grained sand, with high-angle planar tabular, trough and ripple cross-bedding structures and bioturbation features (Figure 6.1.1). *Cylindrichnus* burrows, both in place and as resedimented mudstone intraclasts, are common. Rare resedimented coaly detritus, as coalified or mummified stems and logs, occur about half way upsection (Figure 6.1.2f), but mainly within the inaccessible cliff faces.

Capping the burrowed sands is a succession of interbedded sand and mudstone (Figure 6.1.2e), with intense bioturbation consisting of predominantly *Cylindrichnus* and *Teichichnus* trace fossils. The contact with the underlying sediments is sharp often containing isolated siderite concretions or nodules and coalified logs or coaly laminae. Where accessible, gray, fine-grained bioturbated sands that show parallel lamination, with ripple structures overlie the interbedded and bioturbated fine-grained interval, and minor ironstone (siderite) cementation associated with coaly detritus. The unit becomes muddier upsection, with sands showing current-rippled, wave ripple (Figure 6.1.2g), combined-flow and herringbone structures. The bedding style of this uppermost unit is very even, has a high degree of bioturbation and high amount of fine-grained sediment.

Low cliffs strike along the valley wall at the southern end of the Amphitheatre outcrop exposure. This section starts fairly high uphill (about 2/3 the way upslope) from river level. Here is exposed part of the upper portion of the section that is generally inaccessible within the main Amphitheatre outcrop (Amphitheatre Section #2, Figure 6.1.3). A thick succession of sands dominates the section, comprised of stacked, pin-striped high angle planar tabular cross-bedded facies (Figure 6.1.4 a,b,c, and d), some of which have been deformed into oversteepened cross-bedding (Figure 6.1.4b), large-scale convolutions (Figure 6.1.4g). Flows are predominantly to the north. The trace fossils include *Skolithos*, *Cylindrichnus*, escape burrows, and reworked *Cylindrichnus* burrows as intraclasts derived from underlying estuarine point bar deposits. At the top of the section, the burrowed sands are disconformably overlain by a thin (4 m thick) gray, muddy, fine-grained sand, that is thin-bedded with an even-bedding style, and is intensely burrowed with traces similar to those in the upper portion of the main Amphitheatre section (mainly *Cylindrichnus* and *Teichichnus*). Wightman *et al.* (1992) reported that sea anemone trace fossils and escape burrows were found at this outcrop.

<u>Interpretation:</u> The pebbly sand at the base of the main Amphitheatre section is a remnant of the Lower McMurray fluvial channel sand. Most of the Amphitheatre outcrop exposure is interpreted as part of the Upper McMurray estuarine channel system, with less common lateral accretion estuarine point bar deposits at the base and top of the channel sands. The fine-grained muddy interval with a high degree of bioturbation and continuous, even bedding style is indicative of a vertical accretion abandoned channel fill deposit. The pin-striped sands located along-strike from the main Amphitheatre outcrop are part of a tidal channel complex. These, in turn, are overlain by bioturbated muddy fine-grained sand. This upper muddy sand is interpreted to be flooded estuarine, vertical accretion, abandoned channel or estuarine open-bay deposits.



*Complete Description in Appendix 3.

Figure 6.1.1. Schematic representation of the measured MacKay River Amphitheatre Section #1 (UTM 459970E, 6338850N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.1.2a. Overview of the Amphitheatre sections on the MacKay River. View to the northeast.

Figure 6.1.2b. Northern limit of the main Amphitheatre Section #1, MacKay River.

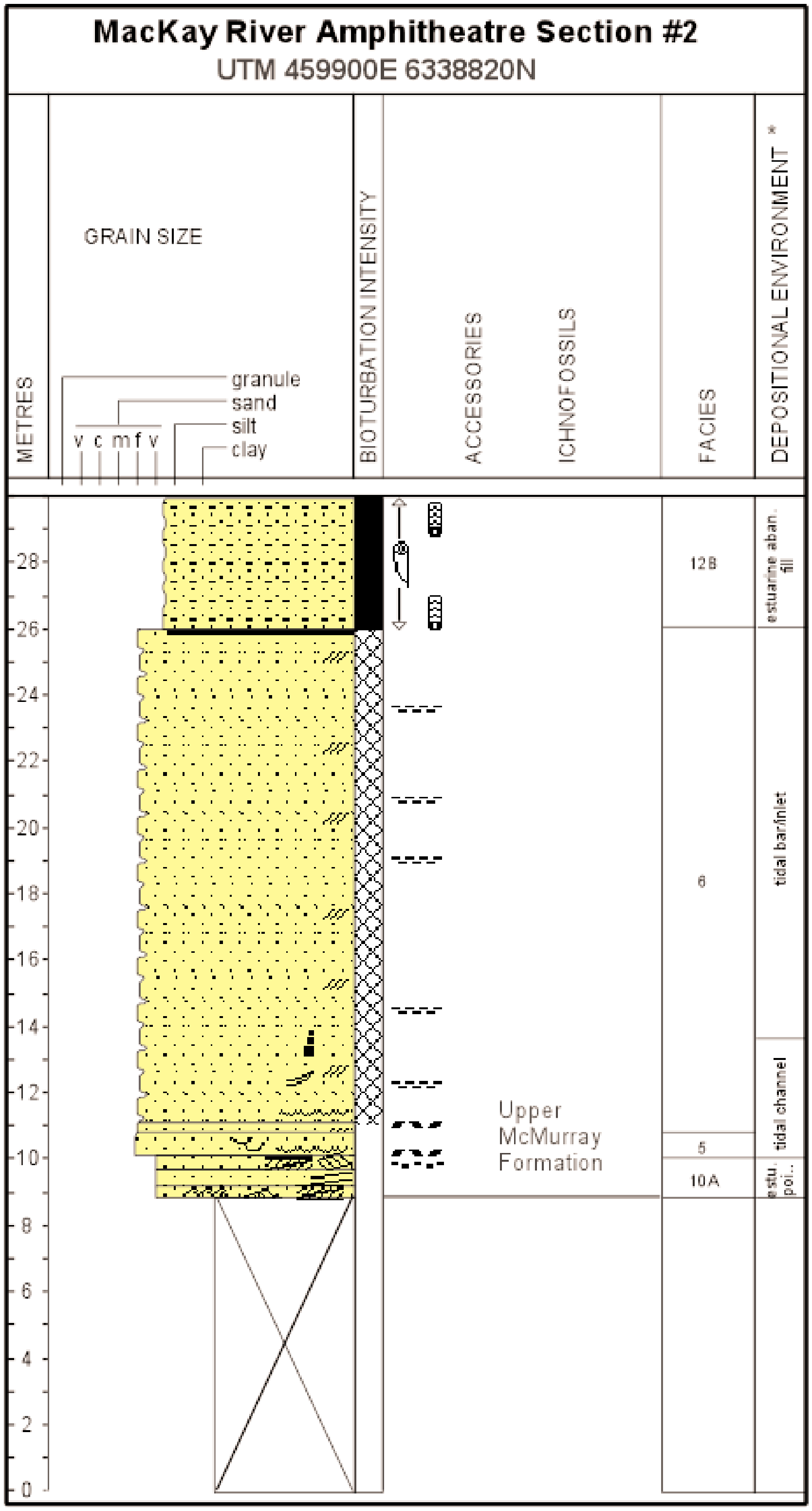
Figure 6.1.2c. Pebbly sand (Lower McMurray Formation) at the base overlain by fine-grained, trough cross-bedded sand, in turn overlain by lateral accretion deposits (Upper McMurray Formation) central portion of the Amphitheatre Section #1, MacKay River.

Figure 6.1.2d. Pebbly sand at the fluvial (Lower McMurray Formation)/estuarine (Upper McMurray Formation) contact, Amphitheatre Section #1, Mackay River.

Figure 6.1.2e. Southern limit of the Amphitheatre Section #1, MacKay River, showing lateral accretion deposits overlain by sandy abandonment fill (Upper McMurray Formation).

Figure 6.1.2f. Coaly debris intermixed with mud and sand at the base of the abandonment fill unit (Upper McMurray Formation) Amphitheatre Section #1, MacKay River.

Figure 6.1.2g. Wave rippled silty sand at the base of the abandonment fill succession (Upper McMurray Formation), Amphitheatre Section #1, MacKay River.



*Complete Description in Appendix 3.

Figure 6.1.3. Schematic representation of the measured MacKay River Amphitheatre Section #2 (UTM 459900E, 6338820N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.1.4a. Large scale, trough cross-bedded sand (Upper McMurray Formation), Amphitheatre Section #2, MacKay River.

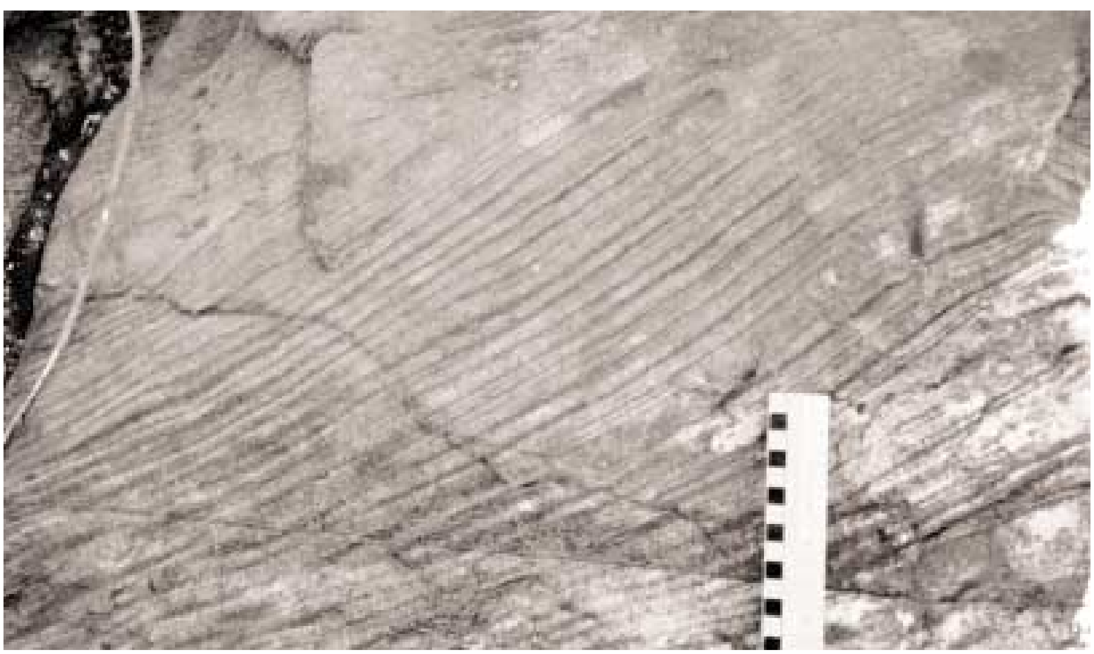


Figure 6.1.4b. Pinstriped, high angle, planar tabular cross-bedding (Upper McMurray Formation), Amphitheatre Section #2, MacKay River.

Figure 6.1.4c. Detail of planar tabular cross-lamination in sand showing subtle variations in bitumen saturation, with heavy saturation in better-sorted sand, and poor saturation in more poorly-sorted fine sand and silt (Upper McMurray Formation), Amphitheatre Section #2, MacKay River.

Figure 6.1.4d. Large scale planar tabular cross-bedding with alteration of paleocurrent directions, minor convolute lamination along cross-beds (Upper McMurrray Formation), Amphitheatre Section #2, MacKay River.

Figure 6.1.4e. Skolithos, Cylindrichnus and escape burrows cross-cutting small scale trough cross-bedding in medium-to coarse-grained sand (Upper McMurray Formation), Amphitheatre Section #2, MacKay River.

Figure 6.1.4f. Mud-filled Cylindrichnus burrows cross-cutting oversteepened planar tabular cross- bedded medium-to coarse-grained sand (Upper McMurray Formation), Amphitheatre Section #2, MacKay River.

Figure 6.1.4g. Large-scale convolute lamination due to dewatering of cross-bedded sand (Upper McMurray Formation), Amphitheatre Section #2, MacKay River.

6.2 MacKay River Viewpoint Section

Map Coordinates: 74E/4 Fort MacKay, UTM 459990E, 6339151N

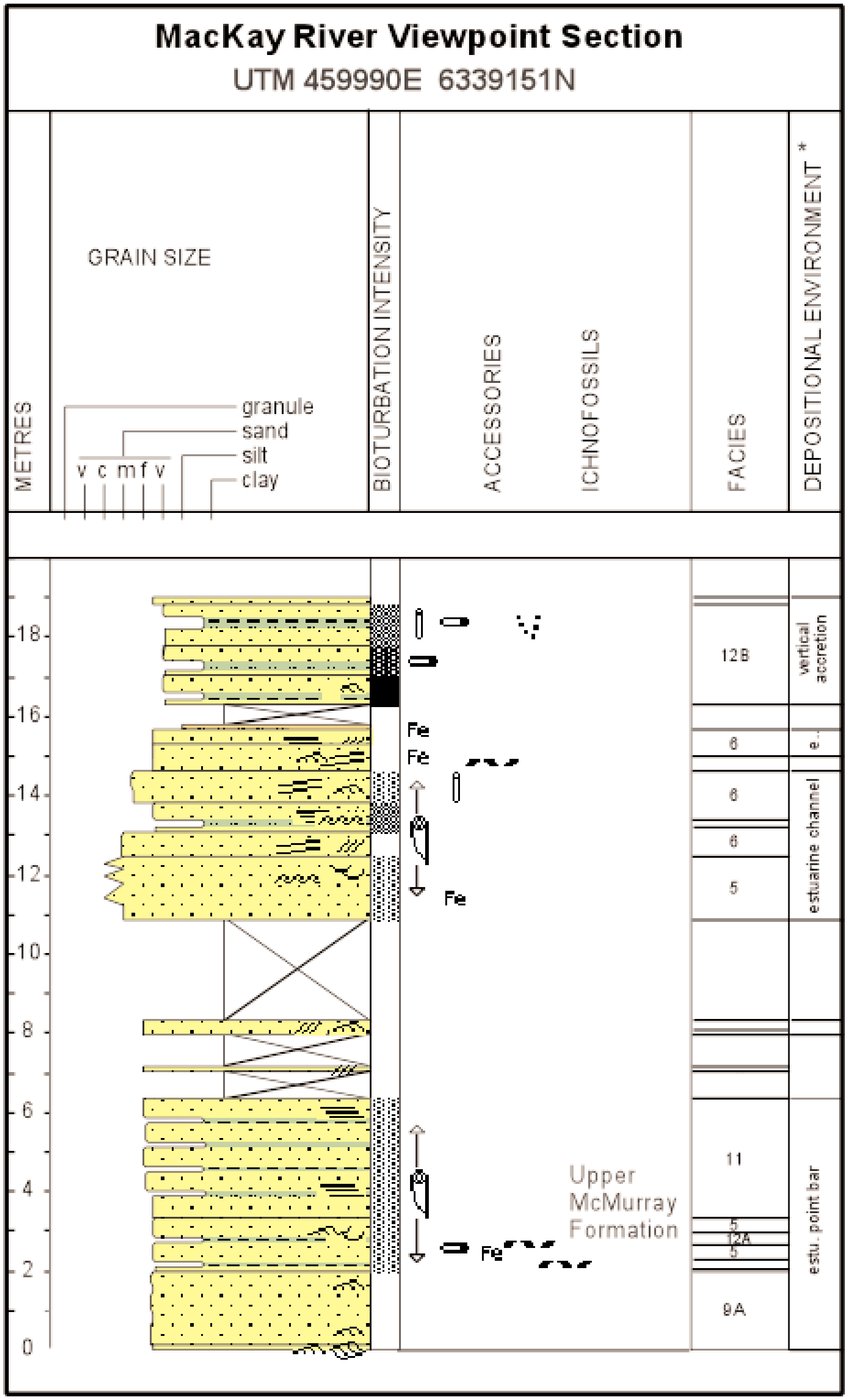
Location and Access: Go north along the dirt road past the Amphitheatre outcrop, continuing until the road comes very close to the river cutbank. On the map, the access to the Viewpoint outcrop is where the dirt track crosses the steep contours at the edge of the MacKay River valley (Figures 6.0.1 and 6.0.2). Stop and access a trail to the west and walk for 1 minute to the overview of the valley. This section starts quite high upslope from the river level. Note: only drive when roads are dry.

Keynote things to see:

- Excellent *Gyrolithes* trace fossils at the top of the section;
- Thick, muddy, vertical accretion abandoned channel fill deposits;
- Estuarine channel and point bar deposits.

Description: At the accessible portion of the Viewpoint Section along the MacKay River is a 19 m thick succession (Figures 6.2.1, 6.2.2a) of well-exposed Upper McMurray mudstone and siltstone interbedded with cross-bedded sand that overlay a cross-bedded fine- to medium-grained sand (6.2.2b). Mudstone intraclasts or reworked *Cylindrichnus* burrow-fills are scattered within the sands. Other trace fossils in the section include *Planolites*, *Skolithos* (Figure 6.2.2c), *Cylindrichnus* and *Teichichnus* and, in the topmost beds, excellent *Gyrolithes* (Figure 6.2.2d). Although the base of the section tends to be more sand dominated, and lacks the *Gyrolithes* traces, no consistent overall coarsening- or fining-upwards occur at this section. Overall paleoflows from the ripple and planar tabular cross-beds are towards the northwest and north. At the top of the section the sediments have an increase in the degree of bioturbation (Figure 6.2.2e), an increase in the diversity and abundance of trace fossils, along with a more even bedding style (Figure 6.2.2e), rare ball-and-pillow structures and double-mud drape lamination.

Interpretation: The Viewpoint Section is interpreted as deposits from an estuarine system, consisting of estuarine point bar deposits in the lowermost 8 m, overlain by about 6 m of estuarine channel-and-point bar deposits. The estuarine channel sediments are capped by a thin (2 m thick) veneer of burrowed, vertical accretion, abandoned channel fill (or brackish-bay) deposits. Rare occurrences of double mud-drape lamination suggest that there was a tidal influence during sedimentation.



*Complete Description in Appendix 3.

Figure 6.2.1. Schematic representation of the measured MacKay River Viewpoint Section (UTM 459990E, 6339151N). Facies designations as listed in Appendix 2. Vertical scale bars are each 1 m in height.

Figure 6.2.2a. Overview of the Viewpoint Section along the MacKay River.

Figure 6.2.2b. Ripple and ripple-drift cross-bedded sand (Upper McMurray Formation), Viewpoint Section, MacKay River.

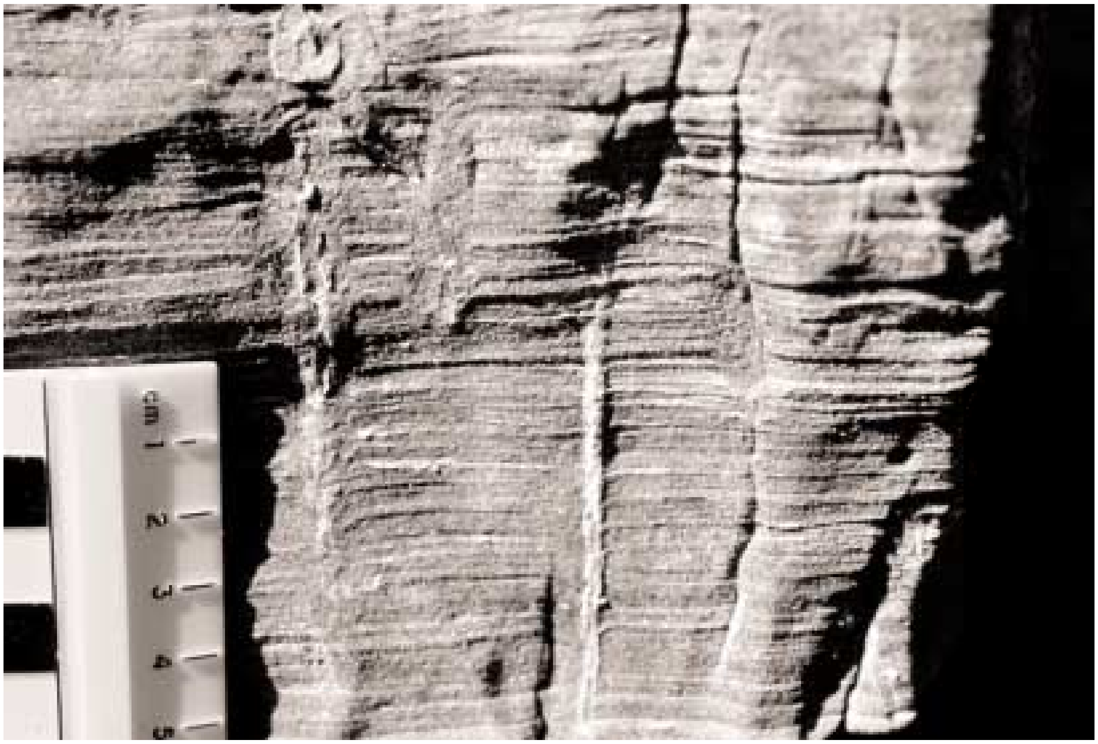


Figure 6.2.2c. Skolithos trace fossils within planar laminated sand near the top of the Viewpoint Section (Upper McMurray Formation), MacKay River.

Figure 6.2.2d. Inclined and vertical *Gyrolithes* and *Cylindrichnus* traces within a burrowed muddy sand (Upper McMurray Formation), Viewpoint Section, MacKay River.

Figure 6.2.2e. Bioturbated, interbedded sand and mud near the top of the Viewpoint Section (Upper McMurray Formation), MacKay River.

6.3 MacKay River Gauging Station Section #2

Map Coordinates: 74E/4 Fort MacKay, UTM 457754E, 6341550N

Location and Access: Continue north-northwest along the dirt road from the Viewpoint Section, stopping at the second fork in the road and park (Figures 6.0.1 and 6.0.2). Walk in along the dirt track to the west, until you come to an overview of the river valley, then turn north along the track. At the end of the track work your way down to the river bottom along the treed slopes. Walk upstream along the valley bottom until you find the water gauging station, marked by a cable across the river, and a dirt road on the other side of the river. Once you hit the gauging station continue upstream about 1 km to a steep cutbank on the northwest valley wall (right side going upstream). Much of the bank is a steep slope of rubbly nodular limestone of the Moberly Member of the Beaverhill Lake Group (Figures 2, 6.3.2a). Note: only access when roads are dry and river is low.

Keynote things to see:

- Nothing (not worth hiking in);
- Mainly covered and steep cliffs.

Description: The cutbank outcrop section at this site is generally poorly exposed (Figure 6.3.2b). The section starts about 15 to 20 m above the river level, and exposes approximately 21 m of Lower McMurray and Upper McMurray sediment (Figure 6.3.1). The lowermost 3 – 4 m of section consists of pebbly sand and very coarse- to fine-grained sand that is poorly sorted. The pebble and granule material is subangular and dominantly quartz (Figure 6.3.2c). Pebble and granular size material occurs throughout as thin pebble trains or along the bases of trough or planar tabular cross-beds (Figure 6.3.2d). Directly overlying the pebbly sand is fine- to medium-grained, organic-rich, sand that is burrowed. This burrowed organic sand may represent the lowermost portion of the Upper McMurray Formation. Following this is a mainly covered succession of recessive, locally rooted, mudstone (Figure 6.3.1, 10.5 m height). The next sand succession is fine-grained with ripple, trough, planar tangential and planar tabular cross-beds. Some mudstone interbeds occur as flasers and inclined heterolithic cross-stratification (Figure 6.3.2e). The top of the McMurray Formation consists of massive, fine-grained sand, with abundant organic material and low bitumen content.

Interpretation: The pebbly sands at the base of the section are interpreted as Lower McMurray fluvial channel sands. Overlying this are the Upper McMurray estuarine channel sands and point bar interbedded sand and mudstone deposits. The massive, organic-rich, fine-grained sands at the top of the McMurray section may be overbank estuarine floodplain sediments.

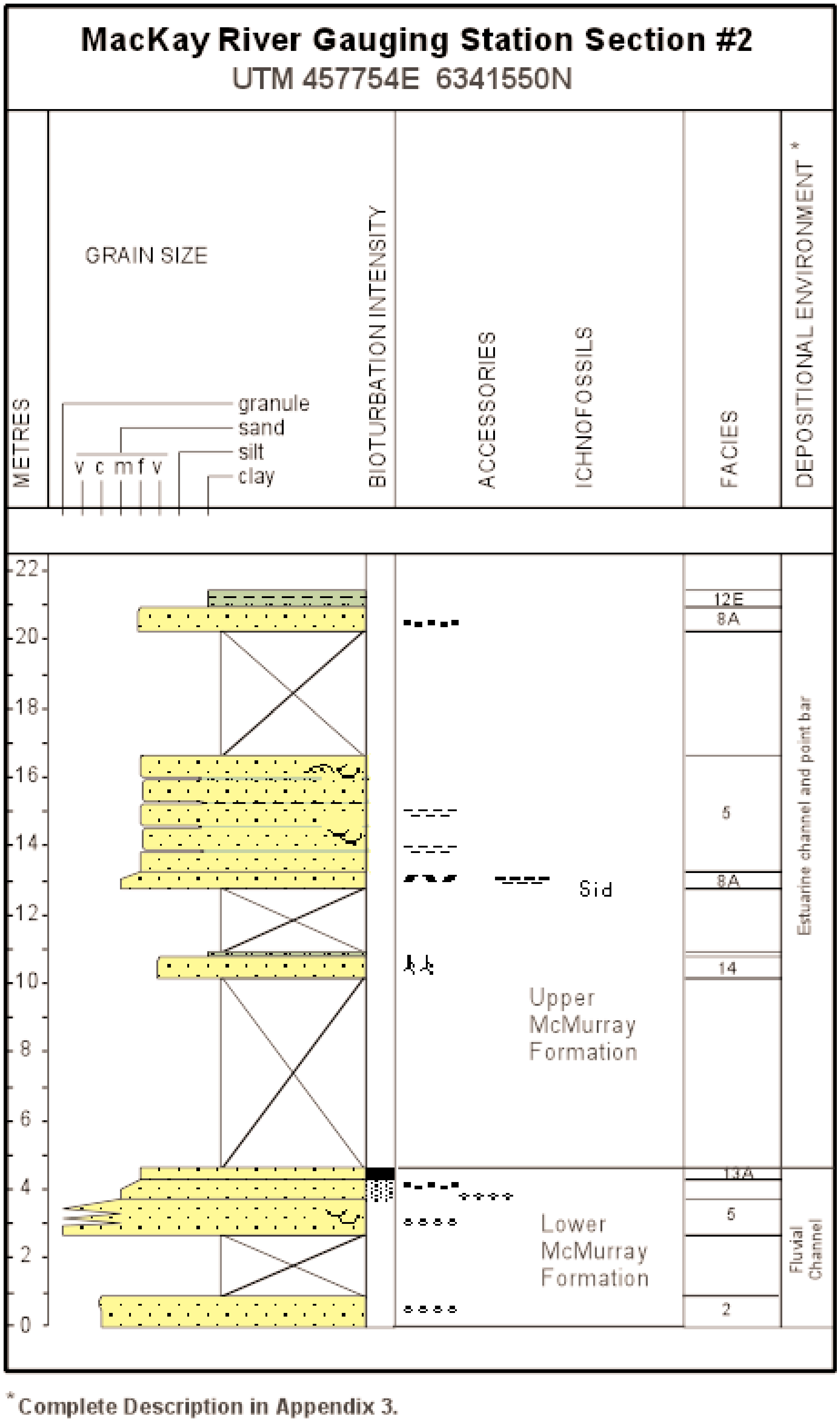


Figure 6.3.1. Schematic representation of the measured MacKay River Gauging Station Section #2 (UTM 457754E, 341550N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.3.2a. Rubbly, nodular limestone of the Moberly Member, just downstream from the MacKay Gauging Station Section #2.

Figure 6.3.2b. Overview of MacKay River Gauging Station Section #2 .

Figure 6.3.2c. Coarse-grained sand with pebbly lags (Lower McMurray Formation), Mackay River Gauging Station Section #2.

Figure 6.3.2d. Medium- to coarse-grained, high angle planar tabular cross-bedded sand (Lower McMurray Formation) MacKay River Gauging Station Section #2.

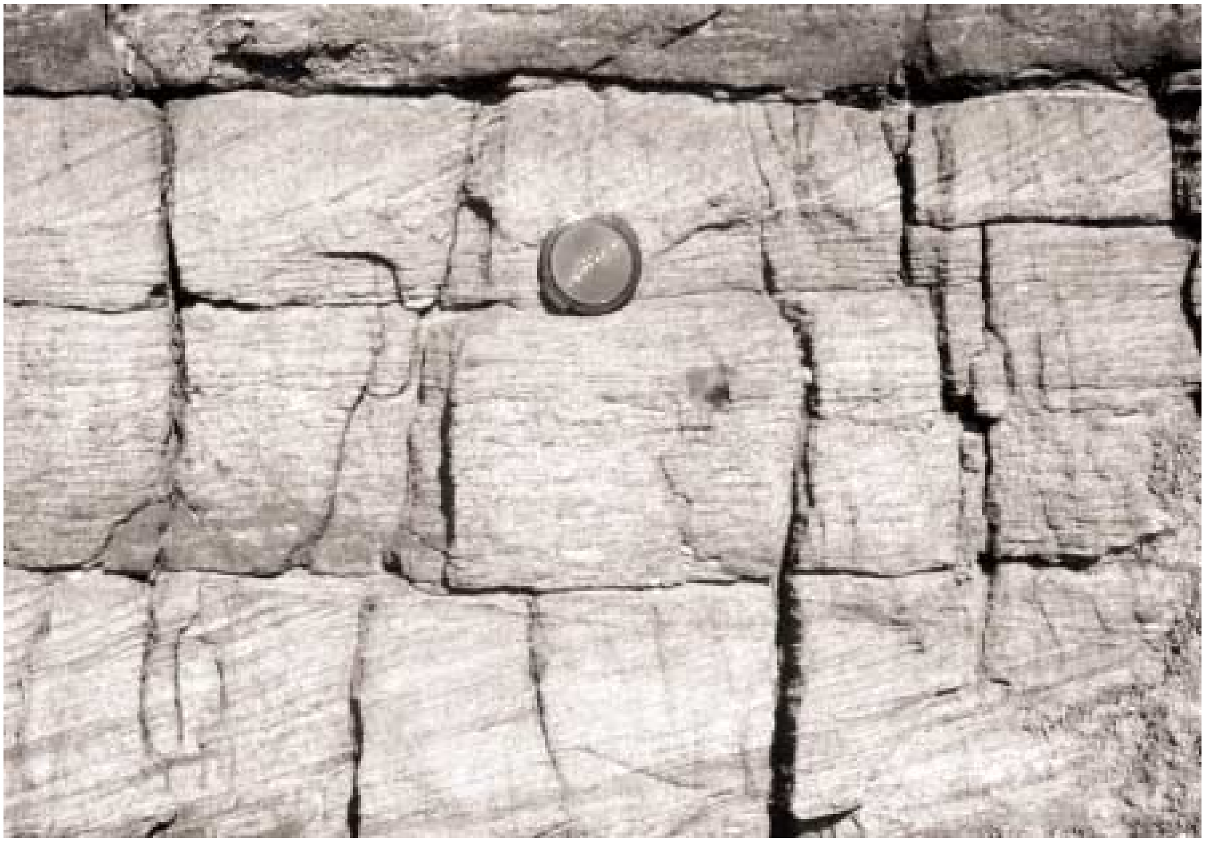


Figure 6.3.2e. High angle, planar tabular and lower angle planar tangential cross-bedded sand with associated rippled sand (Upper McMurray Formation), MacKay River Gauging Station Section #2.

6.4 MacKay River Gauging Station Section #1

Map Coordinates: 74E/4 Fort MacKay, UTM 457473E, 6341450N

Location and Access: Continue walking downstream from the MacKay River Gauging Station Section #2 about 1 km to the next steep cutbank on the northwest valley wall (left side going downstream) (Figures 6.0.1, 6.0.2, 6.4.2a,b). Note: only access when roads are dry and river is low.

Keynote things to see:

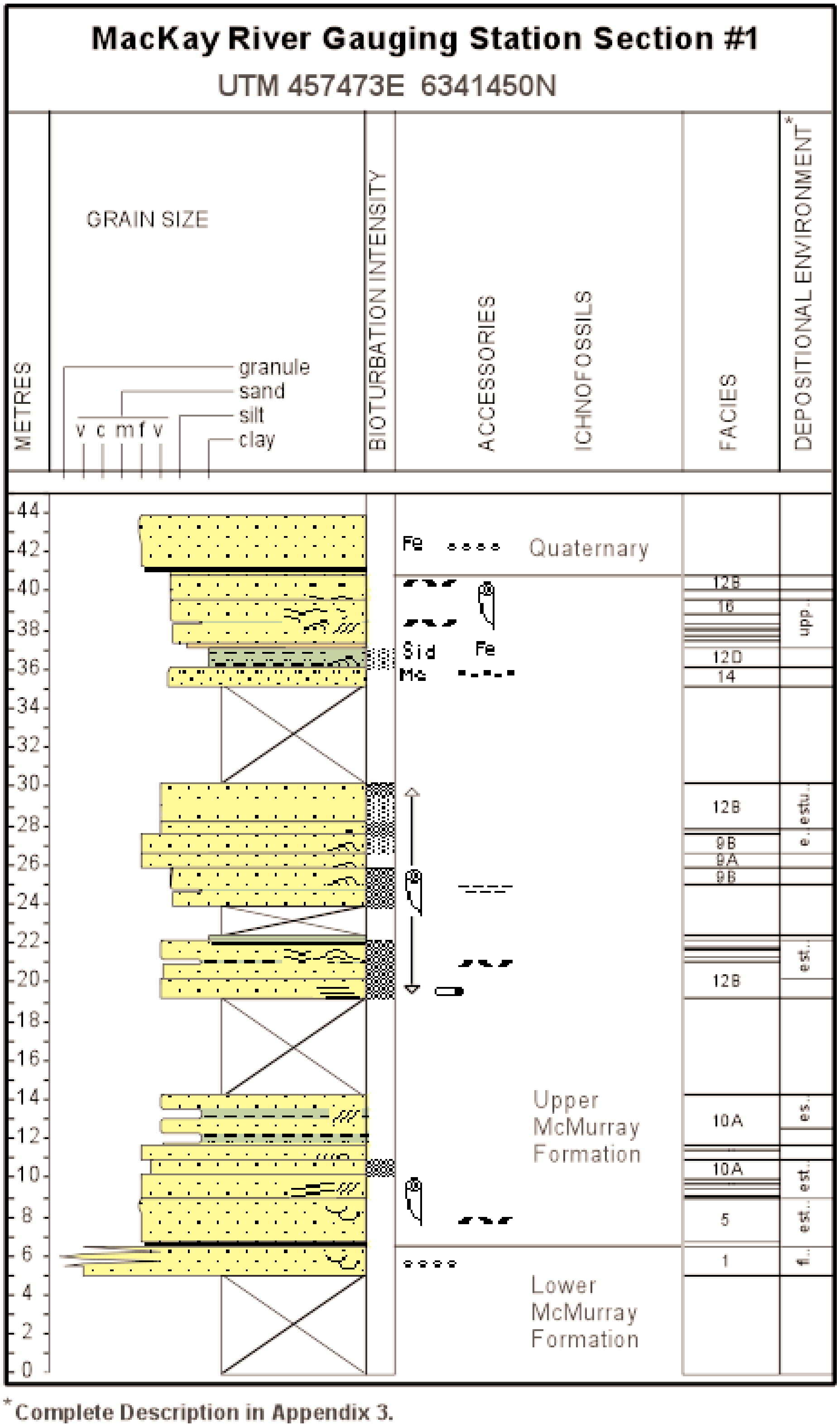
- Little in oil sands, mainly covered and steep cliffs;
- Quaternary sand with abundant white quartzite boulders.

Description: The cutbank outcrop section at this site is generally well exposed, separated by slumped covered intervals that vary from 2 to 5 m in height (Figure 6.4.1). The section starts about 10 to 12 m above the river level, and exposes approximately 44 m of McMurray sediments (Figure 6.4.1). The lowermost 5 m of the section is slumped and covered (Figure 6.4.2a). Overlying this is about 1 to 2 m of very fine-grained to granular and pebbly trough cross-bedded sands (Figure 6.4.1). Granules and pebbles occur as thin pebble trains that line the bases of trough cross-beds. Lithologies of the granules and pebbles are mainly quartz and chert. Paleoflow directions are towards the north in the trough cross-beds.

Abruptly overlying the pebbly sand is a thick fining-upward succession of trough cross-bedded and low-angle, inclined heterolithic stratified sand and mudstone (Figure 6.4.1). These interbedded units form an overall fining-upward package that is about 8 m in thickness. Sandy interbeds in the upper part of this fining-upward package show planar tabular cross-bedding, some of which is capped by ripple drift cross-bedding. Mudstone intraclasts, both as reworked clay clasts and muddy *Cylindrichnus* burrow fills, are associated with the lower trough cross-bedded sand at the base of the fining-upward succession. Paleoflow patterns are towards west, northwest and north. The next part of the section is about half-covered by slumping, and consists of thinly bedded sand and mudstone units (Figure 6.4.2b), with an even bedding style, an occurrence of common *Cylindrichnus* and *Planolites* burrows, discontinuous mud beds, flaser and rippled sands, with scattered mudstone intraclasts (Figure 6.4.1). Wave ripples and buff white paleosols are present within the unit. The uppermost portion of the outcrop becomes muddier upsection, increases in facies complexity, the degree of bioturbation, and in the number of wave-formed sedimentary structures. Organic detritus and sideritized zones also become more common upsection.

Unconformably overlying the McMurray Formation at this site is a 2.5 m thick, medium brown, Quaternary sand with abundant white, rounded to well-rounded, quartzite boulders.

Interpretation: The lowermost pebbly sand is interpreted as fluvial deposits of the Lower McMurray Formation. Overlying this are estuarine channel and point bar deposits of the Upper McMurray Formation. The top of the McMurray at this section is interpreted as being formed within an open-estuarine bay complex within a coastal plain setting.



*Complete Description in Appendix 3.

Figure 6.4.1. Schematic representation of the measured MacKay River Gauging Station Section #1 (UTM 457473E, 6341450N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.4.2a. McMurray succession overlying the sub-Cretaceous unconformity at MacKay River Gauging Station Section #2 and overview of MacKay Gauging Station Section #1.

Figure 6.4.2b. Upper portion of the McMurray succession at MacKay River Gauging Section #1.

6.5 MacKay River Karst-Fill Section #1

Map Coordinates: 74E/4 Fort MacKay, UTM 459500E, 6338650N

Location and Access: This cutbank section is located immediately downstream from the Amphitheatre #1 Section on the opposite cutbank (Figures 6.0.1 and 6.0.2). Access the section by walking downstream from the main Amphitheatre outcrop and fording the river. Note: only access when roads are dry and river is low.

Keynote things to see:

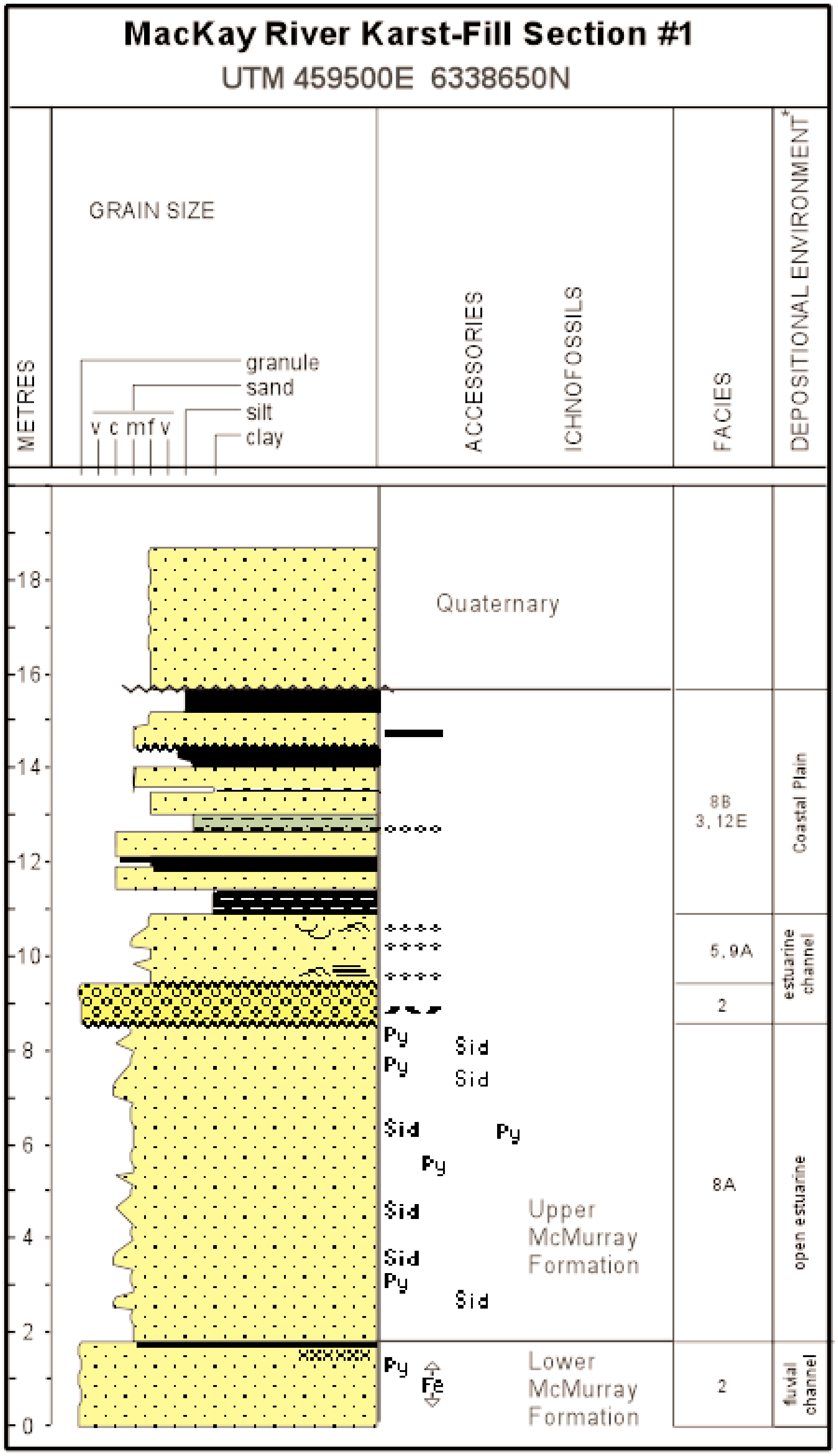
- Paleokarst-fill;
- Sulphide mineralization and alteration of fractured sands.

Description: This measured section starts about 100 m downstream from a major karstic knob-and-hollow topographic feature along the sub-Cretaceous unconformity (Figure 6.5.2a). The upstream end of this outcrop section at this site is generally poorly exposed, with the lower half covered by slumping (Figure 6.5.2b, c). The downstream part of this section starts at river level and exposes approximately 18 m of McMurray sediment (Figure 6.5.1). Along the sub-Cretaceous unconformity, a vertical fault contact occurs between the McMurray oil sands and altered Devonian carbonates. Locally green clay infill occurs within vertical fractures along the faulted contact between the Cretaceous and Devonian successions (Figure 6.5.2d).

The lowermost portion of the measured section consists of a mottled, granular oil sand that is poorly- to very-poorly sorted and has localized sulphide nodules that preferentially develop along fractures paralleling near-vertical faults (Eccles *et al*., 2001). A rind of sulphide mineralization, fractured and altered sand that has a brownish-red to pink colouration caps the basal unit. Overlying this alteration rind is a 6.75 m thick, highly fractured white sand that shows abundant mineralization of siderite and sulphide along fractures. This altered sand forms a local promontory along the cutback section (Figure 6.5.2c). Internally, the sand comprises altered medium to coarse-grained massive sand. Overlying the altered sand is a 4 m thick, upward fining succession that starts at the base with massive to trough cross-bedded sand and gravel that contain abundant white, altered clay clasts randomly dispersed within the sand. Directly overlying the gravelly sand is a organic fine- to medium-grained sand with scattered pebbles. This unit is rippled to parallel laminated at the base, and more massive at the top. Following this are approximately 1.7 m of carbonaceous mudstone and thin coals that are interbedded with coarse- to fine-grained sand. Physical sedimentary structures, where developed, are dominantly parallel stratification, less commonly convolute lamination and rippling (Figure 6.5.1).

A rooted 3 m cap of Quaternary colluvium disconformably overlies the McMurray succession at this site.

Interpretation: The section is interpreted as infill along a karstic sinkhole margin, marked by the altered promontory of sand. Internally the features of the sediments appear to be Lower McMurray fluvial overlain by Upper McMurray open estuarine successions, capped by more organic-rich coastal plain deposits in the upper half of the measured section.



*Complete Description in Appendix 3.

Figure 6.5.1. Schematic representation of the measured MacKay Karst-Fill Section #1 (UTM 459500E, 6338650N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.5.2a. View about 100 m upstream from MacKay River Karst-Fill Section #1 showing the paleo-karst topography of the sub-Cretaceous unconformity.

Figure 6.5.2b. Karst-fill feature (sinkhole) at the base of the McMurray succession directly overlying the sub-Cretaceous unconformity (Lower and Upper McMurray Formation), Mackay River Karst-Fill Section #1. Vertical bar shows the location of section described.

Figure 6.5.2c. Karst feature (sinkhole) within the McMurray succession on the MacKay River (MacKay River Karst-Fill Section #1). Vertical bar shows location of described section.

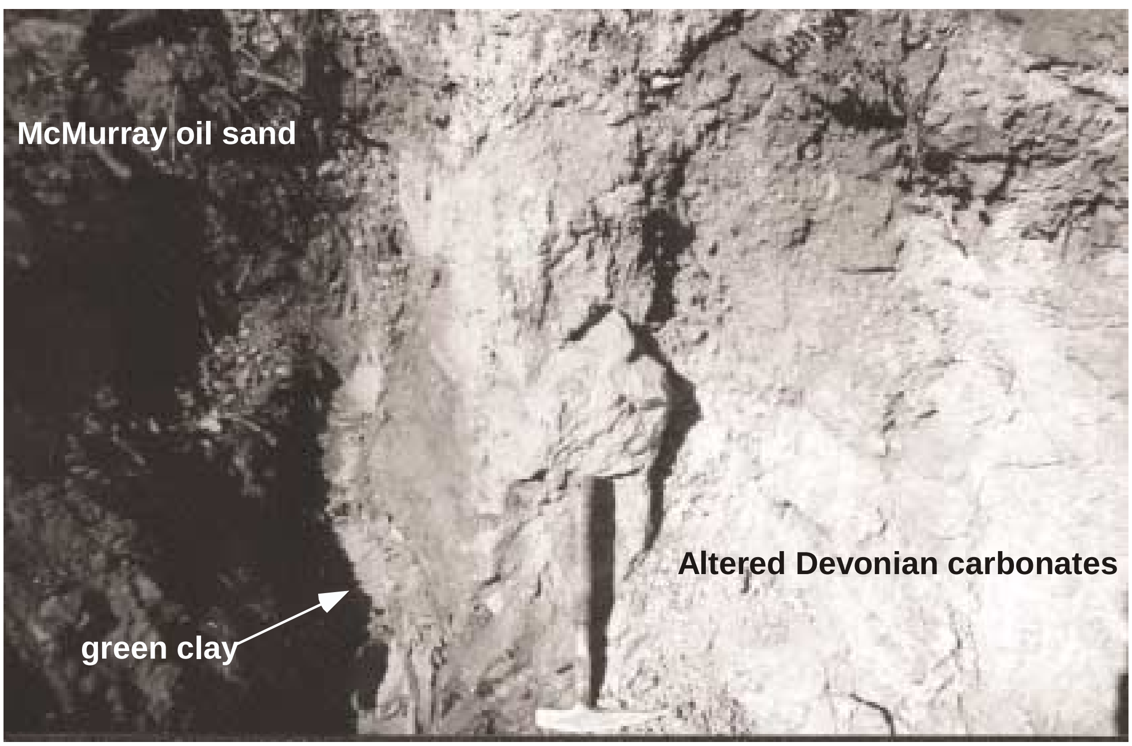


Figure 6.5.2d. Green clay lining along vertical faulted contact between McMurray oil sand and altered Devonian carbonates (about 500 m upstream from MacKay River Karst-Fill Section #1).

6.6 MacKay River Karst-Fill Section #2

Map Coordinates: 74E/4 Fort MacKay, UTM 459500E, 6338650N

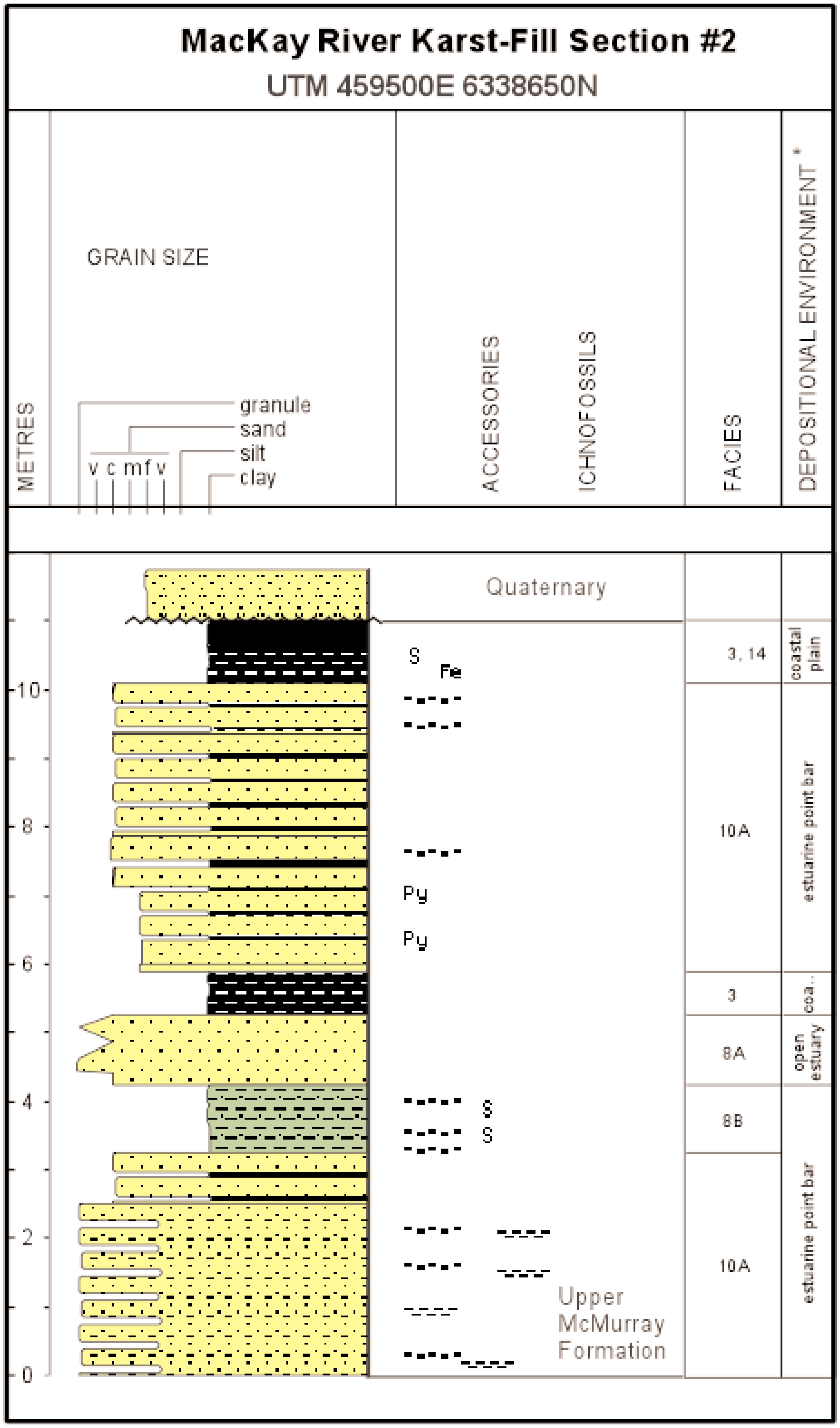
Location and Access: This outcrop section is located approximately 25 m downstream from MacKay River Karst-Fill Section #1 along the same cutbank exposure (Figures 6.0.1 and 6.0.2). Note: only access when roads are dry and river is low.

Keynote things to see:
- Paleokarst-fill;
- Pebbly sands overlain by carbonaceous mudstone and coal.

Description: The cutbank outcrop section at this site is generally poorly exposed, with the lower half covered by slumping. The section starts a few metres above the river level, and exposes approximately 12 m of the McMurray succession (Figure 6.6.1). The lowermost 2 to 3 m of this section consist of pebbly to granular sand that is poorly-sorted and contains abundant reworked organic debris. Pebble and granular size material occurs throughout as thin pebble trains or along the bases of trough cross-beds. The pebble and granule material is subangular and dominantly quartz. Directly overlying the pebbly sand is a very organic mudstone, with native sulphur and a dark brown colouration with a flaky weathering pattern. Following this is approximately 3 m of carbonaceous mudstone and coals that are interbedded with quartzose coarse- to fine-grained sand. The top 2 to 3 m of the outcrop consists of an upward fining succession from coarse-grained sand with abundant organic detritus, overlain by organic coarse sand with discontinuous coals, capped by a thick, dark brown organic-rich carbonaceous mudstone and a coaly interval, that is iron-stained and has native sulphur weathering out. Physical sedimentary structures are dominated by parallel stratification, less commonly convolute lamination and rippling.

A rooted 0.75 to 1 m cap of Quaternary colluvium disconformably overlies the McMurray succession at this site.

Interpretation: The lower pebbly and granular sand is interpreted as coarse-grained alluvial fill possibly fluvial input as karst-fill. Without palynological dating it is difficult to know the age of the fill, however, the abundance of muddy inclined heterolithic stratification is more typical of the Upper McMurray Formation. The coal beds seem to be present over or around the margins of the karst sinkhole; this outcrop may be an analogue (although at a much smaller scale) to the development of the Firebag coal basin to the northwest, where significant coal is present within a heavily karsted area. In the Firebag River area, increased thickness of coals and carbonaceous material accumulated within paleokarstic sinkholes that were subsiding during sedimentation. A similar environment may be represented at this section, and by analogy to the Firebag section, the facies at this section are interpreted as organic-rich vertical accretion deposits that may have been associated that accumulated within boggy paleotopographic lows along an actively subsiding karstic surface.



* Complete Description in Appendix 3.

Figure 6.6.1. Schematic representation of the measured MacKay River Karst-Fill Section #2 (UTM 459500E, 6338650N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

6.7 MacKay River Karst-Fill Section #3

Map Coordinates: 74E/4 Fort MacKay, UTM 459500E, 6338450N

Location and Access: This outcrop section is located at the next cutbank section downstream and on the same side of the river as the cutbank exposure for the MacKay River Karst-Fill Section #1 and Section #2 (Figures 6.0.1 and 6.0.2). Although karst features and sinkhole margins do not occur at this outcrop, its designation as Karst-Fill Section #3 indicates its close proximity, and immediate downstream location with respect to the Karst Fill Section #1 and Section #2. Note: only access when roads are dry and river is low.

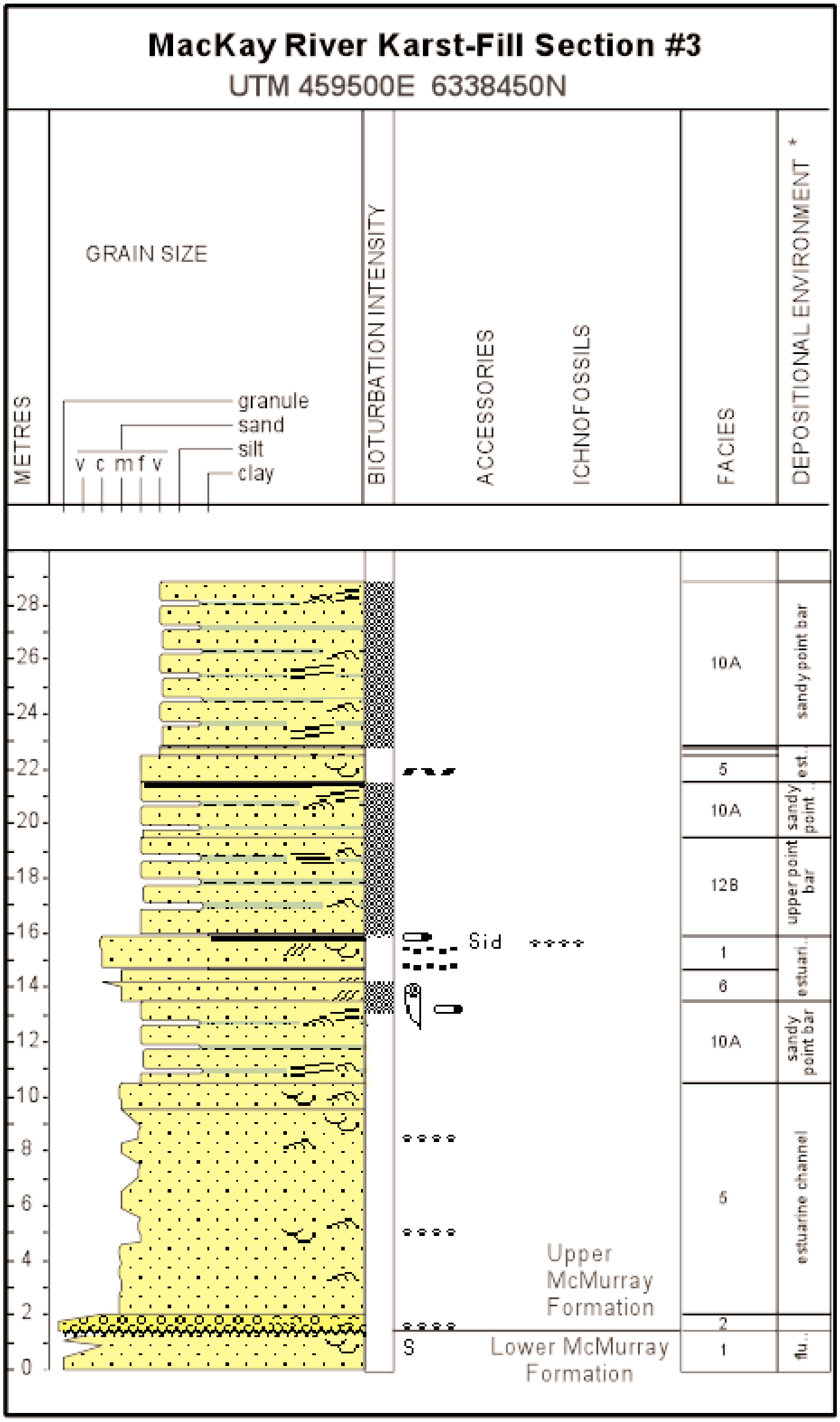
Keynote things to see:

- Weathering profile with mineralization interpreted as the disconformity between the Lower and Upper McMurray Formation;
- Sand-dominated low angle, inclined heterolithic stratification, changing downstream along the outcrop into mud-dominated low angle, inclined heterolithic stratification.

Description: The cutbank outcrop section at this site is generally poorly exposed, with the lower half covered by slumping. The section starts about 15 m above the river level, and exposes approximately 30 m of McMurray sediment (Figure 6.7.1). At the upstream end of the outcrop is 25 m of sand- and mudstone-dominated inclined heterolithic cross-bedding. The coarser interbedded sands display planar tabular and ripple cross-bedding. About 100 m downstream is exposed a pebbly and granular sand that is poorly sorted with vague trough cross-bedding. Directly overlying the pebbly sand is a dark-brown to dark-red/green-brown weathering surface that may have been sideritized with sulphide mineralization, and is now highly weathered. Overlying beds are dominantly medium- to coarse-grained sands, with scattered granule and pebble material and mudstone intraclasts. Physical sedimentary structures are very well developed and include trough cross-bedding, wave and current ripple cross-bedding, sand-dominated inclined heterolithic stratification and planar tabular cross-bedding (Figure 6.7.2). These cross-bedded sands are the downstream lateral equivalents to the sand- and mudstone-dominated inclined heterolithic cross-bedding at the upstream end of the cutbank exposure. The sand-dominated inclined heterolithic stratification at the top of the section shows abundant cross-cutting and sand-on-sand contacts. Approximately 100 m downstream the section grades into a mud-dominated inclined heterolithic stratified unit within the top one-third of the outcrop.

At the upstream end of the exposure the McMurray Formation is unconformably overlain by inaccessible, glauconitic Wabiskaw C sand, that downstream is cutout and unconformably overlain by Quaternary sediment.

Interpretation: The lowest pebbly sands are interpreted as fluvial remnants of the Lower McMurray Formation. The dark-brown to dark-red/green weathered surface is interpreted as the disconformity between the Lower and Upper McMurray Formation. At the upstream end of the exposure are Upper McMurray tidal-estuarine point bar deposits that grade downstream into tidal channel sands. Near the top of the exposure sandy tidal-estuarine point bar deposits grade downstream into muddy estuarine point bar deposits.



*Complete Description in Appendix 3.

Figure 6.7.1. Schematic representation of the measured MacKay River Karst-Fill Section #3 (UTM 459500E, 6338450N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.7.2. Sand-dominated lateral accretion deposits overlying trough cross-bedded sand (below image), (Upper McMurray Formation), MacKay River Karst-Fill Section #3.

6.8 MacKay River West Section

Map Coordinates: 74E/4 Fort MacKay, UTM 454700E, 6336490N

Location and Access: This section is accessible either by helicopter or by boat going upstream and west of Fort MacKay (Figures 6.0.1 and 6.0.2). The section has very steep, vertical to overhanging cliffs, and is generally inaccessible on the face. Note: only access when river is low.

Keynote things to see:

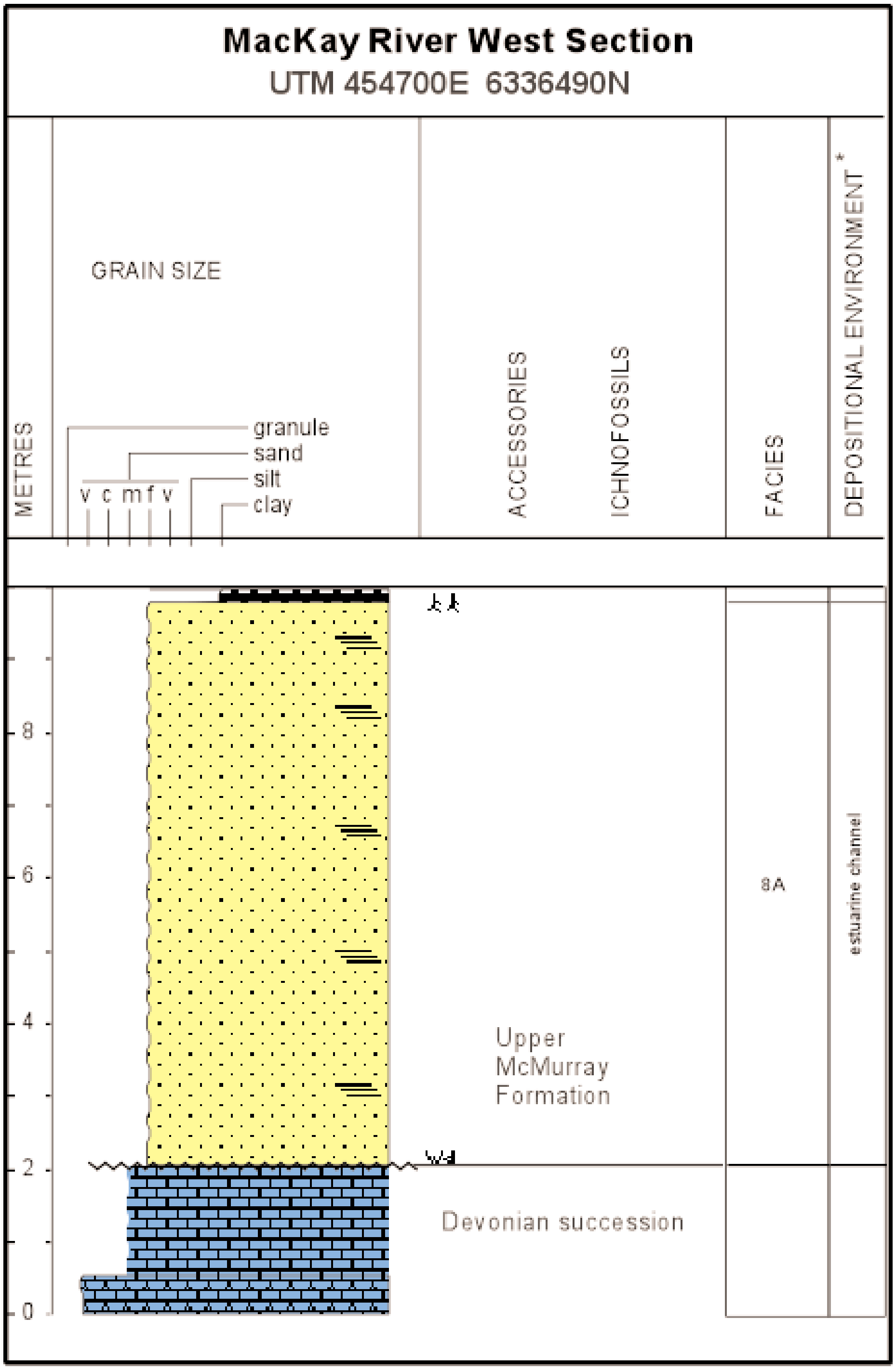
- Little in the McMurray Formation, mainly covered and very-steep cliffs;
- Good collecting site for fossils weathered out of the Devonian;
- Quaternary diamicton (till) and outwash gravel with reworked McMurray oil sand clasts.

Description: At river level a 2 m high bench of the Devonian Moberly Member fossiliferous limestone outcrops, with abundant brachiopods, stromatoporoids and crinoid stems. Fractures within the Moberly limestone are infilled with bitumen.

Overlying the limestone bench is approximately 8 m of estuarine channel sediment of the Upper McMurray Formation (Figure 6.8.1). The sands are dominantly massive, with some parallel lamination and large-scale trough cross-bedding (observable in float). Generally the section lacks any coarsening- or fining-upward successions, but is a rather massive unit of what appear to be stacked channel sands. Isolated float material along the slopes is bioturbated, and some float shows double-mud drapes, flaser ripple cross-beds, and rooted mudstone.

At the downstream end of the outcrop, the McMurray succession is unconformably overlain and scoured out by a Quaternary channel system. Channel fill consists of diamicton; interpreted as till, overlain by glaciofluvial outwash gravels. Within the outwash gravels are reworked balls of McMurray oil sand.

Interpretation: Generally massive sands with high energy and tidal current features are indicative of estuarine-channel sand deposition with a tidal influence, all interpreted as part of the Upper McMurray succession.



*Complete Description in Appendix 3.

Figure 6.8.1. Schematic representation of the measured MacKay River West Section (UTM 454700E, 6336490N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

6.9 Beaver River Sandstone Quarry Section

Map Coordinates: 74E/4 Fort MacKay, UTM 462350E, 6330850N

Location and Access from Fort MacKay: Travel back from the Amphitheatre Section through Fort MacKay to Highway 63 going south. About 0.5 km south of the intersection between the Fort MacKay access road and Highway 63, just north of the bridge over Beaver River (Figures 6.9.1 and 6.9.2), is a small dirt track into the woods on the east (left) side of the highway. Turn onto the dirt track and follow to a small man-made quarry-pond.

Location and Access from Fort McMurray: Travel north on Highway 63 from Fort McMurray to about 0.5 km south of the access road turnoff to Fort MacKay, just north of the highway bridge over the Beaver River (Figure 6.9.1). A small dirt track is located on the east (right) side of the highway. Turn onto the dirt track and follow to the end of the track at a small abandoned quarry (Figures 6.9.1 and 6.9.2).

Keynote things to see:

- Silica-cemented sandstones within the McMurray Formation;
- Plant fossils and root traces;
- Archaeological site.

Description: Along the northern edge of the water-filled abandoned quarry are small, low and isolated outcrops of the 'Beaver River Sandstone' (Figures 6.9.2 and 6.9.3a, b), a silica-cemented unit within the McMurray Formation. Lithologically the silica-cemented sandstone at this site is identical with the underlying bituminous quartz sand of the McMurray Formation, both consisting of angular and rounded quartz and quartzite grains, with fine-grained quartz matrix. Additionally, there is a gradational change over a thickness of <0.5 m, from typical bituminous-saturated sand of the McMurray succession and the non-bituminous, silica-cemented sand of what has been called the Beaver River sandstone. On bedding plane surfaces and in cross section are root trace imprints, some of which are up to 1 cm in diameter. Abundant comminuted organic detritus occurs throughout the sandstone, and isolated loose organic rubble, including fossil stems and branches and coaly debris, are found as float in the area. Limited palynological dating done on a coaly fragment from the sandstone yielded a modest terrestrial assemblage of palynomorphs that appear to be Aptian-Cenomanian in age.

Historically First Nation's people quarried the silica-cemented sandstone at this site (Fenton and Ives, 1982, 1990; Ives and Fenton, 1983). Diagenesis of the Beaver River Sandstone has been examined by Brian Tsang as part of his M.Sc. thesis work at the Department of Geology and Geophysics, The University of Calgary (Tsang, 1998).

Interpretation: The silica cement makes the sandstone distinct lithologically from the other more typically uncemented McMurray Formation sands. The interpretation is that the silica-cemented Beaver River Sandstone was within a paleolow karst feature at the time of cementation, probably associated with silica-saturated connate waters. A number of similar silica-cemented units within the Lower McMurray Formation have also been encountered in subsurface cores from the surrounding area. Quite commonly siderization and siderite cement is associated with the areas that have silica cement. The stratigraphic position, preliminary palynological age date, and lithologic characteristics indicate that the Beaver River Sandstone at the site is part of the Lower McMurray Formation, and not a distinct 'pre-McMurray' succession.

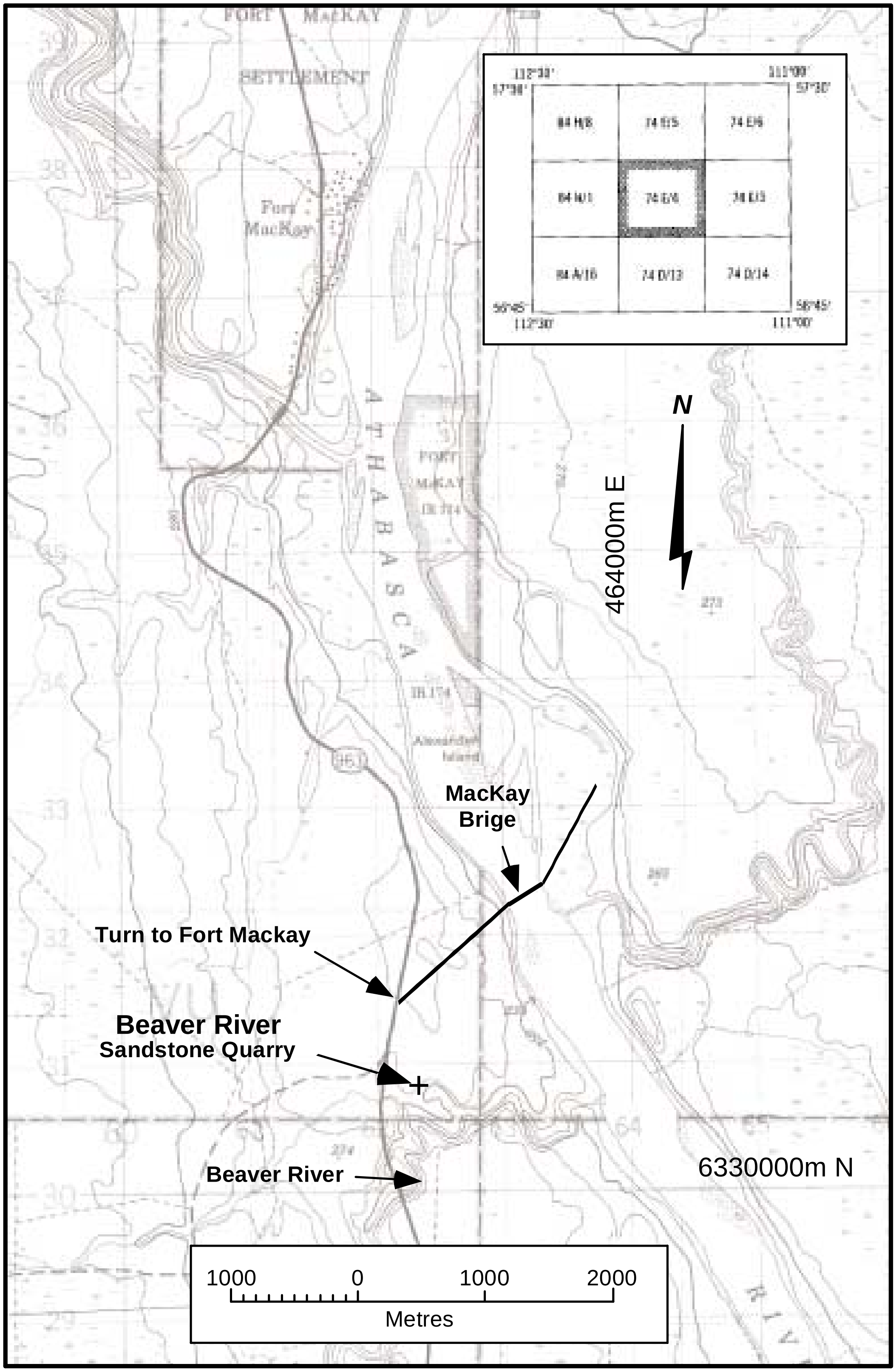


Figure 6.9.1. Map showing location of Beaver River Sandstone Quarry, Fort MacKay.

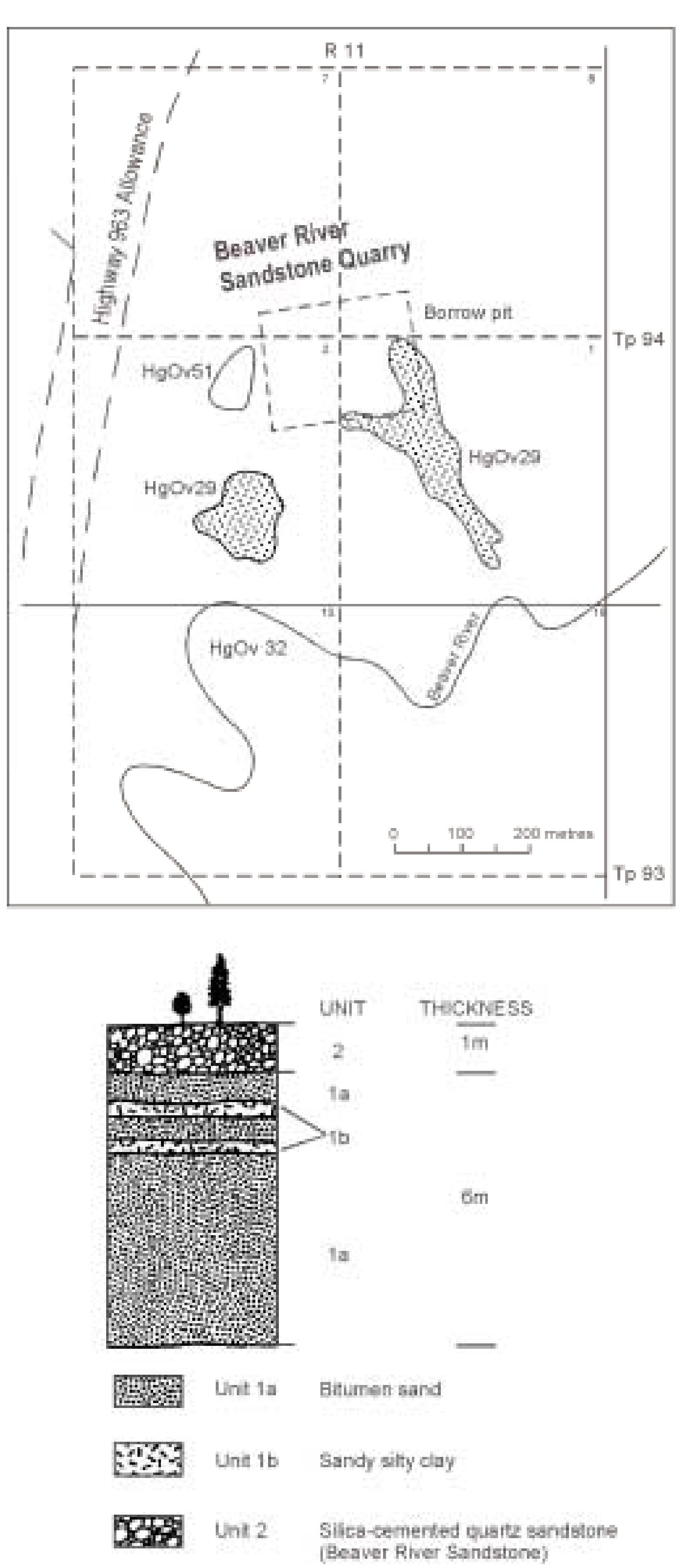


Figure 6.9.2. Detailed map showing the Beaver River Sandstone Quarry (HgOv29) and the borrow pit in which the Beaver River Sandstone is exposed, geologic section at the Beaver River Quarry, borrow pit (UTM 0462350E, 6330850N). (from Fenton and Ives, 1982).

Figure 6.9.3a. Silicified Beaver River Sandstone (Lower McMurray Formation) exposed in a quarry near the bridge crossing the Athabasca River, south of Fort MacKay.

Figure 6.9.3b. Clean, silicified, rooted, quartz sandstone of the Beaver River Sandstone within the Lower McMurray Formation near Fort MacKay.

6.10 MacKay River near Bridge Section

Map Coordinates: 74E/4 Fort MacKay, UTM 460723E, 6336620N

Location and Access: Drive north of Fort McMurray on Highway 63. Turn northwest (left) from Highway 63 onto the Fort MacKay access road, marked by a road sign, just north of the highway bridge over the Beaver River. Continue on the Fort MacKay access road until you reach the bridge over the MacKay River (Figures 6.0.1 and 6.0.2). Park near the bridge, and access the section by going down to the river from the north side of the bridge. The section is immediately upstream of the MacKay River Bridge, on the north bank of the river.

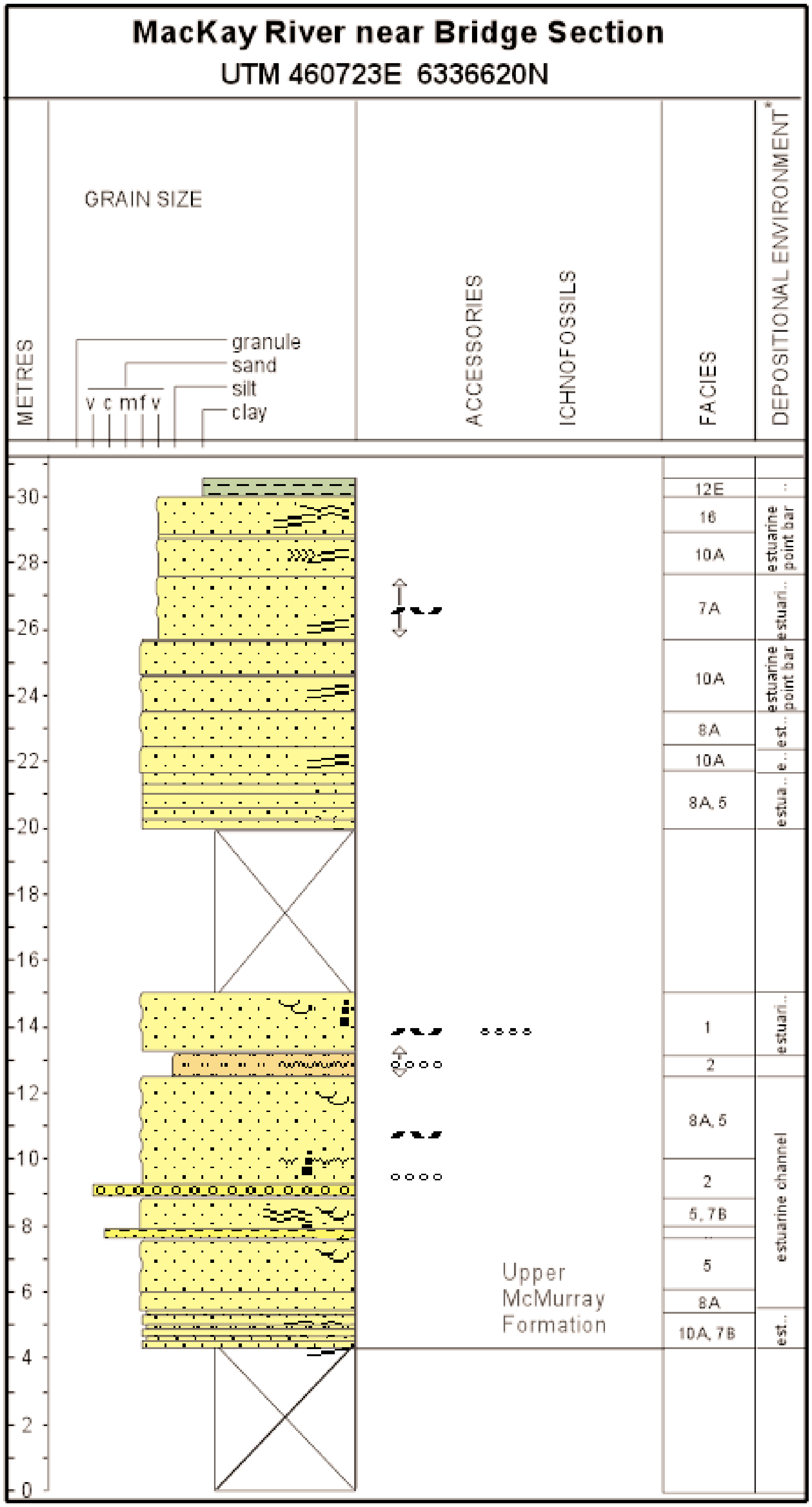
Keynote things to see:

- Mainly covered and steep cliffs;
- Good fining-upward successions of stacked estuarine channel deposits, overlain by estuarine point bar deposits, marked by inclined lateral accretion cross-bedding, with minor herringbone cross-bedding (indicative of a tidal influence).

Description: At river level about 4 m of section is covered in a scree slope. Overlying the scree is approximately 30 m of partially covered sediment of the Upper McMurray Formation (Figure 6.10.1). At the base of the exposure the sands show large-scale trough cross-bedding, with less common gravelly and siltstone interbeds. Within the base of trough cross-beds are local concentrations of mudstone intraclasts. The lower half of the section shows good fining-upwards successions and minor wavy bedding features.

Trough cross-bedded sands are capped by a 5 m thick recessive and covered interval that is overlain by approximately 11 m of medium- to thin bedded sand and mudstone units. These units show well-developed lateral accretion cross-bedding (inclined heterolithic stratification), which towards the top of the section have interbedded mudstone intraclast breccias and minor wavy cross-bedded sands.

Interpretation: At the base of the section, the fining-upward gravelly sands, with large scale trough cross-bedding and local mudstone clast breccias, are interpreted as high energy, main estuarine-channel sand deposits. The lateral accretion cross-beds in the upper half of the succession are estuarine point bar deposits. Although there is no palynological dating from this site, the abundance of inclined heterolithic stratification, the presence of alternating paleoflow features and the common occurrence of resedimented bioturbated mudstones as intraclasts indicate that this section is most likely an Upper McMurray succession.



*Complete Description in Appendix 3.

Figure 6.10.1. Schematic representation of the measured MacKay River near Bridge Section (UTM 460723E, 6336620N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

6.11 MacKay River Upstream of Mouth Section

Map Coordinates: 74E/4 Fort MacKay, UTM 461430E, 6335910N

Location and Access: Drive north of Fort McMurray on Highway 63. Turn northwest (left) from Highway 63 onto the Fort MacKay access road, marked by a road sign, just north of the highway bridge over the Beaver River. Continue on the Fort MacKay access road until you reach the bridge over the MacKay River (Figures 6.0.1 and 6.0.2). Park near the bridge, and access the section by going down to the river from the south side of the bridge. Continue into the river valley, walking downstream about 1 – 2 km downstream. The section is on the west side of the river. Note: only access when river is low.

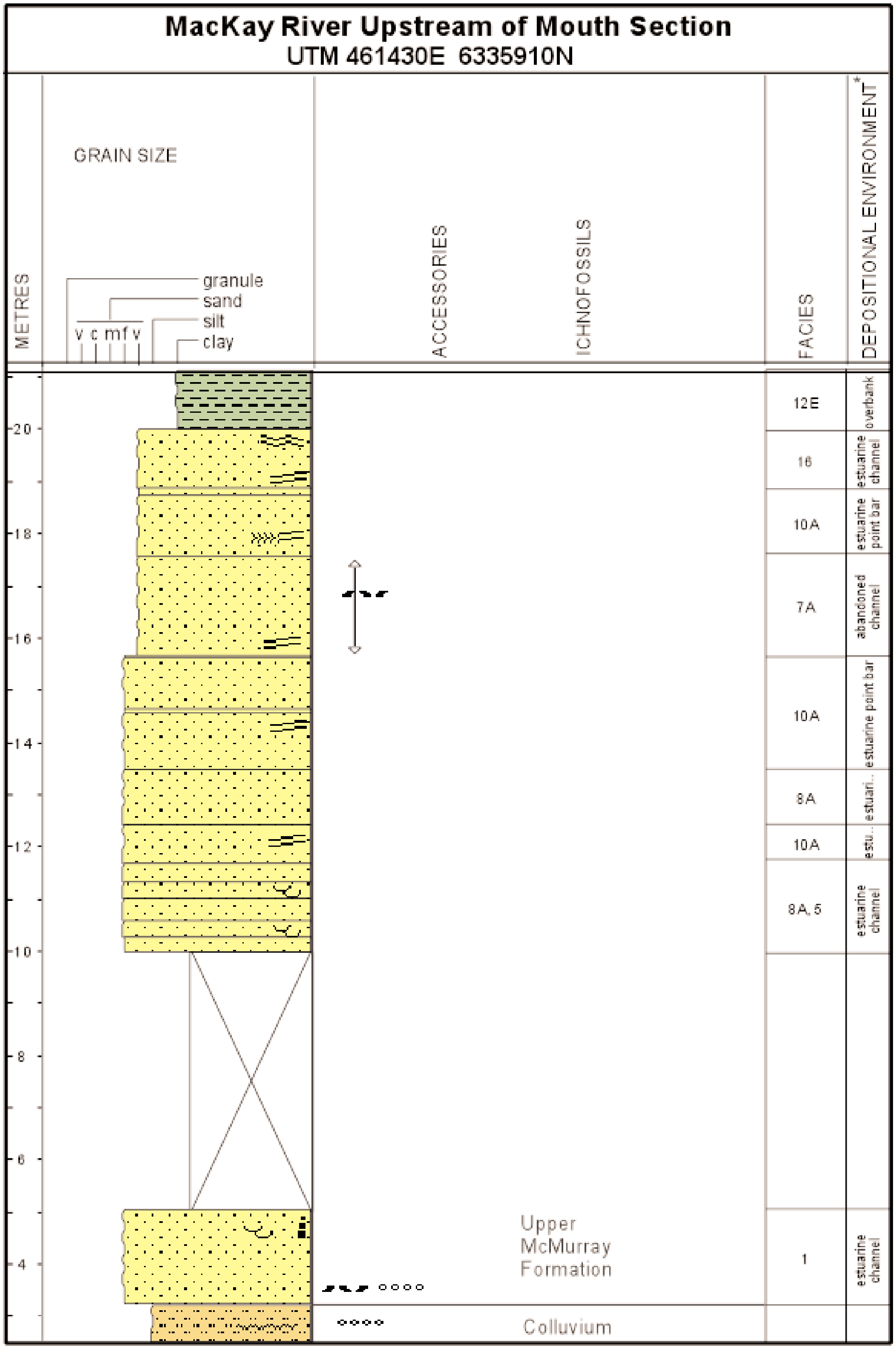
Keynote things to see:

- Lower part of section is coarse-grained, and bitumen-free.
- Good fining-upward successions of bitumen-bearing, stacked estuarine channel and point bar deposits, marked by inclined lateral accretion cross-bedding, with minor herringbone cross-bedding and wavy cross-bedding near the top of the outcrop.

Description: The section starts about 10 to 12 m above river level with exposure of approximately 25 m of partially covered sediment (Figures 6.11.1, 6.11.2.a, b). At the base of the exposure is about 1 m of colluviated pebbly silt. Overlying this is 1.5 to 2 m of very dark gray, bitumen-free, pebbly to coarse medium sand, with dispersed mudstone intraclasts. The sands show large-scale trough cross-bedding (Figure 6.11.1) within an overall fining-upward succession. Next is approximately 5 m of covered section, with oil sand rubble on the slope.

The covered interval is overlain by a 10 m thick unit of thick to medium to bedded oil sand and mudstone units. These units show well-developed lateral accretion cross-bedding (inclined heterolithic stratification) (Figure 6.11.2c), which towards the top of the section have interbedded mudstone clast breccias and minor wavy cross-bedded sands. A thinly laminated siltstone and mudstone (>1 m thick) caps the section (Figure 6.11.2d).

Interpretation: The colluvium at the base of the section is a recent slump deposit. The overlying fining-upward pebbly sands and local mudstone clast breccias with trough cross-bedding are interpreted as high energy, main estuarine-channel sand deposits. The lateral accretion cross-beds in the upper two-thirds of the succession are estuarine point bar deposits. The topmost 2 m of section with the laminated siltstone and mudstone, overlying the fine to well sorted wavy rippled sands, is interpreted as overbank deposits topping the stacked estuarine point bar succession. Although there are no biostratigraphic dates from this section, its present high topographic position, abundance of bioturbated mudstone intraclasts, and common occurrence of inclined heterolithic stratification indicate that this is most likely an Upper McMurray deposit.



*Complete Description in Appendix 3.

Figure 6.11.1. Schematic representation of the measured MacKay River Upstream of Mouth Section (UTM 461430E, 6335910N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 6.11.2a. Overview of Mackay River Upstream of Mouth Section, Mackay River.

Figure 6.11.2b. Thick McMurray succession exposed near the mouth of the MacKay River. Lower portion of section is free of bitumen. Vertical bars show location of the described composite section.

Figure 6.11.2c. Wavy, parallel, thin-bedded, medium-to coarse grained sand with sandy inclined heterolithic stratification (Upper McMurray Formation), MacKay River Upstream of Mouth Section, MacKay River.

Figure 6.11.2d. Thin-and even-bedded fine-sand, siltstone and mudstone overbank deposits (Upper McMurray Formation), top-most unit of the MacKay River Upstream of Mouth Section, MacKay River.

7.0 Ells River Outcrops

Map Coordinates: 74E/4 Fort MacKay, UTM 458600E, 6350800N (for Ells (99-05) Section #5, about mid-way location for the Ells outcrops that were measured).

General Location and Outcrop Selection: From the MacKay River Gauging Station parking access on the dirt track, take the opposite fork in the road at the T-junction, heading north out of the MacKay River valley and into the Ells River valley. Continue north across muskeg highlands until the dirt track drops down into the valley. Park near the oxbow lake by the water pumping station for Fort MacKay. Walk to the ford in the stream and continue along the river bank and wading in the river to get to the cutbank sections. On the Ells River nearly every cutbank on both sides of the river show excellent outcrop exposures, with about 40 suitable outcrops identified from air photograph interpretation of the area. Of these 40 outcrops, about a dozen sections have been measured in detail from the confluence of the Ells River and Joslyn Creek upstream to the Fort MacKay water pumping station (Figures 7.0.1, 7.0.2 and 7.0.3). Note: only access when roads are dry and river is low.

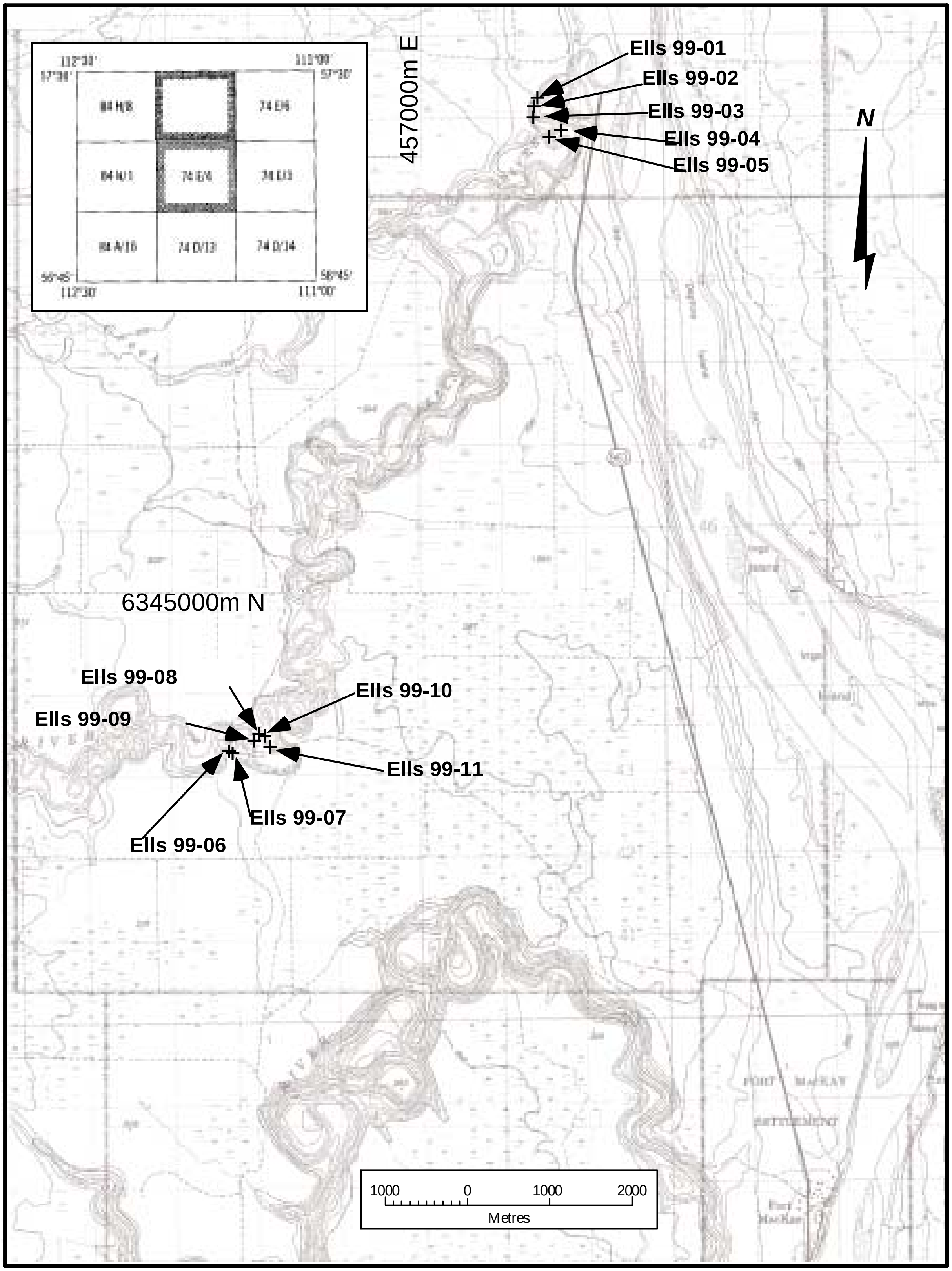


Figure 7.0.1. Map showing access to the Ells River sections about 8.5 km northwest of the Fort MacKay First Nations Settlement by dirt road or about 14 km north to the Ells River mouth sections by boat along the Athabasca River.

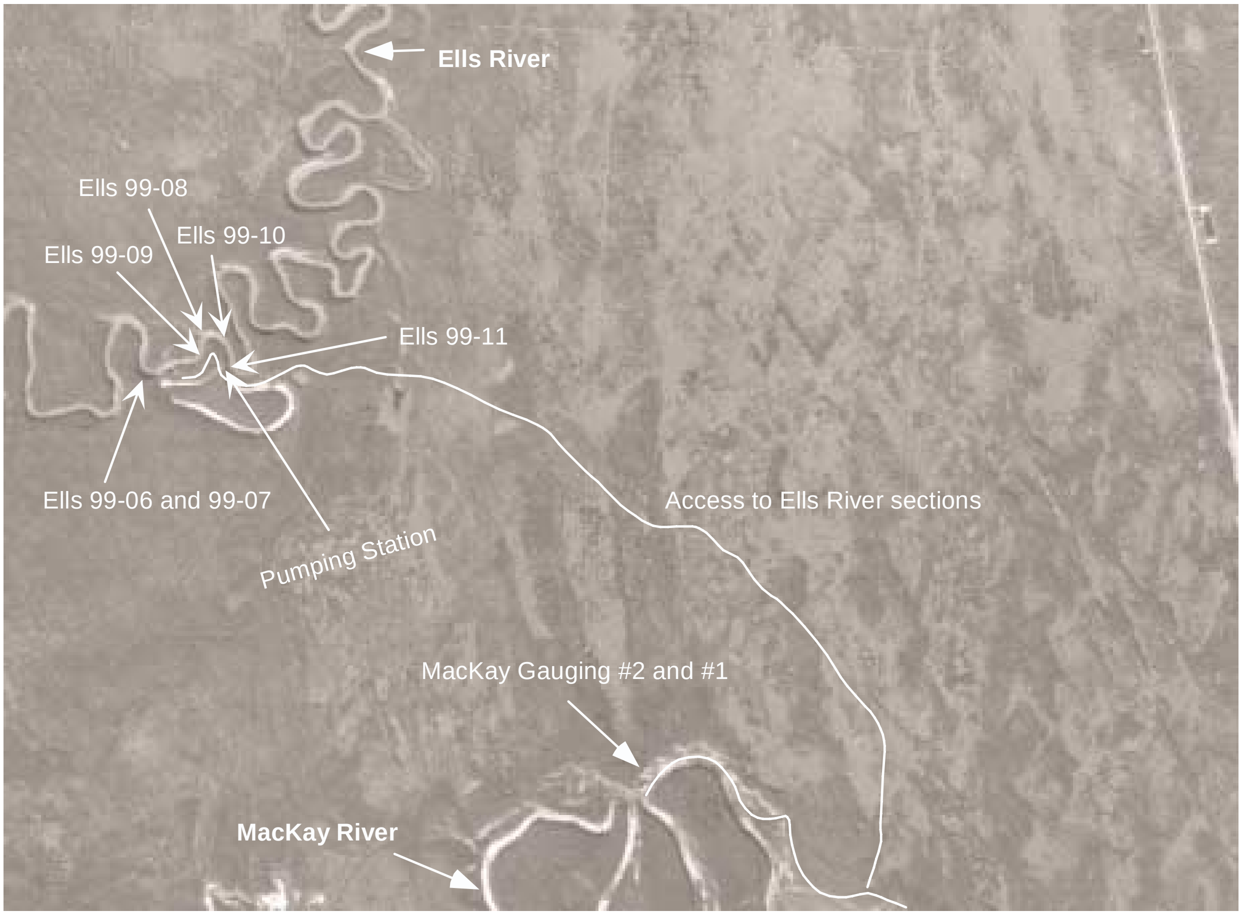


Figure 7.0.2. Aerial photograph showing access to sections on the Ells River near the pumping station.

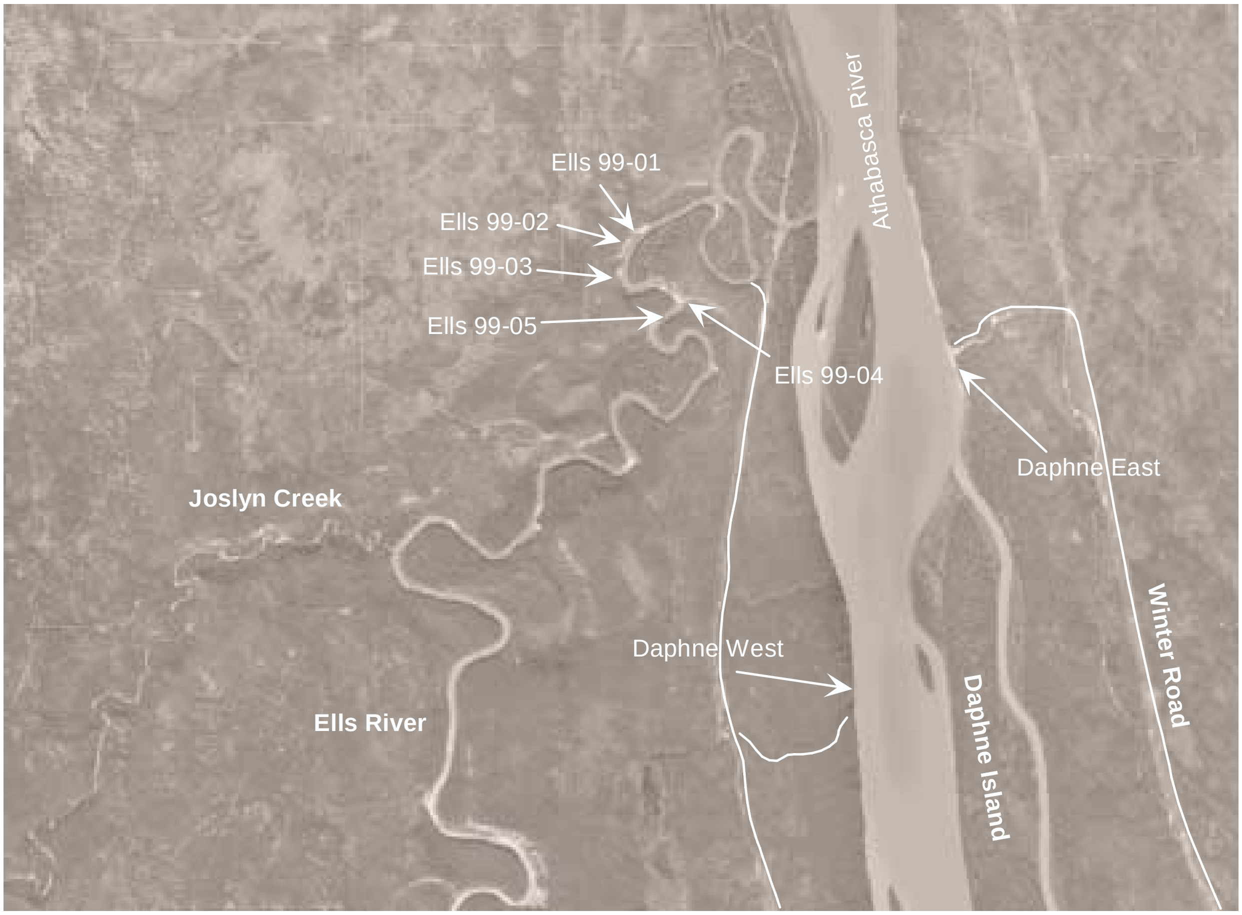


Figure 7.0.3. Aerial photograph showing access to sections near the mouth of the Ells River.

7.1 Ells River (99-01) Section #1

Map Coordinates: 74E/5 Bitumount, UTM 458550E, 6351300N

Keynote things to see:

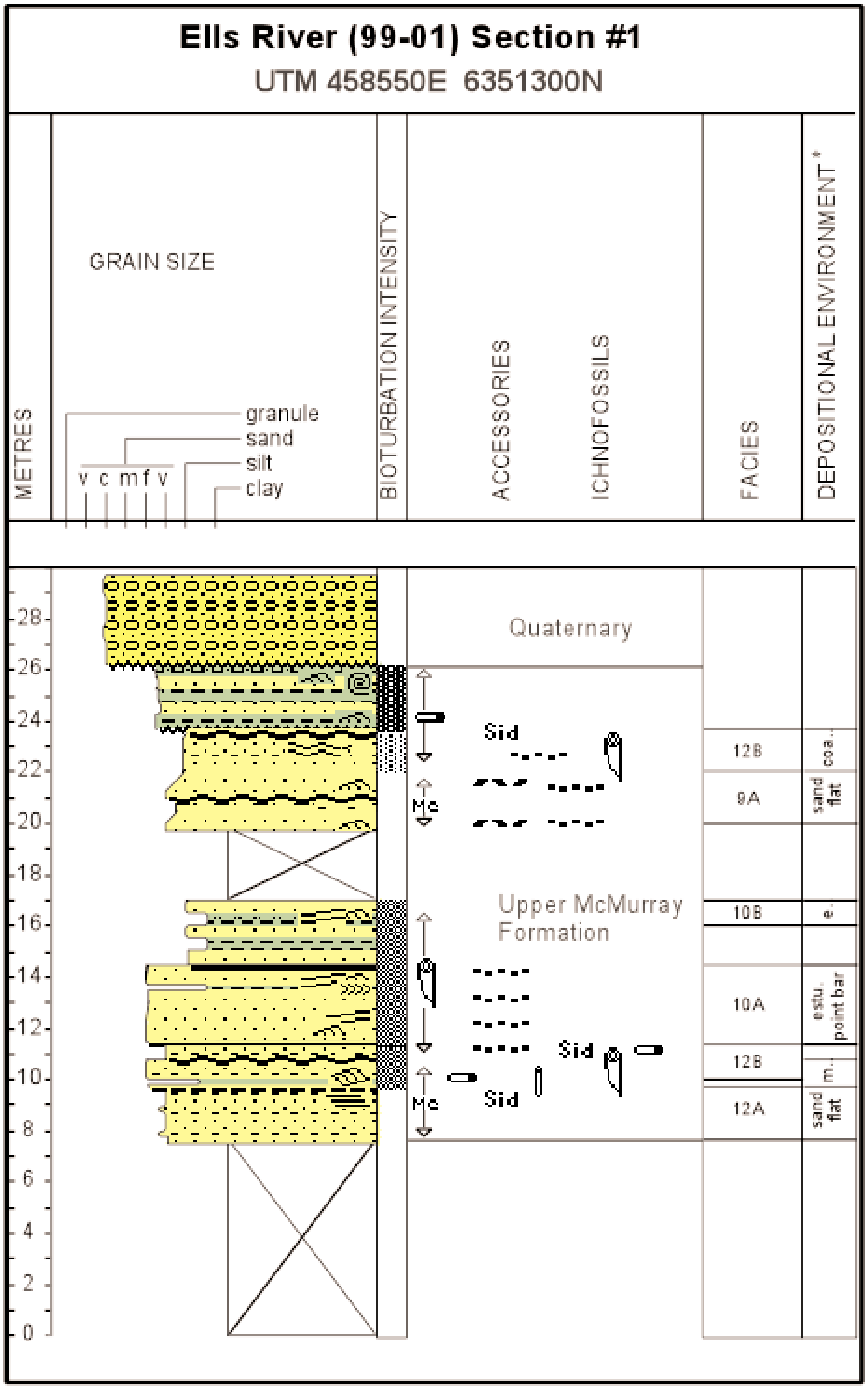
- Interbedded coals and carbonaceous mudstone;
- Lateral continuity and even bedding style;
- Wave-formed sedimentary features;
- Contact between McMurray Formation and Wabiskaw D (Clearwater Formation).

Description: Recent slumping covers about 7.5 m of section. Overlying the covered interval is approximately 18 m of estuarine sediment (Figure 7.1.1.). The sands are associated with medium to thinly interbedded mudstone, coaly silty mudstone, and coal horizons. The bedding style is very even, in comparison with other sections in the study area, and many of the individual beds are traceable along strike for 25 to >100 m. Internally the sands are parallel laminated, and show ripple drift, low-angle inclined cross-bedding and small-scale trough and ripple cross bedding. Burrows are common, both in place and as reworked clasts. Burrow types include *Planolites*, *Skolithos* and *Cylindrichnus*. Upsection there is an increase in the proportion of wave-formed sedimentary structures, including wave-ripples, combined-flow ripples, convolute lamination and chaotic bedding. Sideritized intervals are common, as are the occurrence of dispersed organic detritus and the abundance of mudstone and reworked *Cylindrichnus* burrow intraclasts. Lithologically the McMurray succession here is quite micaceous and is also notable for the increase in the amount of interbedded organic detritus and associated coals.

At the top of the Cretaceous interval is a 2 m thick, very thin bedded and deformed (convoluted with chaotic bedding) muddy sand to sandy mud that is interpreted as the Wabiskaw D interval of the Clearwater Formation that unconformably/disconformably overlies the McMurray Formation in the study area.

At the top of the outcrop, a colluviated Quaternary orange-brown gravel and sand unconformably overlay the Cretaceous succession.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within an estuarine system of point-bars, sand flats, and possibly bay fills, in a nearshore coastal plain setting.



*Complete Description in Appendix 3.

Figure 7.1.1. Schematic representation of the measured Ells River (99-01) Section #1 (UTM 458550E, 6351300N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

7.2 Ells River (99-02) Section #2

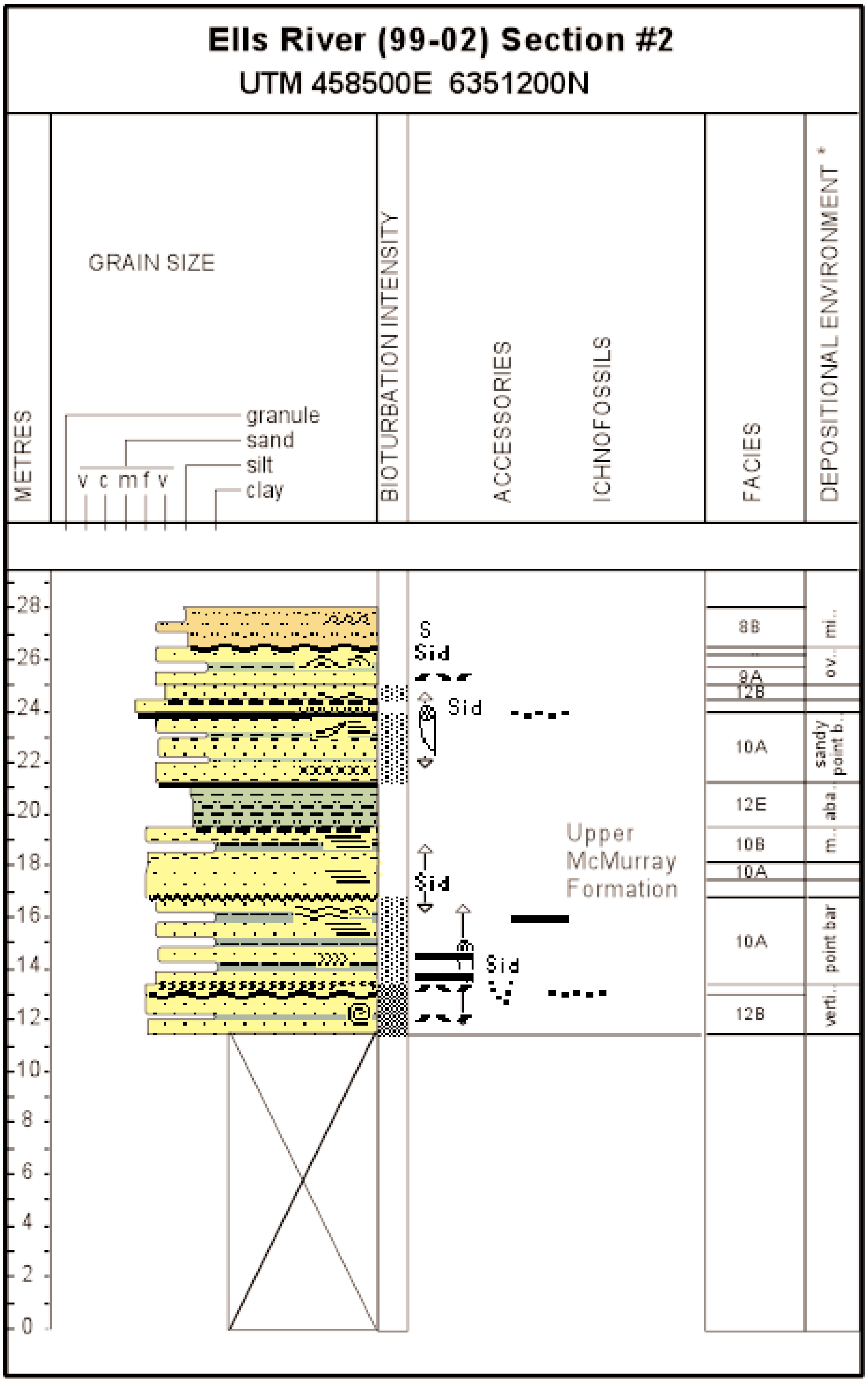
Map Coordinates: 74E/5 Bitumount, UTM 458500E, 6351200N

Keynote things to see:

- Wave-formed structures and parallel lamination, swaley cross-bedding;
- Reworked *Cylindrichnus* burrow fills, interbedded organic horizons and coals;
- *Gyrolithes* trace fossils.

Description: Recent slumping covers about 11.5 m of section. Overlying the covered interval is approximately 16 m of estuarine sediment (Figure 7.2.1.). Internally the sands are parallel laminated, and show convolute bedding, ripple drift, small-scale wave, flaser and ripple cross-bedding, and less commonly swaley cross-bedding. Burrows are common, both in place and as reworked clasts. Burrow types include *Planolites, Gyrolithes* and *Cylindrichnus*. Upsection there is an increase in the proportion of wave-formed sedimentary structures, including wave-ripples, and chaotic bedding. Sideritized intervals are common, as are the occurrence of dispersed organic detritus and the abundance of mudstone and reworked *Cylindrichnus* burrow intraclasts. At the top of the outcrop is 1.5 m thick, thin-bedded and convoluted sandy silt. Lithologically the McMurray succession here is quite micaceous and is also notable for the increase in the amount of interbedded organic detritus and associated coals.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within an estuarine system of vertical accretion abandoned channel deposits, sandy and muddy point-bars and mud and sand flats, in a nearshore coastal plain setting.



*Complete Description in Appendix 3.

Figure 7.2.1. Schematic representation of the measured Ells River (99-02) Section #2 (UTM 458500E, 6351200N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

7.3 Ells River (99-03) Section #3

Map Coordinates: 74E/5 Bitumount, UTM 458450E, 6351050N

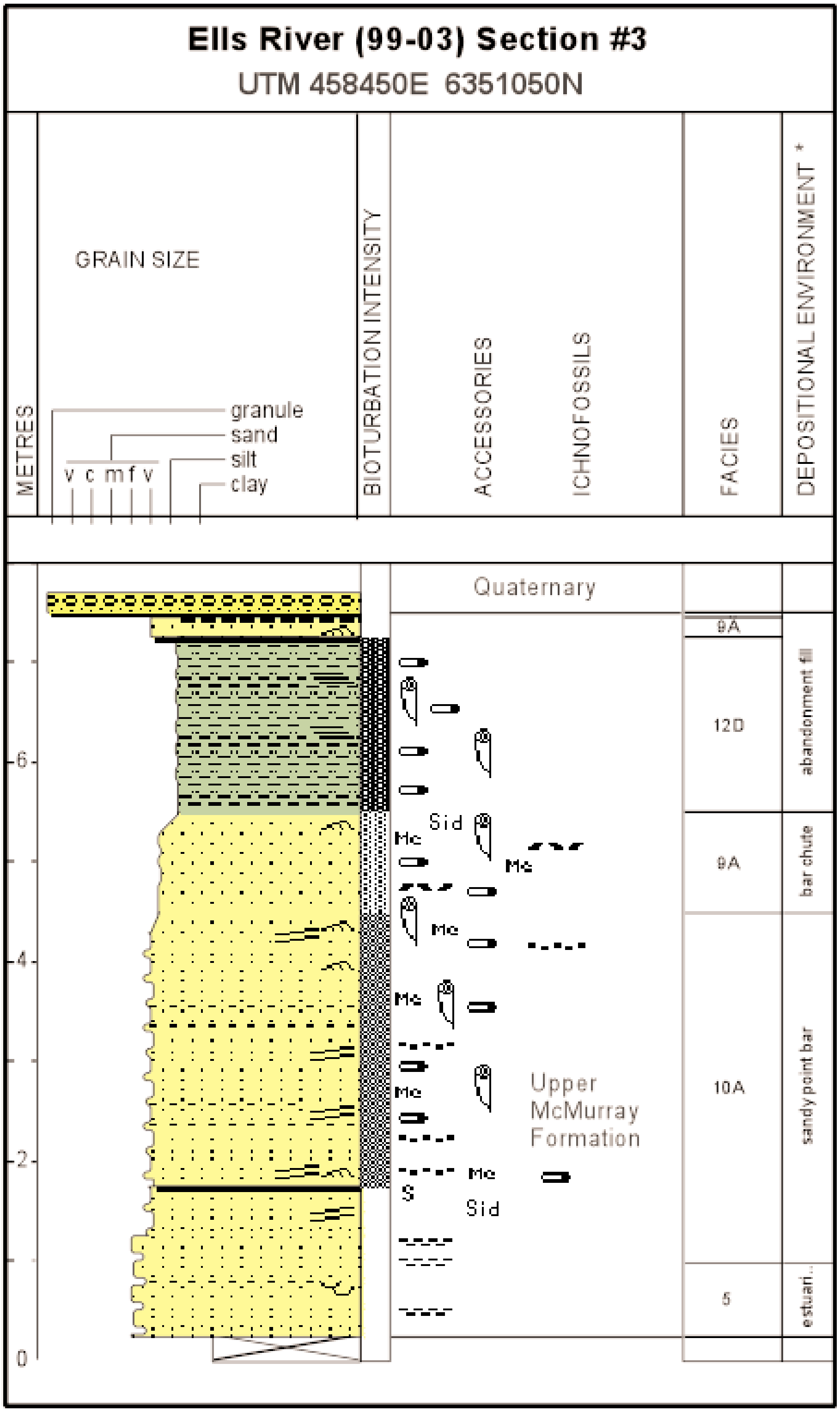
Keynote things to see:

- Single 8-10 m upward fining succession, capped by a vertical accretion abandoned channel deposit;
- Lateral continuity and even bedding style.

Description: From river level about 8 m of section is preserved of estuarine successions (Figure 7.3.1). The sands are medium- to thinly-interbedded with mudstone. The bedding style is very even and many of the individual beds are traceable along strike for the entire outcrop (i.e. 8 to over 100 m). Internally the sands are trough cross-bedded; with low-angle inclined heterolithic lateral accretion and ripple cross-bedding. Overall the entire outcrop shows a single fining-upward succession. Common burrow types include *Planolites* and *Cylindrichnus*. Sideritized intervals are common, as are the occurrence of dispersed organic detritus and the abundance of mudstone and reworked *Cylindrichnus* burrow intraclasts. At the top of the outcrop is a 2 m thick, very thin bedded and parallel laminated heavily burrowed micaceous, silty mudstone. Lithologically the McMurray succession here is quite micaceous and is also notable for the increase in the amount of siderite, along with organic detritus and associated coals.

Unconformably overlying the McMurray Formation at this section is a thin (<1 m) unit of Quaternary colluvium.

Interpretation: The succession is interpreted as part of the Upper McMurray deposited within an estuarine channel to sandy point-bar deposit, capped by the vertical accretion abandoned channel deposit.



*Complete Description in Appendix 3.

Figure 7.3.1. Schematic representation of the measured Ells River (99-03) Section #3 (UTM 458450E, 6351050N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

7.4 Ells River (99-04) Section #4

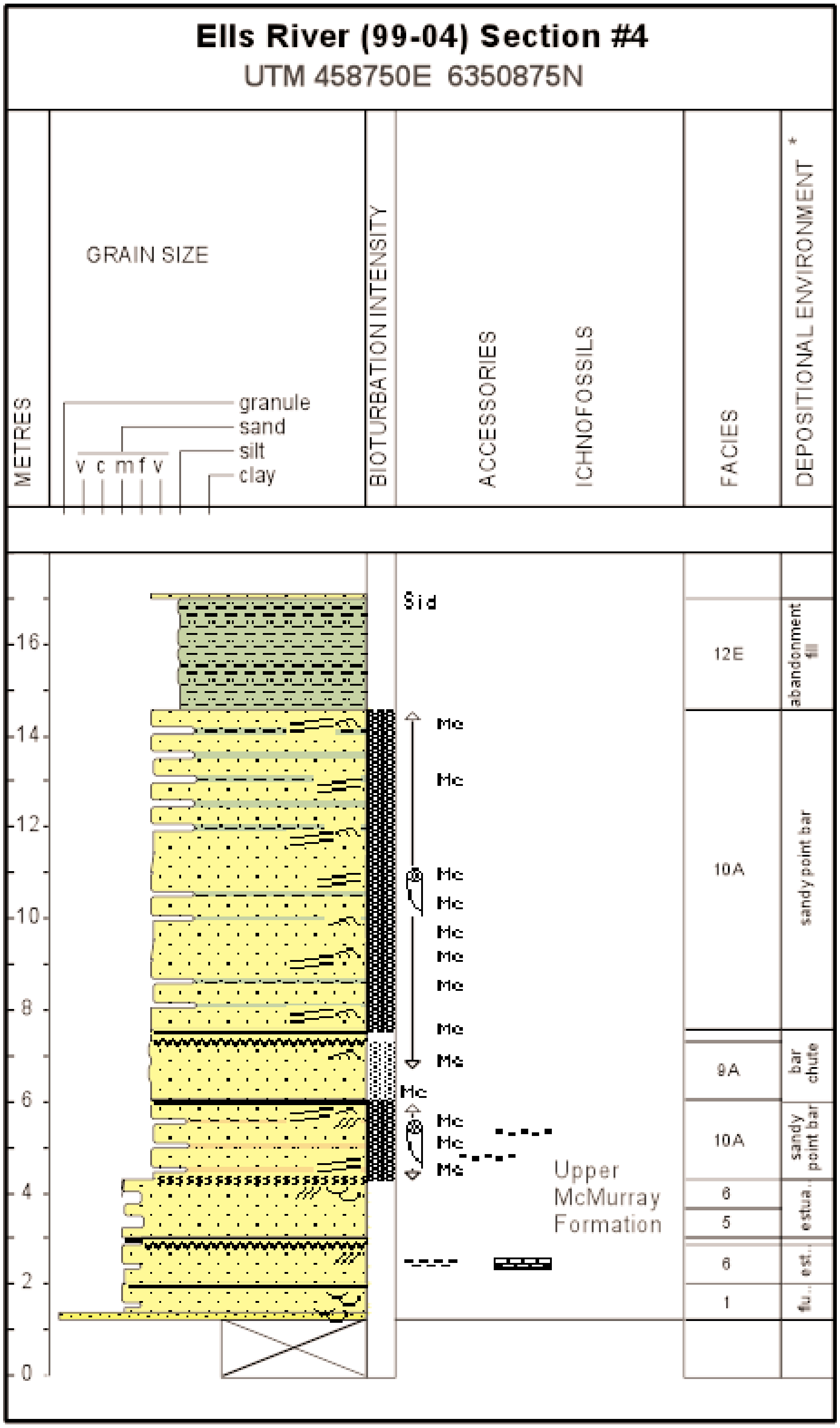
Map Coordinates: 74E/5 Bitumount, UTM 458750E, 6350875N

Keynote things to see:

- Decrease in lateral continuity and a more uneven bedding style;
- Estuarine channel sands to vertically stacked, sandy point bar deposits, capped by vertical accretion, abandoned channel deposits.

Description: From river level about 1.5 m of section is covered. Overlying the covered interval is approximately 16 m of estuarine sediment (Figure 7.4.1). The sands are medium- to thinly-bedded with interbedded mudstone and clayey silts. The bedding style is less even and traceable, in comparison with the previous three Ells River sections, and many of the individual beds are traceable along strike for 10’s of metres as opposed to 100’s of metres in Ells 99-01 through 99-03 outcrops. At the base of the section is a trough cross-bedded medium-grained to pebbly sand, overlain by medium-grained sand with trough and planar tabular cross-beds, with mudstone and organic-rich interlaminae. Overlying these sands are stacked successions of low-angle, inclined heterolithic stratification that each fine-upward into rippled cross-beds. For the most part there is little mudstone preservation within the sand-dominated inclined heterolithic stratified units. Thin localized cut-and-fills occur within the succession. *Cylindrichnus* burrows are common both in place and as reworked mudstone intraclasts. At the top of the outcrop is an inaccessible 2 m thick, thin-bedded silty mudstone that is capped by a tight sideritized interval. Lithologically the McMurray succession here is quite micaceous and contains abundant organic detritus.

Interpretation: The succession is interpreted as Upper McMurray deposited within an estuarine channel to sandy point-bar deposit, capped by a series of stacked sandy point bars, and at the top a vertical accretion, abandoned channel deposit, all within a nearshore coastal plain setting.



*Complete Description in Appendix 3.

Figure 7.4.1. Schematic representation of the measured Ells River (99-04) Section #4 (UTM 458750E, 6350875N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

7.5 Ells River (99-05) Section #5

Map Coordinates: 74E/5 Bitumount, UTM 458600E, 6350800N

Keynote things to see:

- Thick stacked, medium- to coarse-grained Lower McMurray fluvial channel sands with planar tabular cross-beds;
- Unconformity between Lower McMurray and Upper McMurray successions, marked by a transgressive lag, overlain by estuarine channel and point bar sands;
- Switching of paleoflows below and above transgressive lag.

Description: From river level about 1.0 m of section is covered. Overlying the covered interval is approximately 16 m of estuarine sediment (Figure 7.5.1). The sands are medium- to coarse-grained sand with minor interbedded mudstone and clayey silts only at the top of the sand succession. Most of the sands show dominantly planar tabular cross-bedding, with minor rippled interbeds (Figure 7.5.2b). Some of the planar tabular sets show coarsening- then fining-upward trends; others are stacked above one another without any obvious upsection grain-size trends. About a third the way upsection is a 1 to1.25 m thick gravel to pebbly sand that thins to 0.15 m in a downstream direction over the length of the outcrop (i.e., about 15 m laterally) (Figure 7.5.2a). Most notable is that the paleoflow directions in the planar tabular cross-beds above and below this gravelly unit are diametrically opposed to one another (i.e., 180 degrees apart) (Figure 7.5.2a). For the most part there is little mudstone preservation within the sand-dominated, planar tabular cross-bedded units. The topmost sand beds do show some mudstone within inclined heterolithic cross-bedding that is capped by rippled sands (Figure 7.5.1). At the top of the out-crop is an inaccessible 6 to 7 m thick, thin-bedded, recessive, silty mudstone. Lithologically the McMurray succession here is quartzose, lacking the mica and organic material that is abundant in the fine-grained successions that are common elsewhere on many of the Ells River exposures.

Interpretation: Beneath the gravel, the succession is interpreted as Lower McMurray fluvial low-stand deposits, the gravel unit as a transgressive lag above the transgressive surface of erosion, and the upper part as open estuarine bay-fill and sandy estuarine point bar deposits of the Upper McMurray Formation. The top of the succession is interpreted as either estuarine bay-fill or estuarine abandoned channel fill deposits of the upper portion of the Upper McMurray Formation.

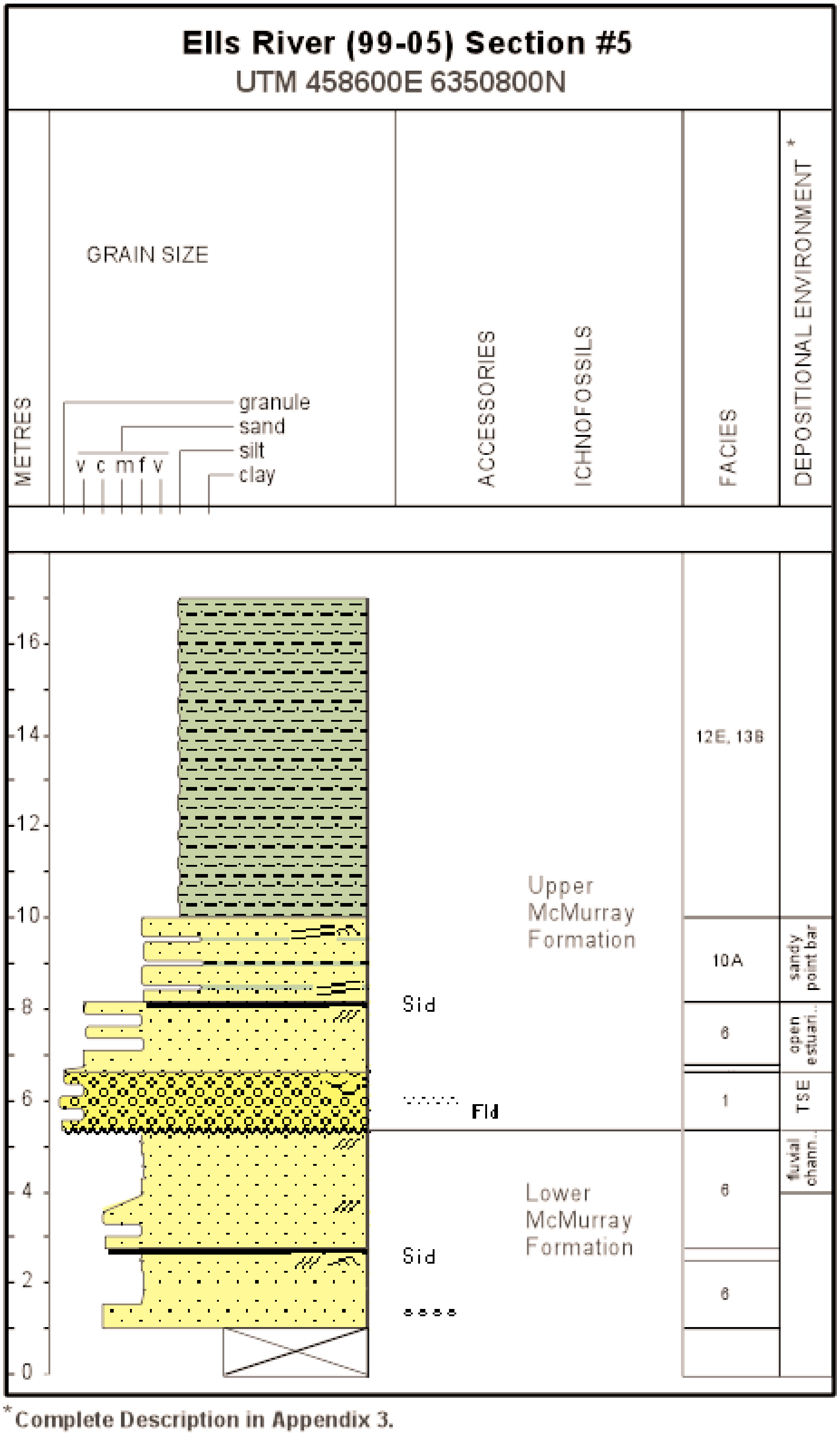


Figure 7.5.1. Schematic representation of the measured Ells River (99-05) Section #5 (UTM 458600E, 6350800N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

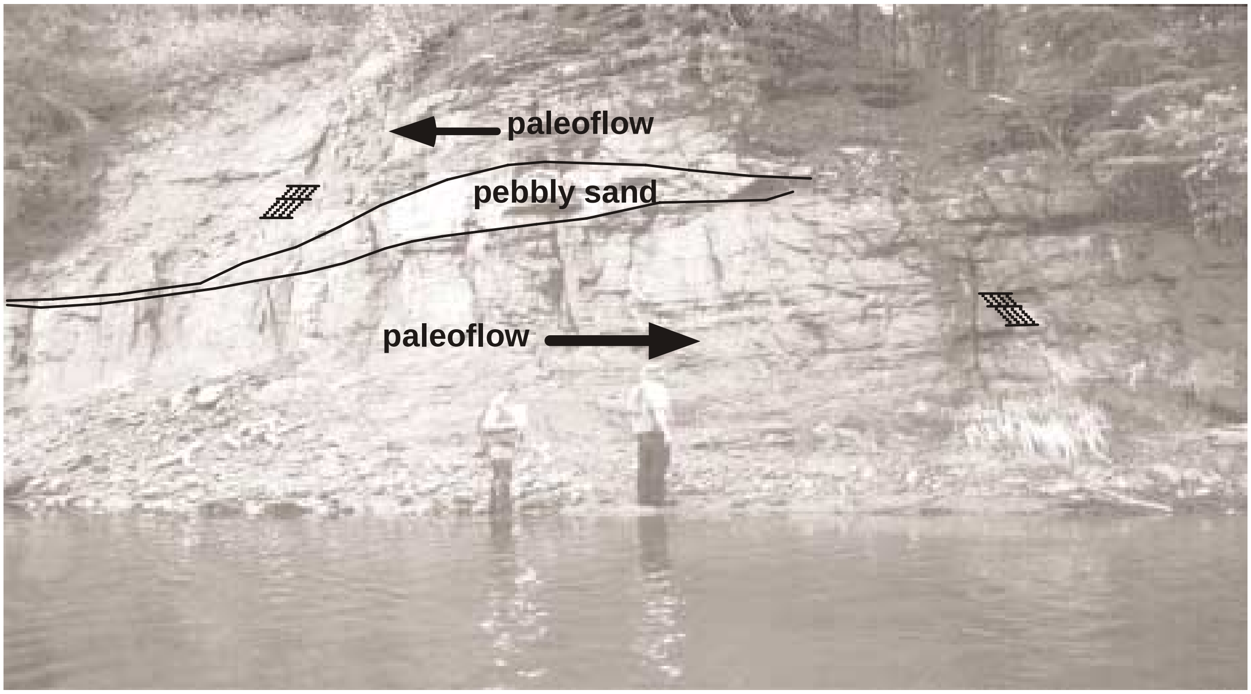


Figure 7.5.2a. Stacked, high-angle, planar tabular cross-bedding (at base Lower McMurray; above is Upper McMurray Formation) separated by a variably thick, pebbly to granular sand at the base of the Upper McMurray succession. Distinct paleoflow reversal above and below the coarse-grained unit. Ells River (99-05) Section #5.


Figure 7.5.2b. Stacked, high-angle planar tabular cross-bedded sand interbedded with thin (<10 cm thick) rippled sand (Lower McMurray Formation), Ells River (99-05) Section #5.

7.6 Ells River (99-06) Section #6

Map Coordinates: 74E/5 Bitumount, UTM 454750E, 6343300N

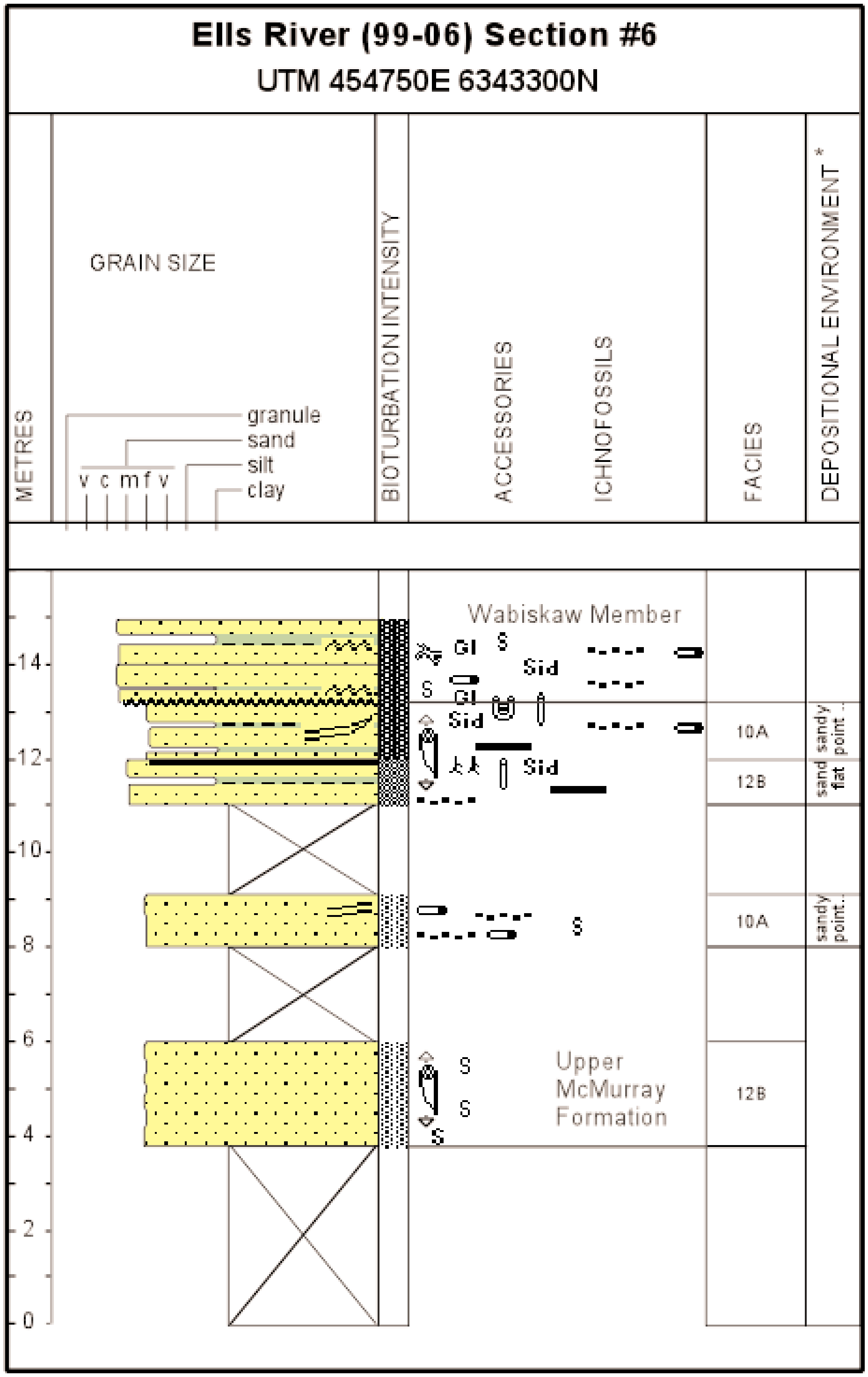
Keynote things to see:

- Decrease in lateral continuity and a more uneven bedding style;
- Estuarine channel sands to sandy point bar deposits, capped by overbank rooted unit;
- Contact between the McMurray Formation and the Wabiskaw D unit.

Description: Recent slumping covers about 3.5 m of section. Overlying the covered interval is approximately 10 m of estuarine sediment (Figure 7.6.1). The sands are medium- to thinly-bedded with interbedded mudstone and clayey silts. The bedding style is more discontinuous compared with other fine-grained successions on the Ells River. At the base of the section, the sand is massive with vague trough cross-bedding (Figure 7.6.2). The top of the McMurray Formation is a thinly bedded, medium-grained sand that is rooted and burrowed, interbedded with coal and mudstone (coastal plain, Figure 7.6.2). Burrow types within the McMurray include *Cylindrichnus* and *Planolites*.

At the top of the outcrop is a burrowed thinly interbedded glauconitic sand and mudstone that has a much more intense degree of bioturbation, along with a more diverse and robust trace fossil. Trace fossils include *Diplocriterion*, *Planolites* and *Thallasinoides*. This unit is interpreted as the Wabiskaw D interval that unconformably overlies the McMurray Formation in the area (Wabiskaw Mbr., Figure 7.6.2).

Interpretation: The succession is interpreted as Upper McMurray that was deposited within a sandy estuarine channel, capped by coastal plain deposits from estuarine bay-fills. The sandy channel sands change into more muddy estuarine deposits about 100 m in a downstream, along-strike direction.



*Complete Description in Appendix 3.

Figure 7.6.1. Schematic representation of the measured Ells River (99-06) Section #6 (UTM 454750E, 6343300N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

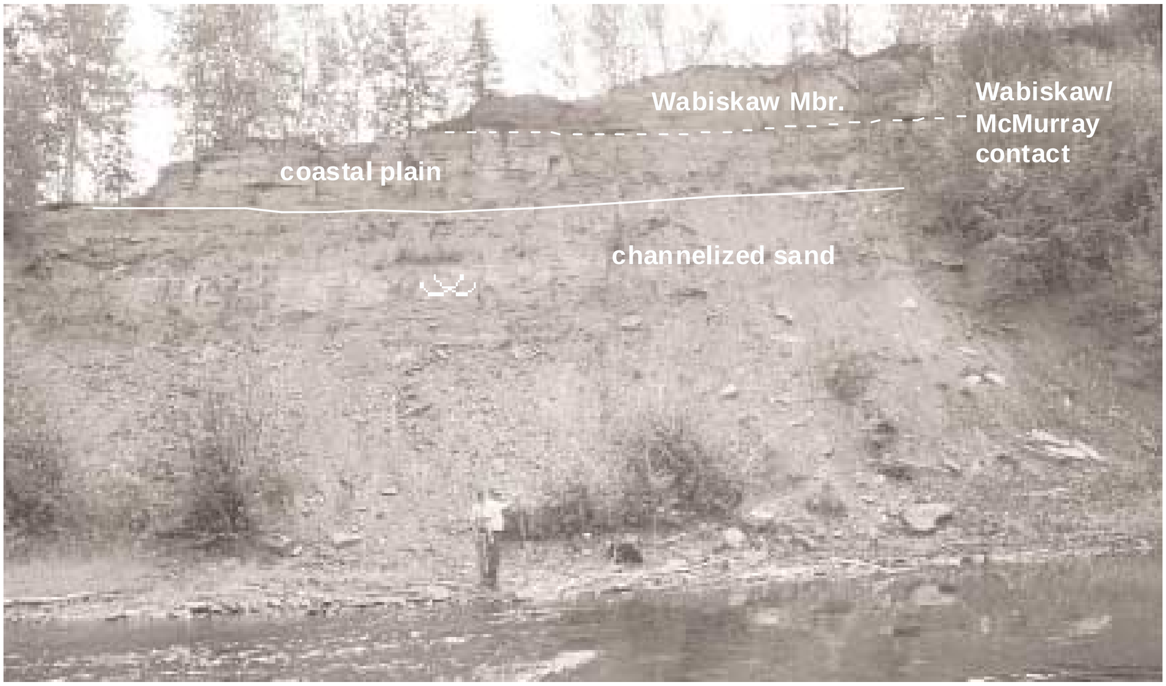


Figure 7.6.2. Channelized estuarine sand overlain by coastal plain deposits of the Upper McMurray Formation, unconformably overlain by the Wabiskaw D interval (Ells River (99-06) section #6 upstream from the pumping station).

7.7 Ells River (99-07) Section #7

Map Coordinates: 74E/5 Bitumount, UTM 45760E, 6343310N

Keynote things to see:

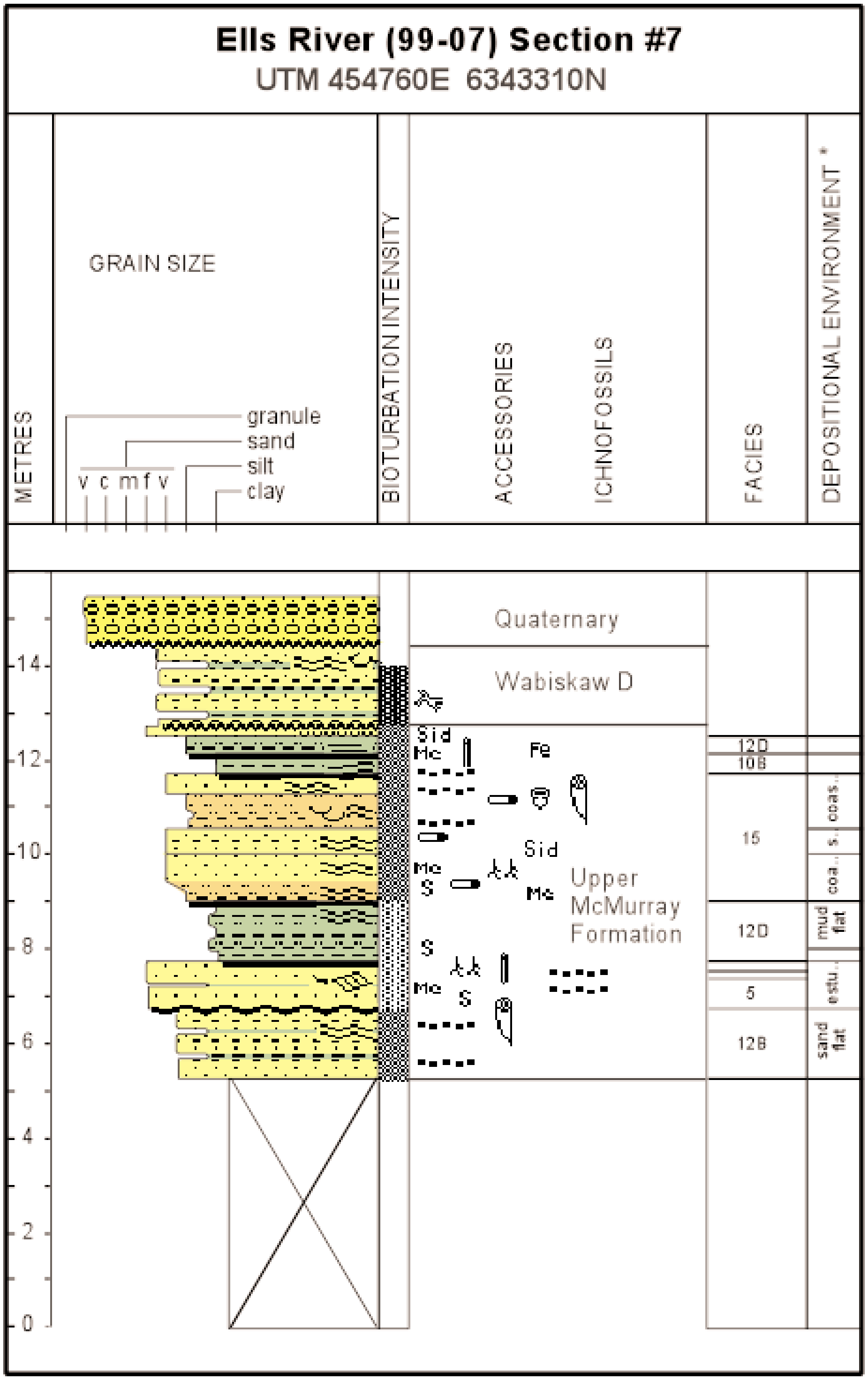
- Interbedded coals and carbonaceous mudstone;
- Lateral continuity and even bedding style;
- Stacked upward coarsening successions, with nested channels and tidal-runnel fills;
- Variable paleoflow patterns.

Description: From river level about 5.5 m of section is covered. Overlying the covered interval is about 9 m of estuarine sediment (Figure 7.7.1). The sands are medium- to thinly-bedded with interbeds of mudstone, coaly silty mudstone, and coal horizons. The bedding style is very even and many of the individual beds are traceable along strike for the entire outcrop (i.e. 10's m to >100 m). Internally most of the sands show wavy, non-parallel bedding, with less common trough cross-bedding, low-angle inclined heterolithic stratification and ripple drift cross-bedding. Overall the entire outcrop shows a series of stacked coarsening-upward successions. Burrows are common and include *Planolites*, *Cylindrichnus, Skolithos,* and *Bergaugeria.* Roots and sideritized intervals are common, as are the occurrence of dispersed organic detritus and the abundance of interbedded recessive mudstone and muddy silts. At about 11.5 m of section is a single, cut-and-fill structure. Just below the top of the section are smaller scale (<0.25 m high), nested, and multiply-stacked cut-and-fill structures, interpreted as possible tidal-runnel fills. Paleoflow patterns are diverse, including: channel axes trending northwest-southeast; laterally adjacent inclined heterolithic deposits oriented northeast-southwest; wave ripple crests oriented northwest-southeast; and current ripples trending northwest-southeast. Lithologically the McMurray succession here is quite micaceous and is also notable for the increase in the amount organic detritus and associated rooted horizons.

At the top of the Cretaceous succession is a 1.5 to 1.75 m thick interval of the Wabiskaw D unit that unconformably overlies the McMurray Formation in this area.

Unconformably overlying the Cretaceous succession at this outcrop is a thin (about 1 m) unit of Quaternary overburden.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within an estuarine sand flat with small channels and muddy and sandy point-bars, capped by rooted overbank horizons. The stacked upward coarsening successions represent the transitions from vertical accretion abandoned channel fill or mudflat deposits to sandy flat or washover deposits within a coastal plain setting.



*Complete Description in Appendix 3.

Figure 7.7.1. Schematic representation of the measured Ells River (99-07) Section #7 (UTM 454760E, 6343310N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

7.8 Ells River (99-08) Section #8

Map Coordinates: 74E/5 Bitumount, Scale 1: 50 000, UTM 0455100E, 6343580N

Keynote things to see:

- Interbedded coals and carbonaceous mudstone;
- Lateral continuity and even bedding style;
- Wave-formed structures;
- Stacked fining-upward successions;
- Variable paleoflow patterns.

Description: From river level about 13.5 m of a partially covered section occurs of estuarine sediments (Figure 7.8.1). Even-bedded, continuous, medium-grained sands (traceable across the outcrop for over 100 m) are interbedded with mudstone and coaly horizons. Internally most of the sands are rippled towards the base of the section, with an increase in the amount of combined-flow and wave-formed structures towards the top. Overall the entire outcrop shows a series of upward fining successions stacked above one another. Burrows are common and include *Planolites* and *Cylindrichnus.* Sideritized intervals are common, as are the occurrence of dispersed organic detritus and the abundance of interbedded recessive mudstone and muddy silts. Paleoflow patterns are diverse, including: channel axes trending southwest; wave ripple crests oriented northeast-southwest; current ripples southeast, northwest, and local troughs oriented northwest. Lithologically the McMurray succession here is quite micaceous and is also notable for the increase in the amount of sideritized zones.

At the top of the Cretaceous succession is a 1.5 to 1.75 m thick interval of the Wabiskaw D unit that unconformably overlies the McMurray Formation in this area.

Unconformably overlying the Cretaceous succession at this outcrop is a thin (about 1 m) unit of Quaternary overburden.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within an estuarine sand and mudflat flat with small channels and muddy point-bars. The stacked fining-upward successions represent the transitions from channel and point bar to mudflat or overbank environments within a coastal plain setting.

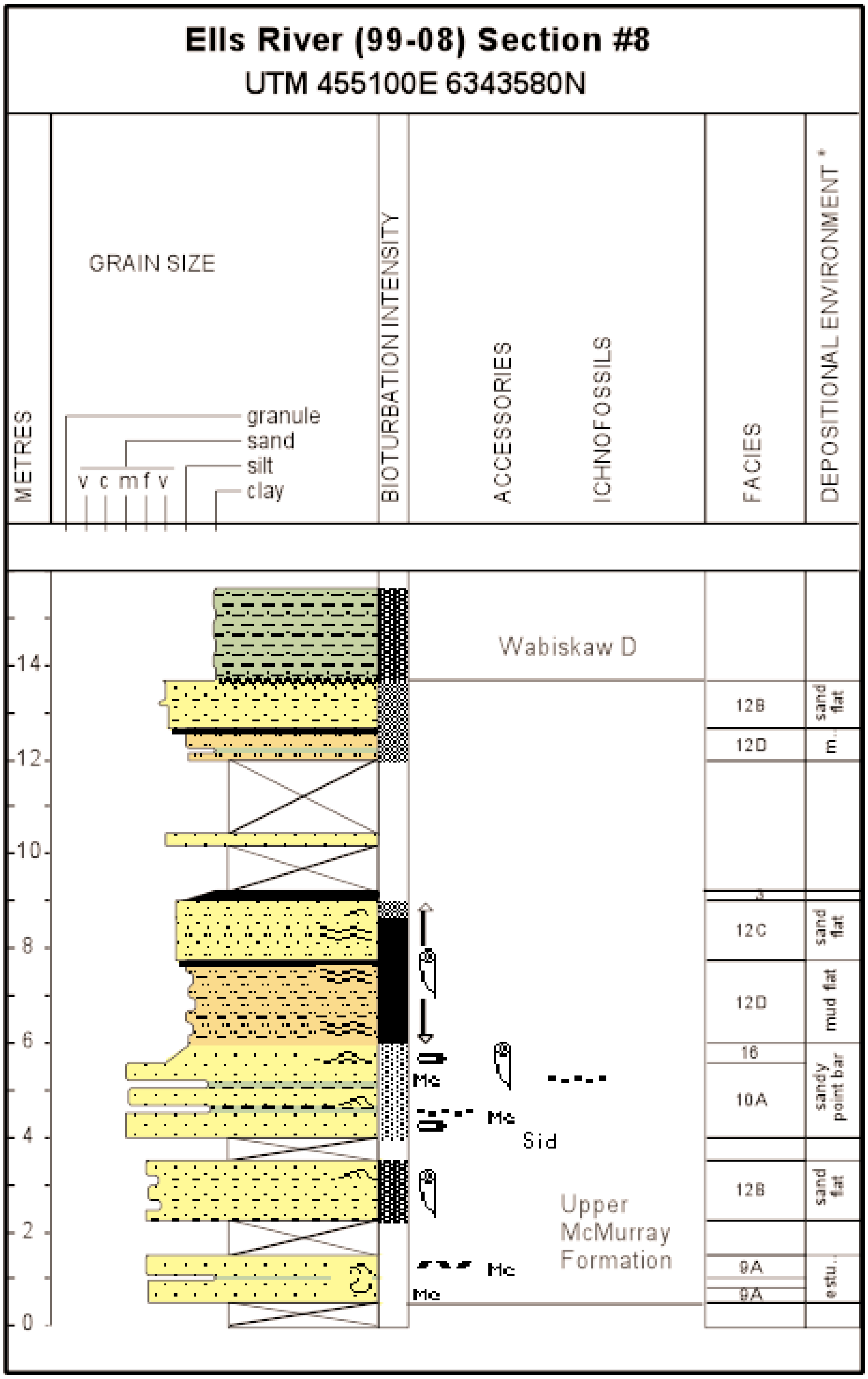


Figure 7.8.1. Schematic representation of the measured Ells River (99-08) Section #8 (UTM 455100E, 6343580N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

7.9 Ells River (99-09) Section #9

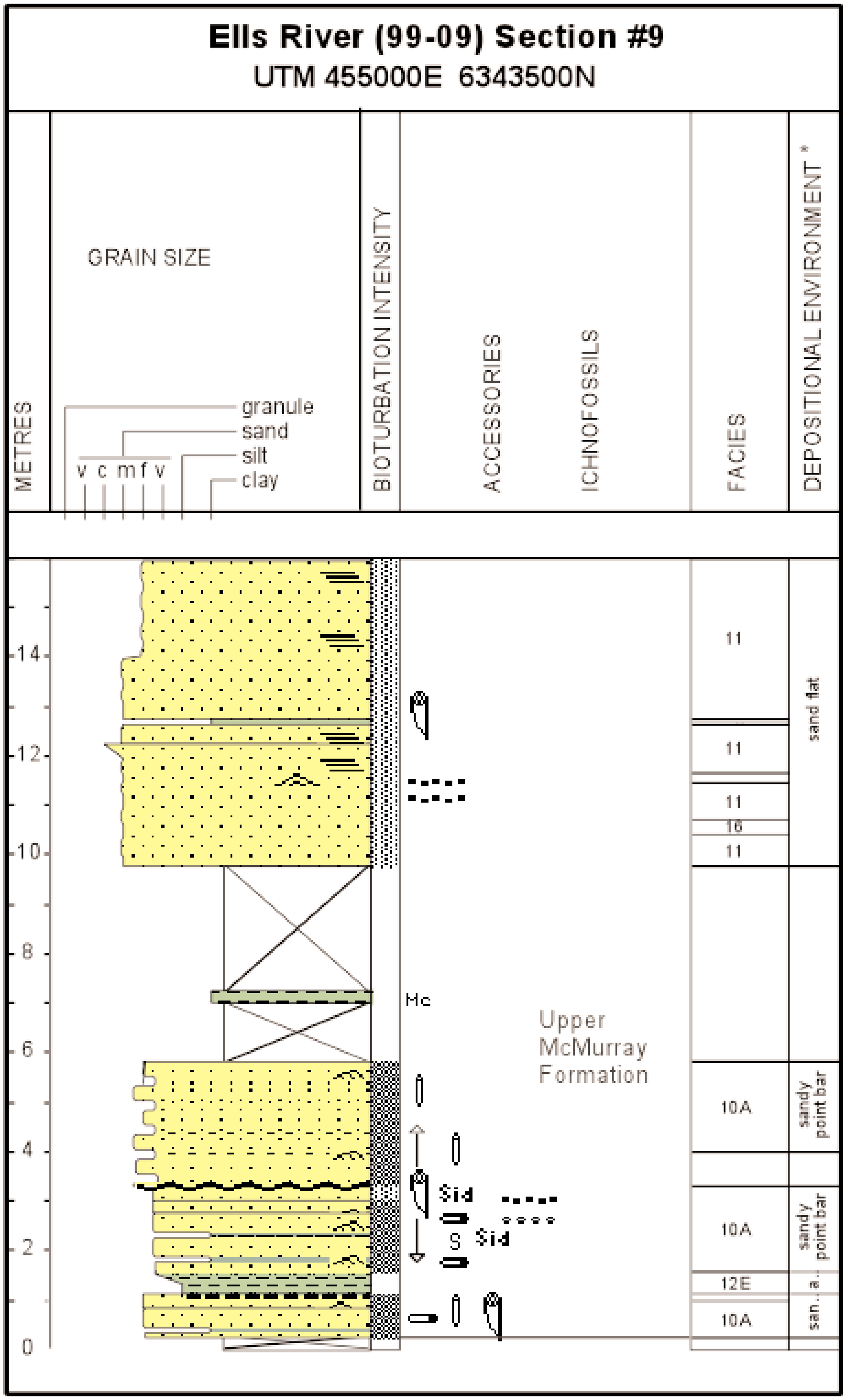
Map Coordinates: 74E/5 Bitumount, UTM 455000E, 6343500N

Keynote things to see:

- Interbedded coals and carbonaceous mudstone;
- Lateral continuity and even bedding style;
- Wave-formed structures and parallel lamination;
- Bay-fill or vertical accretion, abandoned channel fill deposit;
- Variable paleoflow patterns.

Description: From river level about 16 m of a partially covered section occurs of estuarine sediments (Figure 7.9.1). Medium-grained sands are thinly interbedded with mudstone and coaly mudstone. As with many of the other fine-grained outcrops on the Ells River, the bedding style is very even and continuous, with individual beds traceable for over 100 m. Internally most of the sands are wave or current rippled towards the base of the section, with an increase in the amount of parallel lamination and wave-formed structures towards the top (Figure 7.9.2). Overall the entire outcrop shows a upward coarsening succession. Burrows are common in the lower part of the section, including *Planolites, Skolithos* and *Cylindrichnus.* Sideritized intervals are common towards the fine-grained base of the section, along with the increased dispersed organic detritus and interbedded recessive mudstone and muddy silts. Upsection, within the coarser-grained units, bioturbation decreases with the exception of *Cylindrichnus* that was observed within the muddy beds. Paleoflow patterns are variable, including wave ripple crests oriented northwest-southeast, and current ripples with paleoflows to the south and north. Lithologically the McMurray succession here is micaceous and sideritized.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within an estuarine sandflat and mudflat setting at the base, with thick recessive and mainly covered mudstone interval in the middle of the section (from 6 to 10 m height) being either a bay-fill or a vertical accretion abandoned estuarine complex. The uppermost sands, with the wave-ripple and parallel lamination, and minor *Cylindrichnus*-burrowed mudstone, may be from a shoreline or bay setting.



*Complete Description in Appendix 3.

Figure 7.9.1. Schematic representation of the measured Ells River (99-09) Section #9 (UTM 455000E, 6343500N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 7.9.2a. Overview of Ells #9 (99-09) Section #9, Ells River.

Figure 7.9.2b. Wave-rippled, very fine- to fine-grained sand, bedding plane top view showing sinuous, out-of-phase wave-ripples (Upper McMurray Formation), Ells River (99-09) Section #9.

7.10 Ells River (99-10) Section #10

Map Coordinates: 74E/5 Bitumount, UTM 455130E, 6343550N

Keynote things to see:

- Interbedded coals and carbonaceous mudstone;
- Minor interbedded gravels and pebbly sands;
- Wabiskaw D at the inaccessible top part of the outcrop, seen in float.

Description: At the base of the section from river level a sandy mudstone is overlain by about 13.5 m of estuarine sediment (Figure 7.10.1). The sands are medium- to thinly- bedded with associated continuous beds of burrowed mudstone and coaly mudstone (traceable along the outcrop for about 10 to 25 m) (Figures 7.10.2a, b). Traces include common *Cylindrichnus* traces, less common *Skolithos*. Near the base of the section sands are interbedded with mudstone that is interpreted as low angle inclined lateral accretion cross-bedding, 4 m thick (Figure 7.10.2a). The interbedded sand and mudstone is overlain by recessive mudstone. The next unit starts with burrowed sand and mudstone, with siderite concretions at the base (Figure 7.10.1) and dispersed mudstone and *Cylindrichnus* burrow-fill intraclasts upsection. Sedimentary structures include small-scale trough cross-beds, current ripples and wavy, combined-flow ripples. Minor granule to pebble interbeds are present. The overall succession then fines upward for 4 to 5 m where it is capped by a continuous coal and carbonaceous shale horizon (Figure 7.10.2b). A partially covered, recessive clayey silt overlies this organic horizon. Associated trace fossils within this second fining-upward unit include *Cylindrichnus* and *Planolites*. At the top of the McMurray is a siderite concretion zone, overlain by a burrowed sandy-silty micaceous mudstone that has abundant organic debris. Trace fossils include *Bergaugeria* in association with *Planolites* and *Cylindrichnus.* Lithologically the McMurray succession here is quite micaceous, sideritic with abundant organic detritus and laterally continuous coals.

At the top of the outcrop is an inaccessible, 2.5 m thick, black, sandy mudstone that is heavily burrowed with marine traces (as seen in float) and has a wavy to swaley bedding style. This is the Wabiskaw D interval that unconformably overlies the McMurray Formation in this area.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within an estuarine channel to sandy and muddy point-bars, capped by the vertical accretion abandoned channel deposit, and more marine muddy sand at the top, in a nearshore coastal plain setting.

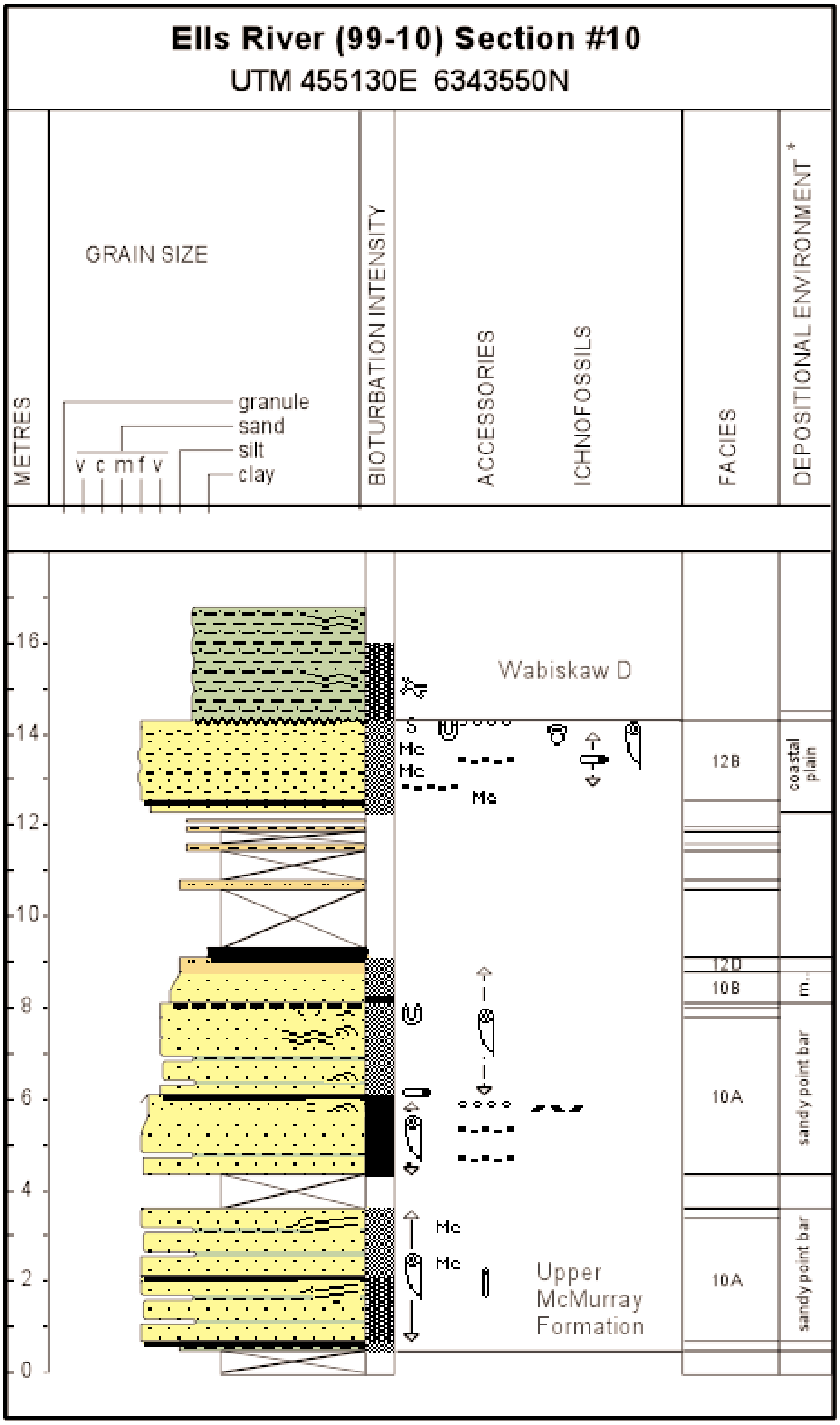


Figure 7.10.1. Schematic representation of the measured Ells River (99-10) Section #10 (UTM 455130E, 6343550N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

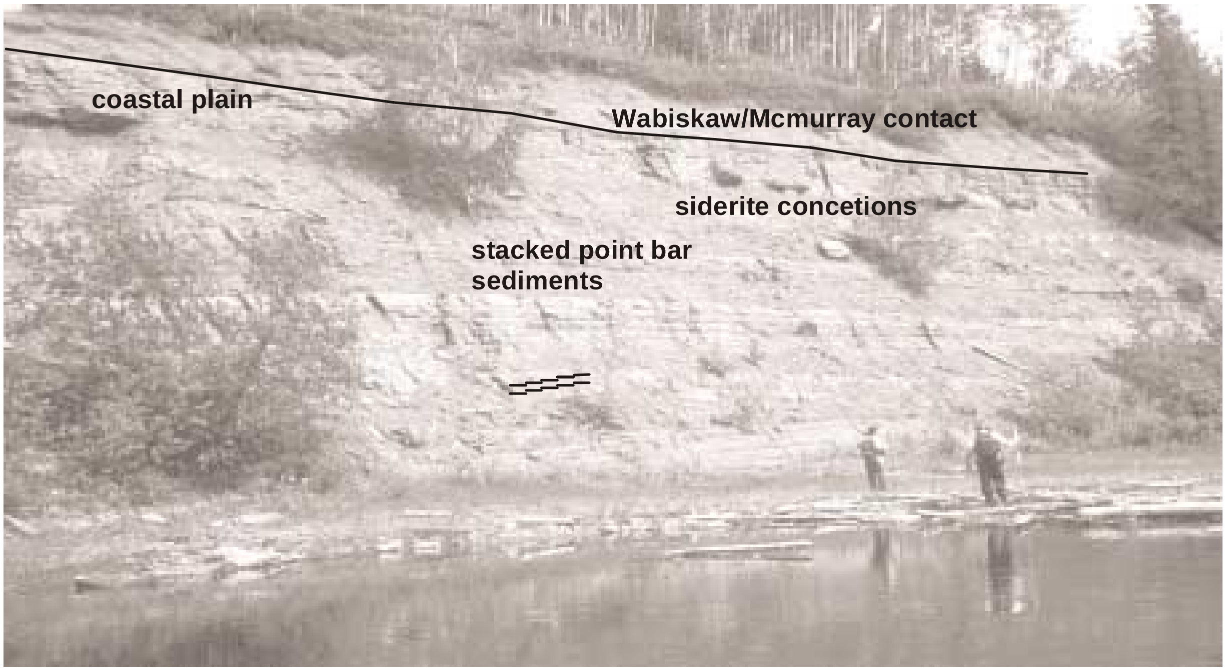


Figure 7.10.2a. Stacked estuarine point bar deposits overlain by coastal plain sediments (Upper McMurray Formation), Ells River (99-10) Section #10.

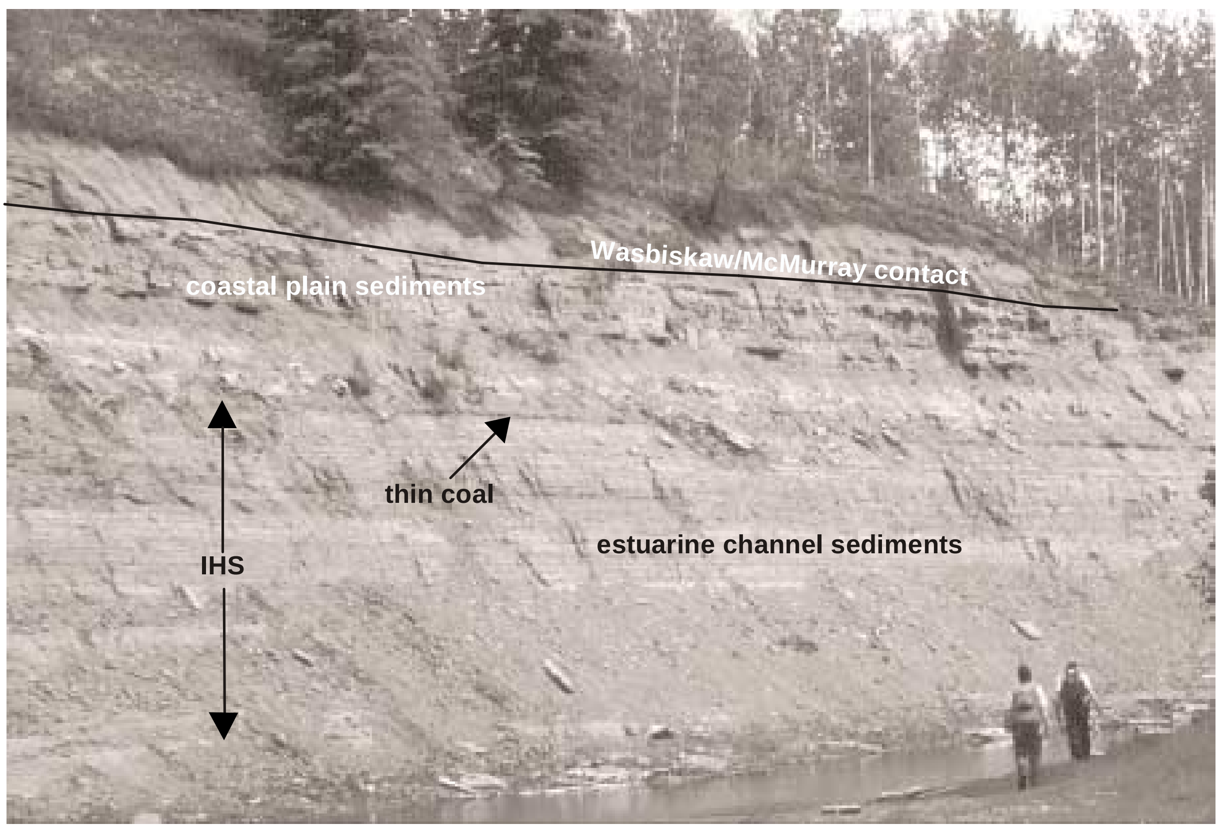


Figure 7.10.2b. Estuarine channel deposits overlain by coastal plain sediments (Upper McMurray Formation) capped by the Wabiskaw Member, Ells River (99-10) Section #10.

7.11 Ells River (99-11) Section #11

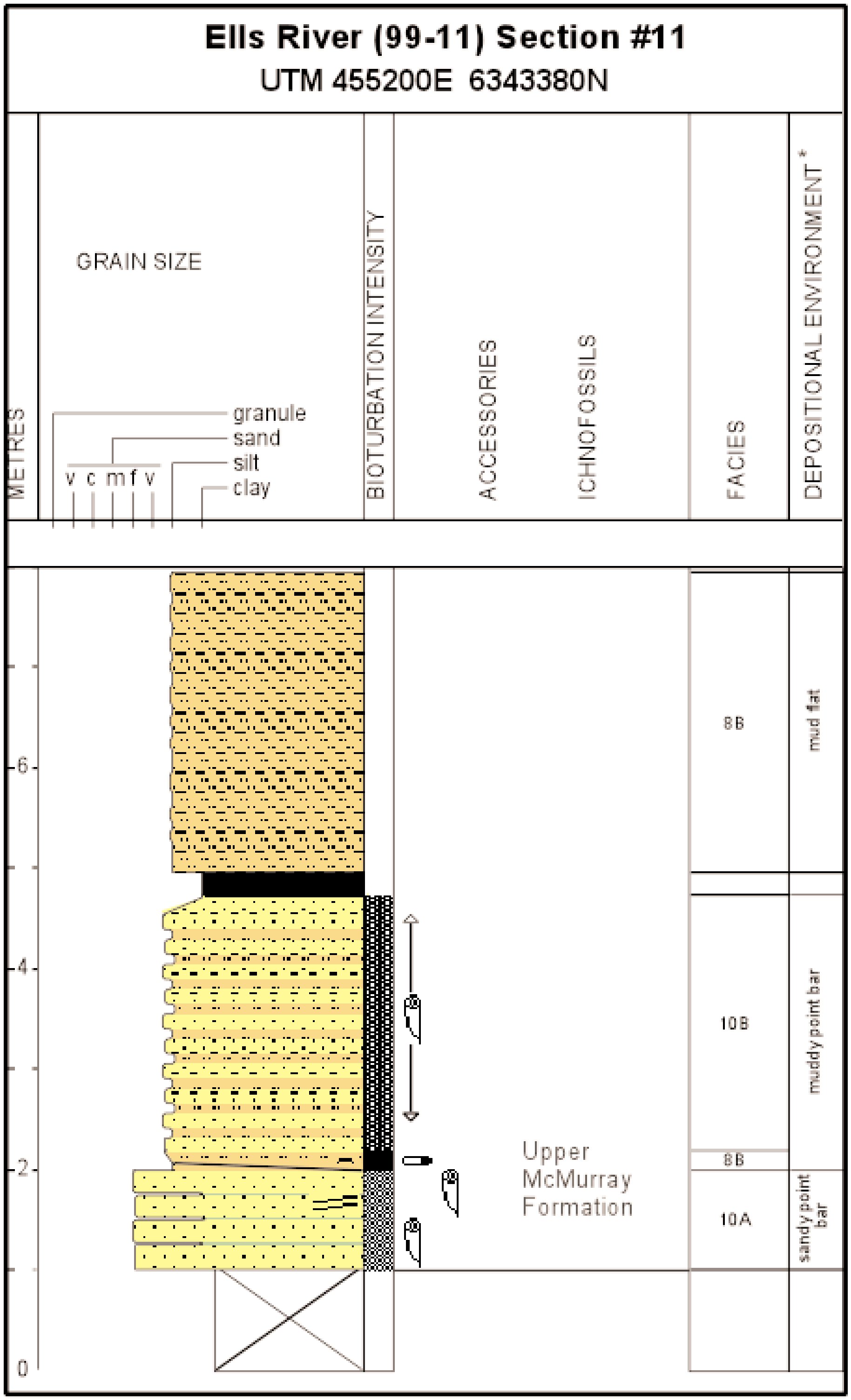
Map Coordinates: 74E/5 Bitumount, UTM 455200E, 6343380N

Keynote things to see:

- Interbedded coals and carbonaceous mudstone;
- Lateral continuity and even bedding style;
- Fining-upward unit with multiply stacked inclined heterolithic stratification.

Description: From river level about 1 m of section is covered, overlain by about 7 m of estuarine sediments (Figure 7.11.1). The interbedded sands, coaly mudstone and mudstone are burrowed with *Cylindrichnus* and *Planolites* traces. Individual beds are continuous and traceable along strike for the extent of the outcrop (>100 m). Near the base of the section sand and mudstone is interbedded at a low angle over about 2 m of section. This is interpreted as low angle, inclined lateral accretion cross-bedding. This low angle stratification is cut out by a discordant upper erosional surface that dips at 10 degrees toward the northeast. The next unit also comprises inclined heterolithic cross-bedding, but is finer-grained than the base, consisting of mainly thinly interbedded, burrow-mottled, muddy sand and silt. This muddy inclined heterolithic stratification is capped by a continuous carbonaceous mudstone and coal horizon, about 0.3 m thick. The overall succession is upward fining for about 4 m to the continuous coal and carbonaceous mudstone horizon. An inaccessible, recessive clayey silt unit overlies these organic zones.

Interpretation: The succession is interpreted as Upper McMurray that was deposited within stacked estuarine sandy and muddy point-bars, capped by the vertical accretion abandoned channel deposit, and a possibly more marine muddy silt at the top, in a nearshore coastal plain setting.



*Complete Description in Appendix 3.

Figure 7.11.1. Schematic representation of the measured Ells River (99-11) Section #11 (UTM 455200E, 6343380N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

8.0 Fort McMurray Outcrops

Map Coordinates: 74D/11 Fort McMurray (UTM 478740E, 6283550N for the Saline Creek Section #3 at the southeastern end; UTM 476200E, 6285050N for the Horse River (Roadcut) Section #4 at the northern end).

General Location and Outcrop Selection: Access to the outcrops around the city of Fort McMurray is via roadways, trails and creek/river courses. Most of the outcrops in the city of Fort McMurray are readily accessible by a superb network of ATV and walking trails. During the commencement of this study, the whole area around Fort McMurray was reconnoitered by helicopter and videotaped (on VHS format available from the Alberta Geological Survey in Edmonton) to assess suitability and accessibility of outcrops to be measured. As described under methodology, in selection of appropriate outcrops, a balance was struck between accessibility, condition of the exposure, and the type of facies and their variation. In the Fort McMurray town site three main drainages were selected for study. These include: Saline Creek, Hangingstone and Horse rivers (Figures 8.0.1, 8.0.2, 8.0.3, and 8.0.4). Other fair to good exposures occur along trails and cut lines near the Fort McMurray airport; southeast of the town site on Highway 69 (Figure 8.0.2). These, however, were not measured in detail, since better outcrops with more significant facies variation occur along Saline Creek.

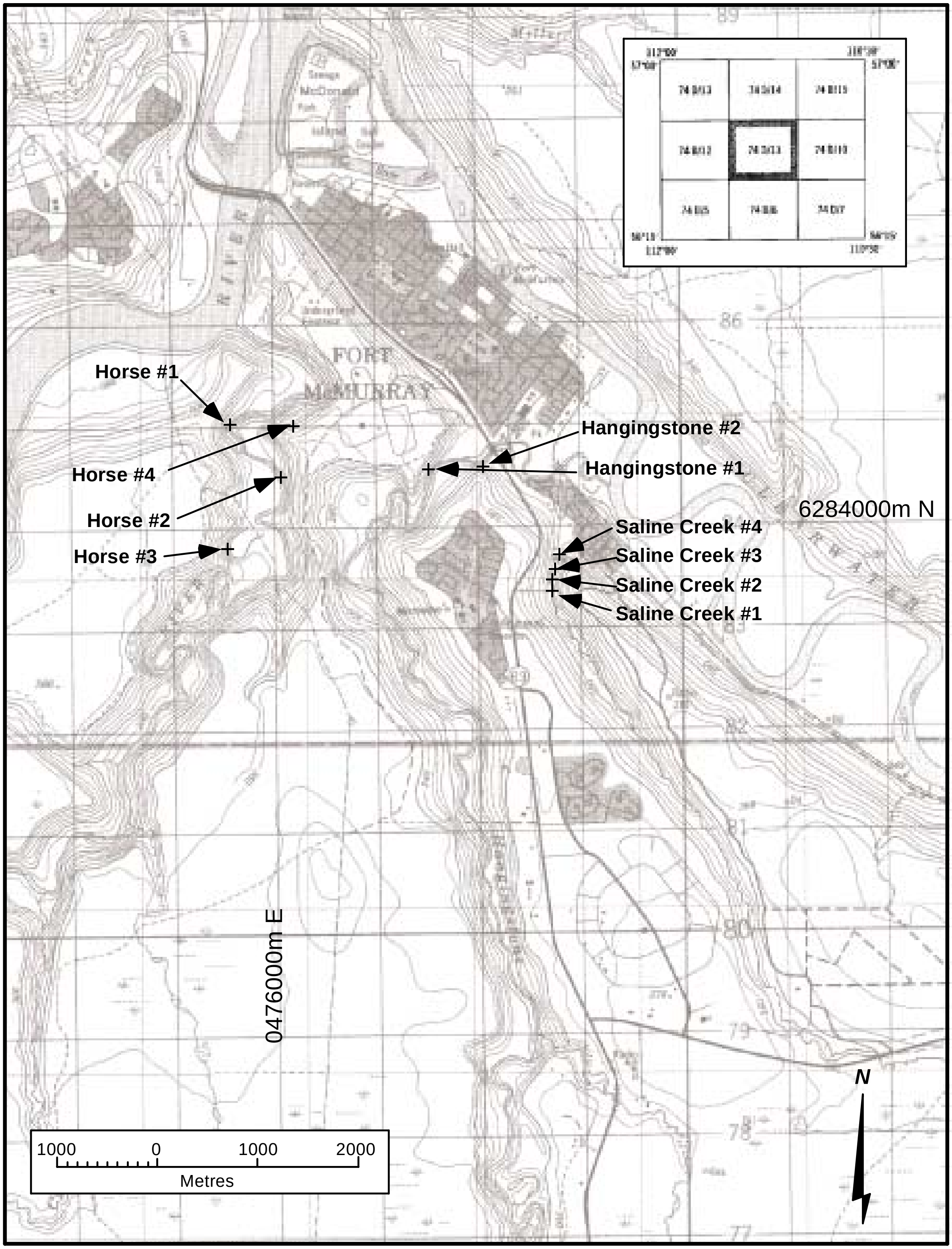


Figure 8.0.1. Map showing Fort McMurray outcrops near the townsite, including the Saline Creek, Hangingstone River and Horse River areas.

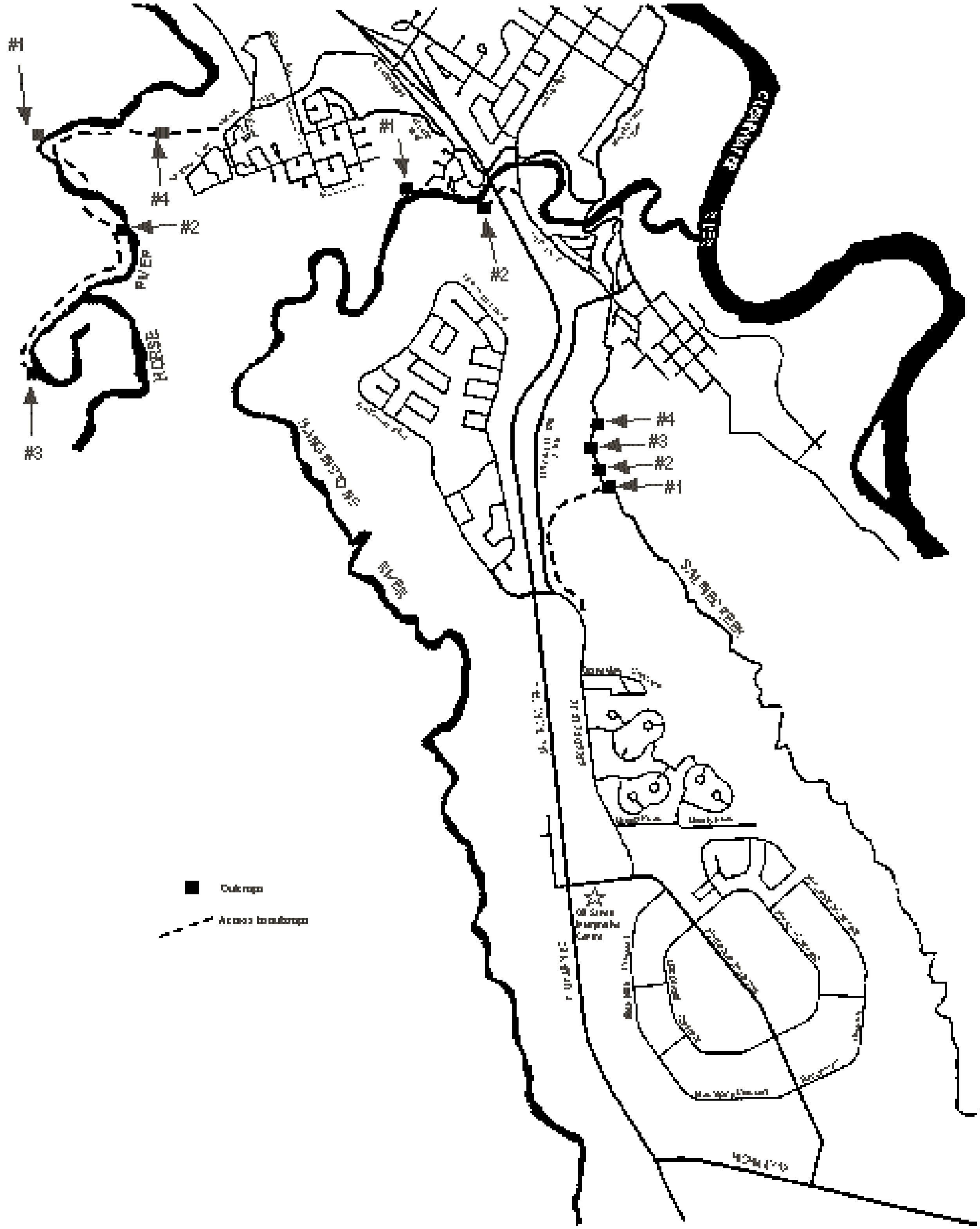


Figure 8.0.2. Detail map showing access to outcrops along Saline Creek, Hangingstone and Horse rivers.

Figure 8.0.3. Aerial photograph showing location and access to sections along Saline Creek and Hangingstone River, Fort McMurray townsite.

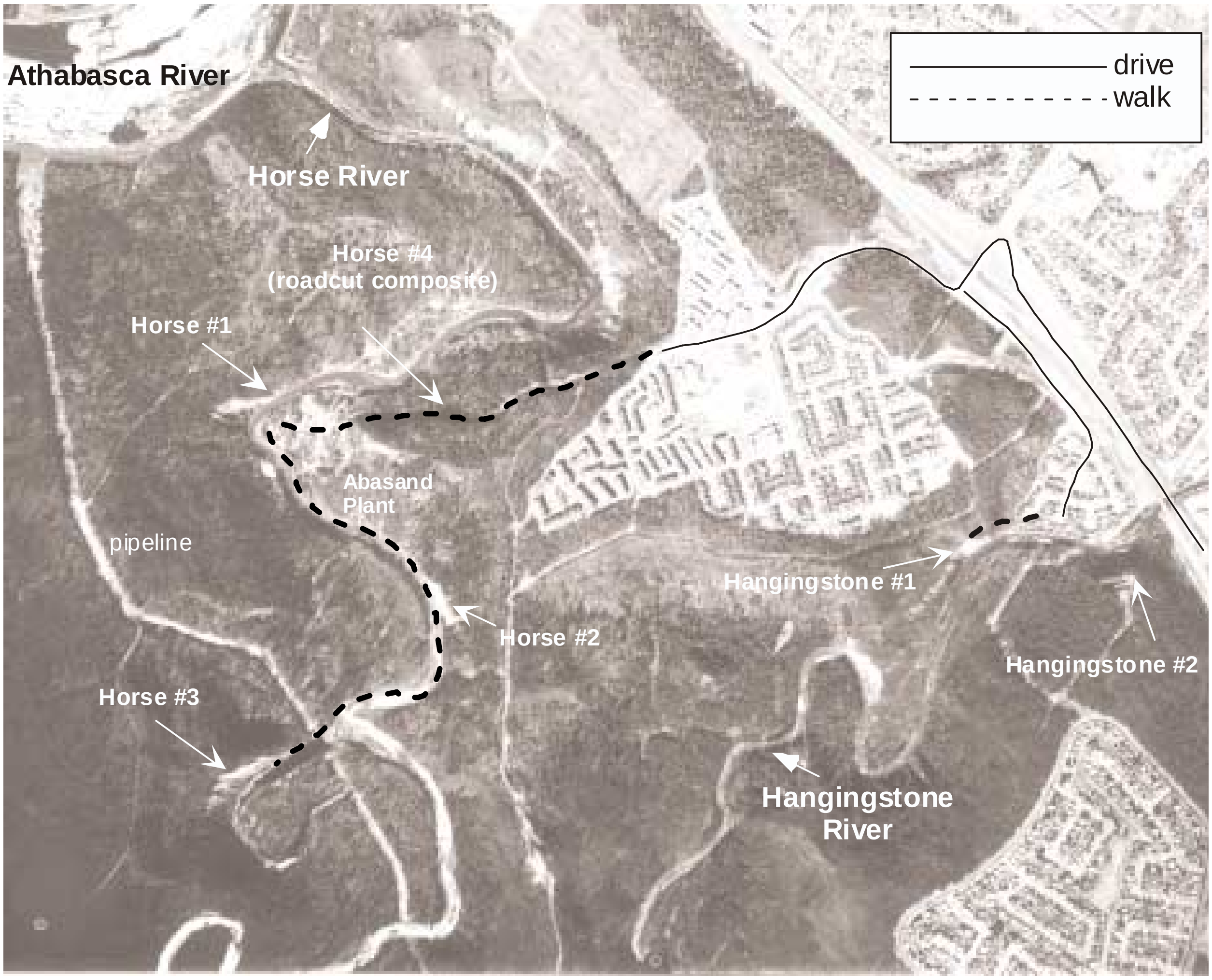


Figure 8.0.4. Aerial photograph showing location and access to McMurray exposures along the Horse and Hangingstone rivers.

8.1 Saline Creek Sections

Map Coordinates: 74D/11 Fort McMurray, UTM 478740E, 6283550N, Saline Creek Section #3.

Location and Access: The Saline Creek sections are located approximately 0.5 km upstream from the mouth of Saline Creek, at its confluence with the Clearwater River (Figures 8.0.1, 8.0.2 and 8.0.3). Drive north on Highway 63 (Memorial Drive/ Saskatchewan Trail) from the southern city limits of Fort McMurray, drive past the Oil Sands Interpretive Centre and the Tourist Information Centre (Port of Entry). Take the next right (east turn) onto Gregoire Drive. Park near the intersection of Gregoire Drive and Highway 63. Walk about 15 minutes downhill along the paved bike trail, cutting eastward to Saline Creek once you see the outcrops to the south near a major culvert (Figure 8.0.2).

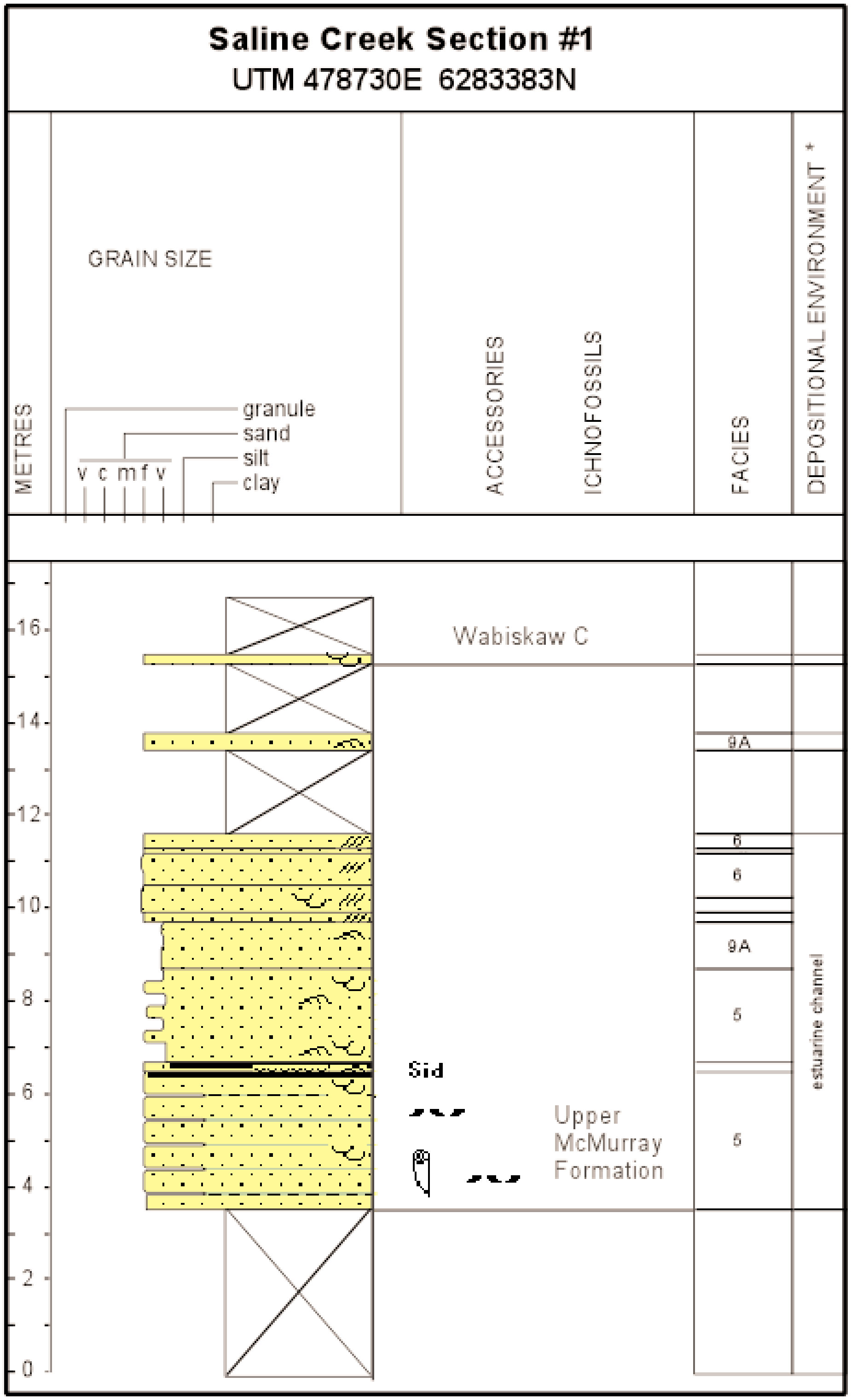
Keynote things to see:

- Thick stacked tidal channel sands;
- Excellent trough and planar tabular, and planar tangential cross-bedding with reversing toeset ripple cross-beds and tidal couplets;
- Multiple cut-and-fills with rapid facies changes.

Description: Along Saline Creek medium-grained, estuarine sediments are well exposed in a series of small cutbank sections, ranging from 8 m to >30 m high (Figures 8.1.1, 8.1.2a, b, c; 8.1.3, 8.1.4a, b; 8.1.5, 8.1.6a; 8.1.7, 8.1.8). The estuarine sediment shows abundant cross-bedding, including trough, high angle planar tabular, planar tangential and rippled units (Figures 8.1.2b, c, d; 8.1.4b, c; 8.1.6a, b; 8.1.8). Rhythmic tidal couplets and reverse flow ripples (Figures 8.1.4c, 8.1.6b) occur along some of the cross-beds. Paleoflow directions on the trough cross-beds are to the northeast; to the east-northeast for planar tabular cross-beds; and dominantly to the north in rippled sands. Mudstone interbeds and lenses are rare. Locally mudstone-clast breccia beds, ranging from 3 to 5 cm thick, occur. Mud-lined *Cylindrichnus* burrows are rare, and are mainly seen as resedimented clasts within the mudstone breccia beds. Other rare occurrences of *Cylindrichnus* are in place burrows found within trough cross-bedded sands at the Saline Creek Section #1 (Figure 8.1.2d).

At the top of the outcrops along Saline Creek is exposed a thin (<1 m), bioturbated, greenish caste sandstone. This is generally inaccessible, but can be seen along the trails, and within overhangs above the main outcrop sections. This is the glauconitic Wabiskaw C unit (Wabiskaw Member, Clearwater Formation) that unconformably overlies the McMurray Formation in this area.

Interpretation: The dominance of high-energy flow features, the relatively uniform paleoflow trends, along with a secondary tidal influence, indicate that these sediments were deposited within high-energy estuarine channels, as bedload dominated systems. The fine-grained nature of the sediment, the occurrence of burrows (both within mudstone intraclasts and in sands), and the tidal sedimentary structures indicate that the sediment does not belong to the Lower McMurray Formation, but rather represents main channel sediments of the Upper McMurray Formation.



*Complete Description in Appendix 3.

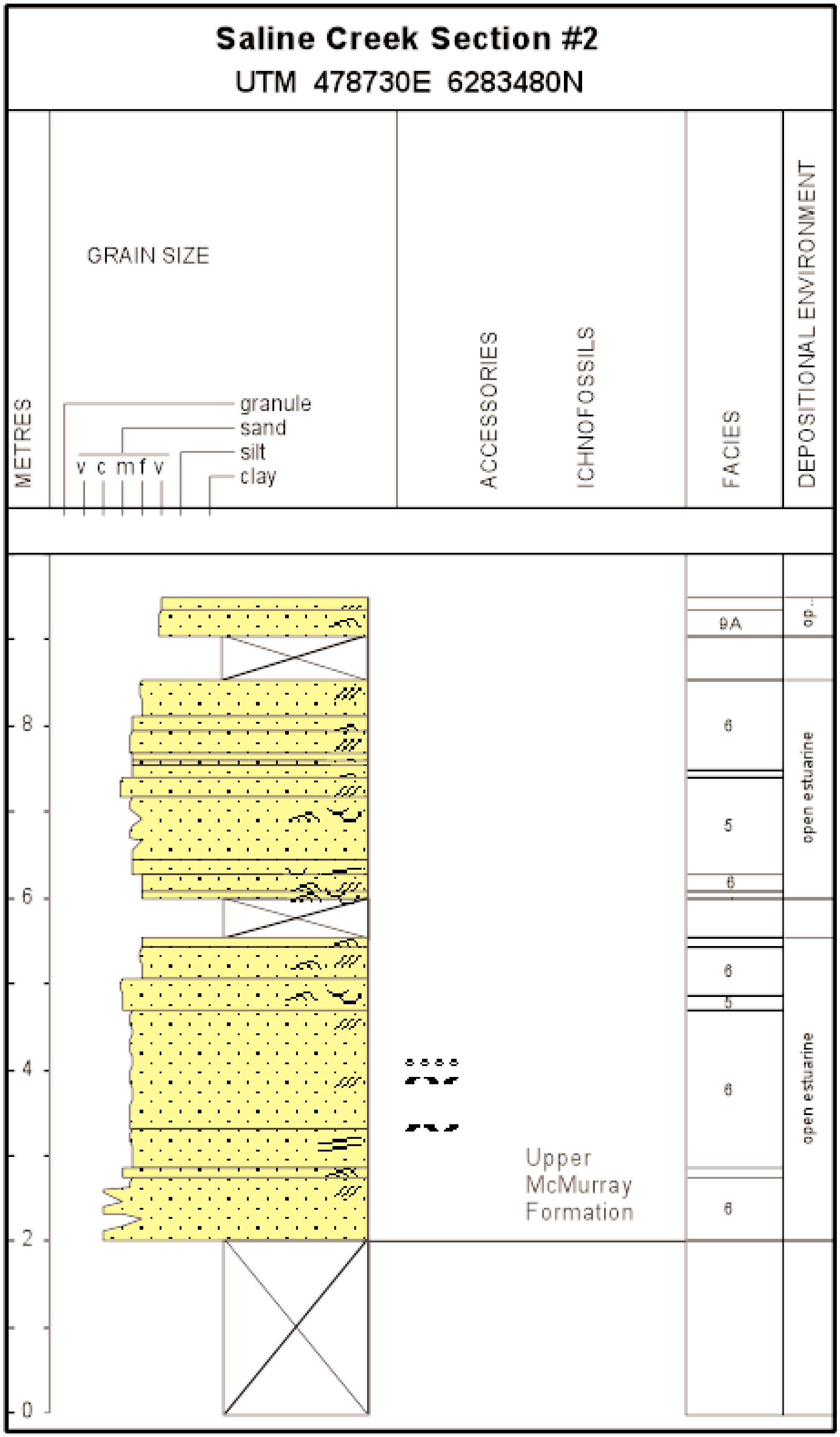
Figure 8.1.1. Schematic representation of the measured Saline Creek Section #1 (UTM 478730E, 6283383N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.1.2a. Overview of Saline Creek Section #1, Fort McMurray townsite.

Figure 8.1.2b. Stacked, medium-scale planar tabular cross-bedded sand capped by rippled sand (Upper McMurray Formation), Saline Creek Section #1, Fort McMurray. About 2 m of vertical section is shown.

Figure 8.1.2c. Bitumen-saturated, trough cross-bedded sand (Upper McMurray Formation), Saline Creek Section #1. About 6 m of vertical section is shown.

Figure 8.1.2d. Rare (in-place) Cylindrichnus (arrow) burrows found within trough cross-bedded sands (Upper McMurray Formation), Saline Creek Section #1.



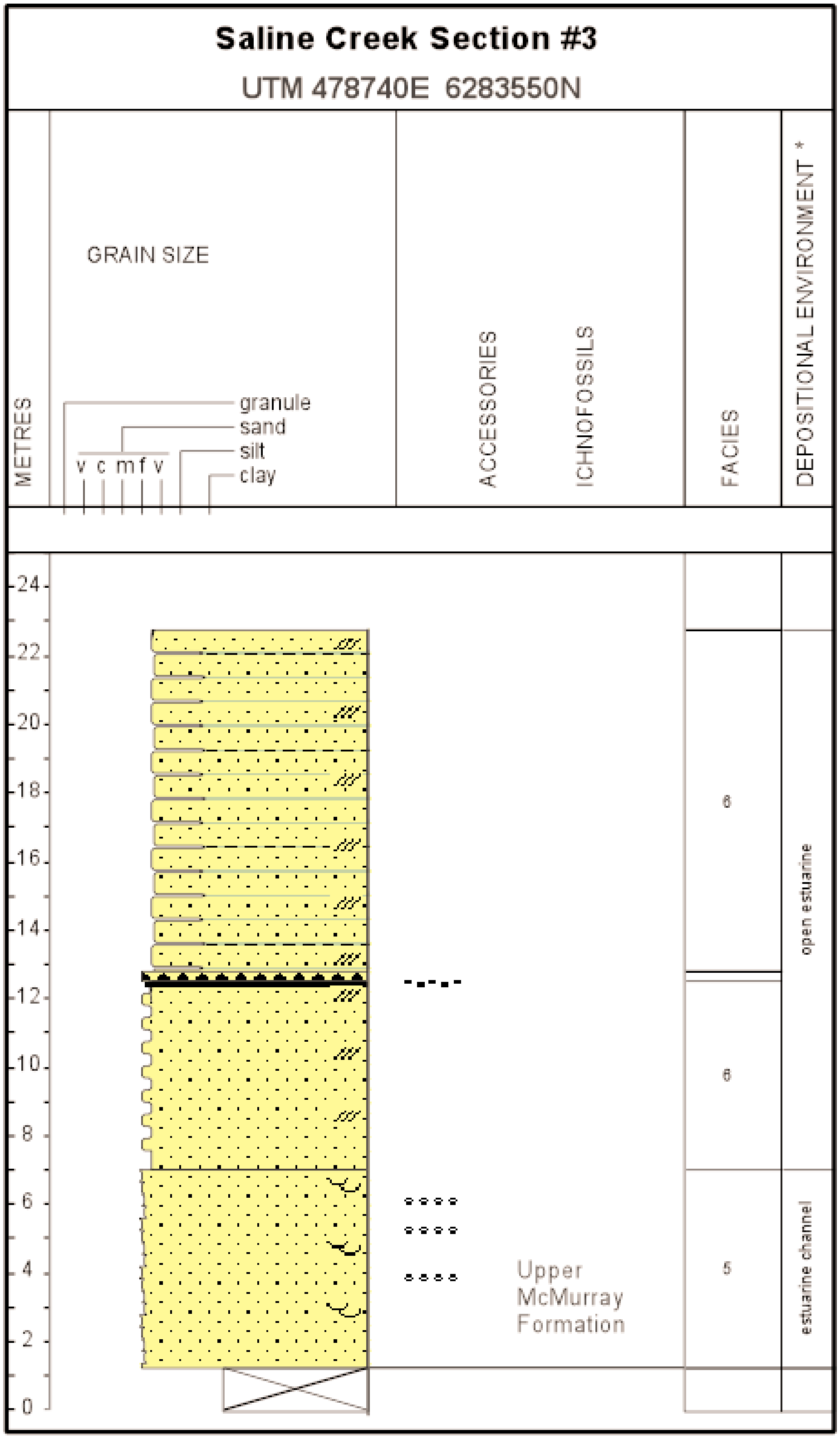
*Complete Description in Appendix 3.

Figure 8.1.3. Schematic representation of the measured Saline Creek Section #2 (UTM 478730E, 6283480N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.1.4a. Overview of Saline Creek Section #2, Fort McMurray.

Figure 8.1.4b. Large-scale trough cross-bedded sand (Upper McMurray Formation), Saline Creek Section #2, Fort McMurray.

Figure 8.1.4c. Bitumen-stained, large-scale trough cross-bedded sand overlying mudstone-clast breccia and capped by rippled sand (Upper McMurray Formation), Saline Creek Section #2, Fort McMurray.



*Complete Description in Appendix 3.

Figure 8.1.5. Schematic representation of the measured Saline Creek Section #3 (UTM 478740E, 6283550N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.1.6a. Stacked, large-scale planar tabular cross-bedded sand underlain by trough cross-bedded sand (Upper McMurray Formation), Saline Creek Section #3, Fort McMurray. Approximately 10 m of section shown.

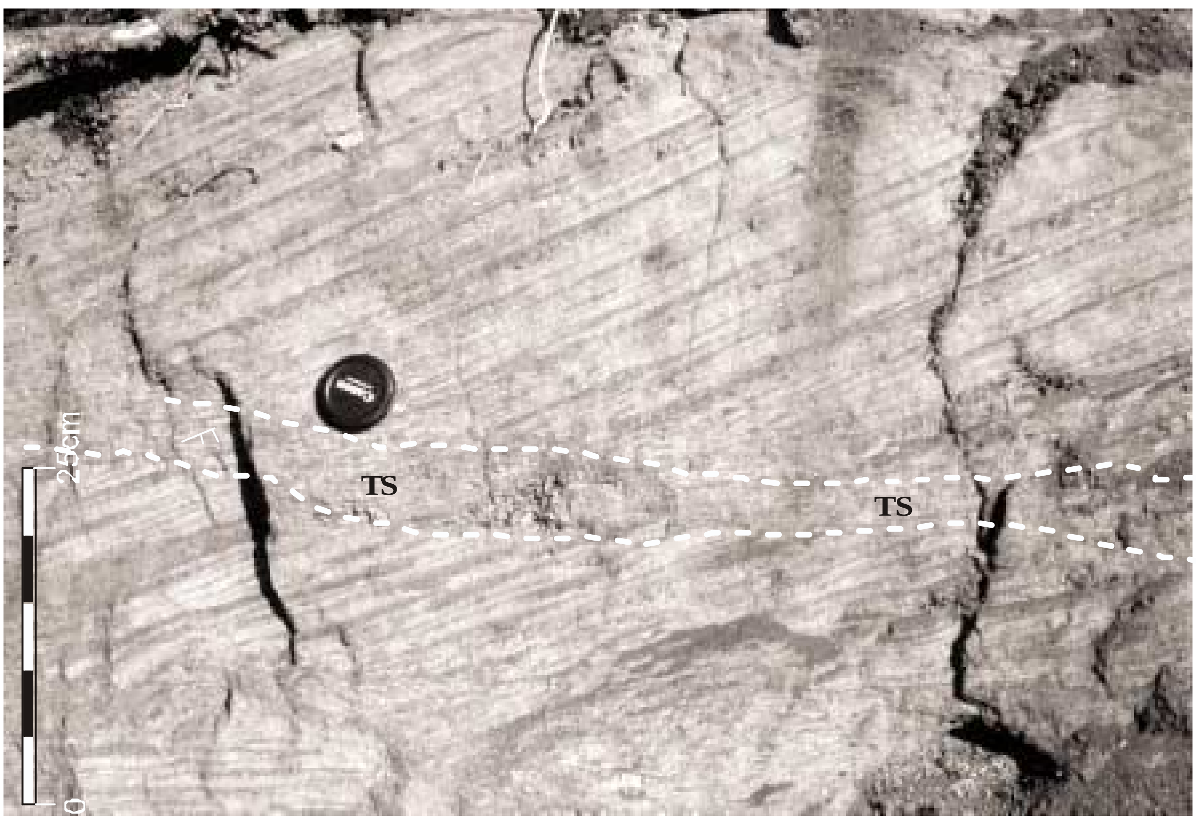
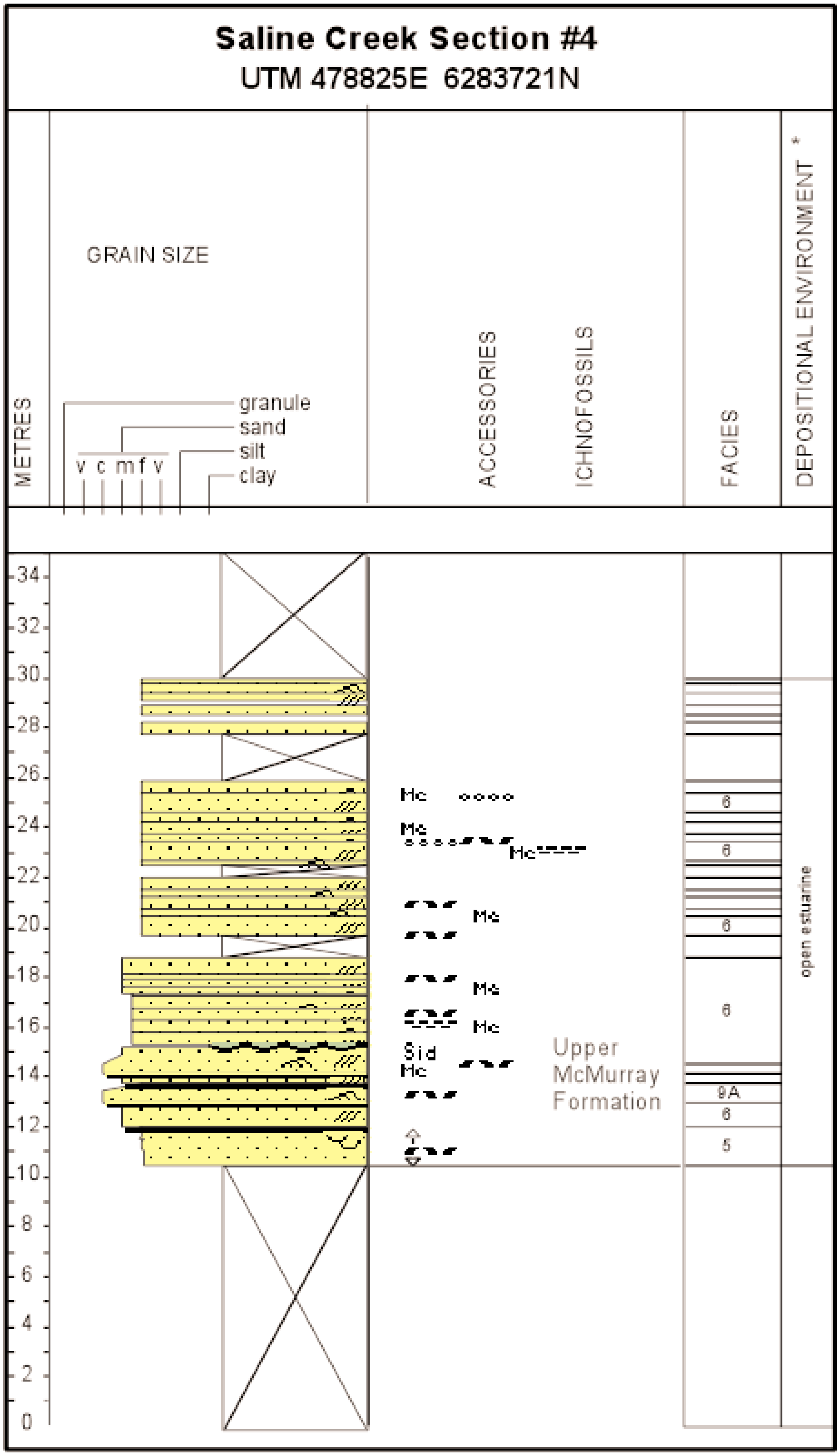


Figure 8.1.6b. Stacked, medium-scale, planar tabular cross-bedded sand with toeset (TS) rippled sand, showing minor convolute bedding at the base (dashed lines) (Upper McMurray Formation), Saline Creek Section #3, Fort McMurray.



*Complete Description in Appendix 3.

Figure 8.1.7. Schematic representation of the measured Saline Creek Section #4 (UTM 478825E, 6283721N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.1.8a Overview of Saline Creek Section #4, Saline Creek, Fort McMurray.

Figure 8.1.8b Close-up of planar tabular cross-bedded, bitumen-saturated, sand (Upper McMurray Formation), Saline Creek Section #4, Saline Creek, Fort McMurray.

8.2 Hangingstone River Sections

Map Coordinates: 74D/11 Fort McMurray, UTM 477530E, 6284570N for the Hangingstone River Section #1.

Location and Access: This section is located approximately 2.0 km upstream from the mouth of the Hangingstone River, at its confluence with the Clearwater River (Figures 8.0.1, 8.0.2 and 8.0.3). Drive north on Highway 63 (Memorial Drive/ Saskatchewan Trail) from the southern city limits of Fort McMurray, drive past the Oil Sands Interpretive Centre and the Tourist Information Centre (Port of Entry). Take the third right (east turn) onto Hospital Street, then an immediate left onto a bridge over Highway 63 (Memorial Drive/ Saskatchewan Trail). Turn left (southeast) onto Abasand Drive and continues into the Grayling Terrace Subdivision. Park at a cul de sac near the river (either Graham Place or Gardiner Place). At the end of each cul de sac is a public access gate to the trail along the north side of the Hangingstone River. Walk upstream (west) along the trail for about 5 minutes to the first outcrop on the north bank is reached (Figure 8.0.2).

Note: During low-water conditions, one can access the opposite, north facing, steep cutbank near the bridge across the Hangingstone River. Here a similar succession of mudstone abandoned channel-fill deposits is overlain by thick estuarine channel sediment of the Upper McMurray Formation, capped by a thin glauconitic Wabiskaw C unit (Figures 8.2.3 and 8.2.3a, b).

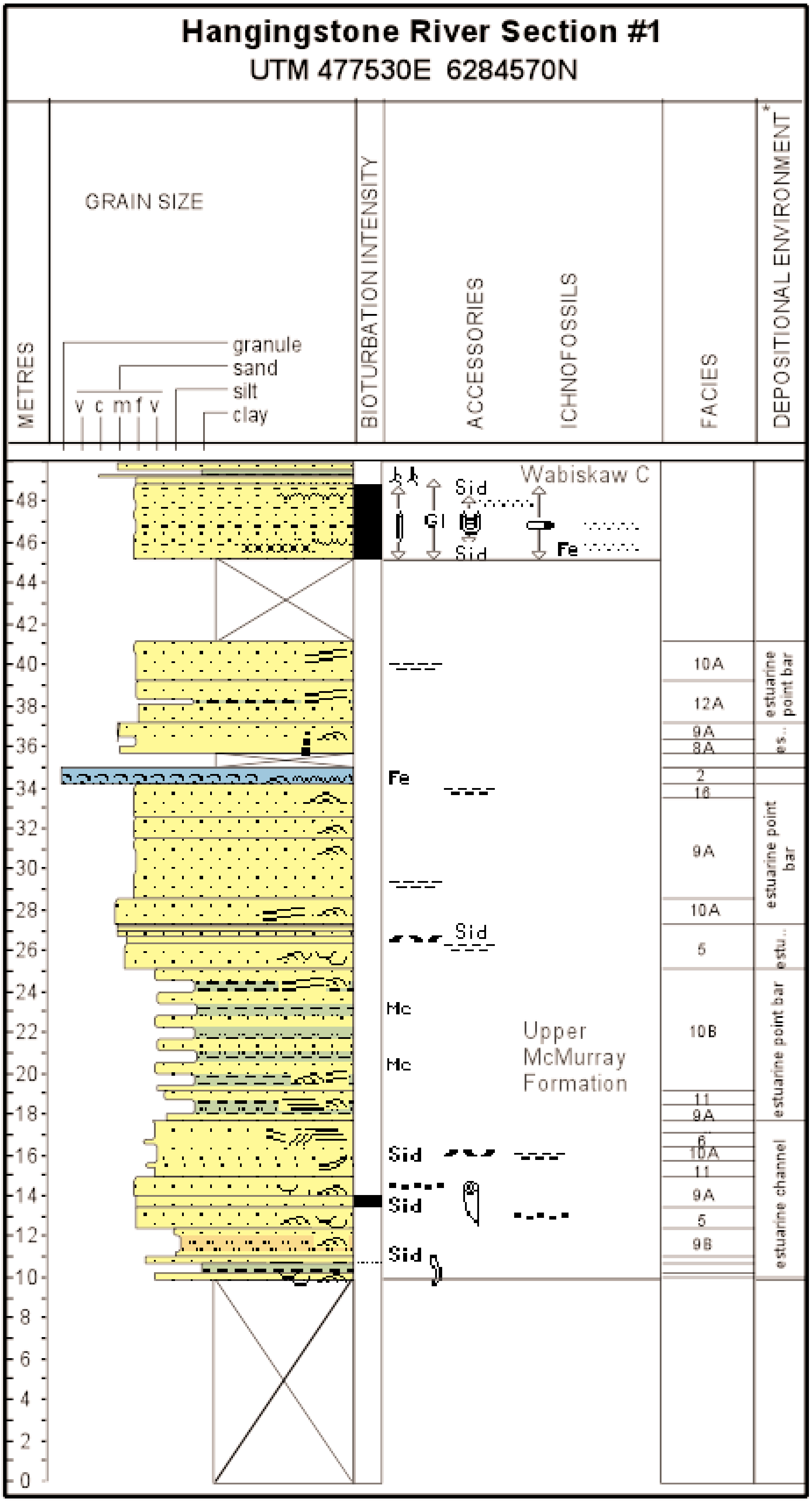
Keynote things to see:

- Thick mudstones at the base of the sections;
- Estuarine channel and point bar deposits;
- Coquinas and ironstone concretions and cemented ledges, from which dinosaur and mosasaur remains have been found in float;
- Contact between the McMurray Formation and the glauconitic Wabiskaw C sand.

Description: In this thick outcrop section, about 50 m high, is exposed the estuarine sediment (Figure 8.2.1). The succession at this outcrop starts with a fine-grained mudstone, mainly slumped at the base of the outcrop. This mudstone is overlain by sediment with abundant cross-bedding, including trough, high angle planar tabular, planar tangential, and low-angle, sandy or muddy inclined units (Figure 8.2.2). Mudstone interbeds and lenses are common, with an increase in frequency and thickness going upsection. Concomitant with this increase in mudstones, is also an increase in bioturbation intensity, with the most common types being *Cylindrichnus* and horizontal *Planolites*, with rare vertical *Skolithos*. Thin, indurated coquina beds are located in the middle and upper parts of the section.

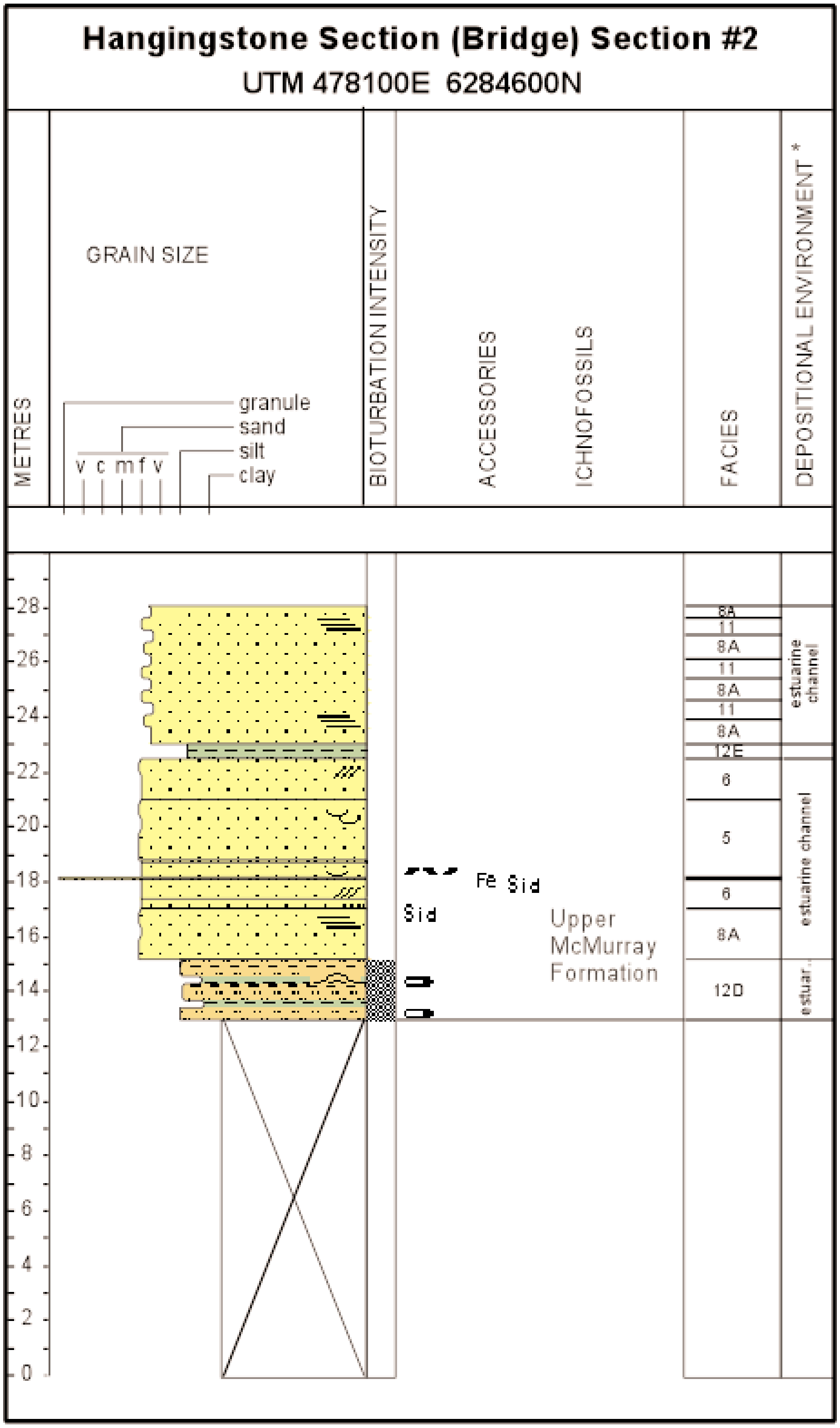
At the top of the outcrop is exposed approximately 4.5 metres of glauconitic, bioturbated, well sorted sand. This is the Wabiskaw C unit (Wabiskaw Member, Clearwater Formation) that unconformably overlies the McMurray Formation in this area. The Wabiskaw C is, in turn, unconformably overlain by Quaternary-age sediment.

Interpretation: The recessive basal mudstone is interpreted as an abandoned channel, vertical accretion deposit. Thick estuarine channel and point bar sands overlie this. Coquinas are interpreted as storm-surge channel deposits. Although there is limited biostratigraphic dating from this outcrop, what is available indicates brackish water (not fluvial) settings. This, in addition to the abundance of burrowing and burrowed mudstone intraclasts, common occurrence of muddy inclined heterolithic stratification, presence of wave-formed features and coquinas indicate that this section comprises Upper McMurray successions.



* Complete Description in Appendix 3.

Figure 8.2.1. Schematic representation of the measured Hangingstone River Section #1(UTM 477530E, 6284570N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 8.2.2. Schematic representation of the measured Hangingstone River (Bridge) Section #2 (UTM 478100E, 6284600N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.2.3a.Thinly-interbedded, burrowed, very fine-grained sand-silt and silty mudstone interpreted as estuarine channel abandonment fill (Upper McMurray Formation) Hangingstone (Bridge) Section #2, Hangingstone River, Fort McMurray.

Figure 8.2.3b. Thick sand succesion comprised of vague, large-scale trough, high-angle planar tabular cross-bedded sand and massive ironstone (sideritized) concretions up to boulder size (Upper McMurray Formation), Hangingstone (Bridge) Section #2, Hangingstone River, Fort McMurray.

8.3.0 Horse River Sections

Map Coordinates: 74D/11 Fort McMurray, UTM 476070E, 6284520N for the Horse River Section #2.

Location and Access: This river valley is accessible by road, trails and river courses near the Abasand subdivision of the Fort McMurray town site (Figures 8.0.1, 8.0.2 and 8.0.4). Note: only access the river sections under low water levels or by helicopter. The road cuts are accessible by foot or 4 x 4 ATV's. Of historical note, part of this area is paved with bitumen from the oil sands. Some ruins of buildings and bridge-supports are all that is left of the Abasand pilot plant that was built at this site in 1940, and processed 19,000 tons of oil sand (yielding 17,000 tons of bitumen).

Drive north on Highway 63 (Memorial Drive/ Saskatchewan Trail) from the southern city limits of Fort McMurray, drive past the Oil Sands Interpretative Centre and the Tourist Information Centre (Port of Entry). Take the third right (east turn) onto Hospital Street, then an immediate left onto a bridge over Highway 63 ((Memorial Drive/ Saskatchewan Trail). Turn right (north) onto Abasand Drive, climb up the steep hill, continuing on Abasand Drive, past the Cemetery Road, until you reach a staging area and parking lot on the right hand (north) side of the drive, across the street from a French-Immersion School and French Community Centre. Park at the staging area (Figure 8.0.2). Continue backpacking on the dirt trail to the left (southwest) from the parking lot, keeping to the right (north) fork, and going down into the Horse River valley. You will come to an open cleared area at the base of the trail in the valley bottom.

The first outcrop section is on the western side of the river across from the building ruins at the bottom of the valley. The only access to this exposure is by wading under low water conditions. The second section is the next cutbank along the southeast bank of the river a few hundred metres upstream from the ruins. Take the dirt trail to its upstream end, then cut down to the bank and continue hiking along the bank to reach the section. Wading the river accesses the third section and walking along the banks until a major geophysical cut line is reached, about 1-2 km upstream. The measured section is located on the northwest cutbank of an abandoned oxbow lake that has a number of beaver dams and lodges (Figures 8.0.1 and 8.0.4).

8.3.1 Horse River Section #1

Map Coordinates: 74D/11 Fort McMurray, UTM 475560E, 6285050N

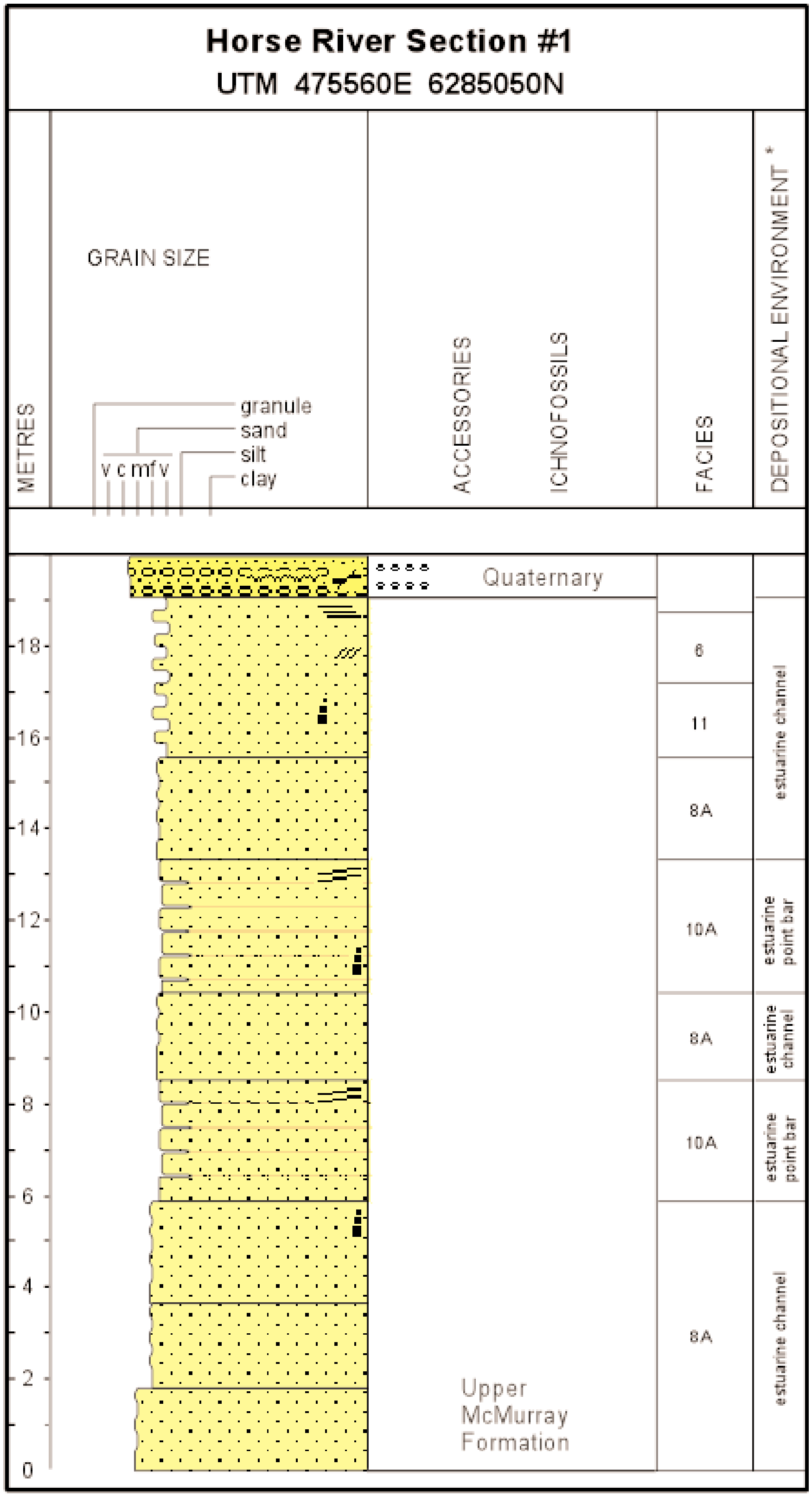
Keynote things to see:

- Alternating massive sands with inclined heterolithic stratified units;
- Estuarine channel and point bar deposits that show opposing paleoflow patterns;
- Quaternary outwash gravel and boulder beds in scoured and/or thrust contact with the McMurray Formation

Description: The section begins at river level where a 6 m thick slightly upward fining succession of coarse- to fine-grained sand occurs (Figure 8.3.1). Internally the sand is mainly massive. The next 10 m of section consists of alternating bioturbated low angle; inclined heterolithic stratified sand and mudstone, about 1.5 m thick that alternate with 1 to 2 m thick massive sands. Overlying these units is a 3.5 m thick massive to planar tabular cross-bedded and parallel laminated sand succession that is generally fining-upward. Prominent trough cross-bedded sands occur in the mainly inaccessible and upper parts of the section. Paleoflow directions within the topmost planar tabular cross-beds are towards the north; whereas, underlying inclined, low angle, heterolithic stratification dips both to the south and to the north.

At the top of the outcrop, the McMurray succession is unconformably overlain and scoured out by a Quaternary outwash and meltwater channel system. Channel fill consists mainly of glaciofluvial outwash gravels and boulders. Locally glacial thrust contact features occur at the margins of the Quaternary channel fill succession, at its lower contact with Cretaceous bedrock.

Interpretation: The upward fining succession is interpreted as a thick estuarine channel sand deposit belonging to the Upper McMurray Formation. Overlying units are interpreted as interfingering estuarine channel and point bar units.



*Complete Description in Appendix 3.

Figure 8.3.1. Schematic representation of the measured Horse River Section #1 (UTM 475560E, 6285050N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

8.3.2. Horse River Section #2

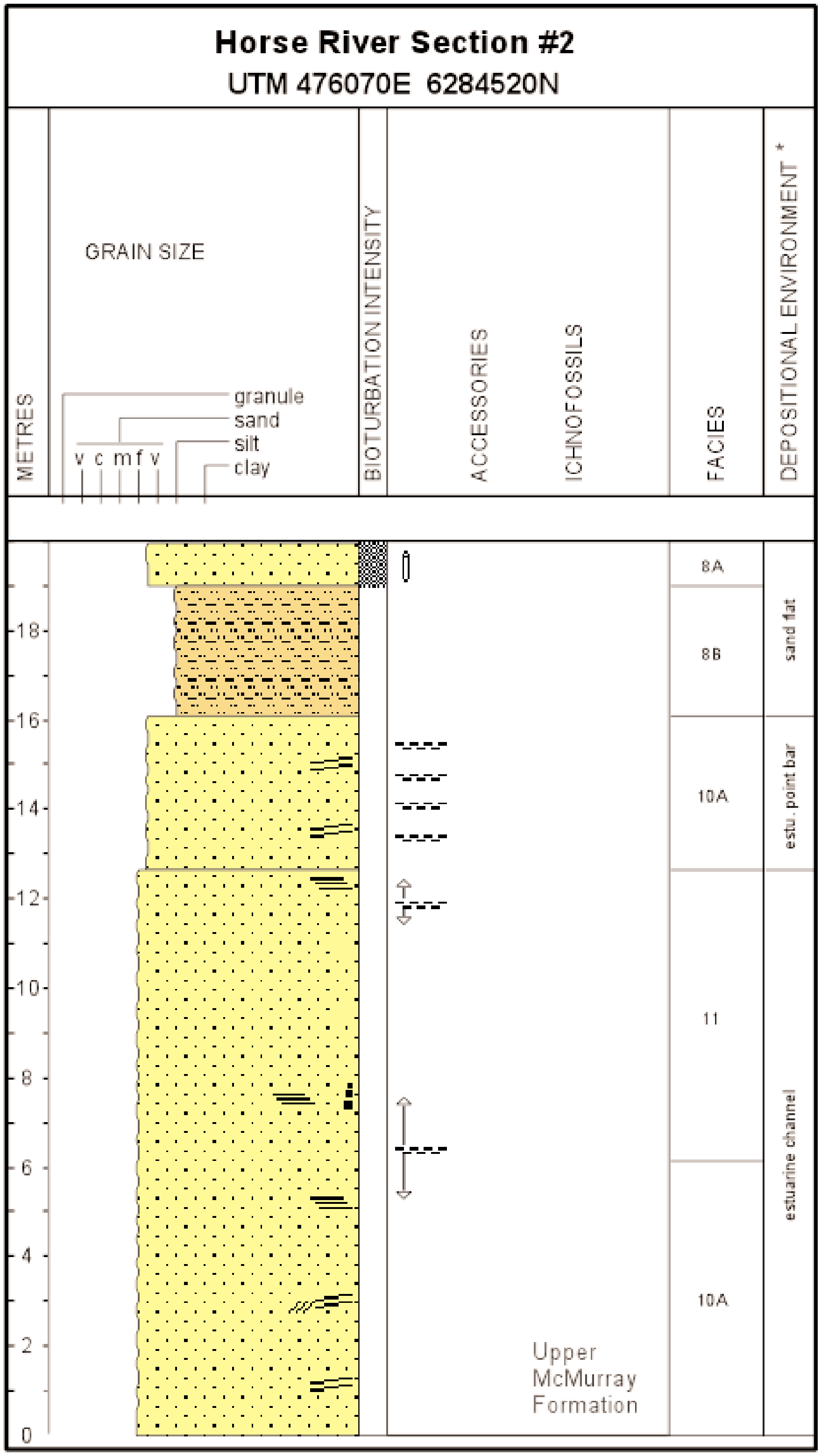
<u>Map Coordinates:</u> 74D/11 Fort McMurray, UTM 476070E, 6284520N

<u>Keynote things to see:</u>

- Massive, laminated and cross-bedded sands cross cut and interfinger with inclined heterolithic stratified sand and mudstone units;
- Rapid lateral and vertical facies changes between estuarine channel and point bar deposits;
- Shoreface sands at the top of the succession, correlative to Horse River #3 shoreface sands.

<u>Description:</u> In this cutbank a 13 m thick succession of slightly upward fining succession of medium to fine-grained sand is variably interbedded with mudstone (Figure 8.3.2). Internally the sands are either massive, are fining-upwards and show parallel lamination, planar tabular or trough cross-bedding (Figure 8.3.3). Laterally along strike the massive and upward fining sands cross cut and interfinger with low angle, inclined heterolithic stratified sand and mudstone. Overlying the stacked, low angle, inclined heterolithic stratified sand and mudstone is a 2 to 2.5 m thick recessive unit of gray clayey sandy silt that lacks observable trace fossils. At the topmost part of the outcrop, the succession consists of 1 to 2 m thick, white, quartz-rich sand that lacks bitumen-staining. The white sand is well-sorted and clean, lacking associated muddy, organic debris and mica that is more typical of the McMurray sands. Rare vertical *Skolithos* and escape trace fossils occur in the topmost sand.

<u>Interpretation:</u> Lateral facies associations in the main part of the section are interpreted as representing the lateral and vertical intertonguing of estuarine channel and point bar sands and mudstone belonging to the Upper McMurray Formation. The upper units within the McMurray at this section are interpreted as sand-flat and shoreline deposits. The upper white sand correlates to the thicker preserved sandy tidal inlet or shoreface deposits of Horse River Section #3, about 700 m upstream and to the west.



*Complete Description in Appendix 3.

Figure 8.3.2. Schematic representation of the measured Horse River Section #2 (UTM 476070E, 6284520N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.3.3. Massive to parallel bedded units at base overlain by large-scale lateral accretion cross-beds (Upper McMurray Formation), Horse River Section #2, Fort McMurray.

8.3.3. Horse River (Oxbow Lake) Section #3

Map Coordinates: 74D/11 Fort McMurray, UTM 475550E, 6283820N

Keynote things to see:

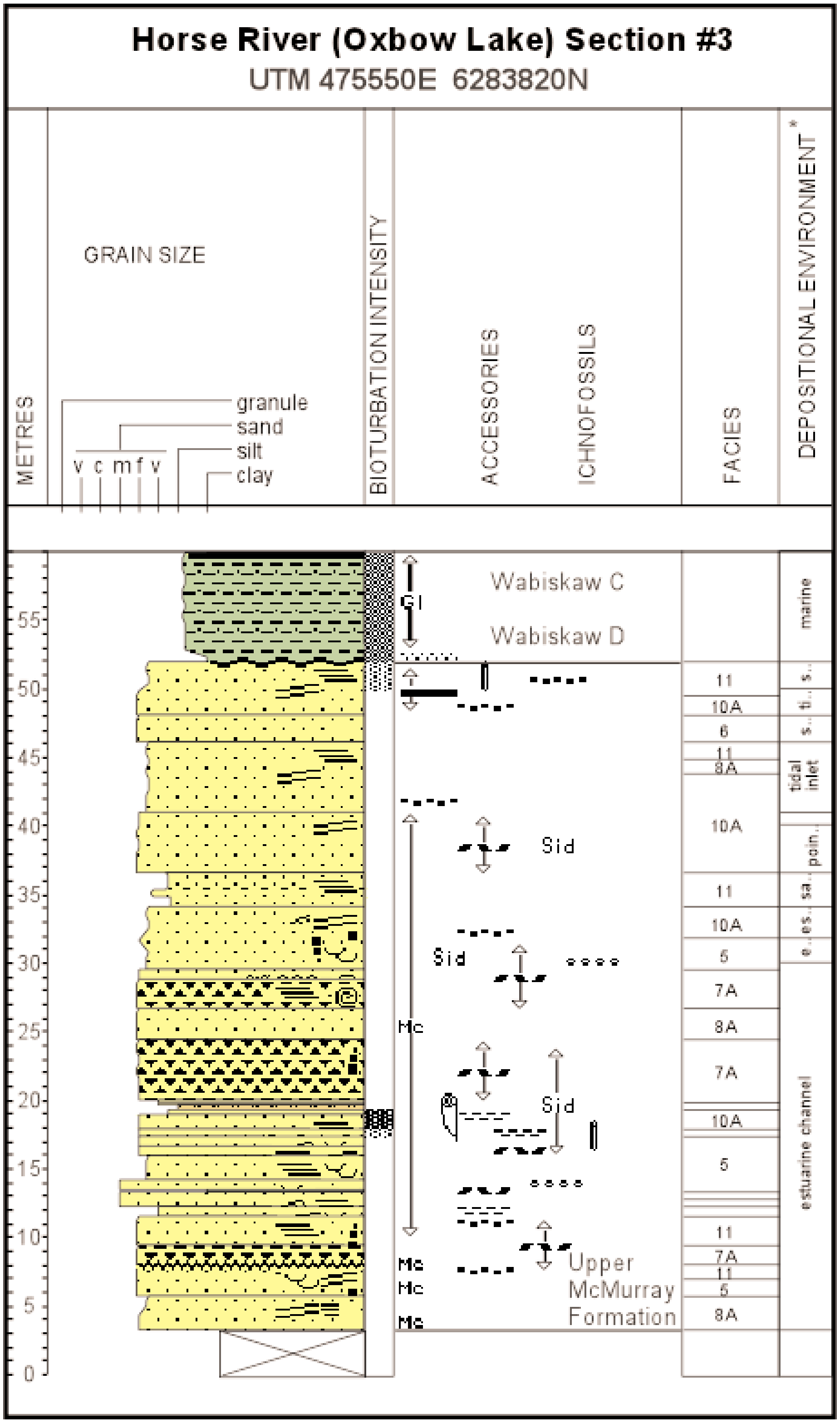
- Mudstone-clast breccias, stratified and cross-bedded sands, inclined heterolithic stratification;
- Rapid lateral and vertical facies changes between estuarine channel and point bar deposits;
- Sigmoidal cross-bedded sands;
- Shoreface sands at the top of the succession, correlative to Horse River #2 shoreface sands;
- Contacts between the McMurray, Wabiskaw D and Wabiskaw C units.

Description: Along this cutbank a 40 m thick succession (Figures 8.3.5a, b) of slightly upward fining, medium- to fine-grained sand occurs that is variably interbedded with mudstone and mudstone-clast breccias (Figures 8.3.4 and 8.3.5e). Internally the sands are massive or variably stratified with parallel lamination, planar tabular and trough cross-bedding, inclined heterolithic stratification, current ripples, ripple drift, and herringbone cross-bedding (Figure 8.3.5d). In the main part of the section, laterally along strike towards the downstream end of the outcrop, the mainly massive sand grades into inclined heterolithic stratified sand and mudstone (Figure 8.3.5a). In other cases shallow scour-fills and slumps of mudstone clast breccias replace the cross-bedded and laminated sands (Figure 8.3.5e).

The next 10 m of section consists of alternating wave-formed sigmoidal and low angle, inclined heterolithic sand and mudstone that internally show some wave-ripple and combined-flow cross-bedding. The sands within this upper unit are white, quartz-rich, well-sorted and clean (Figure 8.3.5c). These sands are similar to the topmost McMurray sand at the Horse River Section #2 and also lack the micaceous, muddy and organic debris that is more common within the Upper McMurray Formation in the area.

Overlying the upper white sand is a 7 to 8 m thick recessive unit (Figures 8.3.5b, c) consisting of dark grey to black clayey mudstone at the base that becomes a more greenish gray clayey sandy silt upsection. These units belong to the Wabiskaw D (dark grey) and Wabiskaw C (greenish) Members of the Clearwater Formation.

Interpretation: The facies associations in the main part of this outcrop are interpreted as representing the lateral and vertical intertonguing of estuarine channel, cutbank collapse intraclasts, and point bar sands and mudstone belonging to the Upper McMurray Formation. At this site the clean quartz sands at the top of the outcrop are interpreted as representing possible shoreline (? barrier island deposits) or tidal inlet deposits within the Upper McMurray Formation.



*Complete Description in Appendix 3.

Figure 8.3.4. Schematic representation of the measured Horse River (Oxbow Lake) Section #3 (UTM 475550E, 6283820N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.3.5a. Overview of Horse River Section #3, Fort McMurray.

Figure 8.3.5b. Overview of Horse River Section #3, Fort McMurray.

Figure 8.3.5c. Whitish tidal inlet sand (possible preserved transgressive shoreface deposit) abruptly overlying bitumen-bearing estuarine sands (Upper McMurray Formation), Horse River Section #3, Fort McMurray.

Figure 8.3.5d. Small-scale herringbone cross-bedding, shown by alternating ripple cross-beds, with minor convolution (Upper McMurray Formation), Horse River Section #3, Fort McMurray. Alternating paleoflows indicative of possible tidal influence.

Figure 8.3.5e. Rotated in situ paleo-slump blocks, showing vertical current rippled sands within estuarine channel deposits about 15 m from the base of the Horse River Section #3 at the eastern end of outcrop (Upper McMurray Formation), Horse River Section #3, Fort McMurray.

8.3.4 Horse River (Roadcut) Section #4

Map Coordinates: 74D/11 Fort McMurray, UTM 476200E, 6285050N

Location and Access: Go back downstream to the dirt track that leads up to the parking lot. The measured section is a composite section that takes into account several discontinuous exposures present along the road from the Abasand subdivision to the Abasand historic site.

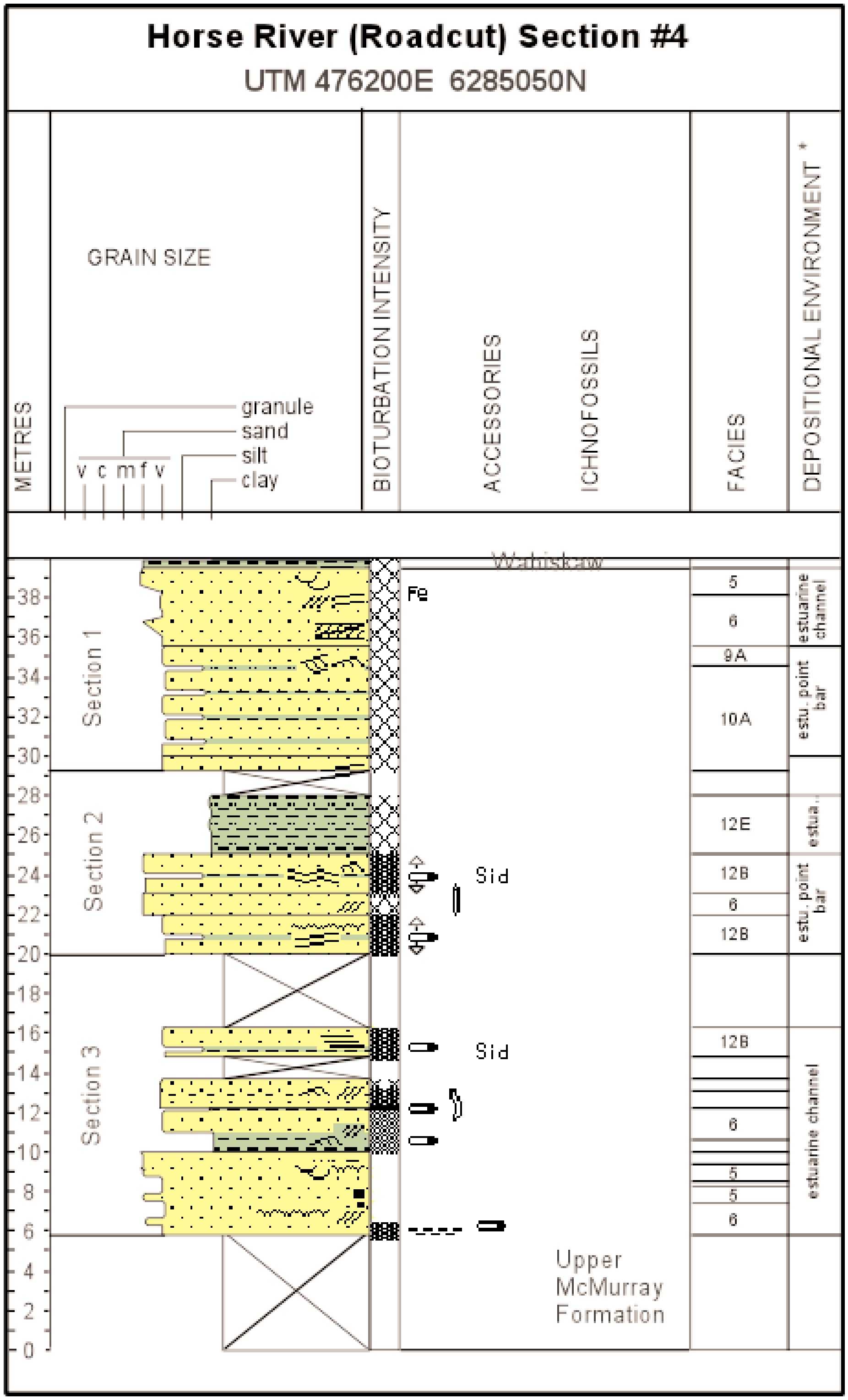
Keynote things to see:

- Mudstone, stratified and cross-bedded sands, inclined heterolithic stratification;
- Rapid lateral and vertical facies changes between estuarine channel and point bar deposits;
- Vertical accretion abandoned channel fill deposits.

Description: The section is mainly covered for the lower 6 m, overlain by about 30 m of McMurray section (Figure 8.3.6). Sediments consist of alternating sand and mudstone-dominated units (Figures 8.3.6, 8.3.7a, b, c). More recessive units are completely covered. Internally the sands are massive or variably stratified with parallel lamination, planar tabular and trough cross-bedding, inclined heterolithic stratification, current ripple, ripple drift and wave-ripple cross-bedding. Burrowing is common within the finer-grained units. *Planolites* is most common, with less common *Skolithos* traces.

At the top of the outcrop, within a metre of the modern soil horizon, is light gray weathered clay, very thin bedded and less than 0.5 m thick. This is interpreted as the Wabiskaw Member of the Clearwater Formation that unconformably overlies the McMurray Formation in the area.

Interpretation: The sands with interbedded mudstones are interpreted as representing the alternation of estuarine channel and point bar sand and mudstone belonging to the Upper McMurray Formation. In the middle part of the succession is a recessive gray mudstone, from 11 to 15 m height, that is even bedded and lacks observable trace fossils. This recessive unit is interpreted as a vertical accretion abandoned estuarine channel fill, similar to units at the top of the Amphitheatre sections near Fort MacKay



*Complete Description in Appendix 3.

Figure 8.3.6. Schematic representation of the measured Horse River (Roadcut) Section #4 (UTM 476200E, 6285050N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 8.3.7a. Section 1 (Upper McMurray Formation) along the road to the Abasand Plant site, Horse River (Roadcut) Section #4, Fort McMurray.

Figure 8.3.7b. Section 2 (Upper McMurray Formation) along the road to the Abasand Plant site, Horse River (Roadcut) Section #4, Fort McMurray.

Figure 8.3.7c. Section 3 (Upper McMurray Formation) along the road to the Abasand Plant site, showing medium-scale interbedded, high angle, planar tabular, cross-bedded sand, Horse River (Roadcut) Section #4, Fort McMurray.

9.0 Athabasca River Outcrops

Map Coordinates: 74E/5 Bitumount, 74D/14 Wood Creek, and 74D/11 Fort McMurray (UTM 446815E, 6272058N for the Crooked Rapids Section #1 at the extreme upstream (southwestern) end; UTM 465959E, 6371974N for Eymundson Creek Mouth Section #4 at the extreme downstream (northern) end) (see Figure 9.0.1 for overview).

General Location and Outcrop Selection: Access to the Athabasca River outcrops is via boat from the Snye Park Landing in Fort McMurray. For the outcrop sections downstream from Fort MacKay an alternate boat access is at the barge landing on the east bank of the Athabasca River, just north of the Muskeg River Bridge across the Athabasca River ('Bridge to Nowhere').

Outcrop sections upstream of Fort McMurray are accessible by boat to Mountain Rapids. The problem with access further upstream involves difficult negotiation of shallow rapids on the Athabasca River between Mountain Rapids and Crooked Rapids. The Crooked Rapids sections can be reached by helicopter or via jetboat or canoe (with shallow draft) under higher water levels.

In the following part three main outcrop sections are described along the Athabasca River upstream from Fort McMurray, including the Crooked Rapids Section #1 and Section #2, the Mountain Rapids Section, and the Athabasca Powerline sections (Figure 9.0.1). The Crooked Rapids sections were taken as the upstream limit for the study area because the next cutbank outcrop upstream from Crooked Rapids shows limited bitumen-staining within a reduced McMurray succession, which is overlain by a thick Clearwater succession (Figure 9.0.2). This then was interpreted as reflecting the main southern limit of outcrop exposures along the Athabasca River drainage of the main bitumen-bearing McMurray Formation.

To the north, seven major outcrops are described along the Athabasca River downstream from Fort McMurray to the southern edge of the Bitumont Basin, near the mouth of Eymundson Creek. This northern limit was determined by accessibility by boat, and the fact that poor exposures of the McMurray Formation occur on the Athabasca River north of the Eymundson Creek Mouth. sections along the Athabasca River were measured that showed good display of sedimentary features, with relatively little disturbance by recent slumping. The major outcrops measured on the Athabasca River downstream from Fort McMurray are the McMurray Formation Type, the Fluvial Marl and Marl Upper, Tar Island Fluvial, Daphne Island West and East, Pierre River Mouth, and Eymundson Creek Mouth (Figure 9.0.1).

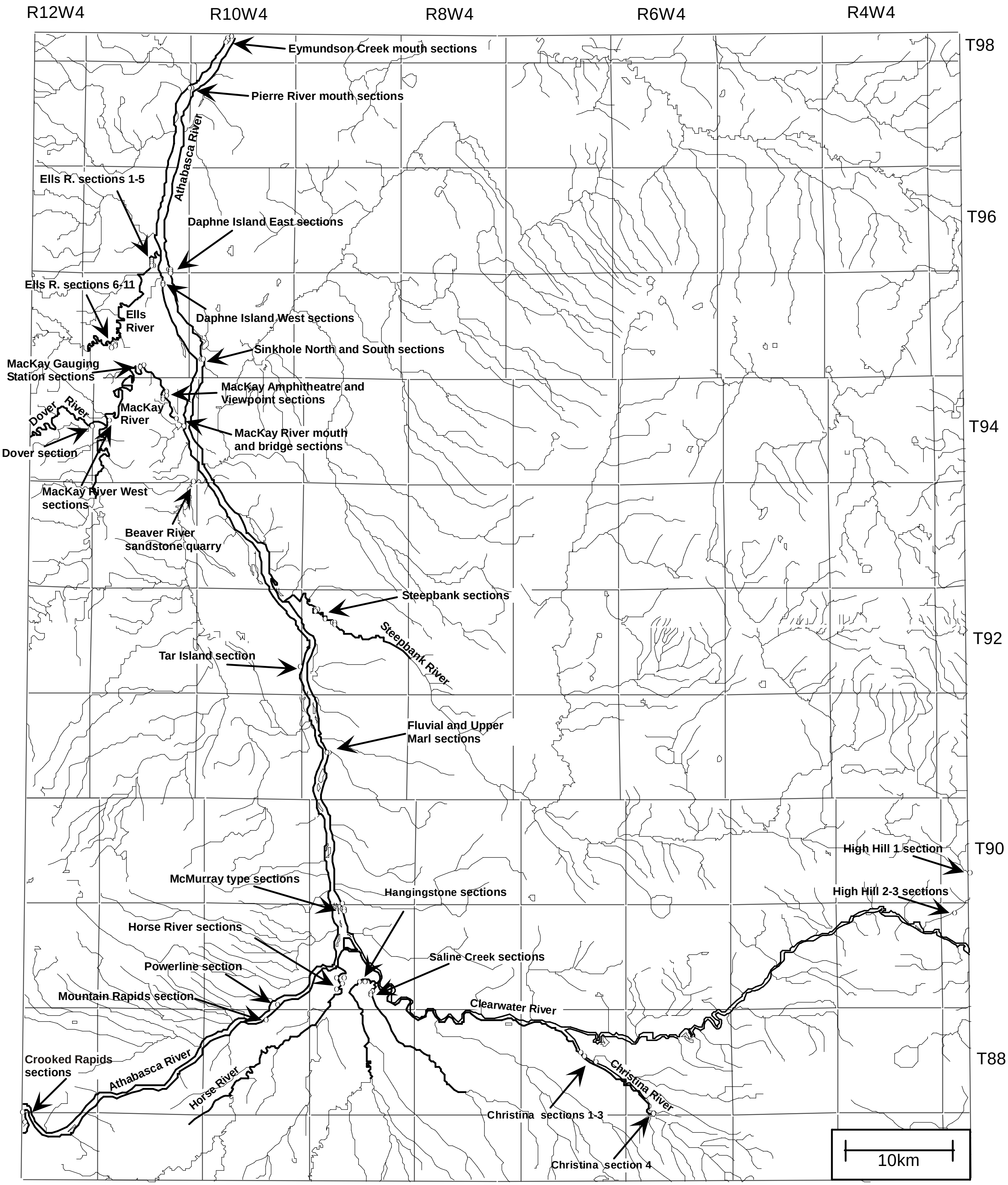


Figure 9.0.1. Map showing river access to major outcrops along the Athabasca River, including the Crooked Rapids, Mountain Rapids, Athabasca Powerline, McMurrray Formation Type, Fluvial and Upper Marl, Tar Island, Daphne Island West, Daphne Island East, Pierre River Mouth, and Eymundson Creek Mouth. Horizontal scale bar is 10 kms.

Figure 9.0.2. Clearwater/McMurray succession exposed upstream from the Crooked Rapids on the Athabasca River (west of Fort McMurray).

9.1 Crooked Rapids Section #1

Map Coordinates: 74D/12 Cascade Rapids, UTM 446815E, 6272058N

Location and Access: Go to the northern tip of the sharp meander bend at Crooked Rapids on the Athabasca River (Figure 9.1.1). Walk south along the bank for about 800 m, until an accessible gully is reached, about 2/3 along the cutbank section (Figures 9.1.1, 9.1.2). The section starts about 2 m above a bench of Moberly Limestone that runs along the cutbank at river level.

Keynote things to see:

- Stacked channel and point bar sands, stratified and cross-bedded sands, inclined heterolithic stratification;
- Rapid lateral and vertical facies changes between estuarine channel and point bar deposits;
- Vertical accretion abandoned channel fill deposits, inaccessible at the top of the section.

Description: The section is mainly covered for the lower 2 m, overlain by about 28 m of McMurray section (Figure 9.1.3). Sediments consist of alternating sand and mudstone-dominated units, each showing large-scale inclined heterolithic stratification throughout most of the exposure (Figures 9.1.3, 9.1.4a, b). Internally the sands are generally fining- upward, with parallel lamination, trough and ripple cross-bedding, and less common mudstone intraclasts (Figure 9.1.3). Burrowing is uncommon as *Skolithos*, *Planolites*, and *Cylindrichnus* traces, mainly within the lowermost sandstone unit.

Interpretation: The sands with interbedded mudstones are interpreted as representing the alternation of estuarine channel and point bar sand and mudstone belonging to the Upper McMurray Formation. At the top of the succession is a recessive gray mudstone, from 5 to 10 m height, that is even bedded and from the float lacks observable trace fossils. This recessive unit is inaccessible, but from the observed bedding style and float characteristics is interpreted as a vertical accretion abandoned estuarine channel fill, similar to other units at the top of the McMurray Formation along the Athabasca River valley.

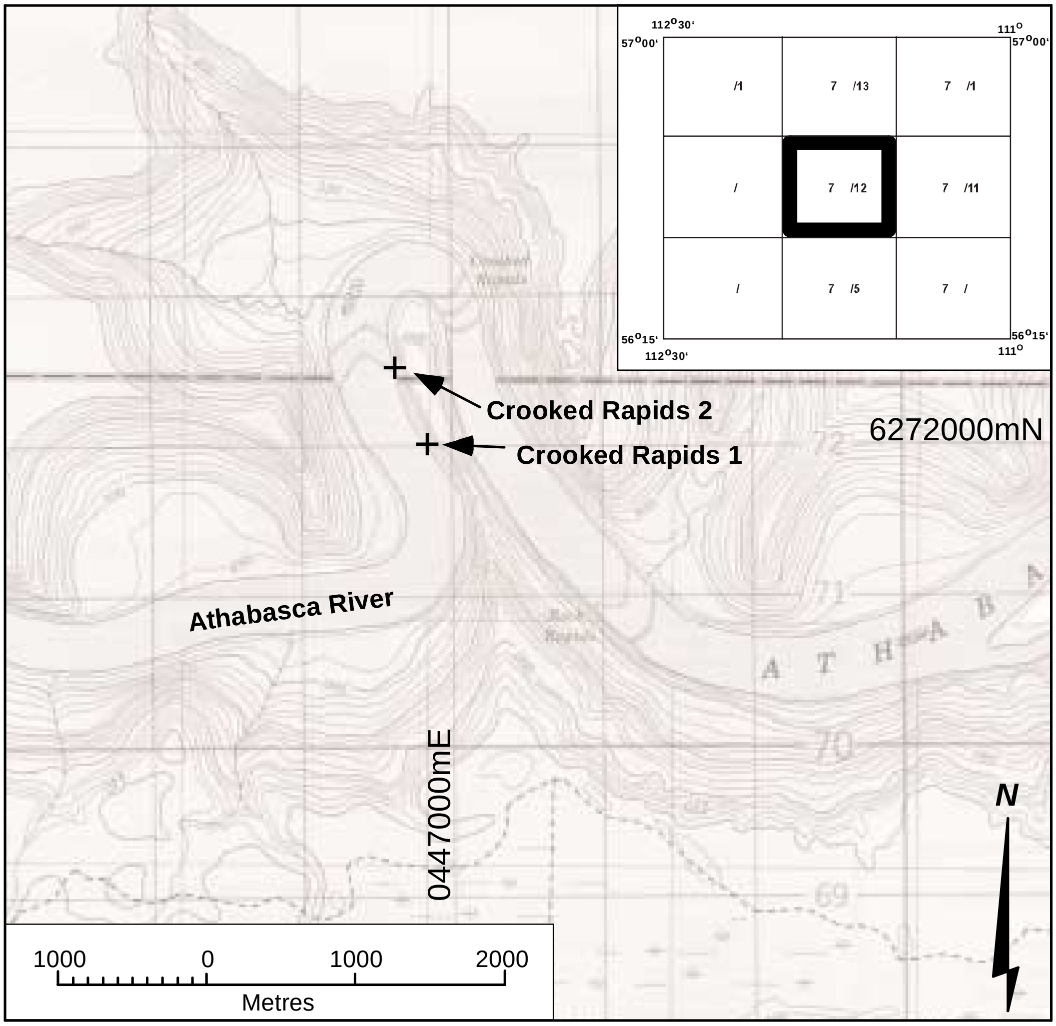


Figure 9.1.1. Map showing access to the Crooked Rapids outcrops along the Athabasca River, about 50 km upstream from Fort McMurray.

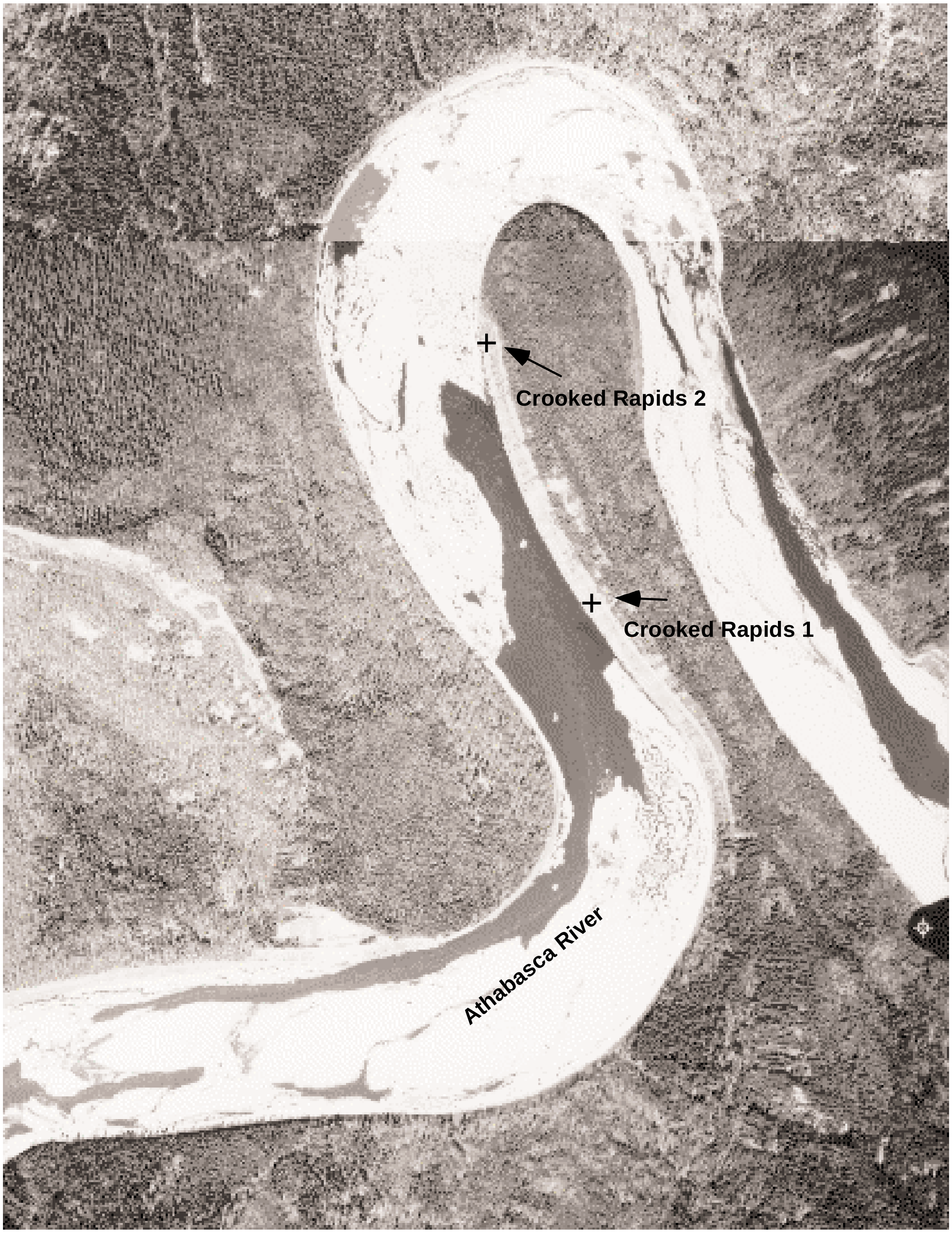
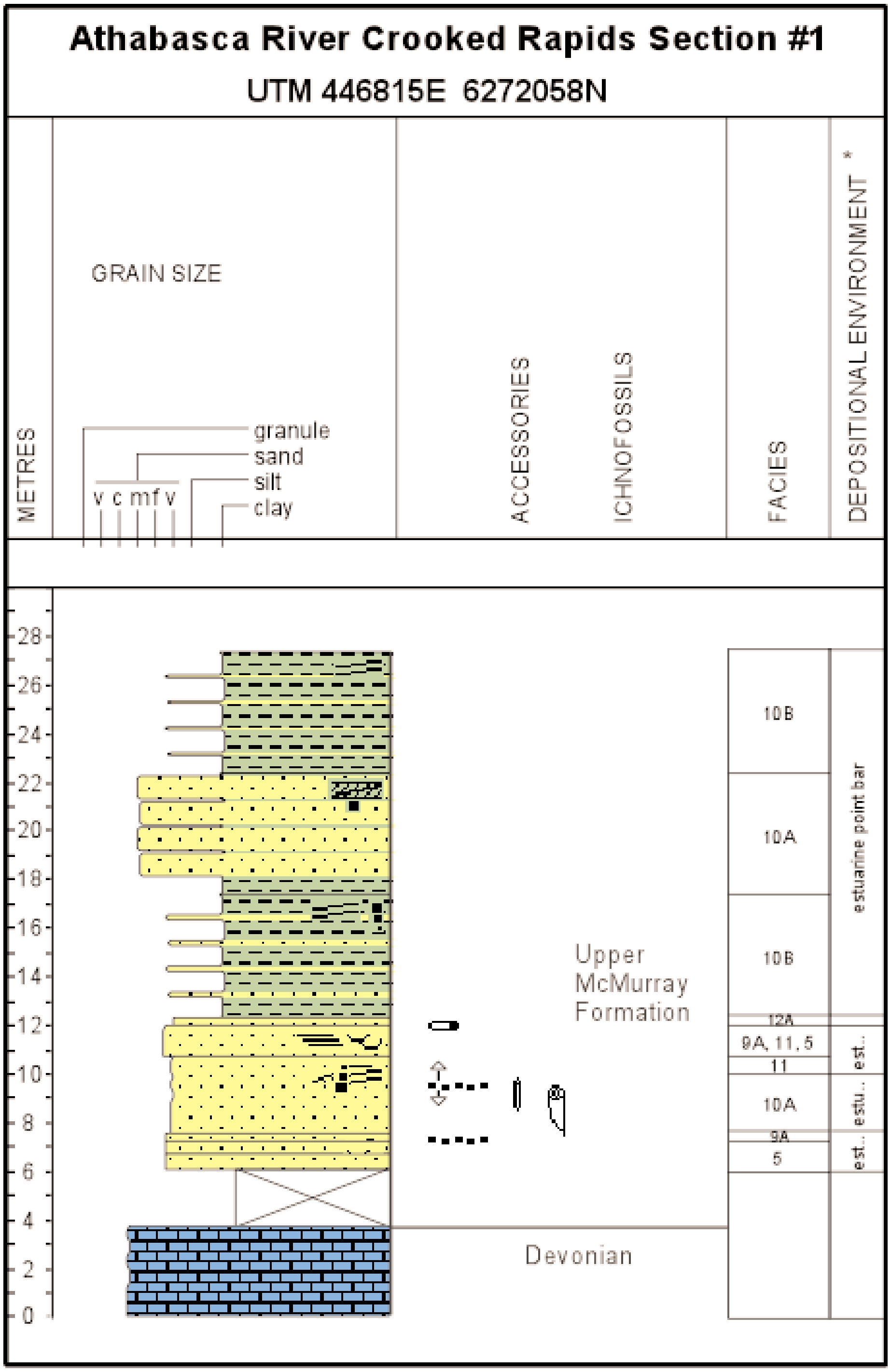


Figure 9.1.2. Aerial photograph showing location and access to the Crooked Rapids outcrops along the Athabasca River, about 50 km upstream from Fort McMurray.



* Complete Description in Appendix 3.

Figure 9.1.3. Schematic representation of the measured Crooked Rapids Section #1 (UTM 446815E, 6272058N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.1.4a. Overview of Crooked Rapids Section #1 on the Athabasca River, west of Fort McMurray.

Figure 9.1.4b. Crooked Rapids Section #1, Athabasca River.

9.2 Crooked Rapids Section #2

Map Coordinates: 74D/12 Cascade Rapids, UTM 446608E, 6272690N

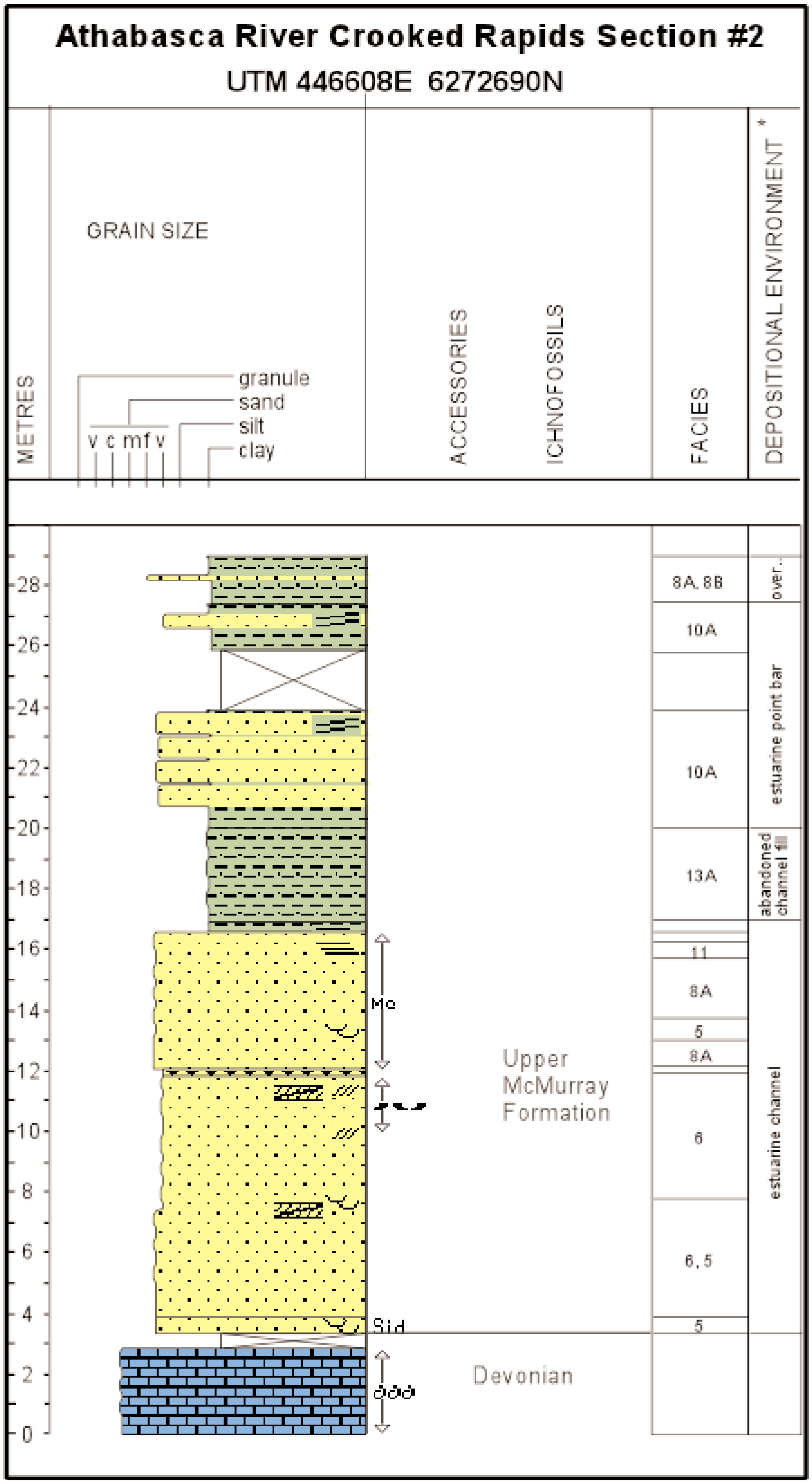
Location and Access: Continue back along the bank towards the sharp meander bend at Crooked Rapids (Figure 9.1.1), until an accessible gully is reached, about 1/3 to the north along the cutbank section (Figures 9.1.1, 9.1.2). The section starts about 0.5 m above a bench of Moberly limestone that runs along the cutbank at river level.

Keynote things to see:

- Stacked channel and point bar sands, stratified and cross-bedded sands, inclined heterolithic stratification;
- Rapid lateral and vertical facies changes between estuarine channel and point bar deposits;
- Vertical accretion abandoned channel fill deposits, over 1 m thick and accessible at the top of the section.

Description: The basal contact of the McMurray Formation with the underlying Moberly limestone is covered. Approximately 25 m of McMurray section is exposed that was measured up the gully (Figure 9.2.1). At the base of the section is thick-bedded fine sand that shows well developed planar tangential and planar tabular cross-bedding, with internal scours, and local sideritization at the base (Figures 9.2.1 and 9.2.2a). The thick-bedded fine sand is capped by a thin (<0.5 m thick) mudstone intraclast breccia. Overlying this is an interbedded succession of sand and mudstone-dominated units, each with large scale inclined heterolithic stratification (Figures 9.2.1, 9.2.2b). Internally the sands are generally fining-upward, stratified with parallel lamination; trough and ripple cross-bedding, with less common mudstone intraclasts. Bedding contacts are commonly scoured. At the top of the measured section is a 1.5 to 2 m thick interbedded sand and mudstone, with an even and horizontal bedding style (Figure 9.2.2b, above the massive sand bluff and beneath the treed interval). The sand interbeds are massive, and siderite concretions are common at the top of the unit.

Interpretation: The thick-bedded fine sands with planar tangential and planar tabular cross-bedding are interpreted as high energy estuarine channel deposits of the Upper McMurray Formation. The channel sediments are overlain by the mudstone intraclast breccia, a possible cutbank collapse breccia. Next are the interbedded sand and mudstones with the inclined heterolithic stratification, interpreted as estuarine point bar deposits. At the top of the succession the more recessive gray sand and mudstone, from 1.5 to 2 m thick, that is even bedded and from the float lacks observable trace fossils, is interpreted as a vertical accretion abandoned estuarine channel fill. Although trace fossils are generally absent from this section, the lateral along-strike changes into bioturbated sands and mudstones at the Crooked Rapids Section #1 indicate a similar environment, mainly within an estuarine complex, but due to higher energy conditions there was little or no bioturbation at this section.



*Complete Description in Appendix 3.

Figure 9.2.1. Schematic representation of the measured Crooked Rapids Section #2 (UTM 446608E, 6272690N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.2.2a. Thick, large-scale, trough cross-bedded sand (Upper McMurray Formation) Crooked Rapids Section #2, Athabasca River, southwest of Fort McMurray. About 12 m of vertical section is shown.

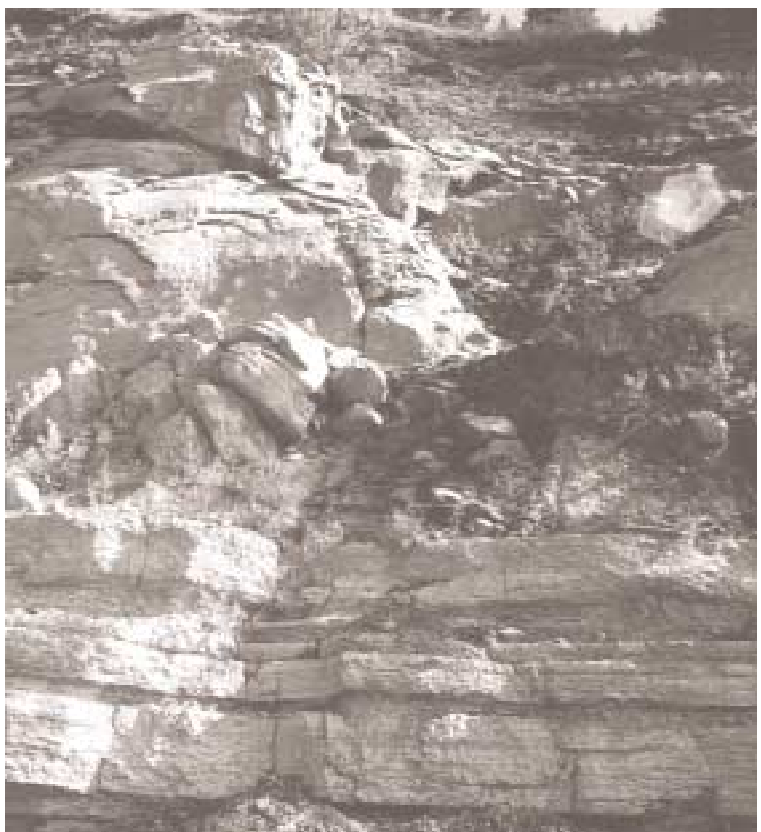


Figure 9.2.2b. Large-scale, sandy inclined heterolithic stratification interbedded with large-scale trough cross-bedded sand, capped by fine-grained vertical accretion sediment, Crooked Rapids Section #2, Athabasca River, southwest of Fort McMurray. About 18 m of vertical section is shown.

9.3 Mountain Rapids Section

Map Coordinates: 74D/12 Cascade Rapids, UTM 468880E, 6281093N

Location and Access: Go by boat to the cutbank section just downstream from Mountain Rapids on the east bank of the Athabasca River (Figure 9.3.1, 9.3.2). The section starts at a bench of Moberly limestone that runs along the cutbank at river level.

Keynote things to see:

- Stacked channel sands, micaceous with abundant carbonaceous debris and mudstone intraclast breccias, with rare *Skolithos* burrows;
- Gradual vertical facies changes from channel to point bar and vertical accretion abandoned channel deposits;
- Thick-bedded sand with coquinas, largely inaccessible, at the top of the section.

Description: The section is mainly covered for the lower 8 m (Figures 9.3.4a, b), where a slumped, 1.5 m thick, fine-grained sand, with trough cross-bedding and rare *Skolithos* burrows, overlies a 2 m high bench of Moberly limestone. The next 7 m of section is an overall fining-upward succession (Figure 9.3.4c) of alternating sand and mudstone intraclast breccia units, which are micaceous and have abundant carbonaceous debris (Figure 9.3.3). The sand interbeds are massive, or show ripple or trough cross-bedding (Figure 9.3.3). Pyrite nodules and pyrite cement occur at the top of the fining-upwards succession. The upper part of the section comprises finely interbedded fine- to very fine-grained sand, siltstone, silty mudstone and mudstone intraclast breccias, mainly parallel bedded (Figure 9.3.4d) with rare inclined heterolithic stratification. Internally the sand and siltstone interbeds are rippled or finely laminated. *Cylindrichnus* and *Planolites* burrows are common (Figure 9.3.3). Upsection, within the topmost 5 m of outcrop, the amount of carbonaceous debris increases, along with an increase in *Planolites* burrows, a decrease in the abundance of *Cylindrichnus*, and the occurrence of coquinas of gastropod interbeds. The only other outcrop where these coquinas have been documented are in the middle part of the McMurray succession at the Hangingstone Section #1 in the town site of Fort McMurray. Coquinas have not been observed in core to date from either the surface mineable nor in situ areas.

Interpretation: The sands with interbedded mudstone intraclast breccias are interpreted as representing the estuarine channel deposits belonging to the Upper McMurray Formation. The carbonaceous sandstone, siltstone and mudstone succession with the *Cylindrichnus* burrows and even bedding style is interpreted as mainly vertical accretion abandoned channel fill deposits, with rare lateral accretion point bar deposits. The topmost interbedded carbonaceous sands and coquinas are possible distributary channel fill, storm-surge channel or washover deposits within a nearshore coastal plain setting, seaward of the main estuarine succession represented by most of the Mountain Rapids outcrop section.

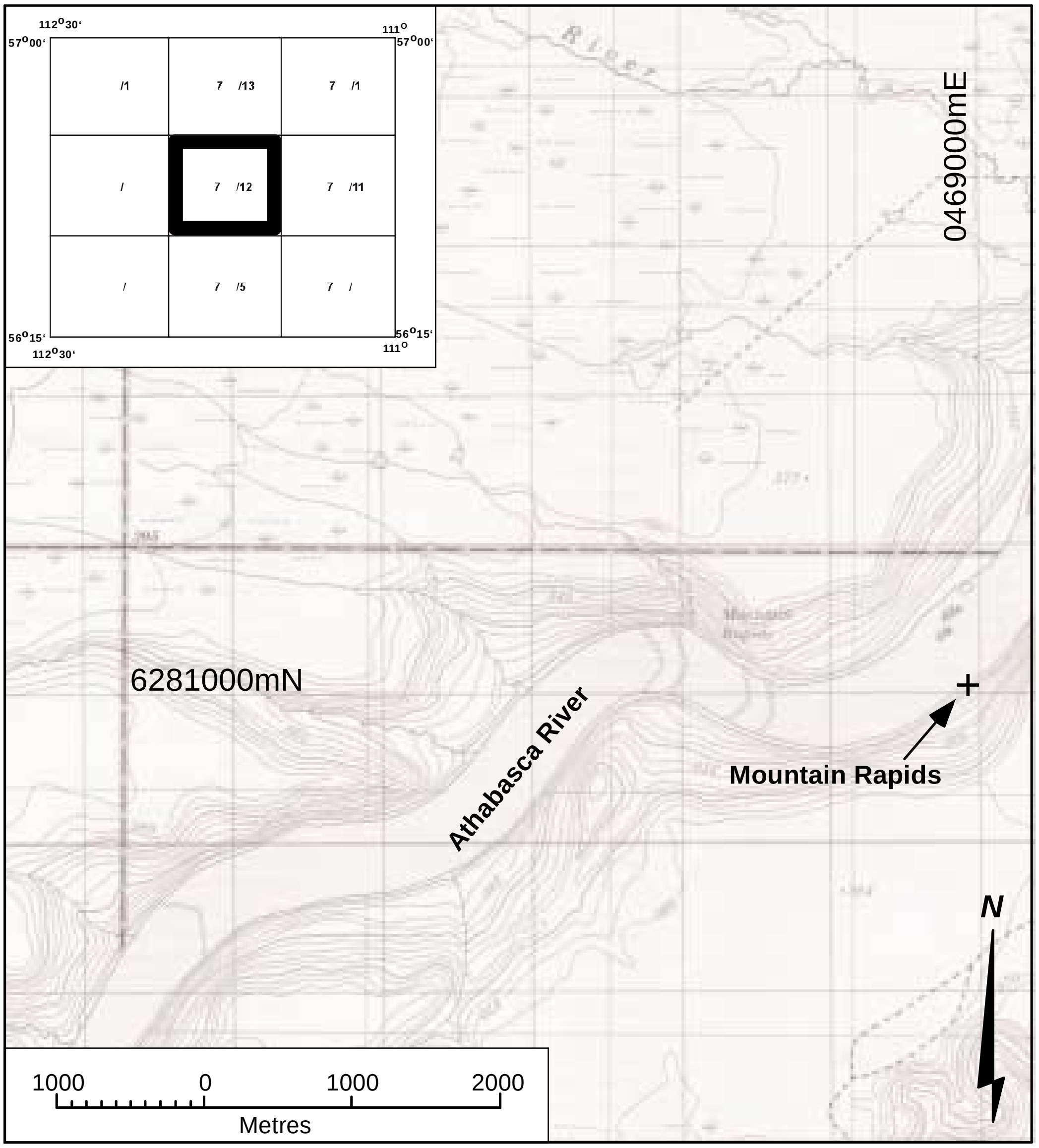
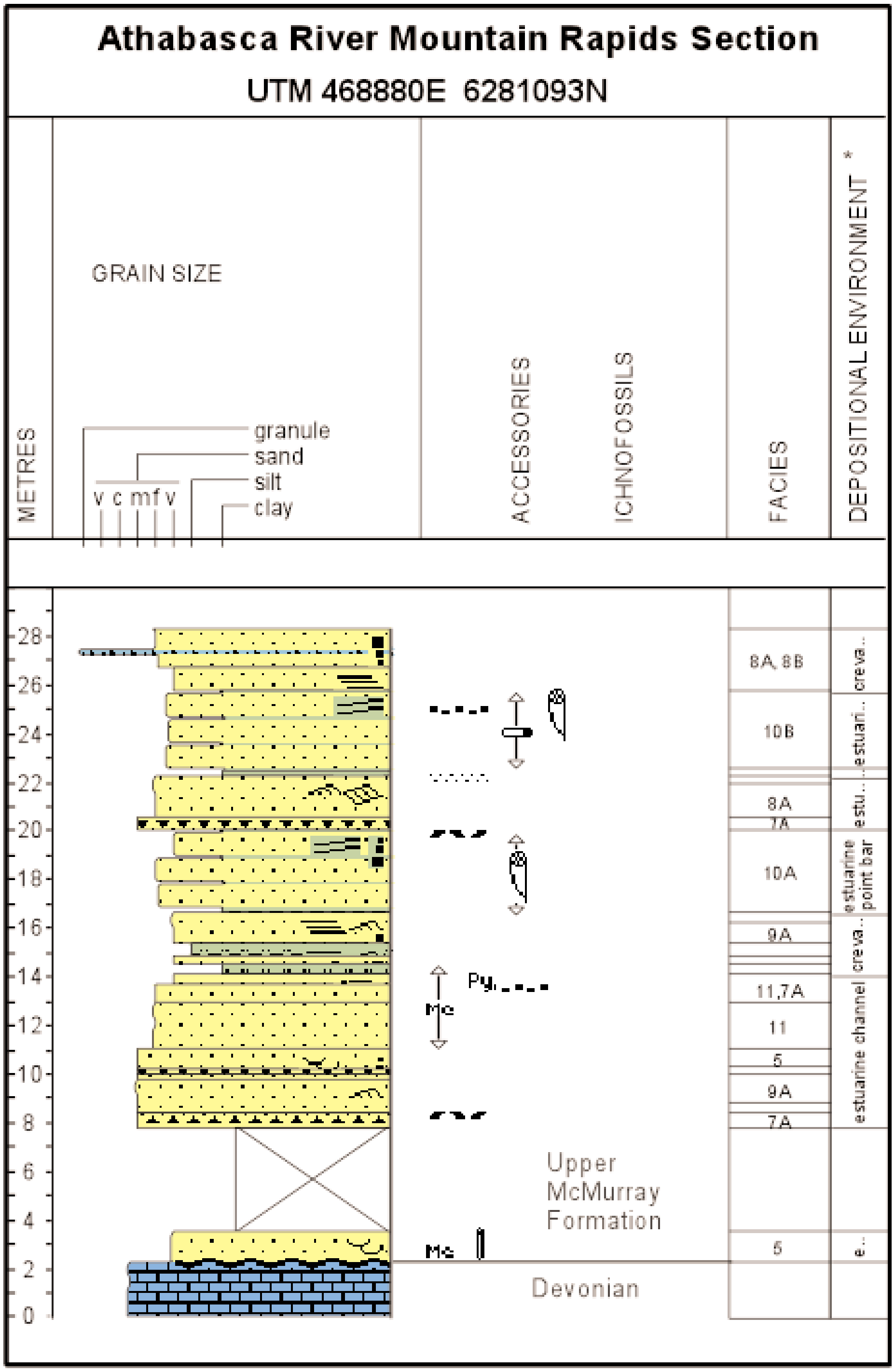


Figure 9.3.1. Map showing access to the Mountain Rapids outcrop along the Athabasca River, about 20 km upstream of Fort McMurray.

Figure 9.3.2. Aerial photograph showing location and access to the Mountain Rapids outcrop along the Athabasca River about 20 km upstream from Fort McMurray.



*Complete Description in Appendix 3.

Figure 9.3.3. Schematic representation of the measured Mountain Rapids Section (UTM 468880E, 6281093N). Facies designations are listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.3.4a. Upper McMurray succession exposed across the river from the Mountain Rapids Section, Athabasca River, southwest of Fort McMurray.

Figure 9.3.4b. Downstream end of the Upper McMurray succession exposed at the Mountain Rapids Section, Athabasca River, southwest of Fort McMurray.

Figure 9.3.4c. Upper McMurray succession exposed at the Mountain Rapids Section, Athabasca River, southwest of Fort McMurray.

Figure 9.3.4d. Upper McMurray succession at the Mountain Rapids Section on the Athabasca River, southwest of Fort McMurray.

9.4 Athabasca Powerline Section

Map Coordinates: 74D/11, Fort McMurray, UTM 470012, 62812431N

Location and Access: This section is located approximately 6 km upstream by boat from Fort McMurray. Go to the cutbank section located on the east bank of the Athabasca River beneath a major power line, downstream from Mountain Rapids Section (Figure 9.4.1, 9.4.2).

Keynote things to see:

- Interbedded estuarine channel and point bar deposits, with pebble lag and a major internal scour surface within the lowermost 3 m;
- Thick, stacked estuarine point bar deposits.

Description: The section is a very steep, largely inaccessible, face of interbedded sand with minor mudstones. Only a very general section was done. Thickness was estimated by surveying from the bank using Impulse Laser survey equipment. Structures were discernable in float blocks, but the face was impossible to climb without climbing gear.

The section consists of about 25 m of McMurray Formation (Figure 9.4.3), the base of which is covered in slump blocks along the bank. The lowest 3 to 4 m of section, which was accessible, consists of interbedded cut-and-fill carbonaceous pebbly sand, largely trough cross-bedded, that laterally interfingers with interbedded sand and mudstone, with inclined heterolithic cross-bedding. Next is a large undulating and scoured surface, with up to 2 m of relief that cross cuts most of the outcrop, and is infilled with a coarse pebble lag. The overlying 20 m of section is totally inaccessible, which from the bank appears to be largely interbedded sand and mudstone with large-scale inclined heterolithic cross-bedding. Much of the finer-grained float material on the bank is bioturbated, including *Planolites*, *Skolithos* and *Cylindrichnus*. Coarser-grained float generally shows cross-bedding, mainly planar tabular, trough and ripple cross-beds, and rare *Skolithos* burrows.

Interpretation: The pebbly sands and pebble lags that occur as cut-and-fills or overlie the major scour surface are interpreted as main estuarine channel deposits belonging to the Upper McMurray Formation. The overlying thick succession of interbedded finer-grained sand and mudstone with the inclined heterolithic stratification and multiple reactivation surfaces (Figure 9.4.3) is interpreted as representing stacked estuarine point bar deposits also belonging to the Upper McMurray Formation.

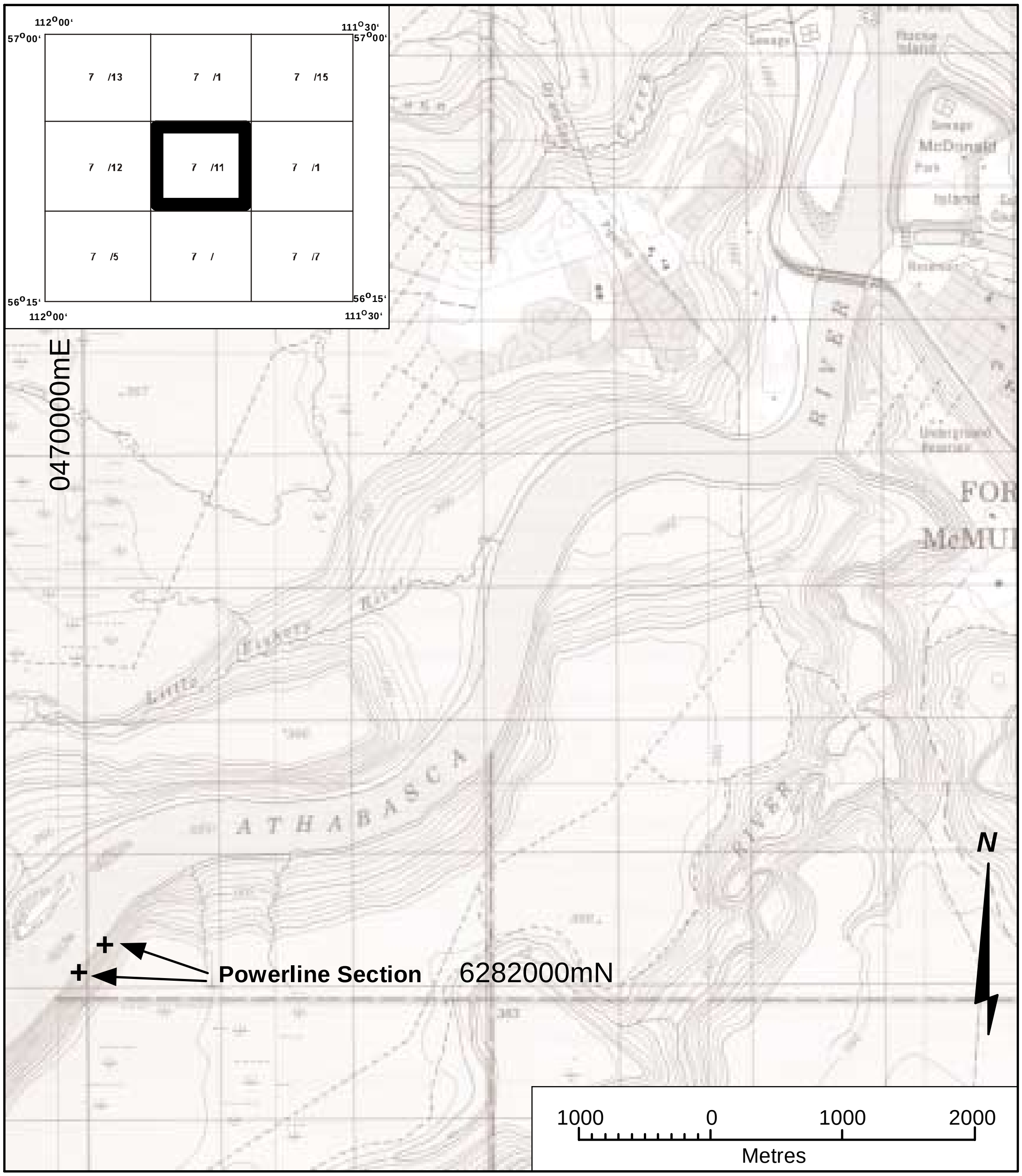


Figure 9.4.1. Map showing access to the Athabasca Powerline Section along the Athabasca River, about 9 km upstream from Fort McMurray.

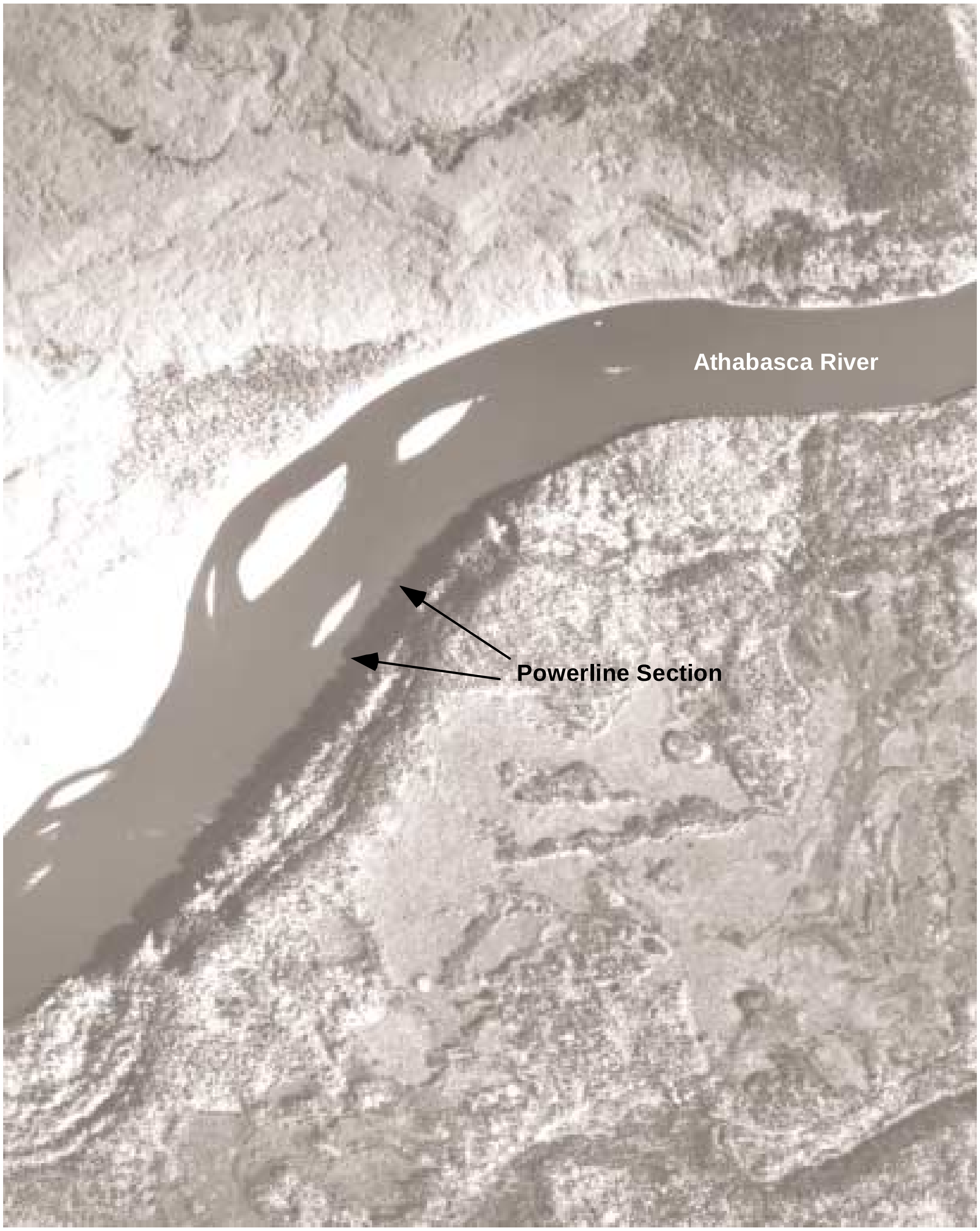
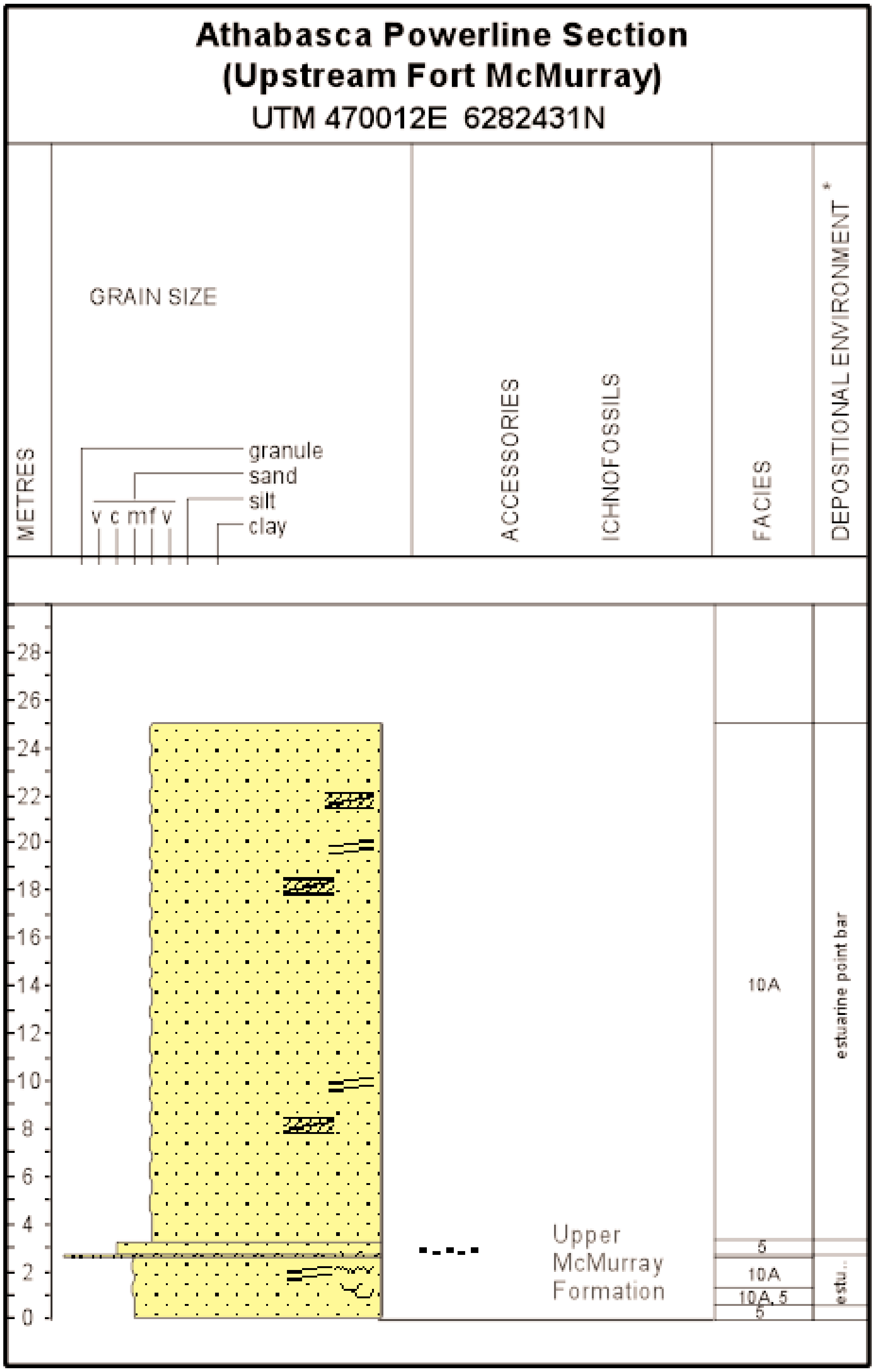


Figure 9.4.2. Aerial photograph showing location and access to the Athabasca Powerline Section along the Athabasca River, about 9 km upstream from Fort McMurray.



* Complete Description in Appendix 3.

Figure 9.4.3. Schematic representation of the measured Athabasca Powerline Section (UTM 470012E, 6282431N). Facies designations are listed in Appendix 2. Vertical scale bars are 1 m in height.

9.5 McMurray Formation Type Section #1

<u>Map Coordinates:</u> 74D/11 Fort McMurray, Scale 1: 50 000, UTM 0476166E, 6291060N.

<u>Location and Access:</u> This section is located approximately 5 km downstream from the confluence of the Athabasca and Clearwater rivers on the east bank of the Athabasca River near the mouth of Clarke Creek (Figures 9.5.1 and 9.5.2).

<u>Keynote things to see:</u>

- Very thick, fining- and thinning-upwards, estuarine channel deposits, largely rippled or trough cross-bedded;
- Well developed alternation of thick vertical accretion abandoned channel mudstones and cross-bedded channel sands;
- Thin (<1.5 m) Wabiskaw D-Fill at the top of the outcrop.

<u>Description:</u> In this outcrop section about 34 m of McMurray section is exposed (Figures 9.5.3, 9.5.4a). At the base the outcrop is a series of stacked, thick, cross-bedded sands, with abundant planar tabular or trough cross-bedding (Figure 9.5.3), that along-strike interfinger with large-scale low-angle inclined heterolithic stratified sand and mudstone (Figure 9.5.4b). Towards the base of the section the finer-grained siltstone/mudstone interbeds are rare. Further upsection the sands become thinner-bedded, finer-grained, and more massive, with an increase in the degree of bioturbation, with the most common types being *Cylindrichnus* and *Planolites*. A 3 to 4 m covered interval separates the interbedded sand and mudstone from a coarse-grained fining-up succession of planar tabular sands, that grade upsection into low-angle sandy, inclined heterolithic stratified sand and mudstone. The low-angle sandy stratified units, in turn, fine-upwards into low- angle, muddy inclined heterolithic-stratified sand and mudstone at the top of the McMurray succession.

At the very top of the outcrop is exposed a thin (<1.5 m) dark gray to black, bioturbated, sandy to silty mudstone, that is the Wabiskaw Member of the Clearwater Formation.

<u>Interpretation:</u> The stacked, thick, cross-bedded sands at the base of the section are interpreted as high energy, main estuarine channel deposits of the Upper McMurray succession. This is overlain by the thinly interbedded, low-angle inclined stratified units, interpreted as small-scale estuarine channel and point bar deposits. Paleoflows are unidirectional, mainly directed towards the north, with rare paleoflows direct towards the south. The finer-grained, smaller estuarine channel and point bar deposits are overlain by a topmost main estuarine channel fill that fines upward into estuarine point bar deposits at the top of the Upper McMurray Formation.

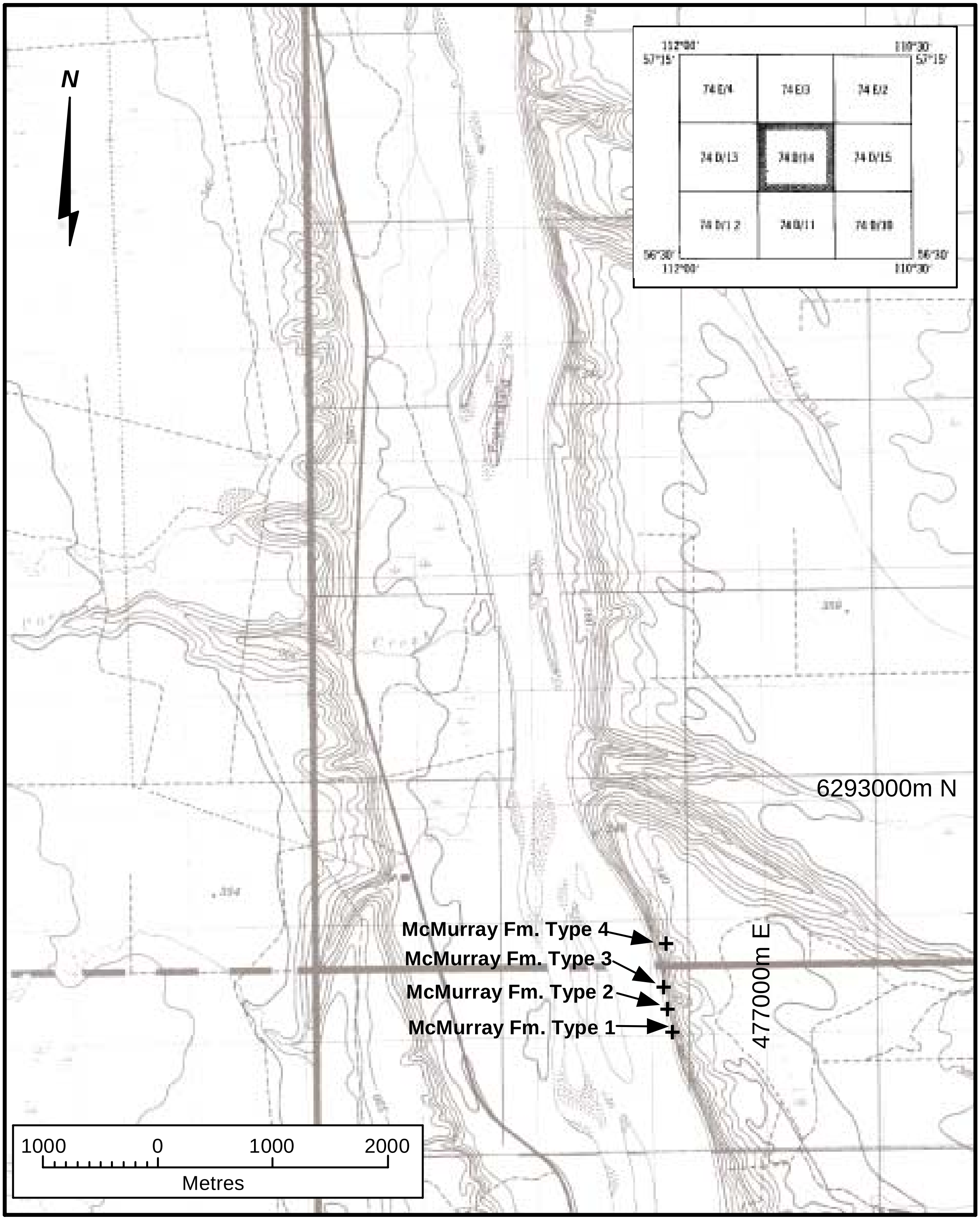
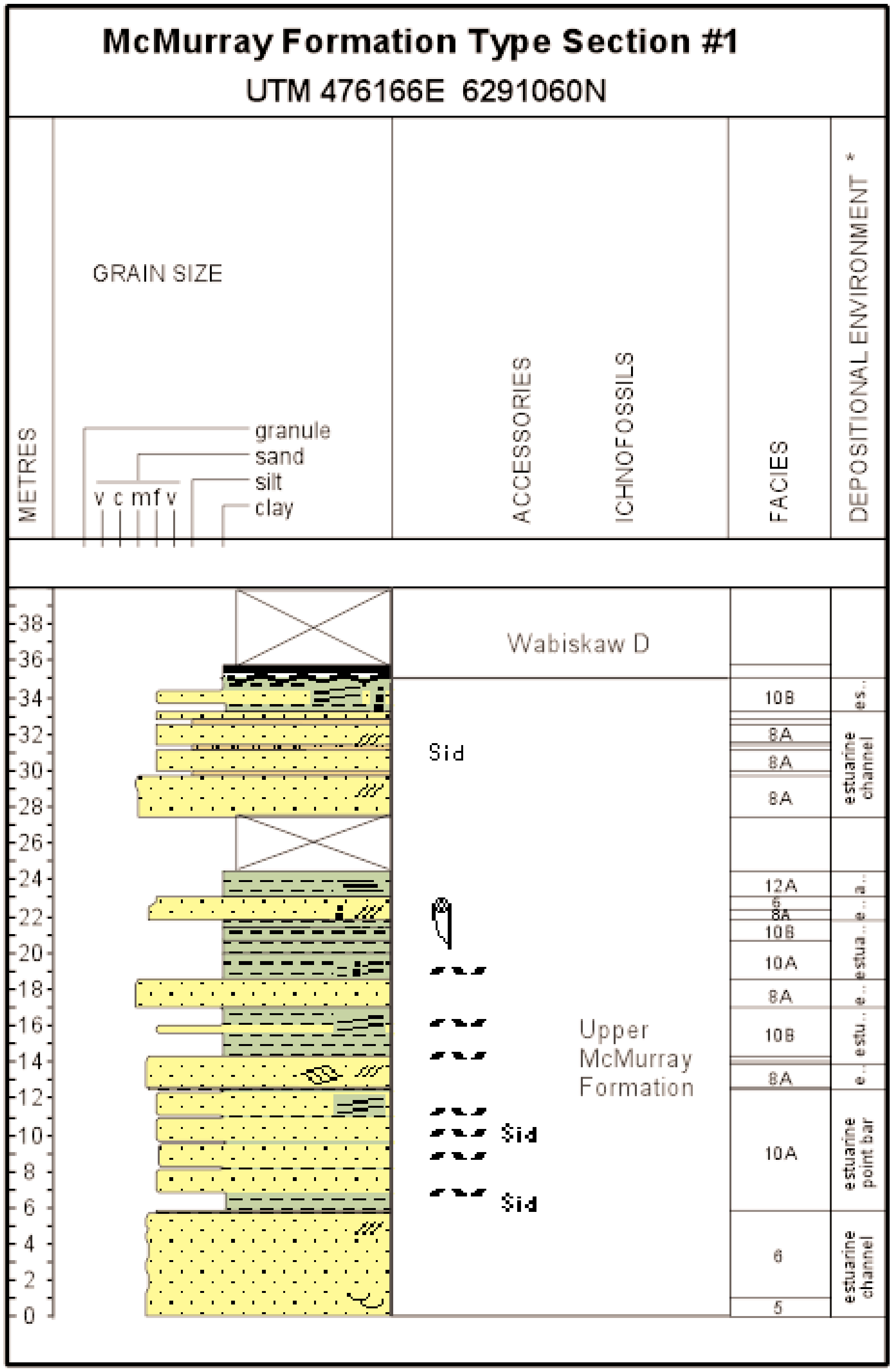


Figure 9.5.1. Map showing access to the McMurray Formation Type Sections #1 to #4 along the east bank of the Athabasca River, about 5 km downstream from the confluence of the Athabasca and Clearwater rivers.

Figure 9.5.2. Aerial photograph showing location of the McMurray Type Sections #1 to #4 on the Athabasca River just north of Fort McMurray.



* Complete Description in Appendix 3.

Figure 9.5.3. Schematic representation of the measured McMurray Formation Type Section #1 (UTM 476166E, 6291060N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.5.4a. View from south to north of the McMurray Formation Type Section along the Athabasca River.

Figure 9.5.4b. Overview of Upper McMurray Formation at the Type Section #1, Athabasca River.

9.6 McMurray Formation Type Section #2

Map Coordinates: 74D/11 Fort McMurray UTM 476157E, 6291350N.

Location and Access: This section is located approximately 5.2 km downstream from the confluence of the Athabasca and Clearwater rivers on the east bank of the Athabasca River near the mouth of Clarke Creek (Figures 9.5.1 and 9.5.2)

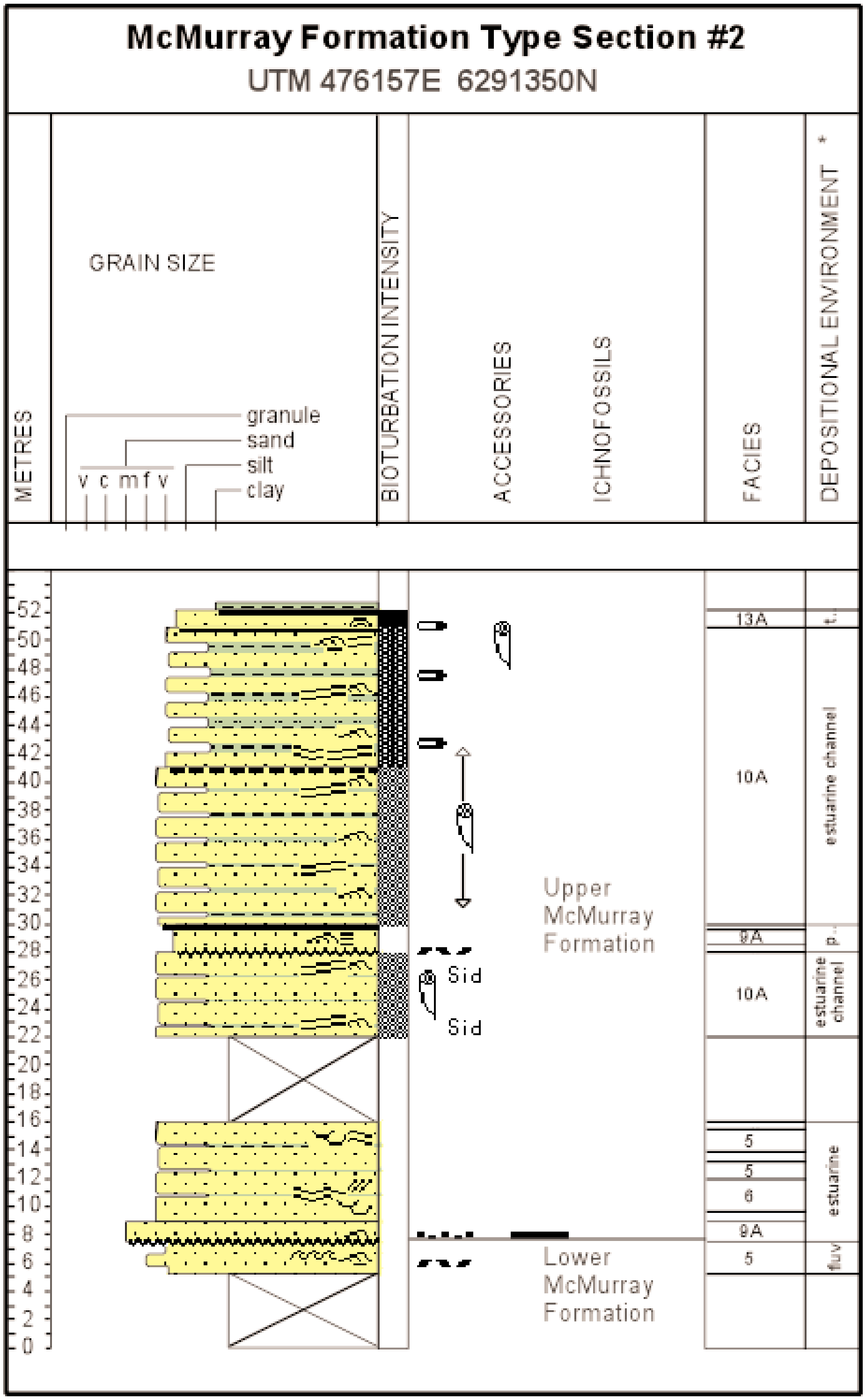
Keynote things to see:

- Thick estuarine channel and point bar sediment with rapid facies changes;
- Well developed cross-bedding and bioturbation features in channel sands;
- Stacked packages of multi-story inclined heterolithic stratified sets;
- Unconformity between the Lower and Upper McMurray successions;
- Possible bay-head delta or bay-fill deposits in the Upper McMurray.

Description: In this thick outcrop section (about 50 m high) a thin remnant (2 m thick) of the fluvial sand occurs at the base (Figure 9.6.1). This fluvial deposit is often not seen due to its relatively unconsolidated nature (lack of bitumen-cement) and slumped nature. When beds are exposed, coarse- to fine-grained sand is seen, with large-scale planar tabular and trough cross-beds (Figures 9.6.2a, b), many of which show cross cutting relationships and opposing flow directions (Figures 9.6.2a, c). Unconformably overlying this unit is the more typically interbedded sand and mudstone of the McMurray Formation. The thick, interbedded sand and mudstone units, in general, show low-angle inclined heterolithic stratification, with moderate to high degrees of bioturbation (Figure 9.6.2d). Mudstone interbeds increase in frequency and thickness going upsection. Concomitant with this increase in mudstones, there is also an increase in bioturbation intensity, with the most common types being *Cylindrichnus* and horizontal *Planolites*, with rare vertical *Skolithos.* Locally, towards the base of the interbedded sand and mudstone unit, there are slight divergences in paleoflows, however, towards the middle and top part of this unit, paleoflow patterns become unidirectional oriented towards the north.

At the very top of the outcrop is exposed a thin (<1 m), bioturbated, black, silty mudstone that is the Wabiskaw D unit (Wabiskaw Member, Clearwater Formation), that unconformably overlies the McMurray Formation in this area.

Interpretation: The pebbly and finer sand at the base of the section with the prominent cross-bedding and lack of interbedded mudstones or bioturbation features is interpreted as Lower McMurray fluvial deposits. This is overlain by a very thick succession of stacked estuarine interbedded sand and mudstone deposits. Some of these estuarine sands are massive or show abundant cross-bedding, and are interpreted as estuarine channel sands. The sands that are interbedded with mudstone as inclined heterolithic stratification that interfingers with and/or is cross cut by the channel sands are interpreted as estuarine point bar deposits. Those units within the middle and upper parts of the measured section that show multiple stacked, and overall upward fining successions of low-angle, inclined heterolithic stratified sand and mudstone, with unidirectional-paleoflows are interpreted as possible bay-head delta or bay-fill deposits. All of the estuarine and bay-head delta deposits are within the Upper McMurray.



*Complete Description in Appendix 3.

Figure 9.6.1. Schematic representation of the measured McMurray Formation Type Section #2 (UTM 476157E, 6291350N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.6.2a. Pinstriped, large-scale cross-bedded, fine-grained sand (Upper McMurray Formation) at the base of McMurray Formation Type Section #2, Athabasca River, north of Fort McMurray.

Figure 9.6.2b. Coarse-grained, trough cross-bedded sand (laterally discontinuous cut and fill), overlying fine-grained, trough cross-bedded sand (Lower McMurray Formation), McMurray Formation Type Section #2, Athabasca River, north of Fort McMurray.

Figure 9.6.2c. Large-scale, trough cross-bedded, fine-grained sand (Upper McMurray Formation) at the base of McMurray Formation Type Section #2, Athabasca River, north of Fort McMurray.

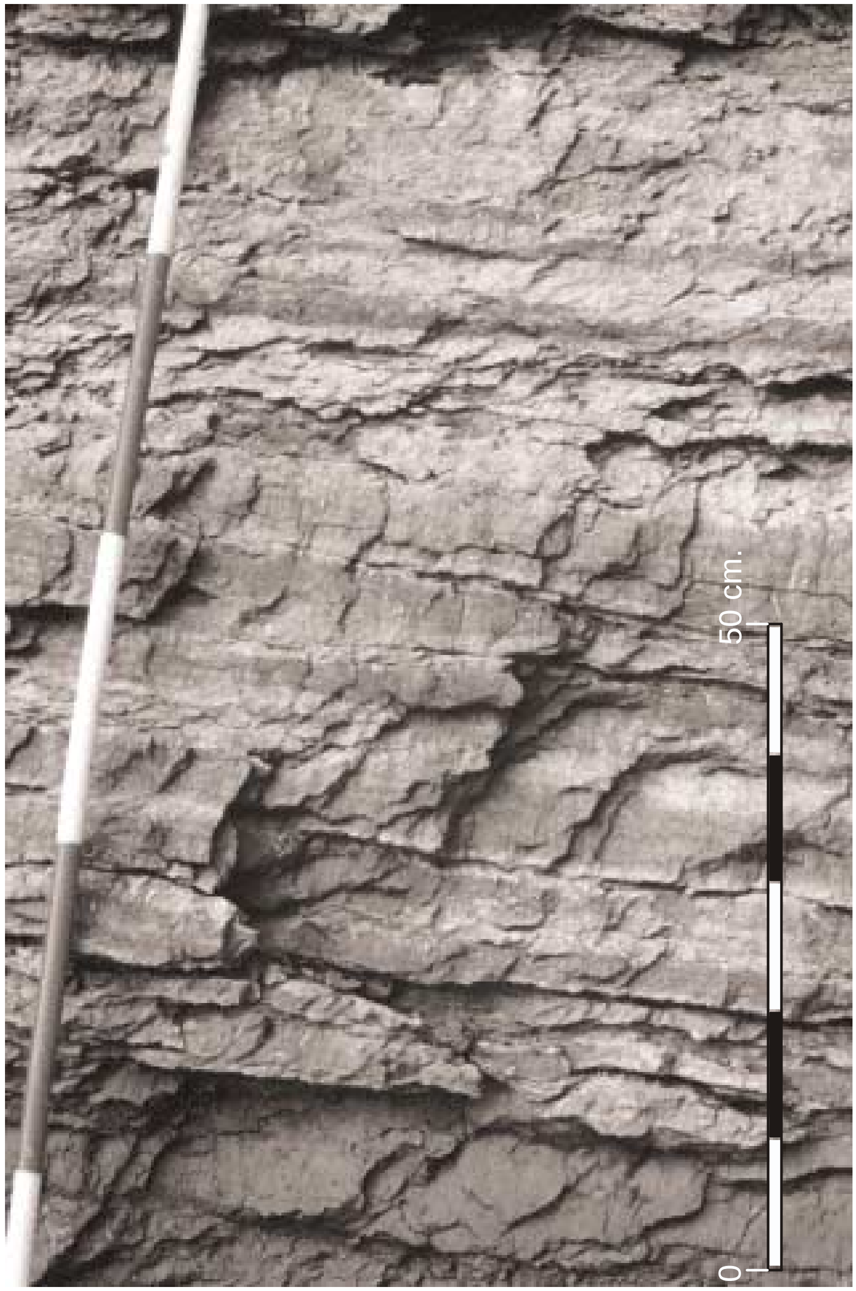


Figure 9.6.2d. Bioturbated, mud-dominated, inclined heterolithic stratification (Upper McMurray Formation), McMurray Formation Type Section #2, on the Athabasca River, north of Fort McMurray.

9.7 McMurray Formation Type Section #3

Map Coordinates: 74D/11 Fort McMurray, UTM 476096E, 6291400N.

Location and Access: This section is located approximately 5.4 km downstream from the confluence of the Athabasca and Clearwater rivers on the east bank of the Athabasca River near the mouth of Clarke Creek (Figures 9.5.1 and 9.5.2).

Keynote things to see:

- Thin remnant of fluvial channel sand at the base;
- Very thick, fining- and thinning-upward, estuarine channel deposits, largely rippled or trough cross-bedded, grading upward into multiple sets of low angle, inclined heterolithic stratified sand and mudstone;
- Well developed alternation of bay fill deposits at the top of the McMurray Formation;
- Thin (<2 m) glauconitic Wabiskaw C sand at the top of the outcrop.

Description: In this outcrop section about 57 m of McMurray section is exposed (Figures 9.7.1, 9.7.2). At the base of the outcrop is a 3 m thick unit of cross-bedded pebbly sands, with abundant trough cross-bedding (Figure 9.7.1). Quartz pebbles are dispersed throughout the sands as discontinuous lenses at the base of trough cross-beds. Mudstone intraclasts and carbonaceous debris are common, with some mummified logs and twigs. At the top of this unit is a indurated siderite-cemented sandstone.

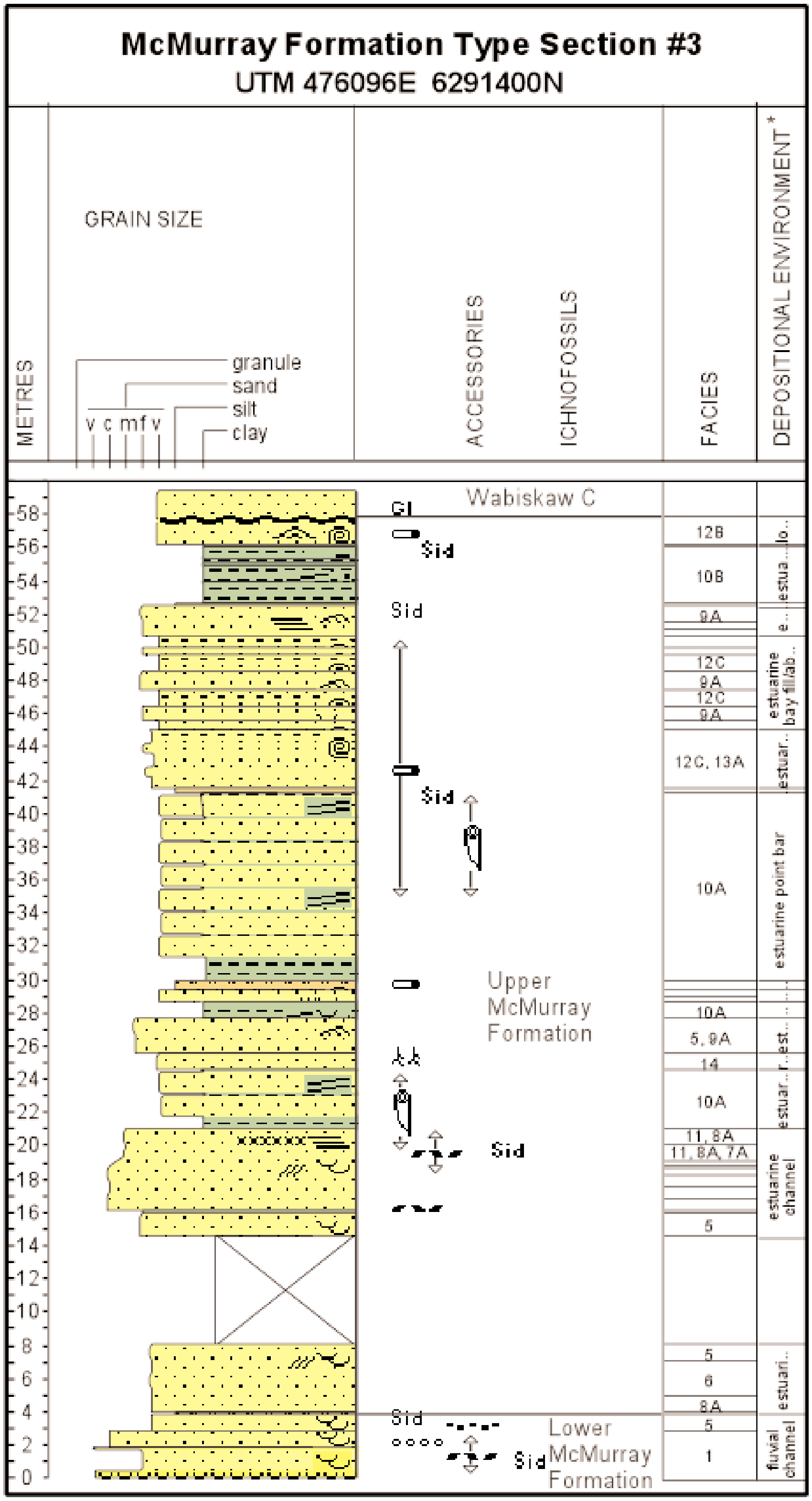
Unconformably overlying the lower cross-bedded sands are massive and cross-bedded fine sands, that lack cement, are unconsolidated and lack bitumen. Internally the sands show planar tabular and trough cross-bedding, with rare dispersed mudstone intraclasts that are bioturbated. Next is a thick (>6 m) covered interval. Further upsection the sand and mudstone interbeds show an overall fining-upward, that becomes thinner-bedded, and more bioturbated at the top. The most common burrows are *Cylindrichnus* and *Planolites*. Rare root traces are within a small coarsening-upward succession (22-26 m from the base) that may represent crevasse splay and overbank sedimentation.

The next succeeding 15 m of section consists of interbedded sand and mudstone with low- angle sandy to muddy (fining-upward), inclined heterolithic stratification. The low- angle, muddy, inclined heterolithic stratified units are abruptly overlain by a bioturbated, complex sand and mudstone unit (42 - 57 m) (Figure 9.7.1). This unit shows a variety of physical sedimentary structures, including large-scale convolute lamination, trough, current- and wave-ripples, parallel lamination and contorted bedding. Siderite bands are common and continuous across the outcrop. Bedding style of this uppermost unit is even and parallel at the base, becoming more wavy and discontinuous upsection. Bioturbation traces are mainly the horizontal *Planolites* type.

At the very top of the outcrop is exposed a thin (<2 m) green, bioturbated, silty sand, that is the Wabiskaw C sand of the Clearwater Formation.

Interpretation: The stacked, thick cross-bedded sands at the base of the section are interpreted as high energy, main fluvial channel deposits of the Lower McMurray Formation. This is capped by the hard, siderite-cemented cap that is interpreted as a disconformity surface between the Lower and Upper McMurray successions. The overlying Upper McMurray succession is dominated by thick, high energy, estuarine channel sands at the base, that become finer-grained and thinner-bedded upsection. The thicker, low-angle inclined stratified units are interpreted as multiply-stacked, estuarine point bar deposits.

The finer-grained, wavy -bedded, convoluted, and bioturbated unit at the top of the Upper McMurray Formation is a possible estuarine bay-fill complex that is unconformably overlain by the marine deposits of the Wabiskaw C unit.



*Complete Description in Appendix 3.

Figure 9.7.1. Schematic representation of the measured McMurray Formation Type Section #3 (UTM 476096E, 6291400N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.7.2. Overview of Upper McMurray sucession at the McMurray Formation Type Section #3 on the Athabasca River, north of Fort McMurray.

9.8 McMurray Formation Type Section #4

Map Coordinates: 74D/11 Fort McMurray, UTM 476120E, 6291840N.

Location and Access: This section is located approximately 6 km downstream from the confluence of the Athabasca and Clearwater rivers on the east bank of the Athabasca River near the mouth of Clarke Creek (Figures 9.5.1 and 9.5.2). Land by boat along the bank, and climb the slump face (about 20 m in height) to a terrace along the Athabasca River valley. Walk inland (away from the river) about 0.5 km to a small scarp face at the eastern edge of the terrace. The section that was measured is located about mid-way along the outcrop face.

Keynote things to see:

- Very thick, fining- and thinning-upwards, estuarine channel deposits, largely rippled or trough cross-bedded;
- Well developed cross-bedding and bioturbation features in channel sands;
- Possible sand-flat deposits at the top of the Upper McMurray succession;
- Thin Quaternary fill (<1 m thick).

Description: In this outcrop section about 14 m of section is exposed. The outcrop is a thick cross-bedded sand unit, with abundant ripples, including current, ripple-drift and wave types; and, less commonly, planar tabular or trough cross-bedded units (Figure 9.6.2). Finer-grained siltstone/mudstone interbeds are rare. Towards the base of the outcrop, the sands are somewhat finer-grained, becoming coarser within the basal 2 m of section, where they have an abundance of ripple-drift and wave-ripple cross-beds. Upsection the cross-bedded sands become thinner-bedded and finer-grained, and show an increase in the degree of bioturbation, with the most common types being *Cylindrichnus* and *Planolites.*

At the very top of the outcrop is exposed a thin (<1 m), rooted, tan-brown unconsolidated quartz sand that is interpreted as Quaternary cover.

Interpretation: The coarsening-upward sand at the base of the section is interpreted as possible crevasse-splay channel deposit of the Upper McMurray succession. This is overlain by a very thick succession of estuarine channel deposits. Most of these estuarine sands are rippled throughout, and where sandy inclined heterolithic stratification occurs the internal ripple-drift and wave-ripples dominant bedding. Such inclined heterolithic stratification is rare. Paleoflows are unidirectional, mainly directed towards the north. Because there is a general absence in the occurrence of lateral accretion cross-bedding, and the dominance of small-scale bedforms, this indicates that there is relatively little migration of meandering channels or lateral migration of point bars. The estuarine sands may be a result of vertical accretion and infill of secondary channels, high upstream within the drowned estuarine valley, perhaps proximal to a sandy tidal-flat setting. Such secondary channels may be vertically-accreting, anastomosed-channel deposits within an overbank to tidal flat area, flanking the main estuarine valley.

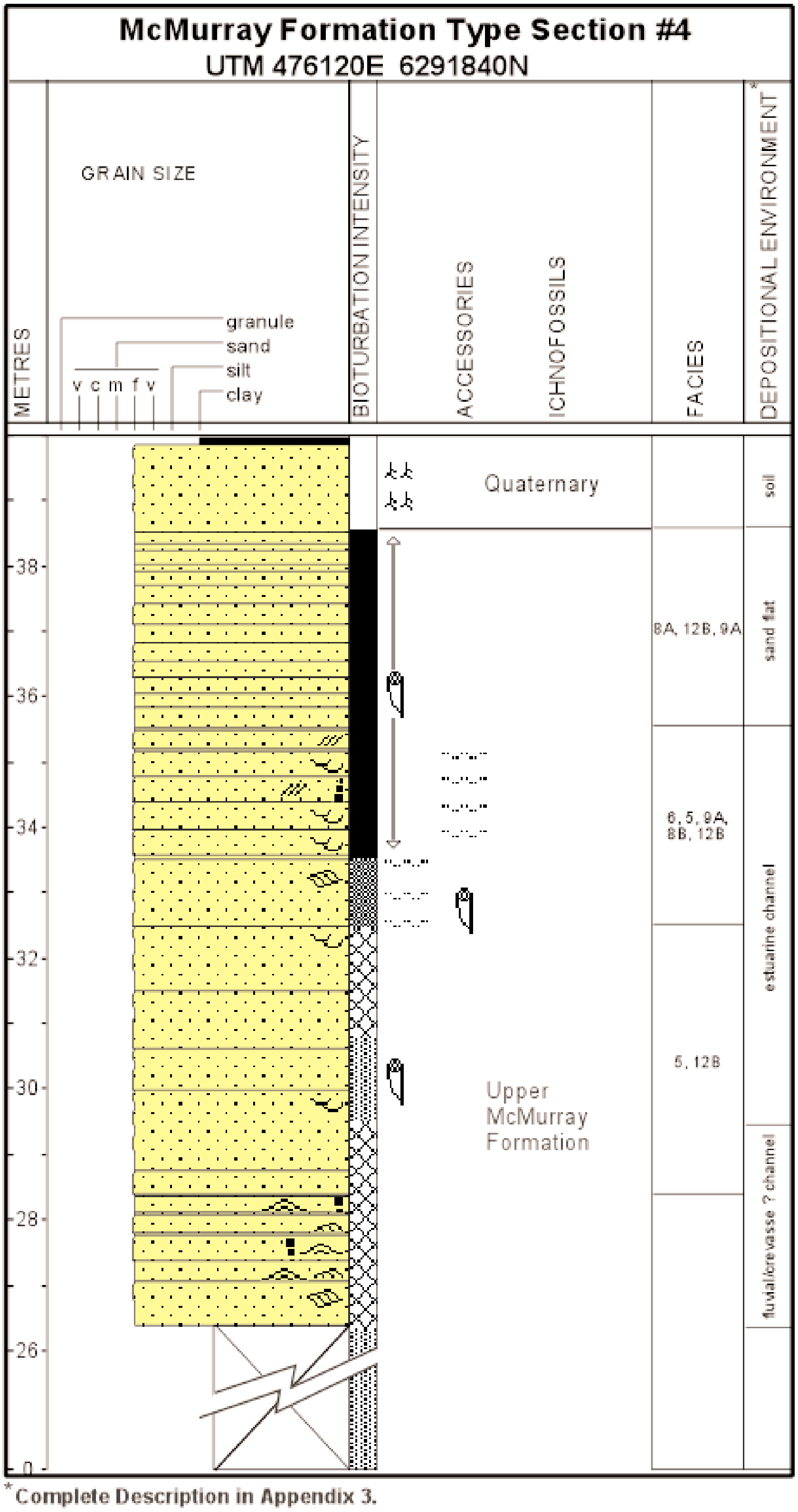


Figure 9.8.1. Schematic representation of the measured McMurray Formation Type Section #4 (UTM 476120E 6291840N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.8.2a. Overview of McMurray Formation Type Section #4, Athabasca River.

Figure 9.8.2b. Closeup of small scale trough and ripple cross-bedded, bitumen-saturated, sand (Upper McMurray Formation), McMurray Formation Type Section #4, Athabasca River.

9.9 Fluvial Marl Section

Map Coordinates: 74D/14 Wood Creek, UTM 474746E, 6305712N.

Location and Access: This section is located approximately 18 km downstream from the confluence of the Athabasca and Clearwater rivers on the east bank of the Athabasca River near the mouth of McLean Creek (Figure 9.9.1, 9.9.2).

Keynote things to see:

- Marly muddy sand, paleosol, carbonaceous mudstone, and fluvial sand, generally slumped;
- Some of the oldest Lower Cretaceous sediment in the area.

Description: In this small outcrop (about 5 m high) some of the oldest Lower Cretaceous sediment that unconformably overlies the Devonian limestone in the area is exposed (Figures 9.9.3, 9.9.4a, b). Here is exposed a slumped section of paleosols and marly muddy sand, with interbedded carbonaceous mudstone and minor cross-bedded granule sand, that occupies a paleotopographic low on the pre-Cretaceous unconformity (Figure 9.9.4a, b, c). Note the general absence of bitumen-staining, the abundance of organics, and siderite concretions, and the generally unconsolidated nature to the sediment (Figure 9.9.4b).

Interpretation: Possible paleosols, lacustrine marl, and fluvial sand remnants are preserved in this generally recessive and slumped outcrop. Regional mapping suggests that this location is typical of those areas that were originally paleotopographic lows along the karstic pre-Cretaceous unconformity. Originally the unit was probably water bearing, and since exposure along the Athabasca River valley has become further eroded and slumped along the bank. One hypothesis that accounts for the lack of bitumen in this part of the section is that the original medium- to heavy-crude was emplaced laterally along-strike at a stratigraphic interval higher than that represented by the marl section. This unit, although Cretaceous in age, may be older than the McMurray Formation.

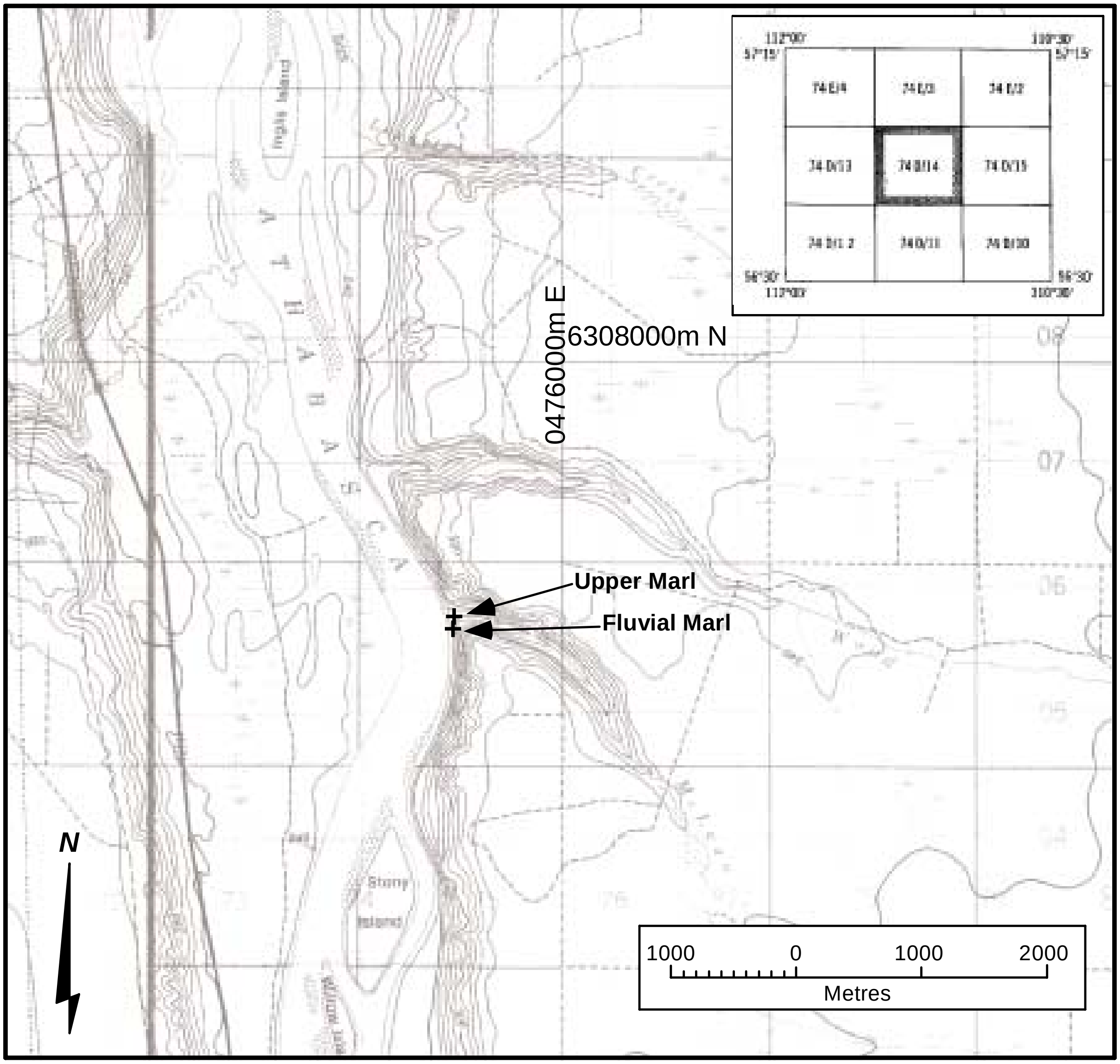


Figure 9.9.1. Map showing access to the Upper and Fluvial Marl sections along the east bank of the Athabasca River, about 20 km downstream from Fort McMurray.

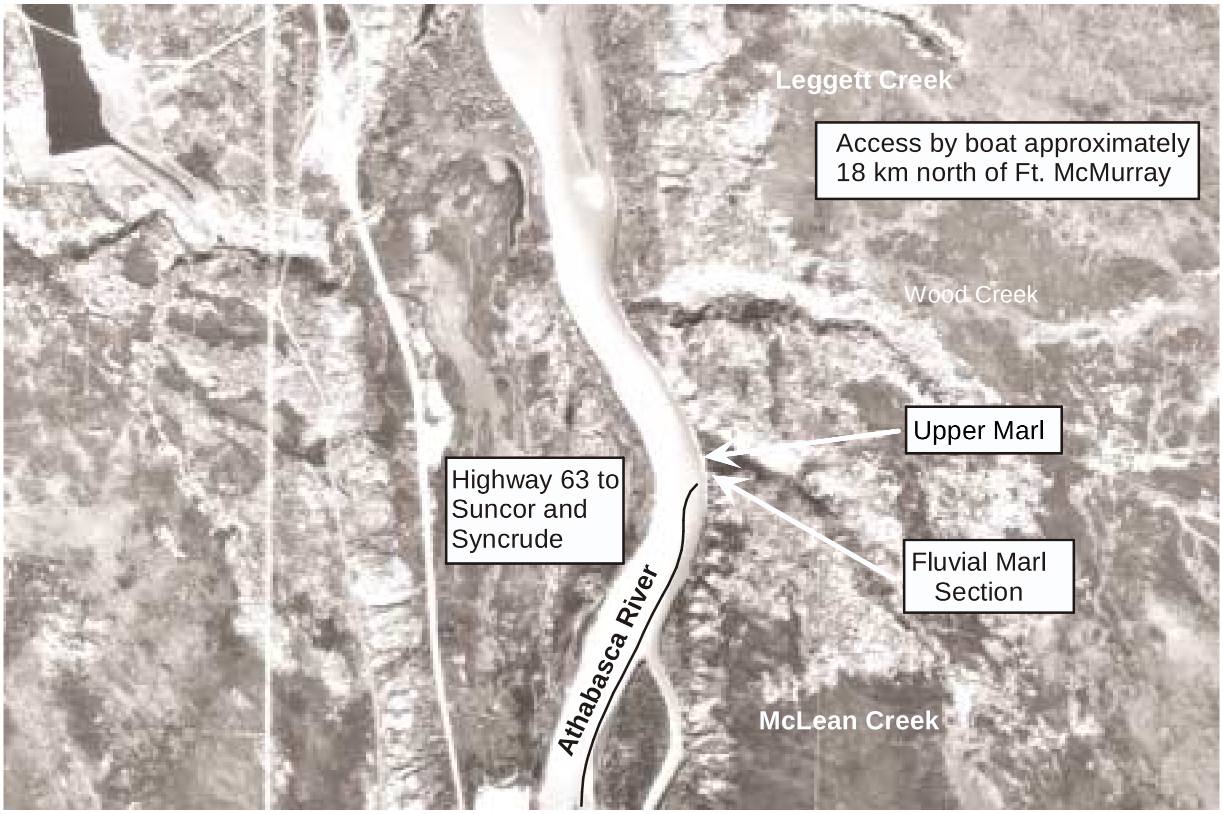
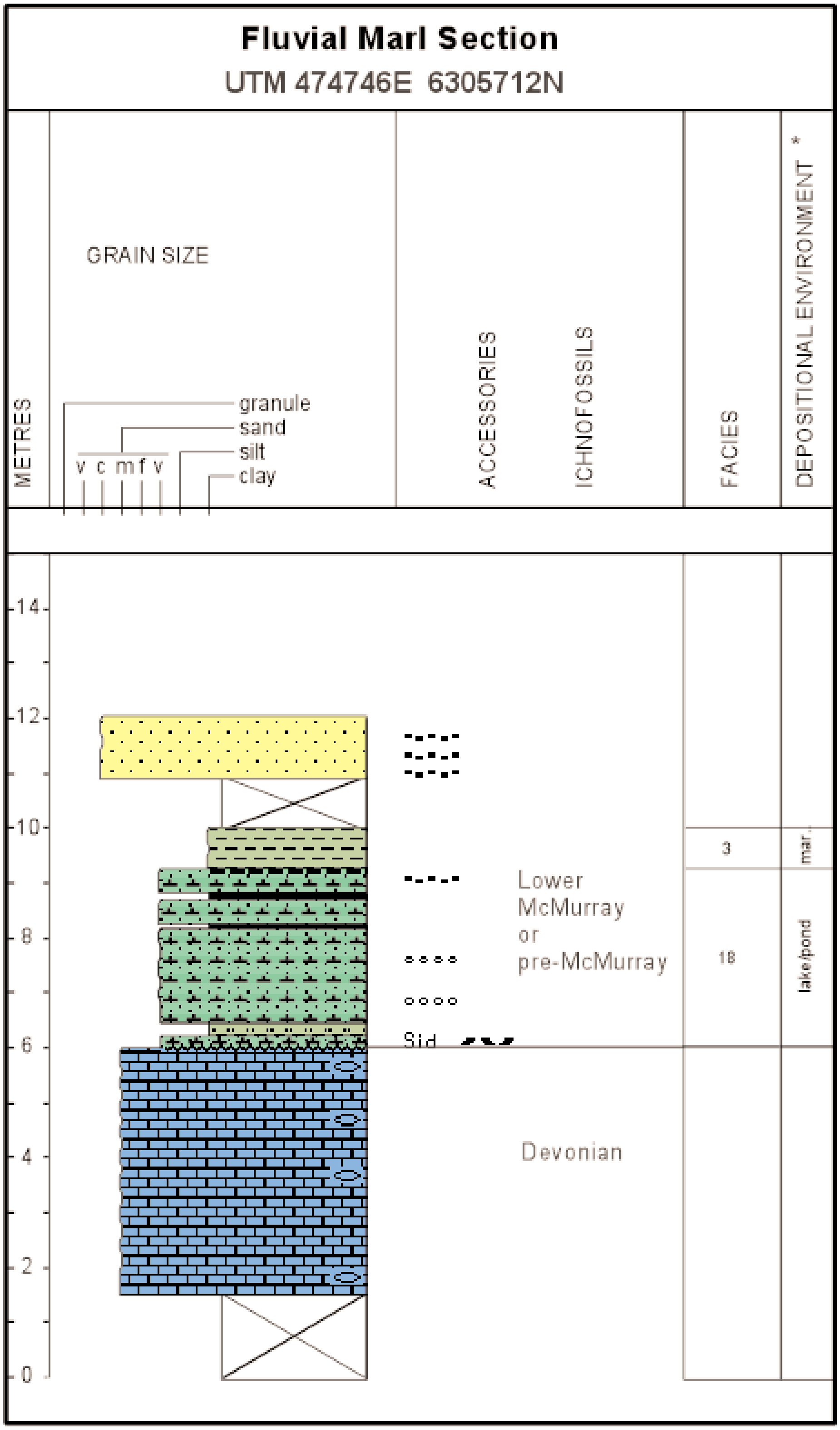


Figure 9.9.2. Aerial photograph showing location and access to the Lower McMurray Fluvial Marl and Upper Marl sections on the Athabasca River, north of Fort McMurray.



*Complete Description in Appendix 3.

Figure 9.9.3. Schematic representation of the measured Fluvial Marl Section (UTM 474746E, 6305712N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.9.4a. Argillaceous limestone of the Devonian Waterways Formation overlain by fluvial marl deposits of the Cretaceous McMurray Formation, Fluvial Marl Section, Athabasca River.

Figure 9.9.4b. Marl deposit occupying a low on the sub-Cretaceous unconformity, Fluvial Marl Section, Athabasca River north of Fort McMurray.

Figure 9.9.4c. Mottled sandy marl with thin coaly beds occupying a paleotopographic low on the sub-Cretaceous unconformity, Athabasca River, north of Fort McMurray. Outcrop is about 5 m high.

9.10 Marl Upper Section

Map Coordinates: 74D/14 Wood Creek, UTM 474800E, 6305750N.

Location and Access: This section is located approximately 18.2 km downstream from the confluence of the Athabasca and Clearwater rivers on the east bank of the Athabasca River near the mouth of McLean Creek (Figure 9.9.1, 9.9.2). From the Fluvial Marl Section continue along the east bank of the Athabasca River for a couple hundred metres, access a low terrace section via small gullies in the bank. The outcrop that was measured is located behind the treed bank in a slumped cutbank on a hill, about 100 m above the river level, and set back in the trees by about 70 m. This section is not easily seen from the river banks. (Good luck!). The measured section starts approximately 13 m above the vegetated bank that sits above the Fluvial Marl Section.

Keynote things to see:

- Even and horizontal bedding style alternating with wavy bedding;
- Large-scale convolute lamination and oversteepened cross-bedding within thick cliff forming sands, that laterally along strike interfinger with mudstone deposits.

Description: In this steep outcrop (about 25 m high) a largely inaccessible, and partially slumped section of interbedded sand and mudstone occurs (Figure 9.10.1, 9.10.2a, b). Towards the base fine sand is interbedded with silty mudstone, partially burrowed and sideritized. Bedding is wavy, with local coarse pebble lags. Sands are generally rippled throughout, and an isolated coal boulder clast occurs within the lowermost sand. Next is a covered, recessive, 3 m thick interval. Overlying the recessive unit, is a 7 m thick succession of bioturbated, fine- to very-fine-grained sand, interbedded with silty mudstone. Bedding is wavy or even and horizontal, and bioturbation is more prominent towards the base, with mainly *Planolites* and *Skolithos* types. Mudstone intraclasts and thin mudstone-breccias occur throughout the interbedded sand and mudstone. Carbonaceous content is high within these interbedded parts of the outcrop. The thick cliff-forming sands are about 6 m high, consisting of pebbly sand that grades upwards into fine- to medium-grained sand with dispersed mudstone intraclasts. Towards the base, within the pebbly units, the sands are sideritized. Cross-bedding is deformed, dewatering features and large-scale convolute laminations are common. Sands are bioturbated, with *Skolithos* traces. Cross-bedding includes planar tabular-tabular, ripple-drift, and, towards the top of the cliff-sands, low-angle, sandy inclined heterolithic stratification. Overlying the cliff-forming sands is an inaccessible, interbedded unit of gray sand and mudstone.

Interpretation: The pebbly and bioturbated sand at the base of the section is interpreted as high energy, estuarine channel deposits of the Upper McMurray succession. This is overlain by a very thick succession of stacked estuarine deposits. Some of these estuarine sands are massive or show abundant cross-bedding, and are interpreted as estuarine channel sands. Other sands occur with mudstone that interfingers with and/or is cross cut by the channel sands. Where accessible, these interbedded units are horizontally-bedded, and may be vertical accretion abandoned channel deposits. Elsewhere along the cliff faces, inaccessible interbedded units show low-angle, inclined heterolithic stratification, interpreted as estuarine point bar deposits, that interfinger along-strike with the main cliff-forming channel sand succession.

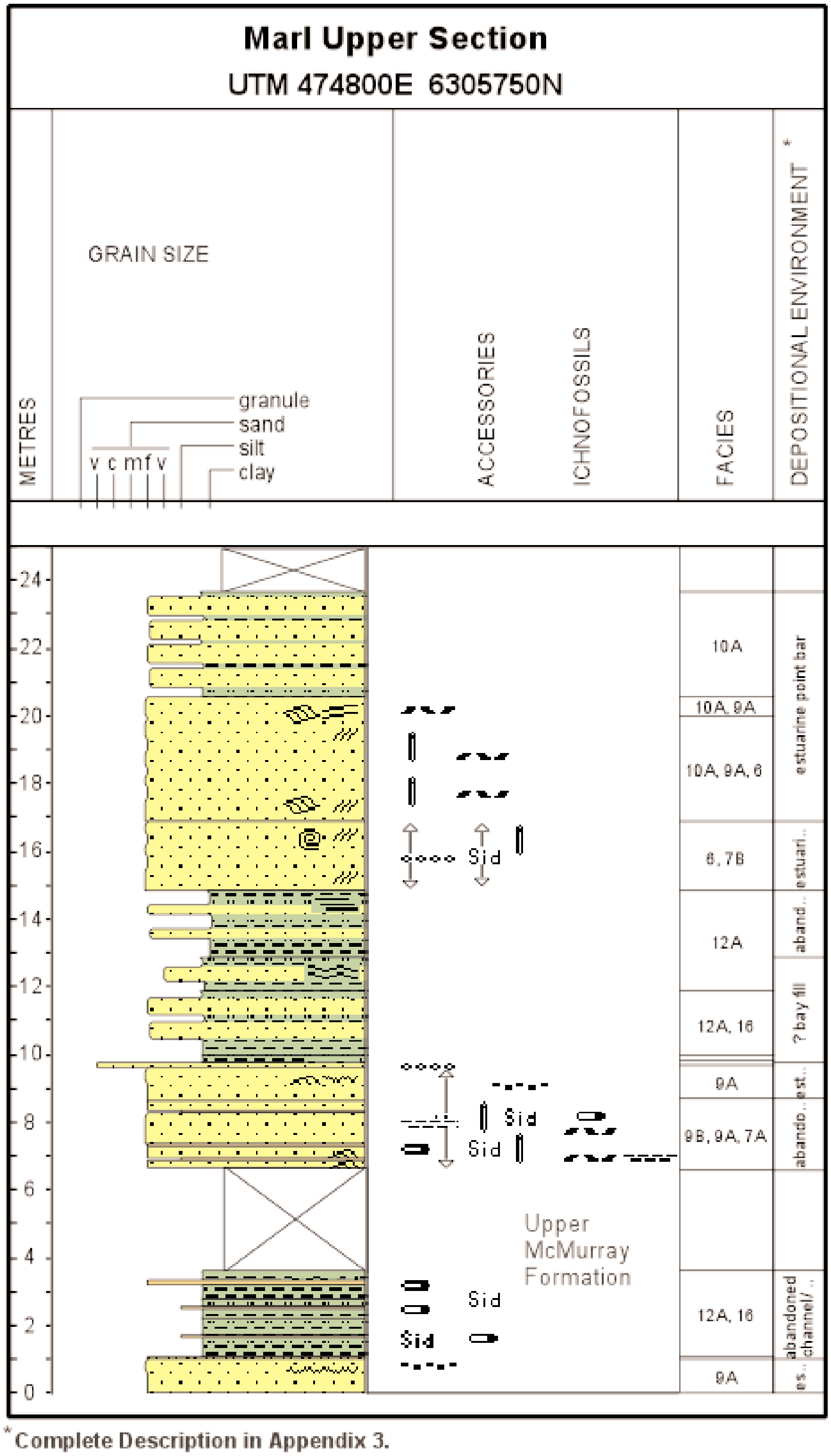


Figure 9.10.1. Schematic representation of the measured Marl Upper Section (UTM 474800E, 6305750N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.


Figure 9.10.2a. Overview of weathered, slumped calcareous marl (Lower McMurray Formation), topographically below the base of the Marl Upper Section, Athabasca River.


Figure 9.10.2b. Overview of thick cross-bedded sands, estuarine channel to point bar deposits (Upper McMurray Formation), Marl Upper Section, Athabasca River.

9.11 Tar Island Fluvial Section

Map Coordinates: 74D/14 Wood Creek, UTM 472210E, 6313710N.

Location and Access: This section is located approximately 0.5 km upstream (south) from the Tar Island tailings pond for the Suncor Mine, along the western bank of the Athabasca River (Figures 9.11.1, 9.11.2).

Keynote things to see:

- Sideritized and ironstone cemented, mudstone-clasts, pebbly sands and conglomerate;
- Thick stacked, Lower McMurray fluvial channel pebbly sand and conglomerate with excellent planar tabular and trough cross-beds;
- Unconformity between Lower McMurray and Upper McMurray successions, marked by a transgressive lag, overlain by estuarine channel and point bar sands;
- Discordant contact between sideritized sands, clean white sands, and bitumen-saturated sand.

Description: At this outcrop (about 9 m high) fluvial sediments are exposed at the base and are unconformably overlain by estuarine sediments (Figures 9.11.3, 9.11.4a to f)). Most notable in the section are the common occurrences of siderite cement and sideritized intraclasts within the fluvial channel deposits, and a prominent conglomerate, up to 1 m thick, along the unconformable contact between the fluvial and estuarine units (Figures 9.11.4f, g). The conglomerate starts as a thin (single pebble thick) layer at the downstream end of the outcrop (or is absent), reaching its maximum at the upstream end of the outcrop. The conglomerate is poorly-sorted but does display a distinct upward fining. The clasts within the conglomerate tend to be fairly well-rounded, and the lithologies are generally more resistant rock types, such as vein-quartz and quartz-pebbles. About half-way upstream along the outcrop exposure there is a prominent, discordant contact showing the lower fluvial succession between the basal unconsolidated white sands and the bitumen-bearing oil sands (Figures 9.11.4b, c). Associated with this discordant contact is an apparent “roll front” in the siderite-cemented unit (lower left of Figure 9.11.4b).

Interpretation: The gravel between the fluvial and estuarine deposits is interpreted as a transgressive lag above the unconformity, and is related to the onset of marine flooding in the area. This marine flooding emplaced the estuarine deposits of the Upper McMurray above the fluvial lowstand deposits of the Lower McMurray. It is possible that this outcrop marks the original oil-water contact within the Lower McMurray sediment, prior to degradation of the oil to bitumen. As with the Fluvial Marl Section, one hypothesis that might explain a lack of bitumen-staining at the base of the section below the sideritized roll-front, is that the original medium- to heavy-crude was emplaced laterally along-strike at a stratigraphic interval higher than that represented by sideritized section. The sideritization may have occurred early in the history of the McMurray succession, and may have been the result of cementation associated with either connate- or groundwater conditions.

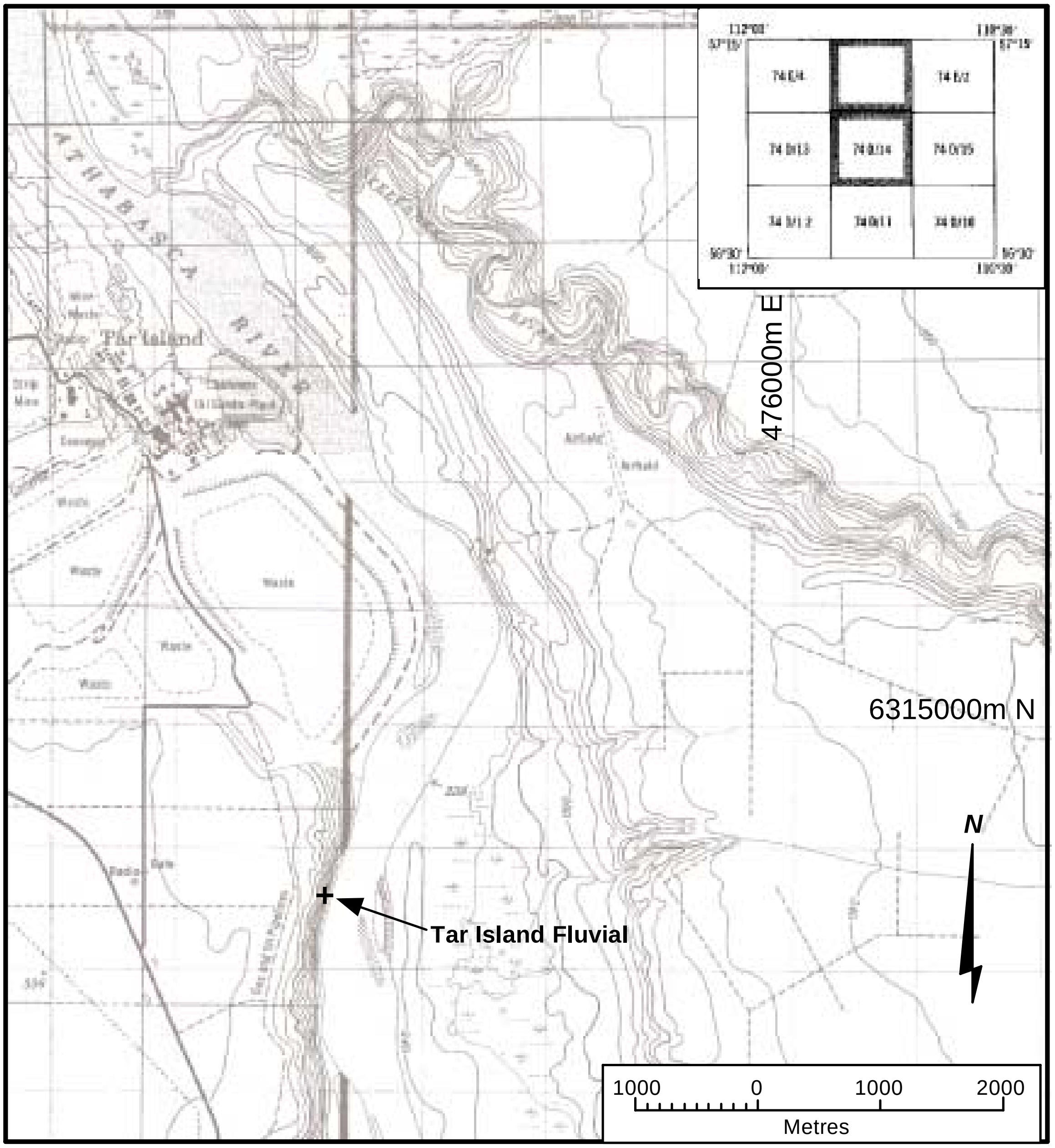


Figure 9.11.1. Map showing access to the Tar Island Fluvial Section along the Athabasca River, about 26 km downstream from Fort McMurray.

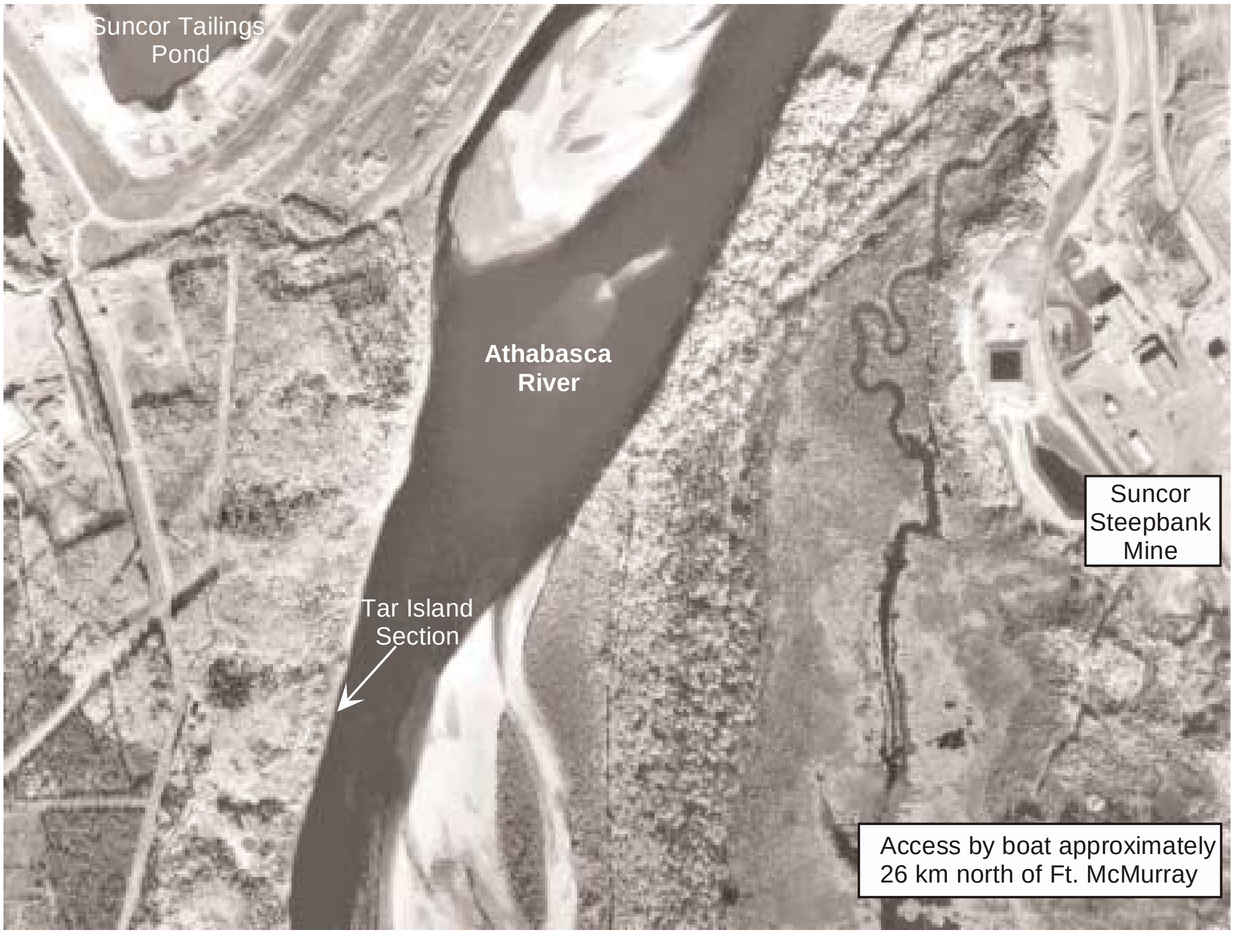
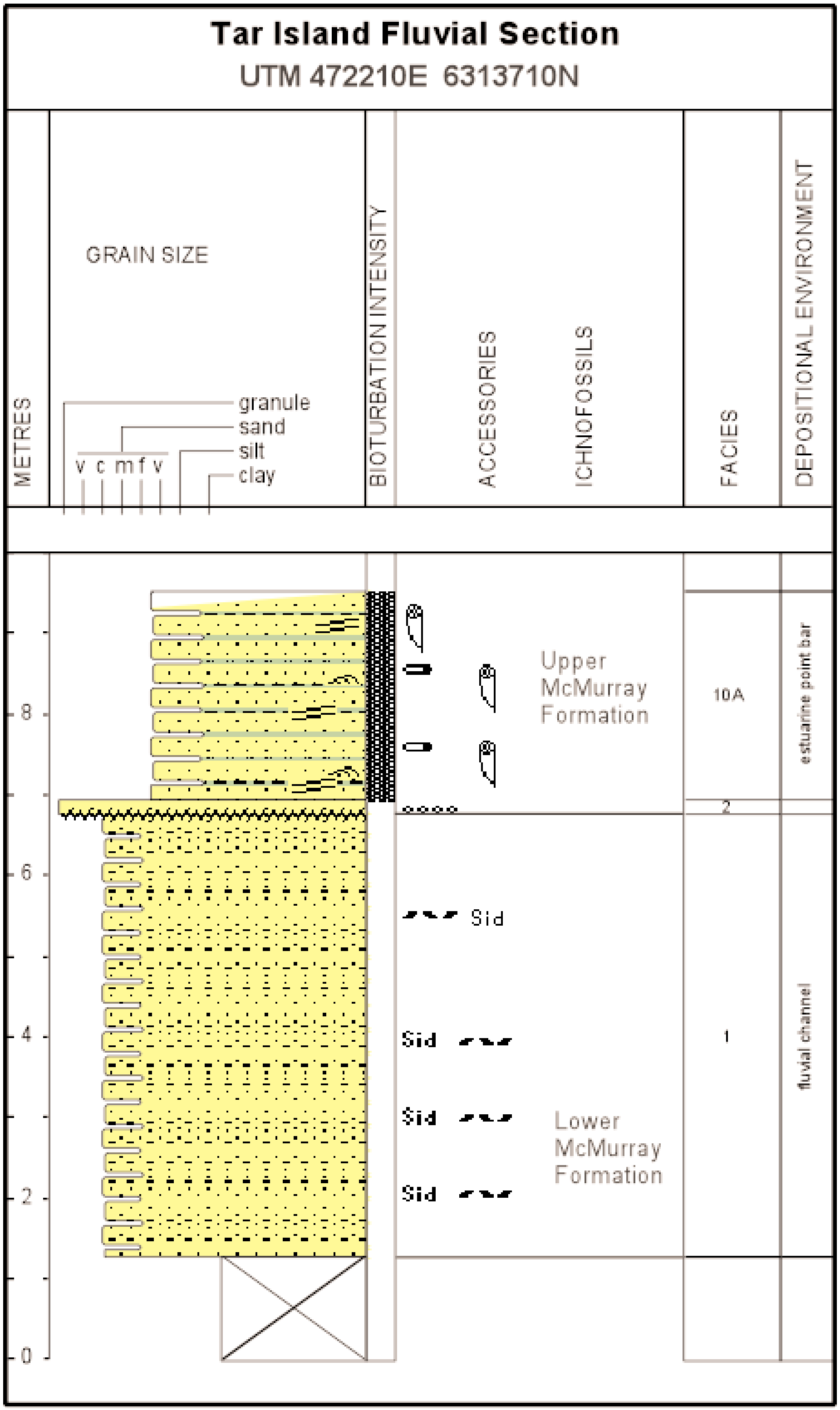


Figure 9.11.2. Aerial photograph showing location of Lower McMurray Tar Island Fluvial Section on the Athabasca River, south of the Suncor tailings pond.



*Complete Description in Appendix 3.

Figure 9.11.3. Schematic representation of the measured Tar Island Fluvial Section (UTM 472210E, 6313710N). Facies designations as listed in Appendix 2.Vertical scale bars are 1 m in height.

Figure 9.11.4a. Coarse-grained, bitumen-free, fluvial trough cross-bedded sand (Lower McMurray Formation), overlain by bitumen-saturated estuarine lateral accretion deposits of the Upper McMurray Tar Island Fluvial Section, Athabasca River, south of Suncor minesite.

Figure 9.11.4b. Overview of the basal oil-water contact within the Lower McMurray succession along the Athabasca River, Tar Island Fluvial Section, south of the Suncor minesite.

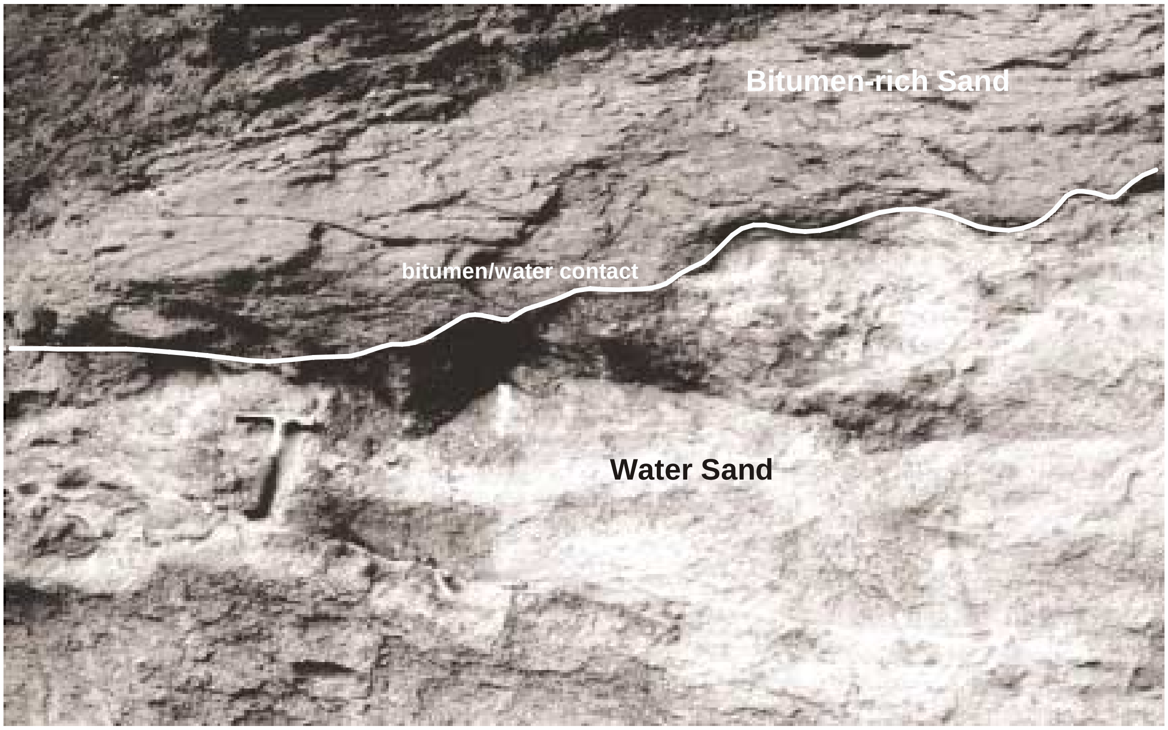


Figure 9.11.4c. Detailed view of the oil/water contact within coarse-grained fluvial deposit of the Lower McMurray Formation, Tar Island Fluvial Section, Athabasca River, south of the Suncor minesite.

Figure 9.11.4d. Trough cross-bedded, coarse-grained sand with siderite clasts (Lower McMurray Formation) Tar Island Fluvial Section, Athabasca River.

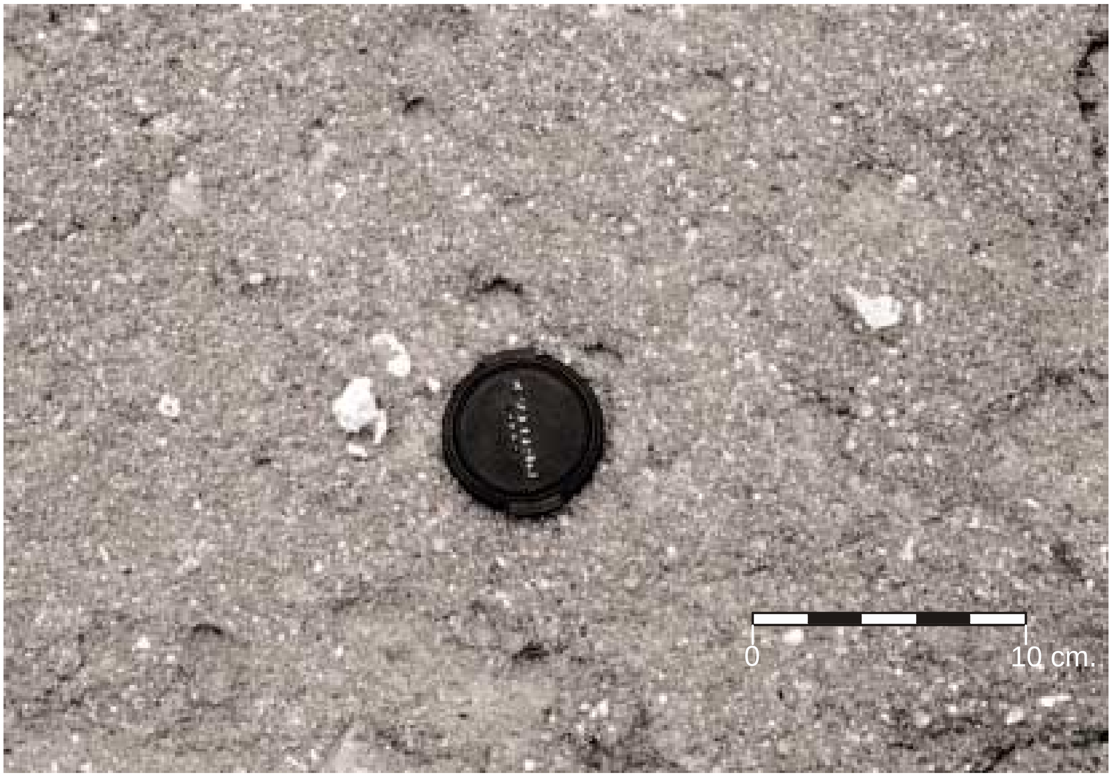


Figure 9.11.4e. Detailed view of poorly-sorted, coarse-to granular-grained, argillaceous, fluvial trough cross-bedded sand (Lower McMurray Formation) Tar Island Fluvial Section, Athabasca River. Larger, white clay clasts (some sideritized) are common.

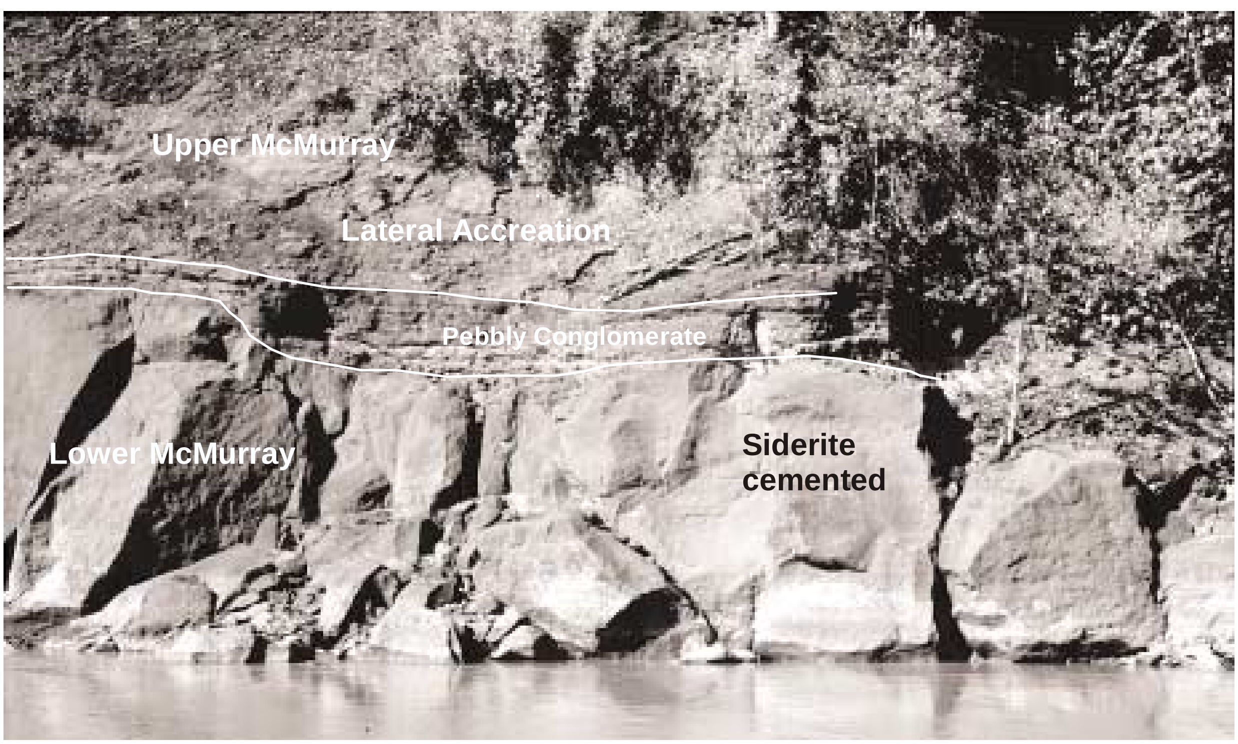


Figure 9.11.4f. Pebbly conglomerate separating siderite-cemented fluvial sands of the Lower McMurray Formation from estuarine sands of the Upper McMurray Formation, Tar Island Fluvial Section, Athabasca River.

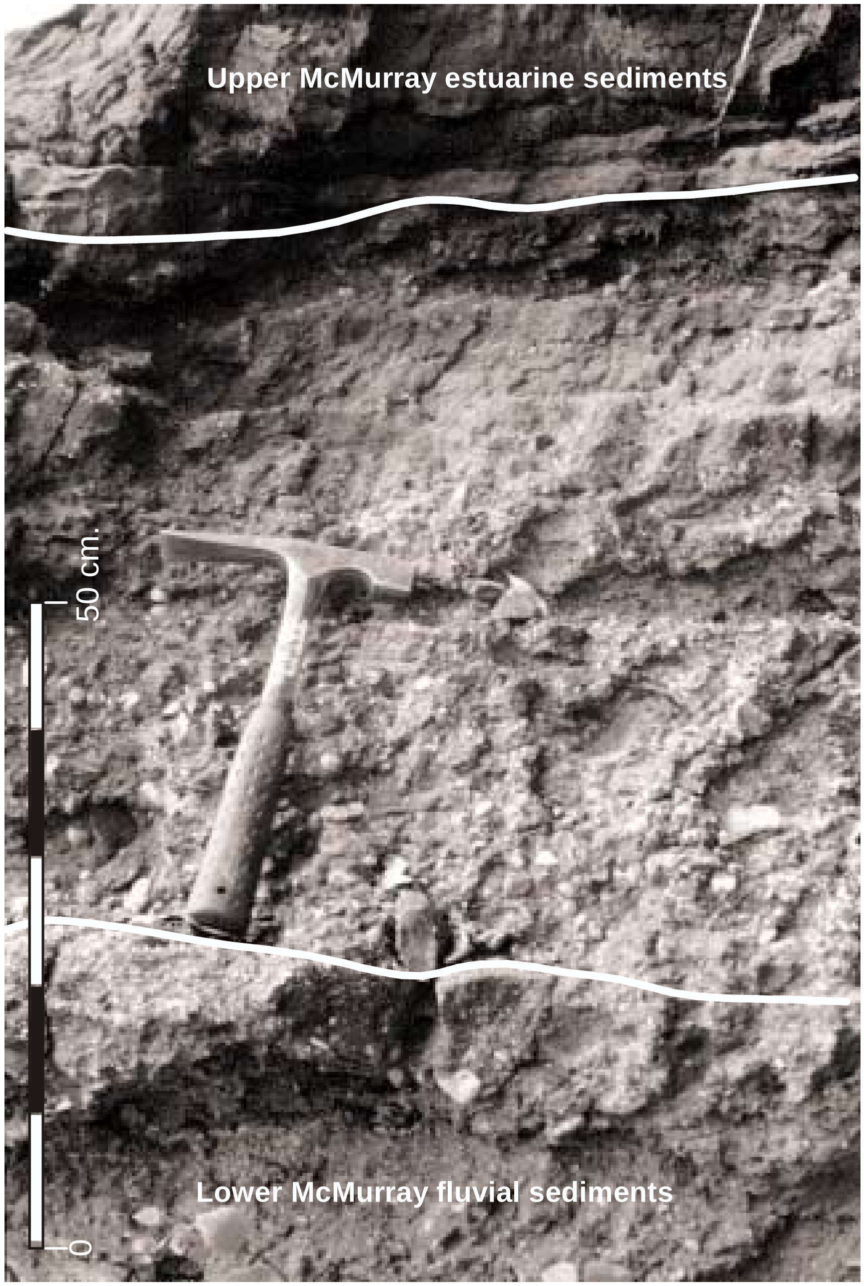


Figure 9.11.4g. Detailed view of the fining-upward pebbly gravel (transgressive lag) separating coarse grained, fluvial deposits of the Lower McMurray Formation from fine-grained, estuarine deposits of the Upper McMurray Formation, Tar Island Fluvial Section, Athabasca River.

9.12 Athabasca Sinkhole South Section

Map Coordinates: 74 D/14 Wood Creek, UTM 463205E, 6342138N

Location and Access: This outcrop section is located about 3.5 km downstream from the Fort MacKay settlement on the east bank of the Athabasca River, between Haight and Ings islands (Figures 9.12.1 and 9.12.2). Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from a landing at the Fort MacKay settlement.

Keynote things to see:

- Estuarine channel sediments as part of a paleo karst-fill within a major depression on the pre-Cretaceous unconformity;
- Alternating very coarse-grained sand to pebbly sands, as channel fills, interfingered with bioturbated finer-grained channel and point bar sediments.

Description: This cutbank is generally poorly exposed, with the lowermost 18 m and the topmost 5 m largely covered by slumping (Figure 9.12.4). The section starts about 18 m above river level and exposes approximately 11 m of McMurray sediment (Figure 9.12.3). The main part of the outcrop consists of pebbly to granular sand that is very poorly-sorted and has abundant internal scours and trough cross-bedding. Finer interbeds are burrowed with *Planolites*. Sands are micaceous and contain mudstone intraclasts. Towards the base of the section, the sands are more massive, with some lateral accretion and trough cross-bedding. Upsection, the finer interbeds show better developed, low-angle inclined heterolithic stratification, trough, ripple and planar tabular cross-bedding. Fining-upward successions also occur. Sediments within the overlying, largely covered, upper part of the section are somewhat finer-grained than below, but show a similar suite of sedimentary structures, including planar tabular and trough cross-bedding, and parallel lamination. Burrow types are mainly *Cylindrichnus*. Sideritization is more common within these upper, finer- grained beds.

Interpretation: The section is interpreted as infill along a karstic sinkhole margin. Sediments appear to be estuarine, as opposed to fluvial in origin, as evidenced by the abundance of trace fossils. The succession exposed is interpreted as part of the lower part of the Upper McMurray Formation, deposited largely as fill within estuarine channels, capped by estuarine point bar deposits. Lateral transitions along the outcrop face show an interfingering of estuarine point bar and channel units.

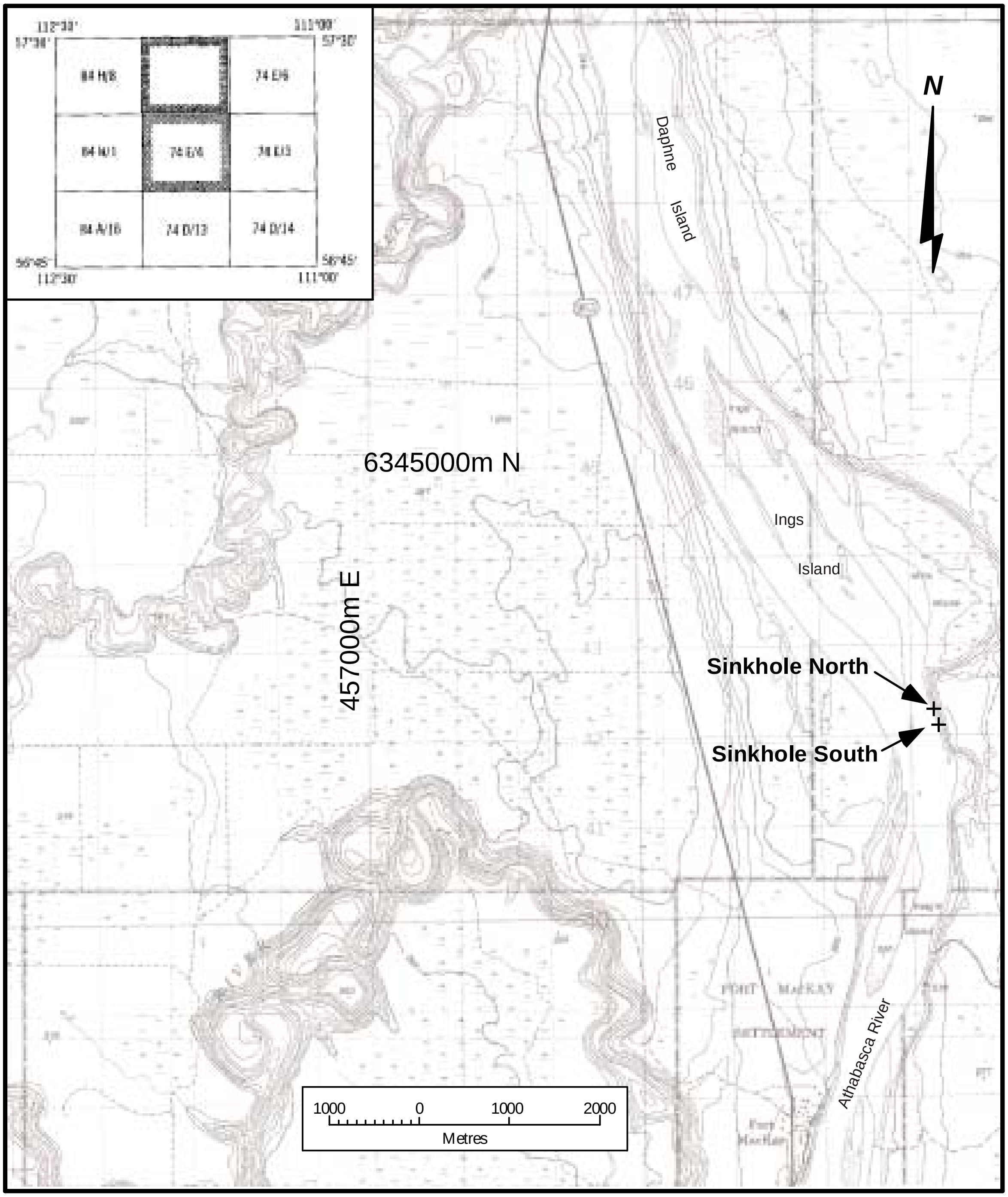


Figure 9.12.1. Map showing access to the Sinkhole North and Sinkhole South sections along the east bank of the Athabasca River, just north of Fort MacKay.

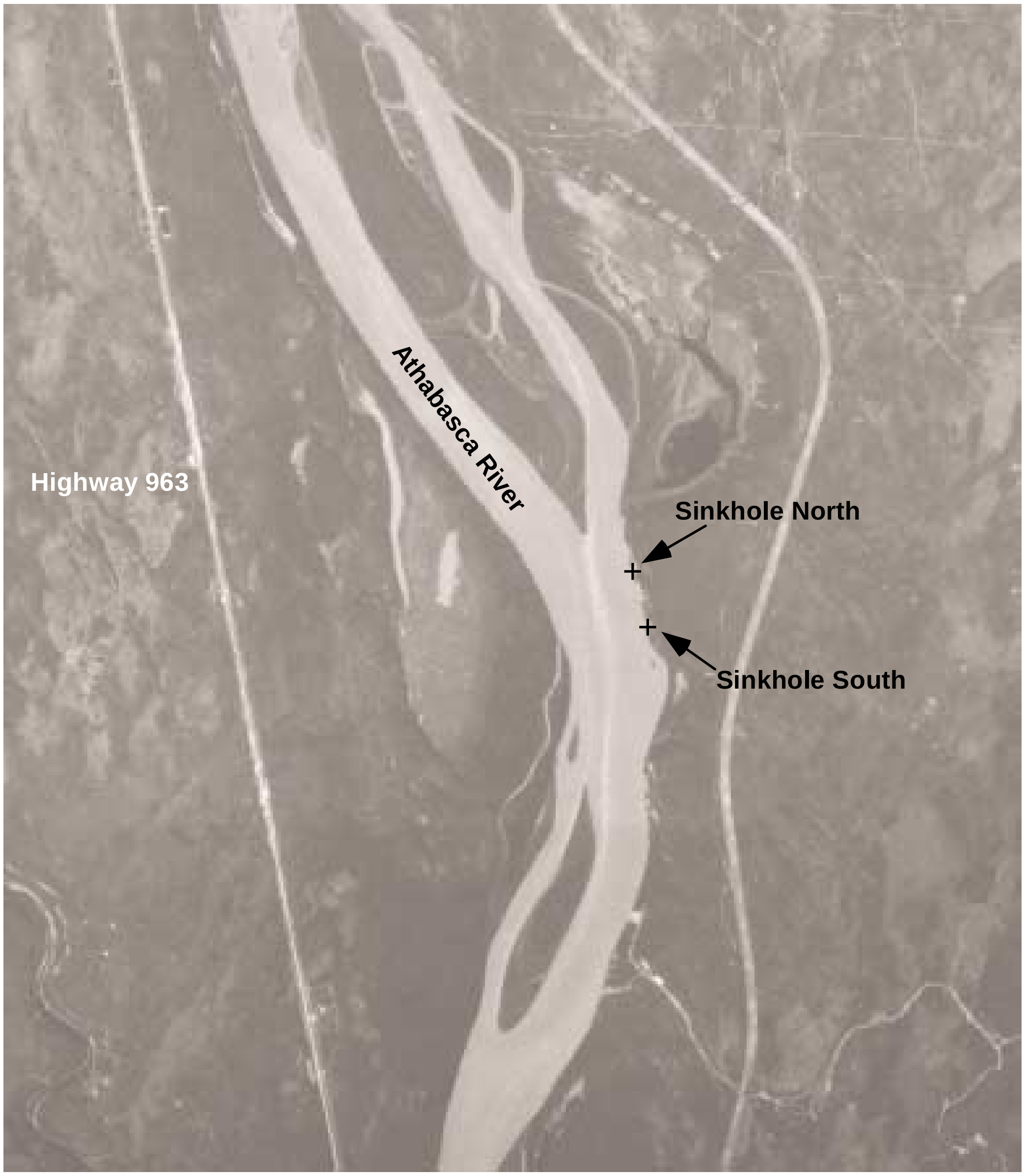


Figure 9.12.2. Aerial photograph showing location and access to the Sinkhole North and Sinkhole South sections on the Athabasca River, north of Fort MacKay.

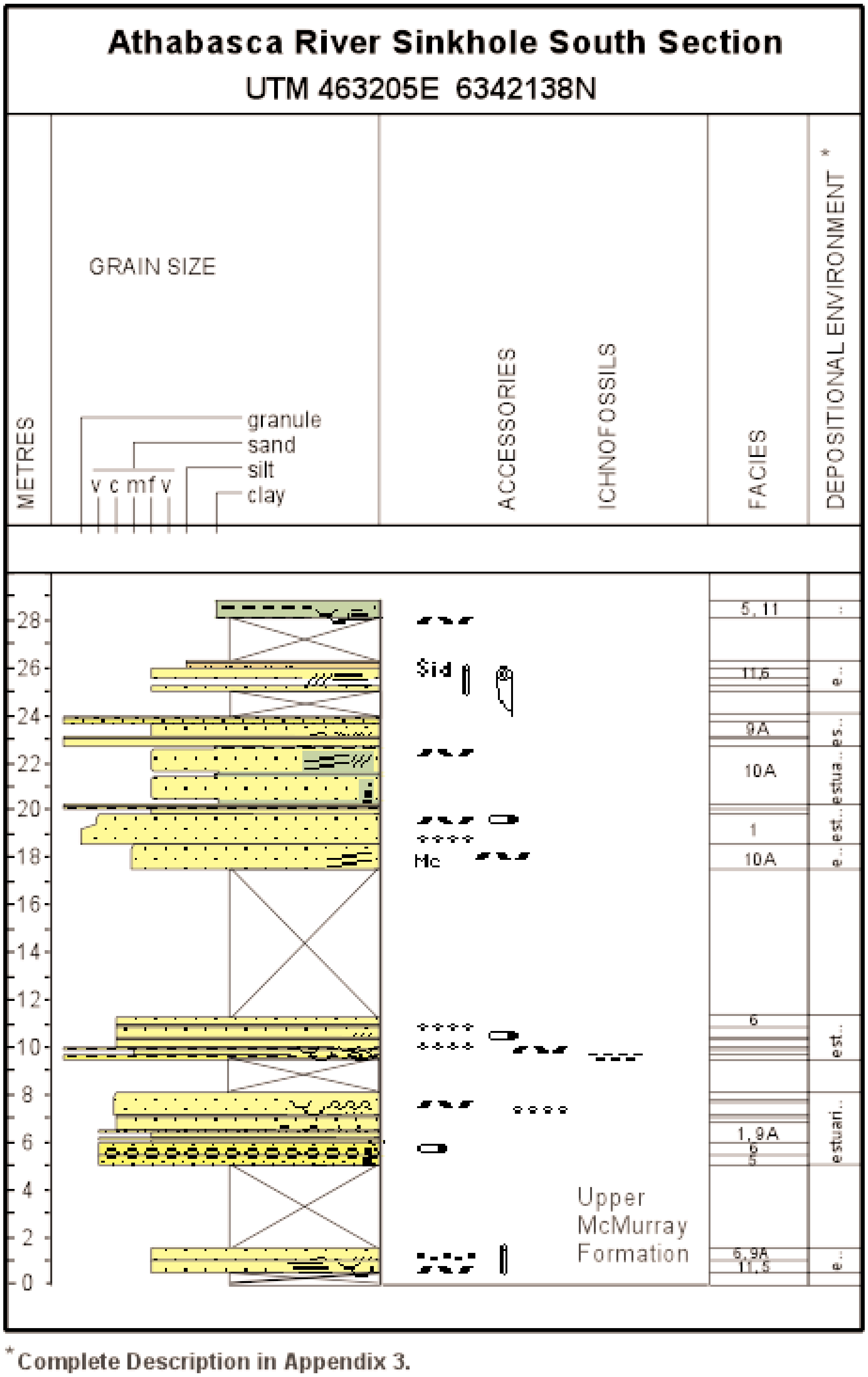


Figure 9.12.3. Schematic representation of the measured Athabasca River Sinkhole South Section (UTM 463205E 6342138N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.12.4a. Overview of slumped Sinkhole South Section, Athabasca River.

Figure 9.12.4b. Overview of slumped Sinkhole South Section, Athabasca River.

9.13 Athabasca Sinkhole North Section

Map Coordinates: 74 D/14 Wood Creek, UTM 463100E, 6342230N

Location and Access: This outcrop section is located about 3.8 km downstream from the Fort MacKay settlement on the east bank of the Athabasca River, between Haight and Ings islands (Figures 9.12.1, 9.12.2). Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from a landing at the Fort MacKay settlement.

Keynote things to see:

- Stacked fluvial, estuarine and tidal channel sediments as part of a paleo-karst-fill within a major depression on the pre-Cretaceous unconformity;
- Thick, mainly covered, recessive interval, capped by a fining-upward succession of sandy to muddy inclined heterolithic stratified sediment;
- Approximately 1 m of Quaternary gravel cover.

Description: This cutbank is generally poorly exposed, with the lowermost 4 m and the middle 16 m largely covered by slumping . At the very base of the section is <0.3 m of marl exposed, with abundant carbonaceous debris. The main part of the section starts about 4 m above the marl level and exposes approximately 35 m of McMurray sediment (Figure 9.13.1, 9.13.2). Here the outcrop consists of pebbly to granular oil sand alternating with fine sand, with abundant internal scours, trough, ripple and planar tabular cross-bedding. Finer interbeds show flaser-bedding, double-mud drapes, and local sideritized mudstone-intraclasts. Towards the base of the section, the sands are more massive, with some trough cross-bedding and parallel lamination. Upsection, the finer-grained interbeds show more well-developed trough, ripple and planar tabular cross-bedding and highly organic double-mud drapes. A 0.5 m thick mudstone-intraclast breccia, that has dispersed organic and a fine to granular sand matrix cap these cross-bedded sands. The next 18 m of section is recessive and largely covered. The top of the McMurray Formation consists of a 2 m thick fining-upward unit of sandy inclined heterolithic stratification, overlain by finer-grained vertical accretion and muddy inclined heterolithic stratification. The top of the McMurray succession is scoured out by Quaternary gravel.

Interpretation: The section is interpreted as alluvial infill along a karstic sinkhole margin. Sediments at the base of the succession are interpreted as lacustrine marl and fluvial channel sediment of the Lower McMurray Formation. This is overlain by the stacked estuarine and tidal channel sediment of the lower part of the Upper McMurray Formation, which above the recessive unit is marked by finer-grained estuarine point bar deposits. As with the Athabasca River Sinkhole South Section, lateral transitions along this section also shows an interfingering of estuarine point bar and channel units.

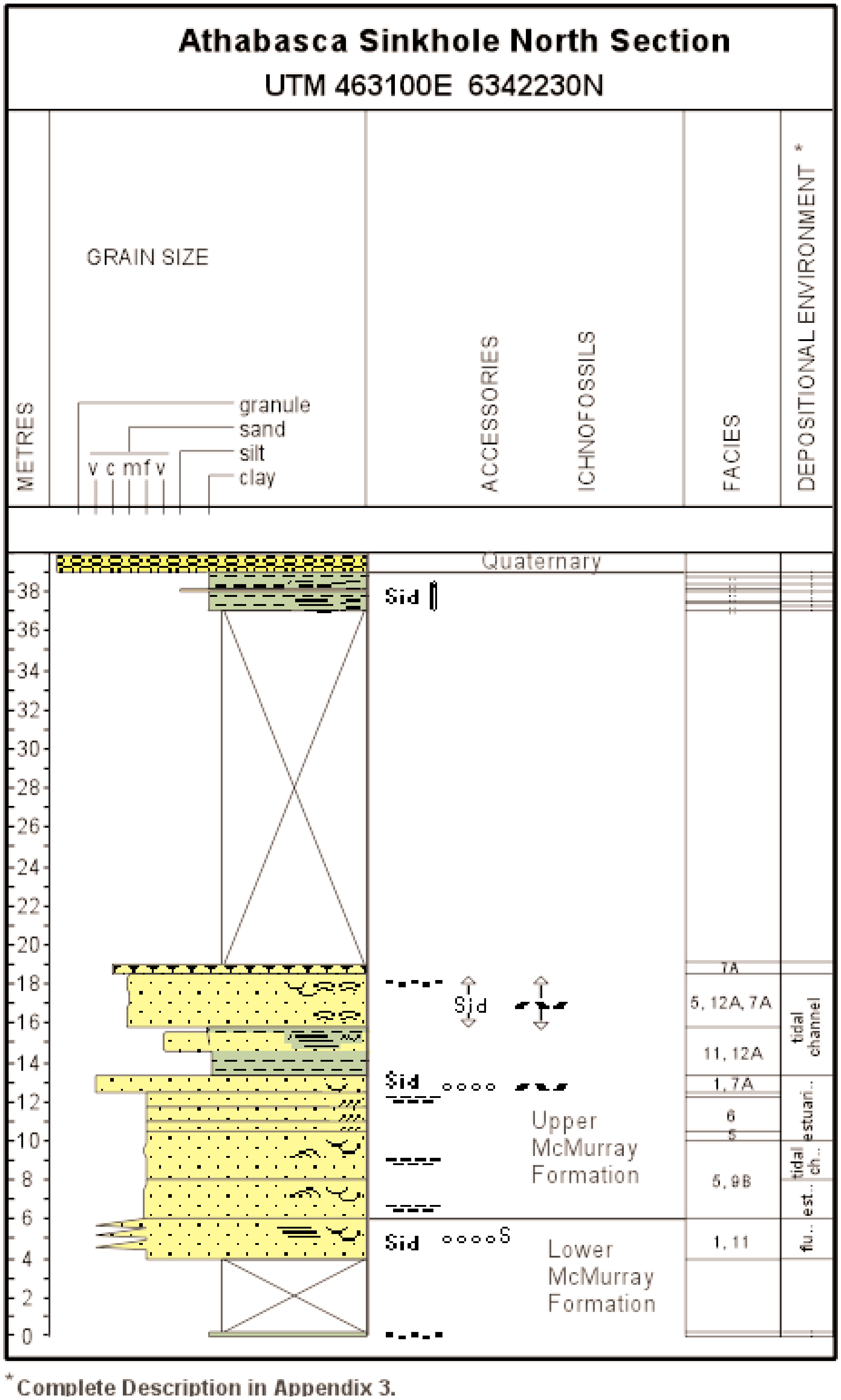


Figure 9.13.1. Schematic representation of the measured Athabasca River Sinkhole North Section (UTM 463100E, 6342230N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

9.14 Daphne Island West Section

Map Coordinates: 74E/5 Bitumount, UTM 459640E, 6349110 N (middle of section)

Location and Access: This outcrop is located about 2 km upstream from the mouth of the Ells River on the west bank of the Athabasca River, west of Daphne Island (Figures 9.14.1 and 9.14.2). Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from a landing at the Fort MacKay settlement.

Due to the significant along-strike variation in sedimentary facies at this outcrop, three vertical sections were measured, each spaced about 100 m apart going from upstream (Daphne Island West #3) to downstream near the mouth of the Ells River (Daphne Island West #1) (Figures 9.14.3, 9.14.4, 9.14.5).

Keynote things to see:

- Stacked and laterally interfingering fluvial, estuarine and tidal channel, and other coastal plain deposits;
- Thick, coaly mudstone in the middle part of the outcrop (Daphne Island West #2);
- Fossilized logs and abundant coal debris.

Description: In the Daphne Island West Section #1 a 4.5 m thick, fining-upwards succession occurs with large-scale trough cross-bedded pebbly sand passing upward into planar tabular, rippled, trough and wave-rippled medium- to coarse-grained sand. This is scoured out and overlain abruptly by low-angle, sandy inclined heterolithic stratified sand, with wave-ripples and abundant bioturbation, including *Cylindrichnus* and *Skolithos*. This rapidly passes upward into even-bedded silty sand, with abundant coal interlaminae and a fossilized log.

In the Daphne Island West Section #2 a stacked sequence of planar tabular, trough and wavy cross-bedded sands cross cut one another with rapid along-strike and vertical facies changes. Lithologies range from very coarse-grained to medium-grained sand. Abruptly overlying the cross-bedded sand unit is a very fine-grained to fine-grained sand that has low-angle, inclined heterolithic stratification, with small internal troughs that dip to the north. Otherwise all other paleoflow directions are towards the west-southwest. The Daphne Island West Section #2 is capped by a coaly mudstone >1 m thick.

The Daphne Island West Section #3 starts, at the upstream end of the outcrop, with about 1 m of medium- to coarse-grained, trough cross-bedded and low-angle, inclined heterolithic stratified sand. This is overlain by a 1 m thick recessive and covered interval. The next unit in outcrop is a fine-grained to very fine-grained sand, about 2 m thick, with southerly (paleo-landward) directed low-angle bedding surfaces (Figure 9.14.6). Internally, the low-angle bedding has trough and planar tabular cross-beds with local *Skolithos* burrows near the top. This is scoured out by 2 to 3 m thick, medium-grained sand with northward (paleo-seaward) directed, low angle bedding, internally with planar tabular cross-beds, horizontal lamination, abundant coal debris, and rare *Skolithos* burrows. The top of the outcrop is an inaccessible 3 to 4 m thick, burrowed silty sand and mudstone with an even and wavy bedding style.

Interpretation: The complex interdigitation of facies and switching paleoflow directions all indicate sedimentation within complex nearshore settings. Fluvial sediments are interpreted to be deposited during prograding regressive phases, and shoreline/coastal plain sedimentation occurring during transgressive phases. In the Daphne Island West Section #1, the lowermost two-thirds of the outcrop is interpreted as a fining-upward succession of fluvial-channel sands (? Lower McMurray Formation). This is scoured out by a sandy estuarine point bar succession, with possible a sand-flat deposits, of the Upper McMurray Formation. The surface of erosion between the Lower and Upper McMurray is interpreted as a transgressive surface of erosion.

In the Daphne Island West Section #2 the Lower McMurray fluvial component is missing. Here the Upper McMurray consists of stacked estuarine channel or open bay deposits, with southwest-west (paleo-landward) directed cross-bedding. Next are upper shoreface sands with low-angle bedding directed northward (paleo-seaward). The thick coaly mudstone at the top of the section is interpreted as coastal plain deposits deposited within a high stand of the Upper McMurray succession.

In the Daphne Island West Section #3 an Upper McMurray tidally-influenced estuarine channel succession grades up into an estuarine-bay deposit. This is scoured out by upper shoreface deposits, of an estuarine-bay. The upper part of the outcrop is inaccessible From the bedding style and degree of bioturbation in the float this upper part also appears to have been deposited within a quiet water estuarine-bay setting.

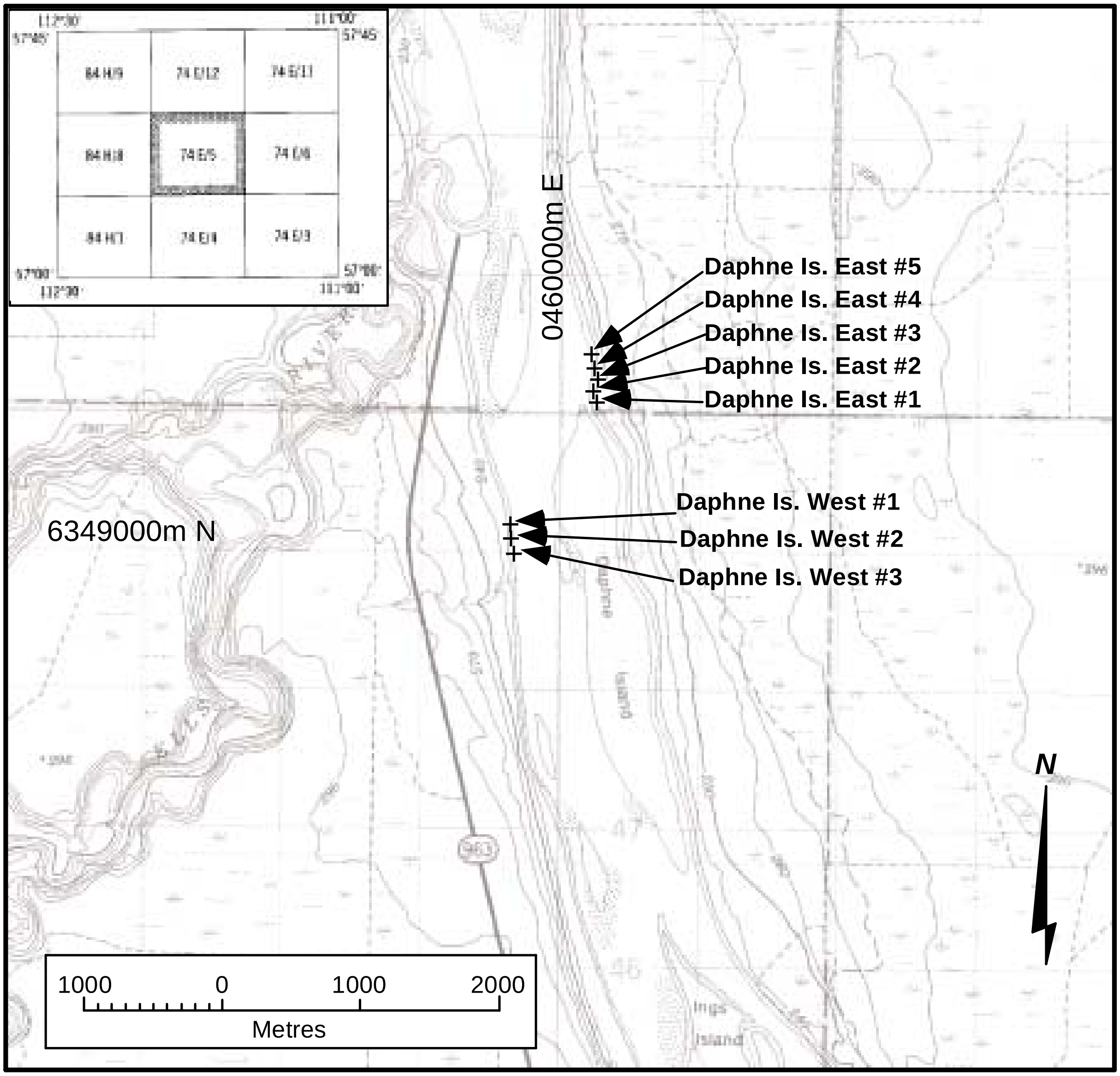


Figure 9.14.1. Map showing access to the Daphne Island outcrops on the Athabasca River, north of Fort MacKay.

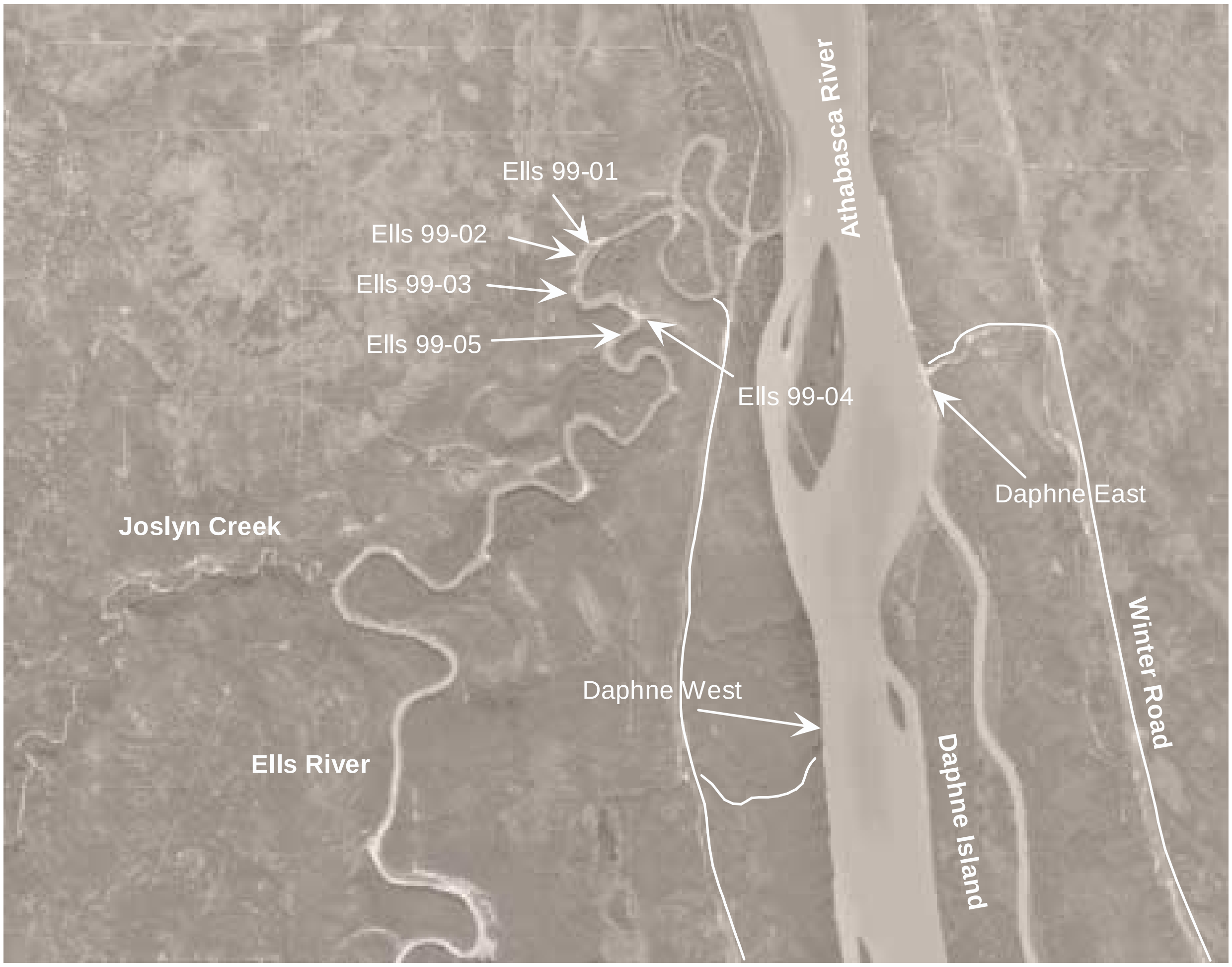
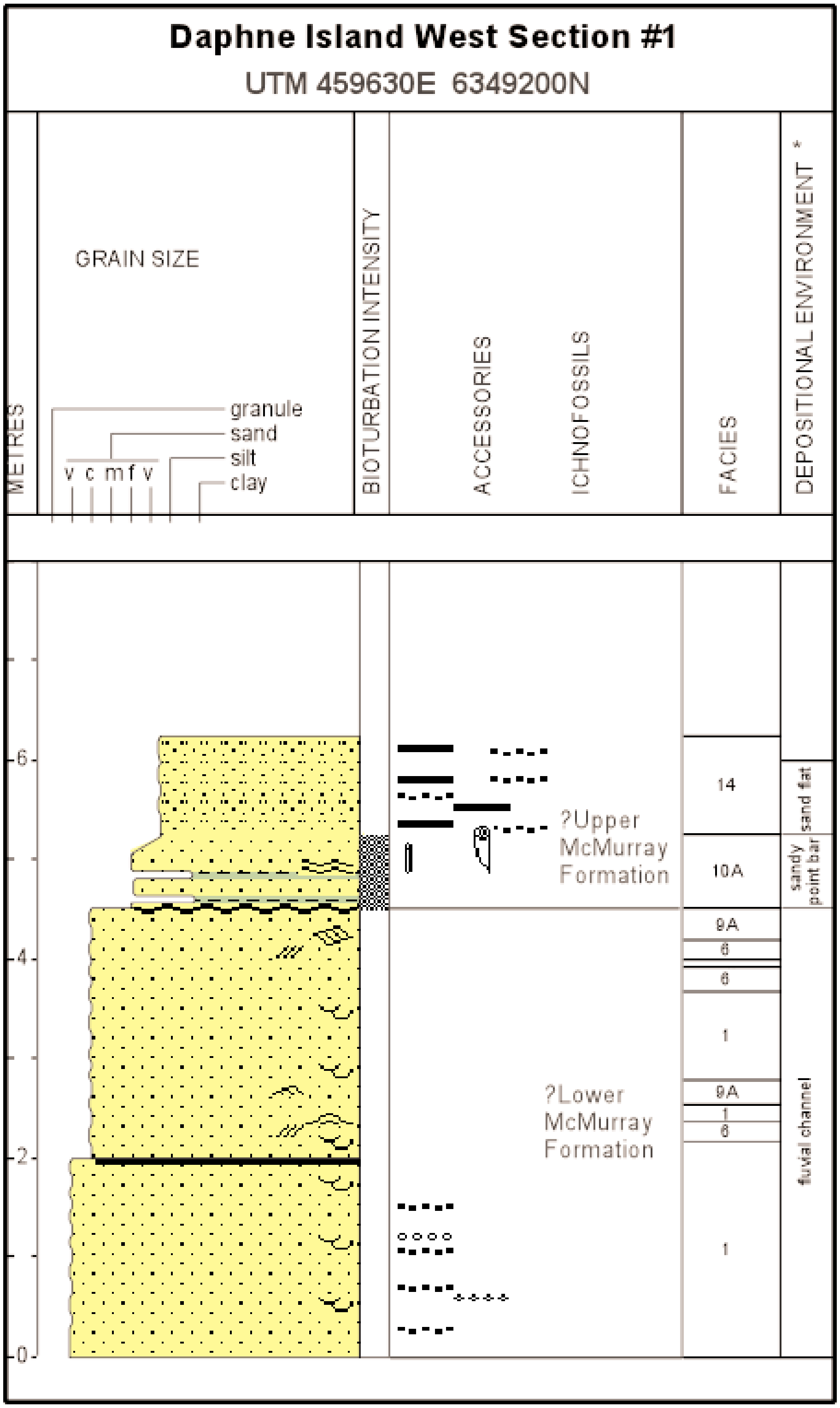


Figure 9.14.2. Aerial photograph showing access to sections near the mouth of the Ells River and sections along the Athabasca River at Daphne Island.



*Complete Description in Appendix 3.

Figure 9.14.3. Schematic representation of the measured Daphne Island West Section #1 (UTM 459630E, 6349200N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

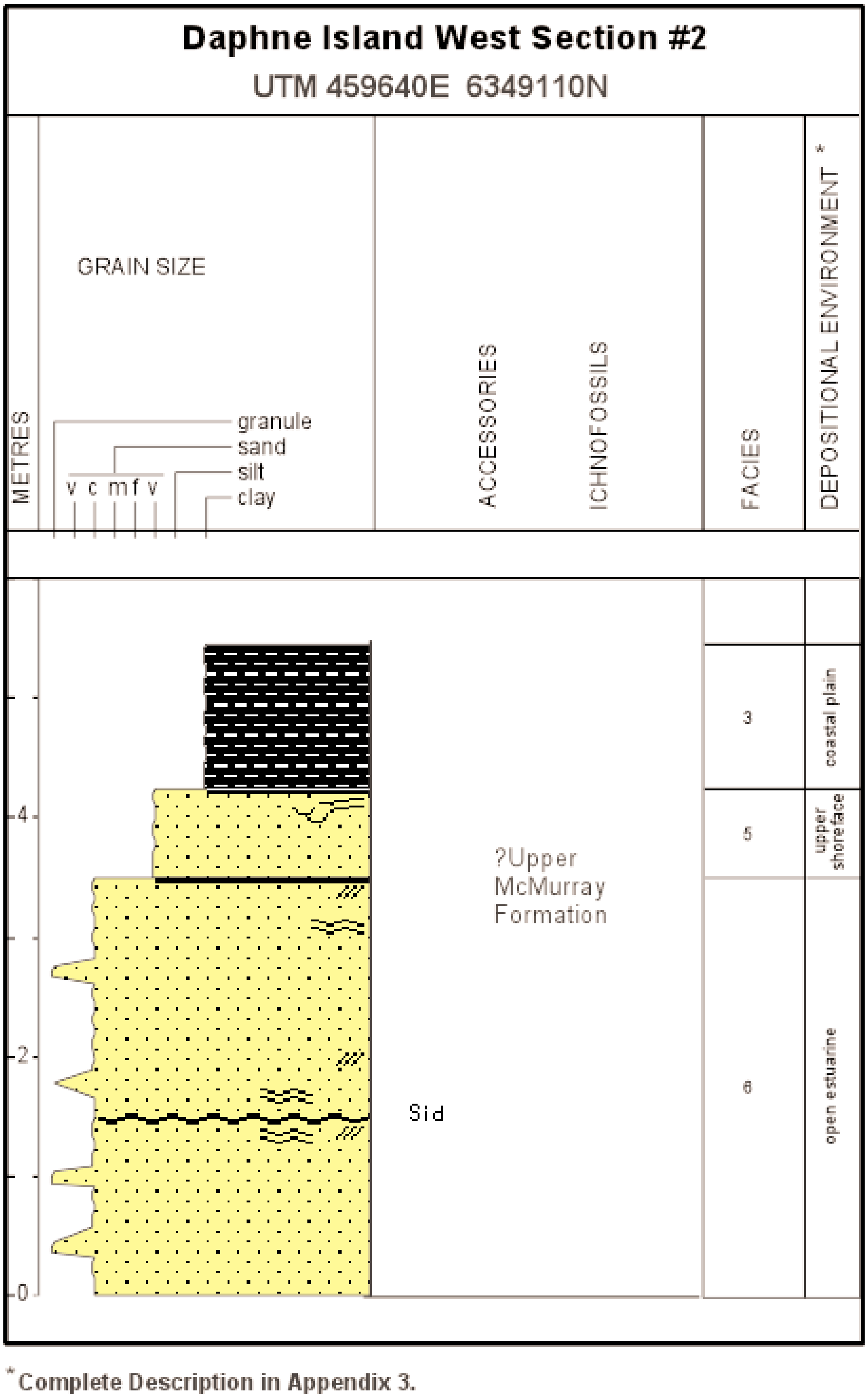
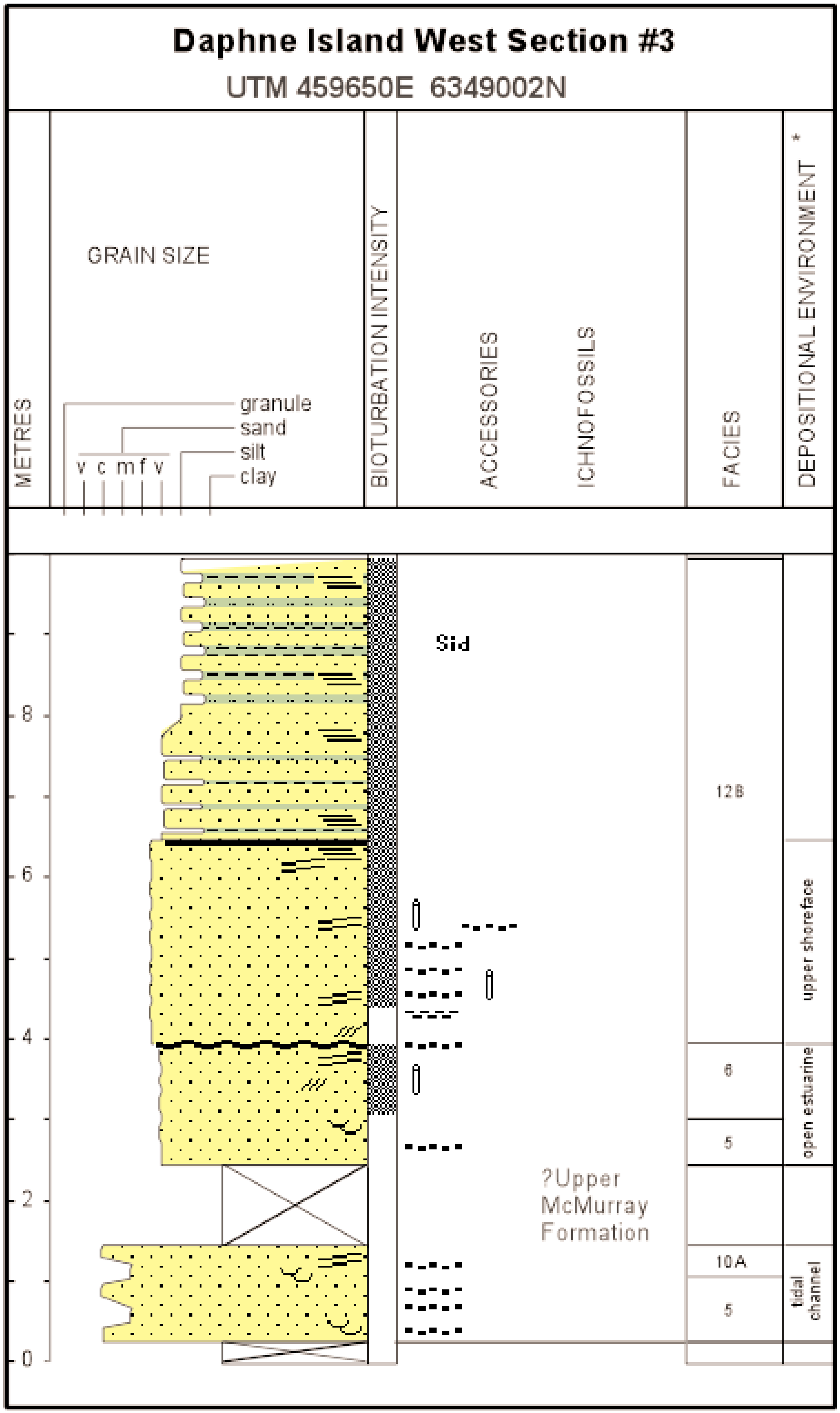


Figure 9.14.4. Schematic representation of the measured Daphne Island West Section #2 (UTM 459640E, 6349110N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 9.14.5. Schematic representation of the measured Daphne Island West Section #3 (UTM 459650E, 6349002N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

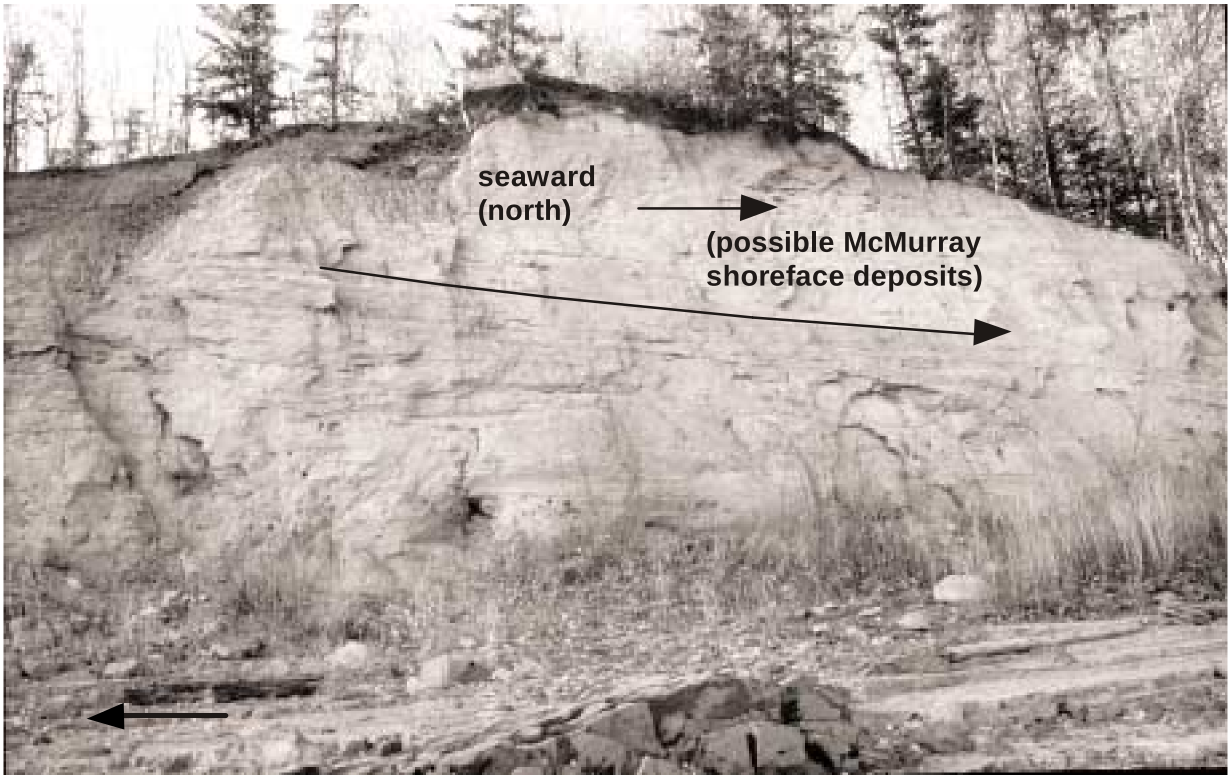


Figure 9.14.6. Clean whitish, sand (bitumen-free) with northerly paleo-seaward dipping surfaces Daphne Island West Section #3 (? Upper McMurray Formation), on the Athabasca River.

9.15 Daphne Island East Section

Map Coordinates: 74E/5 Bitumount, UTM 4602500E, 6350300 N (middle of section).

Location and Access: This outcrop is located about 1 km upstream from the mouth of the Ells River on the east bank of the Athabasca River, at the downstream end of Daphne Island (Figures 9.14.1, 9.14.2). Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from a landing at the Fort MacKay settlement.

Due to the significant along-strike variation in sedimentary facies at this outcrop (Figure 9.15.1), five vertical sections were measured, each spaced about 100 m apart going from upstream at Daphne Island East Section #1 to downstream at Daphne Island East Section #5 across from the mouth of the Ells River (Figures 9.14.1, 9.14.2).

Keynote things to see:

- Stacked and laterally interfingering fluvial, marl and estuarine channel deposits;
- Thick, marl at the downstream and upstream parts of the outcrop (Daphne Island East #4, #3 and #1);
- Large fluvial channel incision in the middle part of the outcrop (Daphne Island East #2) and at the downstream end (Daphne Island East #5).

Description: In the Daphne Island East Section #1 a 4 m thick, fining-upward succession occurs with large-scale, low-angle, sandy inclined heterolithic stratification at the base that becomes more muddy and thinly interbedded towards the top (Figure 9.15.2, 9.15.3a). Internally the inclined heterolithic stratified sand, has current ripples and minor burrowing, including *Skolithos* and *Teichichnus* within the finer-grained interbeds. This unit is scoured out above, and unconformably overlain by white friable marl (Figure 9.15.3b) that is, in turn, scoured-out along-strike (left side of photo, Figure 9.15.3c). The marl is overlain by cross-bedded, fining-upward, pebbly and coarse-grained sand that has abundant iron-staining and siderite cement. Trough cross-beds and, to a lesser extent, planar tabular cross-beds are unidirectional and mainly oriented towards the north (paleo-seaward) direction. The trough cross-bedded sands are scoured out by low-angle, inclined heterolithic stratified pebbly sand, that, replaced by trough cross-bedded, very coarse-grained sand (Figure 9.15.3 c to f).

In the Daphne Island East Section #2 a thin remnant of low-angle, sandy inclined heterolithic stratified sand (<0.5 m thick) is scoured out by trough cross-bedded, pebbly to coarse-grained sand (Figure 9.15.4 base and Figure 9.15.5). The pebbly sand fines upward into rippled medium-grained sand, that is scoured out by another fining-upward, rippled and trough cross-bedded sand (0.5 to 1 m thick). The next 4 to 5 m is an alternating sequence of thick-bedded, planar tabular and planar tangential cross-bedded sand, with unidirectional paleocurrents to the north (paleoseaward). A thin gravel cuts this unit out, and is capped by a 2 to 3 m thick trough cross-bedded, coarse-to very coarse-grained sand (Figure 9.15.4).

In the Daphne Island East Section #3, about 1 m of section is covered at river level. This is overlain by a bioturbated, low-angle, inclined heterolithic stratified sand, that grades upward into muddy, low-angle inclined heterolithic stratified units (Figures 9.15.6, 9.15.7 a to d). Burrows occur throughout the low-angle, inclined heterolithic stratification, mainly *Teichichnus* and *Skolithos* with rare U-shaped burrows at the top. Internally the low angle cross-bedded sands and mudstones show current ripples, flaser-bed ding, and wavy laminations. This low angle cross-bedded sand and mudstone unit is abruptly overlain by a white friable marl that pinches out rapidly along strike. The marl, in turn, is scoured out by a succession of fining-upward sand. Internally the sand contains sideritized mudstone-intraclasts and abundant coal debris. Cross-bedding is planar tabular, or less commonly, low-angle inclined heterolithic stratification. Paleoflow directions are uniformly to the north (paleoseaward) (Figure 9.15.6).

In the Daphne Island East Section #4 about 1 m at the base of the section is covered. This is overlain by about 3 m of sandy, low-angle inclined heterolithic stratified sand and mudstone (Figure 9.15.8). Internally the sand units show trough cross-beds towards the base, which are overlain by planar tabular cross-bedding and ripples. Pyrite concretions occur at the base of the section. Bioturbation increases in intensity upsection, dominantly *Cylindrichnus* and *Planolites*. In a lateral upstream direction along the outcrop, the scale of cross-bedding diminishes, with large-scale troughs and planar tabular cross-bedded sands being replaced by rippled, fine-to very fine-grained sand. Abruptly overlying the low-angle, inclined heterolithic-stratified sand and mudstone (Figure 9.15.9b) is a 1 m thick marl unit that is white, friable, and locally calcareous (Figure 9.15.9a). The next 1-2 m of vertical section is covered. The next exposure is a medium to coarse sand, with trough cross-bedding and planar tabular or planar tangential cross-beds (‘fluvial channel,’ Figure 9.15.9a). This unit is fairly consolidated and local siderite cement occurs at the top. Next is a medium-grey, sandy mudstone, scoured out by a recessive, pebbly to fine-grained sand with tidal (herringbone) cross-bedding. The top of the section consists of rippled, very fine- to fine-grained, burrowed sand.

The Daphne Island East Section #5 is a relatively simple succession comprising stacked trough cross-bedded, coarse-grained to granular sand at the base, that is overlain by a 6 - 7 m thick, fining-upwards succession of low-angle, inclined heterolithic stratified sand and mudstone (Figure 9.15.10). Internally the low-angle bedding is parallel laminated, rippled, or locally shows small planar tabular cross-beds. Burrows were absent. Few reversals in paleoflow directions occur with most of the paleoflows to the north (paleo-seaward) (Figures 9. 15.11a, b).

<u>Interpretation:</u> As with the Daphne Island West locality, the Daphne Island East locality shows very complex interdigitation of facies, multiple channeling and scouring, and the occurrence of major internal erosional unconformities or disconformities. In the Daphne Island East #1 Section the lowest 4 m of section is interpreted as sandy estuarine point bar deposits, overlain abruptly by lacustrine marl. This lacustrine unit is then cut-out by prominent fluvial channel sand that is eroded out by an estuarine point bar succession. Another fluvial channel succession occurs at the top.

The sequence at Daphne Island East #2 is much simpler, with a thin remnant of estuarine point bar sands at the base, scoured out by the base of a fluvial channel. The fluvial succession consists of a series of cross cutting individual fluvial channel sands that show complex vertical and lateral facies changes.

The Daphne Island East Section #3 starts with a thick sandy to muddy estuarine point bar succession that is capped by the lacustrine marl. As in the Daphne Island East Section #1 the base of a fluvial channel cuts out this marl. The overlying fluvial succession consists of a series of interbedded channel sand and sandy point bar deposits.

A similar repetition of events occurs at the Daphne Island East Section #4 where sandy estuarine point bar deposits are overlain by lacustrine marl. The contact with the overlying fluvial channel sand is covered. The fluvial channel sands then grade upward into tidal channel and sand flat deposits. A coarse-grained pebbly and carbonaceous debris unit occurs just above the contact between the fluvial and tidal channels. This is interpreted as the initial transgressive lag deposits associated with the incision and scour of the transgressive surface of erosion between the fluvial and tidal channel sands.

The Daphne Island East Section #5 returns to a relatively simple facies pattern, with a lower 2 m thick fluvial channel sand, overlain by a 6 m thick sandy to muddy estuarine point bar deposit. The contact between the fluvial and estuarine units is covered.

The ages of the various fluvial and estuarine deposits at the Daphne Island East sections are not known. At present, lithostratigraphic correlations are too complex to sort out the relative age of the different units. Approximately 20 samples were taken from the Daphne Island East outcrops for palynological analysis that will aid in biostratigraphic age determination (Dolby, 2001).

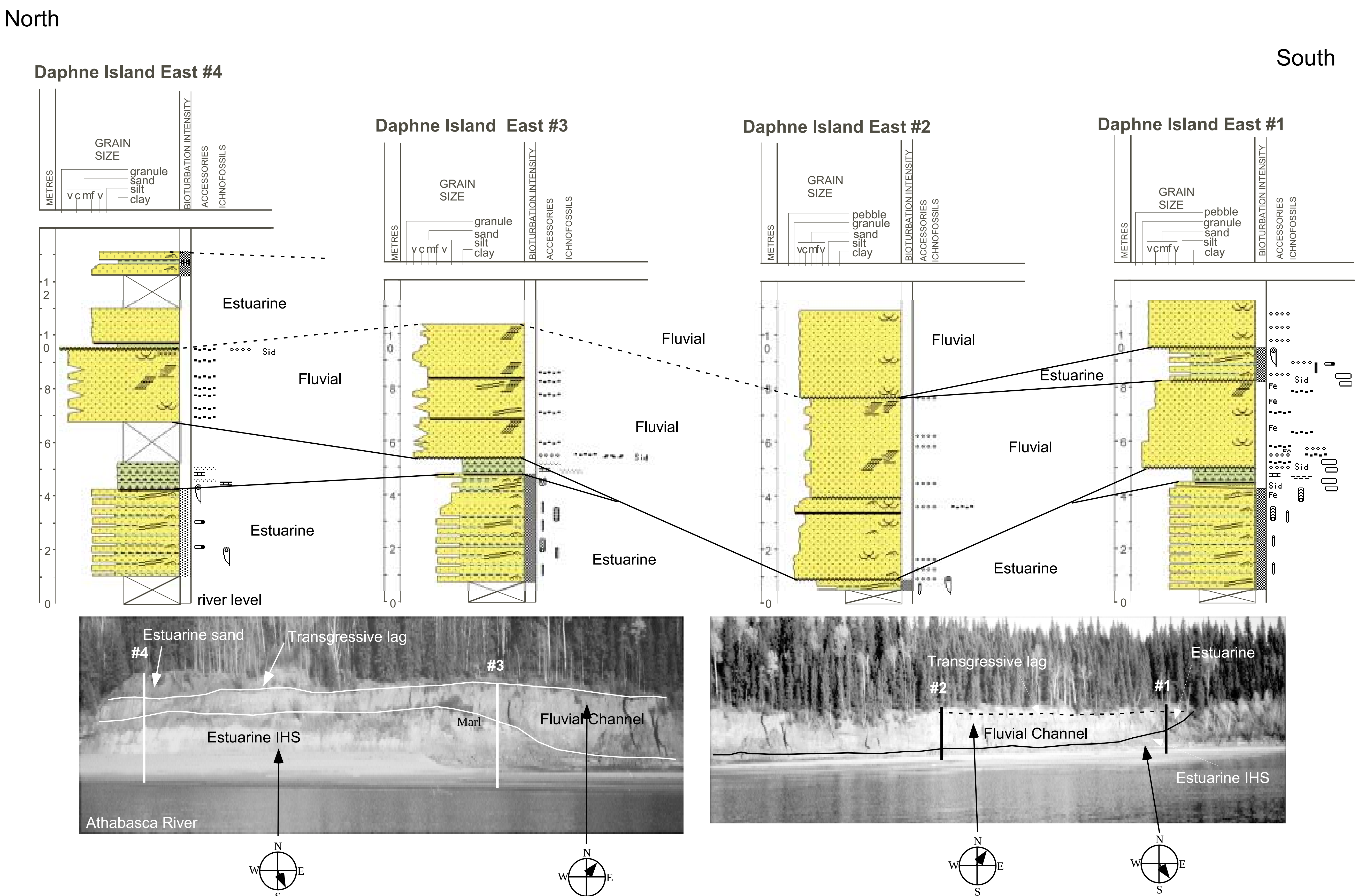
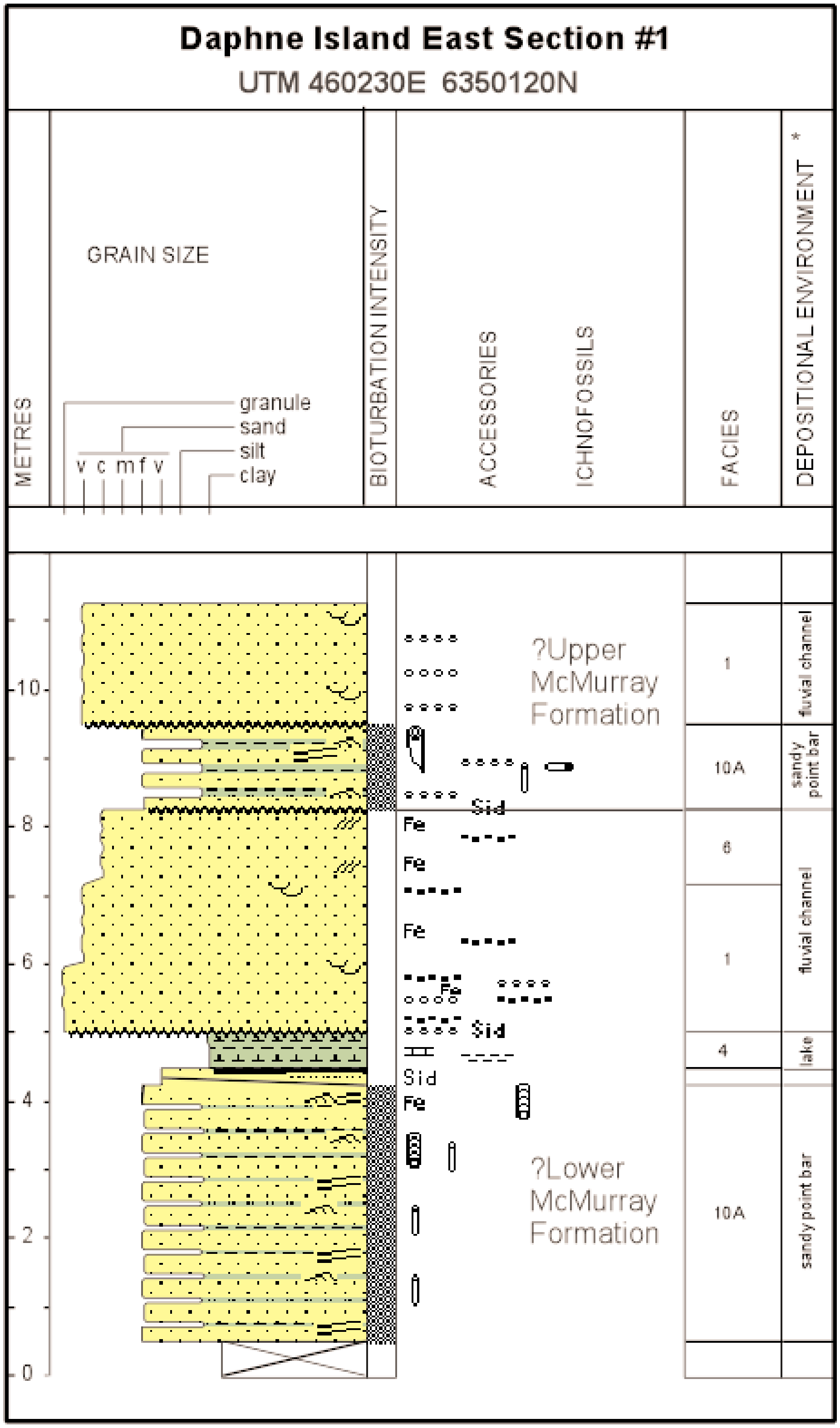


Figure 9.15.1. Photo mosaic and outcrop cross section, Daphne Island East #1 (South, upstream on the Athabasca River) to Daphne Island East #4 (North, downstream on the Athabasca River). Note the significant facies changes, cross-cutting and complex interfingering of estuarine and fluvial successions. View looking east at the outcrop face. Horizontal distance between Daphne Island East #1 and #4 sections is approximately 300 m. Arrows in “compass face indicates paleoflow trends.



*Complete Description in Appendix 3.

Figure 9.15.2. Schematic representation of the measured Daphne Island East Section #1 (UTM 460230E, 6350120N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

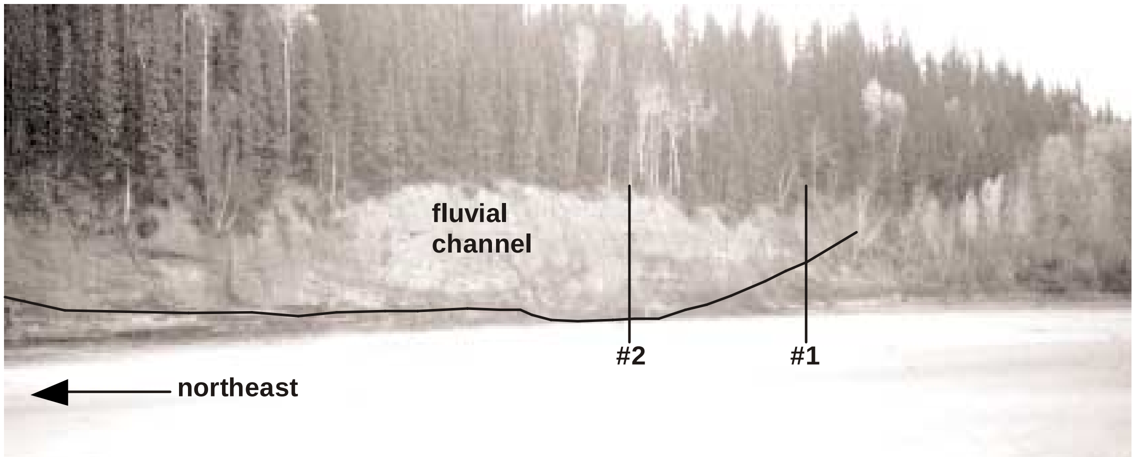


Figure 9.15.3a. Fluvial channel incising into estuarine laterial accretion sediments at the edge of the Bitumont Basin, Daphne Island East (McMurray Formation), Athabasca River.

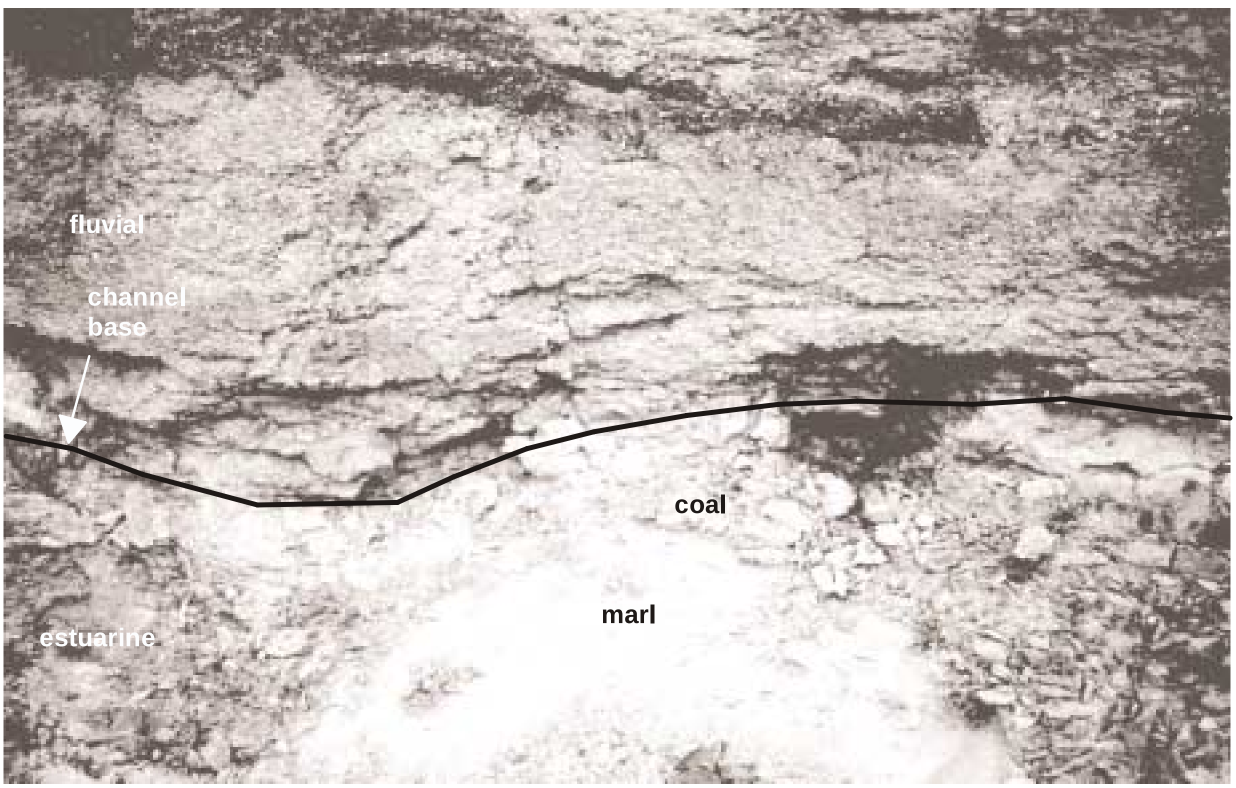


Figure 9.15.3b. Unconformable fluvial-estuarine contact at the southern end of the Daphne Island East Section #1 (McMurray Formation), Athabasca River.

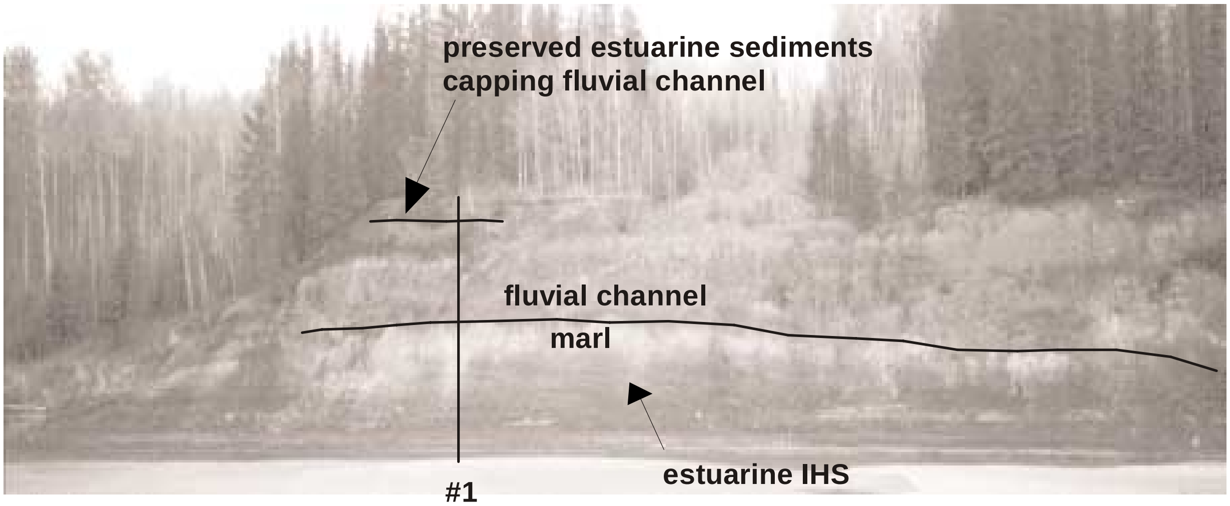


Figure 9.15.3c. Thinner coarse grained, fluvial channel margin sand bound by finer-grained, interbedded estuarine sediments above and below (McMurray Formation), Daphne Island East Section #1, Athabasca River.

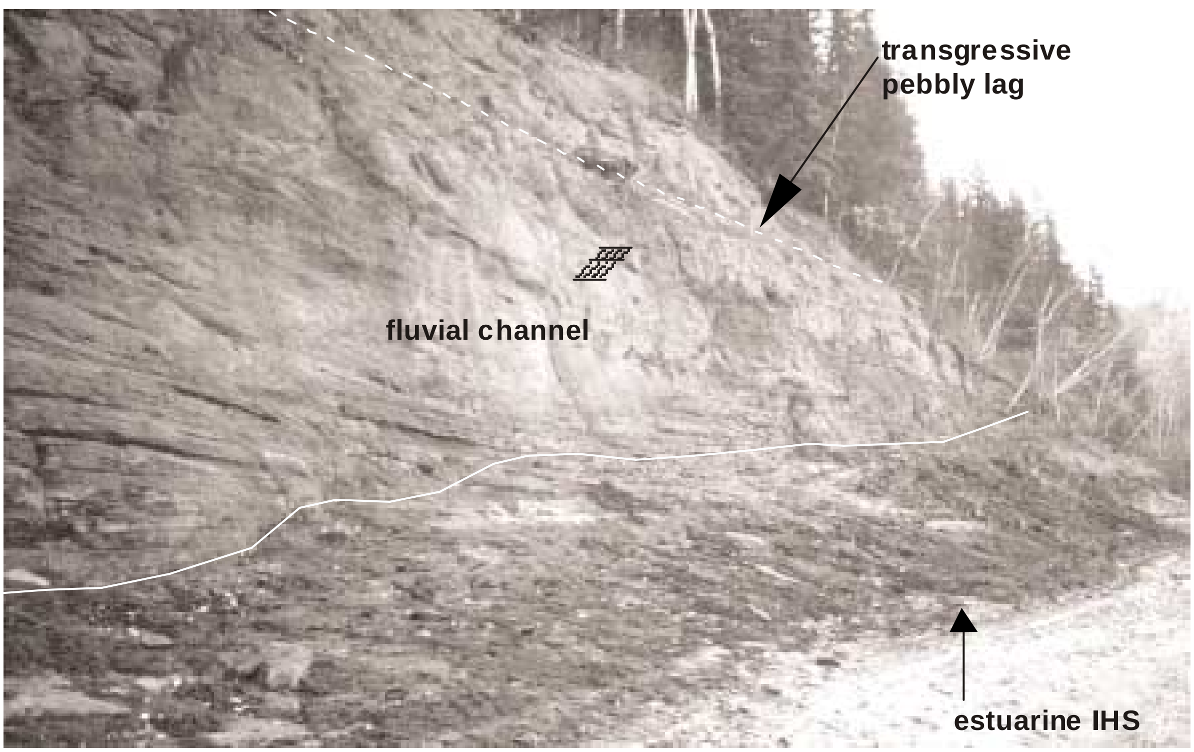


Figure 9.15.3d. Angular unconformity separating estuarine inclined bedding from overlying fluvial channel deposits (McMurray Formation), Daphne Island East Section #1, Athabasca River.

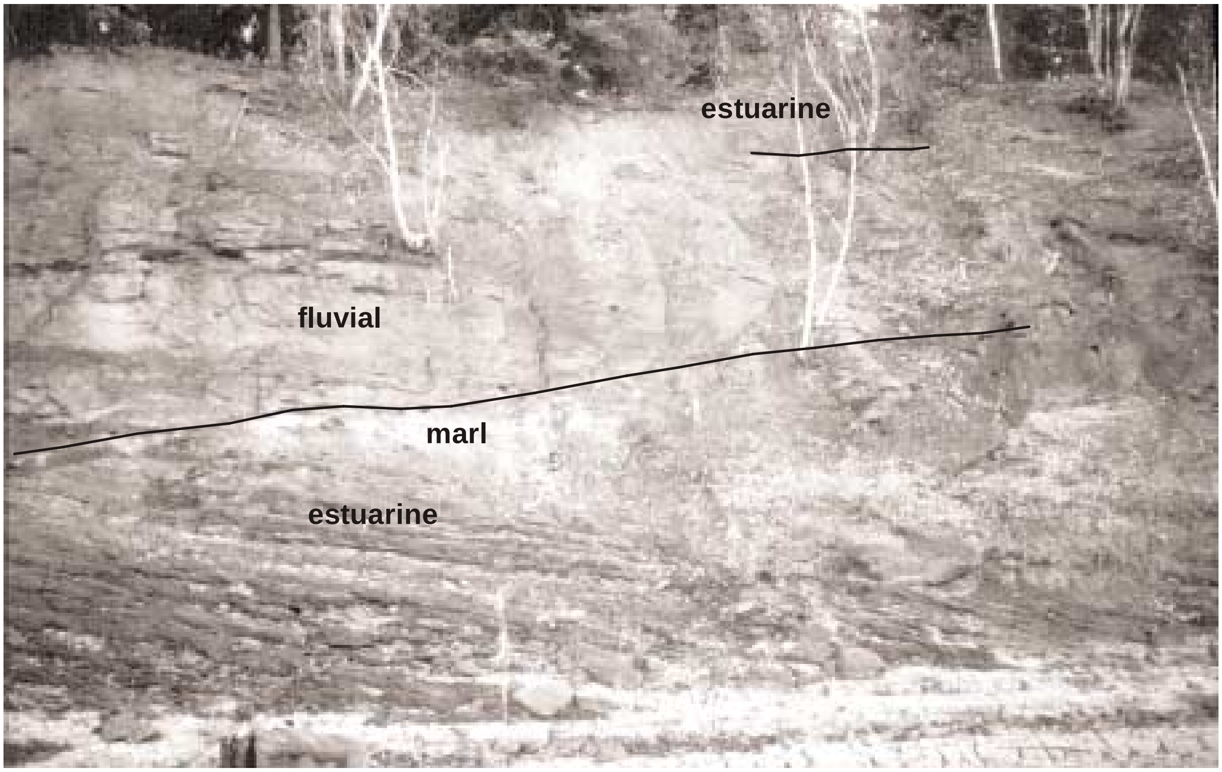


Figure 9.15.3e. Fine-grained, estuarine, lateral accretion deposits unconformably overlain by coarse-grained, fluvial channel deposits (McMurray Formation), Daphne Island East Section #1, Athabasca River.

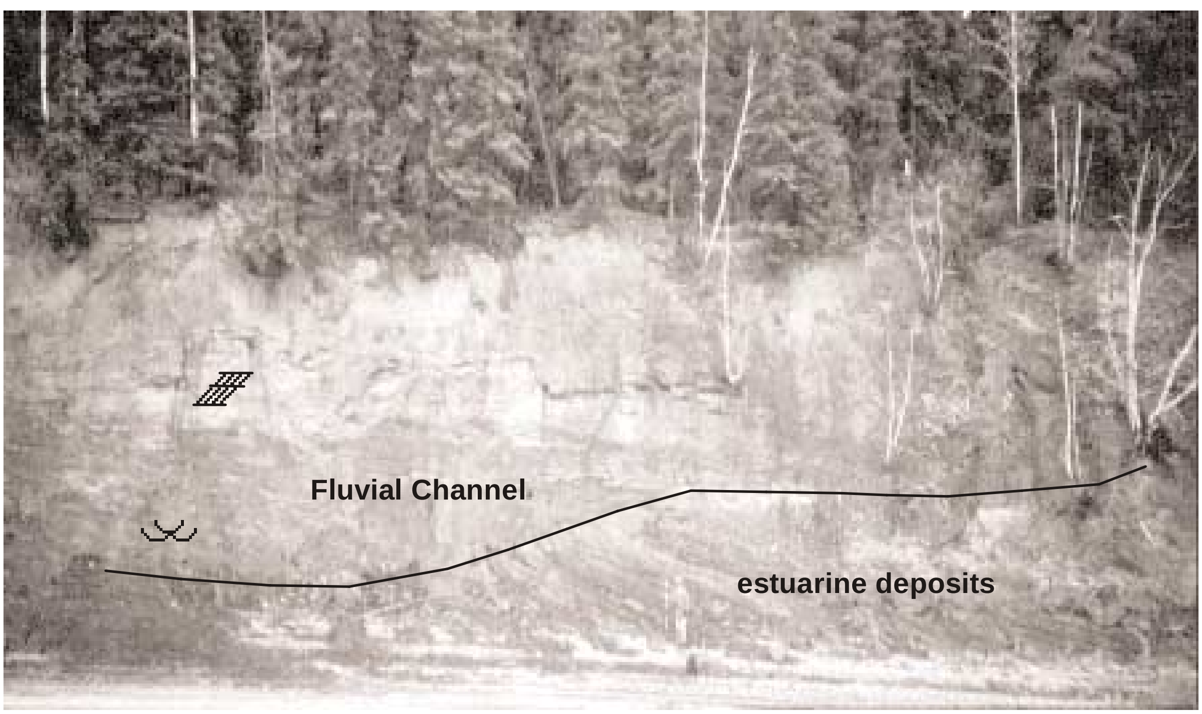


Figure 9.15.3f. Coarse-grained fluvial channel incising into underlying estuarine low-angled inclined bedding (McMurray Formation), Daphne Island East Section #1, Athabasca River.

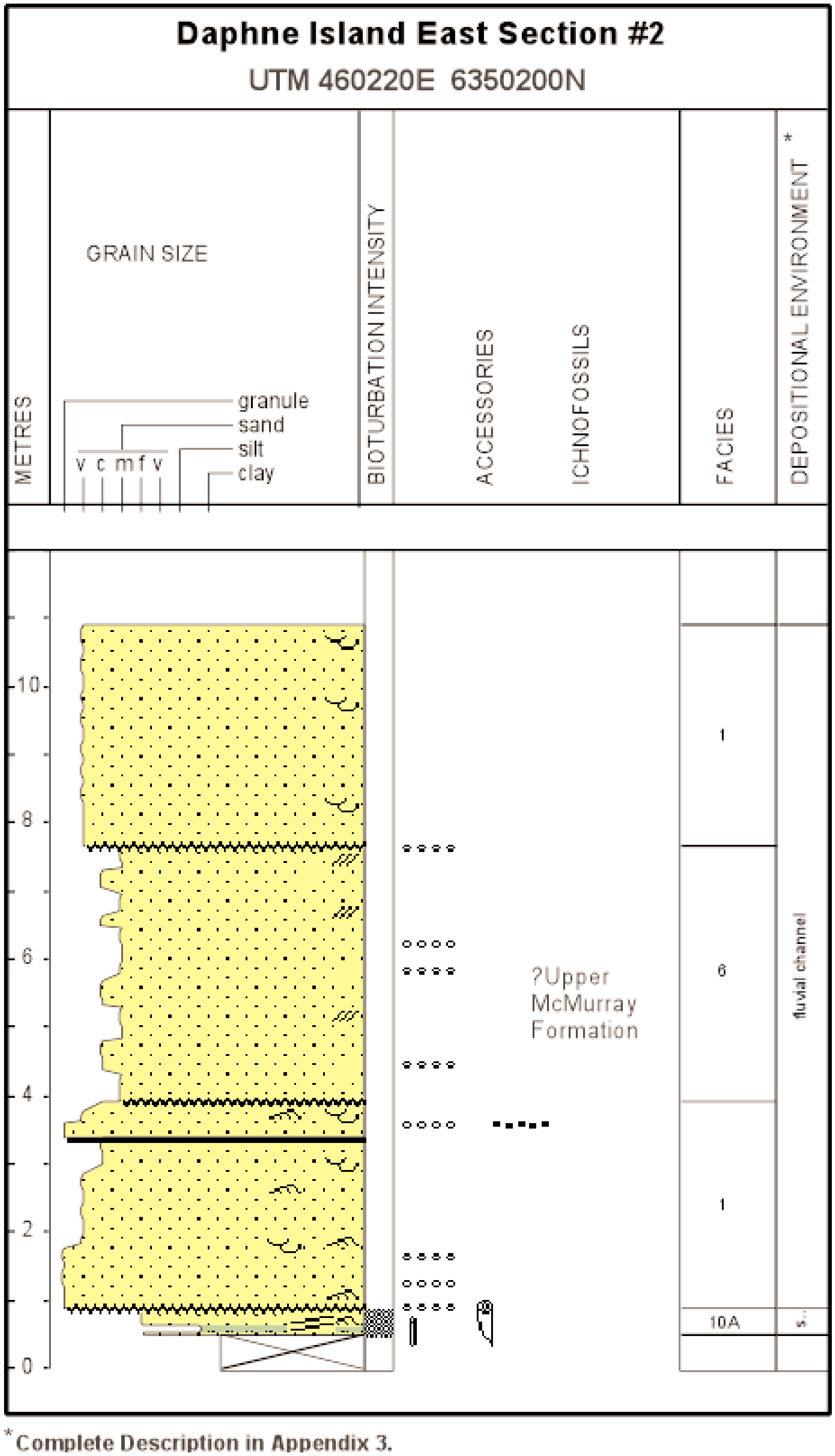


Figure 9.15.4. Schematic representation of the measured Daphne Island East Section #2 (UTM 460220E, 6350200N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

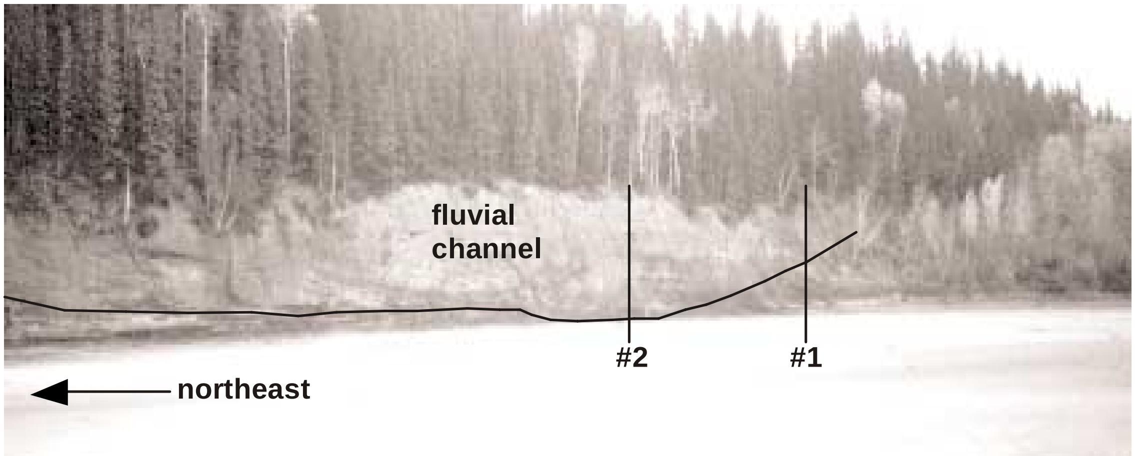


Figure 9.15.5. Fluvial channel incising into estuarine lateral accretion sediments at the edge of the Bitumont Basin (McMurray Formation), Daphne Island East, Athabasca River.

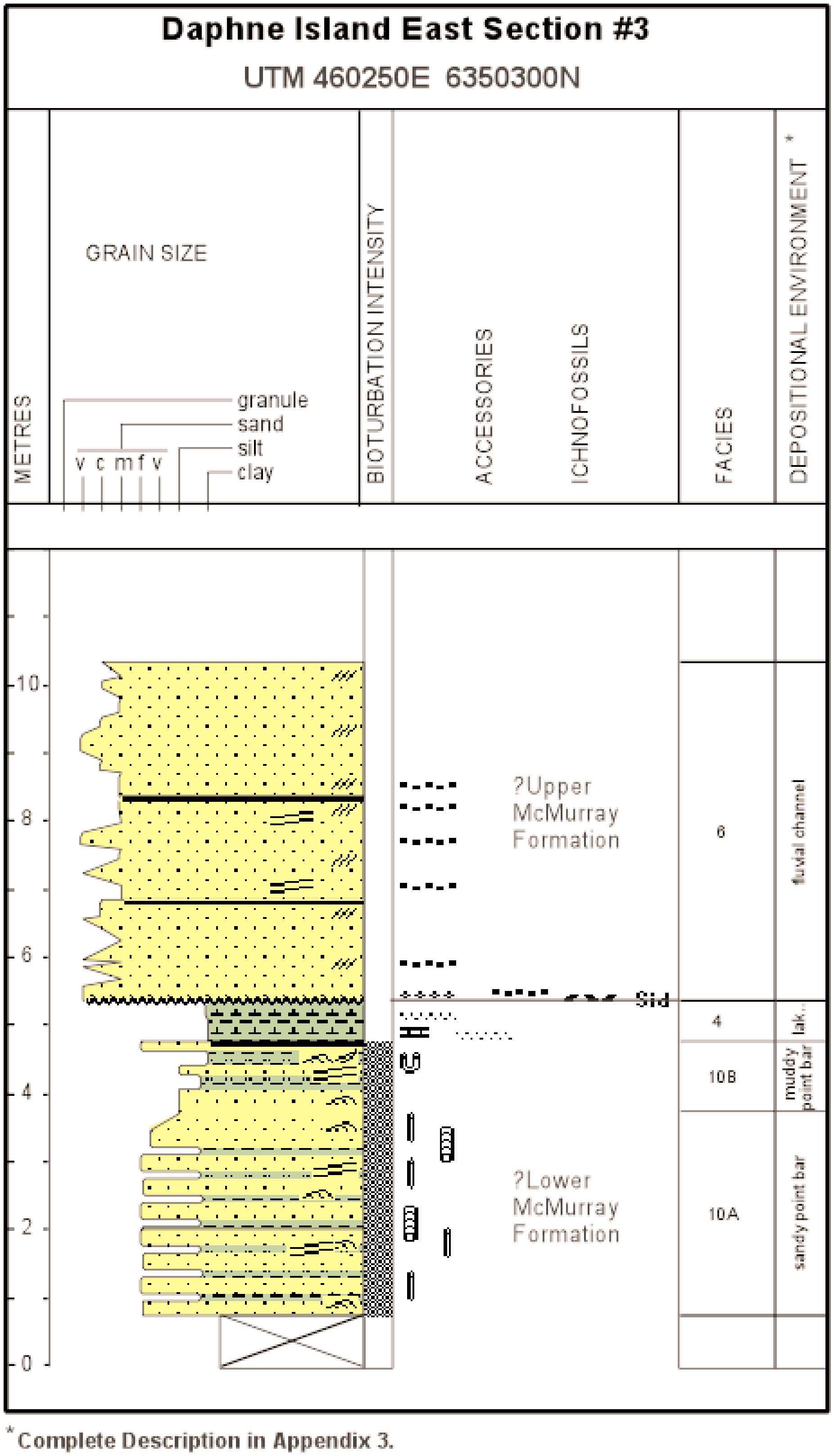


Figure 9.15.6. Schematic representation of the measured Daphne Island East Section #3 (UTM 460250E, 6350300N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

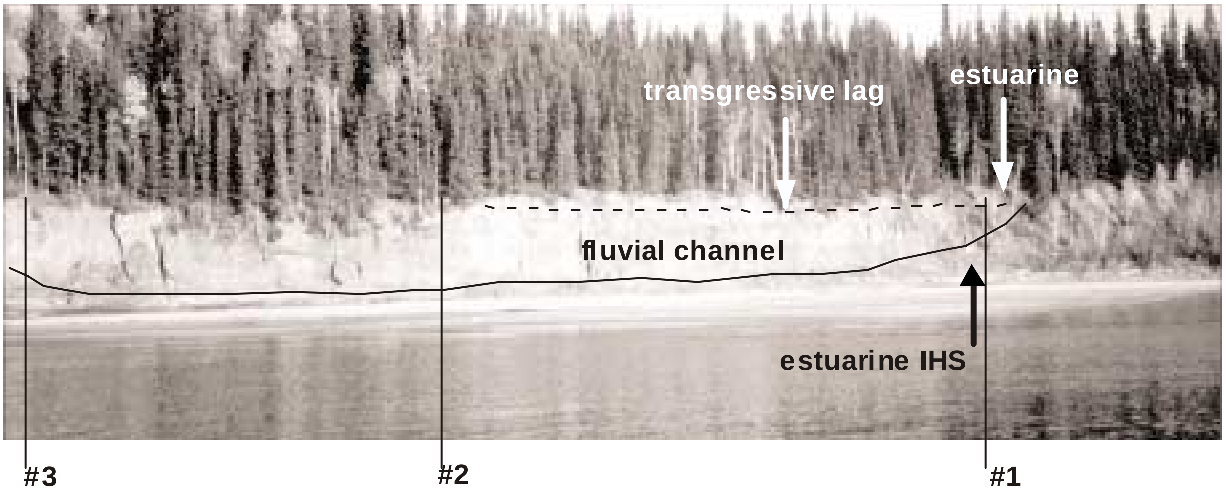


Figure 9.15.7a. Sections 1, 2, and 3 at the middle/southern end of Daphne Island East (McMurray Formation), Athabasca River.

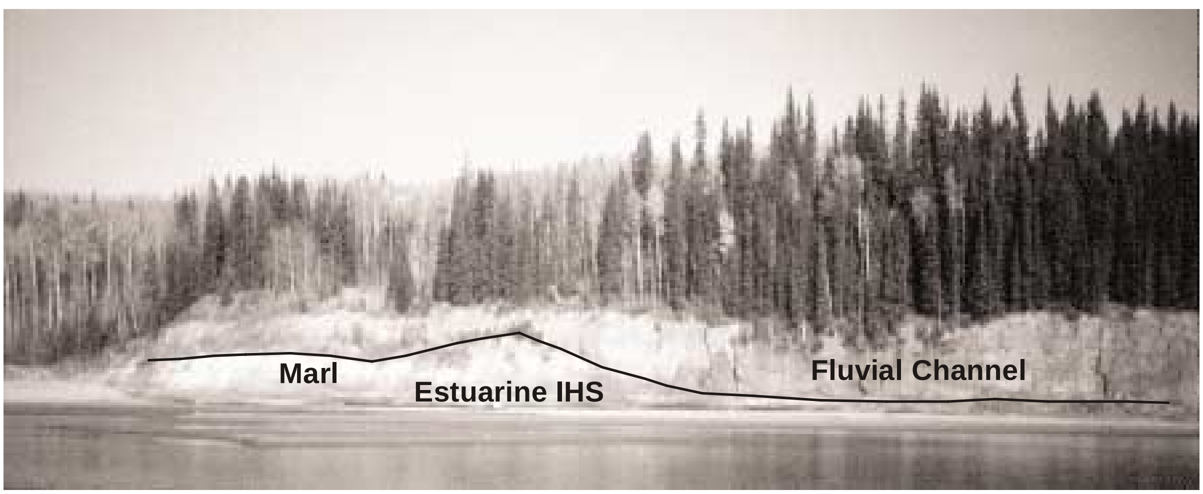


Figure 9.15.7b. Fluvial channel incising into estuarine sediments (McMurray Formation), Daphne Island East, Athabasca River.

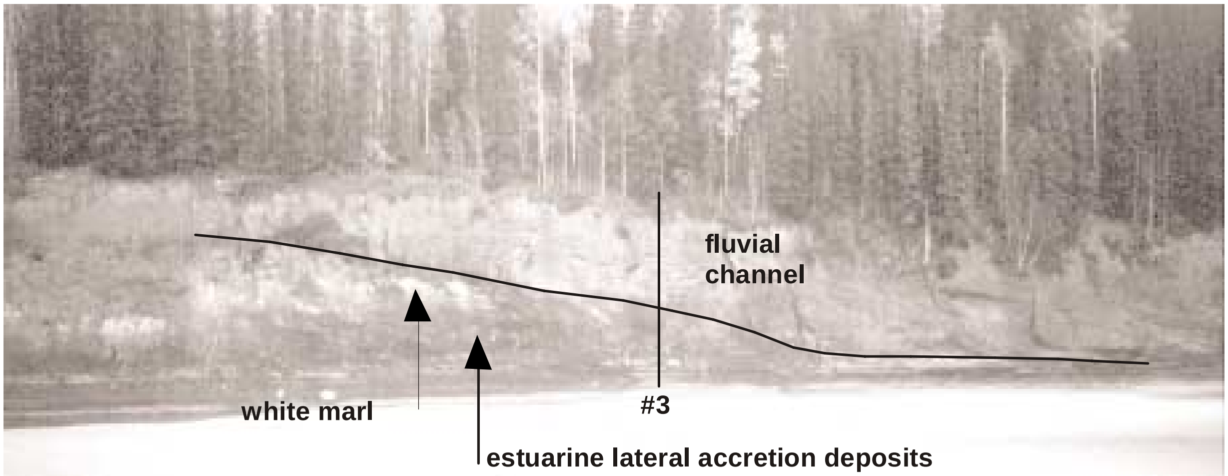


Figure 9.15.7c. Thinning channel margin of fluvial succession (McMurray Formation), Daphne Island East Section #3, Athabasca River.

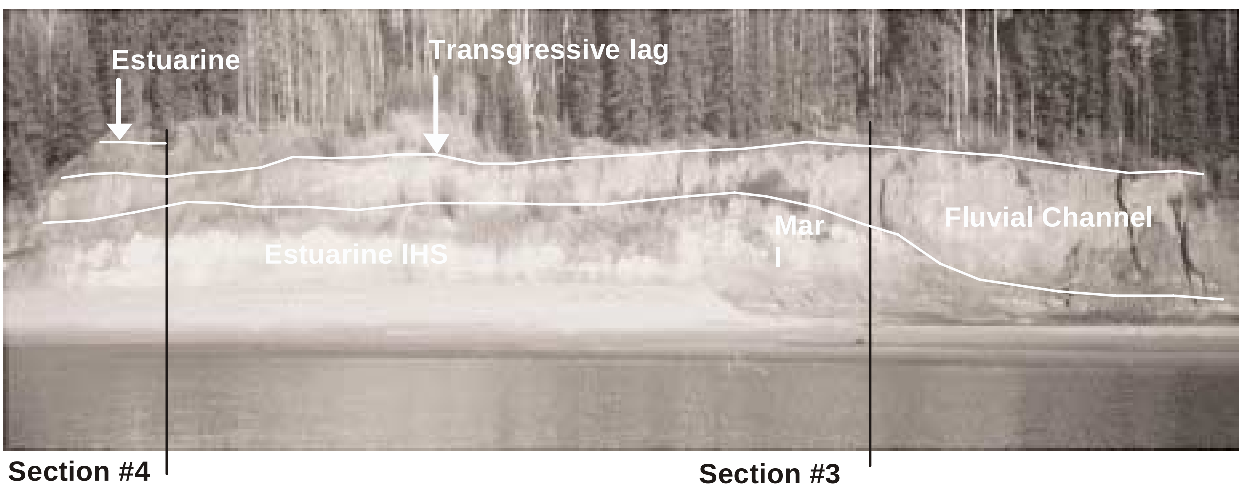
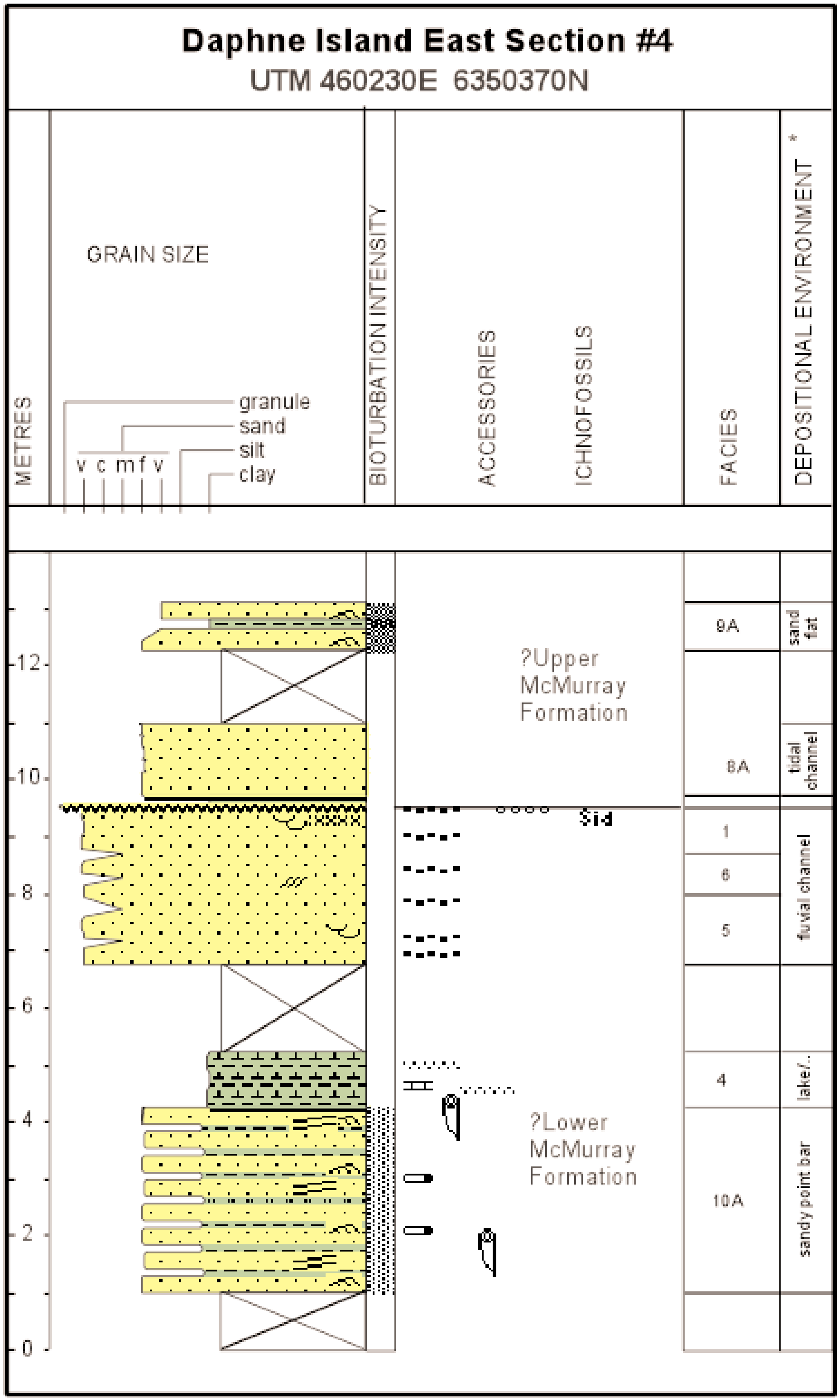


Figure 9.15.7d. Sections 3 and 4 at the northern end of Daphne Island East showing thalweg to channel margin transition.



*Complete Description in Appendix 3.

Figure 9.15.8. Schematic representation of the measured Daphne Island East Section #4 (UTM 460230E, 6350370N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

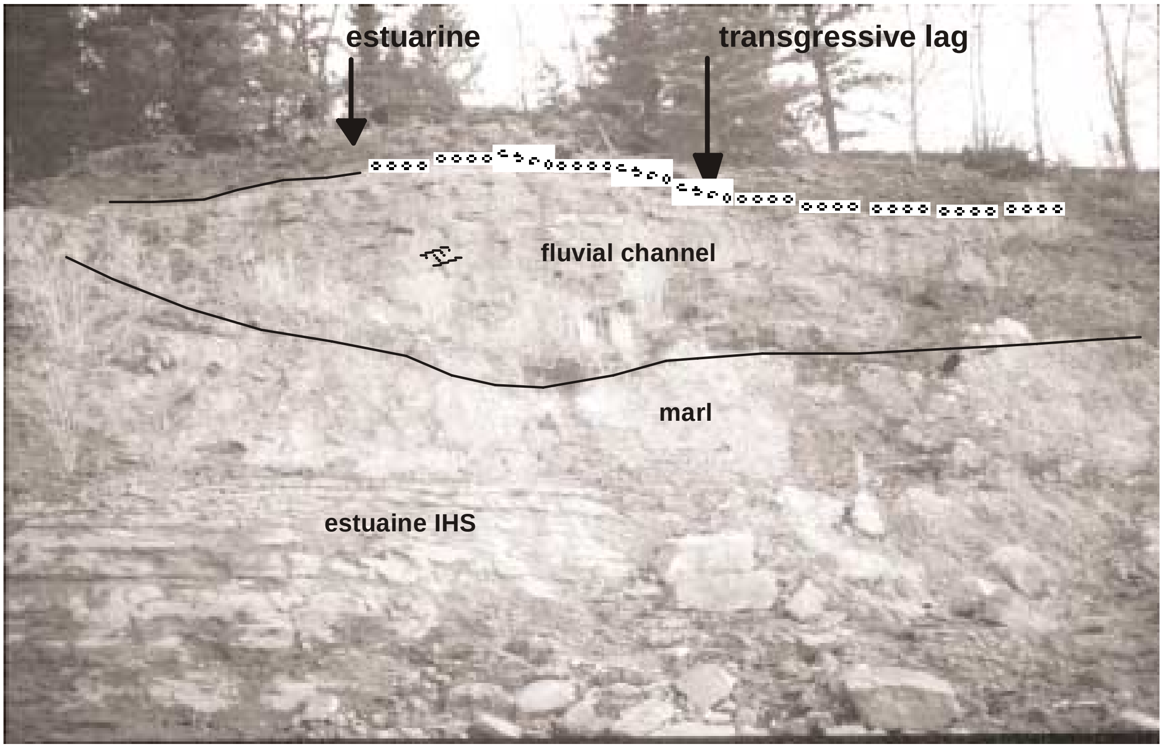


Figure 9.15.9a. Northern margin of the fluvial incised channel (McMurray Formation), Daphne Island East Section #4, Athabasca River.

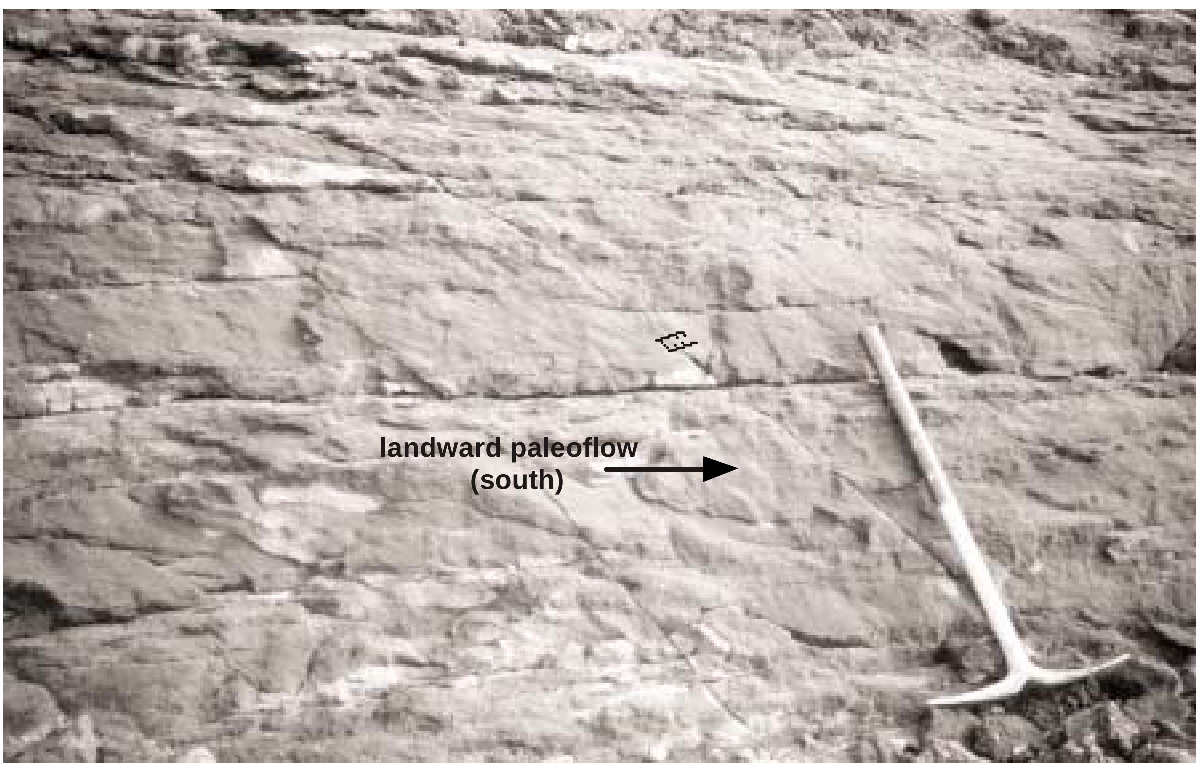
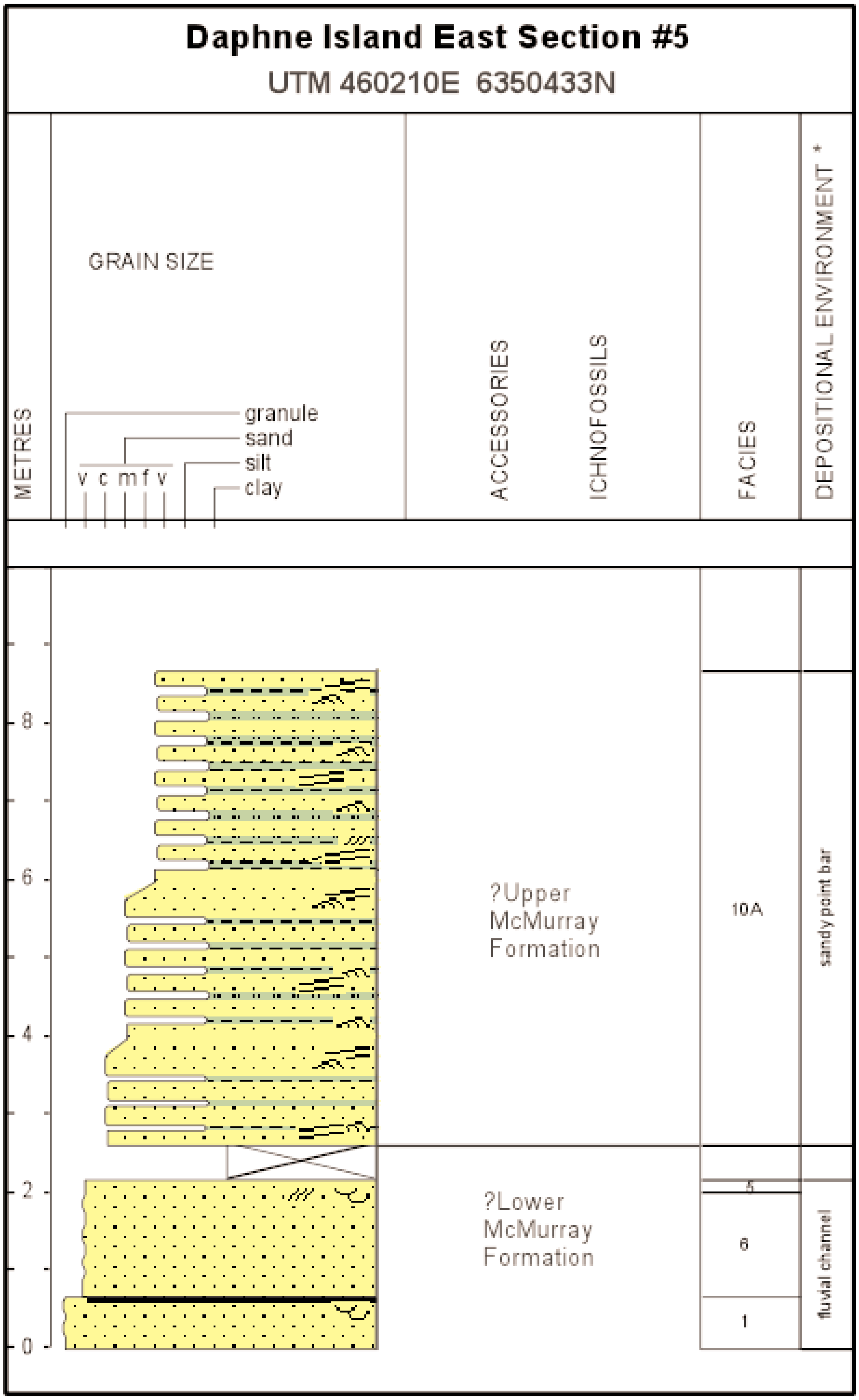


Figure 9.15.9b. Fine grained estuarine lateral accretion deposits at Daphne Island East Section #4, Athabasca River. Small scale, high angle, planar tabular/planar tangential cross-bedding with southern paleo-landward flow direction.



*Complete Description in Appendix 3.

Figure 9.15.10. Schematic representation of the measured Daphne Island East Section #5 (UTM 460210E, 6350433N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.15.11a. North, paleo-seaward dipping, stacked, high-angle, planar tabular cross-bedded sand (McMurray Formation), Daphne Island East Section #5, Athabasca River.

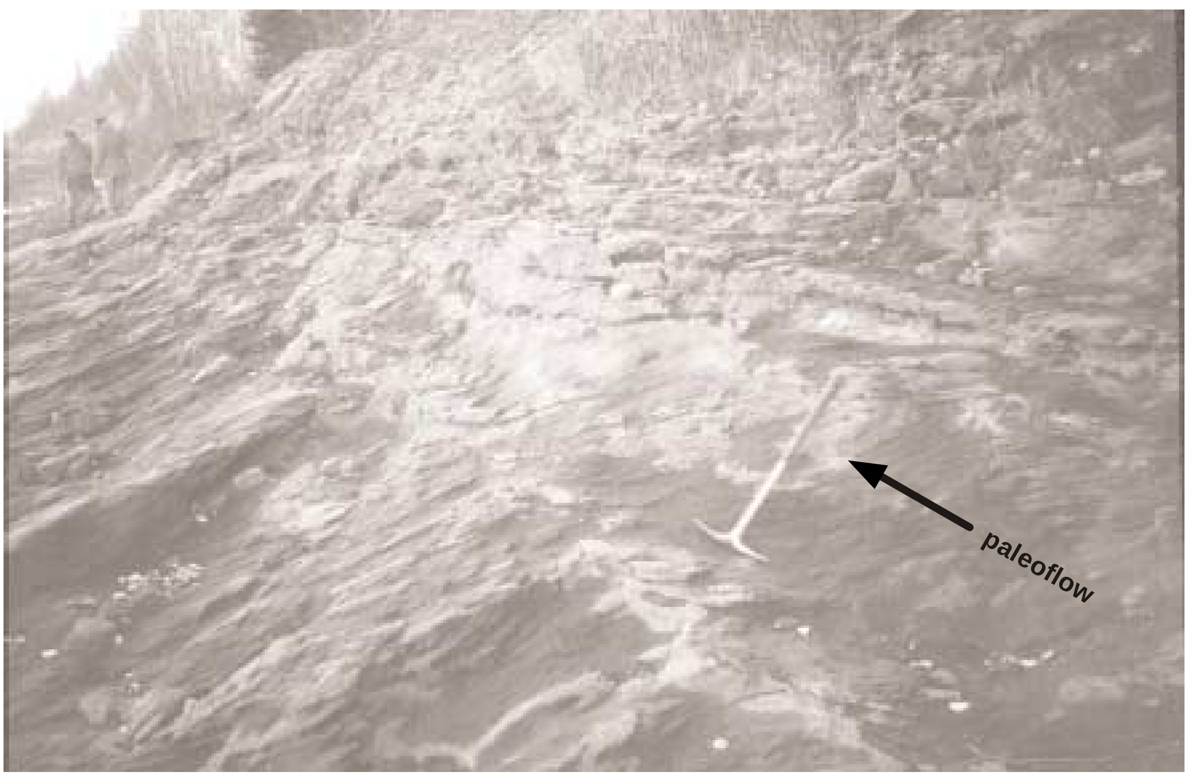


Figure 9.15.11b. South paleo-landward dipping high angle, planar tabular cross-bedded sand (McMurray Formation), Daphne Island East Section #5, Athabasca River.

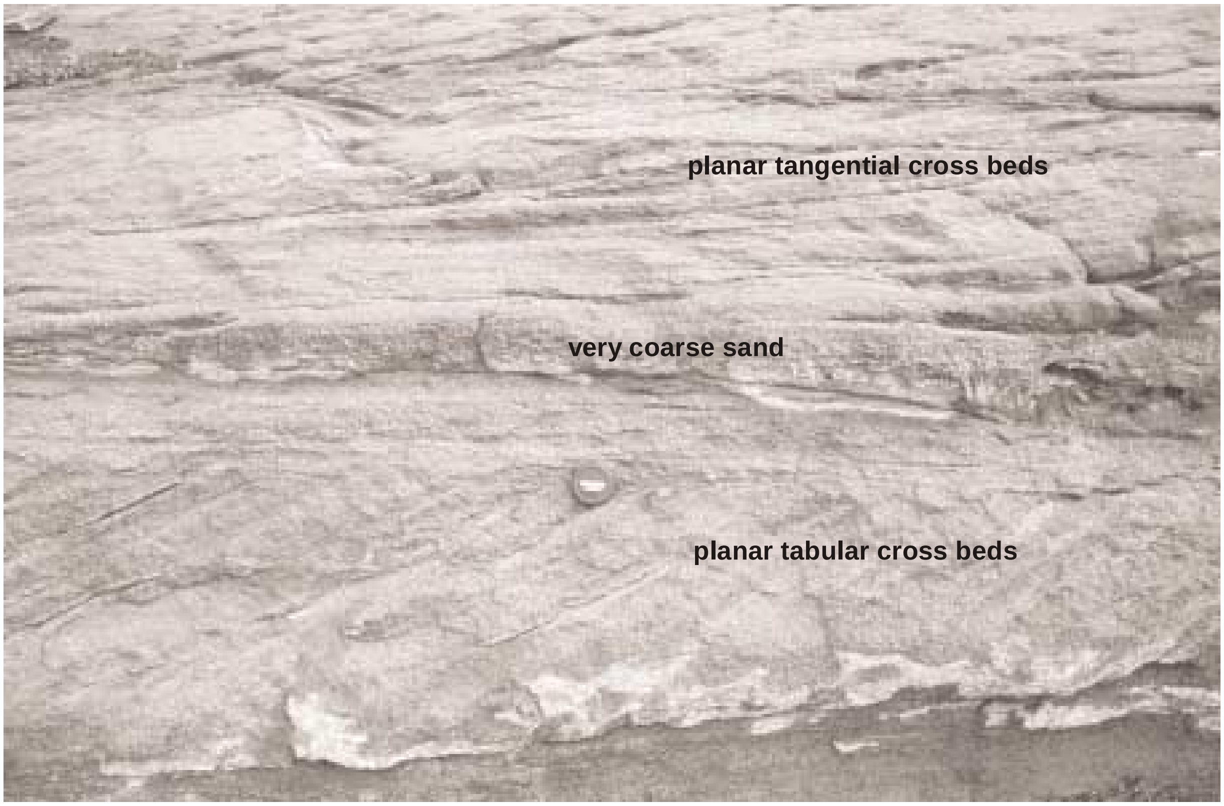


Figure 9.15.11c. North paleo-seaward dipping, medium to very coarse-grained, high-angle, planar tabular and planar tangential cross-bedded sand just above water level (McMurray Formation), Daphne Island East Section #5, Athabasca River.

9.16 Pierre River Mouth (Lower) Section

Map Coordinates: 74E/5 Bitumount, UTM 462150E, 6367150N.

Location and Access: This section is located at the northern end of the Bitumount map sheet, along the west bank of the Athabasca River just upstream from the mouth of Pierre River (Figure 9.16.1, 9.16.2). Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from the landing at the Fort MacKay settlement. This cutbank is very well exposed and generally accessible (Figure 9.16.4a).

Keynote things to see:

- Stacked fluvial, estuarine and tidal channel sediments;
- Very coarse-grained, conglomeratic, sideritized fluvial sediment at the base of the section near river level;
- Bay-fill, rooted and coaly coastal plain sediments at the top of the section.

Description: At the base of the section is 3 to 4 m of cemented, sideritized, gravelly sand, with common quartz granules and pebbles, many subrounded to angular (Figures 9.16.3 and 9.16.4b). Sideritization has occurred either as cement or as replacement of mudstone intraclasts. Well-developed, trough cross-bedding with paleoflows to the north-northeast and northwest are common. No burrows were observed. Overlying the sideritized base, is about 9 m of pebbly to granular sand alternating with fine- to very coarse-grained sand, with abundant internal scours and various types of cross-bedding, including trough, ripple, planar tabular, convoluted and herringbone (Figure 9.16.3). Finer-grained interbeds show tidal features, including flaser-bedding, double-mud drapes, and reverse-flow ripples. The uppermost third of the section is more even-bedded, finer-grained, and with abundant *Planolites* and *Cylindrichnus* burrows, coaly and rooted horizons. Carbonaceous debris is common towards the top, and much of the bedding style comprises wavy-bedding, combined-flow and wave ripples. The top of the McMurray succession is overlain by thin (<0.3 m), unconsolidated, tan Quaternary sand.

Interpretation: The basal 6 m of the succession is interpreted as fluvial channel-and-bar deposits of the Lower McMurray Formation. This is overlain by stacked estuarine and tidal-channel sediment of the lower part of the Upper McMurray Formation. As with the Athabasca River Sinkhole sections, lateral transitions along this outcrop within the lower part of the Upper McMurray Formation show an interfingering of point bar and channel units. The top of the succession with the wavy bedding style, combined flow ripples, abundant burrows, coaly interbeds and rooted horizons are interpreted as coastal plain sediments of the upper part of the Upper McMurray Formation.

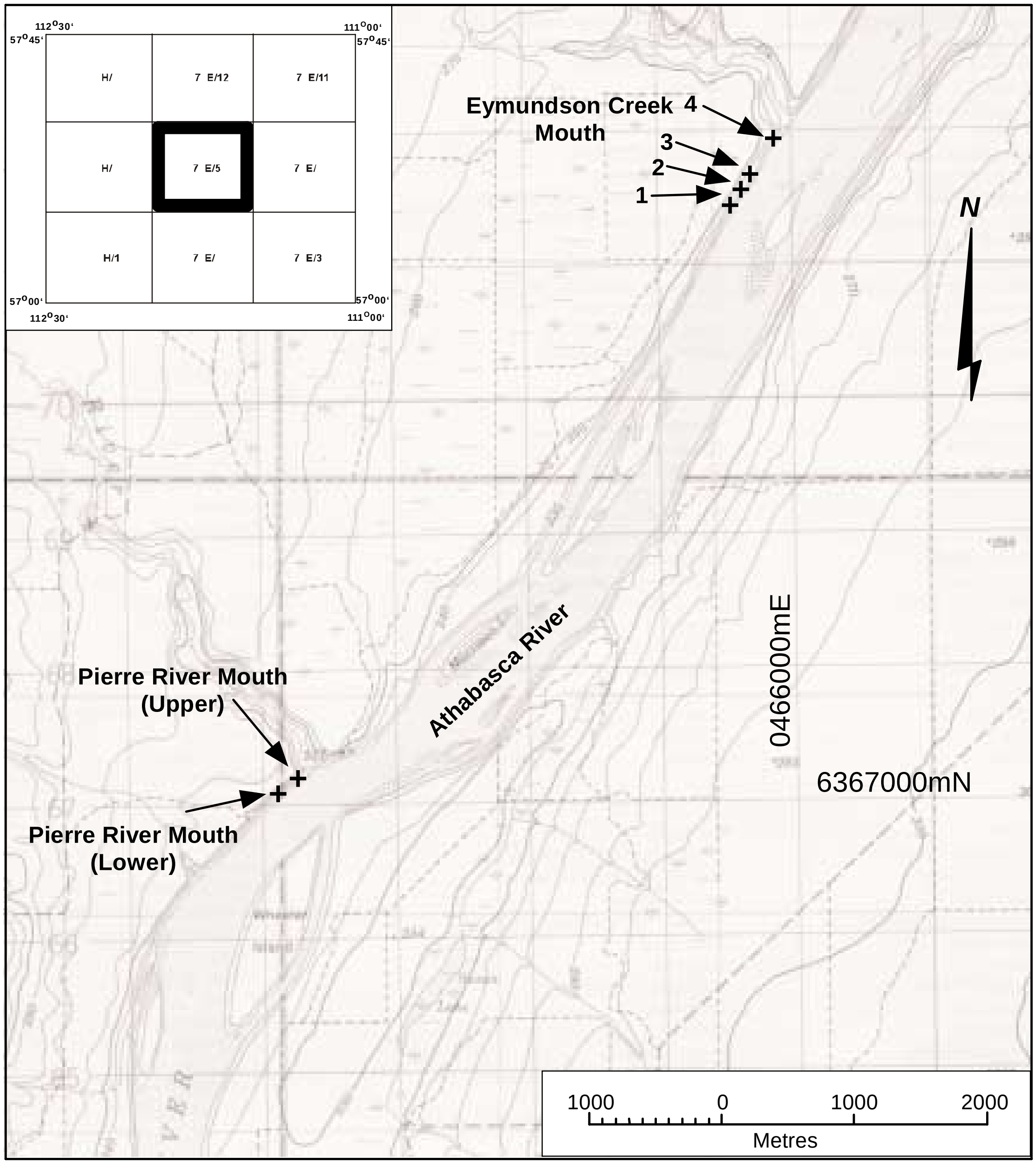
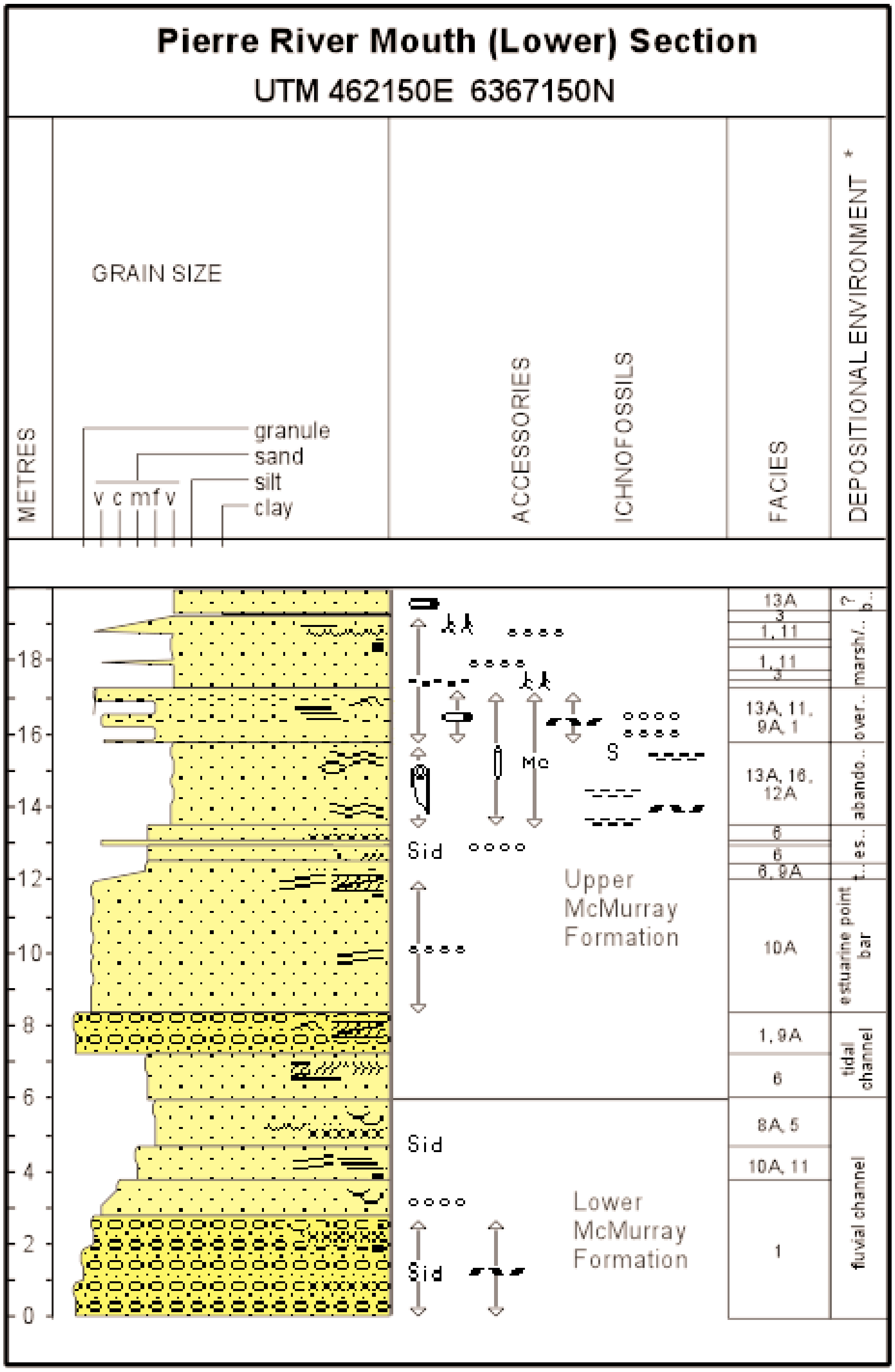


Figure 9.16.1. Map showing access to the Pierre River and Eymundson Creek Sections along the west bank of the Athabasca River, north of Fort MacKay.

Figure 9.16.2. Aerial photograph showing location of the Pierre River sections near the mouth of the Pierre River and the Athabasca River.



*Complete Description in Appendix 3.

Figure 9.16.3. Schematic representation of the measured Pierre River Mouth (Lower) Section (UTM 462150E, 6367150N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.16.4a. Overview of the lower portion of the Pierre River Mouth (Lower) Section on the Athabasca River, north of Fort MacKay.

Figure 9.16.4b. Coarse-grained, cross-bedded sand at the base of the Pierre River Mouth (Lower) Section on the Athabasca River, north of Fort MacKay.

9.17 Pierre River Mouth (Upper) Section

Map Coordinates: 74E/5 Bitumount, UTM 462230E, 6367250N.

Location and Access: This section is located at the northern end of the Bitumount map sheet, along the west bank of the Athabasca River at the mouth of Pierre River (Figure 9.16.1, 9.16.2). Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from the landing at the Fort MacKay settlement. This section is located about 100 - 200 m downstream from the Pierre River Mouth (Lower) Section, and starts about 3/4 up the hill side in a small overhang-bluff section that faces the Athabasca River. A steep scree slope extends from the base of the section down to river level. The easiest access is to climb up the treed slope from the base of the Pierre River Mouth (Lower) Section. This cutbank is very well exposed and generally accessible (Figures 9.17.2a, b), although as mentioned above the base of the section sits on a steep scree slope that extends down to river level.

Keynote things to see:

- Stacked coarsening-upward successions comprising vertical accretion abandoned channel (? drowned estuary), sand flat, marine bay-fill and near shore sediments;
- Excellent trace fossils, including *Planolites*, *Skolithos*, *Gyrolithes*, and *Ophiomorpha*.

Description: At the base of the section is a 1 to 2 m thick, coarsening-upward, sandy mudstone/muddy sand with a high degree of bioturbation (Figures 9.17.1, 9.17.2d). Burrows include *Planolites*, *Skolithos*, and, at the northern end of the outcrop face, excellent *Ophiomorpha* (Figures 9.17.2e, f). Another two coarsening-upward units of burrowed muddy siltstone/silty mudstone overlie this basal unit, each capped by rippled and trough cross-bedded sand. Burrow types include escape traces, *Gyrolithes* and *Skolithos* in the sands, and the horizontal *Planolites* within the mudstone/siltstone. At the top of the exposure is discontinuous interbedded sand and sandy mudstone, locally sideritized, capped by burrowed rippled sand, with *Skolithos* traces. Rare wave-ripples occur within laminated muddy sand at the top of the section (Figure 9.17.2c). In general, the bedding style at this outcrop is even-bedded, with few cross-cutting relationships.

Interpretation: The coarsening-upward successions are all burrowed, and towards the base of each succession are heavily bioturbated or churned. The burrow types are more diverse, compared with other outcrops of the McMurray Formation, including *Skolithos* and *Ophiomorpha*. The occurrence of these two types of trace fossils are most characteristic of the *Cruziana* ichnofacies, that often forms in subtidal, loose substrates, with moderate energy conditions in shallow water. The occurrence of the stacked coarsening-upward successions may indicate progradation within drowned estuaries, bays, and lagoons. This section is interpreted as coastal plain sediments of the upper part of the Upper McMurray Formation, in a more marine influenced setting than other outcrops to the south.

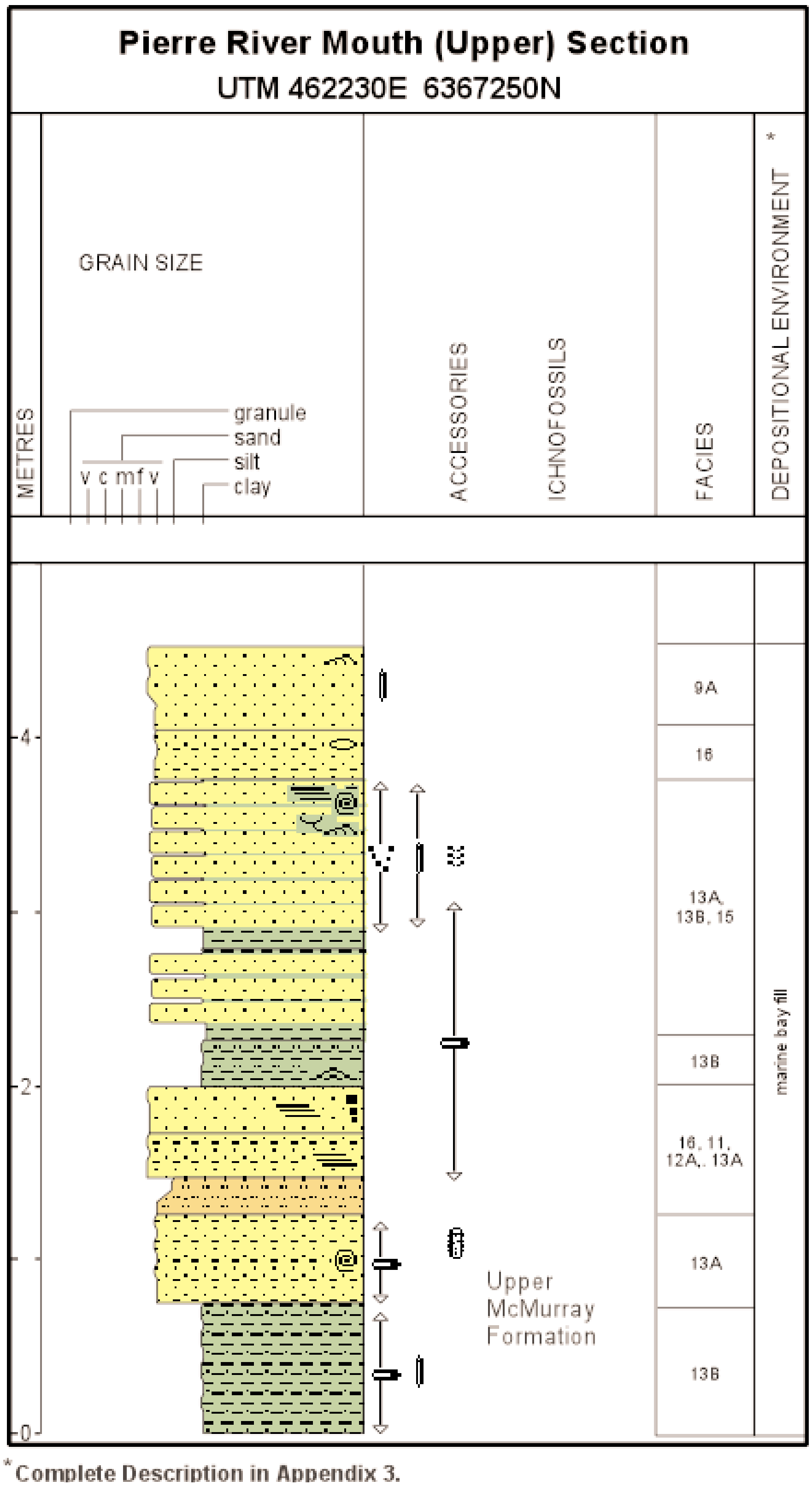


Figure 9.17.1. Schematic representation of the measured Pierre River Mouth (Upper) Section (UTM 462230E, 6367250N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.17.2a. Overview of uppermost section at Pierre River Mouth (Upper) Section, Athabasca River, north of Fort MacKay.

Figure 9.17.2b. Overview of Pierre River Mouth (Upper) Section, Athabasca River, north of Fort MacKay.

Figure 9.17.2c. Wave rippled, laminated, muddy sand at the top of the Pierre River Mouth (Upper) Section, Athabasca River, north of Fort MacKay.

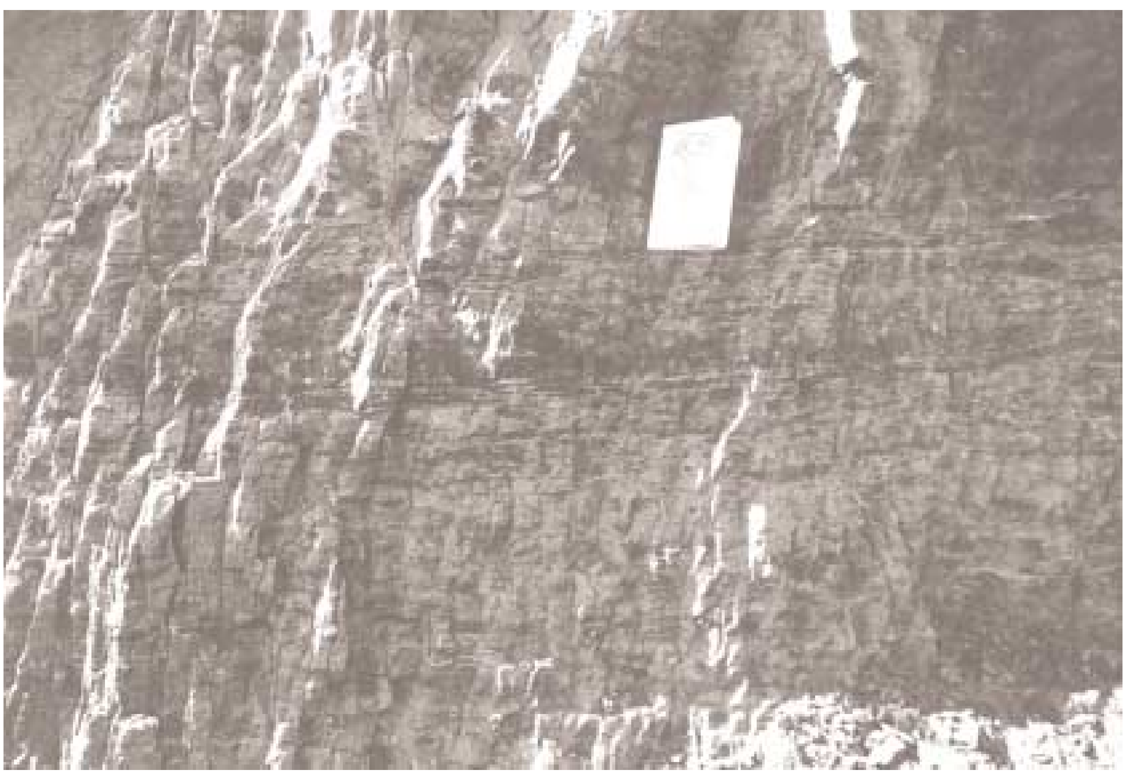


Figure 9.17.2d. Bioturbated sandy mudstone within the upper section at Pierre River Mouth (Upper) Section, Athabasca River, north of Fort MacKay.

Figure 9.17.2e. Burrowed (*Ophiomorpha*?), muddy sand within the uppermost part of the Pierre River Mouth (Upper) Section, Athabasca River, north of Fort MacKay.

Figure 9.17.2f. Possible *Ophiomorpha* burrows within muddy sand at the top of the Pierre River Mouth (Upper) Section, Athabasca River, north of Fort MacKay.

9.18 Eymundson Creek Mouth Section #1

Map Coordinates: 74E/5 Bitumount, UTM 465500E, 6371500N.

Location and Access: This section is located at the northern end of the Bitumount map sheet, along the west bank of the Athabasca River about 800 m upstream of the mouth of Eymundson Creek (Figures 9.18.1, 9.18.2), near Clauson's Landing on the Athabasca River. Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from the landing at the Fort MacKay settlement. This cutbank is very well exposed and generally accessible (Figures 9.18.4a, b).

Keynote things to see:

- Stacked estuarine and fluvial channel sediments;
- Rare organic mudstone interbeds;
- Thin (<0.25 m) Quaternary loess at the top of the section.

Description: At the very base of the section is 3 to 4 m of trough and ripple cross-bedded sand, with scattered mudstone-intraclasts (Figure 9.18.3). A small wedge of rippled sand contains organic mudstone that was sampled for biostratigraphic dating (Figure 9.18.4b). The top of this organic unit has convolute lamination (Figure 9.18.4c, d). Next are a series of stacked planar tabular and trough cross-bedded sands, with internal scours, dispersed mudstone-intraclasts and carbonaceous debris (Figure 9.18.4e). A 0.1 m thick thinly-laminated shaly mudstone caps the McMurray succession. A light-tan, silt unconformably overlies the McMurray Formation, and is interpreted as Quaternary loess.

Interpretation: Convolute lamination and burrowing are rare, but do occur in the lower part of the section. The lowermost 7.5 m of sediment is interpreted as estuarine-channel deposits of the Upper McMurray Formation. The uppermost 2 to 3 m of the McMurray succession lacks any burrow structures, is coarser-grained, pebbly cross-bedded sand, which may be either high-energy estuarine- or fluvial-channel deposits. As with many of the other Athabasca River sections, the face of this outcrop shows complex vertical and lateral facies transitions.

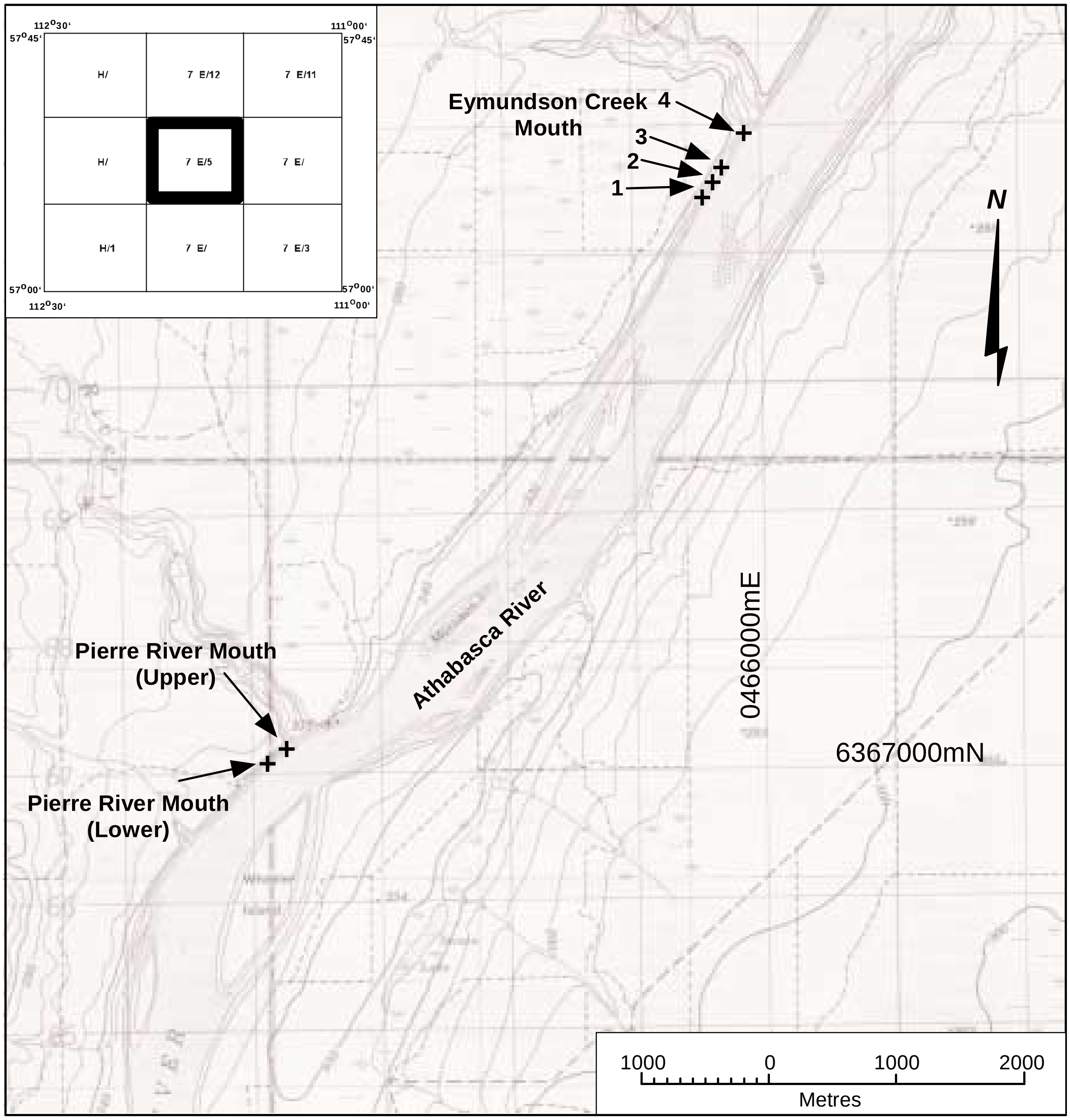


Figure 9.18.1. Map showing access to the Pierre River and Eymundson Creek sections along the west bank of the Athabasca River, north of Fort MacKay.

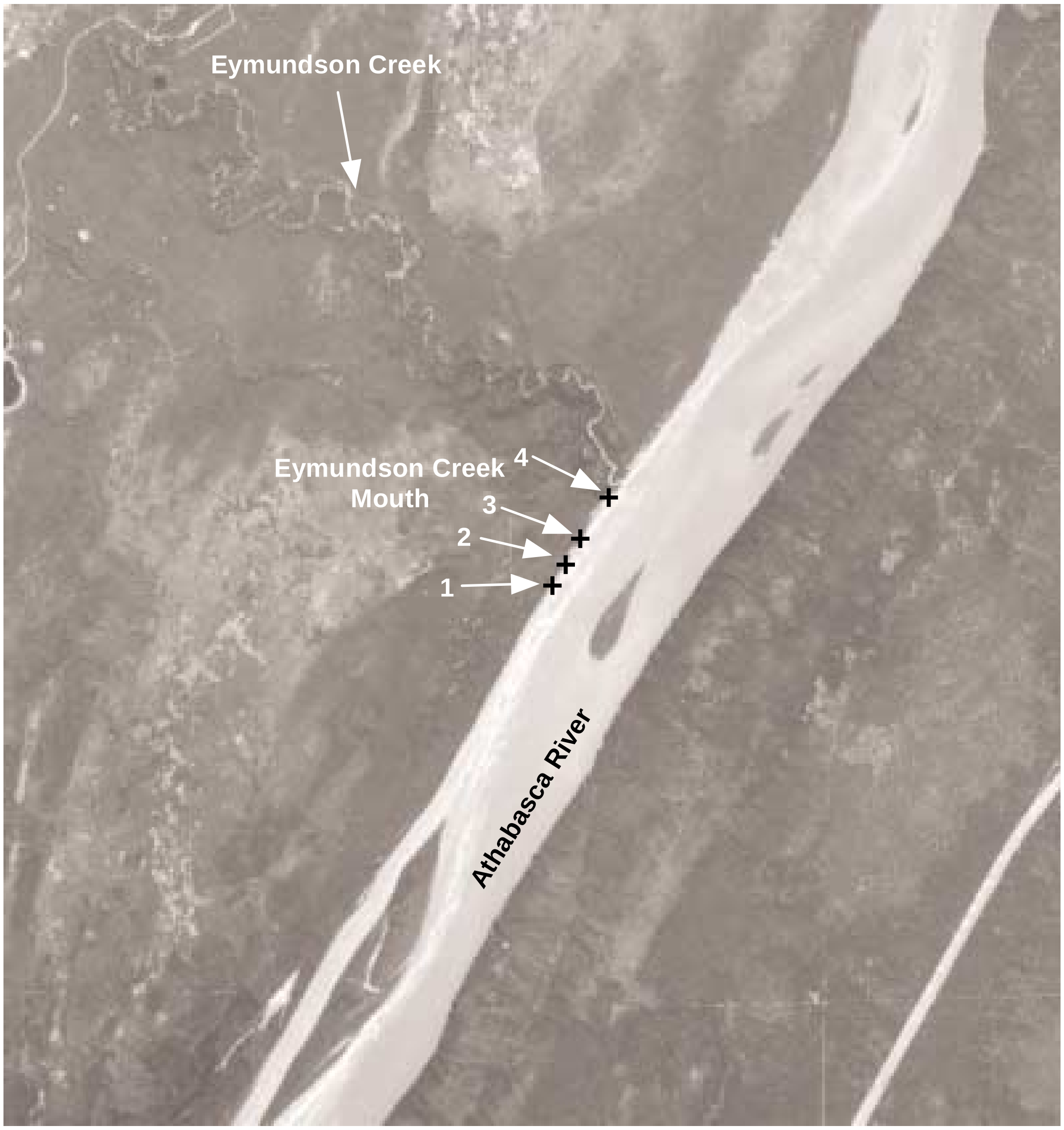
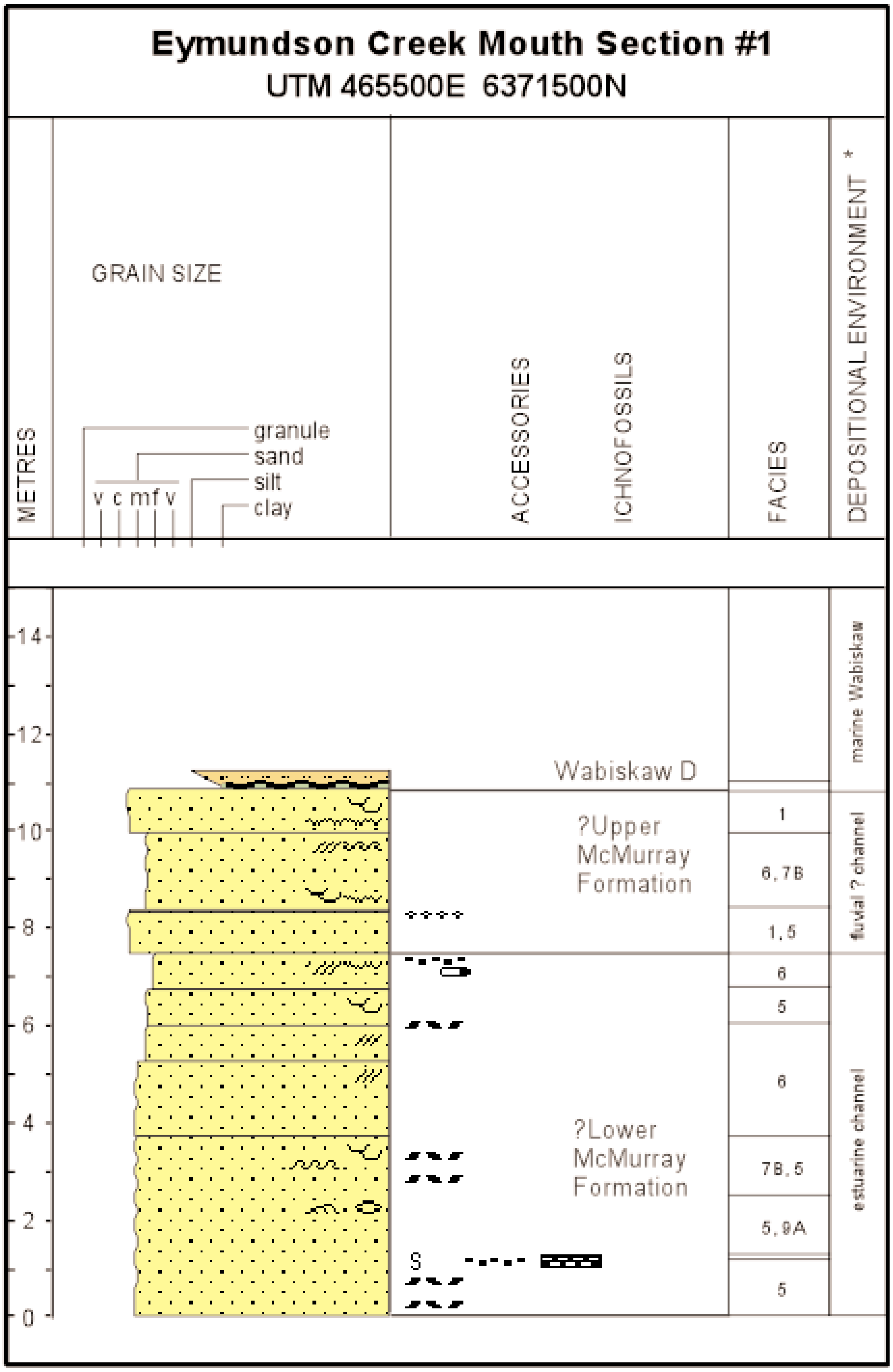


Figure 9.18.2. Aerial photograph showing location of the Eymundson Creek Mouth Sections near the mouth of the Eymundson Creek and the Athabasca River north of Fort MacKay.



*Complete Description in Appendix 3.

Figure 9.18.3. Schematic representation of the measured Eymundson Creek Mouth Section #1 (UTM 465500E, 6371500N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.18.4a. Eymundson Creek Mouth Section #1, Athabasca River, north of Fort MacKay.

Figure 9.18.4b. Trough cross-bedded sand overlain by high angle, planar tabular cross-bedded sand (McMurray Formation), Eymundson Creek Mouth Section #1, Athabasca River, north of Fort Mackay.

Figure 9.18.4c. Inclined, toeset rippled sand (trough cross-bedded) (?Lower McMurray Formation) disconformably overlain by planar laminated sand and burrowed, current rippled sand (?Upper McMurray Formation), Eymundson Creek Mouth Section #1, Athabasca River, north of Fort MacKay.

Figure 9.18.4d. Small scale soft sediment/load structure within pinstriped, fine grained sand (McMurray Formation), Eymundson Creek Mouth Section #1, Athabasca River, north of Fort MacKay.

Figure 9.18.4e. Large scale soft sediment deformation within fine grained, pinstriped sand (McMurray Formation), Eymundson Creek Mouth Section #1, Athabasca River, north of Fort Mackay.

9.19 Eymundson Creek Mouth Section #2

Map Coordinates: 74E/5 Bitumount, UTM 465600E, 6371600N

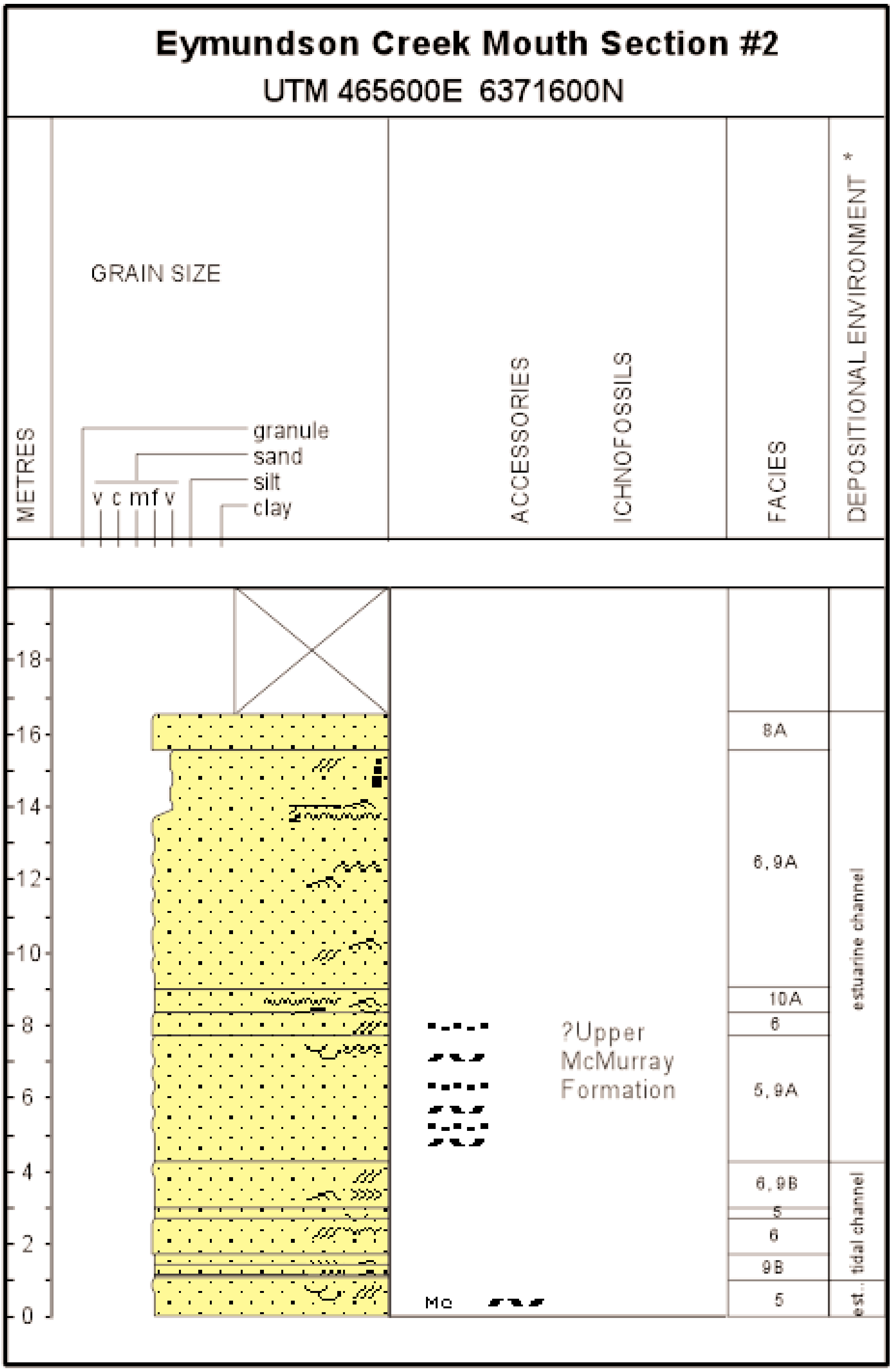
Location and Access: This section is located at the northern end of the Bitumount map sheet, along the west bank of the Athabasca River about 600 m upstream of the mouth of Eymundson Creek (Figures 9.18.1, 9.18.2), near Clauson's Landing on the Athabasca River. Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from the landing at the Fort MacKay settlement. This cutbank is very well exposed and generally accessible (Figure 9.19.2a), except for the topmost 4 m of outcrop that is too steep to climb.

Keynote things to see:

- Stacked estuarine and tidal channel sediments;
- Excellent dewatering structures within large-scale convolute lamination and oversteepened cross-bedding;
- Reverse-flow ripples and herringbone cross-beds on toesets of larger scale, planar tabular and planar tangential cross-beds.

Description: At the base of the section is 3 to 4 m of planar tabular and planar tangential cross-bedded sand, with scattered mudstone-intraclasts (Figure 9.19.1). Reverse-flow ripples commonly occur along the toesets of larger cross-beds. Overlying this unit is 2 to 3 m of large-scale, trough cross-bedded, medium- to fine-grained sand. Some of the cross-bedding is oversteepened, with abundant dewatering structures, including convolute- lamination, dish structures, and fluid-escape tubes. Small-scale planar tabular cross-bedded sands, with reverse-flow toeset ripples (Figure 9.19.2b), cut into the dewatering structures. Upsection, the cross-bedded sand becomes coarser-grained and thick-bedded. Cross-bedding features are complex and change abruptly along-strike. Thick-bedded, planar tabular and planar tangential units grade into wavy-bedded sands, with reverse flow ripples and abundant carbonaceous debris. Internal erosional surfaces are common, but it was impossible to map the geometry of these due to the steepness of the outcrop face. Near the top of the thick-bedded sand is an increase in the abundance of sideritized mudstone-intraclasts, and a slight fining-upwards in grain size. A 1 m thick massive sand caps the measured section.

Interpretation: The very thick bedding style, complex interfingering of different cross-bedding types, and the common occurrence of large-scale dewatering structures indicates very rapid, and complex sedimentation patterns under high-energy conditions. No burrows were noted. A fining-upward in grain size was noted near the top of the measured section; otherwise grain size was uniform throughout the section. Reverse-flow ripples are common on toesets of the larger-scale planar tabular/planar tangential features. This suite of physical sedimentary features suggests that the units at this outcrop were deposited under mainly channeled, high-energy conditions, in which reversing tidal flows were common. The paleoenvironmental interpretation is that these sediments are part of a tide-dominated estuarine channel system within the Upper McMurray Formation.



*Complete Description in Appendix 3.

Figure 9.19.1. Schematic representation of the measured Eymundson Creek Mouth Section #2 (UTM 0465600E, 6371600N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.19.2a. Eymundson Creek Mouth Section #2, Athabasca River, north of Fort MacKay.

Figure 9.19.2b. Large scale, trough cross-bedded sand overlain by small-scale, high-angle planar tabular cross-bedded sand at the base of Eymundson Creek Mouth Section #2, Athabasca River, north of Fort MacKay.

9.20 Eymundson Creek Mouth Section #3

Map Coordinates: 74E/5 Bitumount, UTM 465700E, 6371800N

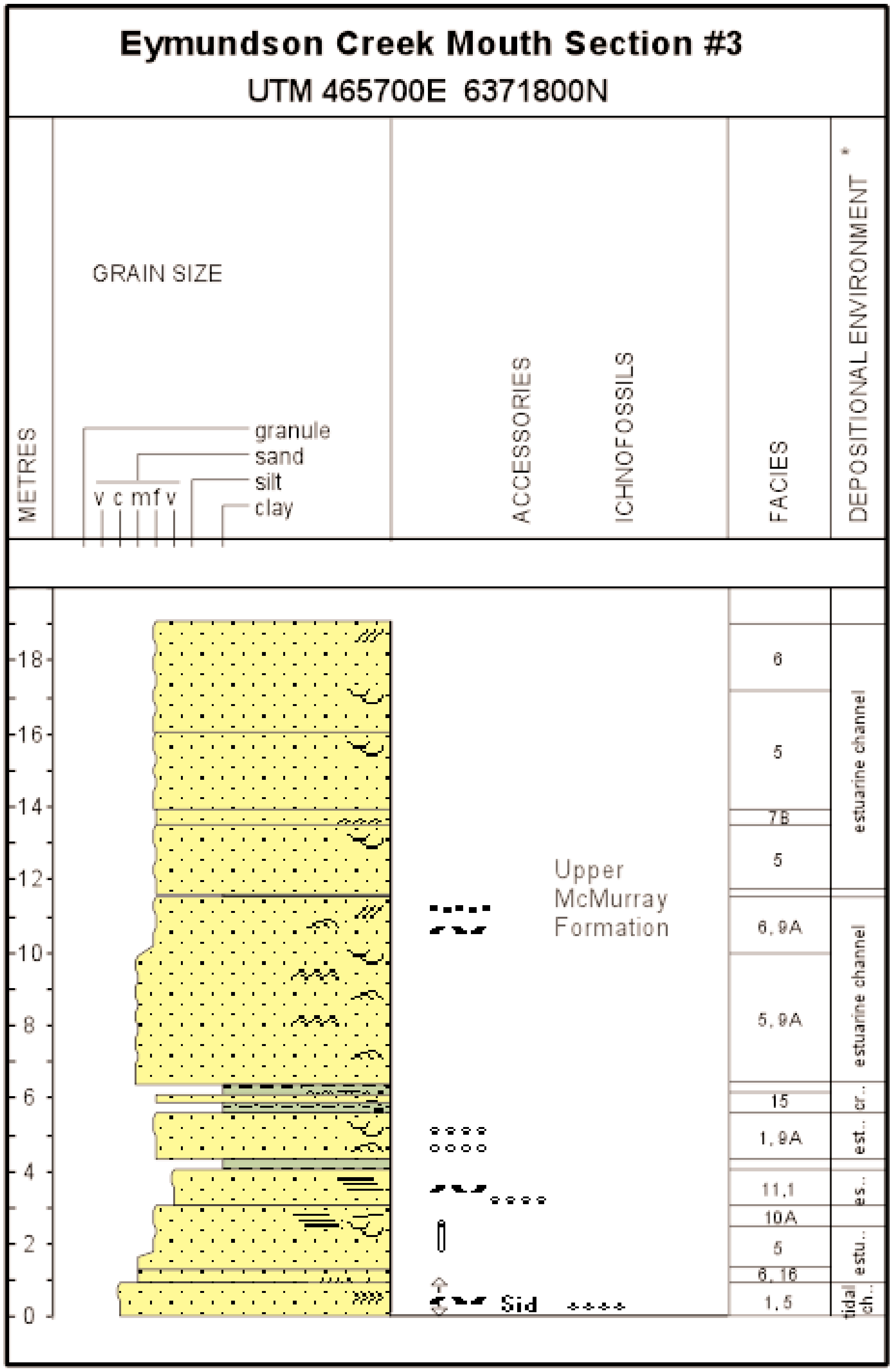
Location and Access: This section is located at the northern end of the Bitumount map sheet, along the west bank of the Athabasca River about 400 m upstream of the mouth of Eymundson Creek (Figures 9.18.1, 9.18.2), near Clauson's Landing on the Athabasca River. Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from the landing at the Fort MacKay settlement. This cutbank is very well exposed and easily accessible (Figure 9.20.2).

Keynote things to see:

- Stacked estuarine and tidal channel sediments;
- Minor estuarine point bar and crevasse splay channel deposits;
- Apparently bi-directional cross-bedding (north- and south-directed); about midway upsection are eastward-directed planar tabular cross-beds within a thick estuarine channel succession.

Description: At the base of the section is 1 m of trough cross-bedded, pebbly coarse-grained sand, with large-scale herringbone structures and scattered mudstone-intraclasts (Figure 9.20.1). Overlying the unit with the herringbone structures is a large-scale (4 to 5 m thick), fining-upward sequence of trough to parallel and low angle, pebbly to sandy inclined heterolithic stratification, with dispersed mudstone-intraclasts, organic detritus, convolute lamination, and wavy bedding. The rest of the succession consists of cross-bedded medium-grained sand, with very rare mudstone-intraclasts or coaly debris. Internal erosional surfaces and channel-fills are common. Channel-fill sands are cross-bedded, with convolute-lamination, ripples, troughs and planar tabular cross-bedding. Burrows are rare, mainly the vertical *Skolithos* types, within the finer interbeds at the base of the section.

Interpretation: The thick bedding style, complex interfingering of different cross-bedding types, and the common occurrence of convolute lamination indicates very rapid, and complex sedimentation patterns under high-energy conditions. Rare burrows were noted. This suite of physical sedimentary features suggests that the units at this outcrop were deposited within high-energy, tidal and estuarine channels. The finer-grained interbeds towards the base of the section may be overbank and crevasse splay deposits associated with the lower tidal and estuarine channel fill units. All units are interpreted as part of the Upper McMurray Formation.



*Complete Description in Appendix 3.

Figure 9.20.1. Schematic representation of the measured Eymundson Creek Mouth Section #3 (UTM 465700E, 6371800N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.20.2. Overview of Eymundson Creek Mouth Section #3, Athabasca River, north of Fort MacKay.

9.21 Eymundson Creek Mouth Section #4

Map Coordinates: 74E/5 Bitumount, UTM 465959E, 6371974N

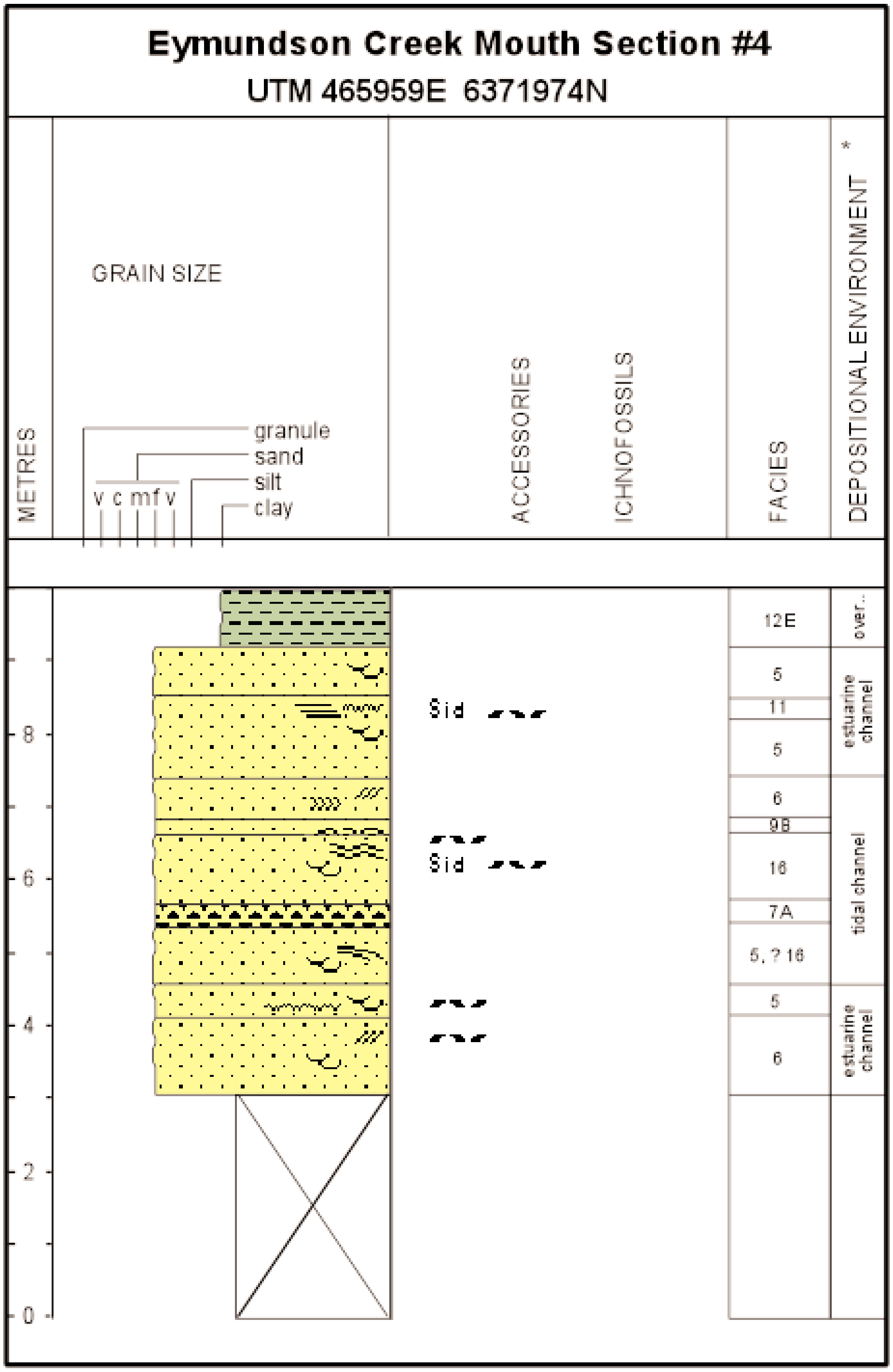
Location and Access: This section is located at the northern end of the Bitumount map sheet, along the west bank of the Athabasca River about 20 m upstream of the mouth of Eymundson Creek (Figures 9.18.1, 9.18.2), near Clauson's Landing on the Athabasca River. Access the section by boating downstream from Fort McMurray, the barge landing on the Athabasca River, or by gaining access to the Athabasca River from the landing at the Fort MacKay settlement. Recent slumping has exposed an excellent cutbank section at this site (Figure 9.21.2). The measured section starts approximately 3 m above river level (Figure 9.21.1).

Keynote things to see:

- Stacked estuarine and tidal channel sediments;
- 0.5 - 1 m thick mudstone intraclast breccia in the middle of the section;
- About a 1 m thick overbank cap to the section

Description: The base of the section starts with thick- to medium-bedded, trough and planar tabular cross-bedded sand, with common internal scours and dispersed mudstone- intraclasts. A 0.5 to 1 m thick mudstone-intraclast breccia overlies the basal cross-bedded sand. This breccia occurs at the base of a channel-fill sand, that internally has wavy, discontinuous laminations, trough-, planar tabular and herringbone cross-bedding. The next succeeding channel-fill sand lack the herringbone cross-bedding but does show good trough cross-bedding, planar lamination, and internal scours. The top of the channeled succession is abruptly overlain by a thinly laminated silty mudstone/mudstone that lacks bioturbation features.

Interpretation: The very thick bedding style, common occurrence of internal scours, along with the predominance of trough and planar tabular cross-bedding, indicates sedimentation under high-energy conditions. The middle channel-fill with large-scale herringbone cross-bedding and wavy bedding indicates a tidal influence. No burrows were noted. The sediments at this outcrop section are interpreted as being deposited within interfingering and stacked estuarine and tidal channels. The channels were abruptly abandoned, with only fines deposited rapidly as finely laminated, overbank siltstone and mudstone. All deposits are interpreted as belonging to the Upper McMurray Formation.



*Complete Description in Appendix 3.

Figure 9.21.1. Schematic representation of the measured Eymundson Creek Mouth Section #4 (UTM 465959E, 6371974N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 9.21.2. Overview of Eymundson Creek Mouth Section #4, Athabasca River, north of Fort MacKay.

10.0 Steepbank River Outcrops

Map Coordinates: 74E/3 Hartley Creek, UTM 473675E, 6319100N (for Steepbank River Section #3.1)

General Location and Outcrop Selection: Access to the Steepbank River outcrops is by boat and wading from the mouth of the river at its confluence with the Athabasca River. Note: only access the river sections via the river mouth under low water levels. Alternative routes are by private-road access (permission has to be obtained from Suncor Ltd.) to the Steepbank Mine and by hiking down the steep treed slopes to the river level, or by helicopter.

Almost every cutbank along the Steepbank River exposes outcrops within the valley (Figure 10.0.1), whereas up on the muskeg highlands there is little or no outcrop exposed in the meander beds. From air photograph interpretation about 25 outcrops have been identified. Vertical sections of many of these were previously measured and described by Flach (1977; 1984) and published in other field guides or reports (cf. Flach and Mossop, 1985; Mossop *et al*., 1982; Mossop and Flach, 1983; Pemberton *et al.*, 1982; Wightman and Pemberton, 1997; Wightman *et al*., 1992, 1997). Recent excavations at the Suncor Steepbank Mine show that lateral variation of sand versus mud-filled channel plugs are locally very significant in the area (Figure 10.0.3).

During the present study four selected outcrops were remeasured to identify facies in light of the present classification scheme (Appendix 2) and to document vertical and lateral facies variation. Numbering of outcrops on the Steepbank River follows that used by Flach (1977, 1984) and Flach and Mossop (1985). The following outcrops are described: Steepbank River #3, Steepbank River #4, Steepbank River #7, and Steepbank River #9 (Figures 10.0.1 and 10.0.2). These Steepbank River sections also provide outcrop control for synthetic seismic modeling and subsurface facies modeling in the area (cf. Langenberg *et al*., 1999, 2001; Hein *et al.*, 2001).

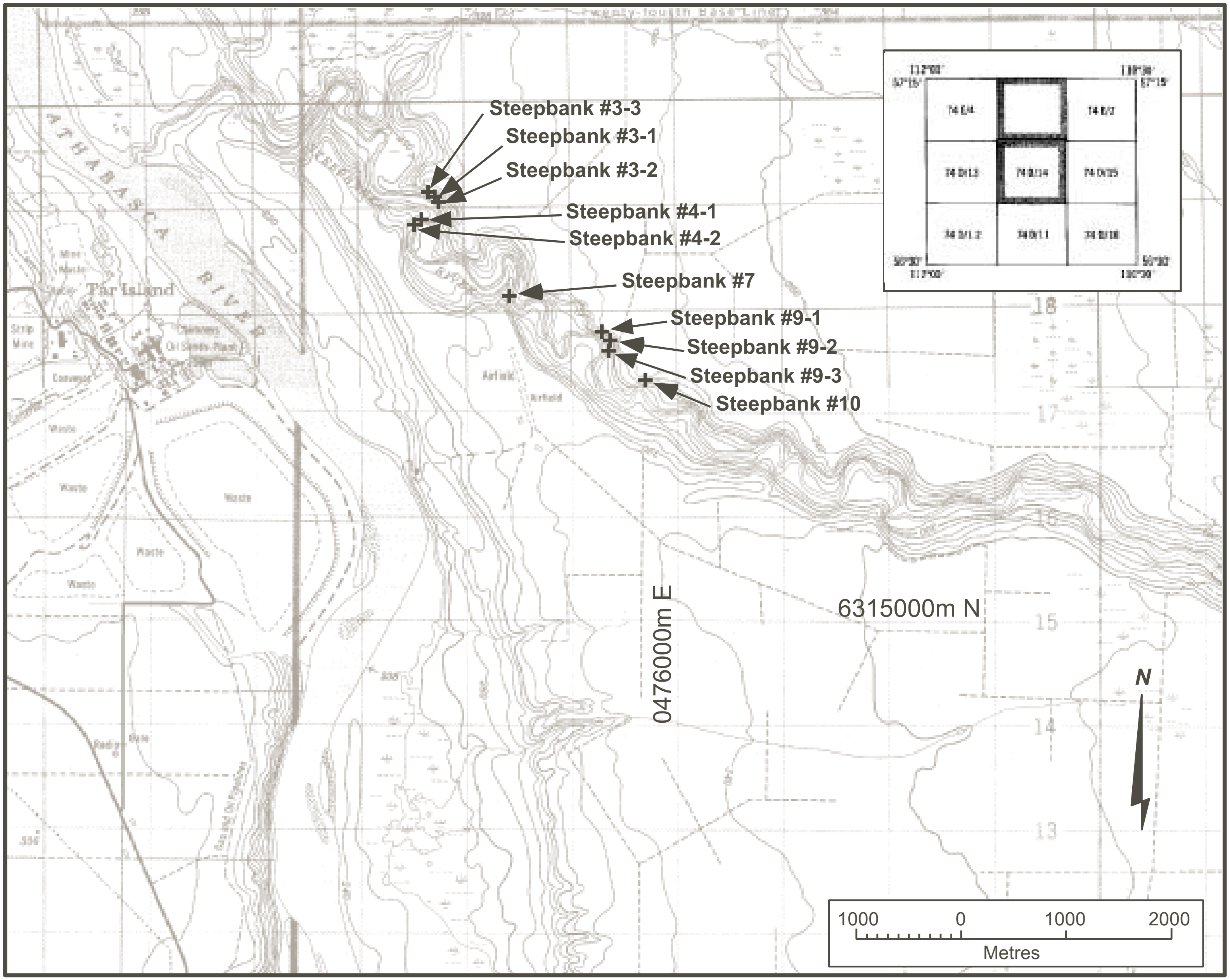


Figure 10.0.1. Detailed map showing location of the outcrop sections measured along the Steepbank River.

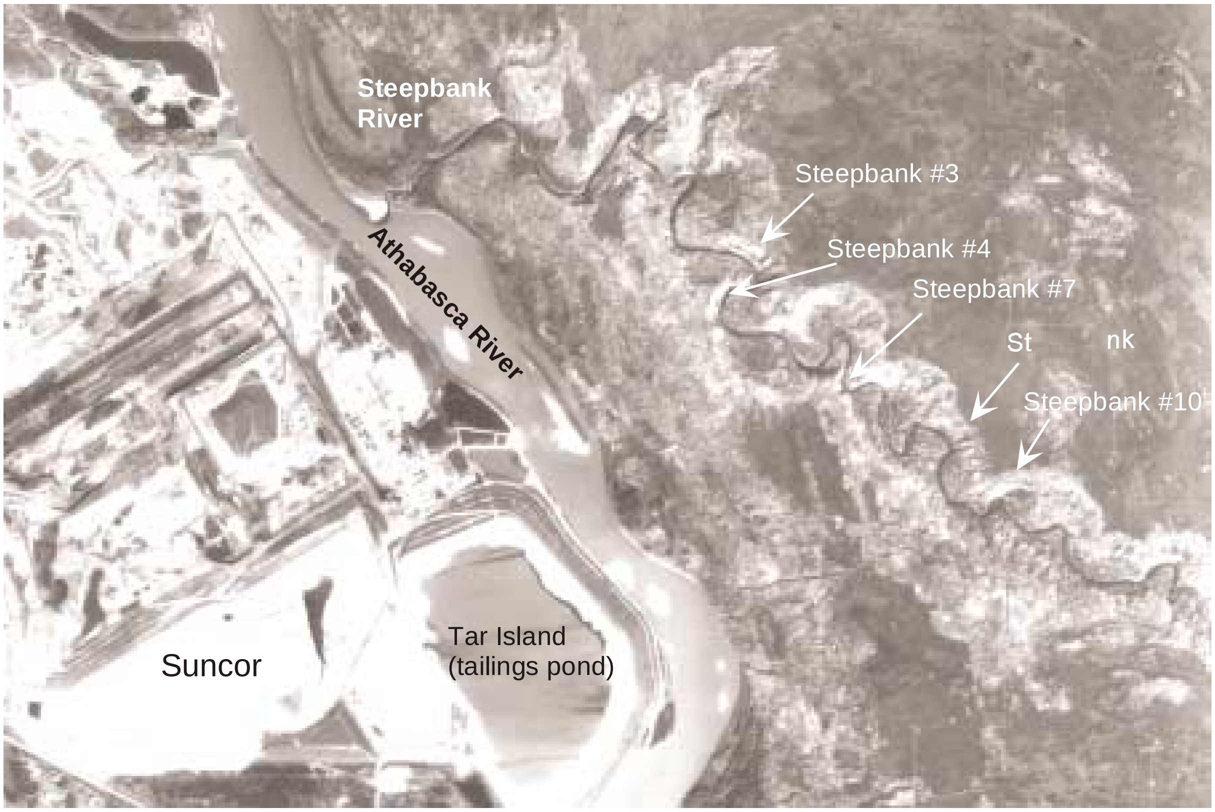


Figure 10.0.2. Aerial photograph showing location of McMurray exposures on the Steepbank River across from the Suncor mine site.

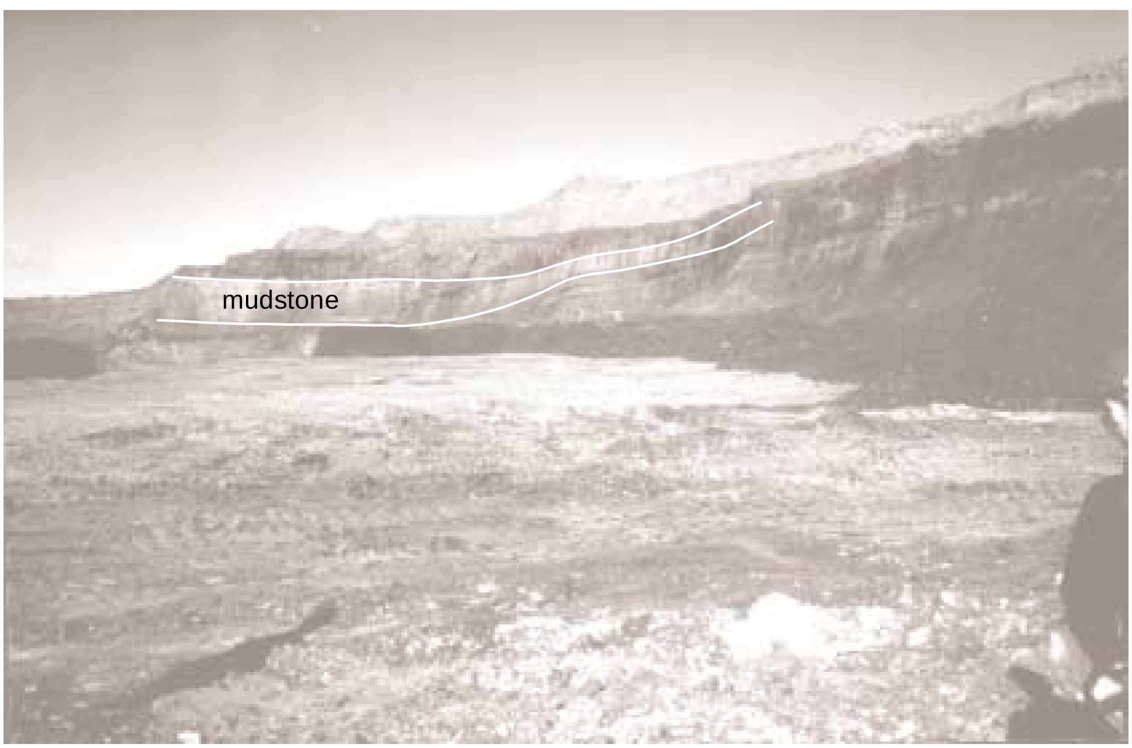


Figure 10.0.3. Mine face displaying muddy abandonment plug within estuarine channel deposits (Suncor Steepbank Mine).

10.1 Steepbank River Sections #3.1, #3.2 and #3.3

Map Coordinates: 74E/3 Hartley Creek, UTM 473675E, 6319100N (for Steepbank River Section #3.1)

Keynote things to see:

- Thick estuarine channel and point bar sediment with rapid facies changes;
- Well-developed cross-bedding and bioturbation features in channel sands;
- Stacked packages of multi-story, low-angle inclined heterolithic stratified sets;
- Contact between the McMurray and Wabiskaw D successions.

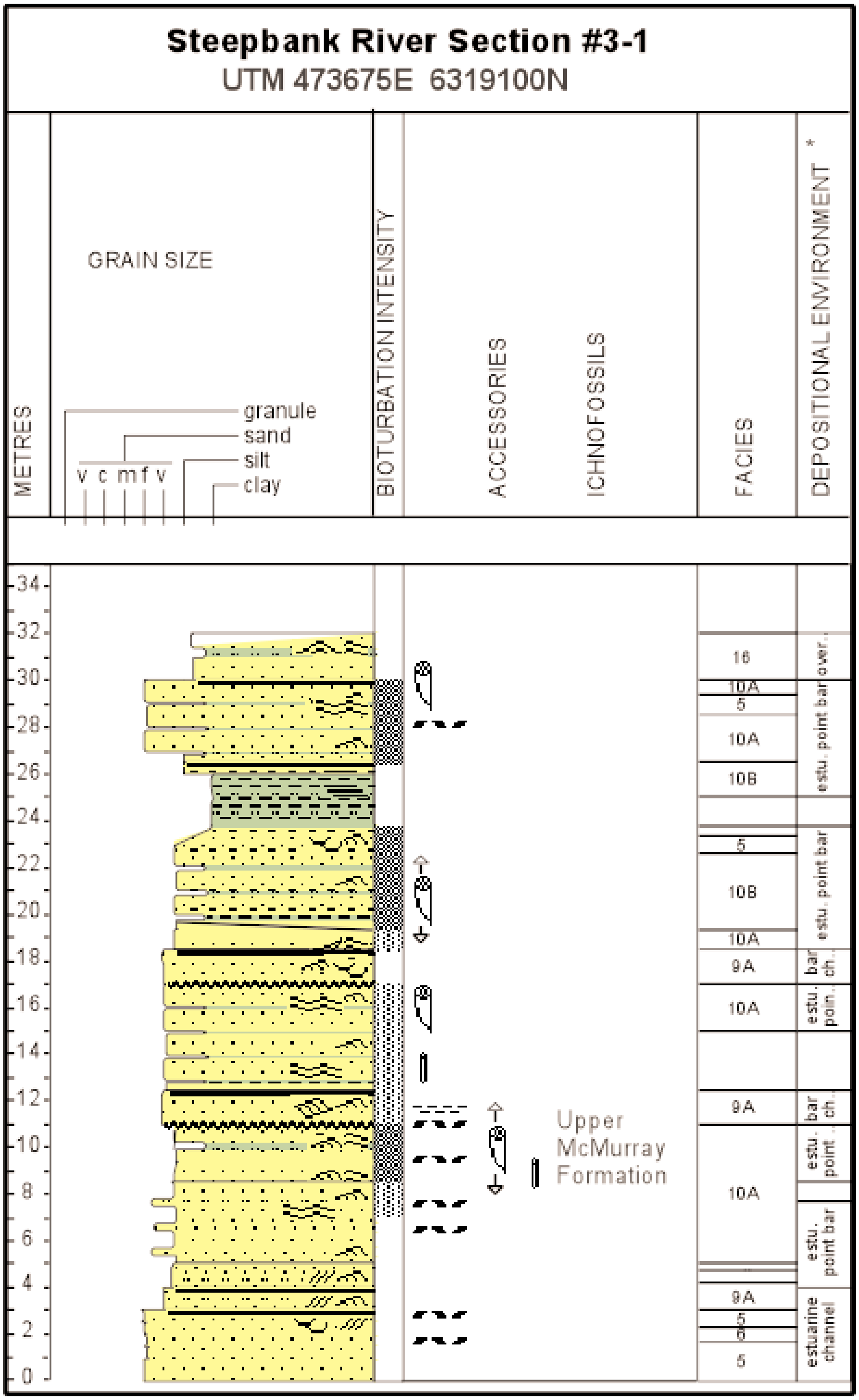
Description: About 22 m of covered section is at the base of Steepbank River Section #3.1 (Figure 10.1.1). The sub-Cretaceous unconformity is exposed in Steepbank River Section #3.2 and Section #3.3 (Figures 10.1.2, 10.1.3, 10.1.4a, b, c). In Section #3.3 thin (about 1 m) massive pebbly-granule sands of the Lower McMurray Formation sit on Devonian limestone (Figure 10.1.3). The Lower McMurray is disconformably overlain by about 40 m of the Upper McMurray Formation. At this outcrop in Section #3.2 no Lower McMurray is preserved, with Upper McMurray sediments sitting on the sub-Cretaceous unconformity (Figure 10.1.2). By contrast, in Section #3.1, the contact with the Devonian is not exposed and the lowest sediment that is exposed belongs to the Upper McMurray Formation (Figure 10.1.1). The Upper McMurray succession at Section #3.3 has notable lateral and vertical alternations of trough cross-bedded and rippled sands, with dispersed mudstone-intraclasts and mudstone-intraclast breccia beds. These grade upwards and laterally into, low-angle inclined heterolithic stratification of burrowed sand and mudstone (Figure 10.1.3, from 1 m to 20.5 m height; Figure 10.1.4b, d). Overlying the low-angle, inclined heterolithic stratified unit is burrowed, mainly massive sand that, in turn, grades vertically into more sets of low-angle, inclined heterolithic stratified burrowed sand and mudstone (Figure 10.1.3, from 20.5 m to 29.25 m height). Upsection the stacked, low-angle inclined heterolithic stratified units are capped by even-bedded sand and mudstone. The interbedded sand/mudstone is burrowed, with wave-formed and swaley cross-bedding, mudstone-intraclasts, and, towards the top, larger-scale cut-and-fill structures. Burrow types are predominantly *Cylindrichnus* in the lower parts of the Upper McMurray, becoming more common upsection, with mainly *Planolites* and *Cylindrichnus* types.

At the base of Section #3.2 is a 5 m thick fining-upward succession from trough cross-bedded fine-grained sand to rippled sand and mudstone, with rare mudstone intraclasts. This is overlain by a 2 m thick mudstone-intraclast breccia, which is capped by a 0.1 m thick ironstone concretionary bed. Overlying the thick sands is 12 m of interbedded sand and mudstone that shows low-angle, inclined heterolithic stratification, dispersed mudstone-intraclasts, and rippled sands. Near the top of the succession is interbedded silty sand /mudstone, with abundant *Cylindrichnus* burrows. The top of the section is inaccessible and cliff forming. However, from the float, it appears to be a unit of heavily- burrowed, rippled to planar tabular cross-bedded, fine-grained sand.

The stratigraphy exposed in Section #3.1 is higher than the successions measured in Section #3.2 and Section #3.3. At the top of Section #3.1 transitions are into thinner and muddier sediments with an abundance of burrows, parallel lamination, lenticular-bedding, wave-ripples and thin mudstone-intraclast breccias. Towards the base of Section #3.1, the lowermost bed is similar to the lower parts of Section #3.2, consisting of thick-bedded, trough and planar tabular cross-bedded, fine-grained sand, with rare mudstone-intraclasts. Less common is burrowed and rippled sand, with *Cylindrichnus* and rare *Skolithos*. Overall the Section #3.1 deposits tend to be muddier and more highly burrowed than Section #3.2 and Section #3.3. Localized sandy cut-and-fill successions incise the muddy, low-angle inclined heterolithic stratification. Common vertical and lateral variability of facies within the sands and mudstones occurs at the Steepbank #3 outcrop, with complex interfingering of facies, in what initially may be interpreted (from a distance) to be a single set of large-scale, low-angle inclined heterolithic stratification.

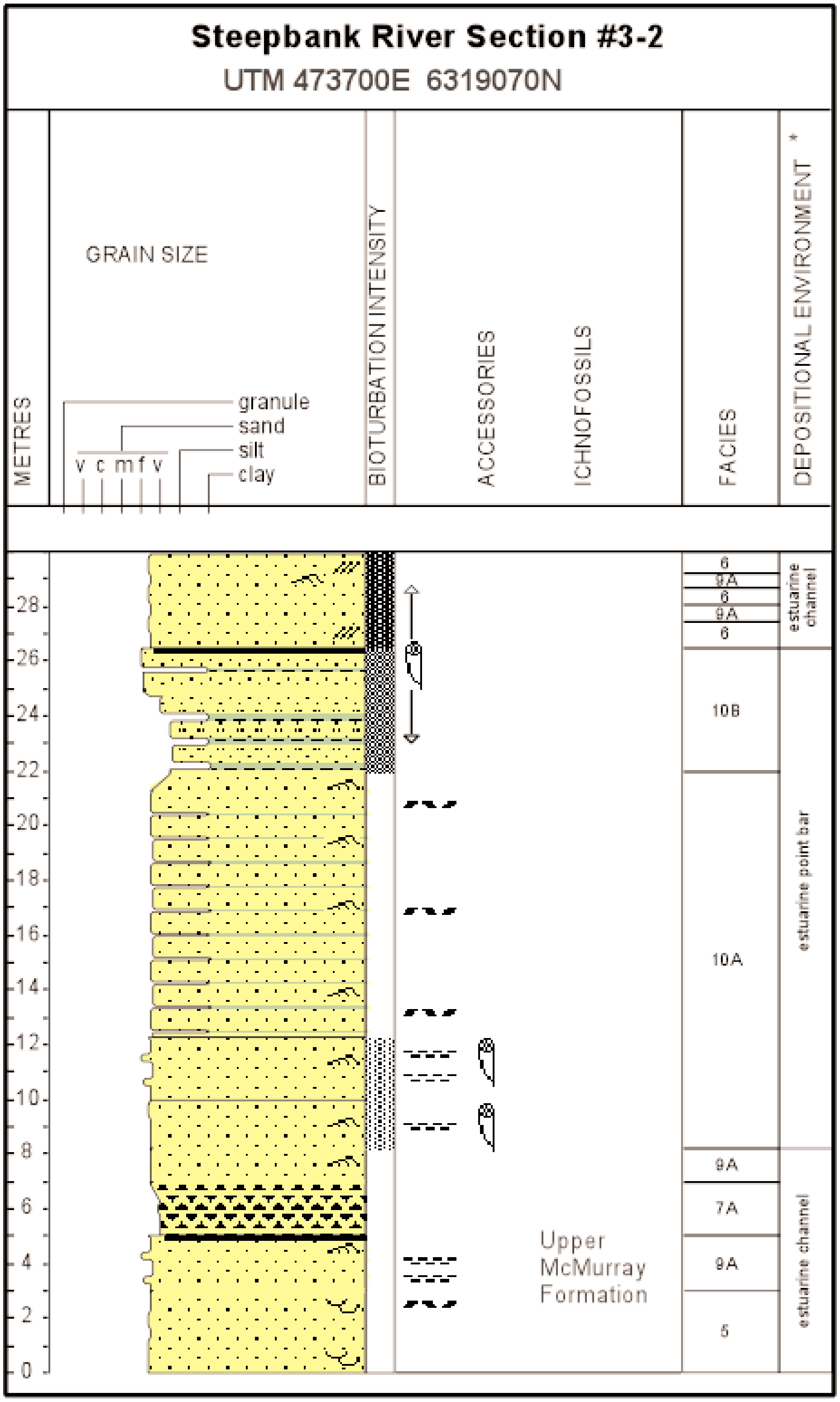
Unconformably overlying the McMurray Formation at this section is a black, wavy, discontinuous silty mudstone, with marine traces (including *Diplocriterion*); abundant reworked organic debris, and wave-ripples. This is the Wabiskaw D of the Clearwater Formation that unconformably overlies the McMurray Formation in this area.

Interpretation: The fining-upward successions from trough cross-bedded and massive sands > mudstone-intraclast breccias > low-angle, inclined heterolithic stratified sand/mudstone are interpreted as reflecting deposition from estuarine-channel/cutbank > estuarine point-bar/point-bar top > overbank settings. These fining-upward successions are multiply stacked upon one another, and also change laterally into one another along strike. The upper part of Section #3.3 with the micaceous sand, wave-formed structures, more even-bedding style, and increased intensity of bioturbation, is interpreted as being from a mixed sand/mudflat environment, with more of a brackish influence than the lower estuarine system. Localized sandy cut-and-fill successions incise the muddy, low-angle inclined heterolithic stratification at Section #3.3, and these are interpreted as bar-chute deposits. The topmost part of the succession may represent off-channel bay-fill or vertical accretion abandoned channel-fill successions that cap the stacked lateral accretion point bar successions (Figure 10.1.3, from 30 m to 32 m height). The complex interbedding of estuarine channel and point bar sediments in the coarser-grained parts of the succession, and the incision of bar-chute channel sands into muddy point bar sediments, all show evidence of sand-on-sand contacts and the absence of persistent mudstone capstones over the stacked estuarine channel and point bar units.



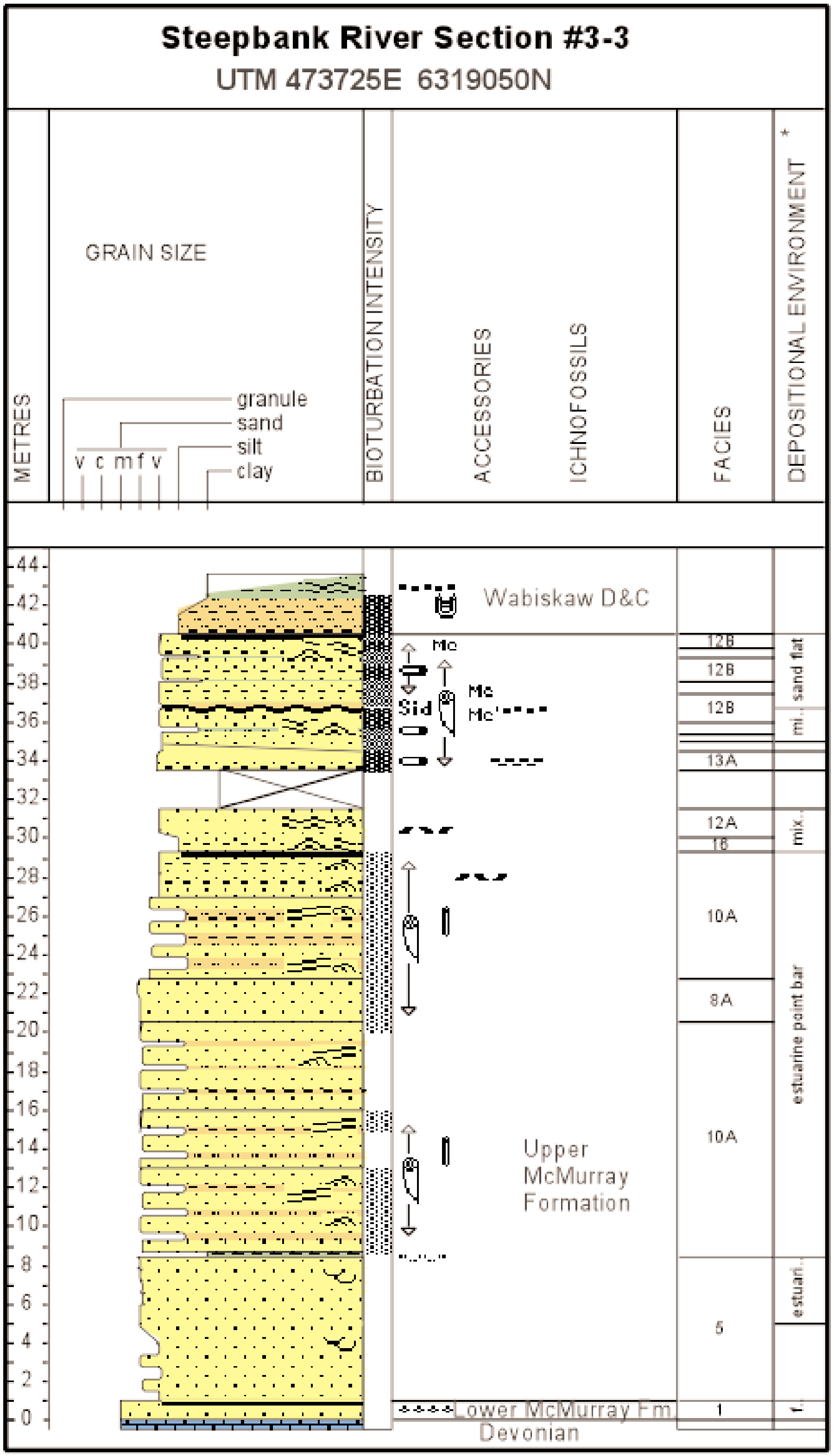
*Complete Description in Appendix 3.

Figure 10.1.1. Schematic representation of the measured Steepbank River Section #3-1 (UTM 473675E, 6319100N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 10.1.2. Schematic representation of the measured Steepbank River Section #3-2 (UTM 473700E, 6319070N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 10.1.3. Schematic representation of the measured Steepbank River Section #3-3 (UTM 473725E, 6319050N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

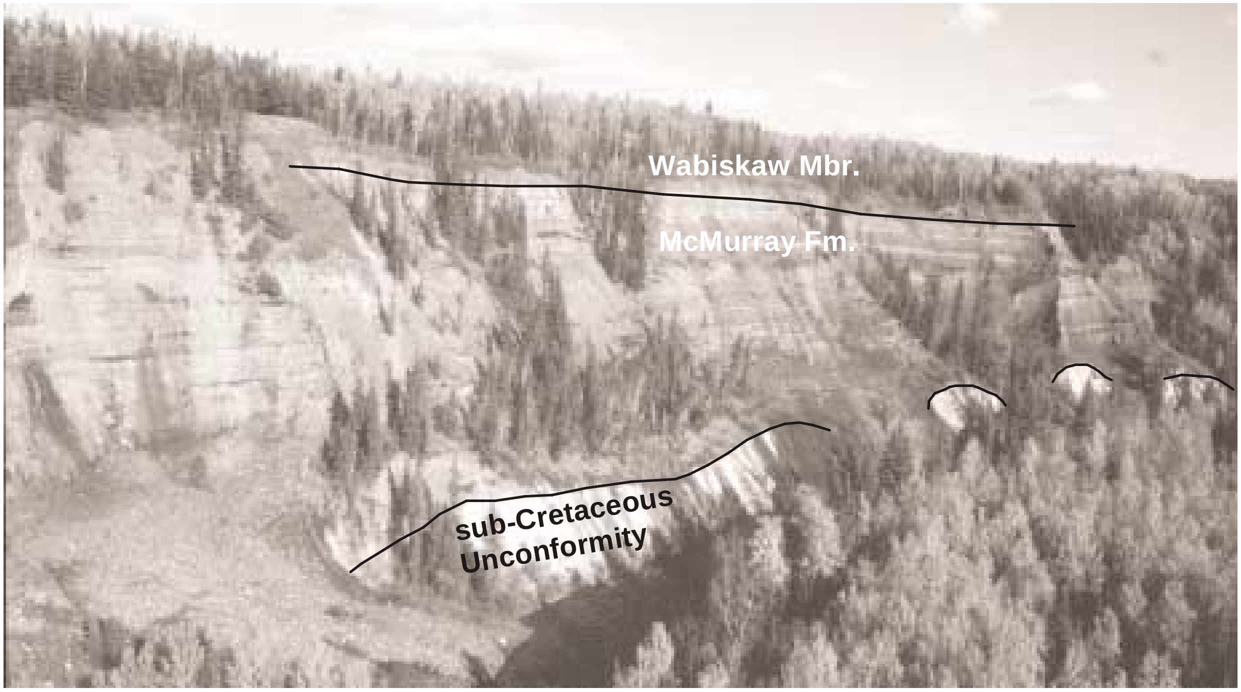


Figure 10.1.4a. Overview of Outcrop #3, showing the Devonian carbonates at the base, sub-Cretaceous unconformity (shown by lower black line), McMurray Formation and overlying Wabiskaw Member of the Clearwater Formation, Steepbank River. About 35 m of vertical section is shown. View to the northeast.

Figure 10.1.4b. Overview of Outcrop #3, showing the Devonian carbonates (white block at the base), overlain by large-scale, inclined heterolithic stratification, showing changing dip directions (Upper McMurray Formation), Steepbank River. About 30 m of vertical section is shown. View to the northeast.

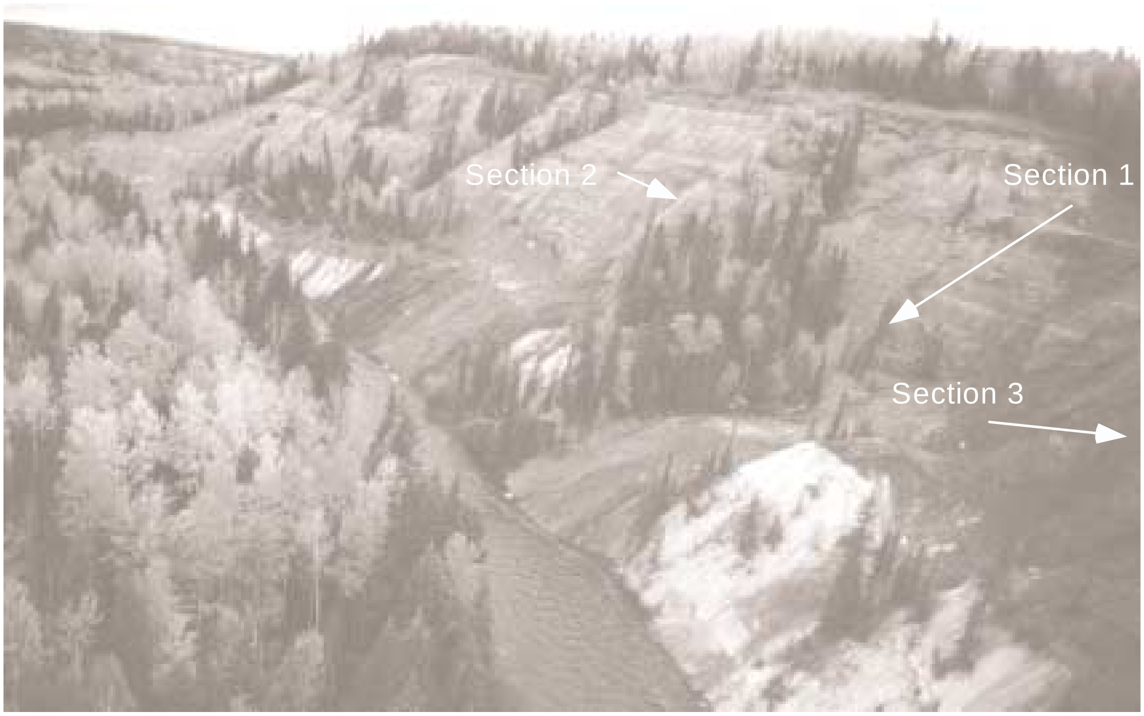


Figure 10.1.4c. Overview of Outcrop #3, showing the Devonin carbonates (white at the base, extending from the lower right corner to the upper left corner of the photo), and McMurray Formation, with access to Sections #3-1 and #3-2 shown by the arrows, Steepbank River.

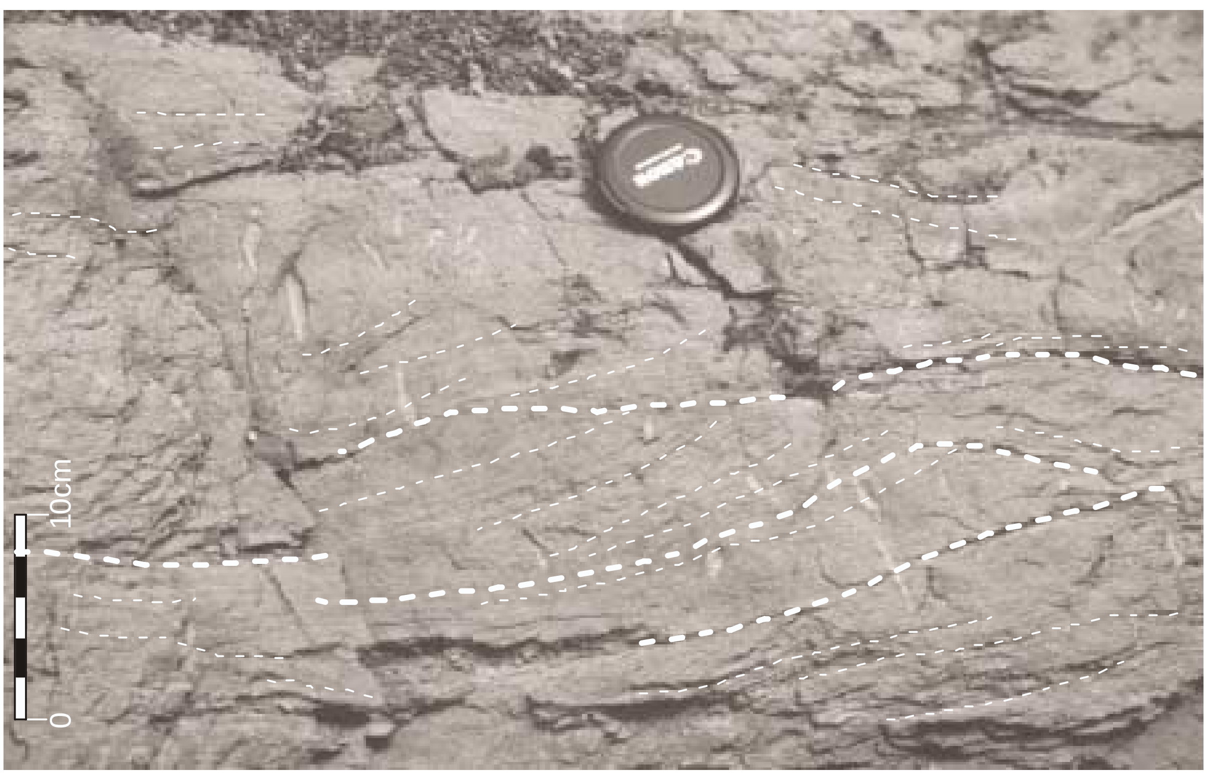


Figure 10.1.4d. Small-scale, trough cross-bedded sand, with in situ *Cylindrichnus* burrows (Upper McMurray Formation), Steepbank River, Section #3.

10.2 Steepbank River Sections #4.1 and #4.2

Map Coordinates: 74E/3 Hartley Creek, UTM 473600E, 6318860N (for Steepbank River Section #4.1)

Keynote things to see:

- Thick estuarine channel and point bar sediment with rapid facies changes;
- Well-developed cross-bedding and bioturbation features in channel sands;
- Stacked packages of multi-story, low-angle inclined heterolithic stratified sets;
- Contact between the McMurray channel sand and Wabiskaw successions.

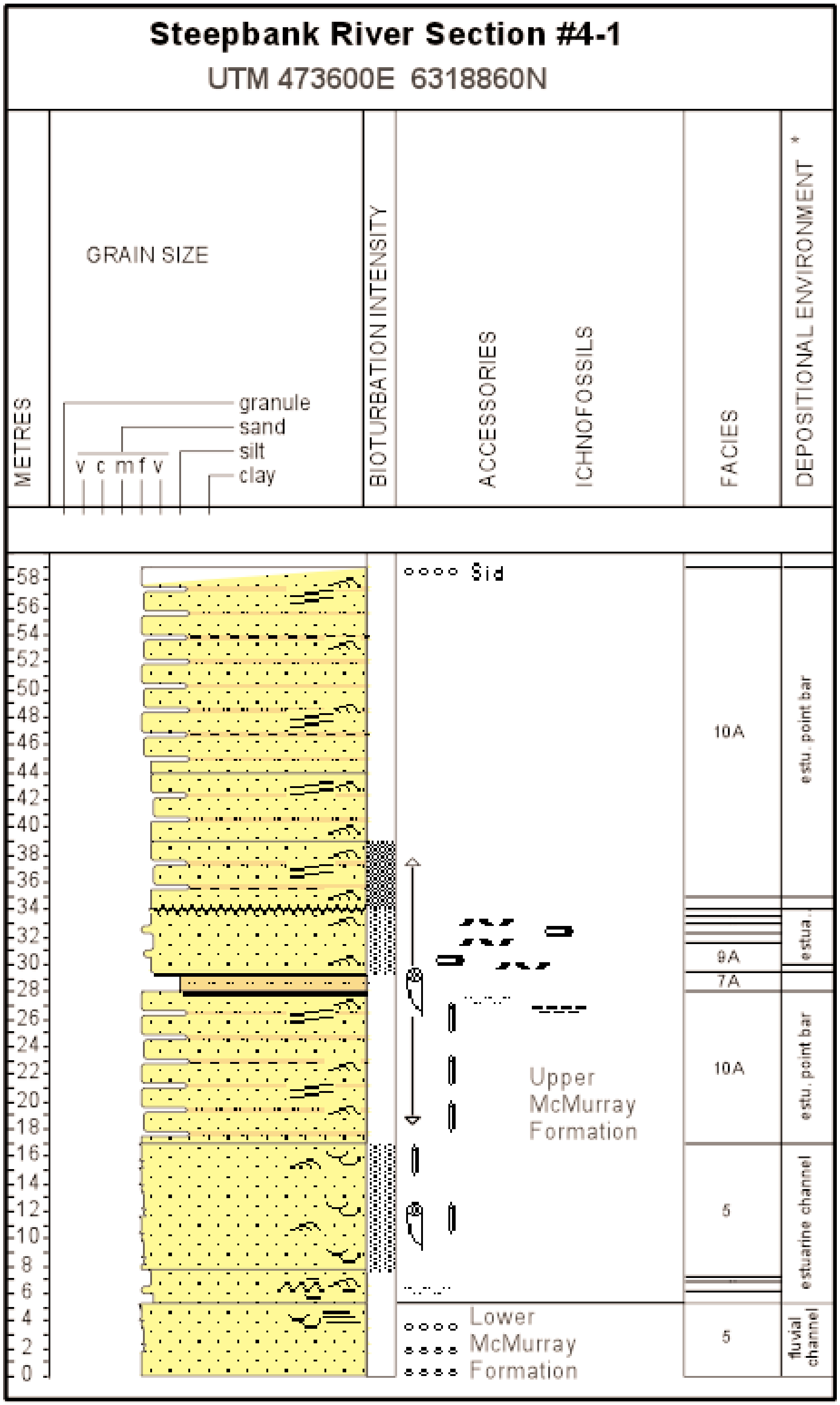
Description: This outcrop (Figures 10.0.1, 10.0.2) shows a well-exposed succession of McMurray channel-fill sands overlain by multiple sets of low-angle, inclined heterolithic stratification, capped by a 5 m thick veneer of Wabiskaw Member sediment. The Wabiskaw succession is generally poorly exposed in the recessive, grassy top of the outcrop (Figure 10.2.3a). The sections at this outcrop start with a thin (5 to 6 m thick), trough cross-bedded, pebbly/granule sand (Figures 10.2.1, 10.2.2 and 10.2.3b). In Section #4.1 about 54 m of Upper McMurray sediment overlies the Lower McMurray unit, whereas in Section #4.2 the contact between the Lower and Upper McMurray is not exposed (Figures 10.2.1 and 10.2.2).

In the Upper McMurray at Section #4.1 there are pronounced interfingering and alternations of the following sediments: trough cross-bedded and rippled sands, mudstone-intraclast breccias, and burrowed, low-angle, inclined heterolithic stratified units of cross-bedded sand and mudstone (Figure 10.2.1, from 5 to 59 m height; Figure 10.2.1). At the base of the Upper McMurray the sediment size is coarse-grained sand, with prominent medium-scale trough cross-bedding (Figure 10.2.3c). Upsection the grain size becomes finer, and the dominant stratification is stacked, multiple sets of low-angle, inclined heterolithic stratification (Figure 10.2.3a). Burrow types are predominantly *Cylindrichnus* and *Skolithos.* Locally, within a rippled sand containing mudstone intraclasts, an abundance of *Planolites* burrows occur with *Cylindrichnus* (Figure 10.2.1, from about 29.5 to 34 m height). The upper part of the McMurray Formation at this section is micaceous, with a local ironstone concretionary bed capping the succession. Reactivation structures and internal scours occur throughout the succession.

In Section #4.2 a 14 m thick recessive unit covers the base of the outcrop (Figure 10.2.2.). The first exposed units belong to the Upper McMurray Formation and comprise poorly- sorted, trough cross-bedded and rippled sand with mudstone-intraclasts. Next is a 4 m thick channel-fill of sand and mudstone-intraclast breccias, capped by rippled sand (Figure 10.2.2, from 36 to 43 m). Overlying the channel-fill is a 22 m thick succession of interbedded trough and ripple cross-bedded sand with sand/mudstone that show low-angle, inclined heterolithic stratification. At the base of this stacked unit is a silty mudstone with ripple drift, *Cylindrichnus* and *Skolithos* burrows (Figure 10.2.2, from 48- 50 m height). About 6 m below the top of the McMurray Formation is a prominent, iron-stained, siderite-cemented zone. The cemented zone is overlain and fines into silty sand with trough cross-bedding. The overall succession is coarsening- then fining-upward to the top of the McMurray succession. This section is notable for the vertical and lateral variability of the sands and mudstones and the complex interfingering of these facies. Furthermore, channel sands extend to the top of the Upper McMurray Formation at this site.

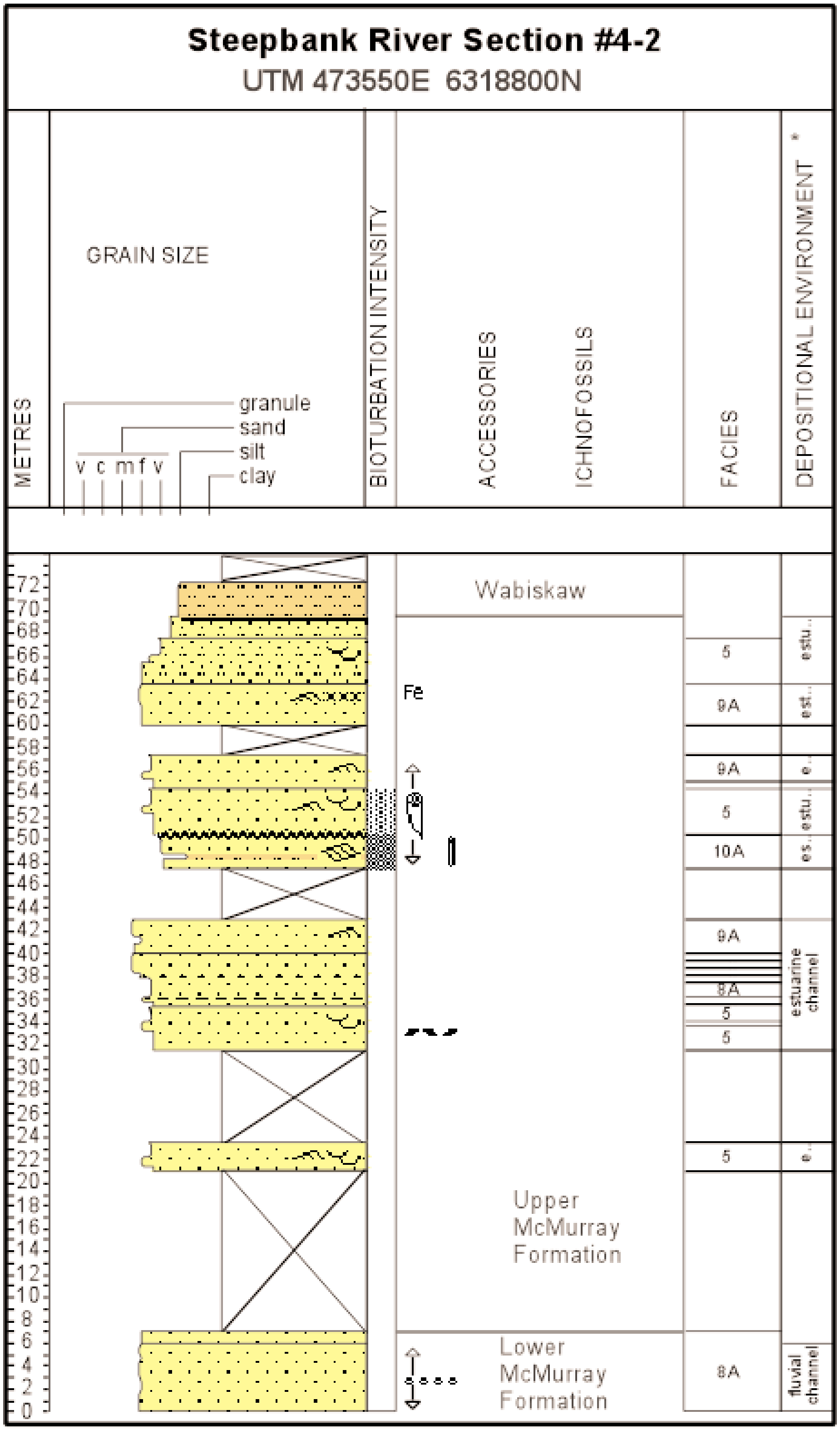
At the Steepbank River #4 sections about 5 m of siltstone/silty mudstone of the Wabiskaw Member unconformably overlies the McMurray succession.

Interpretation: In Section #4.1 complex interfingering of: cross-bedded sand, mudstone-intraclast breccias, and burrowed, low-angle, inclined heterolithic stratified units are interpreted as representing the deposits of stacked, multi-story, estuarine channel and point-bar successions. In Section #4.2 the thick recessive unit at the base is interpreted as a vertical accretion, abandoned channel-fill deposit. The overlying Upper McMurray cross-bedded sand with mudstone-intraclast breccias reflect deposition from estuarine-channel and cutbank settings. Coarsening-upward successions may represent deposition by crevasse splays onto point bar tops or overbank settings near channel margins. Fining-upward sequences record normal processes of meandering point-bar /cut-bank migration and aggradation.



*Complete Description in Appendix 3.

Figure 10.2.1. Schematic representation of the measured Steepbank River Section #4-1 (UTM 473600E, 6318860N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 10.2.2. Schematic representation of the measured Steepbank River Section #4-2 (UTM 473550E, 6318800N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

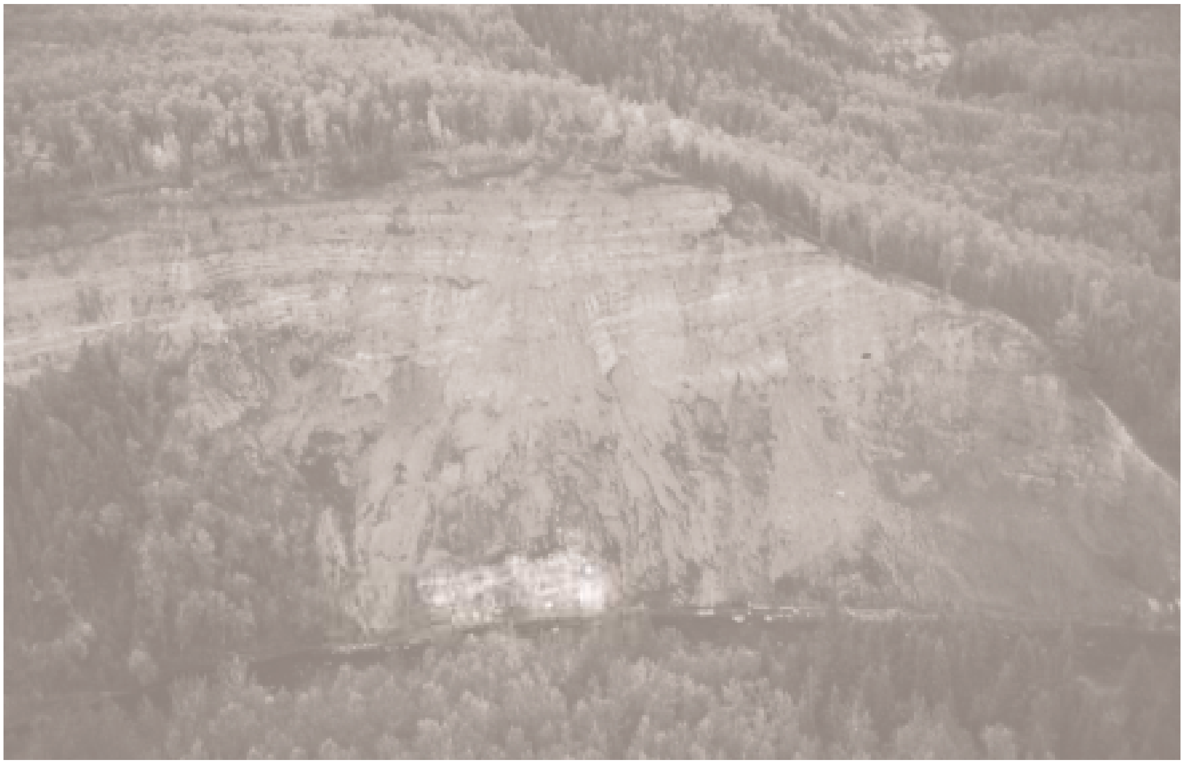


Figure 10.2.3a. Overview of estuarine channel succession of trough cross-bedded sand overlain by cross-cutting lateral accretion deposits (Upper McMurray Formation), Steepbank River Outcrop #4.

Figure 10.2.3b. Coarse-grained, small-scale trough cross-beds in poorly saturated, bitumen-stained, sand (Lower McMurray Formation), Section 4-1, Steepbank River Outcrop #4.

Figure 10.2.3c. Medium-scale, trough cross-bedded coarse sand (Upper McMurray Formation), about 14 m above the base, Steepbank River Section #4-1 .

10.3 Steepbank River Section #7

Map Coordinates: 74E/3 Hartley Creek, Scale 1: 50 000, UTM 474440E, 6318110N

Keynote things to see:

- Thick estuarine channel/cutbank, point bar and vertical accretion, abandoned channel deposits;
- Well-developed cross-bedding and bioturbation features in the channel sands.

Description: This outcrop (Figures 10.0.1, 10.0.2) shows a well exposed succession of McMurray channel fill sands overlain by multiple sets of low angle inclined heterolithic stratification, capped by 2 to 3 m of unconsolidated Quaternary sand and gravel (Figures 10.3.1 and 10.3.2). The section described as follow is slightly modified from that published by Mossop *et al.* (1982).

At this outcrop Devonian limestone outcrops for the basal 5 to 6 m from river level, with a covered contact between the Devonian limestone and the McMurray Formation. About 50 m of Upper McMurray succession is exposed. The Upper McMurray at this section is sand-dominated but does show some interbedding with mudstone as low-angle, inclined heterolithic stratification. Structures within the sands are trough and ripple cross-bedding, with abundant mudstone-intraclasts towards the base of the McMurray (Figure 10.3.1 and 10.3.2). A slight coarsening-upward trend occurs from the base of the section to the mudstone-intraclast zone. The next part of the exposure shows an overall fining-upward succession of mainly rippled sands with low-angle, inclined heterolithic stratification (Figure 10.3.1). The intensity and diversity of burrows increases upsection. *Cylindrichnus* and *Skolithos* dominate lower intervals, whereas near the top *Bergaugeria* also occurs.

At the top of the section is about 2 m of Quaternary sand and gravel that unconformably overlie the Cretaceous succession.

Interpretation: The Upper McMurray sediments within the lower coarsening-upward succession with abundant mudstone-intraclasts, are interpreted as main estuarine channel/cutbank deposits that are overlain by estuarine point bar and vertical accretion abandoned channel deposits.

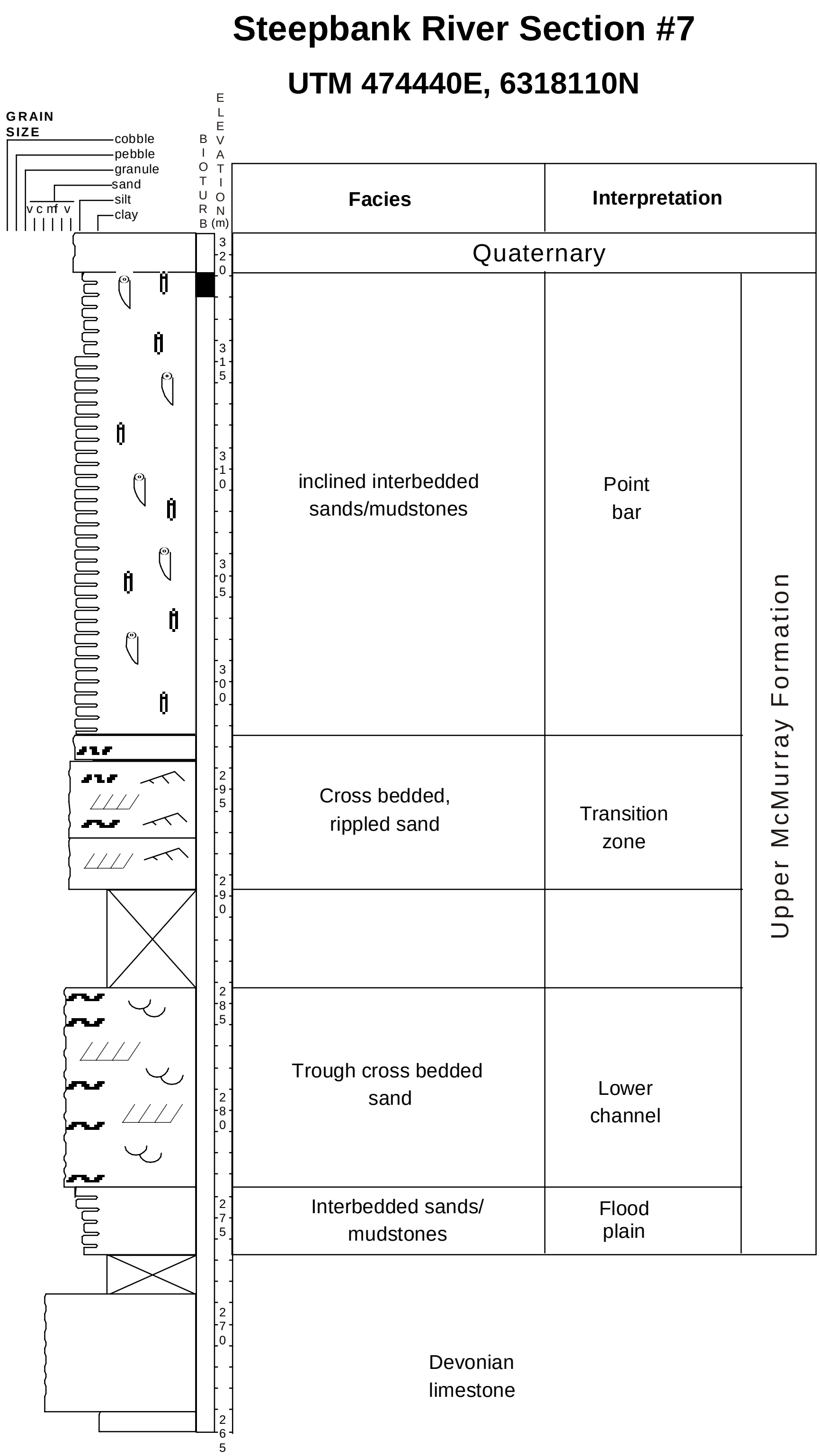


Figure 10.3.1. Schematic representation of the measured Steepbank River Section #7 (UTM 474440E, 6318110N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height. (from Wightman et al., 1992)

Figure 10.3.2. Overview of thick estuarine channel succession (Upper McMurray Formation), Steepbank River Outcrop #7.

10.4 Steepbank River Sections #9.1, #9.2 and #9.3

Map Coordinates: 74E/3 Hartley Creek, UTM 475300E, 6317760N (for Steepbank River Section #9.1)

Keynote things to see:
- Multiply stacked estuarine channel and mud- or sand-dominated point bar deposits;
- Complex interbedding of sand and mudstone facies;
- Well-developed cross-bedding and bioturbation features in channel sands.

Description: This outcrop (Figures 10.0.1, 10.0.2) shows a well-exposed succession of McMurray channel fill sands, with minor interbedded sets of low-angle, inclined heterolithic stratification, capped by 1 to 2 m of unconsolidated Wabiskaw silty sand (Figures 10.4.1 to 10.4.4). The sections at this outcrop start at river level, where a thin (<1 m) Lower McMurray pebbly/granule sand is exposed at the base of Section #9.1 (Figure 10.4.1) and is mainly covered in Section #9.2 and Section #9.3 (Figures 10.4.2 and 10.4.3). The contact between the Lower and Upper McMurray Formation is also mainly covered.

In Section #9.1 about 40 m of the Upper McMurray succession is exposed. This succession is sand-dominated, but does show some mudstone interbeds within low-angle, inclined heterolithic stratification. Structures within the sands are trough, ripple-drift and ripple cross-bedding. Stacked fining-upward successions occur, along with stacked sets of low-angle, inclined heterolithic stratification, some of which are sandier and other portions are muddier (Figure 10.4.1). Sands are burrowed at the top with mainly *Cylindrichnus* traces.

Section #9.2 shows a complex interbedding of sand and mudstone, with an abundance of sedimentary structures, including convolute and chaotic bedding, parallel lamination, low- angle, inclined stratification, trough, ripple and planar tabular cross-bedding, wave-ripples, and wavy bedding (Figure 10.4.2). Mudstone intraclasts are more common towards the base of the section, associated with the chaotic bedding. Siderite occurs as concretions in the lower third of the section and as replacement of the mudstone-intraclasts. Mudstone interbeds are common as part of the low-angle, inclined heterolithic stratification. Locally, within the low-angle inclined stratification, cross-bedding in the sands includes high-angle planar tabular, trough, ripple and wavy types. The topmost 1 m of the McMurray Formation is light-brown silty sand that is rippled and rooted (Figures 10.4.4a, b), with *Cylindrichnus* and *Planolites* burrows.

In Section #9.3 about 37 m of the Upper McMurray Formation is exposed (Figure 10.4.3). The section is sand-dominated, but does show interbedding with mudstone within low-angle, inclined heterolithic stratified sets. Structures within the sands are trough, ripple and planar tabular cross-bedding (Figure 10.4.3). A slight fining-upward occurs within the section, from stacked sets of planar tabular cross-bedded sands to parallel-laminated silty sands at the top. The upper silty sands are burrowed, with dominantly *Cylindrichnus*.

The McMurray Formation is abruptly overlain by a 1 to 2 m thick, salt-and-pepper, medium- to fine-grained sand, that is thin-bedded with wavy lamination or, as shown in Section #9.3, by a 2 m thick glauconitic silty sand. These sands are interpreted as Wabiskaw marine sands. It is noteworthy that the sands extend to the top of the Upper McMurray Formation at Section #9.1. At Section #9.2 the top of the McMurray succession consists of rooted and burrowed sand, abruptly overlain by the Wabiskaw marine sand, with no intervening mudstone barriers.

Interpretation: In the Steepbank River #9 sections the low-angle, inclined heterolithic stratification is pervasive, but is not uniform. There are marked discordances in the bedding and paleoflow orientations. The complex vertical and lateral changes in grain size and physical sedimentary structures indicate that this is a series of multiply-stacked inclined units, and not a single set. The sand with the chaotic bedding and mudstone- intraclasts is interpreted as an estuarine channel deposit, which is overlain by a thin, sand-dominated, low-angle, inclined heterolithic unit, interpreted as lateral accretion deposits from a sandy point bar. The remainder of the McMurray succession is interpreted as a series of stacked sandy and muddy point bar deposits, with the topmost rooted and burrowed zones comprising sand-flat deposits.

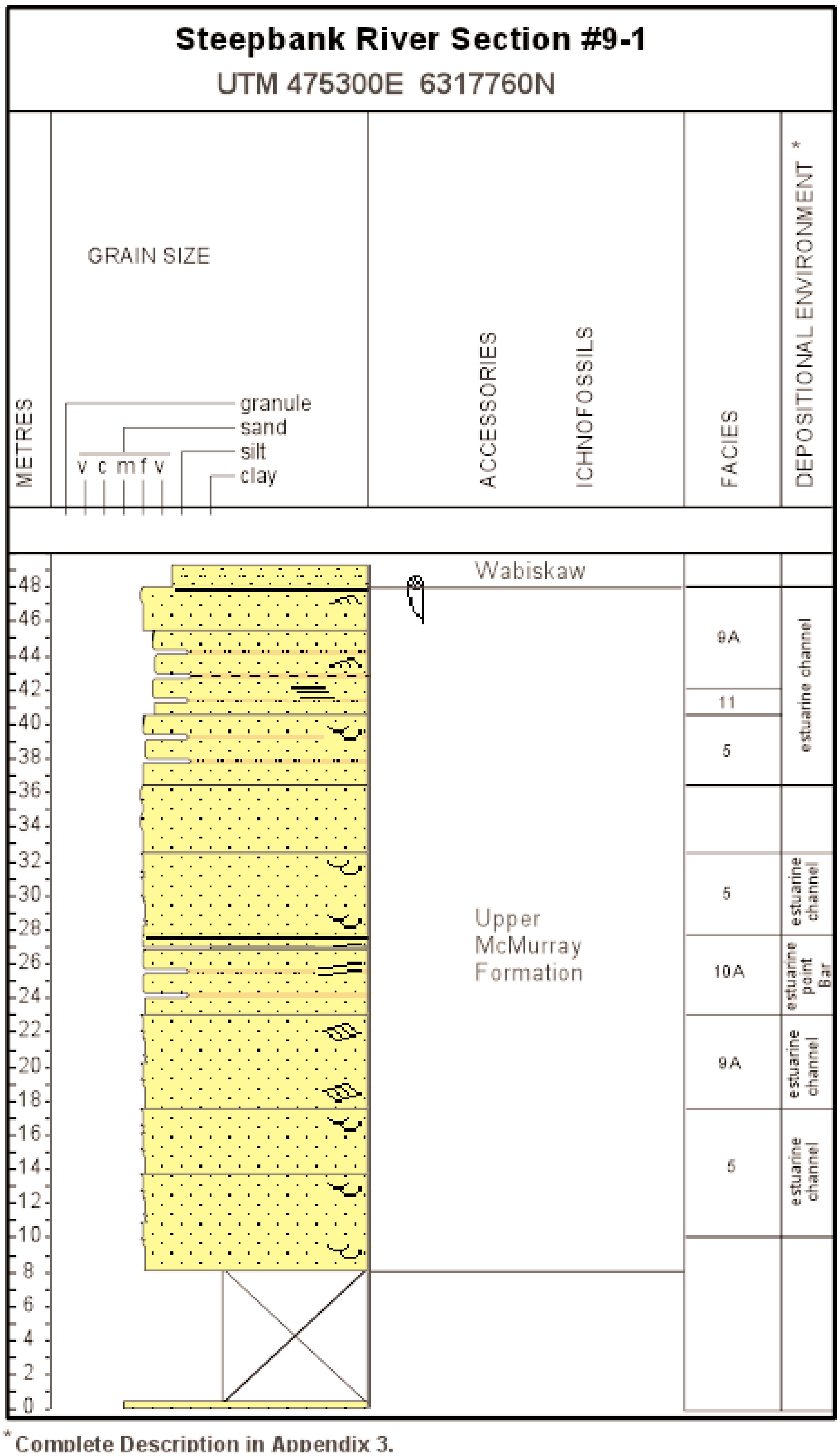
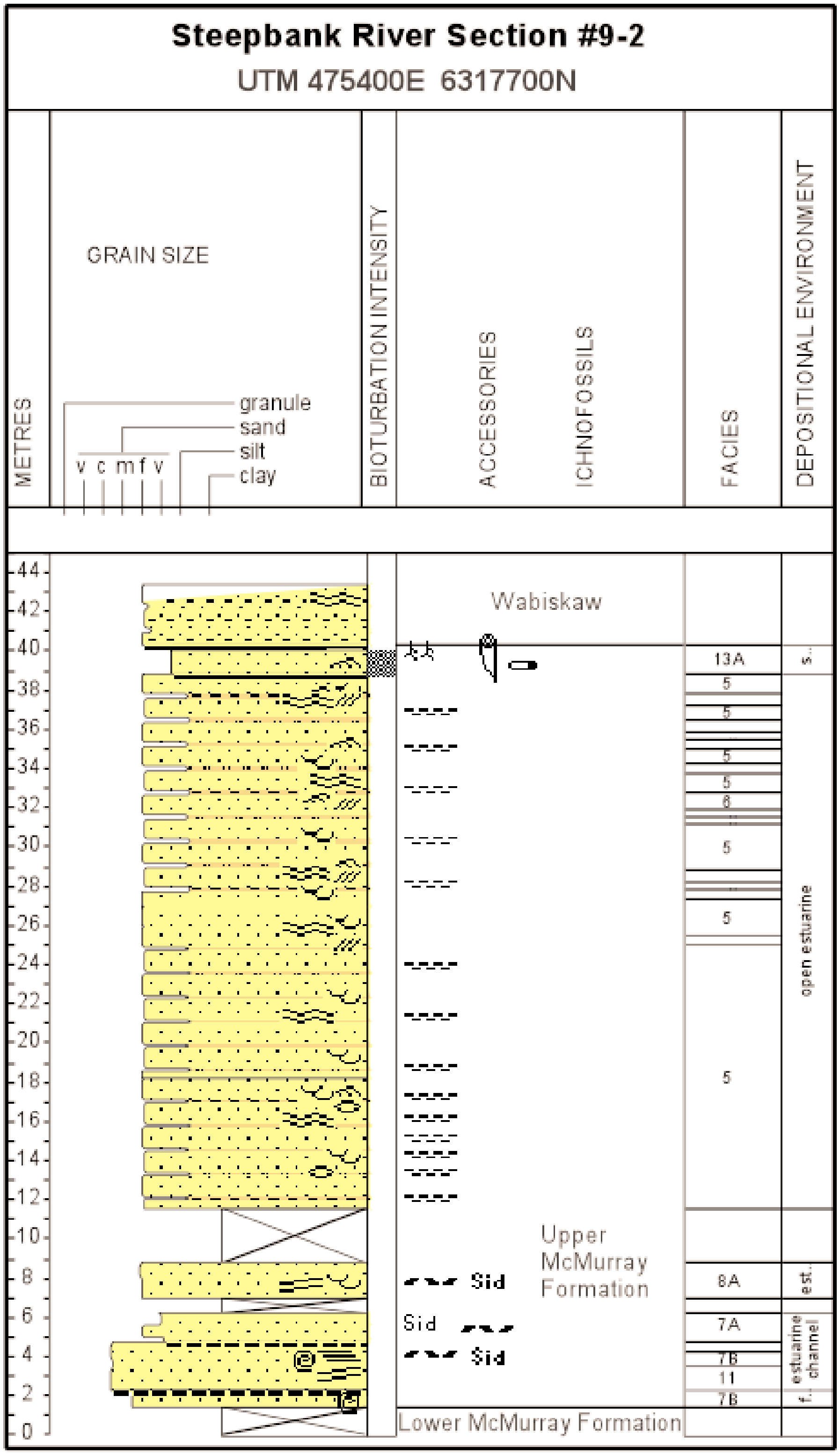
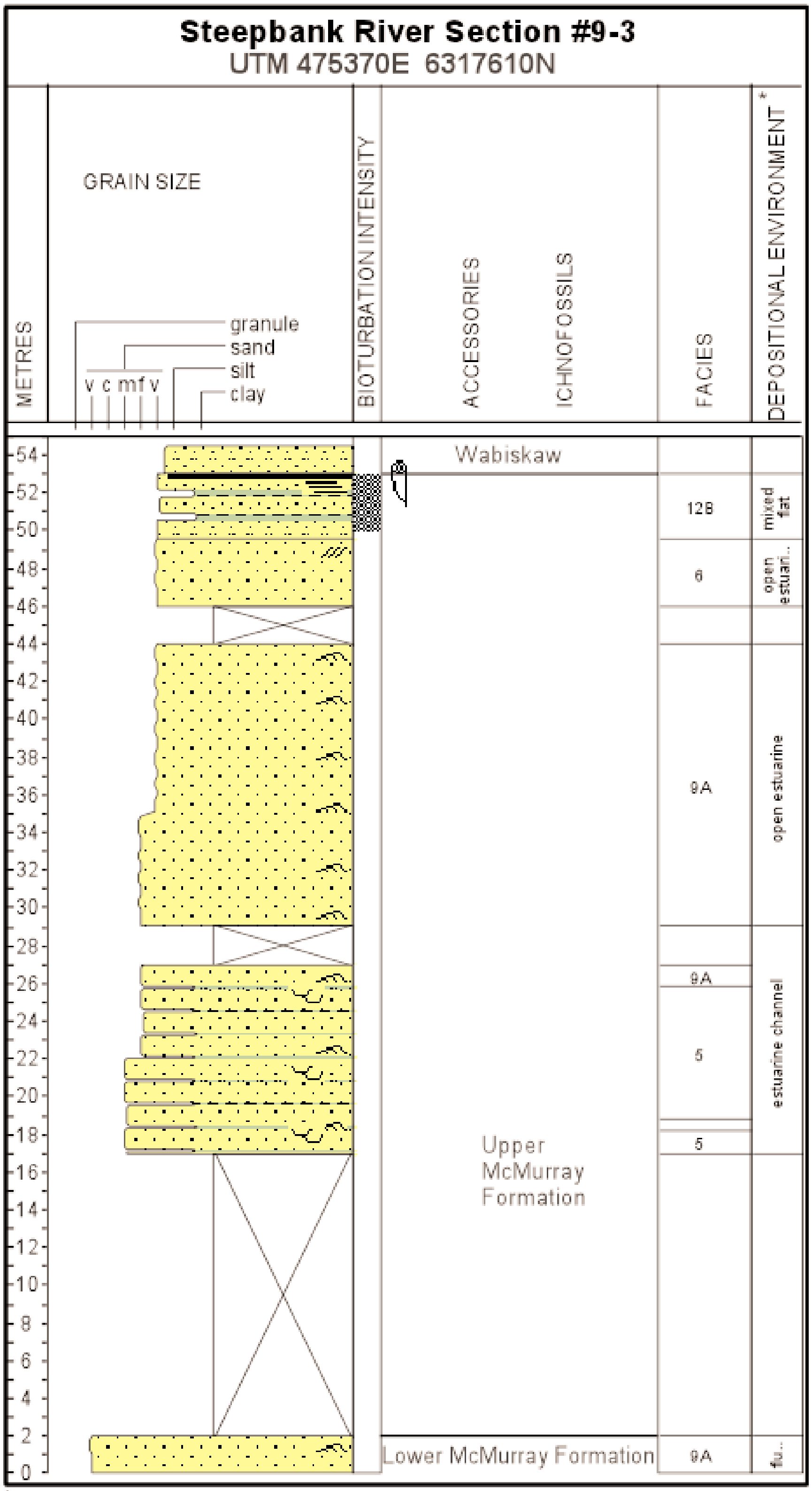


Figure 10.4.1. Schematic representation of the measured Steepbank River Section #9-1 (UTM 475300E, 6317760N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 10.4.2. Schematic representation of the measured Steepbank River Section #9-2 (UTM 475400E, 6317700N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.



*Complete Description in Appendix 3.

Figure 10.4.3. Schematic representation of the measured Steepbank River Section #9-3 (UTM 475370E, 6317610N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 10.4.4a. Overview of thick estuarine succession consisting of stacked trough and high-angle planar tabular cross-bedded sand (Upper McMurray Formation), Steepbank River Outcrop #9.

Figure 10.4.4b. Rooted (arrows) muddy sand, capped by burrowed mudstone (Upper McMurray Formation), 25 m level in Section #9-2, Steepbank River Outcrop #9.

Figure 10.4.4c. Rooted (arrows) siltstone (Upper McMurray Formation), Section #9-2 Steepbank River Outcrop #9.

11.0 Christina River Outcrops

Map Coordinates: 74D/11 Fort McMurray, UTM 498075E, 6278050N for the Christina Section #1 at the extreme downstream (northwestern) end; UTM 512121E, 6265989N for Christina Section #4 at the extreme upstream (southeastern end) (see Figures 11.0.1 and 11.0.3 for overview).

General Location and Outcrop Selection: This section is accessible by a 4x4 ATV dirt track along the south bank of the Clearwater River, or alternatively, an easier access is either via boat or helicopter. Access to the Clearwater River is via boat from the Snye Park Landing in Fort McMurray. Travel upstream from the confluence of the Clearwater and Athabasca rivers at Fort McMurray for about 27 km until the mouth of the Christina River, at its confluence with the Clearwater River. Enter the Christina River valley, continuing upstream for about 3.5 km.

Along the Christina River there are about 25 cutbank sections, on alternating meander bends of the river, showing well-exposed (unless recently slumped) successions. Three of these cutbank sections, near the mouth of the Christina River, were measured in detail (Figures 11.0.1 and 11.0.2). One other section was measured about 15 km upstream from the mouth of the river (Figures 11.0.3 and 11.0.4). This was accessed by helicopter.

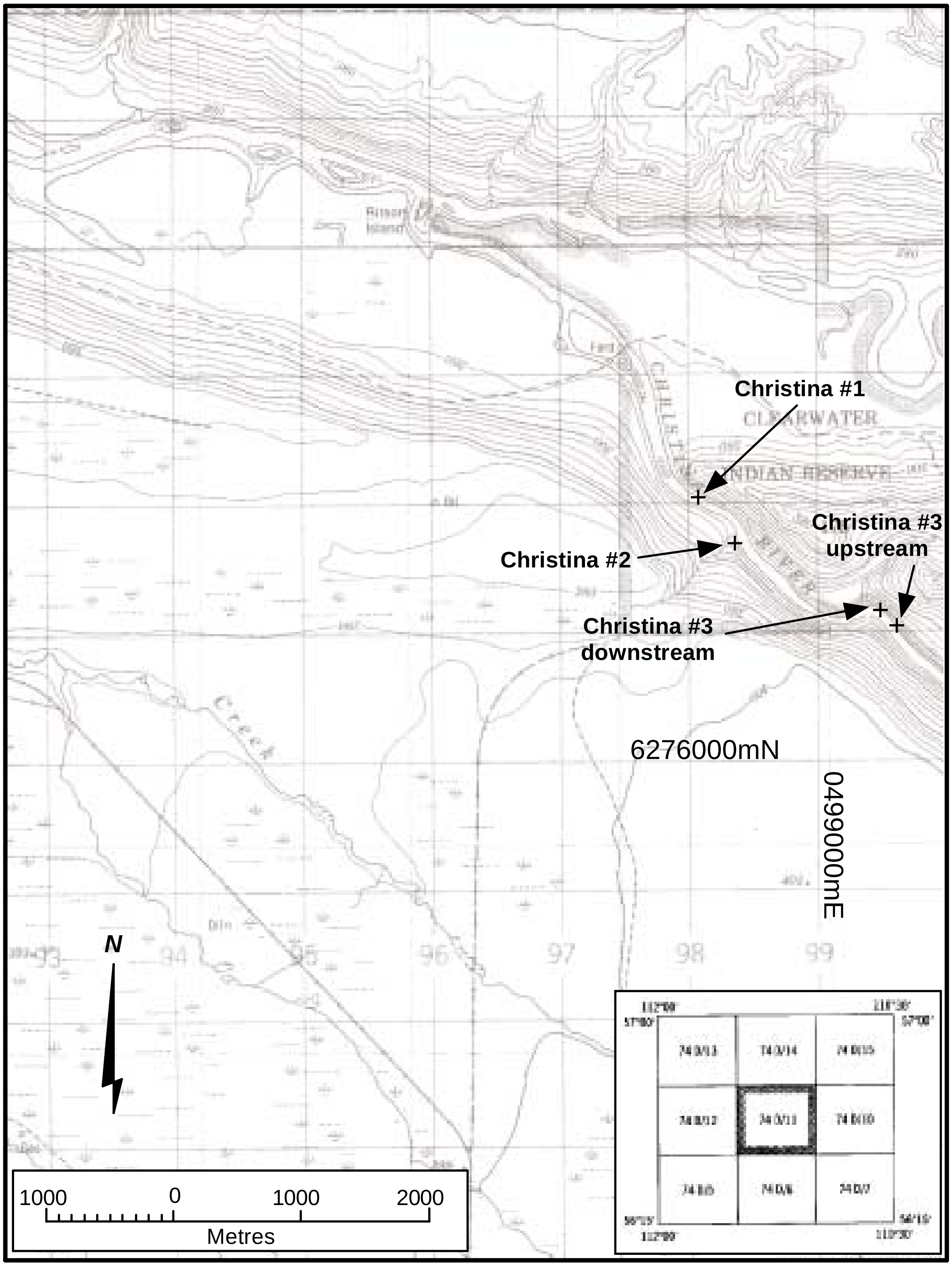


Figure 11.0.1. Map showing location and access to the Christina River #1, #2 and #3 sections on the Christina River, southeast of Fort McMurray.

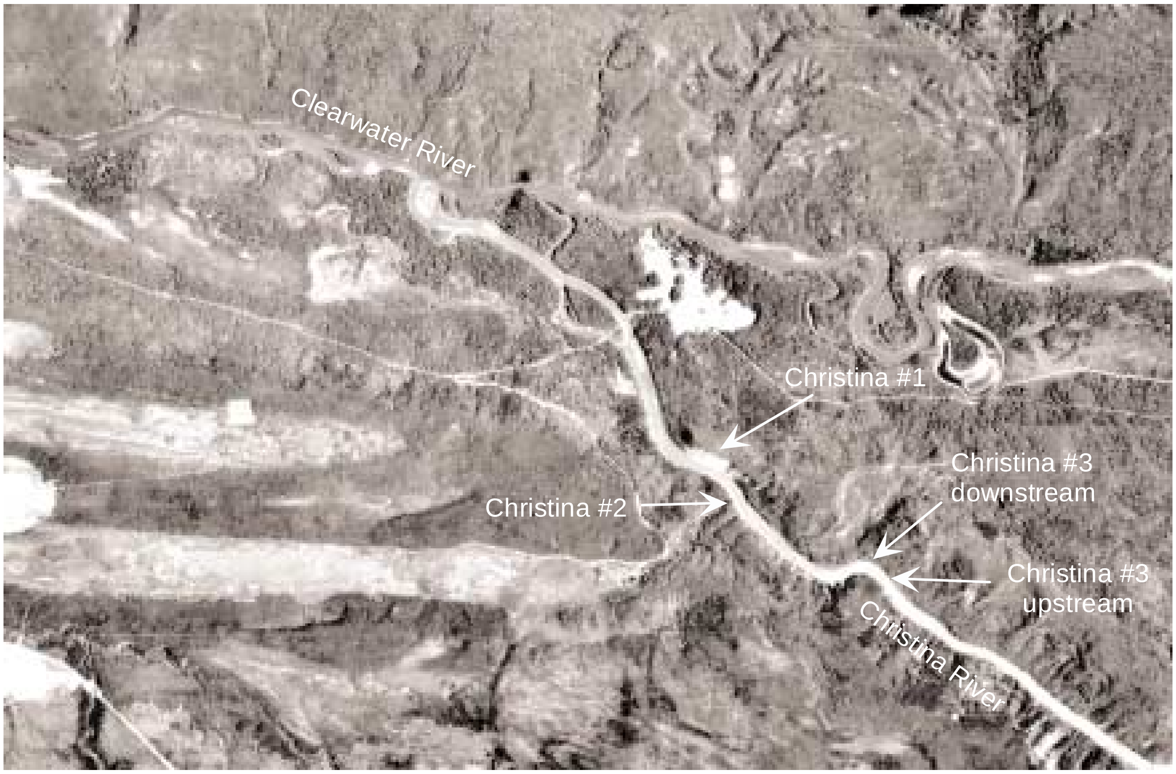


Figure 11.0.2. Aerial photograph showing location of Christina River #1, #2, and #3 sections.

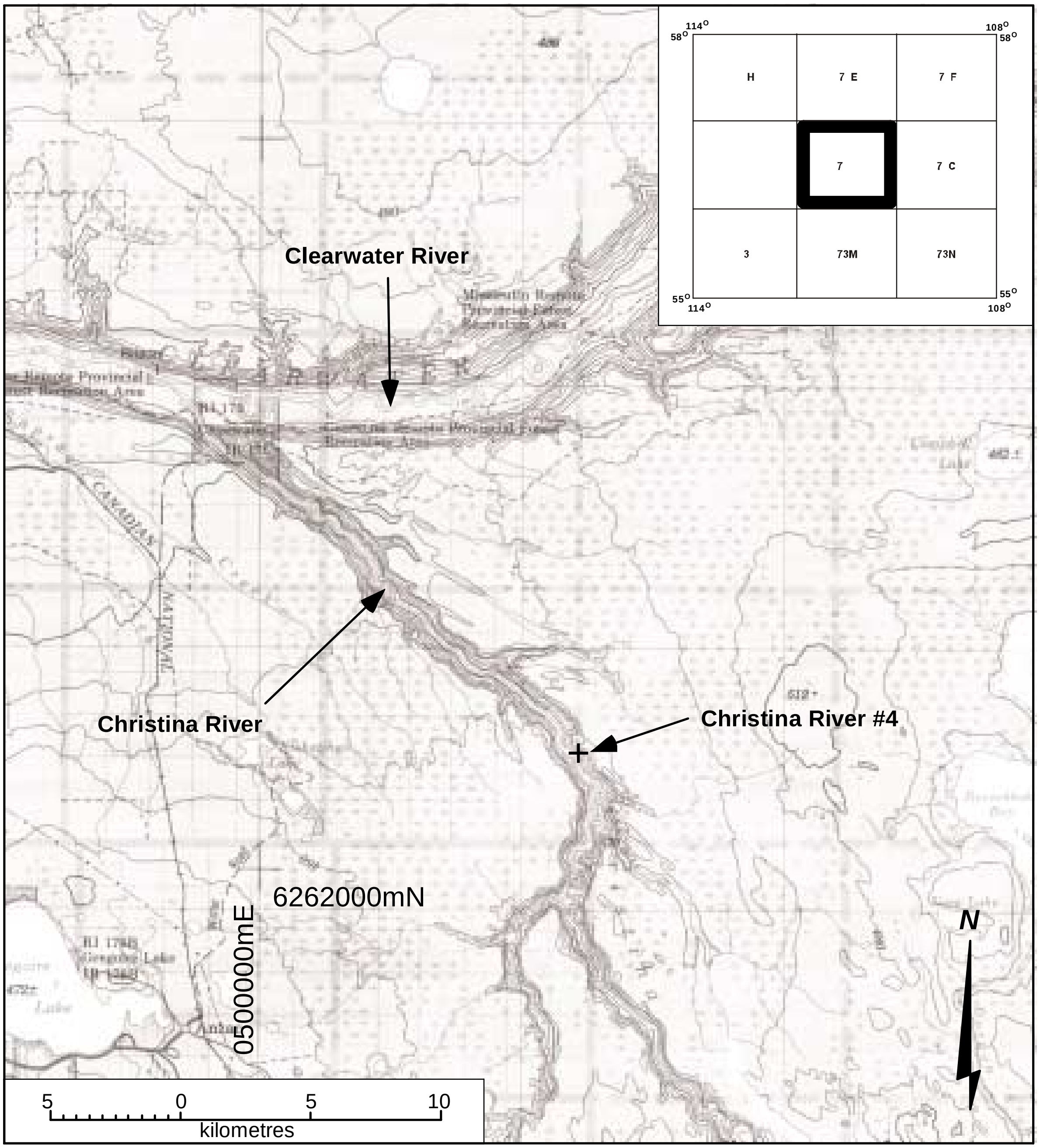


Figure 11.0.3. Map showing location and access to the Christina River Section #4 about 15 km upstream of the mouth of the Christina River.

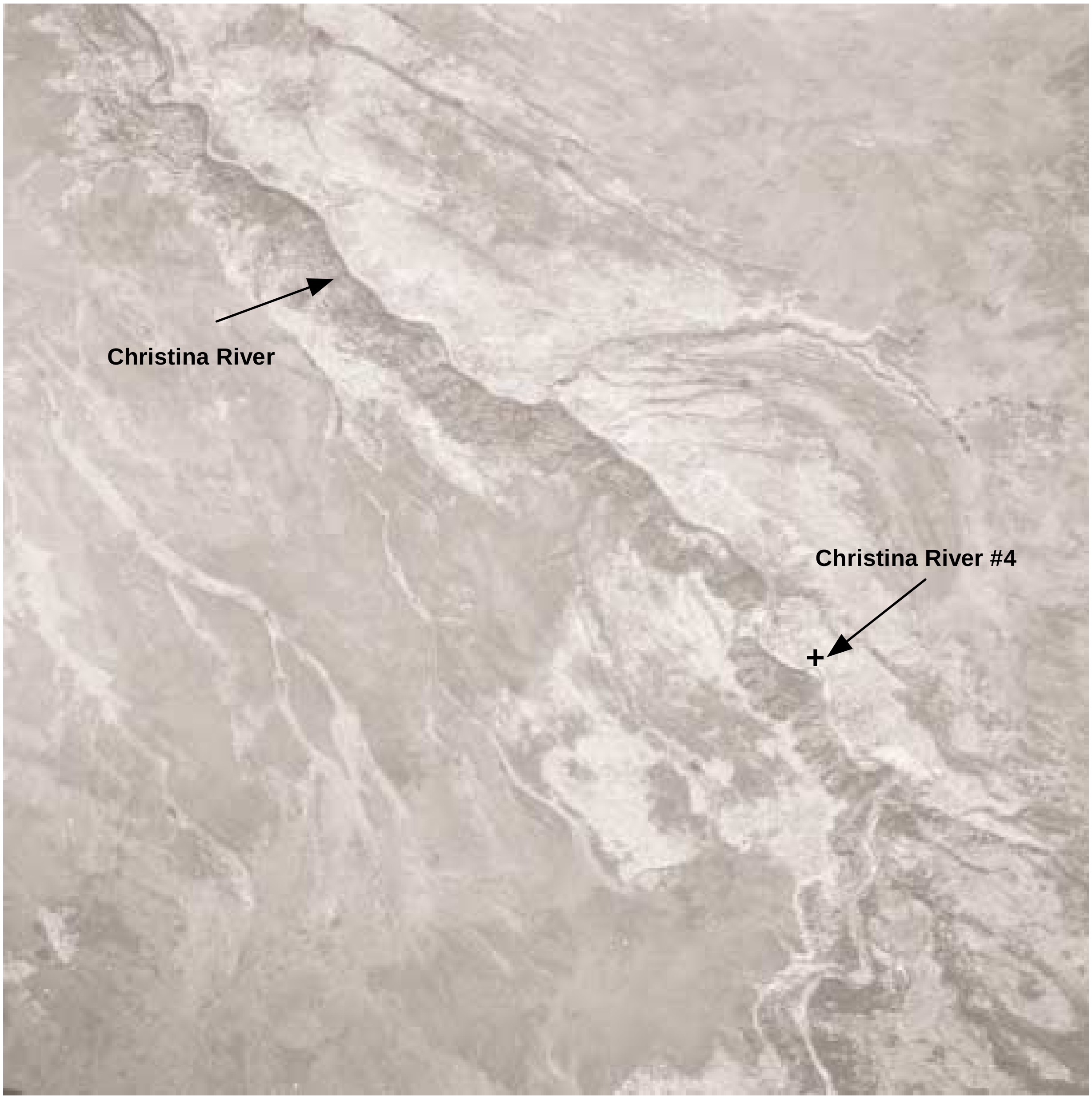


Figure 11.0.4. Aerial photograph showing location and access to the Christina River Section #4 about 15 km upstream of the mouth of the Christina River.

11.1 Christina River Section #1

Map Coordinates: 74D/11 Fort McMurray, UTM 498075E, 6278050N

Keynote things to see:

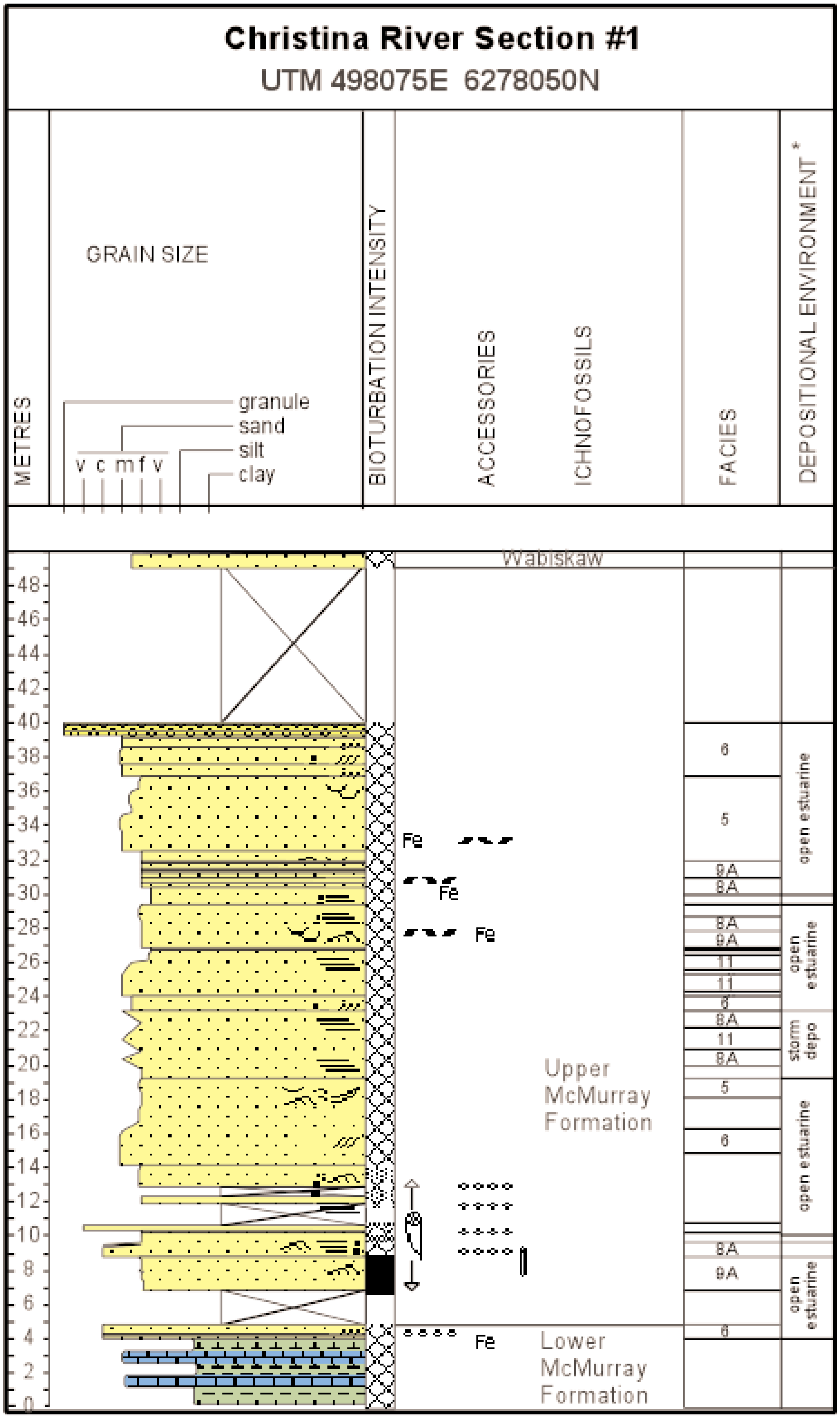
- Limestone knob with sulphide mineralization and nodules of sulphide-rind resedimented into Lower McMurray fluvial pebbly sand;
- Well-developed cross-bedding and bioturbation features in channel sands, with local paleoflow reversals;
- Estuarine and fluvial channel sands within the Upper McMurray succession.

Description: This outcrop (Figures 11.0.1, 11.0.2) shows a well-exposed succession of McMurray alternating fluvial and estuarine channel fill interbedded with open estuarine sands. A thin veneer of Quaternary sand overlies a thick covered interval at the top of the section (Figures 11.1.1, 11.1.2a, c). At river level a 4 m high knob of the Devonian Christina Formation laminated limestone outcrops at the base of the cutbank section (Figures 11.1.2a, b). Fractures within the limestone are infilled with bitumen. At the top and around the edges of the limestone knob is a red, iron-stained, sideritic drape, 0.15 m thick, which shows sulphide mineralization and marks the pre-Cretaceous unconformity surface. Overlying and draping off the limestone knob is a poorly exposed, thin remnant of fluvial pebbly and granule coarse to medium sand, interpreted as the Lower McMurray Formation (Figure 11.1.1).

The Lower McMurray sands have prominent planar tabular cross-beds and, as isolated float, quartz pebbles that weathered out of the outcrop. The quartz pebbles are well- rounded and up to 2 cm in length. Slumping covers the uppermost contact of the Lower McMurray fluvial pebbly sands with the overlying Upper McMurray succession. Above the covered interval is a partially covered 7 m thick succession of the Upper McMurray Formation coarse- to medium-grained sands, mainly massive to parallel-laminated, with scattered pebbles and granules. Cross-bedding, when developed, includes low-angle, inclined heterolithic stratification, ripple and planar tabular sets. Finer-grained interbedded units are burrowed, mainly with *Planolites* and *Cylindrichnus*, and small-scale *Skolithos*. Generally the section lacks good upward coarsening or fining trends, but rather shows stacked channel-fills that cross cut one another both vertically and laterally along-strike. Paleoflows are mainly directed to the northwest, but with some flow reversals to the southeast, mainly as smaller reverse flow toeset ripples or overbank deposits (Figure 11.1.2d).

The remainder of the exposed outcrop section appears to be a coarse-grained, high- energy, open-estuarine deposit, or a local fluvial channel succession of sands. The sands coarsen-upward into pebbly granule-sand and gravel at the top of the exposed Cretaceous section. Cross-bedding and parallel stratification is well-exposed in the thick McMurray sand section, including planar tabular, trough, ripple, and climbing-ripple sets. Flaser-ripples and reactivation structures are less common. Local sideritized mudstone-intraclast breccias predominate. Main channel paleoflows are consistently towards the northwest. Locally overbank ripple-drift sands show southeast-directed paleoflows. A thin (<1.5 m) Quaternary sand occurs at the top of the outcrop, above a 7 m thick covered interval at the top of the Cretaceous.

Interpretation: The Lower McMurray at the base of the section shows planar tabular cross-bedded pebbly sand, a lack of obvious fining-upward trends, the absence of low-angle, inclined heterolithic stratification, and no burrowing. These features suggest that these are fluvial channel sands, probably a braided stream setting, based upon comparisons with other better-exposed outcrops. The lower part of the Upper McMurray is interpreted as alternations of high-energy channel sands that change upsection into either open-estuary or fluvial-dominated successions. As the succession coarsens upwards there is an increase in the occurrence of multiply-stacked, planar tabular cross-bed sets that suggests either a change to fluvial braided channel or open estuarine sand flat environments near the top of the McMurray Formation.



*Complete Description in Appendix 3.

Figure 11.1.1. Schematic representation of the measured Christina River Section #1 (UTM 498075E, 6278050N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

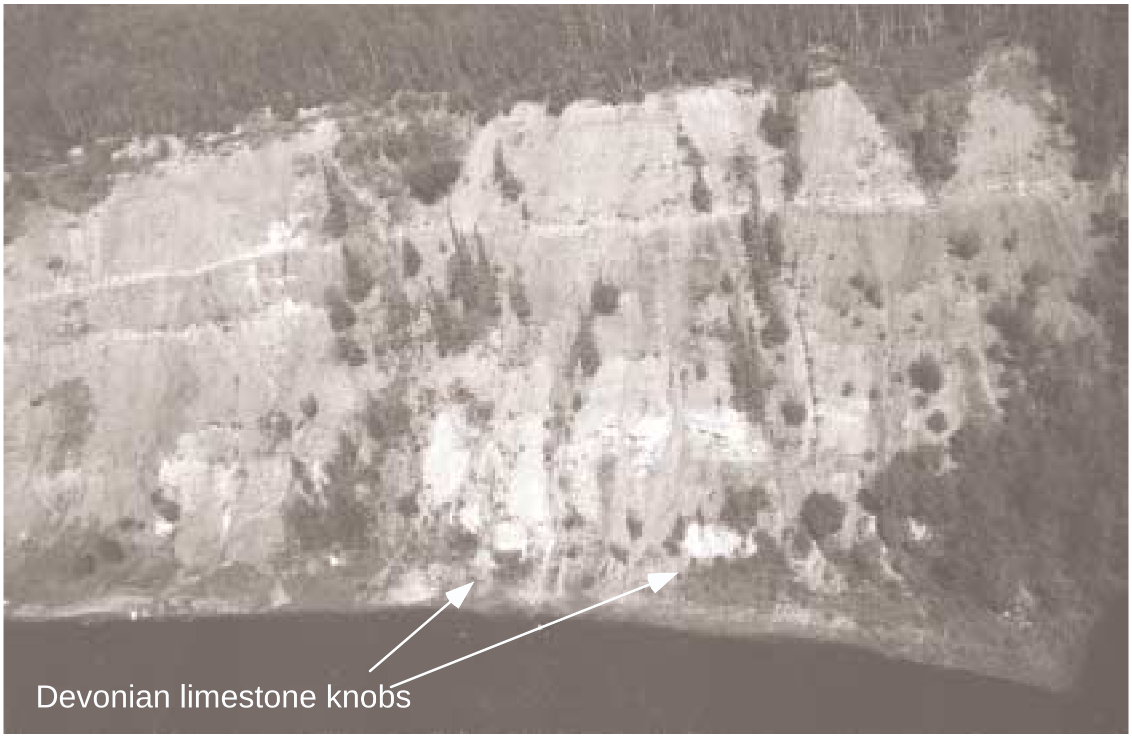


Figure 11.1.2a. Thick, high energy, cross-bedded estuarine sand, variably bitumen saturated (Upper McMurray Formation), overlying karstic limestone knob and hollow topography, Christina River Section #1, Christina River, southeast of Fort McMurray.

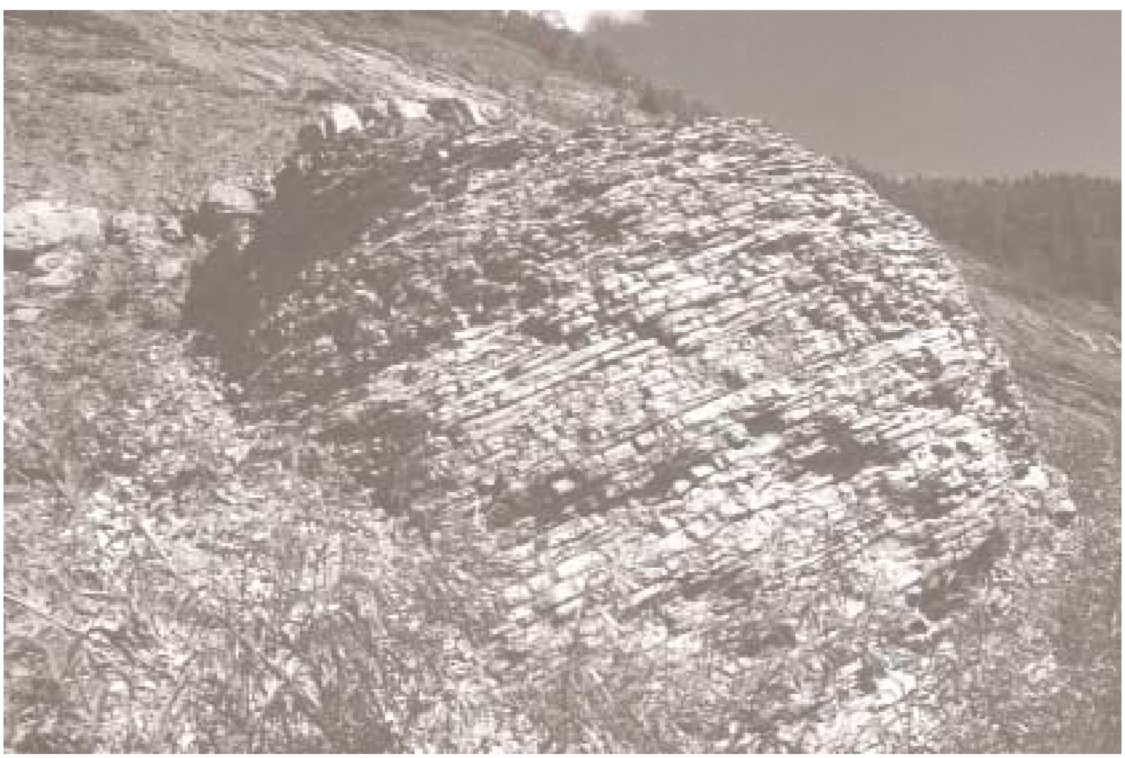


Figure 11.1.2b. Detailed photograph of one of several karstic Devonian limestone knobs exposed at the base of Christina River Section #1, southeast of Fort McMurray.

Figure 11.1.2c. Thick Upper McMurray succession exposed near the mouth of the Christina River, Christina River Section #1, southeast of Fort McMurray.

Figure 11.1.2.d. Detailed photograph of rippled sand overlain by high-angle, planar tabular cross-bedded sand (Upper McMurray Formation), Christina River Section #1, southeast of Fort McMurray.

11.2 Christina River Section #2

Map Coordinates: 74D/11 Fort McMurray, UTM 498350E, 6277620N

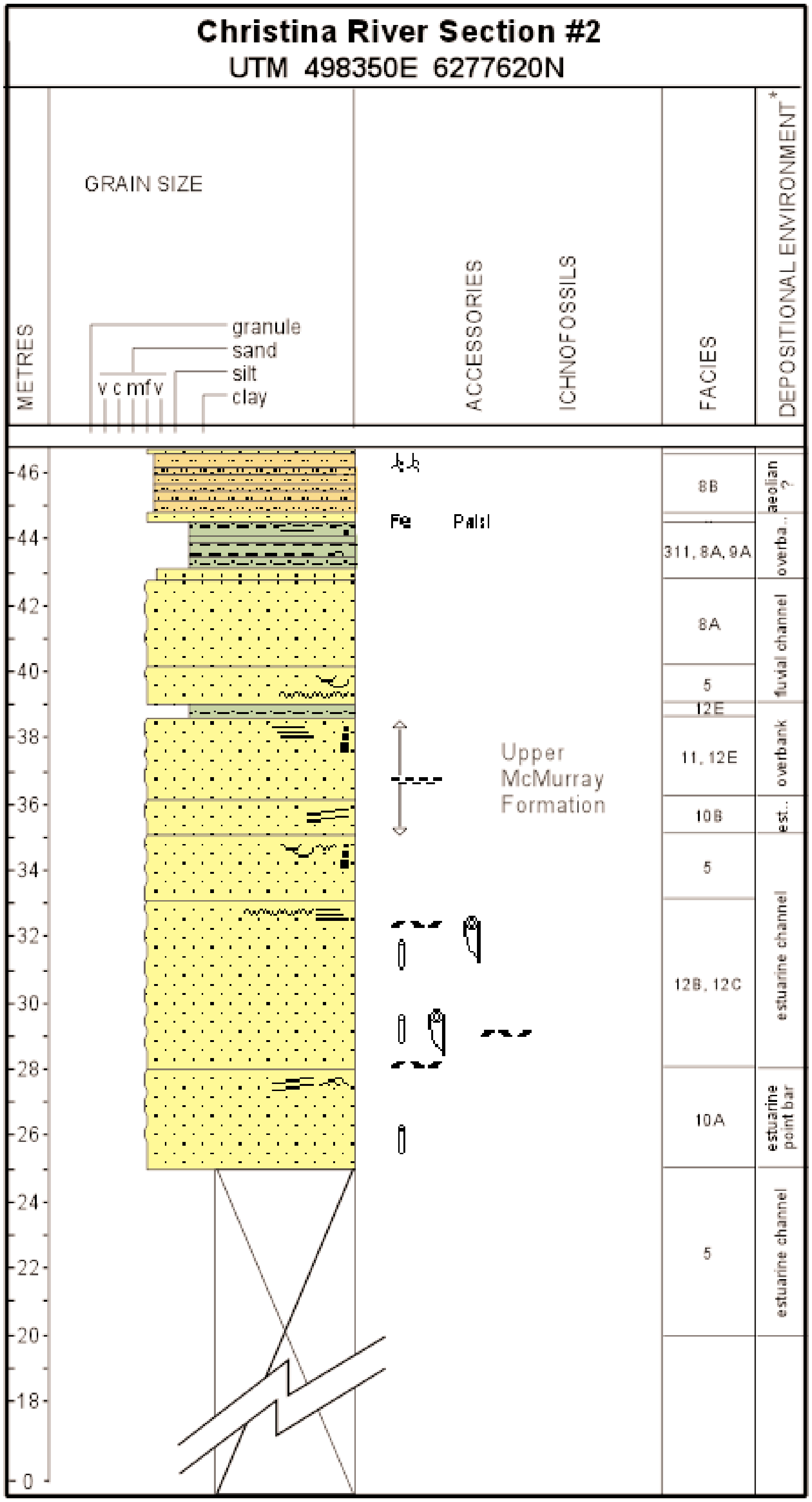
Keynote things to see:

- Stacked estuarine channel and point bar deposits of the Upper McMurray Formation;
- Thick vertical accretion abandoned estuarine channel succession with excellent *Cylindrichnus* traces;
- Fluvial and aeolian sucession in the uppermost 10 m of the outcrop.

Description: This outcrop (Figures 11.0.1, 11.0.2) shows a well-exposed succession of McMurray estuarine channel and point bar deposits, capped by 10 m thick fluvial channel to overbank rooted horizon, with possible aeolian sediment (Figures 11.2.1, 11.2.2). From river level a 25 m thick covered interval occurs, comprising a slumped succession of what appears to be the Upper McMurray Formation. The sands are coarse- to medium-grained, mainly massive to parallel-laminated, with siderite concretions. Sandy shale blocks are burrowed, mainly with *Planolites* and *Cylindrichnus*. Overlying this is a 3 m thick unit of low-angle, inclined heterolithic stratified sand and mudstone, with superimposed ripple cross-bedding along the inclined stratification. Next is a 5 m thick scour fill of medium- to coarse-grained sand, horizontally laminated, with scattered *Cylindrichnus* and *Skolithos* burrows, and dispersed mudstone-intraclasts. The next 3 m of section consists of interbedded trough cross-bedded sand, alternating with sand /mudstone packages that start with low-angle, inclined heterolithic stratification grading upwards into parallel-bedded vertical accretionary units.

The remainder of the exposed outcrop section appears to a succession of channel sands that fine upwards into silty sand/sandy siltstone at the top of the outcrop, just below an inaccessible covered interval. Channel sands are mainly massive, but with minor scour fill lamination. Finer interbeds are parallel laminated, rarely rippled, with local siderite nodules and roots. Some of the silty sand/sandy siltstone shows large-scale master bedding surfaces with compound cross-bedding, similar to that produced by aeolian sand dunes.

Interpretation: The Upper McMurray at the base of the section with the low-angle, inclined heterolithic stratification and minor burrowing is interpreted as estuarine point bar deposits that overlie a largely slumped estuarine channel succession. The parallel laminated and burrowed sands are interpreted as vertical accretionary abandoned channel deposits. Overlying units with the trough cross-beds and low-angle, inclined heterolithic stratification are grading upwards into estuarine and channel deposits. The next fining-upward succession to the recessive mudstone lacks bioturbation, and may reflect fluvial point-bar top or overbank sedimentation. The rest of the section appears to be stacked fluvial-channel successions, overlain by thin paleosols, rooted zones and aeolian sediment from overbank settings. The measured section at this locality is similar to the Christina Section #1 that also shows a fluvial succession at the top of the outcrop beneath the Quaternary cover.



*Complete Description in Appendix 3.

Figure 11.2.1. Schematic representation of the measured Christina River Section #2 (UTM 498350E, 6277620N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

11.3 Christina River Downstream Section #3

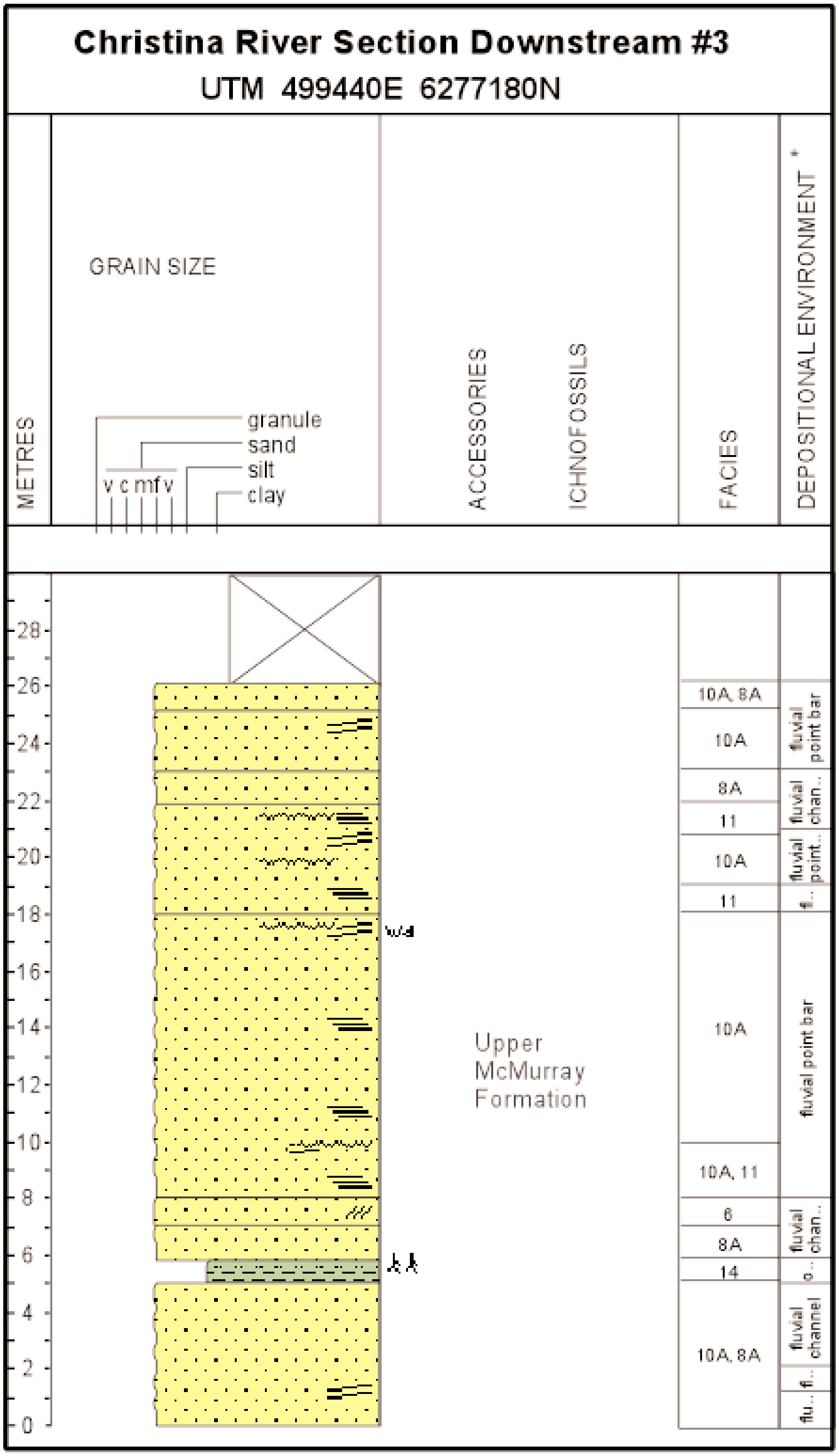
Map Coordinates: 74D/11 Fort McMurray, UTM 499440E, 6277180N

Keynote things to see:

- Thick vertical accretion abandoned estuarine channel succession with intense degree of bioturbation at the base of the section;
- Thick interbedded fluvial channel and point bar deposits of the Upper McMurray Formation;
- Thick vertical accretion abandoned fluvial channel succession with no bioturbation at the top of the section.

Description: This outcrop (Figures 11.0.1, 11.0.2) shows a well-exposed succession of McMurray interbedded estuarine channel and point bar deposits, that are overlain by fluvial channel and point bar deposits, with thick vertical accretion abandonment fill mudstones (Figures 11.3.1, 11.3.2). From river level an 8 m thick covered interval occurs. Overlying this is a 5 m thick lens of bioturbated silty mudstone, that is eroded downstream and upsection by a channel-fill about 10 m thick. The channel-fill comprises stacked scour fills, each of which is infilled with variably cross-bedded sands, including planar tabular, low-angle inclined stratification, and large-scale trough cross-bedding. Commonly, the cross-bedded sands vertically and laterally cross-cut one another, and interfinger with parallel stratified sands. The next distinctive sand package is about 3 to 4 m thick and consists of interbedded sand/mudstone as low-angle, inclined heterolithic stratification. Mudstone interbeds are not bioturbated, are about 0.1 to 0.2 m thick, and comprise about 10% of the measured section. This is overlain by a 3 m thick massive sand, that grades, in turn, into brown, horizontally-stratified muddy silt/silty mudstone, again lacking bioturbation structures and has no bitumen-staining.

Interpretation: The bioturbated silty mudstone at the base of the section is interpreted as an abandoned estuarine channel or bay-fill succession of the Upper McMurray Formation. The thick channel sands with multiple internal scour fills and complex cross-bedding types overlie this. These channel sands generally lack mudstone interbeds and do not show apparent bioturbation structures; bioturbated mudstone intraclasts are notably absent. The channel sands are interpreted as possible braided-fluvial channel sands within the Upper McMurray succession. Overlying interbedded mudstone/sands with low-angle, inclined heterolithic stratification are interpreted as lateral accretion deposits from fluvial point bars, whereas the more massive sands are interpreted as fluvial channel sands. The muddy siltstone with the good horizontal lamination and lacking bioturbation features are interpreted as fluvial overbank floodplain sediments.



*Complete Description in Appendix 3.

Figure 11.3.1. Schematic representation of the measured Christina River Section Downstream #3 (UTM 499440E, 6277180N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

11.4 Christina River Upstream Section #3

Map Coordinates: 74D/11 Fort McMurray, UTM 499520E, 6277150N

Keynote things to see:

- Thin estuarine point bar deposits of the Upper McMurray Formation;
- Minor rooted overbank deposits.

Description: This outcrop (Figures 11.0.1, 11.0.2) shows a well-exposed thin succession of McMurray interbedded estuarine channel and point bar deposits, that are overlain by rooted mudstone (Figures 11.4.1, 11.4.2). At the base of the section is a 5 m thick, generally massive sand that upstream shows prominent scour fills, with vague low-angle cross-bedding that dips to the south-southwest. Abruptly overlying the massive sand is a nearly 1 m thick unit of coaly and rooted sandy mudstone/silty mudstone. This unit is eroded by a thick, massive channel-fill sand, that shows up to 10 m relief on the basal scour contact. The channel-fill sands comprise 1 to 2 m thick sands that drape and infill the sour fill, and internally are cross-bedded with mudstone as low-angle, inclined stratification. The rest of the outcrop is less massive, more thin-bedded, with low-angle inclined stratified sand/mudstone that alternates and laterally interfingers with other scour-fill sands. Internally the sands may be massive, show low-angle, inclined stratification or show well-developed parallel lamination. No burrow structures were noted.

Interpretation: The absence of any observed burrowing or bioturbated mudstone intraclasts, the relatively low proportion of interbedded mudstones, and the prominence of the major 10 m thick scour-surface indicates that the environment of deposition was a high-energy channeled setting, most likely as fluvial valley-fills. The more massive sands with some planar tabular or trough cross-bedding, and parallel lamination are interpreted as fluvial channel sands. These alternate with the sandy low-angle, inclined heterolithic stratification, interpreted as fluvial point bar deposits. The rare rooted mudstone is an overbank deposit.

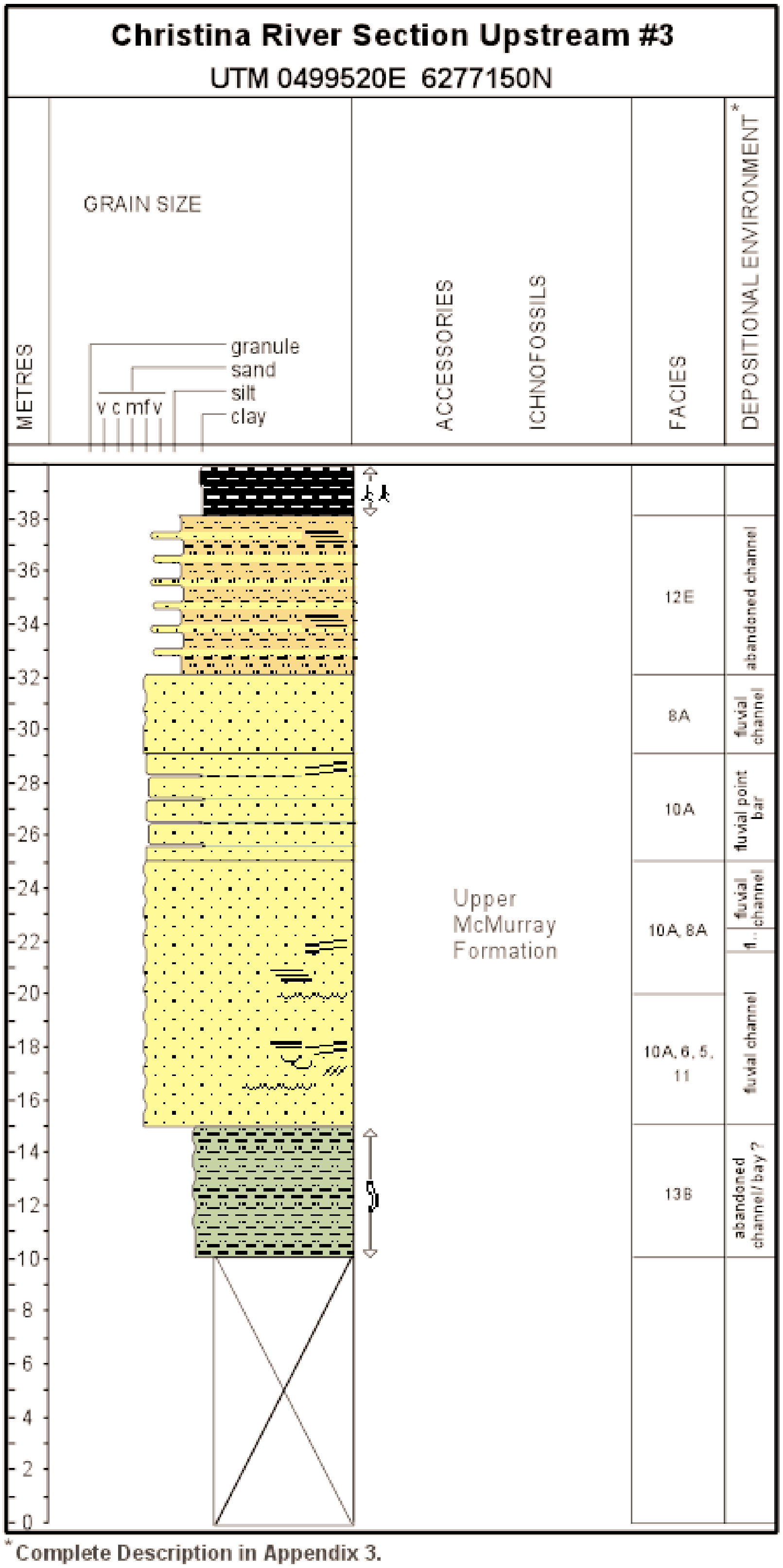


Figure 11.4.1. Schematic representation of the measured Christina River Section Upstream #3 (UTM 0499520E 6277150N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

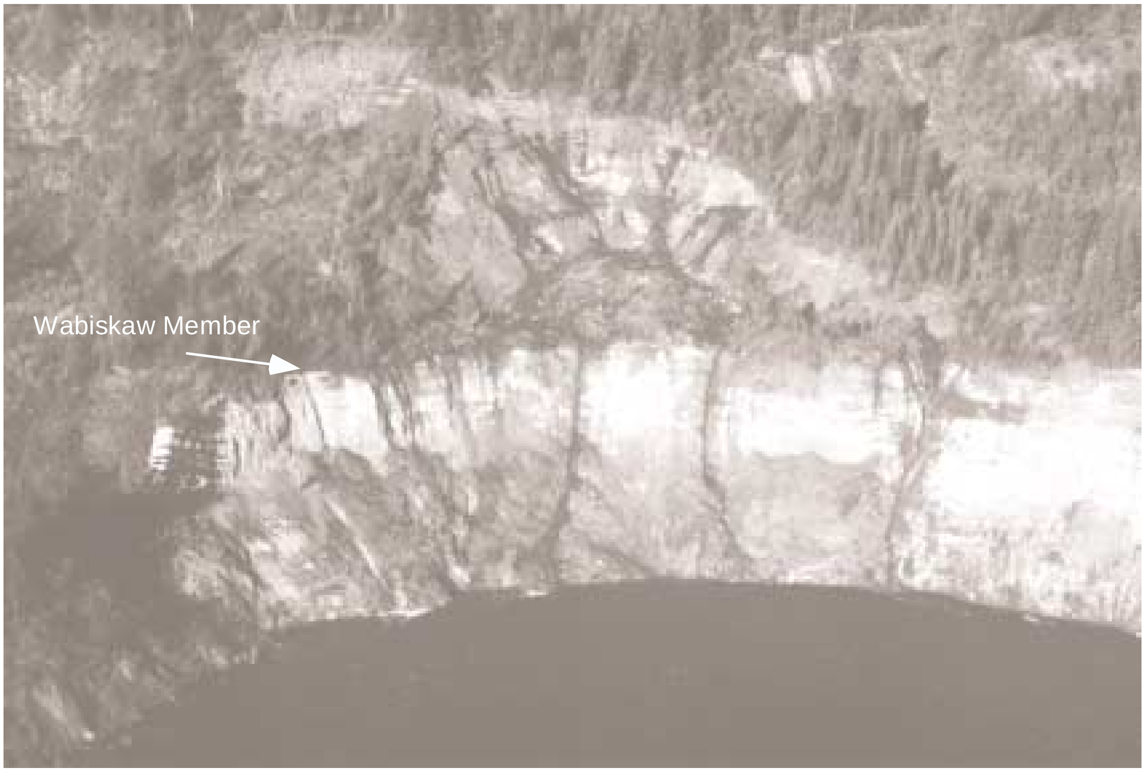


Figure 11.4.2a. Thick, bitumen-free, cross-bedded sand of the McMurray Formation capped by the Wabiskaw Member along the Christina River, Christina River Section #3, southeast of Fort McMurray.

Figure 11.4.2b. Thick, clean, bitumen-free, cross-bedded sand (Lower or Upper McMurray Formation), exposed along the Christina River, Christina River Section #3, southeast of Fort McMurray.

11.5 Christina River Section #4

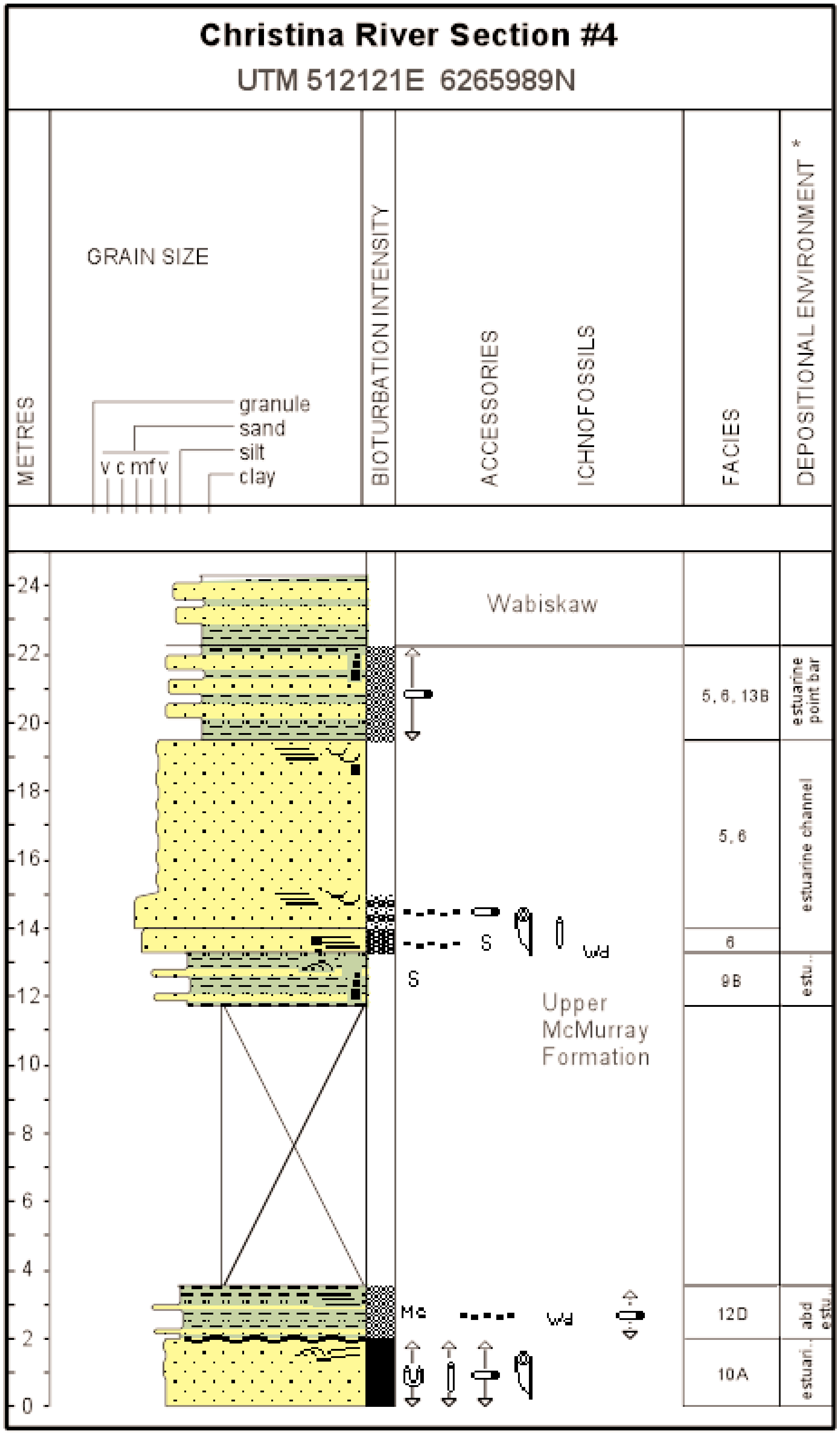
Map Coordinates: 74D/11Fort McMurray, UTM 0512121E, 6265989N

Keynote things to see:

- Thin estuarine point bar deposits of the Upper McMurray Formation at the base overlain by thick mainly recessive, vertical accretion abandoned estuarine channel or bay-fill succession;
- Very low levels of bitumen-saturation to barren sands throughout the McMurray Formation;
- 2 m thick marine Wabiskaw D-fill at the top of the outcrop (generally inaccessible).

Description: This outcrop (Figures 11.0.3, 11.0.4) shows a well-exposed succession of McMurray interbedded estuarine channel and point bar deposits, interbedded with thick vertical accretion abandonment-fill sand mudstone, capped by a Wabiskaw D-fill succession (Figures 11.5.1, 11.5.2). At the base of the McMurray section is a 2 m thick, fine-grained sand that is quartz-dominated with abundant mica. Internally the basal unit shows prominent low-angle, inclined heterolithic stratification, with parallel lamination and ripple cross-bedding along the low-angle dipping stratification. Common trace fossils include *Arenicolites*, *Skolithos*, *Planolites*, and rare *Cylindrichnus*. Abruptly overlying the basal unit is a 10 m thick, largely covered, recessive dark gray silty/sandy mudstone that gradually fines upwards into mudstone. Abundant coaly debris and mummified wood fragments occur in the basal 2 m of the mudstone. This unit is abruptly overlain by 6 to 7 m thick channel-fill sand. The channel-fill sands are 1 to 2 m thick, internally trough or planar tabular cross-bedded, and parallel-laminated. The channel-fill sand gradually fines upward into 2 m thick, muddy sand near the top of the McMurray Formation. This muddy sand shows a parallel and even bedding style, internally the sands have small-scale trough or planar tabular cross-beds, with discontinuous sandy mudstone interlaminae. The muddy sand is burrowed, mainly with horizontal *Planolites* traces. A highly bioturbated, 2 m thick, Wabiskaw D-fill mudstone/muddy sand unconformably overlies the muddy sand.

Interpretation: The relatively common occurrence of bioturbation both within the low-angle, inclined heterolithic stratified sand/mudstones and within the finer parts of channel-fills indicates that the environment of deposition was a brackish setting, most likely as estuarine valley or bay-fills. The thin-bedded sands with the low-angle, inclined heterolithic stratification are interpreted as lateral accretion deposits from estuarine point bars. *Arenicolites* was observed at the base of the estuarine point bar deposits, and along with the associated *Skolithos*, *Planolites* and *Cylindrichnus* traces, is part of the *Skolithos* ichnofacies. This ichnofacies is typical of that produced on shifting substrates, within nearshore settings, under moderate to relatively high-energy conditions. The overlying thick, mainly recessive, organic sandy silty mudstone, with the even bedding style and small scale bedforms, is interpreted as a vertical accretion, abandoned estuarine channel or bay-fill succession. A thick estuarine channel sand, overlies this, and is, in turn, capped by another vertical accretion, abandoned estuarine channel deposit. Such interbedding of active and inactive channel deposits most likely reflects interactions between estuarine channel and overbank settings within an overall transgressive sequence. The unconformity at the top of the McMurray Formation marks the maximum flooding surface of erosion, associated with transgression, and is abruptly overlain by the marine Wabiskaw D-fill succession.



*Complete Description in Appendix 3.

Figure 11.5.1. Schematic representation of the measured Christina River Section #4 (UTM 512121E, 6265989N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 11.5.2a. Overview of Christina River Section #4.

Figure 11.5.2b. Large-scale cross-bedded, mainly barren, estuarine channel and point bar sands (Upper McMurray Formation) Christina River Section #4.

12.0 Dover River Section

Map Coordinates: 74E/4 Fort MacKay, UTM 453070E, 6336004N

Location and Access: It is easiest to access the Dover outcrops by helicopter. However, alternate access by canoe is possible. To do so, canoe upstream along the MacKay River to the mouth of the Dover River. Then hike or canoe upstream along the Dover River a couple of km. The measured outcrop is on the north side of the river near a large beaver dam (Figures 12.0.1, 12.0.2).

Keynote things to see:

- Excellent fluvial channel fill (Lower McMurray) at the base of the section, overlain by thick estuarine point bar and channel successions (Upper McMurray);
- Very thick, stacked marine bay fills with multiple depositional events associated with deposition of the Wabiskaw D-fill;
- Contact between the Wabiskaw D and Wabiskaw C, with a 1 to 2 m Wabiskaw C cap to the Cretaceous succession, unconformably overlain by unconsolidated Quaternary sand.

Description: This outcrop (Figures 12.0.1, 12.0.2) shows a well-exposed thick succession of McMurray fluvial and estuarine channel/point bar deposits, interbedded with thin vertical accretion abandonment-fill mudstone, capped by about 14 m of the Wabiskaw D and C units (Figures 12.1.1, 12.1.2a, b). At the very base of this section is a 5 m thick succession of well-exposed fine-grained sand (pebbly in float that slumped along the bank of the river). This basal sand shows prominent, large-scale trough cross-bedding, multiple scour-fills, and dispersed mudstone-intraclasts (Figure 12.1.2c). Most of the overlying section at the north end of the outcrop exposes dominantly fine-grained sand, with sandy, low-angle inclined heterolithic stratification, alternating with planar tabular cross-beds (Figure 12.1.2d), and ripple cross-bedding (Figure 12.1.2e). *Cylindrichnus* burrows, both in place and as resedimented mudstone-intraclasts, are common, along with the less common *Skolithos* in coarser-grained beds, and *Planolites* in finer-grained beds. The sandy, low-angle inclined heterolithic stratified succession fines upwards into a more muddy, low-angle inclined heterolithic stratified sand/mudstone, capped by even and horizontally-bedded sand/mudstone. Units are rippled and burrowed throughout, mainly with *Planolites*, and less commonly *Cylindrichnus* towards the base.

The overlying Wabiskaw D-fill unit is largely recessive at the base where it locally scours out the top of the McMurray Formation. The Wabiskaw D-fill is marked by interbedded and heavily bioturbated sand and black mudstone. Intense bioturbation occurs, as shown by *Teichichnus*, *Skolithos* and *Planolites* traces. Locally very thick, discontinuous lenses of highly organic, black mudstone occurs within the Wabiskaw D-fill succession. The Wabiskaw D-fill is, in turn, scoured out by a recessive, medium-bedded, glauconitic, fine-grained sand, that is burrowed, commonly with *Teichichnus* traces. Unconformably overlying the Wabiskaw C unit is about 2 m of light-tan to brown, unconsolidated, Quaternary sand.

Interpretation: The trough cross-bedded fine sand at the base of the section is interpreted as a remnant of the Lower McMurray fluvial-channel sand. The overlying fining-upward units with sandy to muddy, low-angle inclined heterolithic stratification are interpreted as estuarine point bar successions. These are overlain by the bioturbated muddy fine-grained sand, interpreted as a flooded estuarine, vertical accretion, abandoned channel deposit of the Upper McMurray Formation. Stacked marine-bay fills (with two cycles in the Wabiskaw D, and one in the Wabiskaw C, preserved at this outcrop) abruptly overlie the McMurray succession. This is the only occurrence in outcrop of multiple fill events for the Wabiskaw-D succession, and shows that locally multiple phases of transgression occurred in the area.

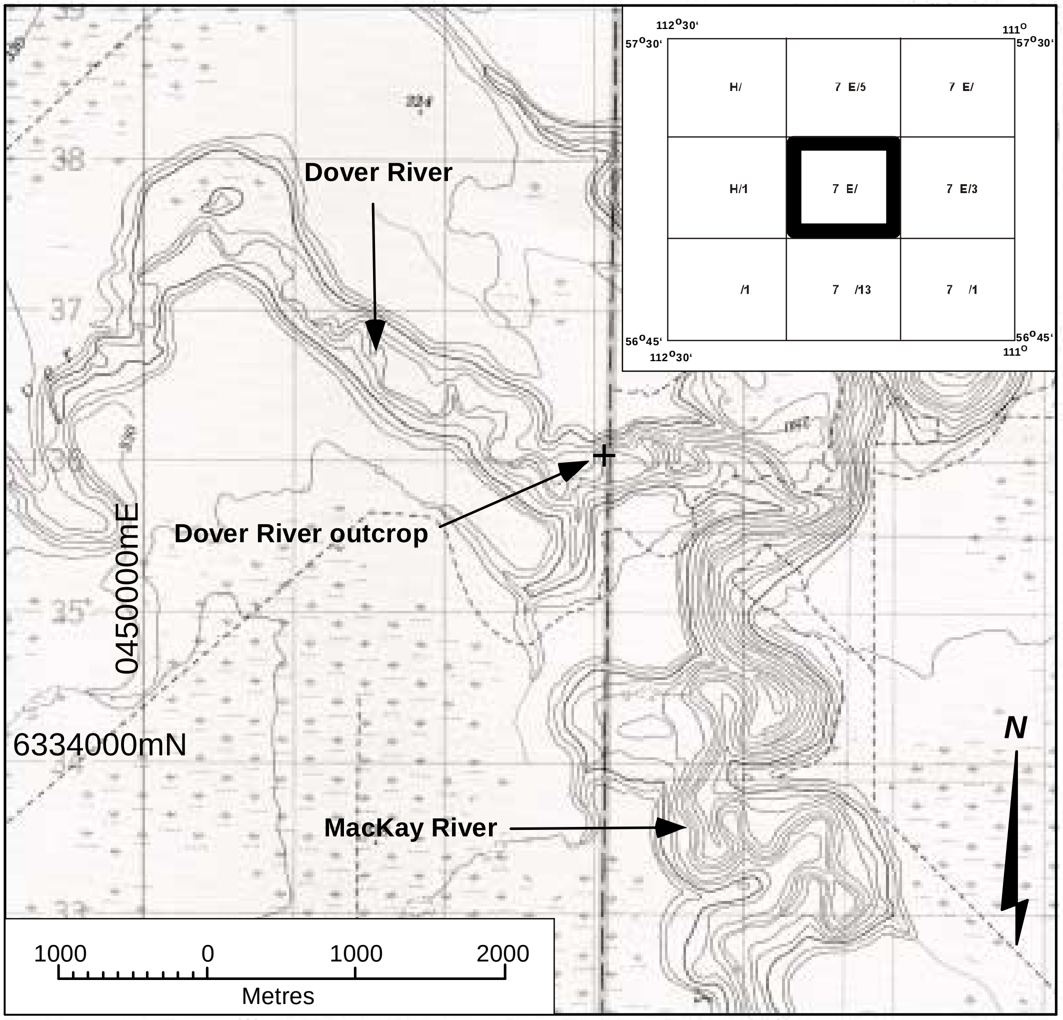


Figure 12.0.1. Map showing location of Dover River Section, north of Fort McMurray.

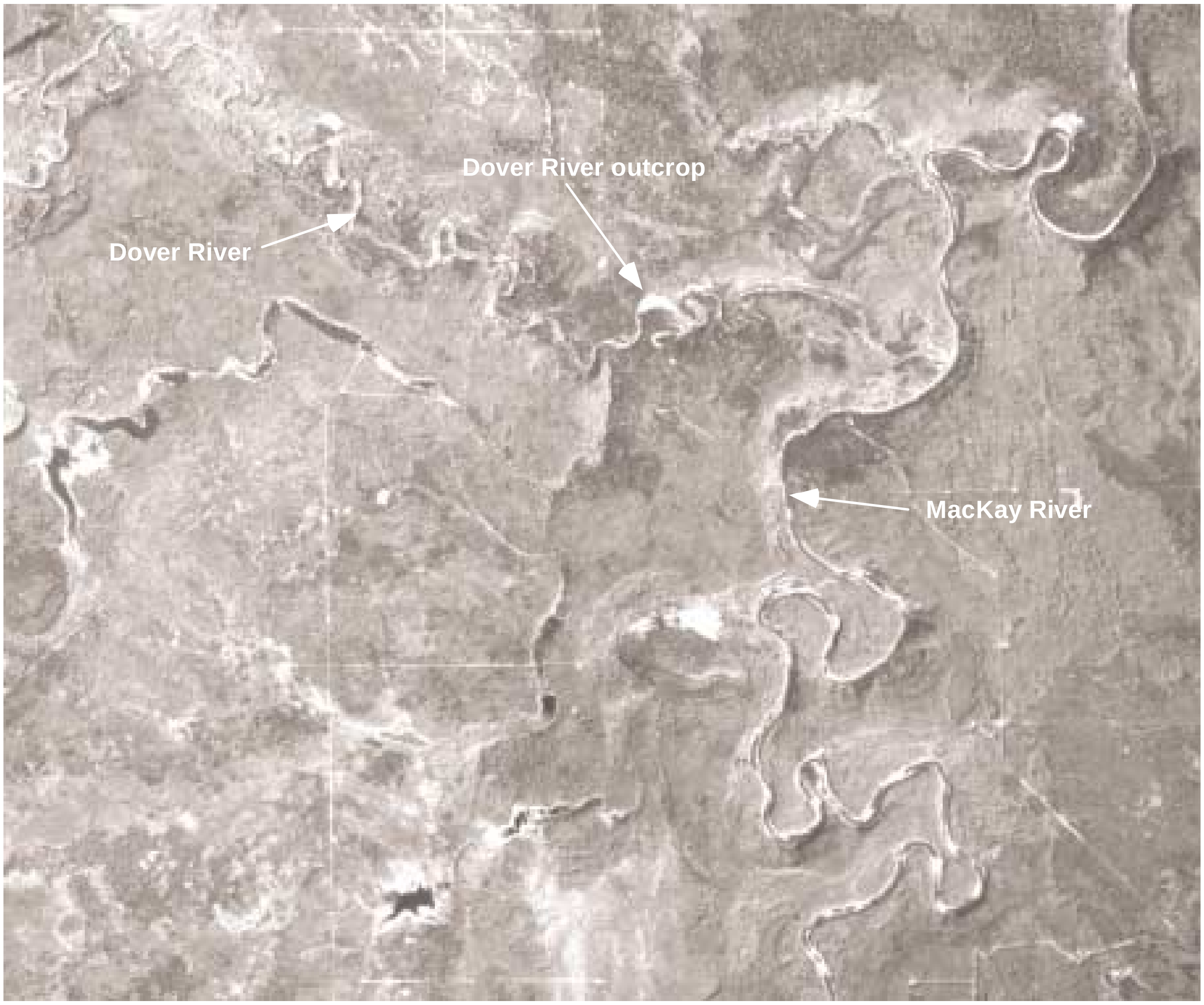
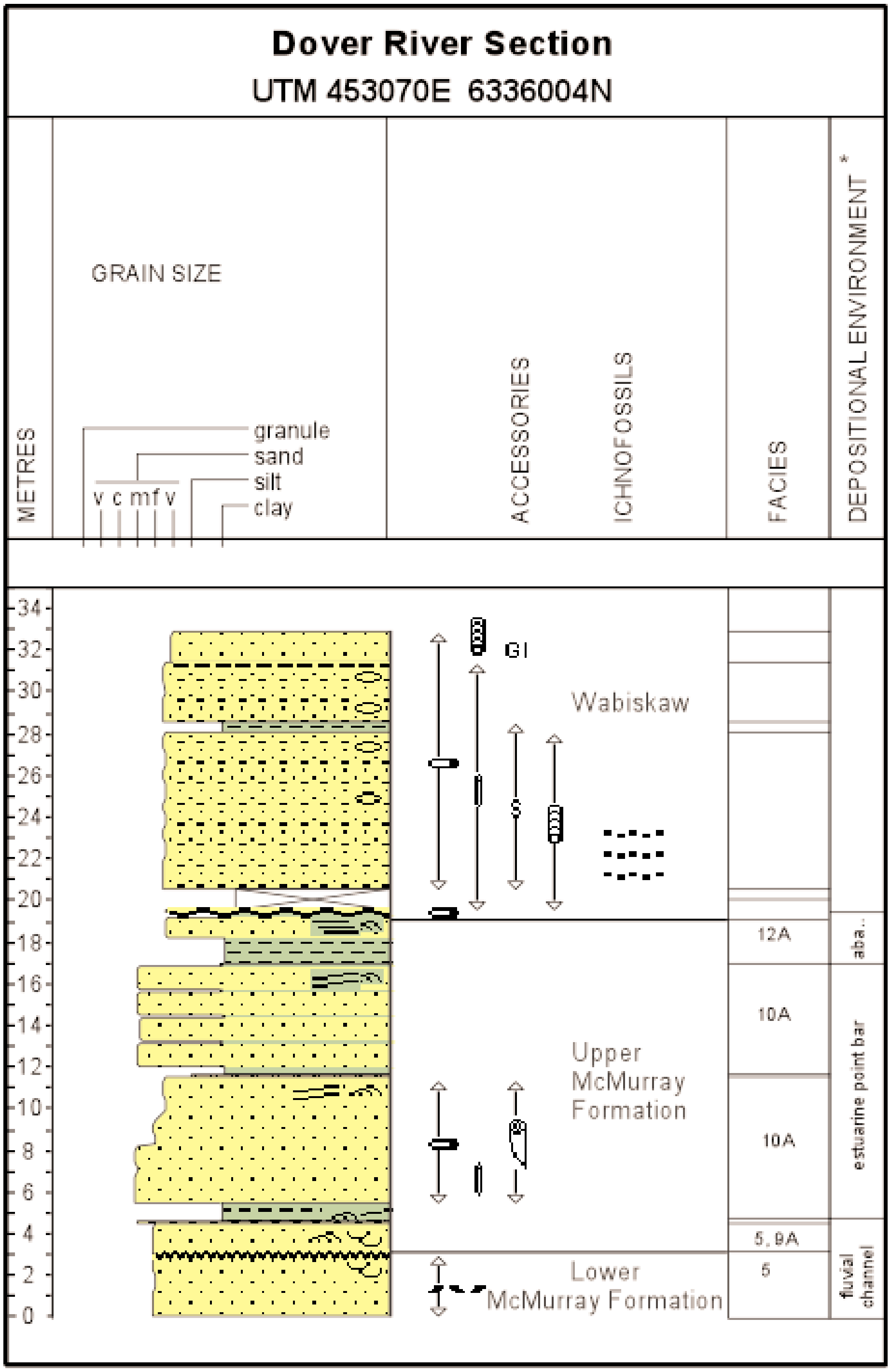


Figure 12.0.2. Aerial photograph showing location of Dover River Section, north of Fort McMurray.



*Complete Description in Appendix 3.

Figure 12.1.1. Schematic representation of the measured Dover River Section (UTM 453070E, 6336004N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

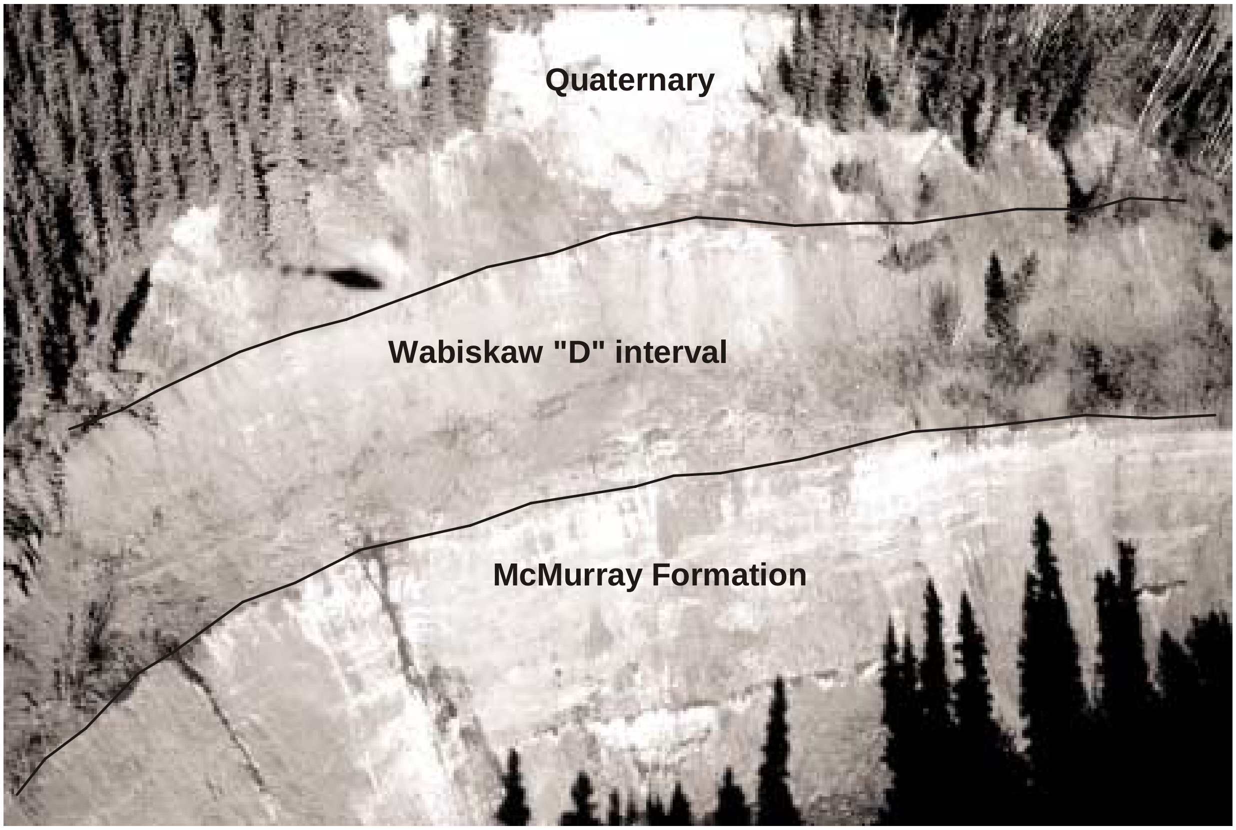


Figure 12.1.2. Overview of thick Wabiskaw D interval overlying estuarine sands (Upper McMurray Formation), Dover River Section, north of Fort McMurray.

13.0 High Hill River Outcrops

Map Coordinates: 74D Fort McMurray, UTM 532600E, 6290820N (for the High Hill River Section #2).

General Location and Outcrop Selection: These outcrops occur on the High Hill River, a generally remote and inaccessible tributary to the Clearwater River. The only reasonable access is via helicopter, or by jetboat during very high water conditions. Three outcrops were measured about 1 to 2 km upstream from the mouth of High Hill River (Figures 13.0.1, 13.0.2)

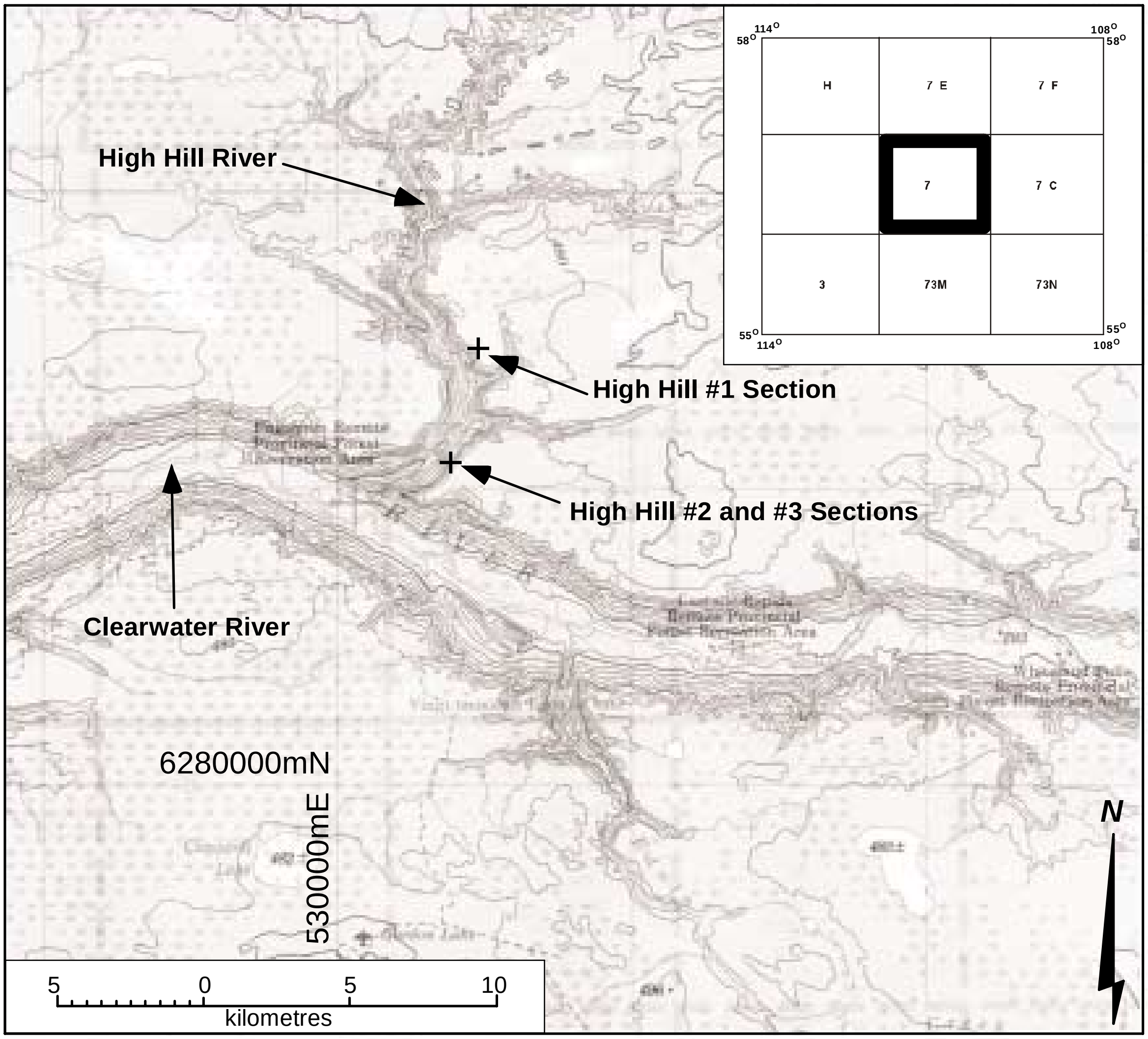


Figure 13.0.1. Map showing location of High Hill sections on the High Hill River, east of Fort McMurray.

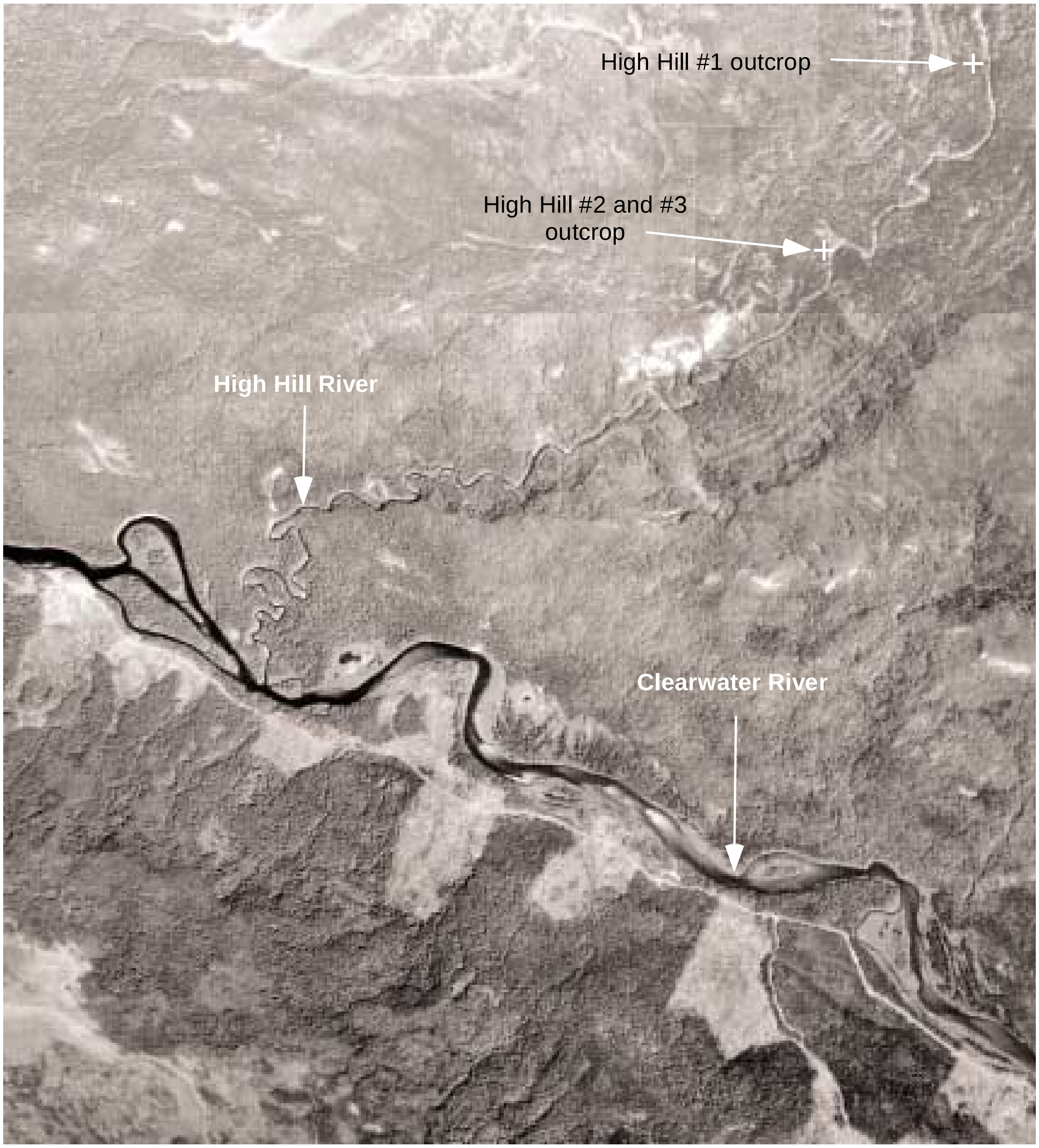


Figure 13.0.2. Aerial photograph showing location of High Hill sections on the High Hill River, east of Fort McMurray.

13.1 High Hill River Section #1

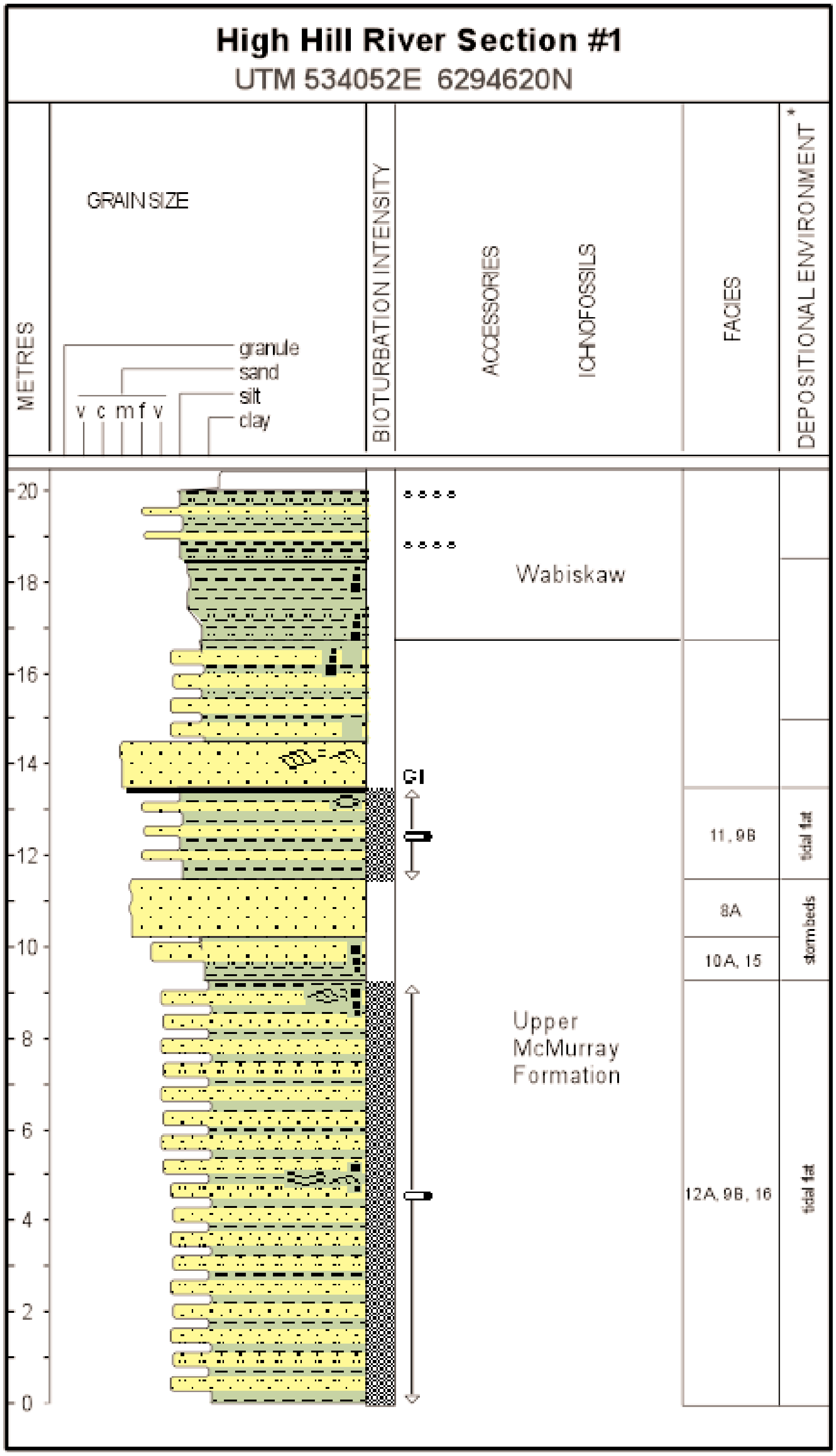
<u>Map Coordinates:</u> 74D Fort McMurray, UTM 534052E, 6294620N

<u>Keynote things to see:</u>

- A single 9 to10 m thick coarsening-upward unit of shaly mudstone to silty sand, with good wave-ripple and graded lamination, wavy bedding, and bioturbation structures;
- Excellent, stacked, thinner (1 to 2 m thick), coarsening-upward units of mudstone to sand, with hummocky and swaley cross-bedding, ripple drift, and combined flow ripples;
- Large-scale siderite concretions at the top of individual coarsening-upwards packages;
- Unconformably overlying the McMurray succession are stacked, fining-upward units of Wabiskaw C, glauconitic sand, silty sand and mudstone, wavy and lenticular bedded, with isolated shell debris dispersed within the coarser interbeds;
- Unconformably overlying the Wabiskaw C interval is a 0.25 to 2 m thick Quaternary sandy silty mud with dispersed pebbles (diamict) (Figures 13.1.1, 13.1.2).

<u>Description:</u> This outcrop (Figures 13.1.2a, b) shows a well-exposed thick succession of coarsening-upward McMurray tidal flat, lower shoreface and storm deposits (Figure 13.1.2c), capped by a largely slumped Clearwater succession (Figures 13.1.2c, d). The section starts about 13.5 m above river level on small cutbanks set back from the river above a treed, grassy, covered slope. The base of the section consists of about 10 m of a coarsening-upward succession, starting with dark-gray, organic, shaly mudstone that grades upwards into a light-green/buff silty fine-grained sand. The mudstone and silty sand is burrowed throughout, with mainly *Planolites* traces. Delicate combined-flow and current-ripple cross-beds are preserved in the coarser-grained silt and sand. The bedding style is wavy and bioturbation structures are prominent. This coarsening-upward package is abruptly overlain by thinner (<1 m), stacked, coarsening-upward mudstone to fine-grained sand, delicately interbedded. Topping this is lenticular, massive, sand that appears to be part of a large concretionary, ball-and-pillow structure, 0.5 to 1.25 m high x 7 m across. Overlying the concretionary sand is a 2 m thick sandy mudstone, lenticular-bedded and highly bioturbated with horizontal *Planolites* traces. This marks the top of the McMurray succession, and is unconformably overlain by marine nearshore and lower shoreface deposits of the Wabiskaw C interval and overlying regional marine shales of the Clearwater Formation. The top of the Clearwater succession is, in turn, unconformably overlain by poorly-sorted Quaternary pebbly, sandy, silty mud diamicton.

<u>Interpretation:</u> The dominance of coarsening-upward cycles, along with wave-formed and combined-flow features, large scale ball-and-pillow structures, and bioturbation features, indicate that these sediments were largely deposited within nearshore settings. The coarsening-upward trends may reflect progradation of muddy shorelines or tidal flats. The ball-and-pillow features are associated with large-scale collapse and liquefaction of sands on a depositional slope, such as the front of a shoreface or the progradational edge of a tidal flat. The topmost McMurray deposits lack the ball-and-pillow structures and wavy- bedding. Instead the top of the McMurray succession has horizontal, sand-filled, *Planolites* burrows within a lenticular, even-bedded, sandy mudstone. This may represent a low-energy tidal flat or a lower shoreface succession. The McMurray Formation is overlain unconformably by the transgressive more offshore marine successions of the Wabiskaw C unit.



*Complete Description in Appendix 3.

Figure 13.1.1. Schematic representation of the measured High Hill River Section #1 (UTM 534052E, 6294620N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 13.1.2a. Thick, bitumen-free sand (McMurray Formation) exposed on the High Hill River, east of Fort McMurray.

Figure 13.1.2b. Heavily slumped mudstone with minor sand interbeds within the Clearwater Formation upstream on the High Hill River.

Figure 13.1.2c. Bitumen-free, high energy cross-bedded sand overlain by cross cutting lateral accretion deposits, High Hill River Section #1, east of Fort McMurray.

13.2 High Hill River Section #2

Map Coordinates: 74D Fort McMurray, UTM 532600E, 6290820N

Keynote things to see:

- Thick fluvial channel bitumen-free sands, with excellent trough and planar tabular cross-bedding with multiple cut-and-fills and rapid facies changes along strike;
- Very thick muddy, low-angle inclined heterolithic stratification that laterally grades into vertical accretion along strike, and is overlain by thick burrowed sandy vertical accretion fill;
- Unconformity between the McMurray sands and overlying glauconitic sands of the Wabiskaw C interval.

Description: This outcrop (Figures 13.2.1, 13.2.2a) shows a well-exposed thick succession of McMurray fluvial deposits (Figure 13.2.2b), capped by a thick estuarine section that was measured at the down-stream end of the outcrop, and described under High Hill River Section #3. At the High Hill River Section #2, the measured outcrop begins 1.5 m above river level and the exposure shows about 39 m of vertically continuous, partly inaccessible, McMurray Formation and Wabiskaw Member units, capped by a thin Quaternary covered on upper treed and grassy slopes (Figure 13.2.2a). The basal 6 to 7 m of sediment consists of pebbly to medium-grained sand, with abundant planar tabular and trough cross-bedding (Figure 13.2.2b), parallel lamination, local rippling in finer interbeds and dispersed coal fragments throughout (Figure 13.2.1). Stacked fining-upward successions occur, starting with pebbly to coarse-grained sand that grades upwards to fine-grained sand. Multiple internal scours cross cut one another within this lowermost unit. The sands are abruptly overlain by a 0.3 m thick organic mudstone. This organic mudstone grades upwards into a 15 m thick, largely inaccessible unit, of muddy, low-angle inclined heterolithic strata that change vertically and laterally along strike into even- and horizontally-bedded mudstone/sandy mudstone. The top of the McMurray Formation is unconformably overlain by about 1 to 2 m of glauconitic sand of the Wabiskaw C Member of the Clearwater Formation.

Interpretation: The lowermost cross-bedded pebbly sand is interpreted as a fluvial channel succession, possibly a preserved remnant of the Lower McMurray Formation. This is overlain by an organic horizon that has been sampled for palynological dating, and is interpreted as overbank deposits, most likely at the top of the Lower McMurray. Next are the thick muddy, low-angle inclined heterolithic stratification of the Upper McMurray, that overall coarsen upwards from organic mudstone to silty mudstone. These interfinger with and are overlain by what appear to be vertical accretionary mudstone units that along strike locally become sandy. Units may represent muddy bay-head delta to bay-fill deposits. The fact that the vertical accretionary deposits coarsen upwards from mudstone to sand, then fining back to mudstone may be due to progradational events associated with bay-head deltas, followed by fining at the top reflecting transgressive flooding events associated with the emplacement of the Wabiskaw marine units.

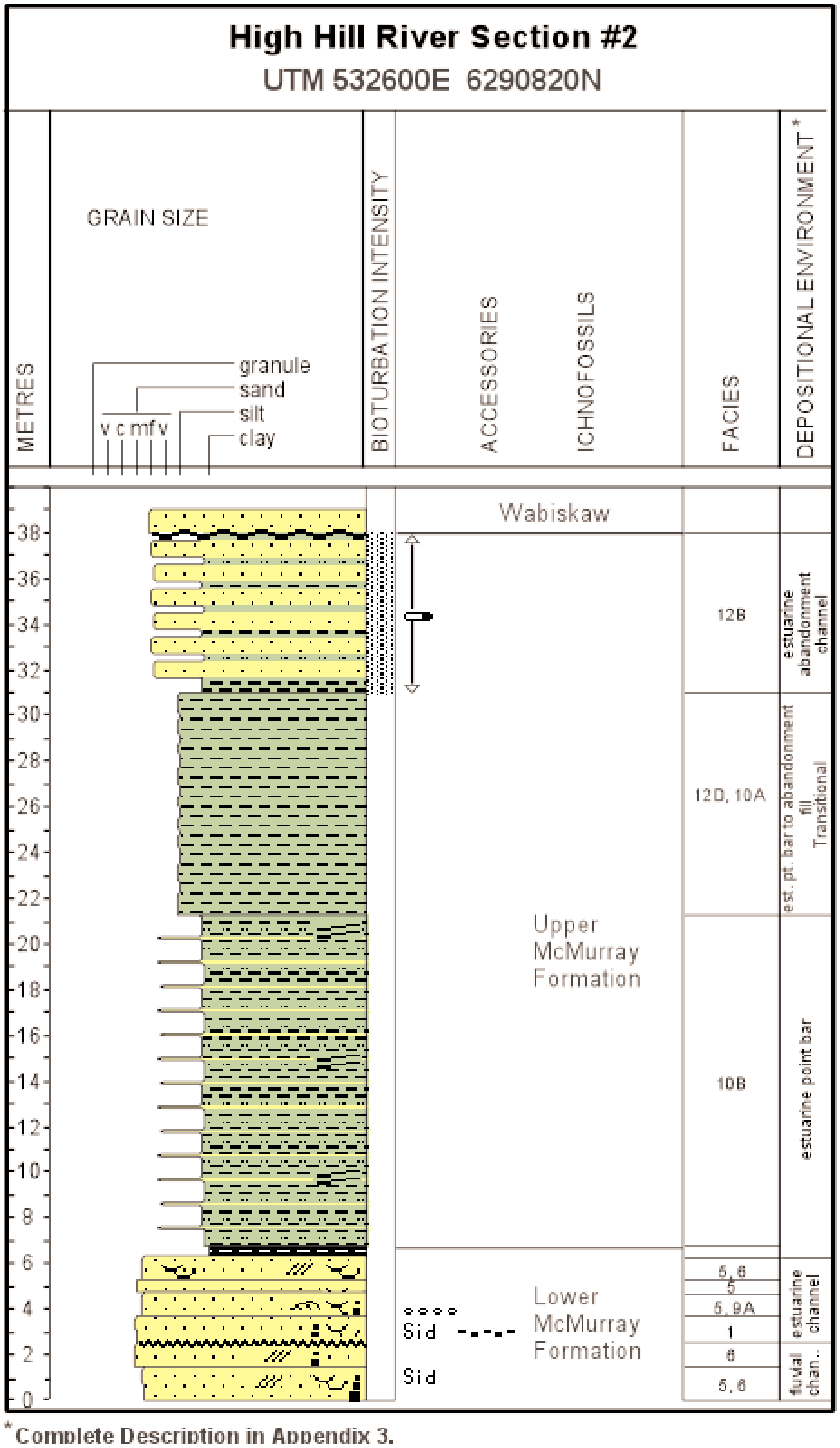


Figure 13.2.1. Schematic representation of the measured High Hill River Section #2 (UTM 532600E, 6290820N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 13.2.2a. Bitumen-free, clean, unconsolidated sand (McMurray Formation), High Hill River, east of Fort McMurray.

13.3 High Hill River Section #3

Map Coordinates: 74D Fort McMurray, UTM 532600E, 6290820N

Keynote things to see:

- Thick water sands, with no oil- or bitumen-staining, in the outcrop;
- Excellent trough and ripple cross-bedding;
- Stacked, generally fining up successions from 0.3 to 1.3 m thick (Figures 13.3.1, 13.3.2).

Description: This section comprises the downstream and slightly younger succession to that described in the High Hill River Section #2 (Figure 13.3.2a). The measured outcrop section begins 5.75 m above river level and the exposure shows 39 m of vertically continuous, mainly inaccessible sediment. Here the Upper McMurray Formation and Wabiskaw Member units are capped by a thin Quaternary unit, which is largely covered on the upper treed and grassy slopes (Figures 13.3.2b, c). Only the basal 6 m of sediment was accessible to be measured (Figure 13.3.1). It consists of pebbly to coarse-grained sand, with abundant trough cross-bedding, parallel lamination, and local rippling in finer beds. A discontinuous organic unit occurs within the lowermost 2 m of section, and was sampled for palynological dating. Further upsection coaly interbeds are more discontinuous, mainly as streaks within otherwise cross-laminated sands. Stacked fining- upward successions grade from pebbly sand to fine-grained sand. At the top of the measured part of the section the sands become somewhat finer-grained, with trough and planar tabular cross-beds, and an increase in the proportion of organic rich muddy interbeds.

The rest of the exposure is inaccessible, but appears to consist of >30 m of muddy, low-angle inclined heterolithic stratification alternating with sandy channel fills and sandy, low-angle inclined heterolithic stratification. At the top of the exposure, the McMurray Formation is unconformably overlain by about 1to 2 m of glauconitic sand of the Wabiskaw C Member of the Clearwater Formation.

Interpretation: The lowermost cross-bedded pebbly sand and sand unit is interpreted as a fluvial channel succession, possibly a preserved remnant of the Lower McMurray Formation. This is interbedded with organic horizons that are interpreted as overbank deposits. Next are the thick muddy to inclined heterolithic stratified Upper McMurray units, that by comparison with other measured outcrop sections are interpreted to represent the lateral and vertical accretion of estuarine point bar and channels. The topmost Wabiskaw C unit is a marine nearshore transgressive sand.

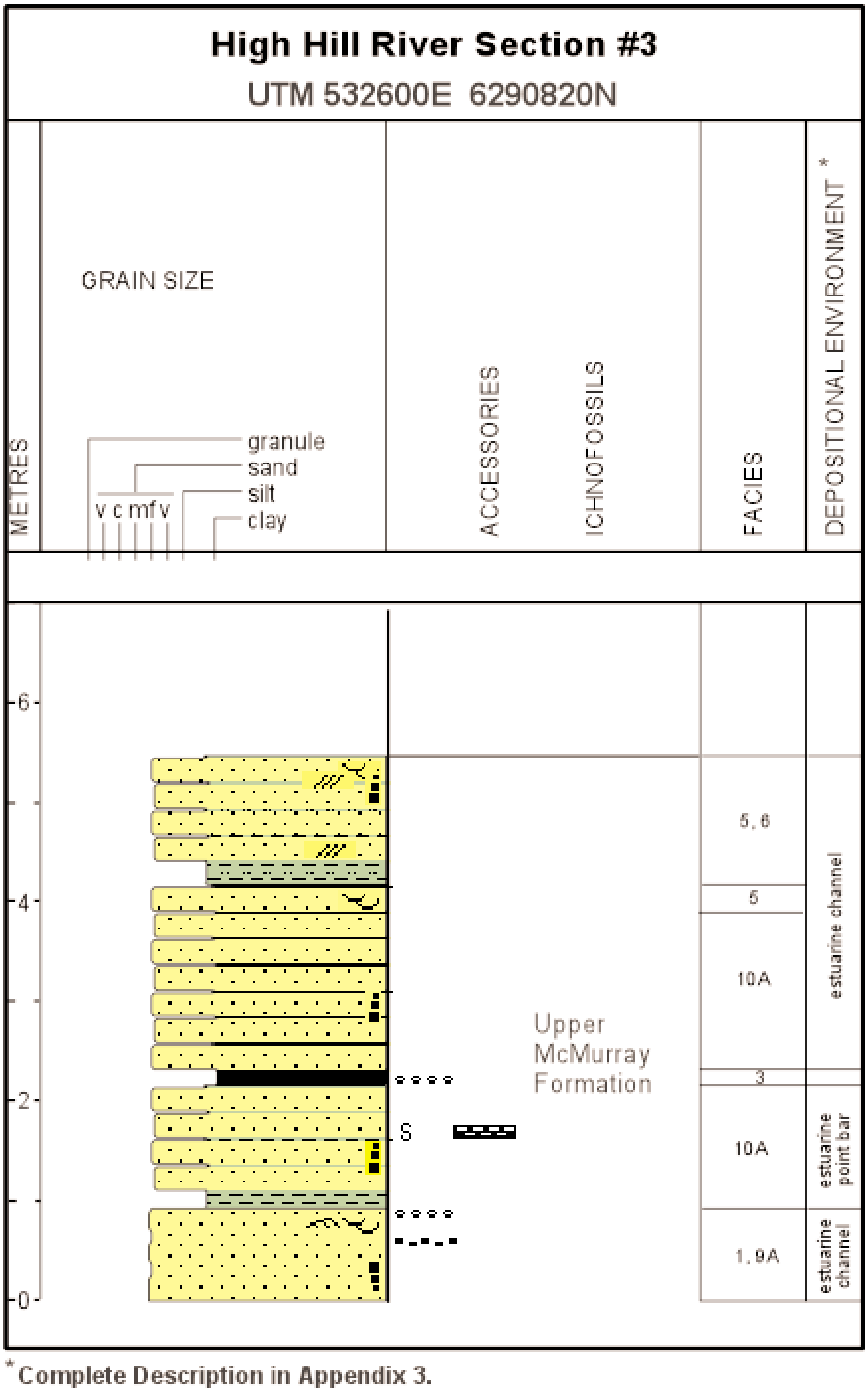


Figure 13.3.1. Schematic representation of the measured High Hill River Section #3 (UTM 532600E, 6290820N). Facies designations as listed in Appendix 2. Vertical scale bars are 1 m in height.

Figure 13.3.2a. Western edge of the High Hill Section #3 on the High Hill River, east of Fort McMurray.

Figure 13.3.2b. Lateral accretion deposits at the top of the High Hill River Section #3.

14. Figures

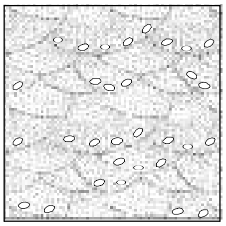
Appendix 1 List of Measured Stratigraphic Sections in the Study Area with UTM Designations and 1:50 000 Scale Map Refrerence Numbers

#	Name of Section	River	Map #	Map Name	Easting	Northing
6.1	MacKay River Amphitheatre #2	MacKay	74E/4	Fort MacKay	459970E	6338850N
6.1	MacKay River Amphitheatre #1	MacKay	74E/4	Fort MacKay	459900E	6338820N
6.1	MacKay River Amphitheatre #1A	MacKay	74E/4	Fort MacKay	459850E	6338750N
6.2	MacKay River Viewpoint	MacKay	74E/4	Fort MacKay	459990E	6339151N
6.3	MacKay River Gauging Station #2	MacKay	74E/4	Fort MacKay	457754E	6341550N
6.4	MacKay River Gauging Station #1	MacKay	74E/4	Fort MacKay	457473E	6341450N
6.5	MacKay River Karst-Fill #1	MacKay	74E/4	Fort MacKay	459500E	6338650N
6.6	MacKay River Karst-Fill #2	MacKay	74E/4	Fort MacKay	459500E	6338650N
6.7	MacKay River Karst-Fill #3	MacKay	74E/4	Fort MacKay	459500E	6338450N
6.8	MacKay River West	MacKay	74E/4	Fort MacKay	454700E	6336490N
6.9	Beaver River Sandstone Quarry	Beaver	74E/4	Fort MacKay	462350E	6330850N
6.10	MacKay River Near Bridge	MacKay	74E/4	Fort MacKay	460723E	6336620N
6.11	MacKay River Upstream of Mouth	MacKay	74E/4	Fort MacKay	461430E	6335910N
7.1	Ells River (99-01) Section #1	Ells	74E/5	Bitumount	458550E	6351300N
7.2	Ells River (99-02) Section #2	Ells	74E/5	Bitumount	458500E	6351200N
7.3	Ells River (99-03) Section #3	Ells	74E/5	Bitumount	458450E	6351050N
7.4	Ells River (99-04) Section #4	Ells	74E/5	Bitumount	458750E	6350875N
7.5	Ells River (99-05) Section #5	Ells	74E/5	Bitumount	458600E	6350800N
7.6	Ells River (99-06) Section #6	Ells	74E/5	Bitumount	454750E	6343300N
7.7	Ells River (99-07) Section #7	Ells	74E/5	Bitumount	454760E	6343310N
7.8	Ells River (99-08) Section #8	Ells	74E/5	Bitumount	455100E	6343580N
7.9	Ells River (99-09) Section #9	Ells	74E/5	Bitumount	455000E	6343500N
7.10	Ells River (99-10) Section #10	Ells	74E/5	Bitumount	455130E	6343550N
7.11	Ells River (99-11) Section #11	Ells	74E/5	Bitumount	455200E	6343380N
8.1	Saline Creek #1	Saline Ck.	74D/11	Fort McMurray	478730E	6283383N
8.1	Saline Creek #2	Saline Ck.	74D/11	Fort McMurray	478730E	6283480N
8.1	Saline Creek #3	Saline Ck.	74D/11	Fort McMurray	478740E	6283550N
8.1	Saline Creek #4	Saline Ck.	74D/11	Fort McMurray	478825E	6283721N
8.2	Hangingstone River #1	Hangingstone	74D/11	Fort McMurray	477530E	6284570N
8.2	Hangingstone River (Bridge) #2	Hangingstone	74D/11	Fort McMurray	478100E	6284600N
8.3.1	Horse River #1	Horse	74D/11	Fort McMurray	475560E	6285050N
8.3.2	Horse River #2	Horse	74D/11	Fort McMurray	476070E	6284520N
8.3.3	Horse River #3	Horse	74D/11	Fort McMurray	475550E	6283820N
8.3.4	Horse River (Roadcut) #4	Horse	74D/11	Fort McMurray	476200E	6285050N
9.1	Crooked Rapids #1	Athabasca	74D/12	Cascade Rapids	446815E	6272058N
9.2	Crooked Rapids #2	Athabasca	74D/12	Cascade Rapids	446608E	6272690N
9.3	Mountain Rapids	Athabasca	74D/12	Cascade Rapids	468880E	6281093N
9.4	Athabasca Powerline	Athabasca	74D/11	Fort McMurray	470012E	6282431N
9.5	McMurray Fm. Type #1	Athabasca	74D/11	Fort McMurray	476166E	6291060N
9.6	McMurray Fm. Type #2	Athabasca	74D/11	Fort McMurray	476157E	6291350N
9.7	McMurray Fm. Type #3	Athabasca	74D/11	Fort McMurray	476096E	6291400N
9.8	McMurray Fm. Type #4	Athabasca	74D/11	Fort McMurray	476120E	6291840N
9.9	Fluvial Marl	Athabasca	74D/14	Wood Creek	474746E	6305712N
9.10	Marl Upper	Athabasca	74D/14	Wood Creek	474800E	6305750N
9.11	Tar Island Fluvial	Athabasca	74D/14	Wood Creek	472210E	6313710N
9.12	Athabasca Sinkhole South	Athabasca	74D/14	Wood Creek	463205E	6342138N
9.13	Athabasca Sinkhole North	Athabasca	74D/14	Wood Creek	463100E	6342230N
9.14.	Daphne Island West #1	Athabasca	74E/5	Bitumount	459630E	6349200N
9.14.	Daphne Island West #2	Athabasca	74E/5	Bitumount	459640E	6349110N
9.14.	Daphne Island West #3	Athabasca	74E/5	Bitumount	459650E	6349002N
9.15.	Daphne Island East #1	Athabasca	74E/5	Bitumount	460230E	6350120N
9.15.	Daphne Island East #2	Athabasca	74E/5	Bitumount	460220E	6350200N
9.15.	Daphne Island East #3	Athabasca	74E/5	Bitumount	460250E	6350300N
9.15.	Daphne Island East #4	Athabasca	74E/5	Bitumount	460230E	6350370N
9.15.	Daphne Island. East #5	Athabasca	74E/5	Bitumount	460210E	6350433N

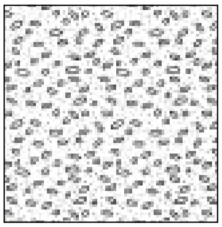
9.16	Pierre River Mouth (Lower)	Athabasca	74E/5	Bitumount	462150E	6367150N
9.17	Pierre River Mouth (Upper)	Athabasca	74E/5	Bitumount	462230E	6367250N
9.18	Eymundson Creek Mouth #1	Athabasca	74E/5	Bitumount	465500E	6371500N
9.19	Eymundson Creek Mouth #2	Athabasca	74E/5	Bitumount	465600E	6371600N
9.20	Eymundson Creek Mouth #3	Athabasca	74E/5	Bitumount	465700E	6371800N
9.21	Eymundson Creek Mouth #4	Athabasca	74E/5	Bitumount	465959E	6371974N
10.1	Steepbank River #3.1	Steepbank	74E/3	Hartley Creek	473675E	6319100N
10.1	Steepbank River #3.2	Steepbank	74E/3	Hartley Creek	473700E	6319070N
10.1	Steepbank River #3.3	Steepbank	74E/3	Hartley Creek	473725E	6319050N
10.2	Steepbank River #4.1	Steepbank	74E/3	Hartley Creek	473600E	6318860N
10.2	Steepbank River #4.2	Steepbank	74E/3	Hartley Creek	473550E	6318800N
10.3	Steepbank River #7	Steepbank	74E/3	Hartley Creek	474440E	6318110N
10.4	Steepbank River #9.1	Steepbank	74E/3	Hartley Creek	475300E	6317760N
10.4	Steepbank River #9.2	Steepbank	74E/3	Hartley Creek	475400E	6317700N
10.4	Steepbank River #9.3	Steepbank	74E/3	Hartley Creek	475370E	6317610N
11.1	Christina River #1	Christina	74D/11	Fort McMurray	498075E	6278050N
11.2	Christina River #2	Christina	74D/11	Fort McMurray	498350E	6277620N
11.3	Christina River #3 Downstream	Christina	74D/11	Fort McMurray	499440E	6277180N
11.4	Christina River #3 Upstream	Christina	74D/11	Fort McMurray	499520E	6277150N
11.5	Christina River #4	Christina	74D/11	Fort McMurray	512121E	6265989N
12.0	Dover River	Dover	74/E4	Fort MacKay	453070E	6336004N
13.1	High Hill River #1	High Hill	74D	Fort McMurray	534052E	6294620N
13.2	High Hill River #2	High Hill	74D	Fort McMurray	532600E	6290820N
13.3	High Hill River #3	High Hill	74D	Fort McMurray	532600E	6290820N

Appendix 2 Graphic Key and Tabulation of Facies Classification, McMurray Formation, Athabasca Oil Sands Deposit, Fort McMurray Area (modified from Hein et al., 2000)

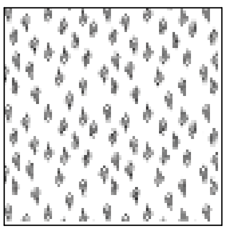
Facies 1: Coarse Grained to Pebbly, Poorly Sorted, Trough Cross-Bedded Sand



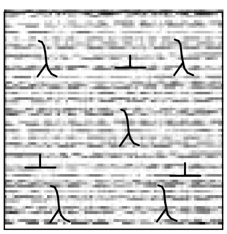
Facies 2: Very fine Grained to Pebbly, Poorly Sorted, Graded Gravel



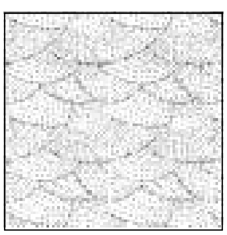
Facies 3: Carbonaceous to Coaly, Rooted Silty Mudstone



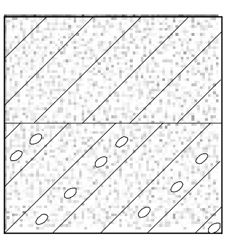
Facies 4: Mottled Argillaceous Sandy Marl



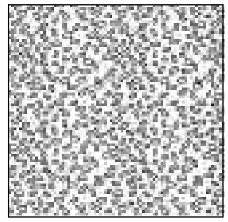
Facies 5: Fine to Medium Grained, Trough Cross-Bedded Sand



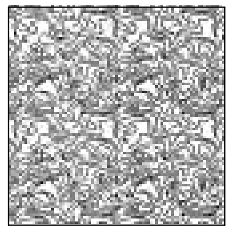
Facies 6: Fine Grained to Pebbly, Planar-Tabular Cross Bedded Sand



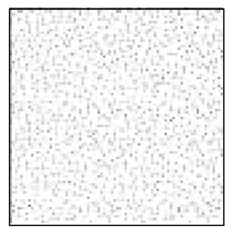
Facies 7A: Fine to Medium Grained, Poorly Sorted, Mudstone-Clast Breccia



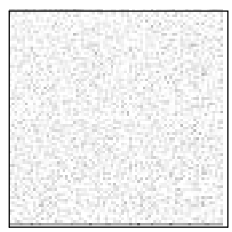
Facies 7B: Slumped Sand and Mudstone



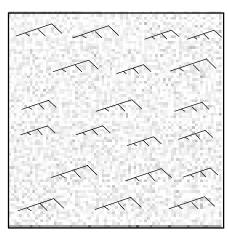
Facies 8A: Fine to Coarse Grained, Massive Sand



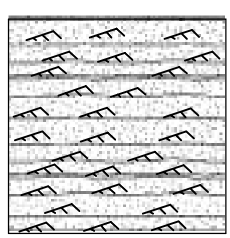
Facies 8B: Poorly to Well Sorted, Massive Sandy Silt/Silty Sand



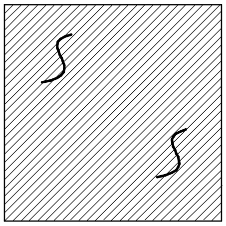
Facies 9A: Very Fine to Fine Grained, Ripple Cross-Bedded Sand



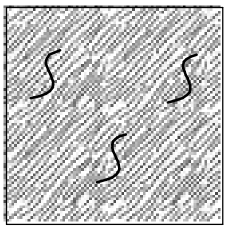
Facies 9B: Very Fine to Fine Grained, Flaser Bedded Sand and Mudstone



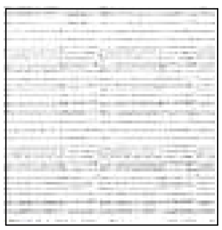
Facies 10A: Bioturbated, Inclined Heterolithic Stratified Muddy Sand



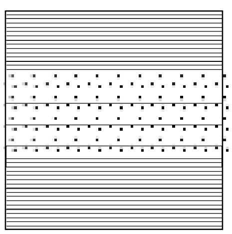
Facies 10B: Bioturbated, Inclined Heterolithic Stratified Sandy Mudstone



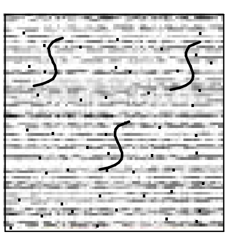
Facies 11: Very Fine to Medium Grained, Stratified Sand



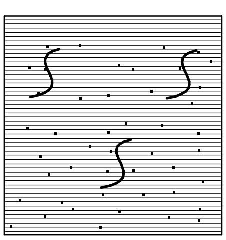
Facies 12A: Rhythmically Laminated Sand and Mudstone



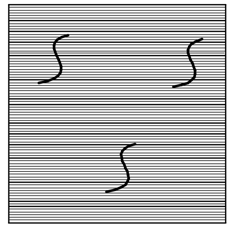
Facies 12B: Very Fine to Fine Grained, Bioturbated, Muddy Sand



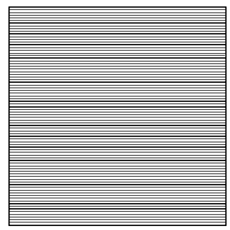
Facies 12C: Very Fine to Fine Grained, Bioturbated, Sandy Mudstone



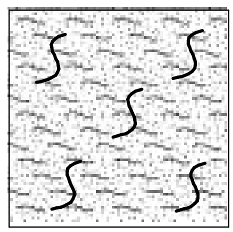
Facies 12D: Laminated to Thinly Interbedded, Bioturbated Silty mudstone



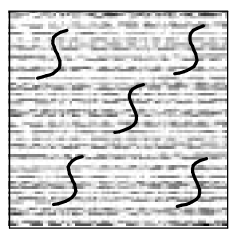
Facies 12E: Thinly Laminated Silty Mudstone/Mudstone



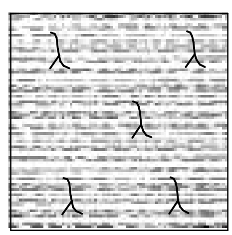
Facies 13A: Very Fine Grained, Heavily Burrowed Muddy Sand,



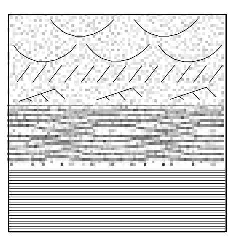
Facies 13B: Intensely Burrowed, Silty Mudstone/Muddy Silt



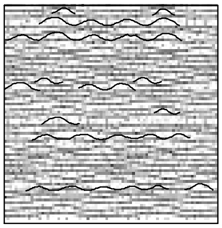
Facies 14: Coaly and/or Rooted, Sandy-Muddy Siltstone to Silty Mudstone



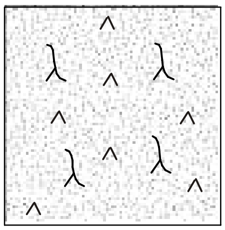
Facies 15: Coarsening-Upward Mudstone-Siltstone-Sand



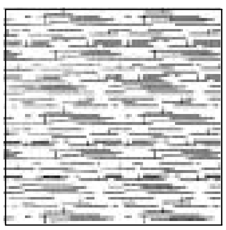
Facies 16: Very Fine to Fine Grained, Well Sorted, Wave Rippled Sand



Facies 17: Silicified Sandstone ('Beaver River Sandstone')



Facies 18: Poorly Sorted, Karstic Calci-/Siliciclastics



Appendix 3 Graphic Key to Symbols and Detailed Applecore Logs of Measured Stratigraphic Sections

Graphic Legend for Outcrop Logs

UTM Coordinates: 1:50 000 Maps

LEGEND

LITHOLOGY

SAND/SANDSTONE	sandy silt	organic shale	LIMESTONE
silty sand	SHALE/MUDSTONE	coal	Calcareous shale
shaly sand	silty shale	conglomerate	Coquina
SILT/SILTSTONE	sandy shale	breccia	

CONTACTS

Scoured	Bioturbated	Undulating

PHYSICAL STRUCTURES

- Current Ripples	- Trough Cross-strat.	- Oscillatory Ripples
- Climbing Ripples	- Planar Tabular Bedding	- High Angle Tabular Bedding
- Low Angle Tabular Bedding	- Flaser Bedding	- Wavy Parallel Bedding
- Lenticular Bedding	- Herringbone Cross-strat.	- Hummocky Cross-strat.
- Convolute Bedding	- Chaotic Bedding	- Scour
- Graded Bedding	- Reverse Graded Bedding	- Fault
- Reactivation Surface	- Double Mud Drapes	- Load Casts
- Tight zone		

LITHOLOGIC ACCESSORIES

- Sand Lamina	- Shale Lamina	- Pebbles/Granules
- Coal Lamina	- Organic Shale Lamina	- Calcareous
Sid - Siderite	Gl - Glauconitic	Py - Pyrite
- Rip Up Clasts	- Coal Fragments	Wd - Wood Fragments
- Shell Fragments	Palsl - Paleosol Horizon	Mc - Micaceous
S - Sulfur	Fld - Feldspathic	Fe - Iron

ICHNOFOSSILS

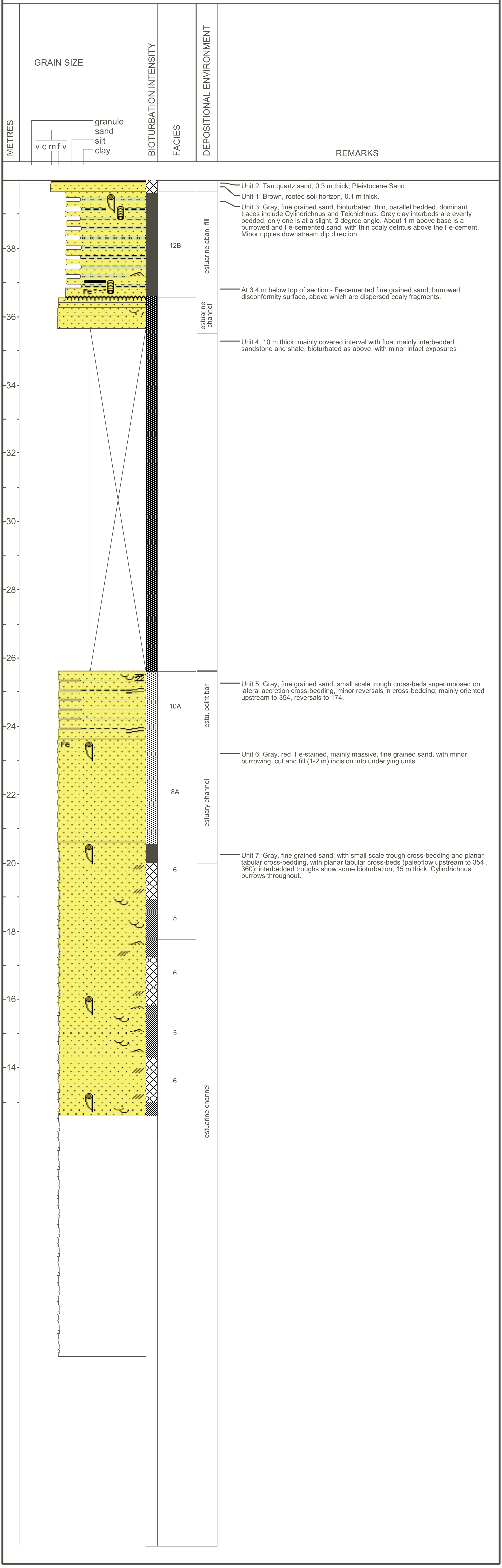
- Rootlets	- Skolithos	- Planolites
- Gyrolithes	- Diplocraterion	- Arenicolites
- Ophiomorpha	- Escape Trace	- Cylindrichnus
- Thalassinoides	- Teichichnus	

BIOTURBATION

- Abundant
- Common
- Moderate
- Rare
- Barren

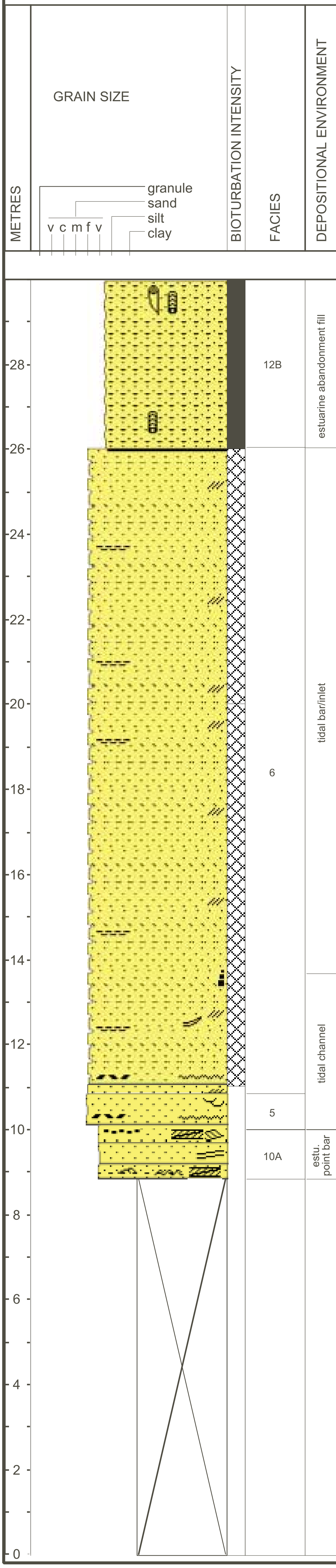
MacKay River Amphitheatre #1 Section

UTM 0459970E 6338850N



MacKay River Amphitheatre #2 Section

UTM 0459900E 6338820N



REMARKS

Unit 1: Gray, muddy, fine grained sand, evenly, thin bedded, and bioturbated as in upstream section.

Unit 2: Gray, fine grained sand, with sets of stacked planar tabular cross-beds, the thickest set is at the base, 1.5 m thick, prominent double-mud drapes on the foresets. Base of this unit contains mudstone rip-up clasts, scoured lower surface. No traces. Unit is 12 - 15 m thick. Paleoflows uniformly to north, 350 to 360.

Unit 3: Gray, fine grained sand, planar tabular crossbed set with double mud drapes on foresets; Paleoflow to north, 354 degrees.

Unit 4: Gray, fine grained sand, with large trough crossbed set, 0.8 - 1 m thick, with scattered shale clasts along crossbeds.

Unit 5: Gray, fine grained sand with rotated twigs along crossbeds. Paleoflow to the north, 360.

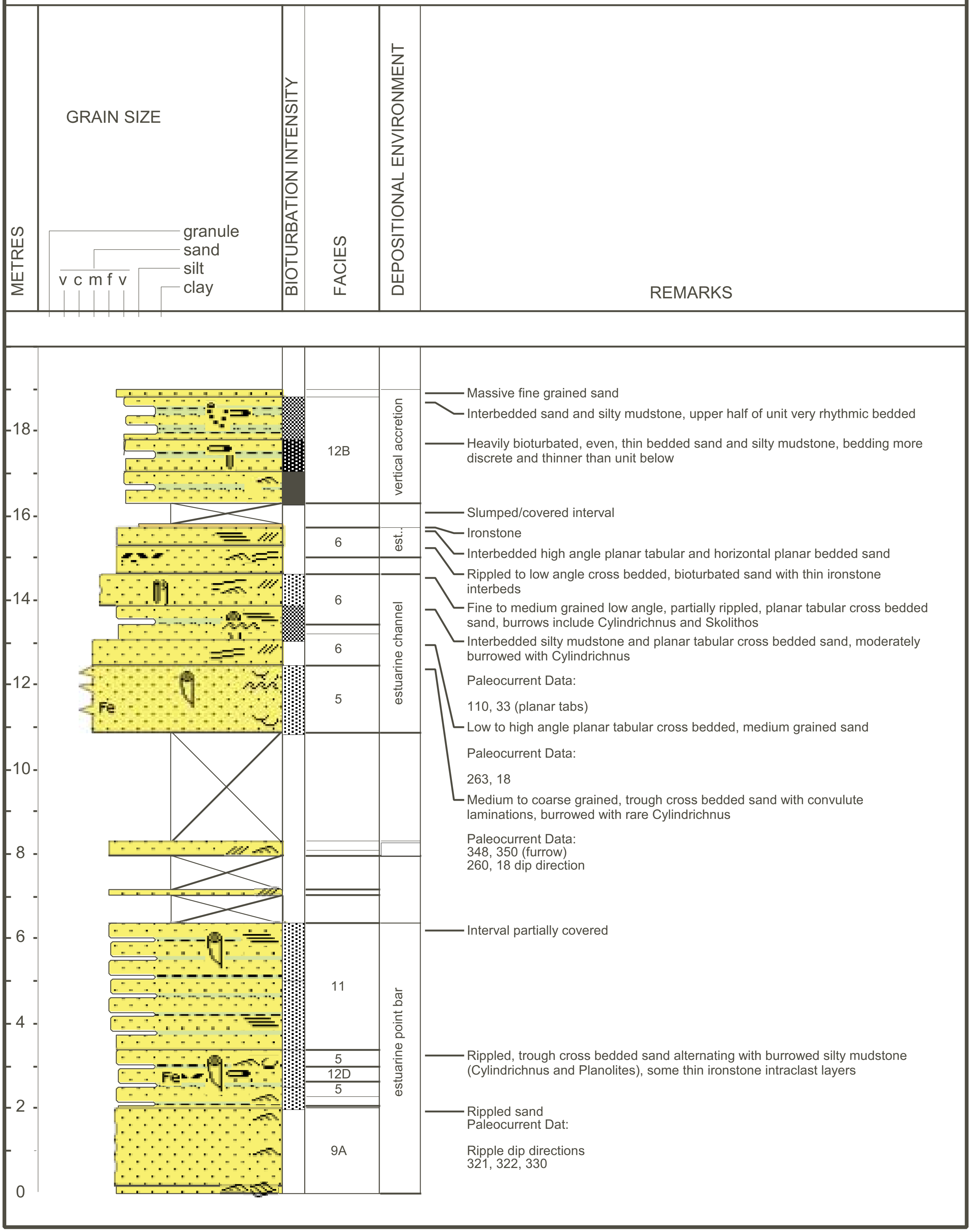
Unit 6: Gray shaly sand, inclined lateral accretion crossbeds, with ripple drift sand alternating with shale; no burrows; Lateral accretion crossbeds dip to north; ripple drift climbs to the south (i.e. reversing); 0.3 m thick.

Unit 7: Gray, very fine grained sand, mainly massive, with vague low-angle crossbedding dipping north (? low angle troughs or lateral accretion crossbedding).

Unit 8: Gray, very fine grained, muddy sand, with large scale lateral accretion crossbedding dipping south, with ripples and convolute ripples migrating to the south, 174 - 180. Muddy partings between sand.

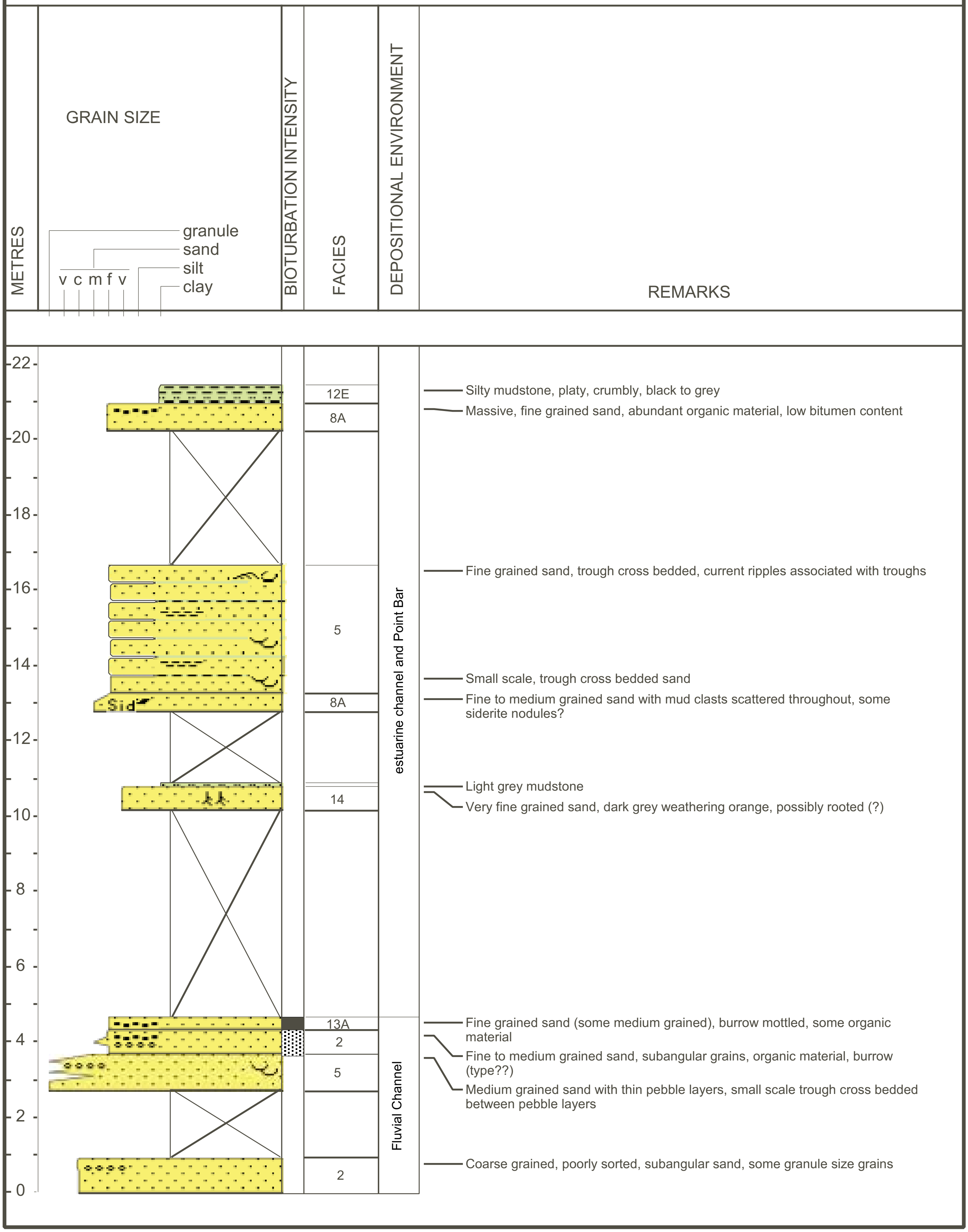
MacKay River Viewpoint Section

UTM 0459990E 6339151N



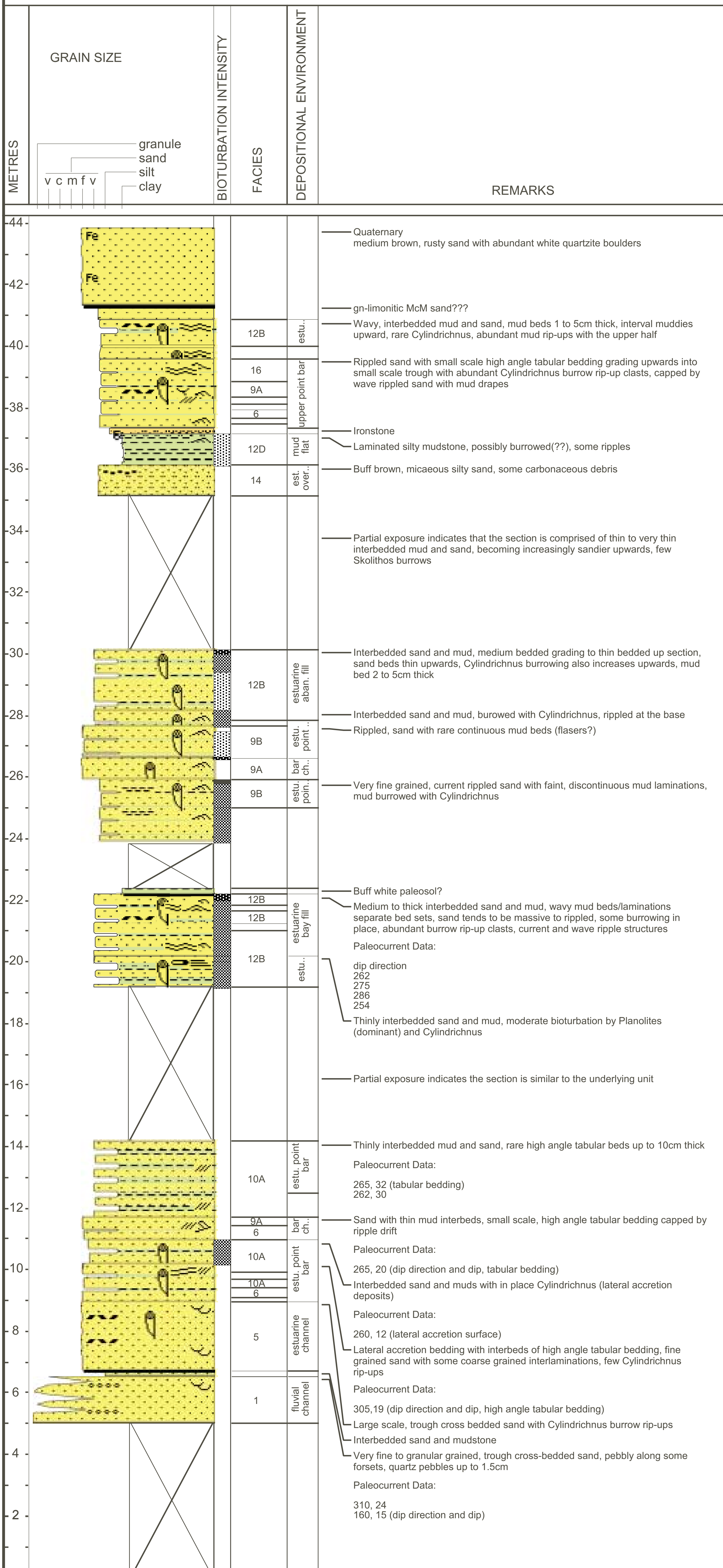
MacKay River Gauging Station #2 Section

UTM 0457754E 6341550N



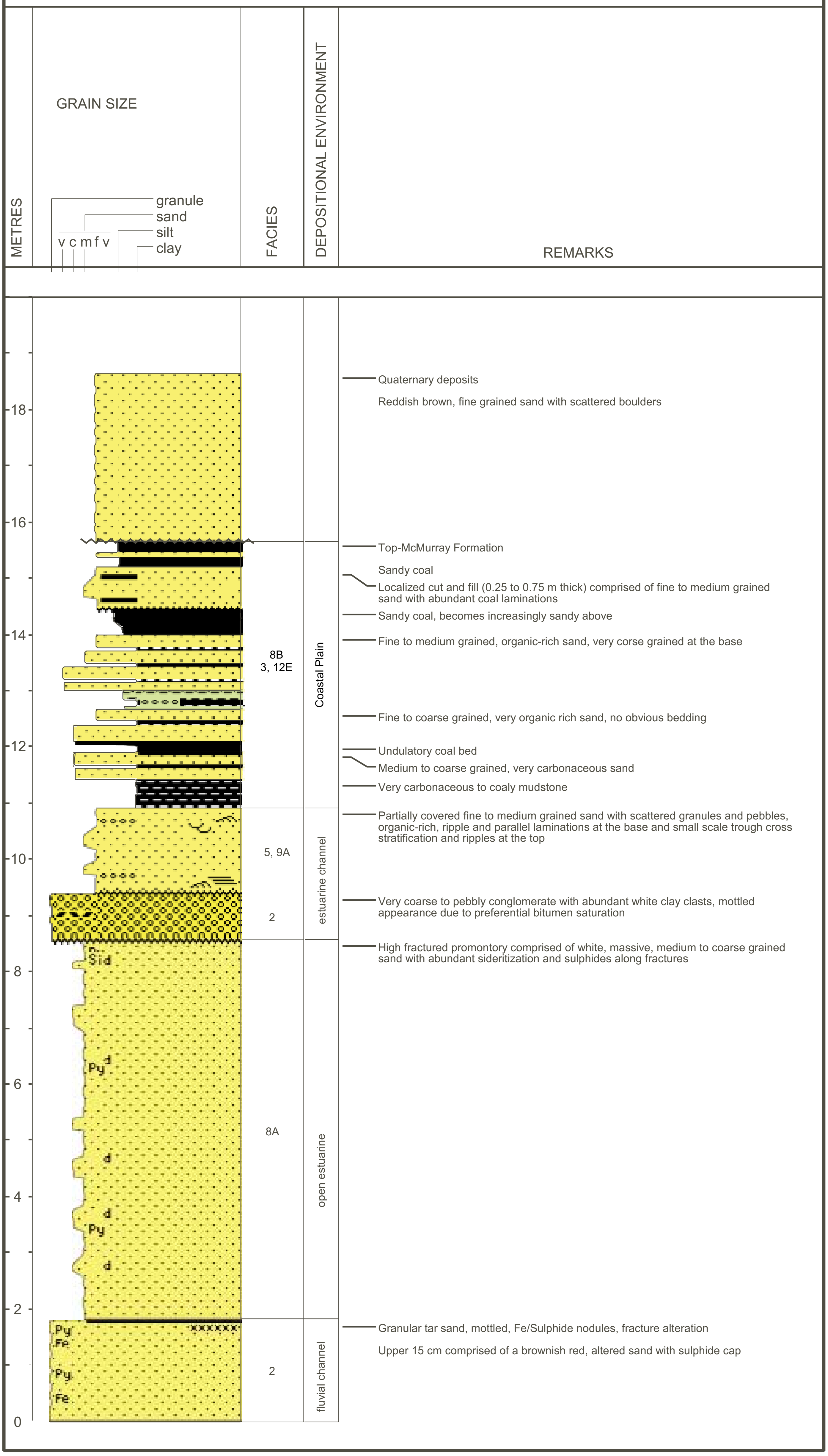
MacKay River Gauging Station #1 Section

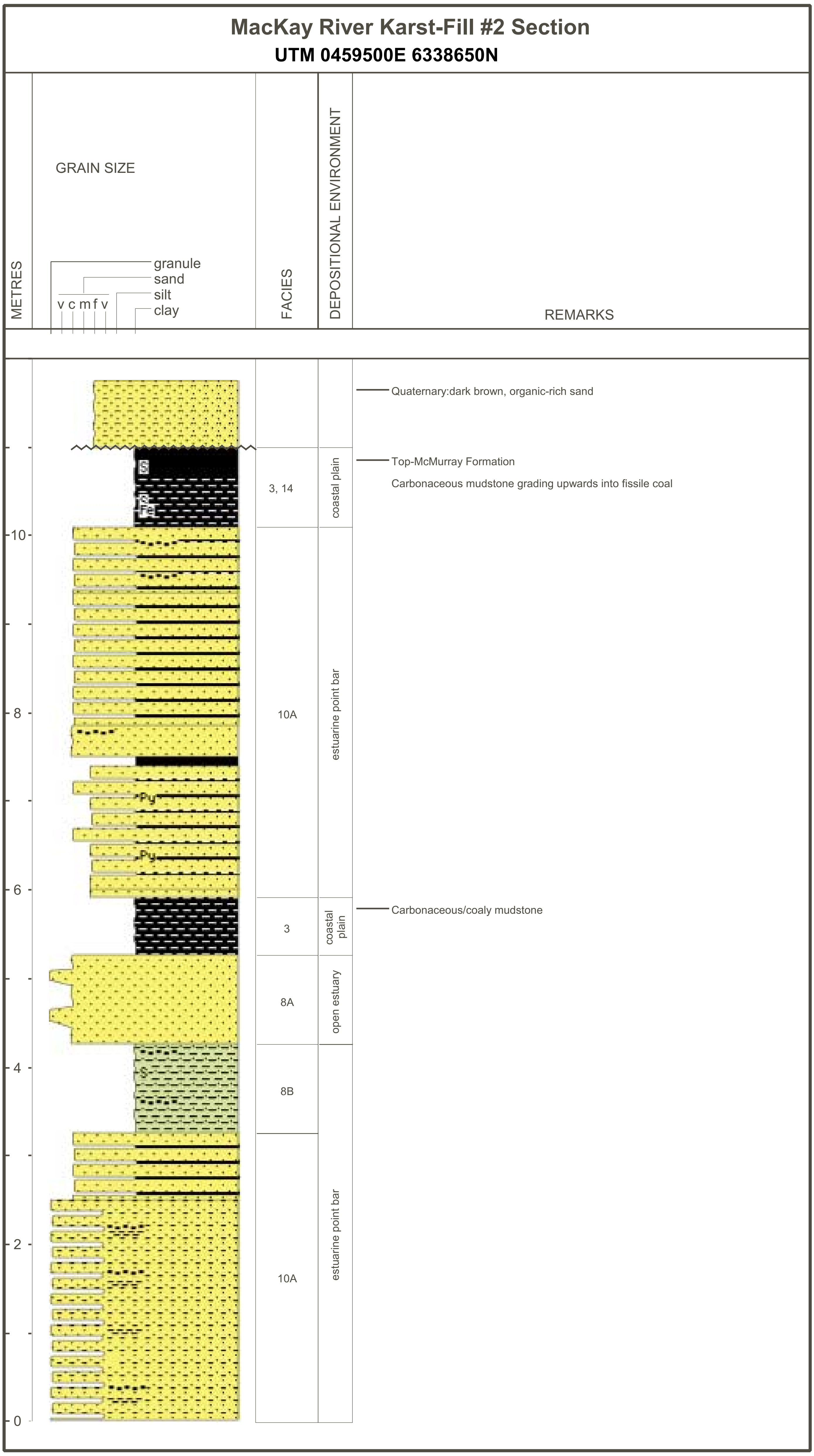
UTM 0457473E 6341450N

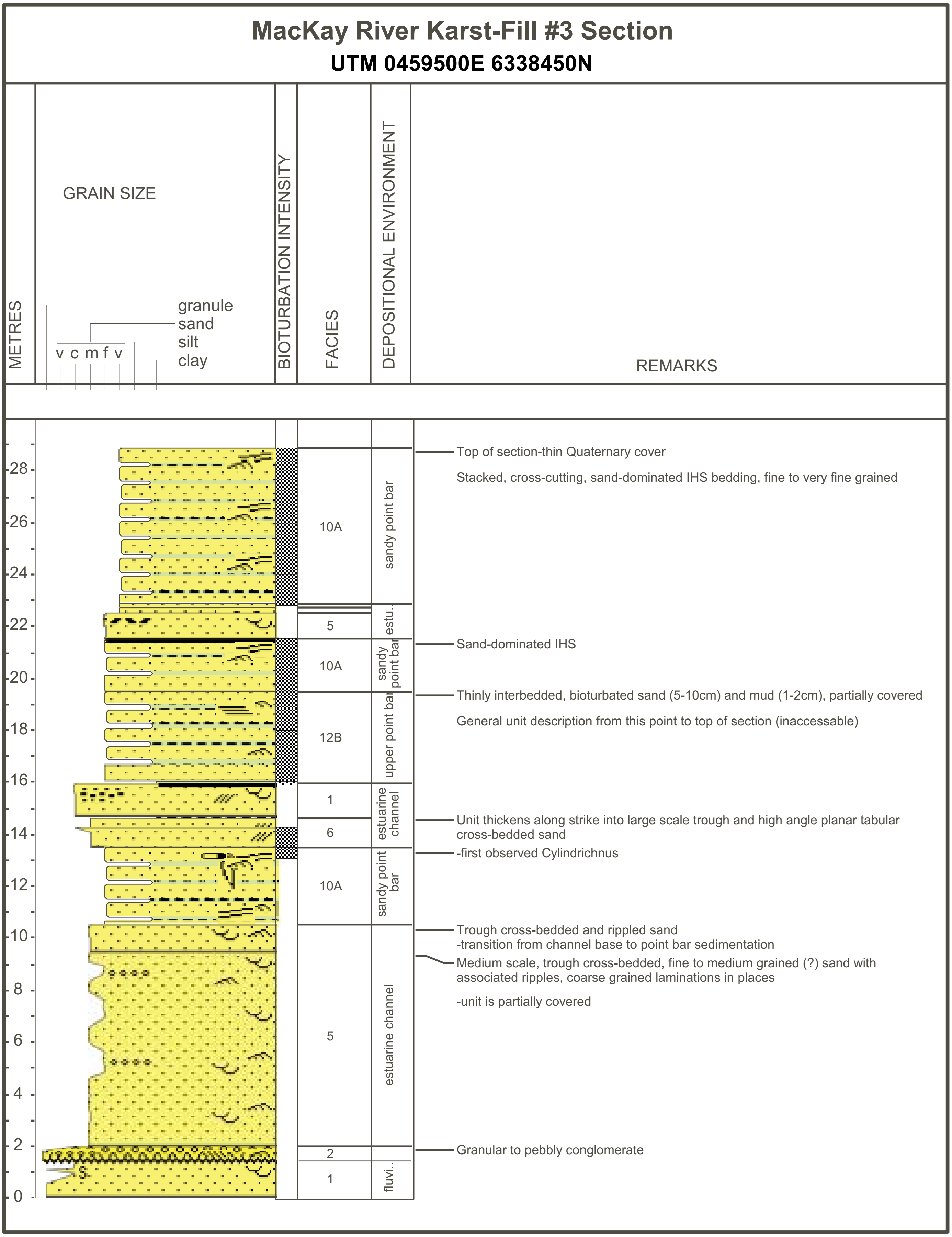


MacKay River Karst-Fill #1 Section

UTM 0459500E 6338650N

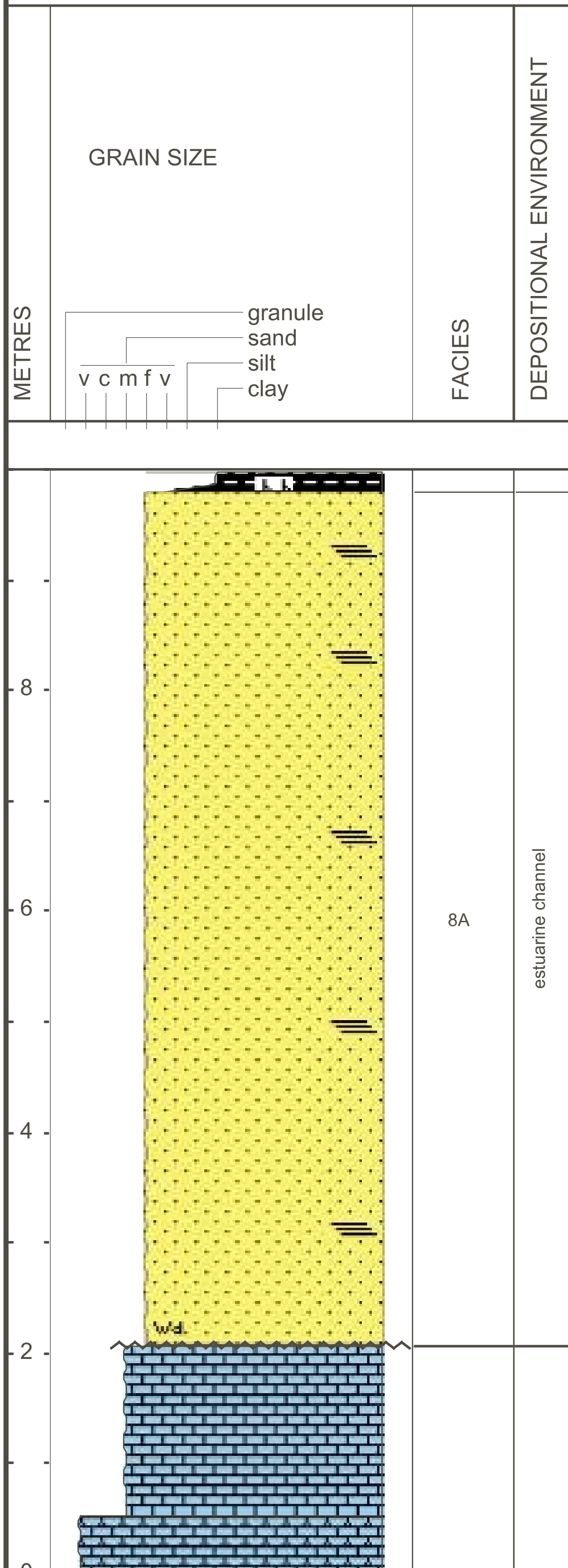



MacKay River Karst-Fill #2 Section
UTM 0459500E 6338650N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
Quaternary:dark brown, organic-rich sand
Top-McMurray Formation
Carbonaceous mudstone grading upwards into fissile coal
3, 14
coastal plain
10A
estuarine point bar
Py
Carbonaceous/coaly mudstone
3
coastal plain
8A
open estuary
8B
10A
estuarine point bar
10
8
6
4
2
0


MacKay River Karst-Fill #3 Section
UTM 0459500E 6338450N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10A
5
10A
12B
1
6
10A
5
2
1
sandy point bar
estu..
sandy point bar
upper point bar
estuarine channel
sandy point bar
estuarine channel
fluvi..
Top of section-thin Quaternary cover
Stacked, cross-cutting, sand-dominated IHS bedding, fine to very fine grained
Sand-dominated IHS
Thinly interbedded, bioturbated sand (5-10cm) and mud (1-2cm), partially covered
General unit description from this point to top of section (inaccessable)
Unit thickens along strike into large scale trough and high angle planar tabular cross-bedded sand
-first observed Cylindrichnus
Trough cross-bedded and rippled sand
-transition from channel base to point bar sedimentation
Medium scale, trough cross-bedded, fine to medium grained (?) sand with associated ripples, coarse grained laminations in places
-unit is partially covered
Granular to pebbly conglomerate

MacKay River West Section

UTM 0454700E 6336490N



REMARKS

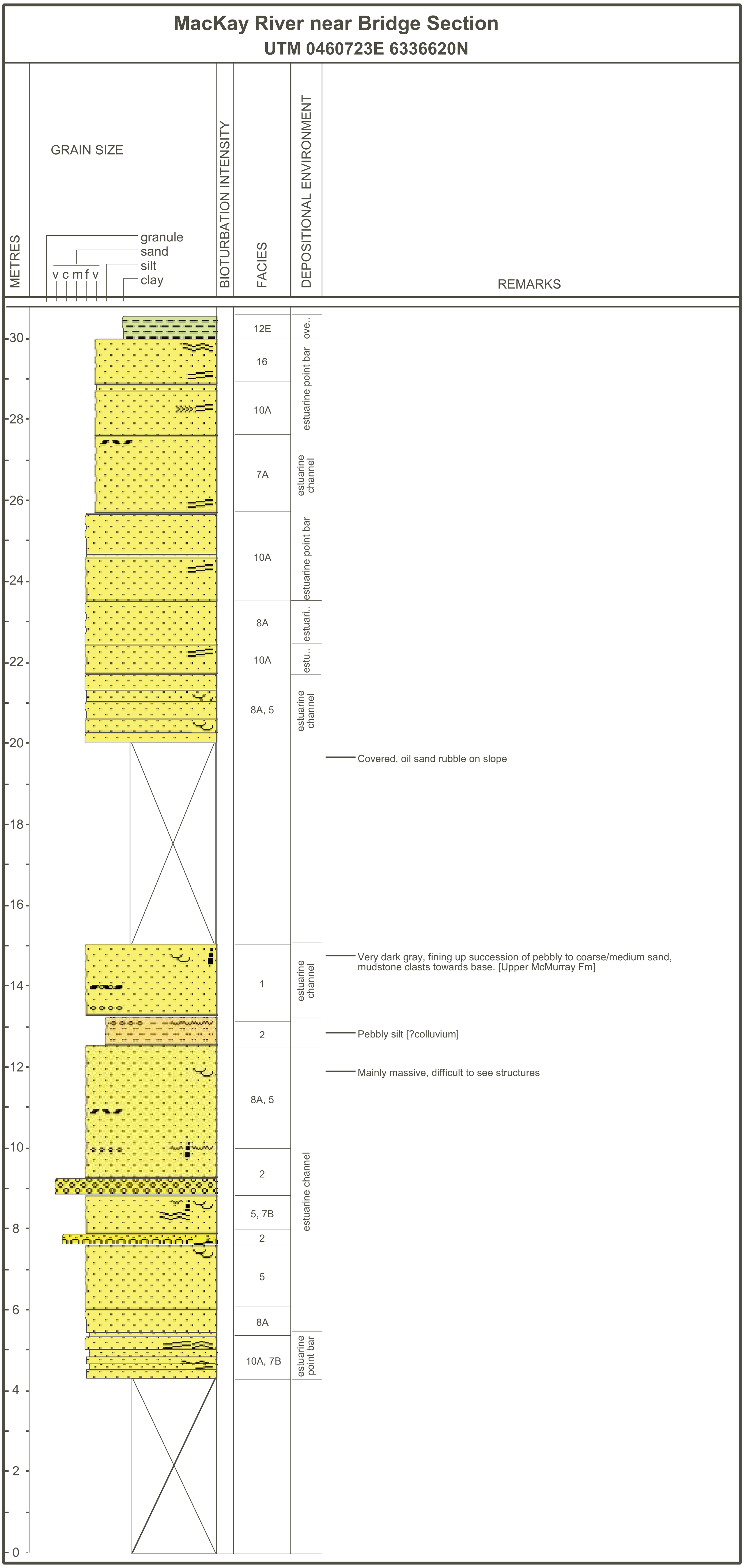
Modern soil cap, rooted.

McMurray Formation
Vertical walls, inaccessible; ~ 6-8 m of mainly massive sand, cutout downstream by 2.5 m of till and glaciofluvial outwash, including resedimented tarsand balls in the outwash gravels, capped by a rooted, modern soil horizon.

Fe-stained and cemented along unconformity surface. Unconformity has a pronounced undulatory surface along the bank, associated with folding of the carbonates, due to salt solution tectonics.

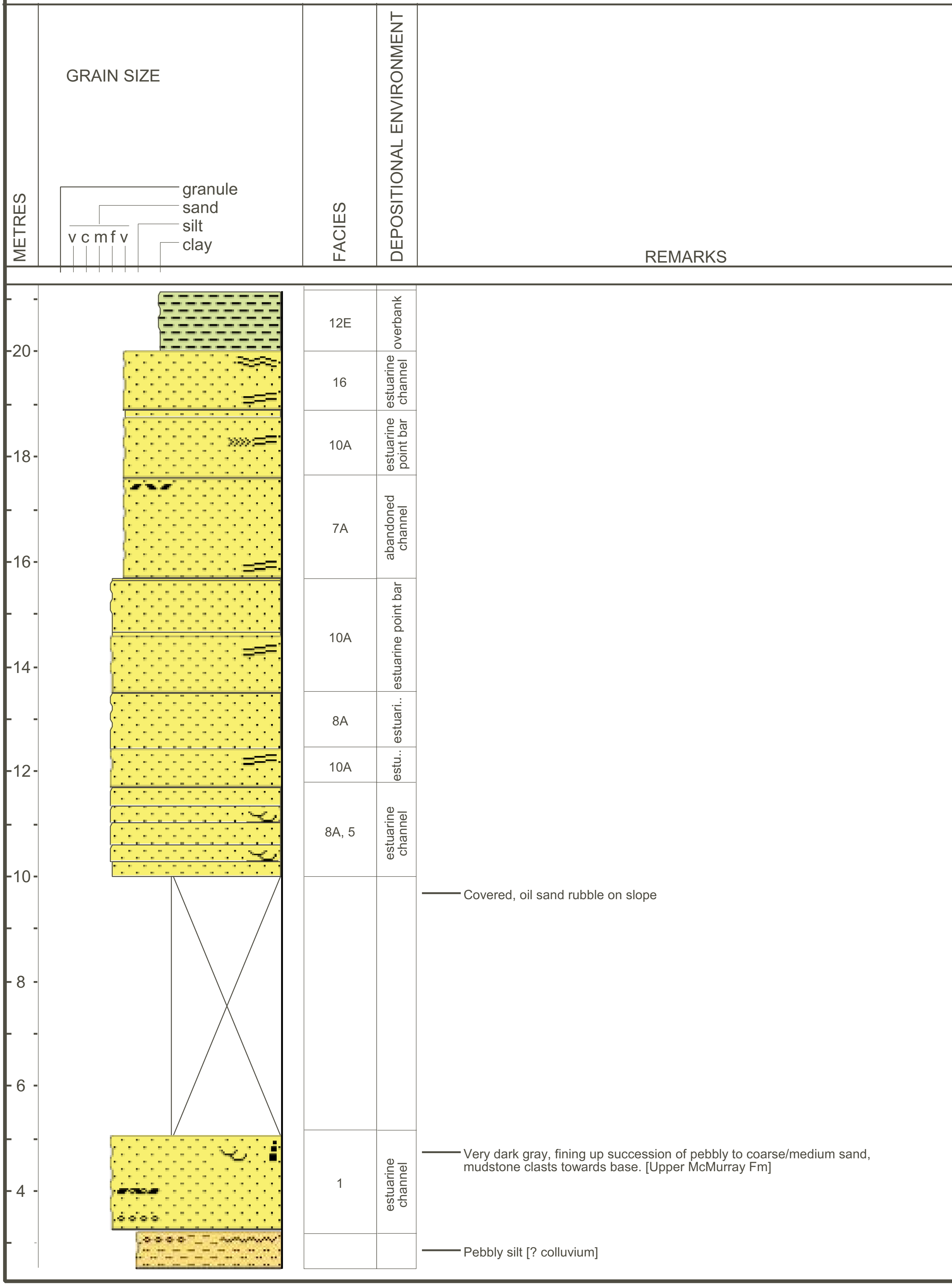
Moberly Member
Fossiliferous limestone, including brachiopods, stromatoporoids, and crinoid stems. Fractures infilled with bitumen. The cracks are bitumen filled without tarsand fill. Top 1/4 of exposed limestone along the riverbed is more fossilferous; lower part at the water's edge is rubbly, cherty and tar stained.

More nodular and less fossiliferous towards base.


MacKay River near Bridge Section
UTM 0460723E 6336620N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
12E
16
10A
7A
10A
8A
10A
8A, 5
1
2
8A, 5
2
5, 7B
2
5
8A
10A, 7B
ove..
estuarine point bar
estuarine channel
estuarine point bar
estuari..
estu..
estuarine channel
estuarine channel
estuarine channel
estuarine point bar
Covered, oil sand rubble on slope
Very dark gray, fining up succession of pebbly to coarse/medium sand, mudstone clasts towards base. [Upper McMurray Fm]
Pebbly silt [?colluvium]
Mainly massive, difficult to see structures

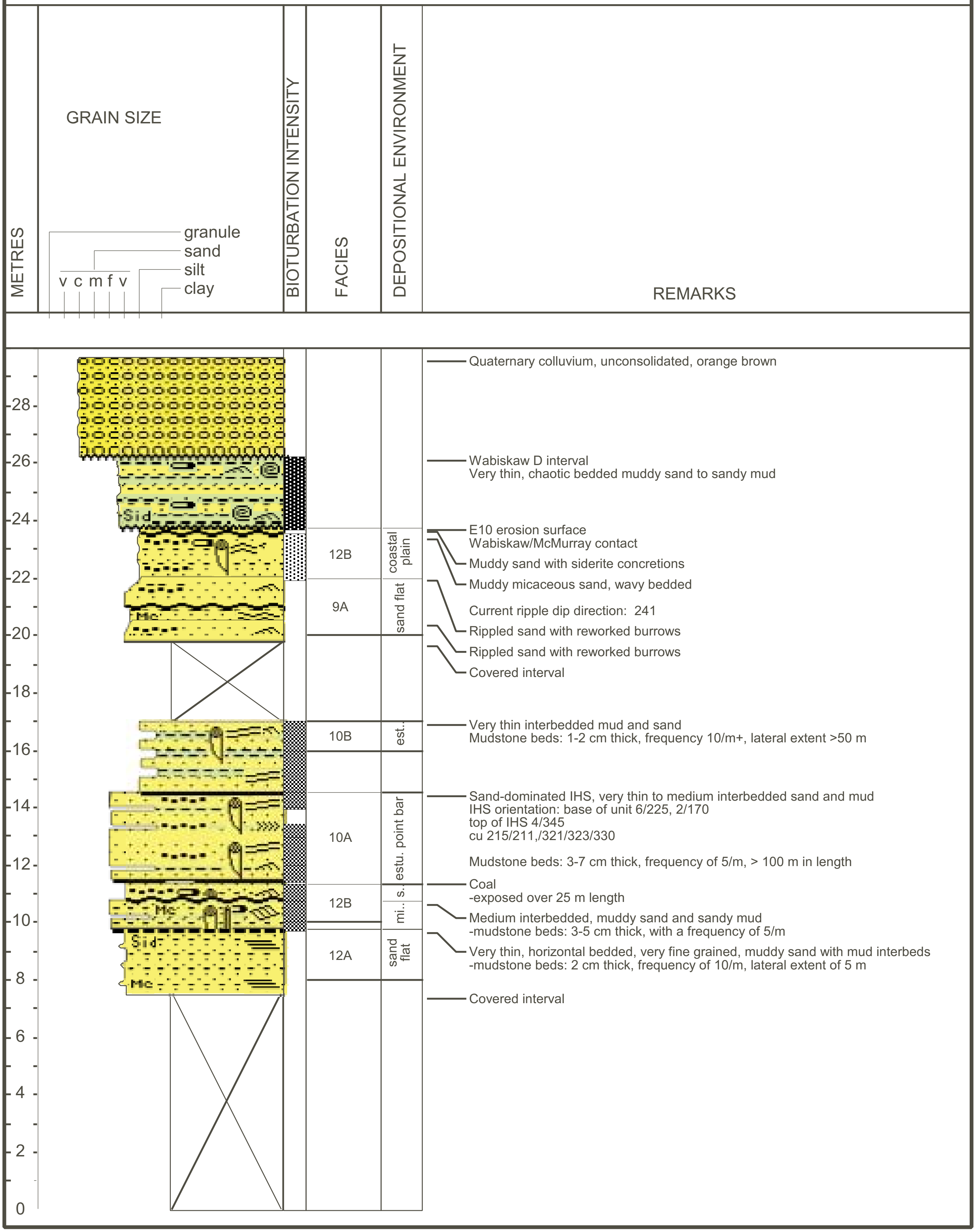
MacKay River Upstream of Mouth Section

UTM 0461430E 6335910N



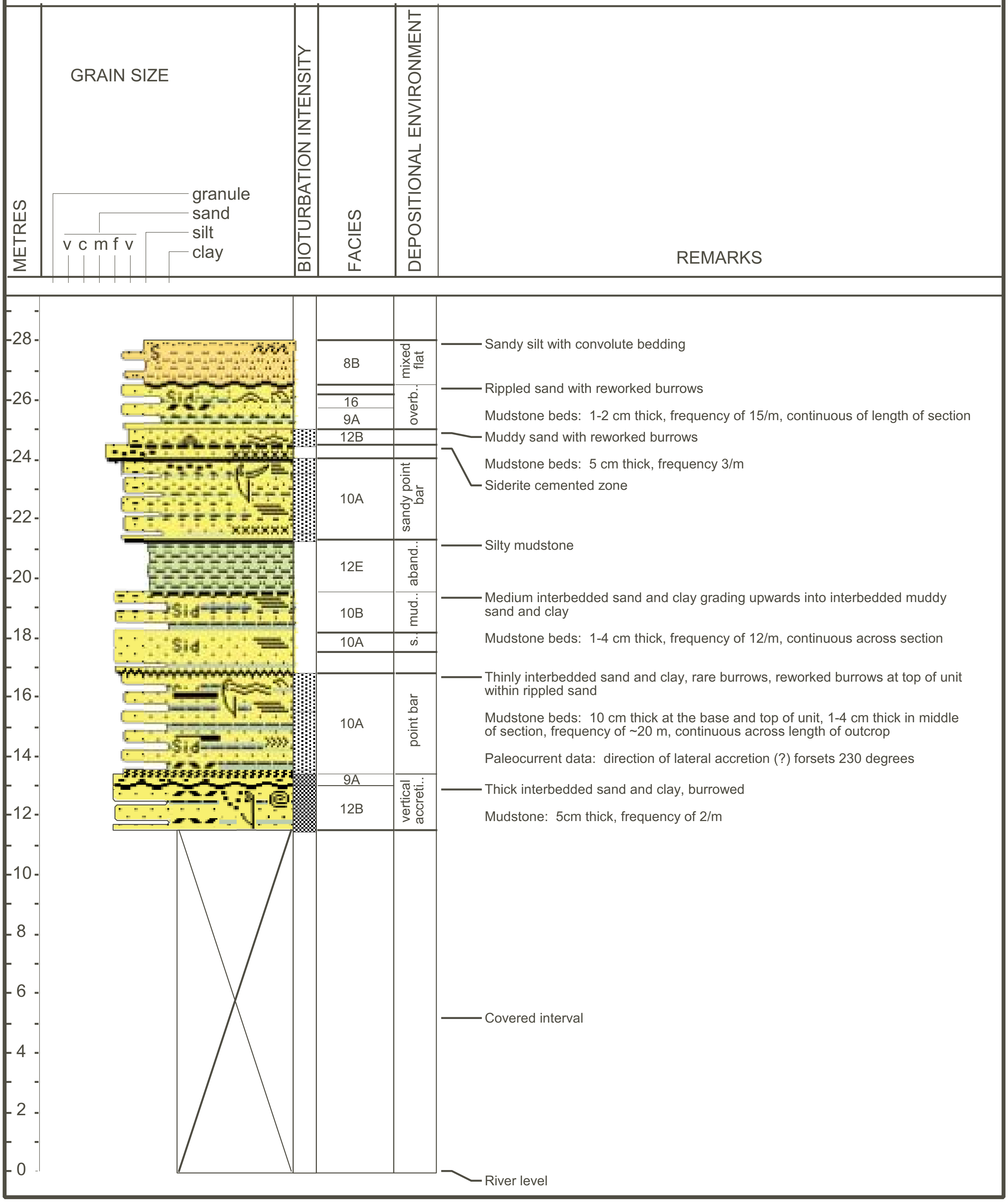
Ells River 99-01 Section

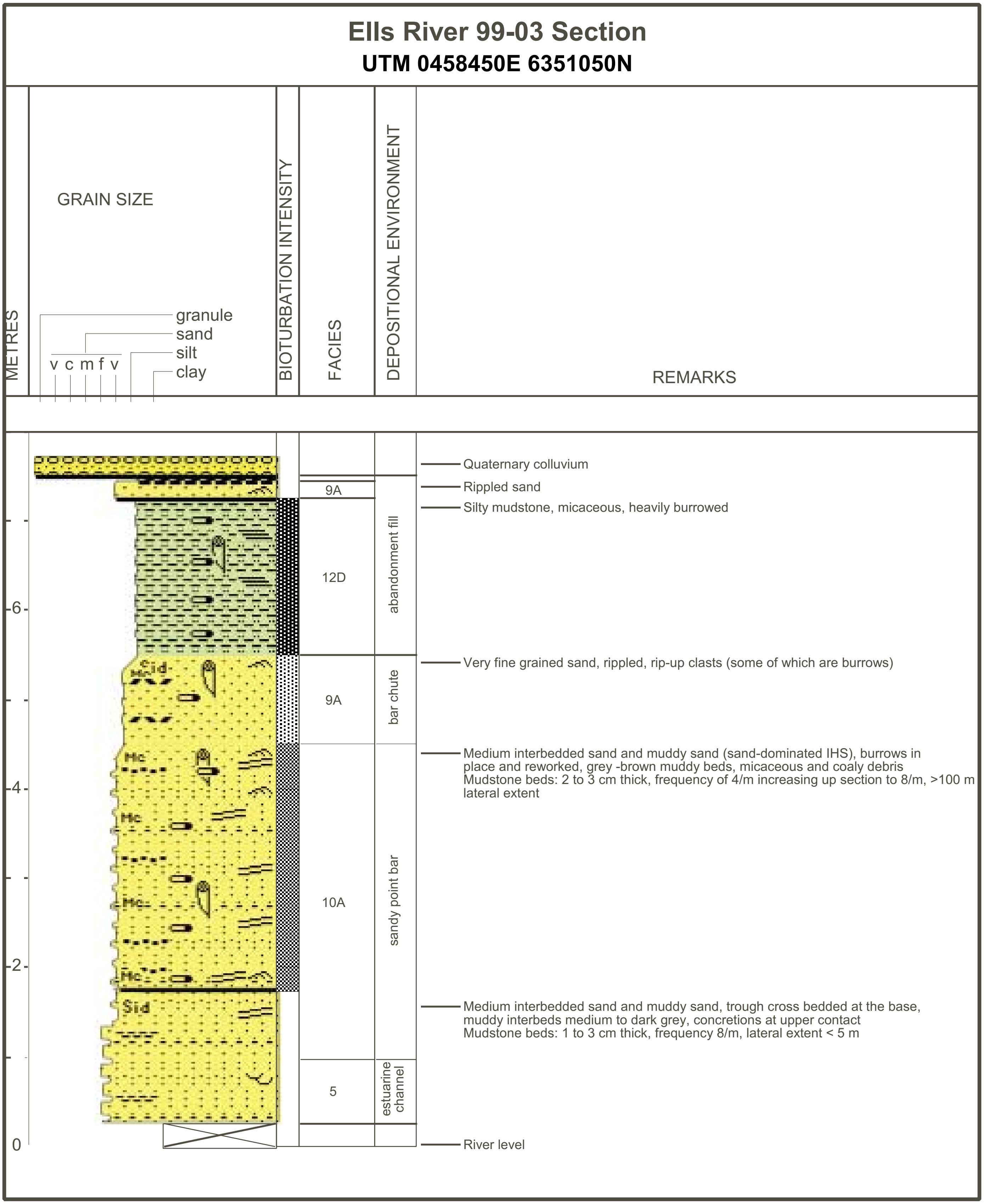
UTM 0458550E 6351300N



Ells River 99-02 Section

UTM 0458500E 6351200N

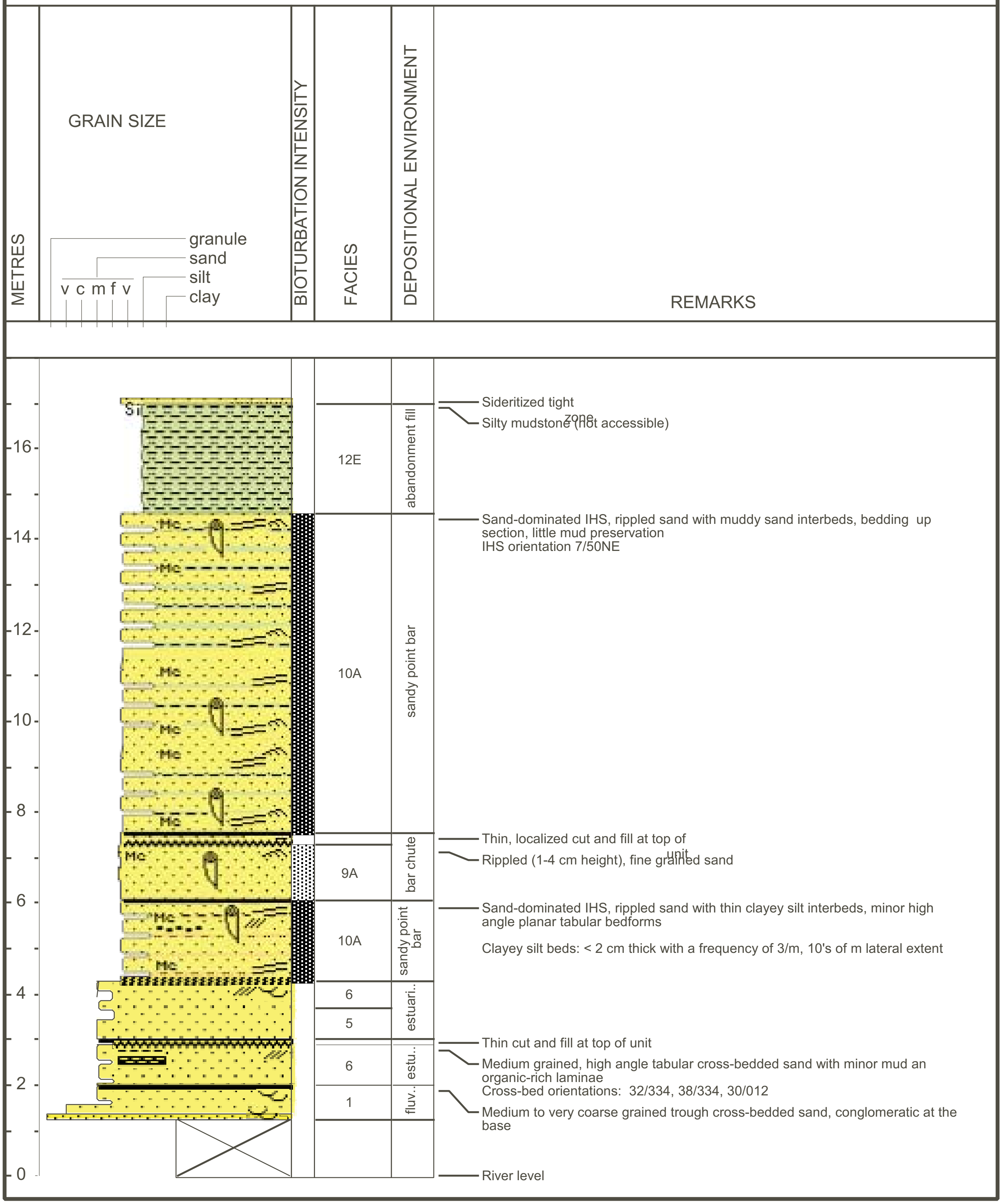




Ells River 99-03 Section
UTM 0458450E 6351050N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
6
4
2
0
9A
12D
9A
10A
5
abandonment fill
bar chute
sandy point bar
estuarine channel
Sid
Mc
Quaternary colluvium
Rippled sand
Silty mudstone, micaceous, heavily burrowed
Very fine grained sand, rippled, rip-up clasts (some of which are burrows)
Medium interbedded sand and muddy sand (sand-dominated IHS), burrows in place and reworked, grey -brown muddy beds, micaceous and coaly debris
Mudstone beds: 2 to 3 cm thick, frequency of 4/m increasing up section to 8/m, >100 m lateral extent
Medium interbedded sand and muddy sand, trough cross bedded at the base, muddy interbeds medium to dark grey, concretions at upper contact
Mudstone beds: 1 to 3 cm thick, frequency 8/m, lateral extent < 5 m
River level

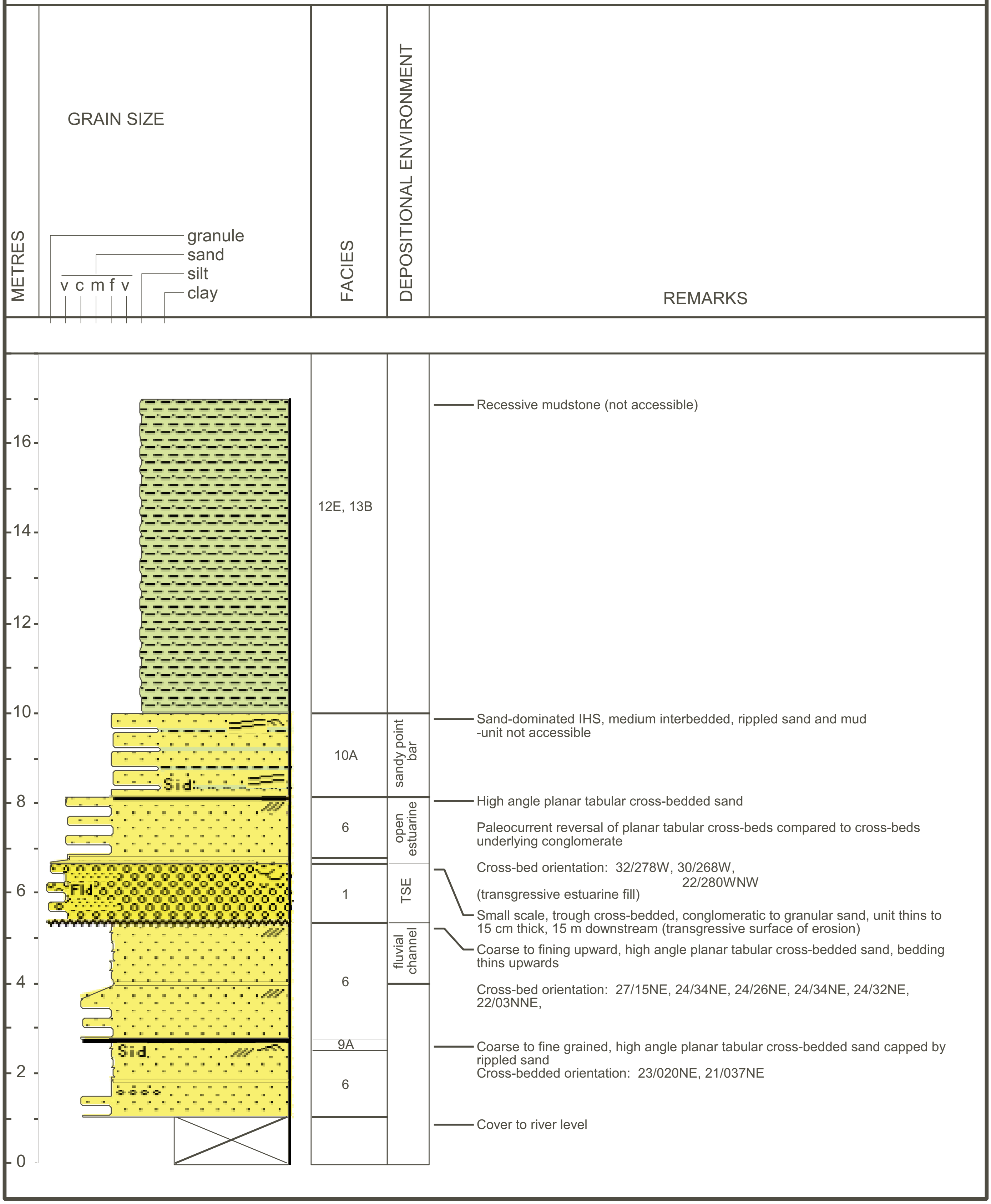
Ells River 99-04 Section

UTM 0458750E 6350875N



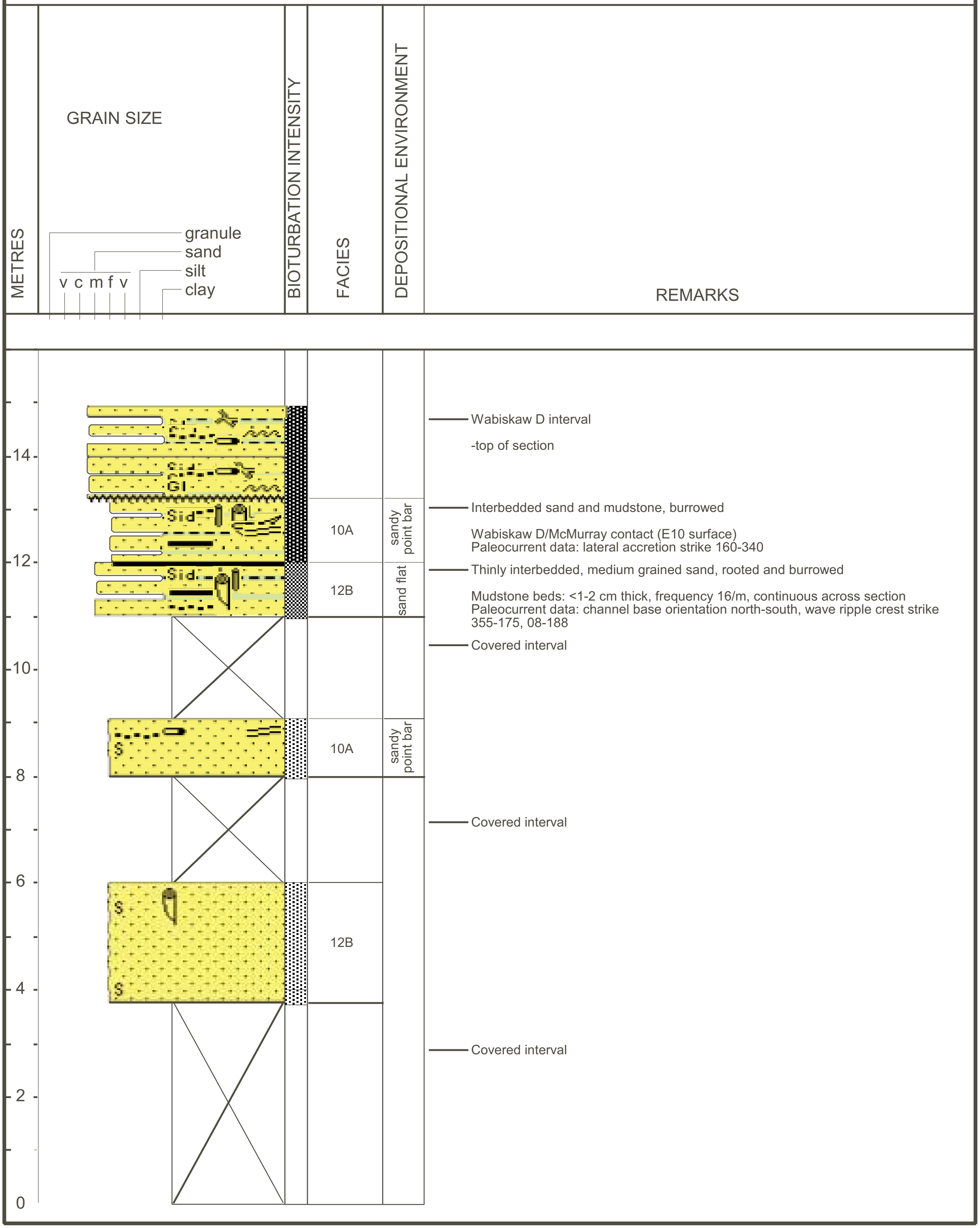
Ells River 99-05 Section

UTM 0458600E 6350800N



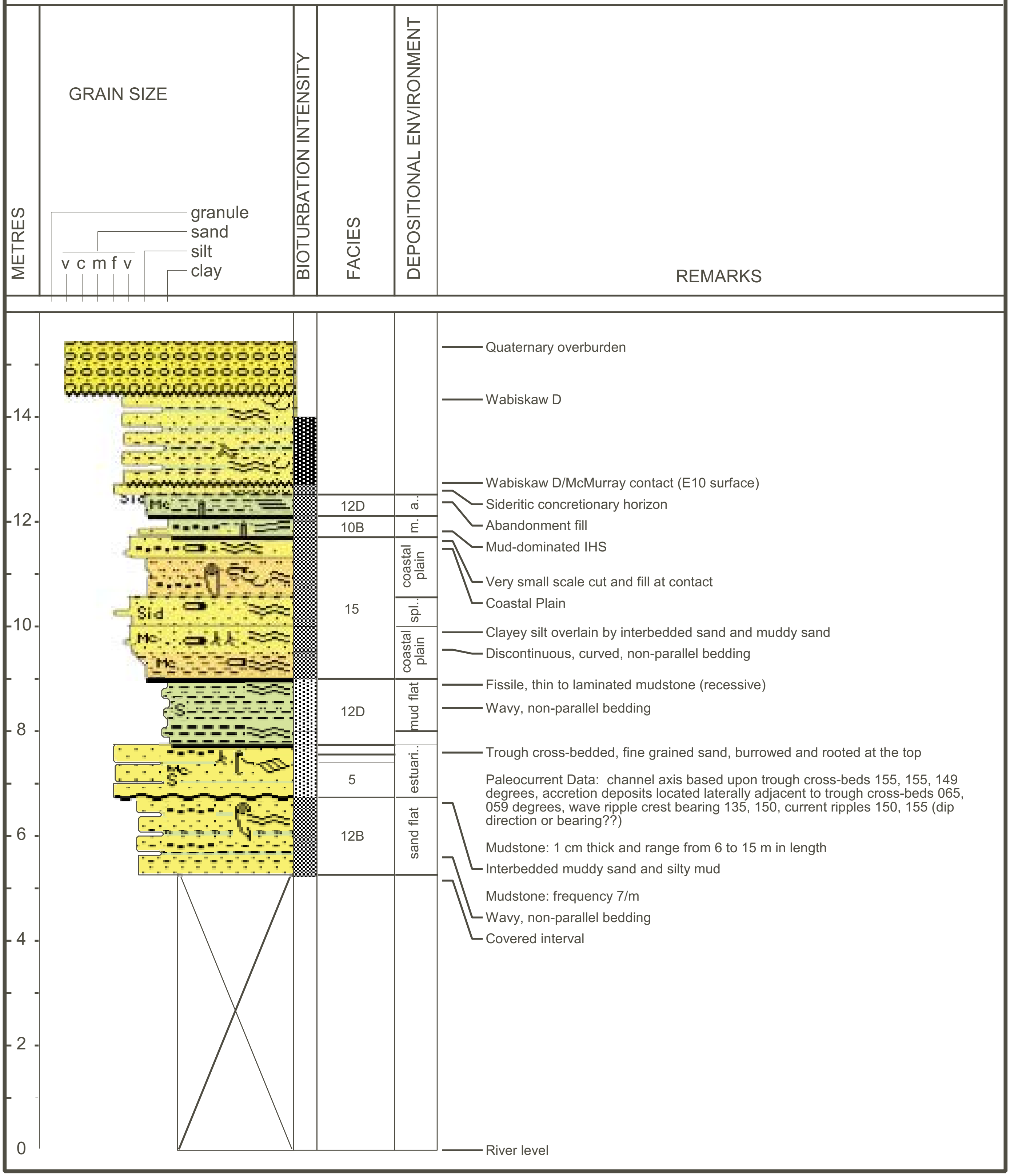
Ells River 99-06 Section

UTM 0454750E 6343300N



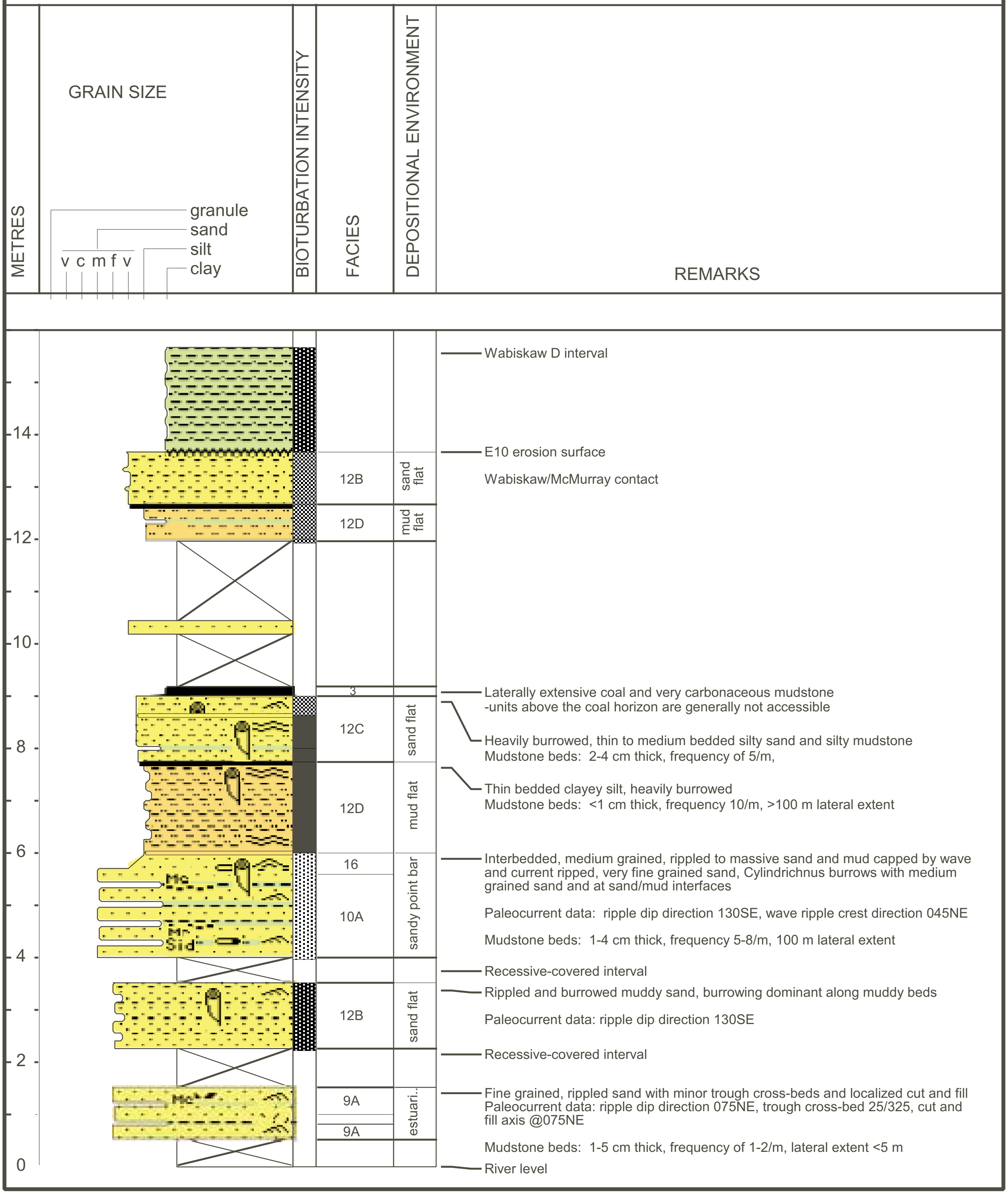
Ells River 99-07 Section

UTM 0454760E 6343310N



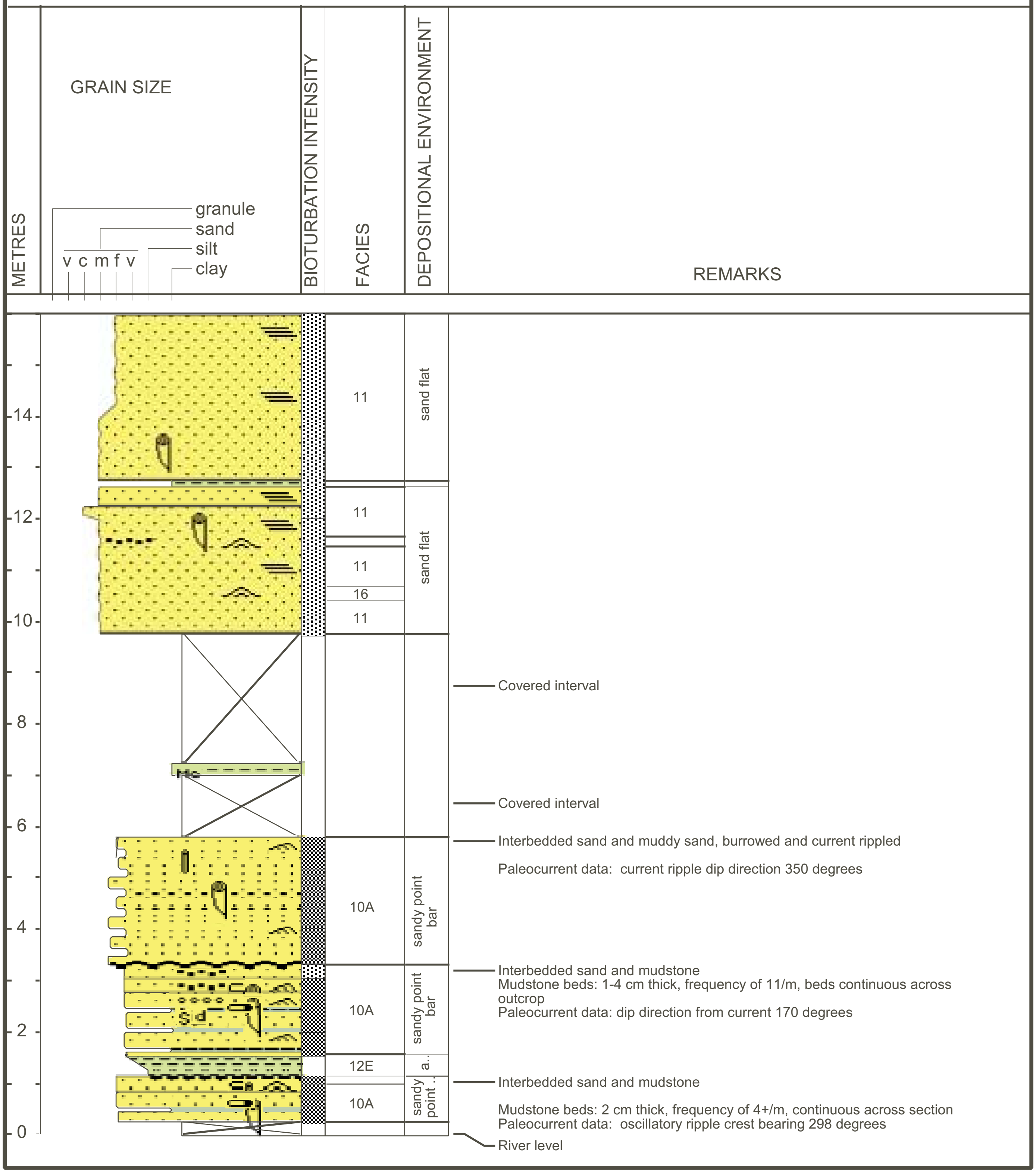
Ells River 99-08 Section

UTM 0455100E 6343580N



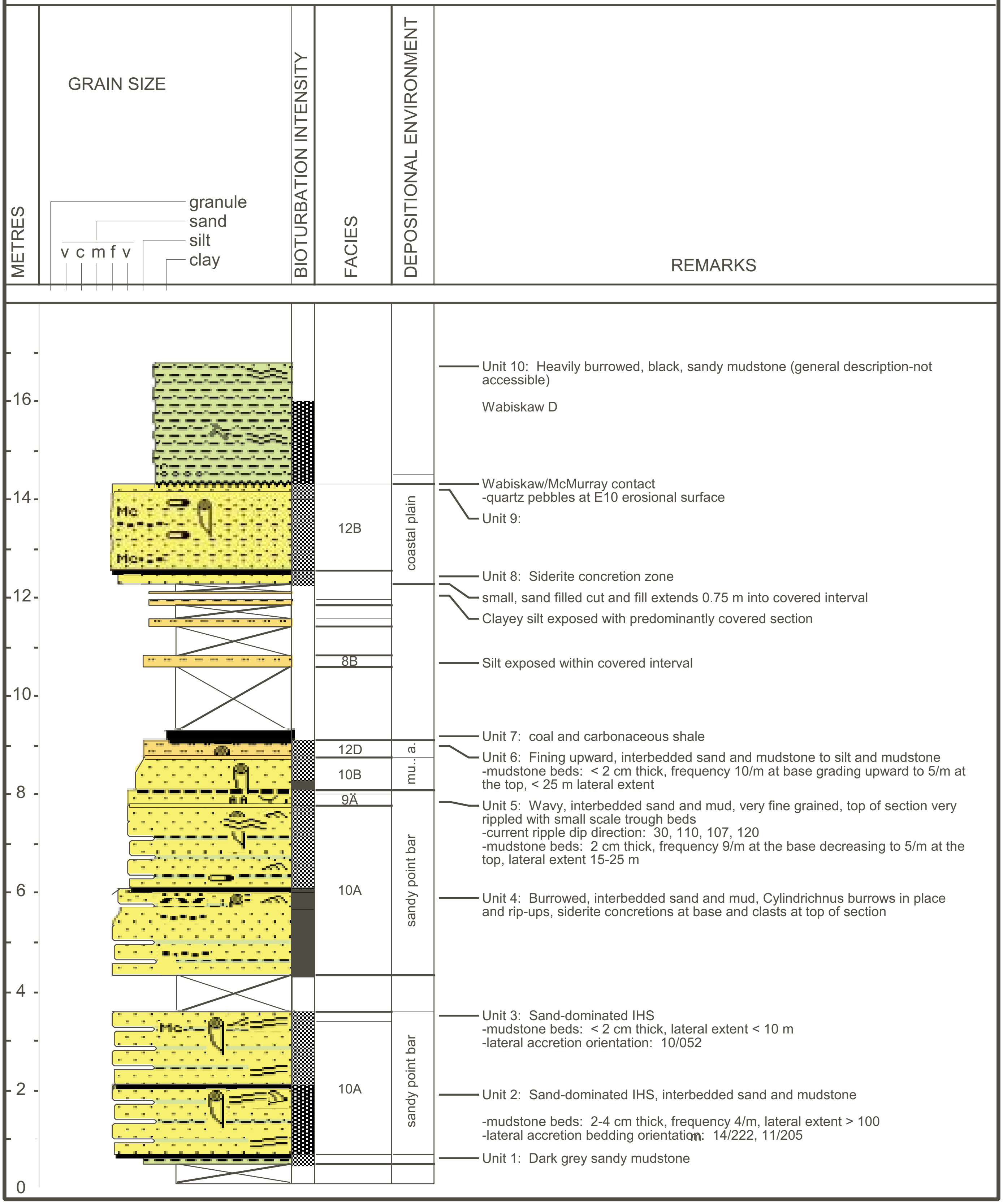
Ells River 99-09 Section

UTM 0455000E 6343500N



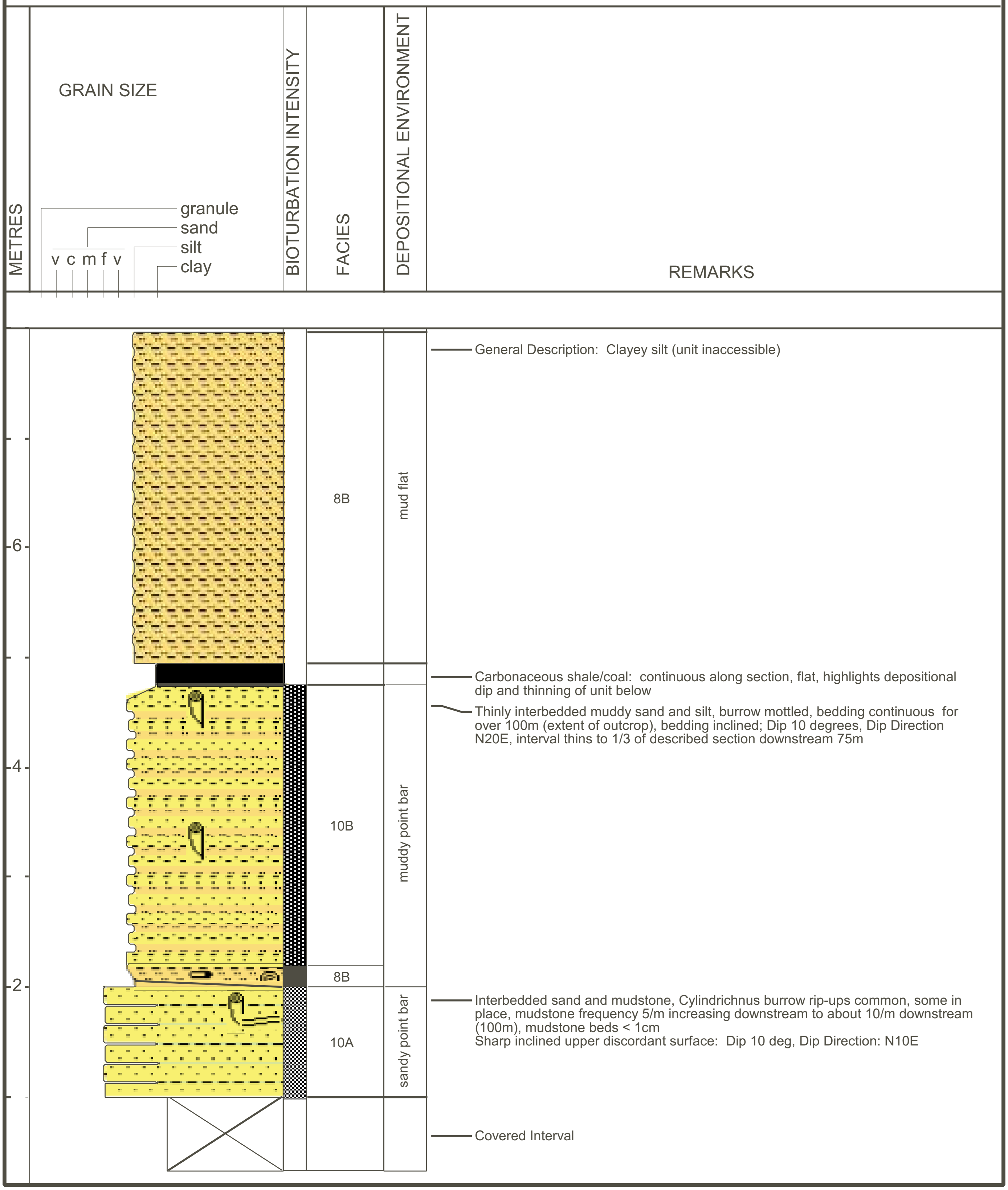
Ells River 99-10 Section

UTM 0455130E 6343550N



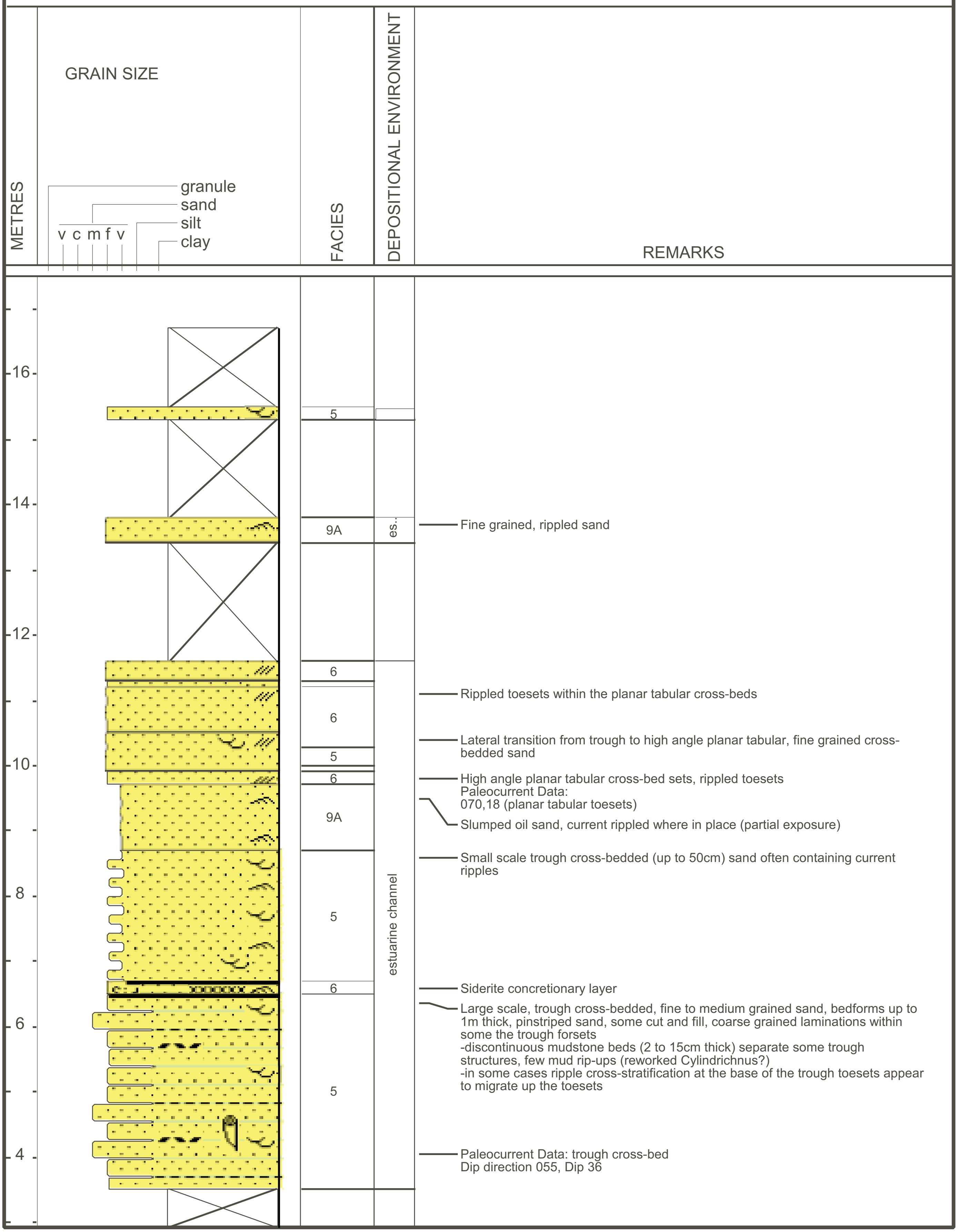
Ells River 99-11 Section

UTM 0455200E 6343380N



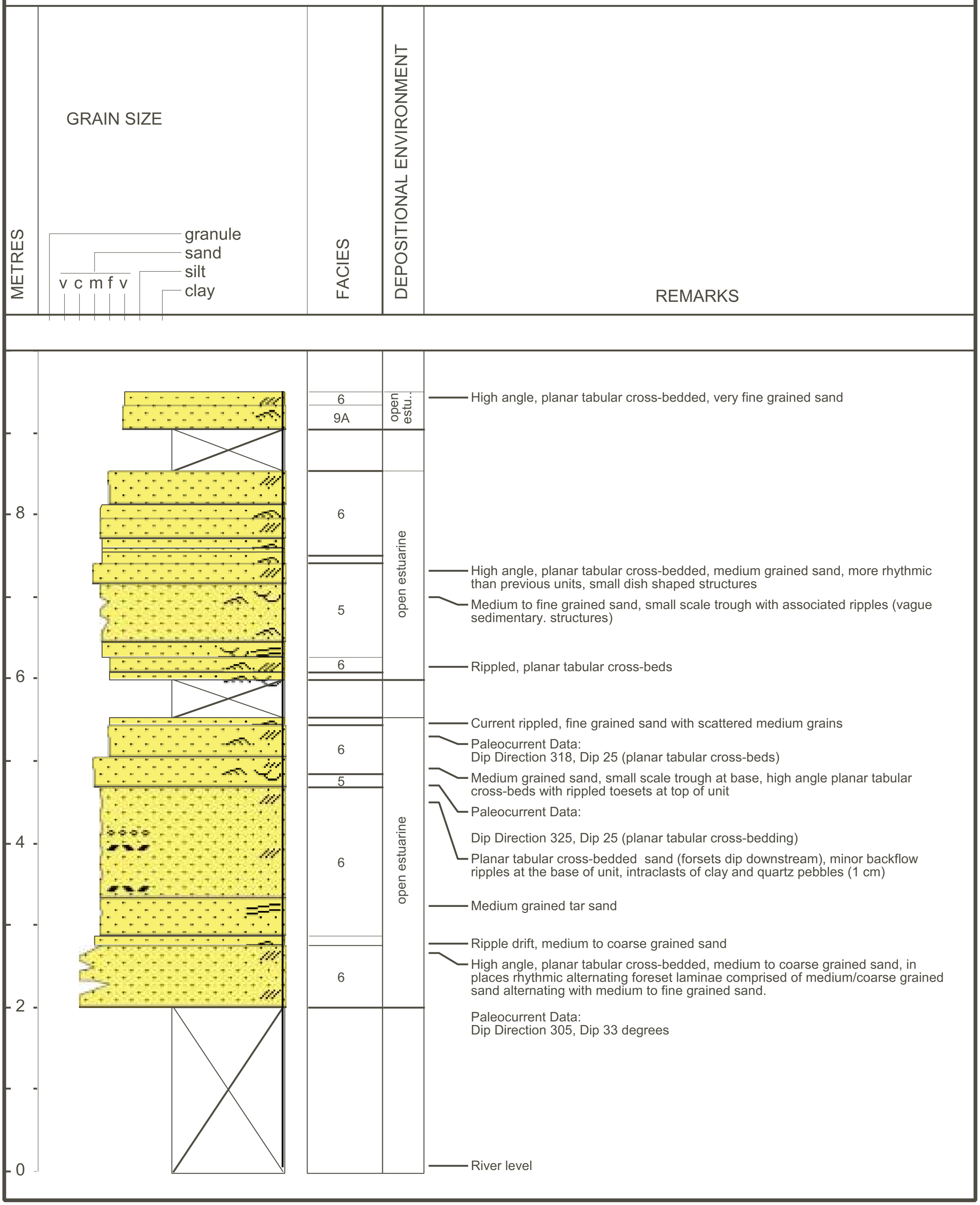
Saline Creek #1 Section

UTM 0478730E 6283383N



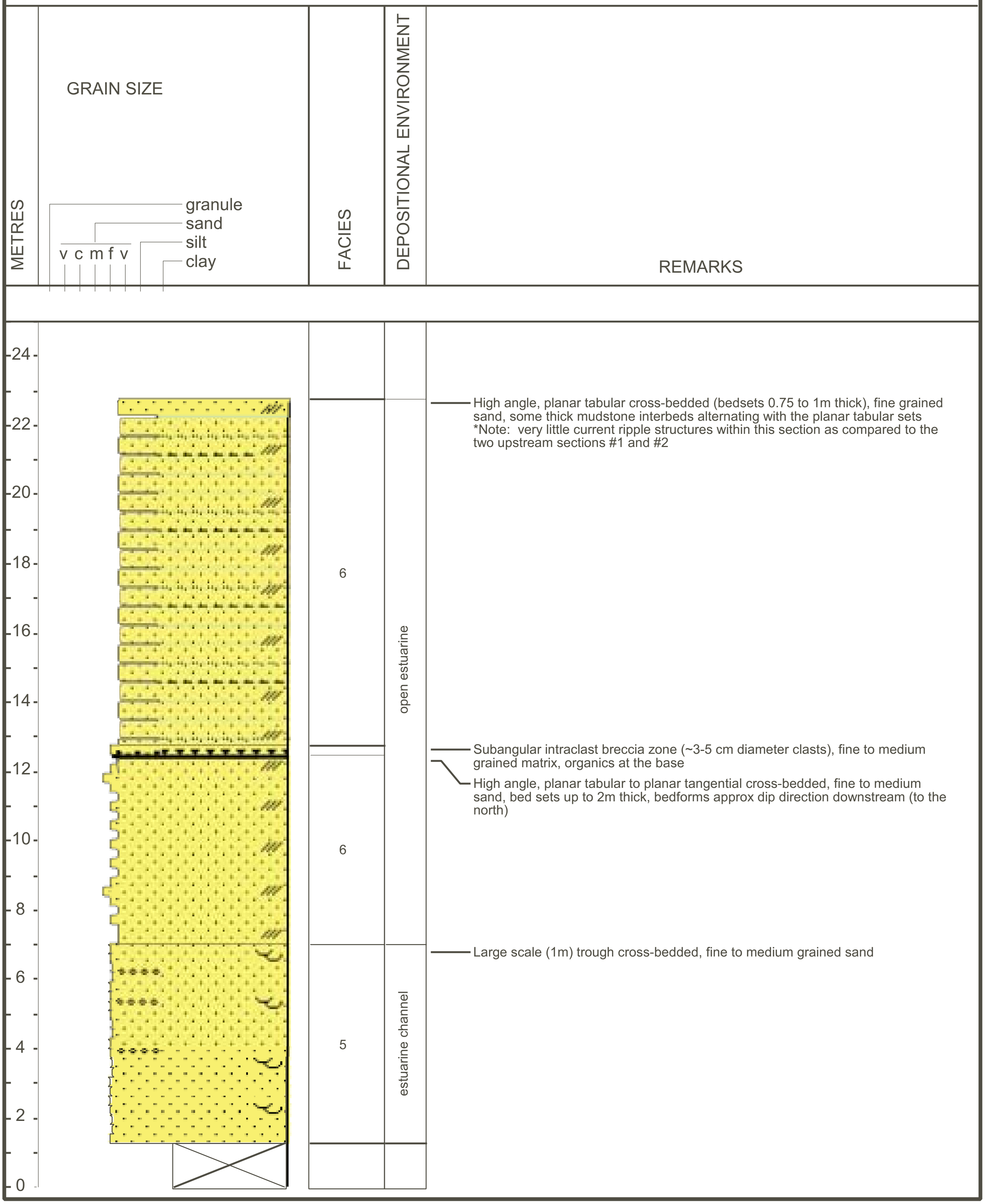
Saline Creek #2 Section

UTM 0478730E 6283480N

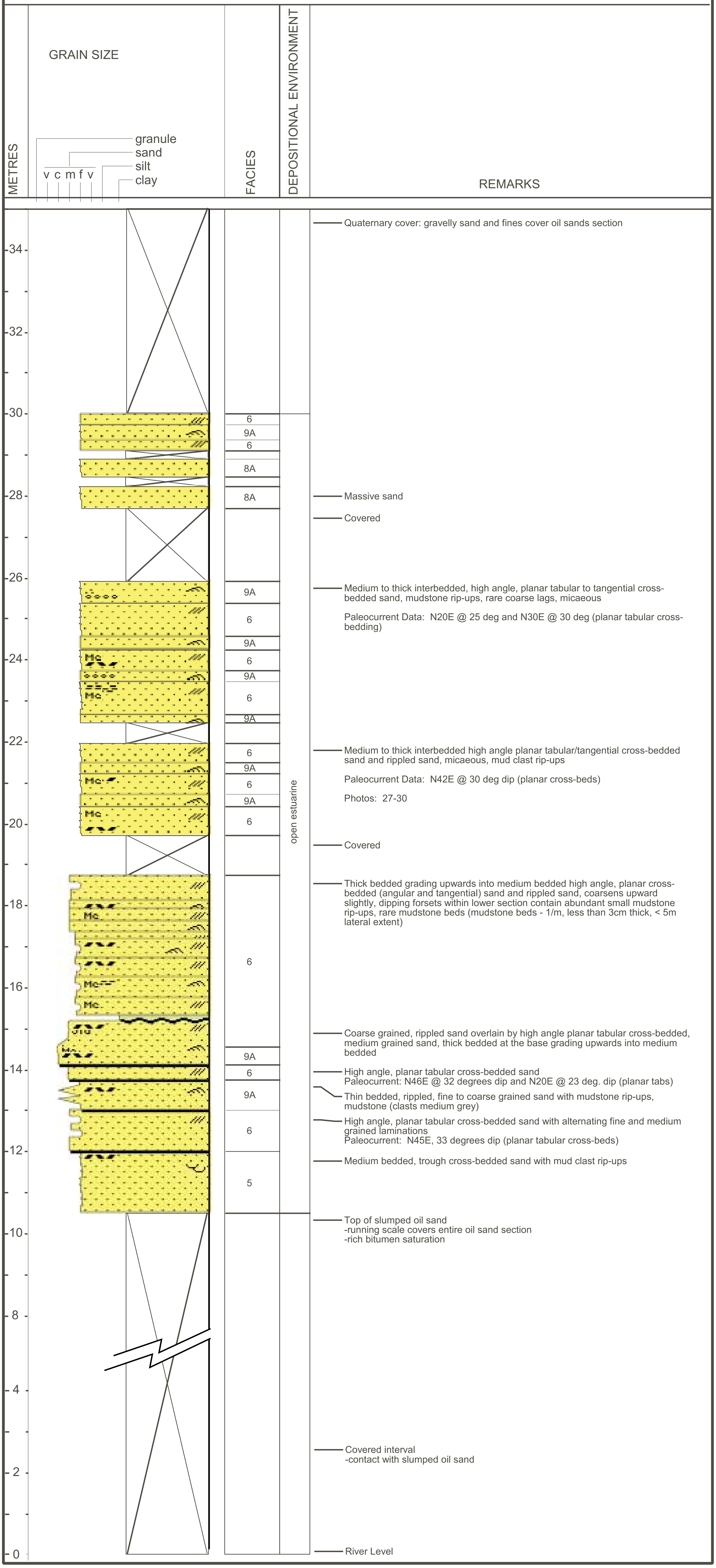


Saline Creek #3 Section

UTM 0478740E 6283550N

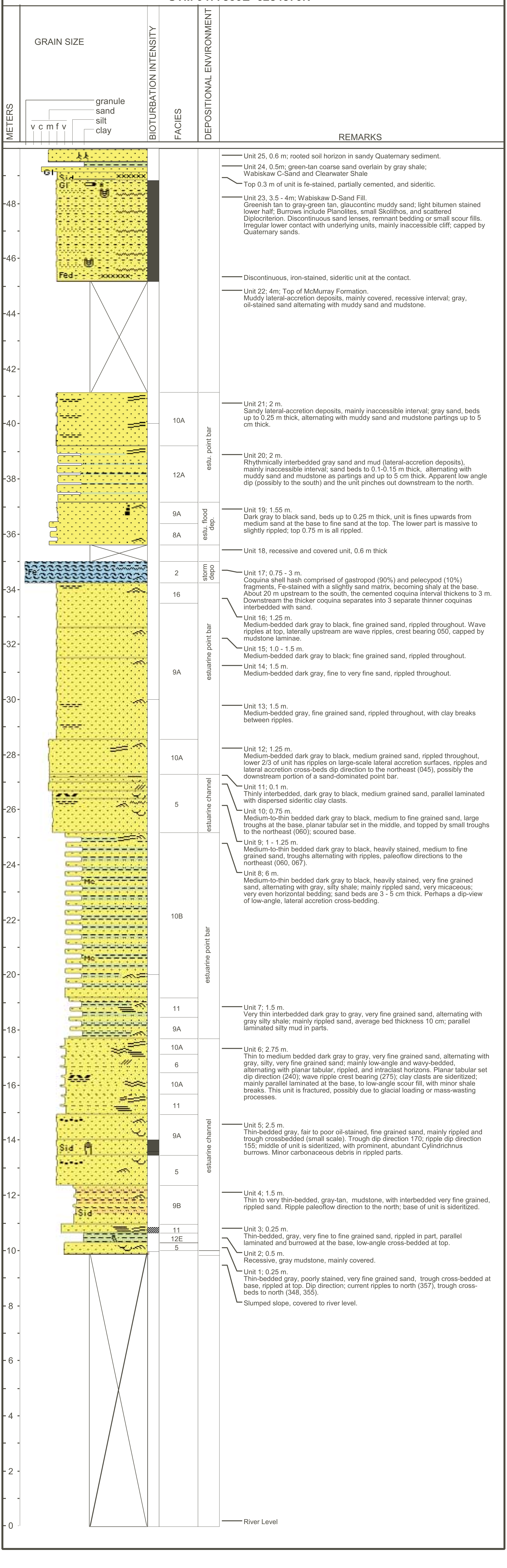


Saline Creek #4 Section
UTM 0478825E 6283721N



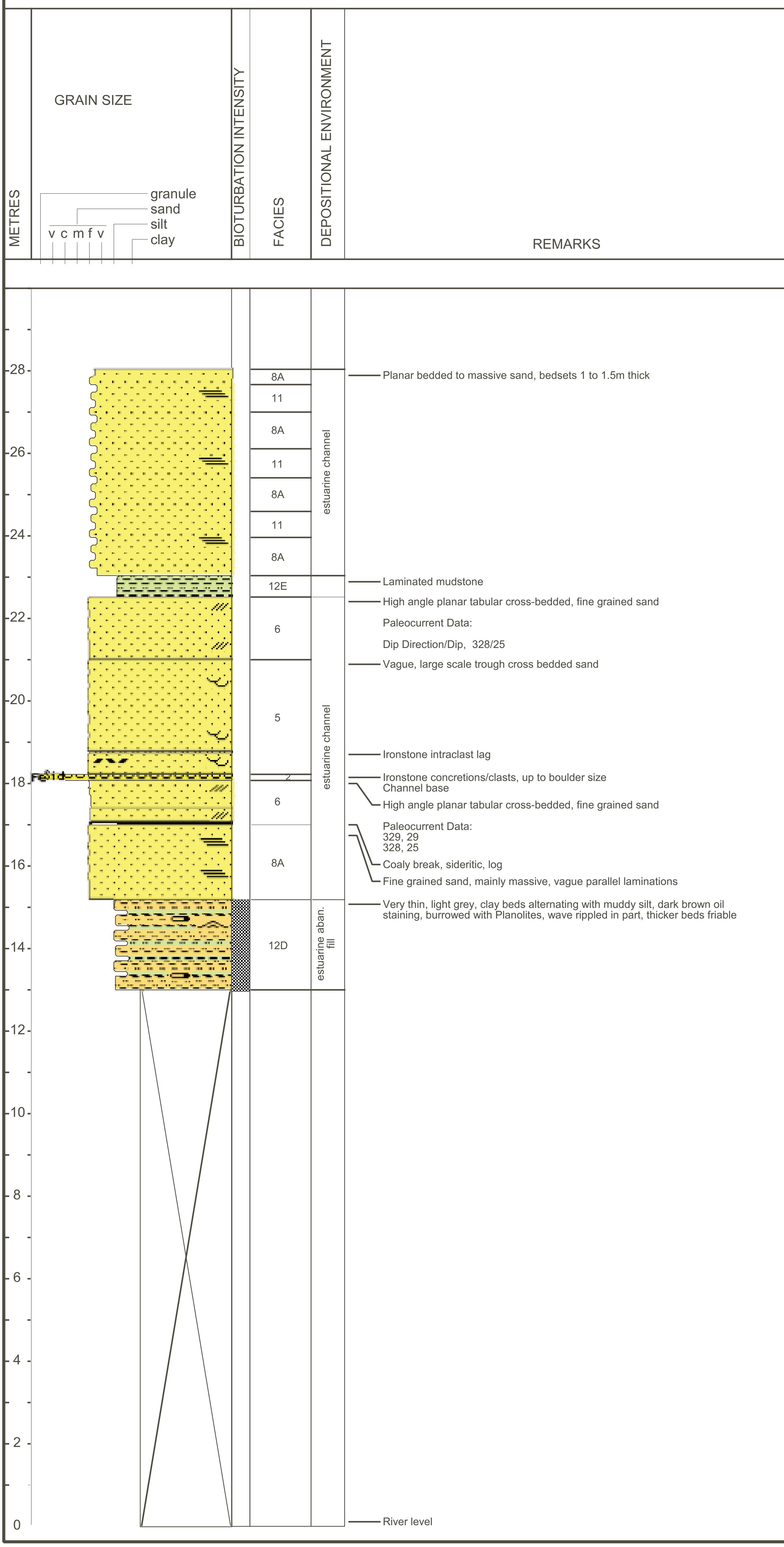
Hangingstone River #1 Section

UTM 0477530E 6284570N



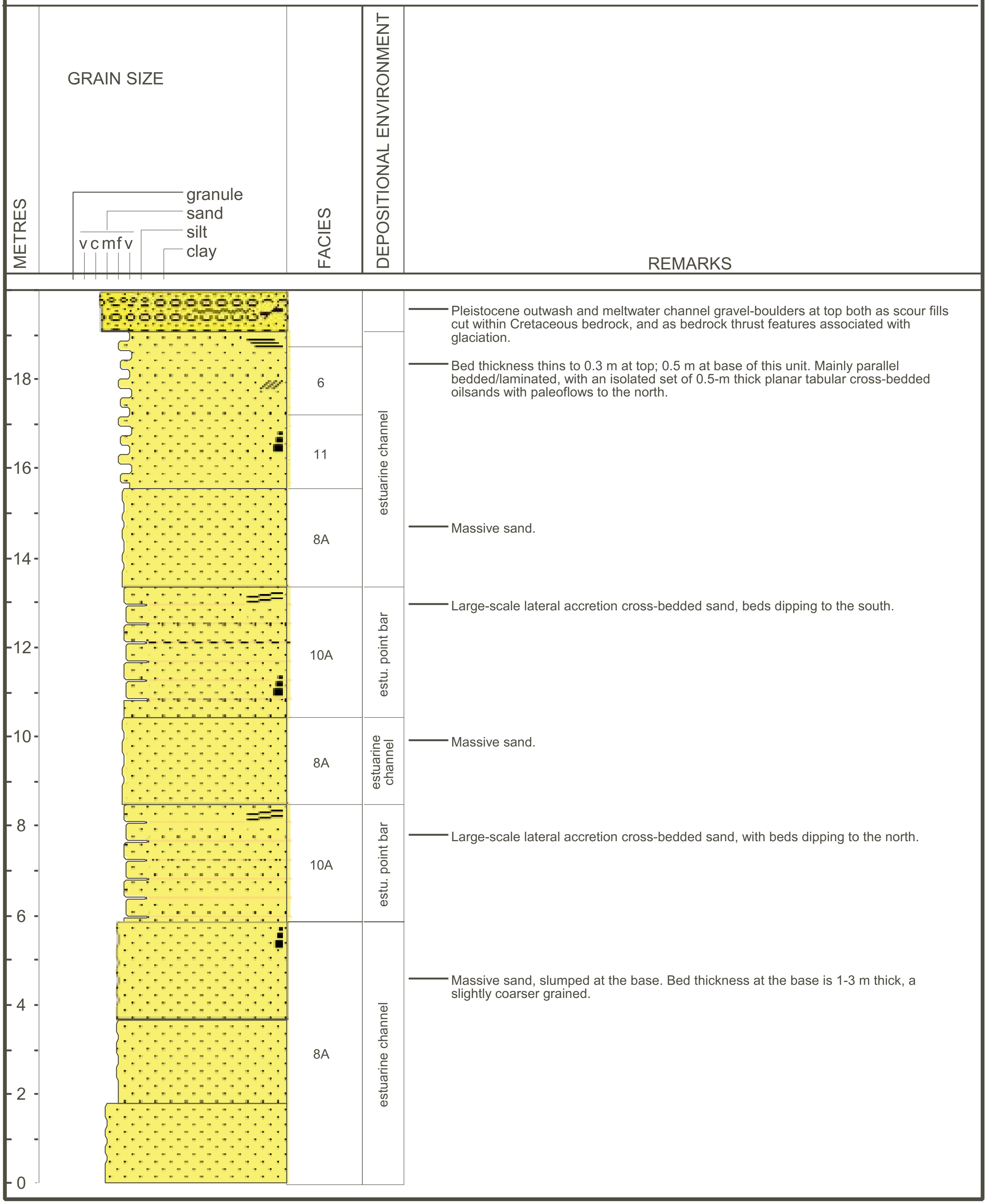
Hangingstone Section (Bridge) #2 Section

UTM 0478100E 6284600N



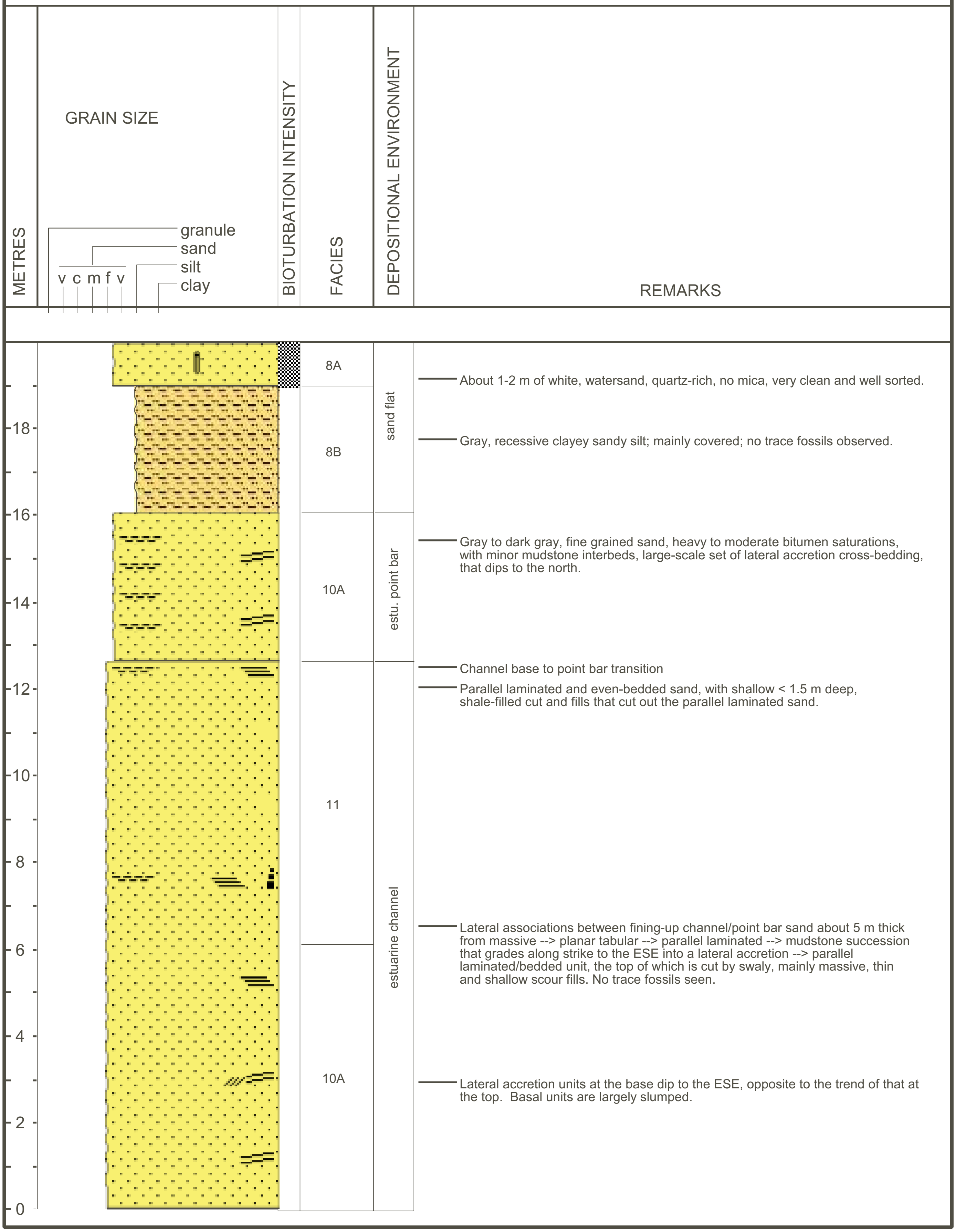
Horse River #1 Section

UTM 0475560E 6285050N



Horse River #2 Section

UTM 0476070E 6284520N

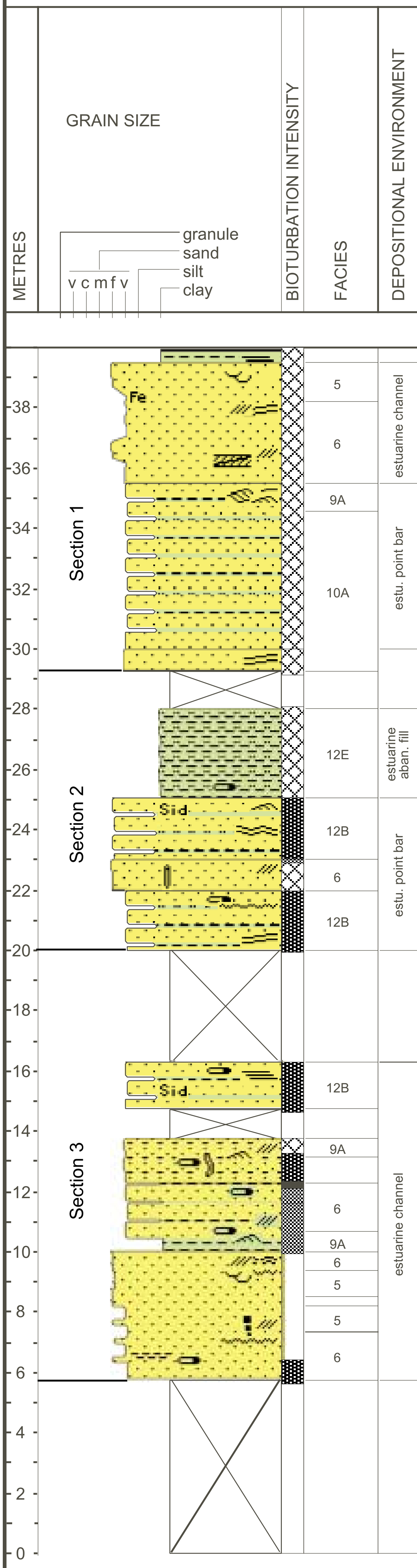


Horse River (oxbow Lake) #3 Section

UTM 0475550E 6283820N

Horse River (Roadcut) #4 Section

UTM 0476200E 6285050N



REMARKS

Rooted, soil horizon

Unit 12, < 0.5 m Wabiskaw Member (Clearwater Formation)
Light gray clay, very thin bedded, structureless

Unit 11, 4 m; McMurray Formation
Scour-fill with mud-drapes grading up into siderite-Fe-stained/cemented lens, overlain by low-angle cross-bedding dipping to the east, capped by parallel, laminated fine sand. Basal scour-fill is 1.5m deep x 8-9 m wide.

Unit 10, Lateral equivalents cut out are comprised swaley to trough cross-bedded fine to very fine grained sand, overlying small-scale planar tabular cross-bedded sand alternating with massive thin-bedded sand. S&D pl tab: 025/40 ESE.

Unit 9, 9.5 m
Large-scale, lateral accretion cross-bedding set, 9.5 m thick, comprising sand with interbedded mudstone, large sets dipping to the ESE; sands on dipping surfaces are internally rippled, with flow to the ESE; and at the top ripple-drift to the ESE.

Unit 8, 3 m
Recessive, gray mudstone, generally inaccessible, no trace fossils observed.

Unit 7, 2 m
Thin bedded, bioturbated and rippled fine grained sand with interbedded mudstone. Contacts of interbeds are all bioturbated, mainly horizontal Planolites burrows. Sands have wavy, undulatory upper bed contacts, (wave ripples or linguoid ripples?).

Unit 6, 1 m
Gray-tan, fine grained sand, planar tabular cross-bedded, with Skolithos burrows at the top of the sand; paleocurrent direction @ 240 degrees.

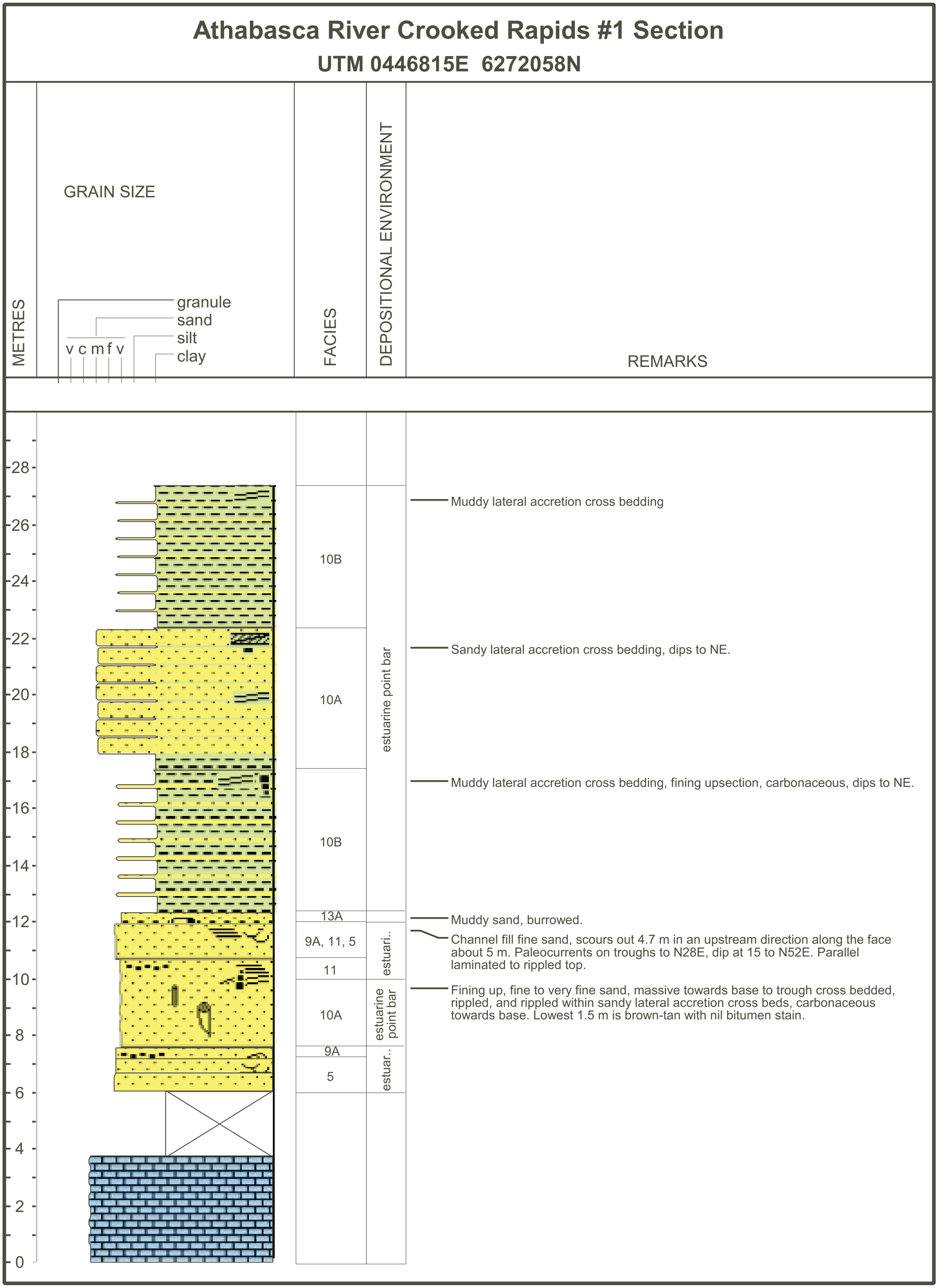
Unit 5, 2 m
Thin, horizontal bedded at the base from 0.1 m with low-angle truncations, to more even bedded at the top, beds up to 0.3 m thick. Mudstone interbeds are burrowed; few of the burrows extend down from the mudstone into the underlying sand.

Unit 4, 1.5 m
Light gray to tan, very fine to fine grained sand, with interbedded partially sideritized mudstone; vague parallel lamination, burrowed.

Unit 3, 1.5 m
Light gray to tan, very fine to fine grained sand, with interbedded bioturbated mudstone; burrowed, with other unidentified types in lower 2/3; top 1/3 is rippled; at top small planar-tabular cross-bed set S&D: 346/26ENE.

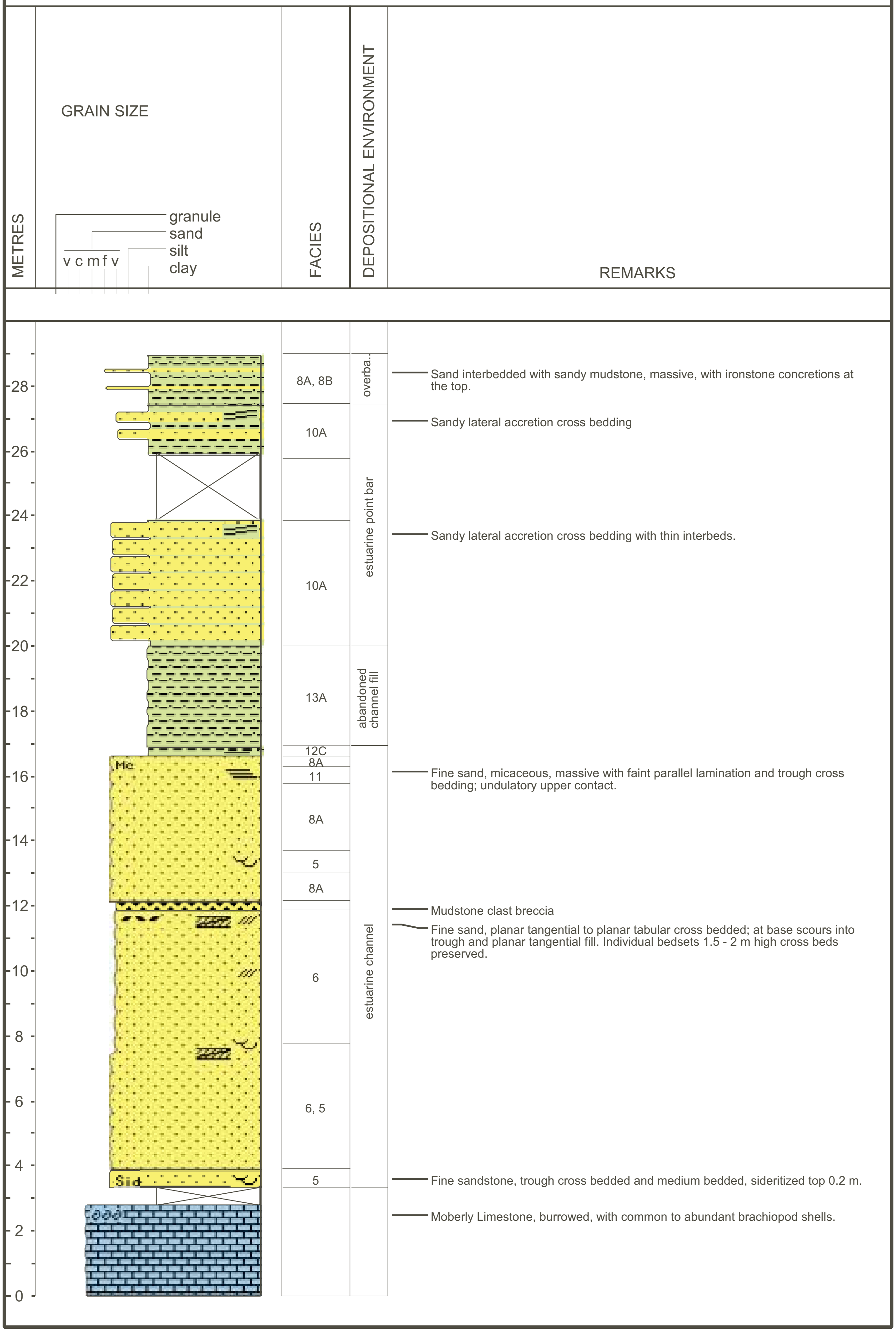
Unit 2, 2.25 m
Dark gray, very fine to fine grained sand, with interbedded bioturbated mudstone; burrowed, mainly Planolites, with other unidentified types. Mudstone interbeds are 2-5 cm thick. Middle of unit has one planar tangential cross-bed; S&D: 343/30 ENE; rippled at base.

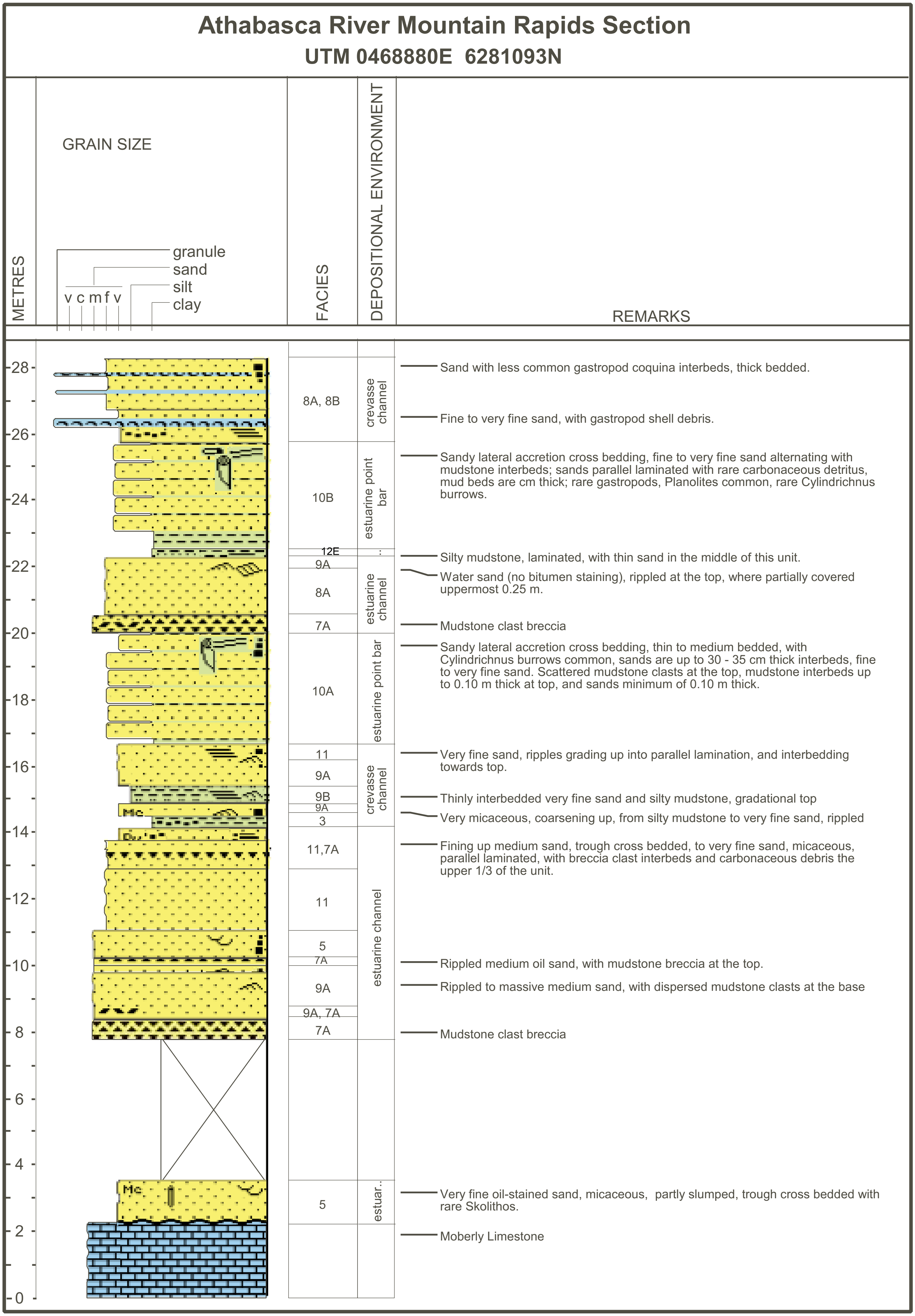
Unit 1, 4.2 m
Medium bedded, gray to black, fine to very fine grained sand. Bedding comprised of high angle, planar tabular cross-beds alternating with trough cross-beds pinch and swell, dip to the west and pinch out to the east. Planar tabular cross-beds S&D: 318/31ENE; 304/38ENE; 324/29ENE.


Athabasca River Crooked Rapids #1 Section
UTM 0446815E 6272058N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10B
10A
10B
13A
9A, 11, 5
11
10A
9A
5
estuarine point bar
estuari..
estuarine point bar
estuar..
Muddy lateral accretion cross bedding
Sandy lateral accretion cross bedding, dips to NE.
Muddy lateral accretion cross bedding, fining upsection, carbonaceous, dips to NE.
Muddy sand, burrowed.
Channel fill fine sand, scours out 4.7 m in an upstream direction along the face about 5 m. Paleocurrents on troughs to N28E, dip at 15 to N52E. Parallel laminated to rippled top.
Fining up, fine to very fine sand, massive towards base to trough cross bedded, rippled, and rippled within sandy lateral accretion cross beds, carbonaceous towards base. Lowest 1.5 m is brown-tan with nil bitumen stain.

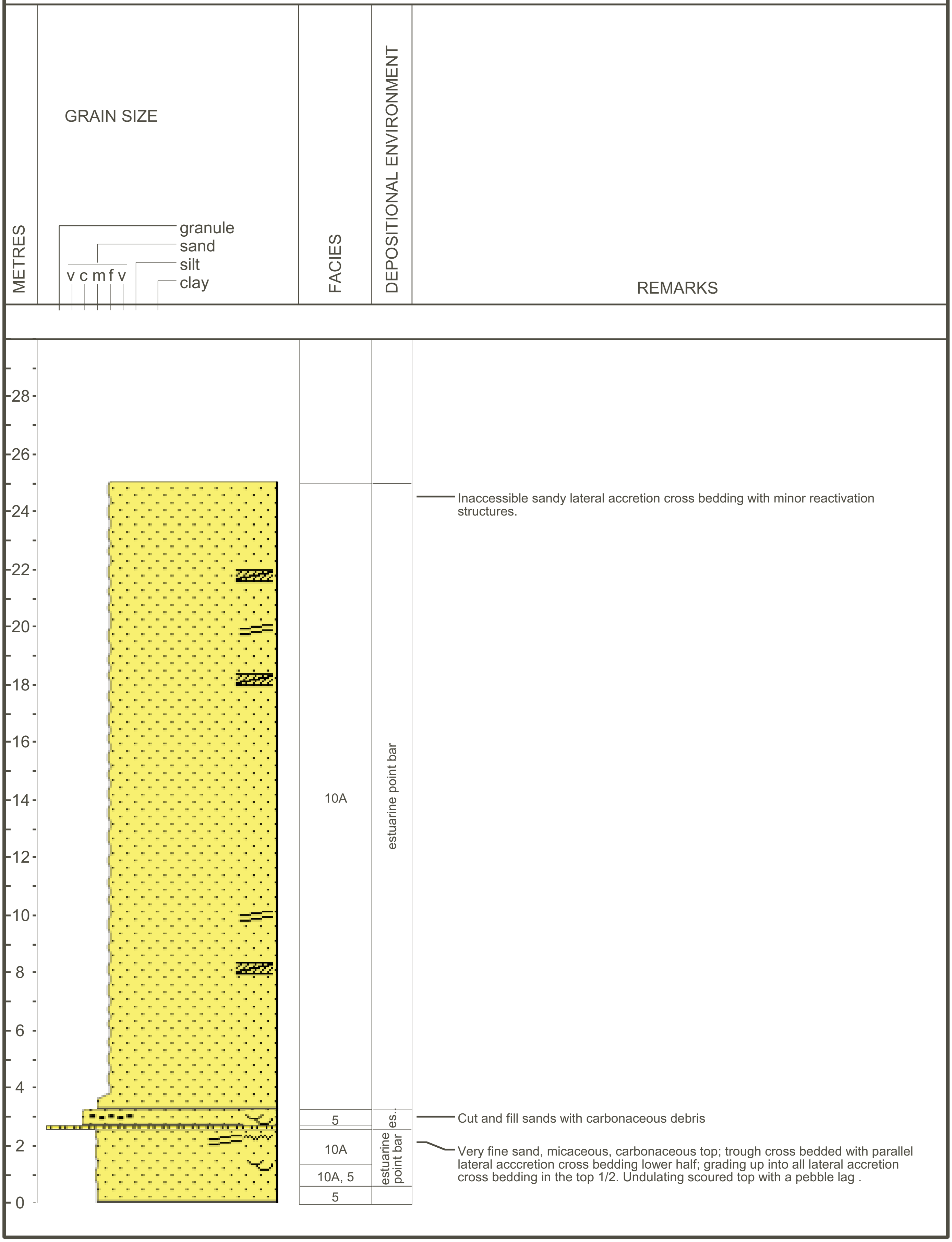
Athabasca River Crooked Rapids #2 Section

UTM 0446608E 6272690N



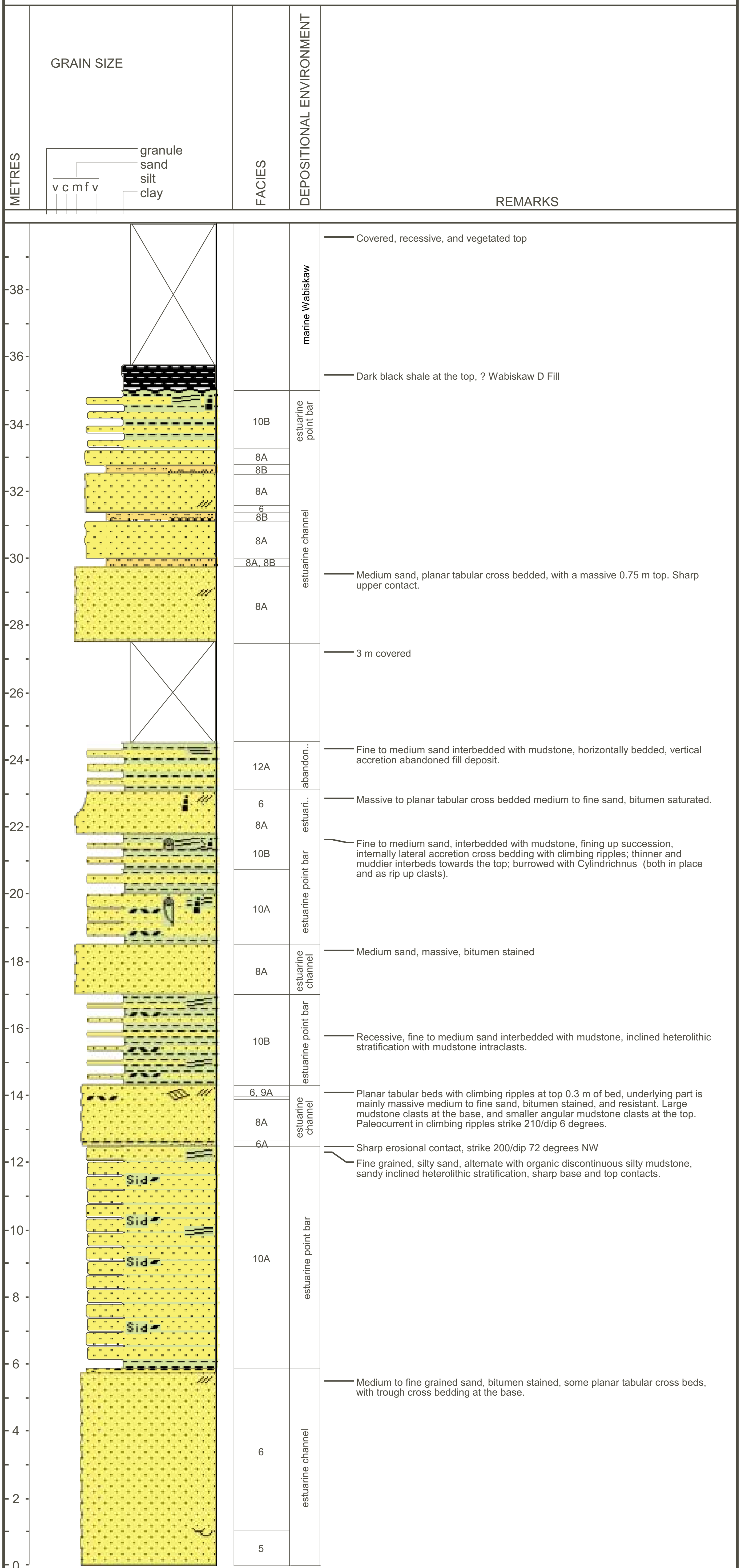

Athabasca River Mountain Rapids Section
UTM 0468880E 6281093N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Mc
Mc
8A, 8B
10B
12E
9A
8A
7A
10A
11
9A
9B
9A
3
11,7A
11
5
7A
9A
9A, 7A
7A
5
crevasse channel
estuarine point bar
estuarine channel
estuarine point bar
crevasse channel
estuarine channel
estuar..
Sand with less common gastropod coquina interbeds, thick bedded.
Fine to very fine sand, with gastropod shell debris.
Sandy lateral accretion cross bedding, fine to very fine sand alternating with mudstone interbeds; sands parallel laminated with rare carbonaceous detritus, mud beds are cm thick; rare gastropods, Planolites common, rare Cylindrichnus burrows.
Silty mudstone, laminated, with thin sand in the middle of this unit.
Water sand (no bitumen staining), rippled at the top, where partially covered uppermost 0.25 m.
Mudstone clast breccia
Sandy lateral accretion cross bedding, thin to medium bedded, with Cylindrichnus burrows common, sands are up to 30 - 35 cm thick interbeds, fine to very fine sand. Scattered mudstone clasts at the top, mudstone interbeds up to 0.10 m thick at top, and sands minimum of 0.10 m thick.
Very fine sand, ripples grading up into parallel lamination, and interbedding towards top.
Thinly interbedded very fine sand and silty mudstone, gradational top
Very micaceous, coarsening up, from silty mudstone to very fine sand, rippled
Fining up medium sand, trough cross bedded, to very fine sand, micaceous, parallel laminated, with breccia clast interbeds and carbonaceous debris the upper 1/3 of the unit.
Rippled medium oil sand, with mudstone breccia at the top.
Rippled to massive medium sand, with dispersed mudstone clasts at the base
Mudstone clast breccia
Very fine oil-stained sand, micaceous, partly slumped, trough cross bedded with rare Skolithos.
Moberly Limestone

Athabasca River Powerline Section
(Upstream Fort McMurray)
UTM 0470012E 6282431N

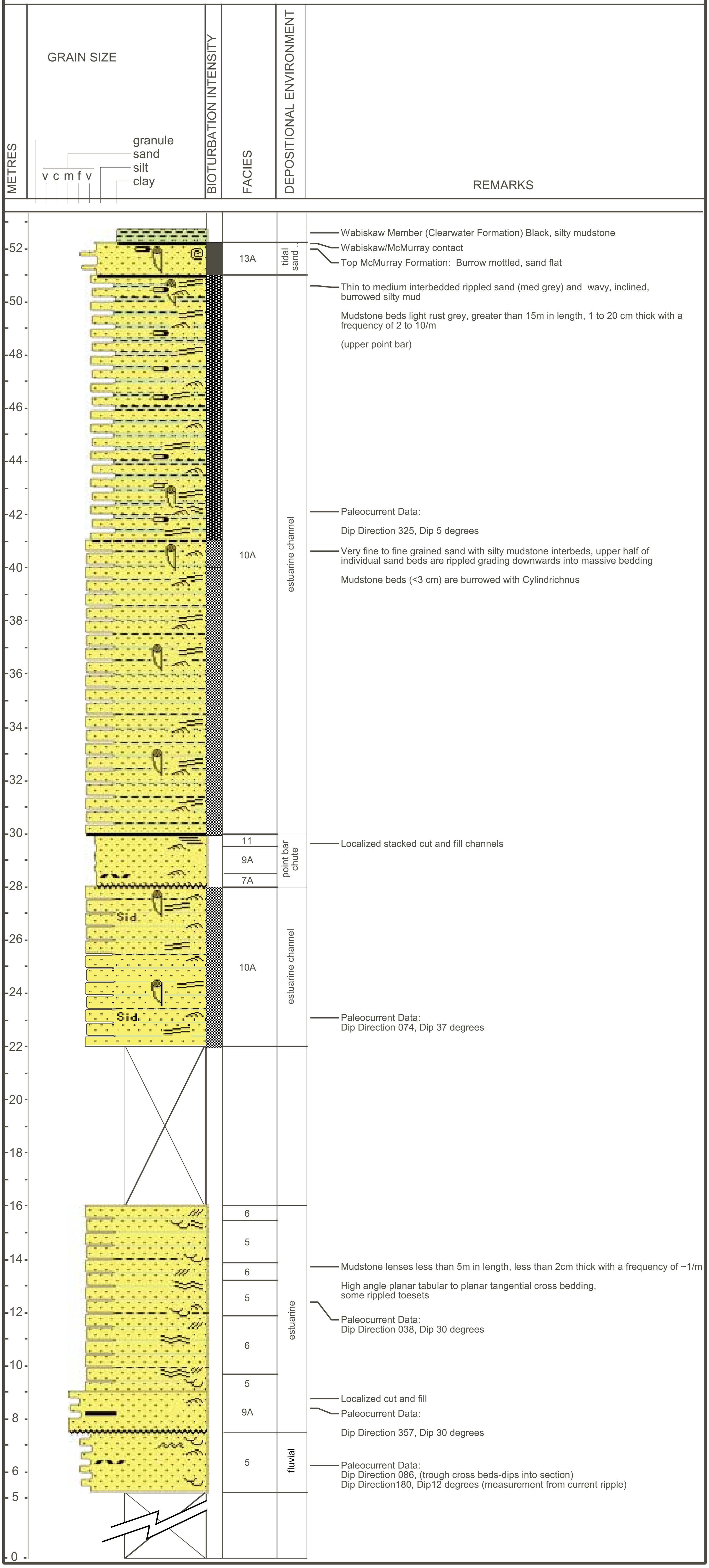


McMurray Formation Type #1 Section

UTM 0476166E 6291060N

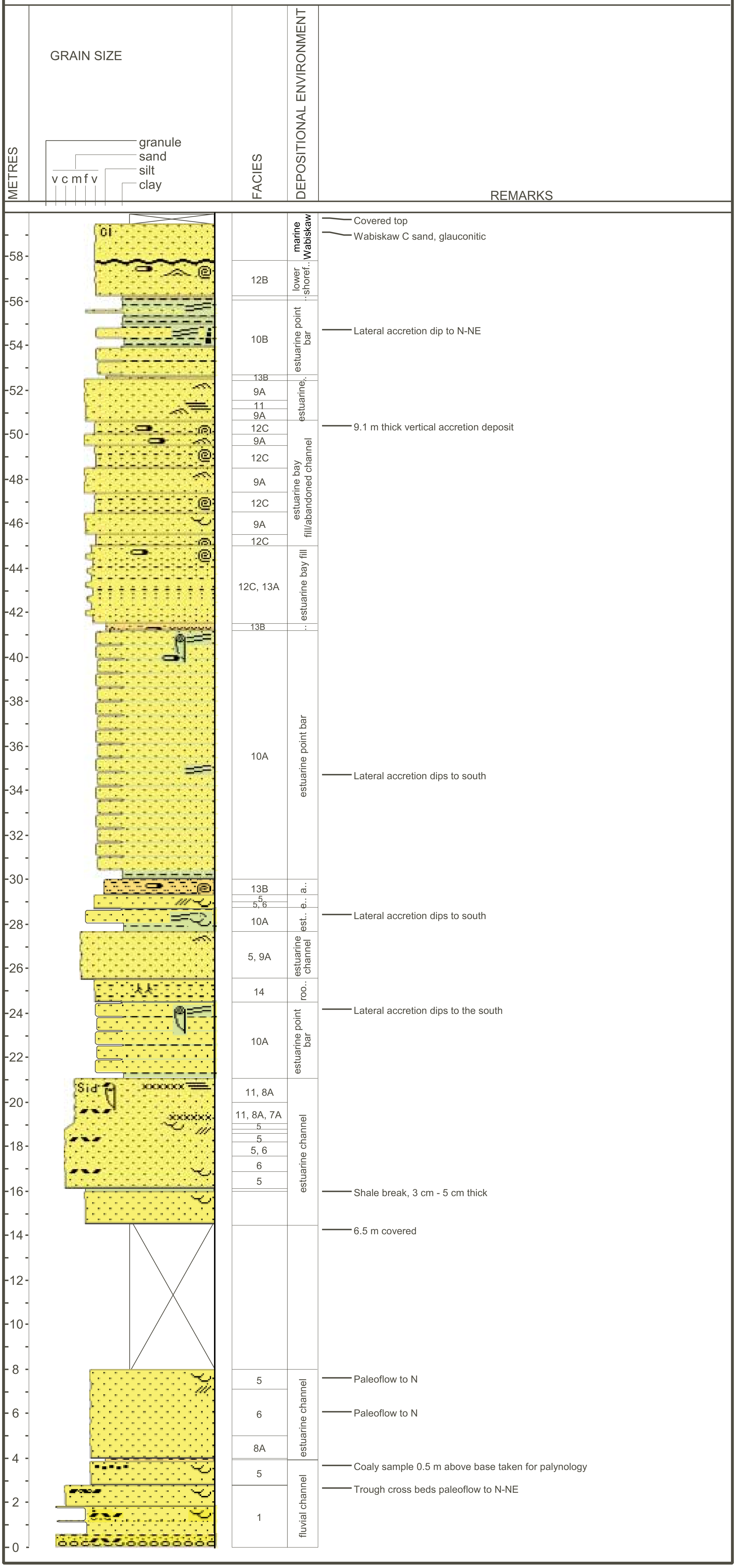


McMurray Formation Type #2 Section
UTM 0476157E 6291350N



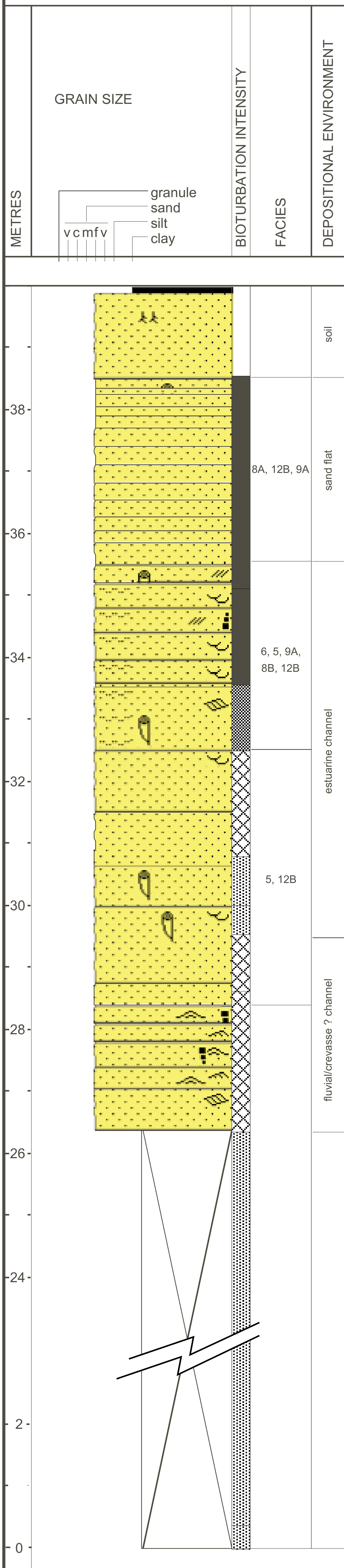
McMurray Formation Type #3 Section

UTM 0476096E 6291400N



McMurray Formation Type #4 Section

UTM 0476120E 6291840N



REMARKS

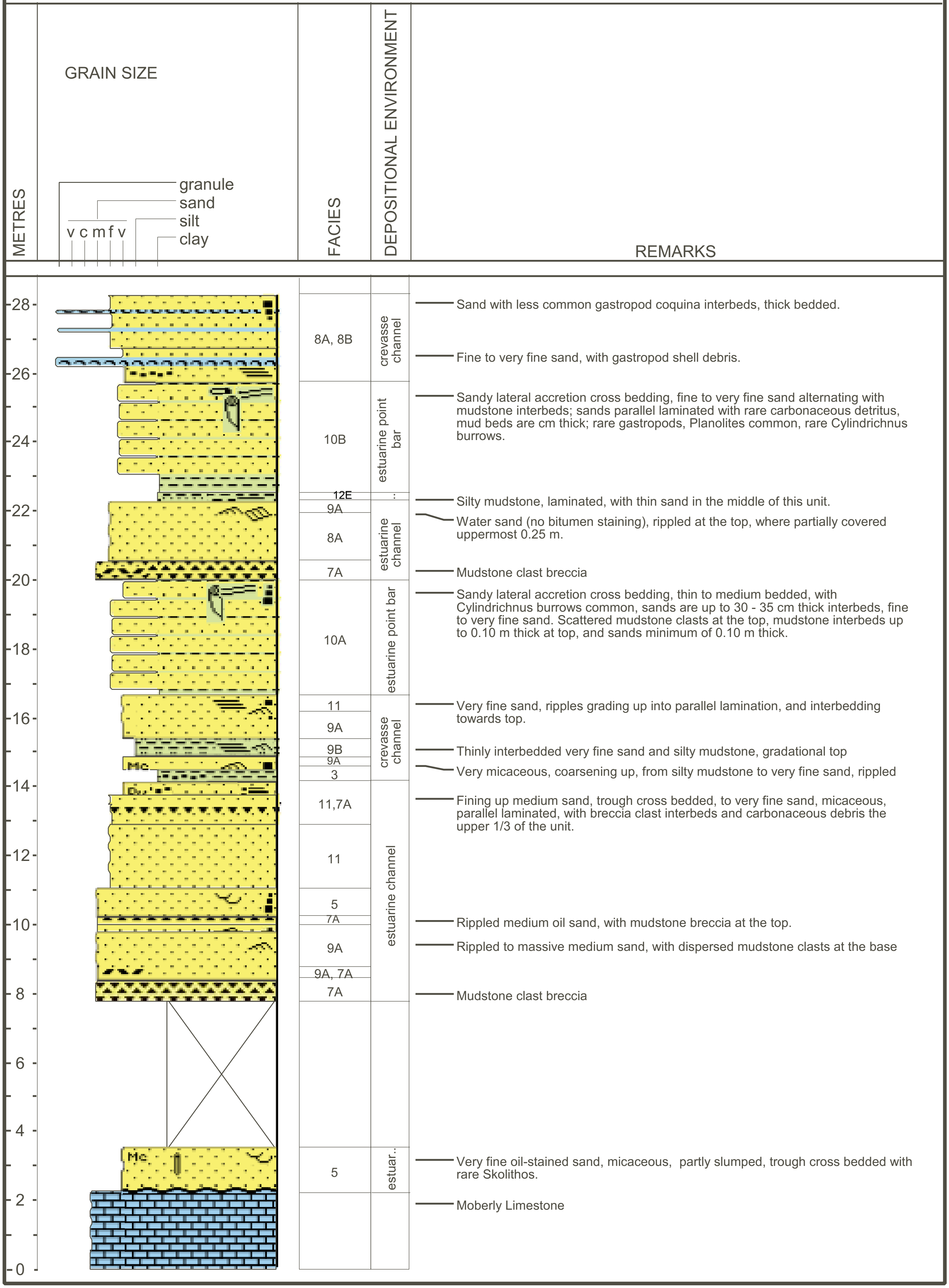
Unit 1: Tan-brown unconsolidated quartz sand, rooted. Pleistocene Sand. Thin rooted soil horizon at the top; 1.5 m thick.

Unit 2: Gray-tan fine to very fine sand, mainly massive, with vague ripples and well defined Cylindrichnus burrows; 2.5 - 3 m thick. Possible Sand Flat.

Unit 3: Thinning and fining-upward succession of dark gray to black, fine to medium oil sand at the base to fine oil sand at the top. Ripple drift and planar tabular crossbedding at the top separated by silty interbeds. Flows all to the north. Towards the base ripple drift on dipping (? lateral accretion crossbeds) , and ripple drift alternating with small scale trough crossbedded sands, 30 - 50 cm thick. Upsection bedding thins to 1-2 cm. Minor wave ripple crossbedding in float; 9.14 m thick. Possible Estuarine Valley-Fill.

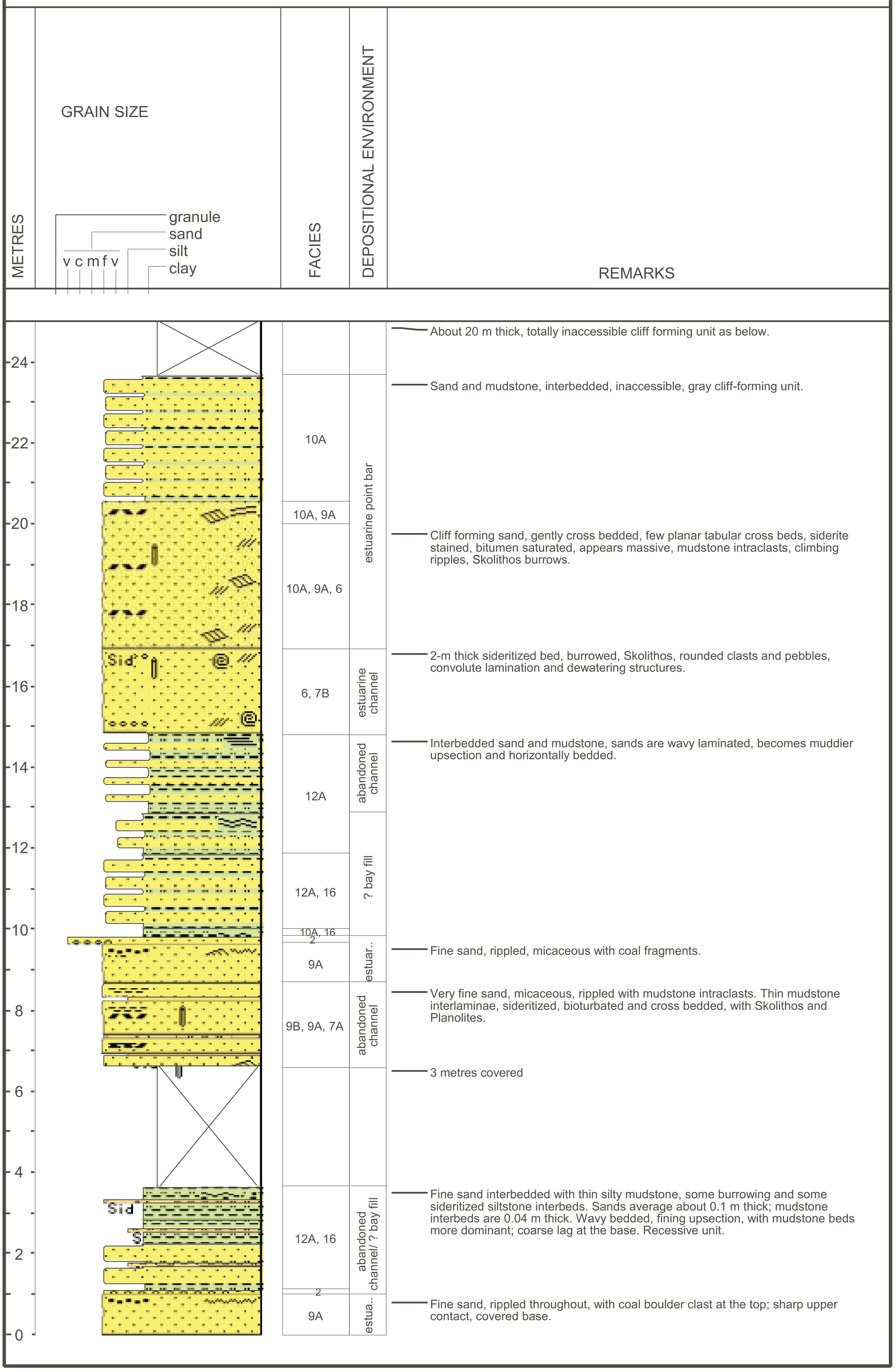
Athabasca River Mountain Rapids Section

UTM 0468880E 6281093N



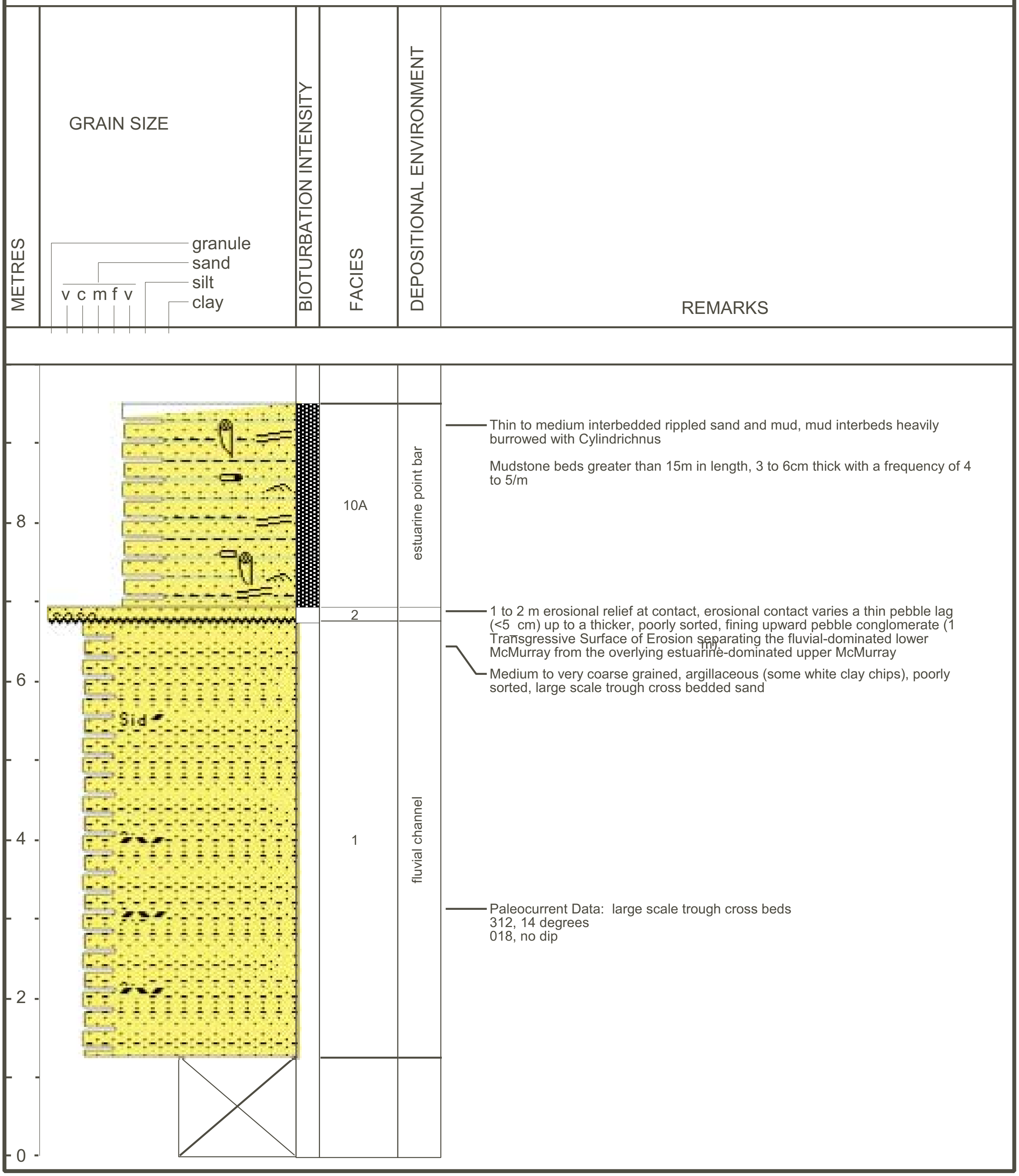
Marl Section (Upper)

UTM 0474800E 6305750N



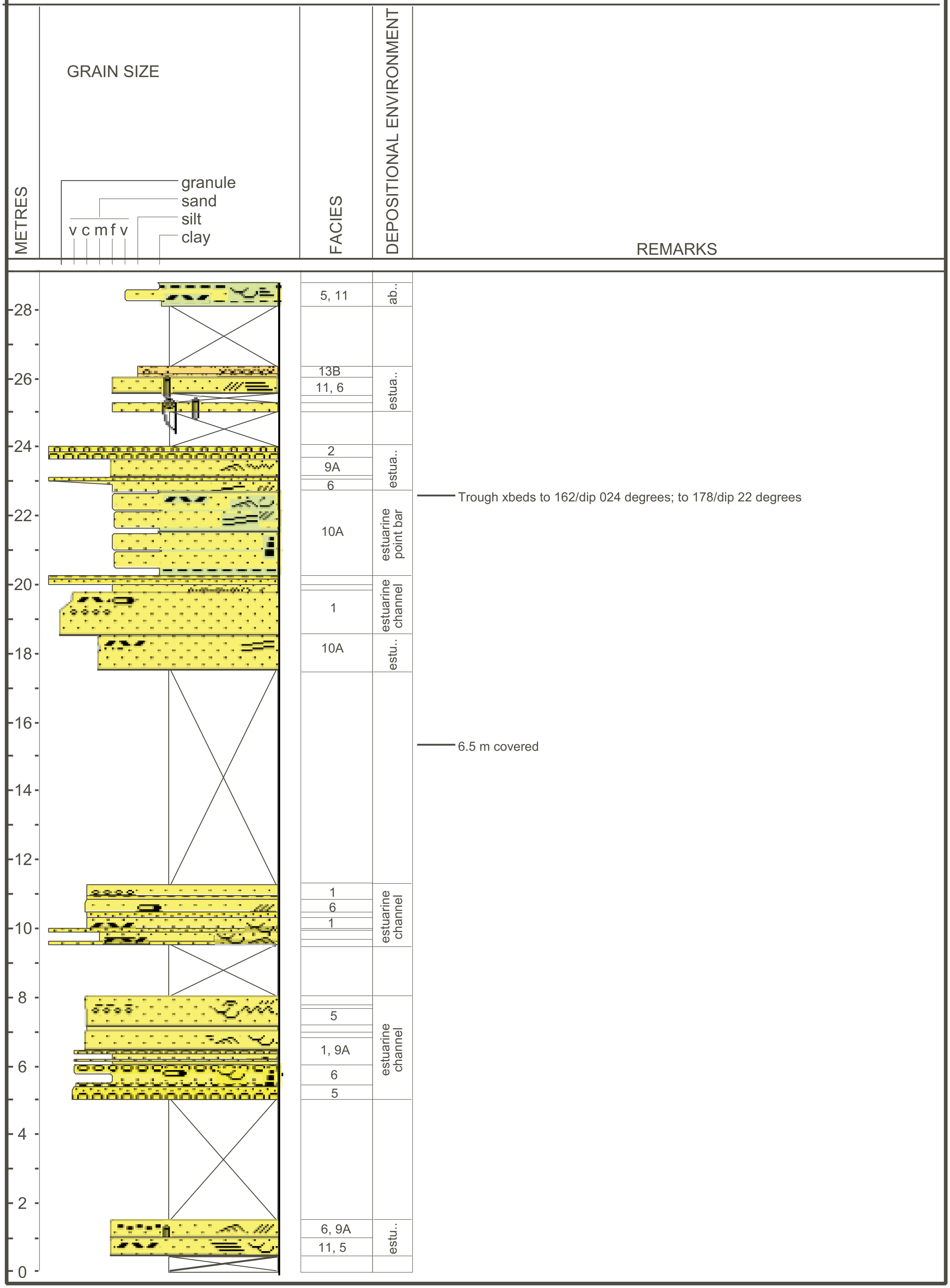
Tar Island Fluvial Section

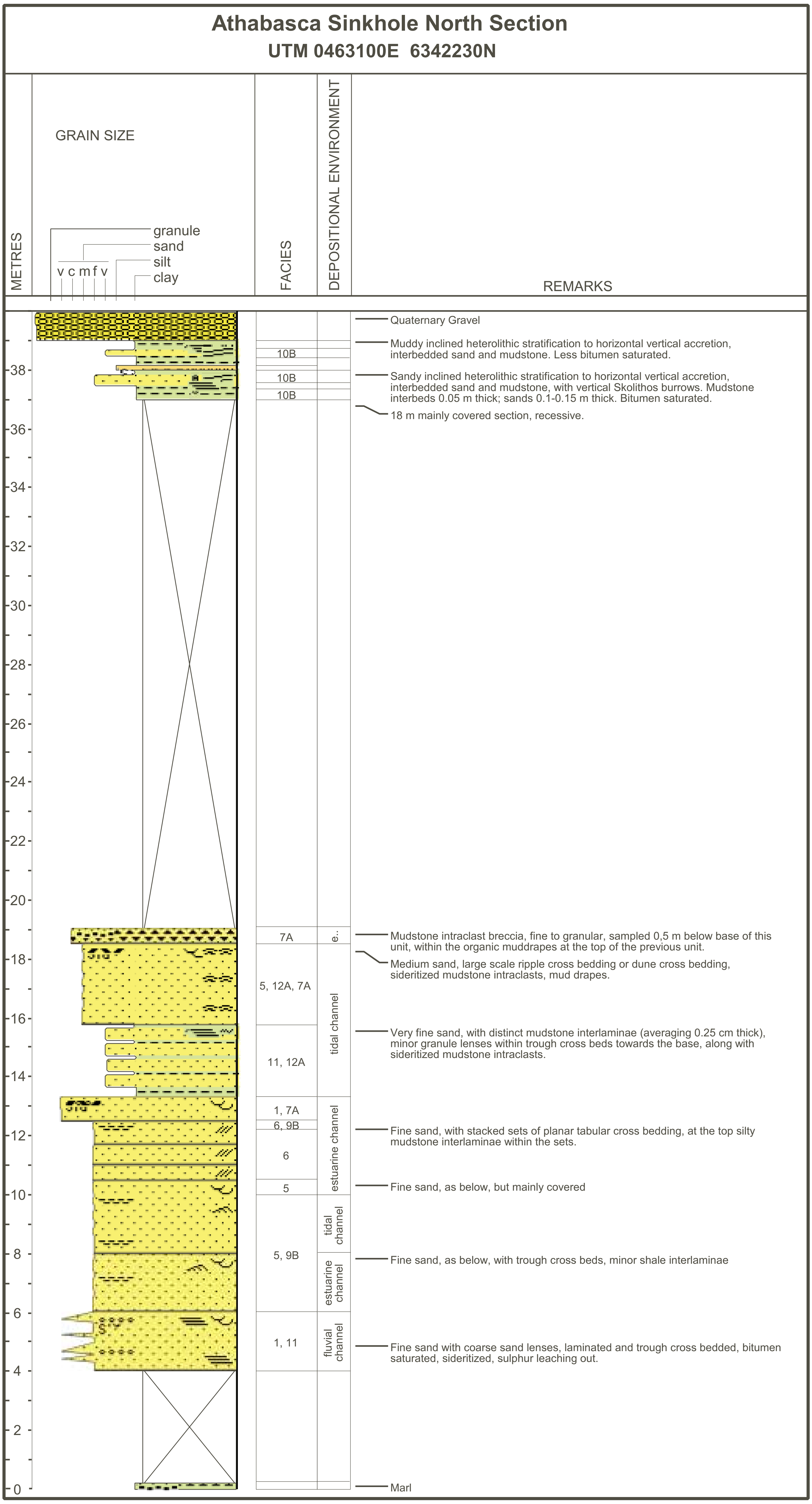
UTM 0472210E 6313710N



Athabasca River Sinkhole South Section

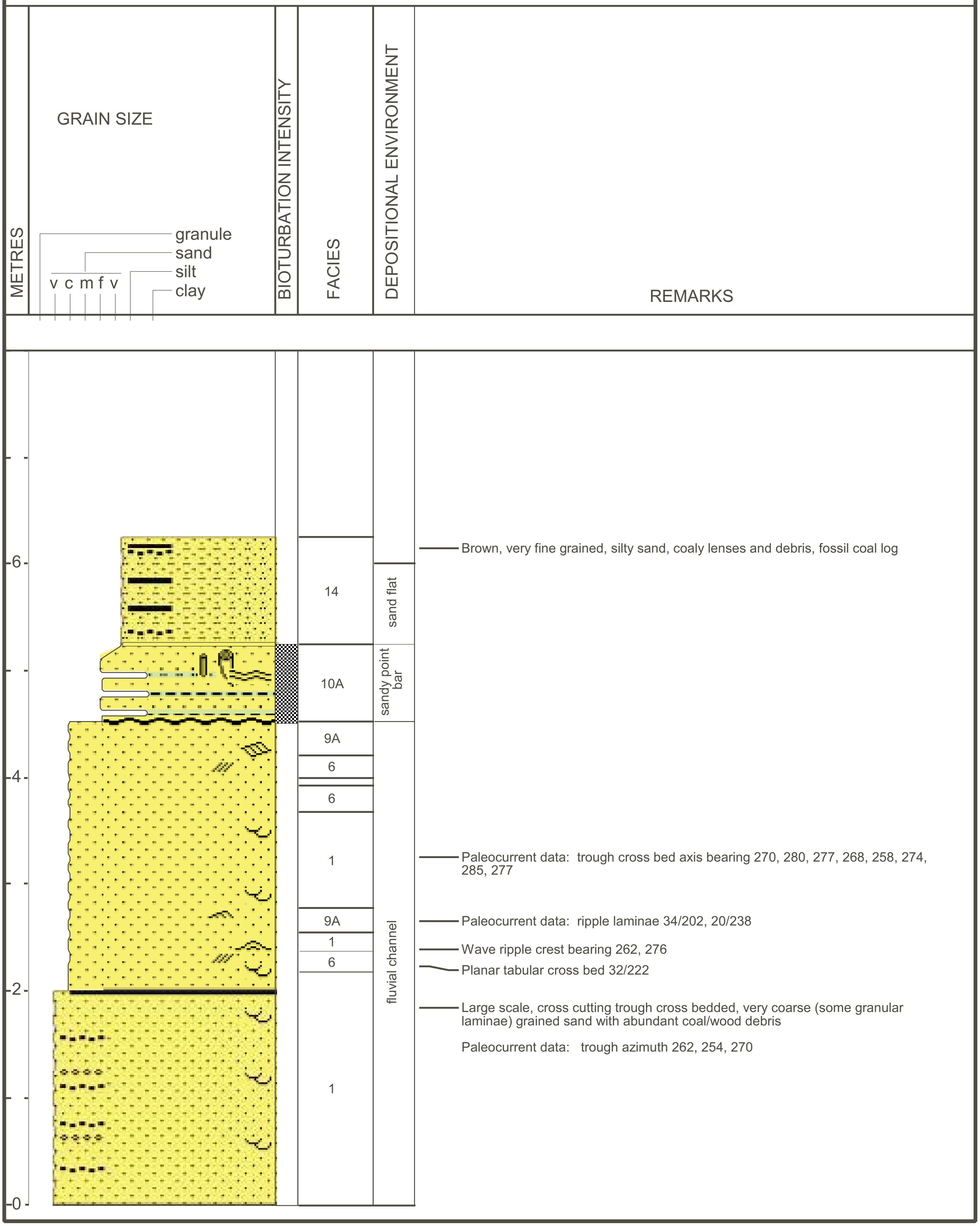
UTM 0463205E 6342138N




Athabasca Sinkhole North Section
UTM 0463100E 6342230N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10B
10B
10B
7A
5, 12A, 7A
11, 12A
1, 7A
6, 9B
6
5
5, 9B
1, 11
e..
tidal channel
estuarine channel
tidal channel
estuarine channel
fluvial channel
Quaternary Gravel
Muddy inclined heterolithic stratification to horizontal vertical accretion, interbedded sand and mudstone. Less bitumen saturated.
Sandy inclined heterolithic stratification to horizontal vertical accretion, interbedded sand and mudstone, with vertical Skolithos burrows. Mudstone interbeds 0.05 m thick; sands 0.1-0.15 m thick. Bitumen saturated.
18 m mainly covered section, recessive.
Mudstone intraclast breccia, fine to granular, sampled 0,5 m below base of this unit, within the organic muddrapes at the top of the previous unit.
Medium sand, large scale ripple cross bedding or dune cross bedding, sideritized mudstone intraclasts, mud drapes.
Very fine sand, with distinct mudstone interlaminae (averaging 0.25 cm thick), minor granule lenses within trough cross beds towards the base, along with sideritized mudstone intraclasts.
Fine sand, with stacked sets of planar tabular cross bedding, at the top silty mudstone interlaminae within the sets.
Fine sand, as below, but mainly covered
Fine sand, as below, with trough cross beds, minor shale interlaminae
Fine sand with coarse sand lenses, laminated and trough cross bedded, bitumen saturated, sideritized, sulphur leaching out.
Marl

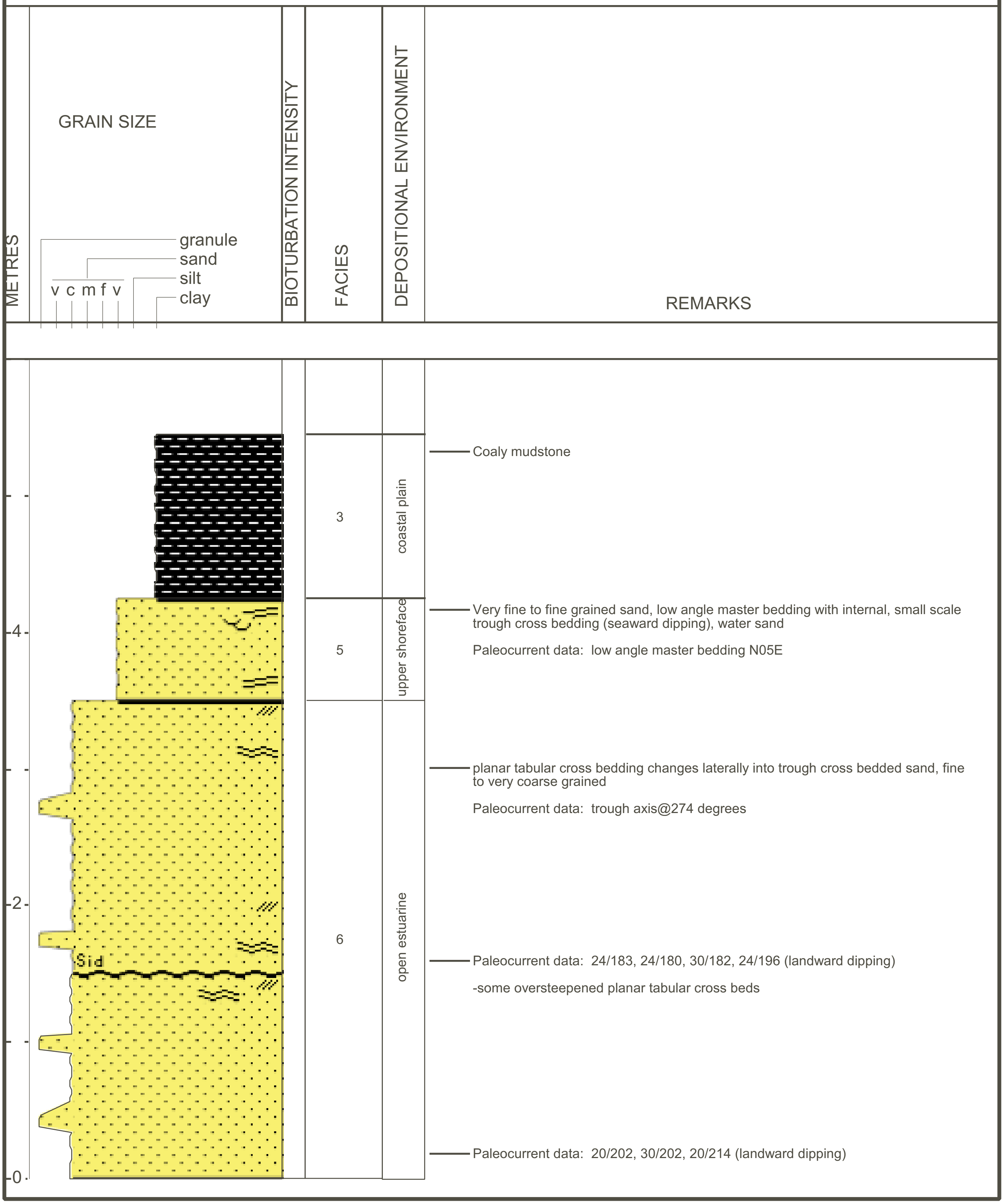
Daphne Island West #1 Section

UTM 0459630E 6349200N



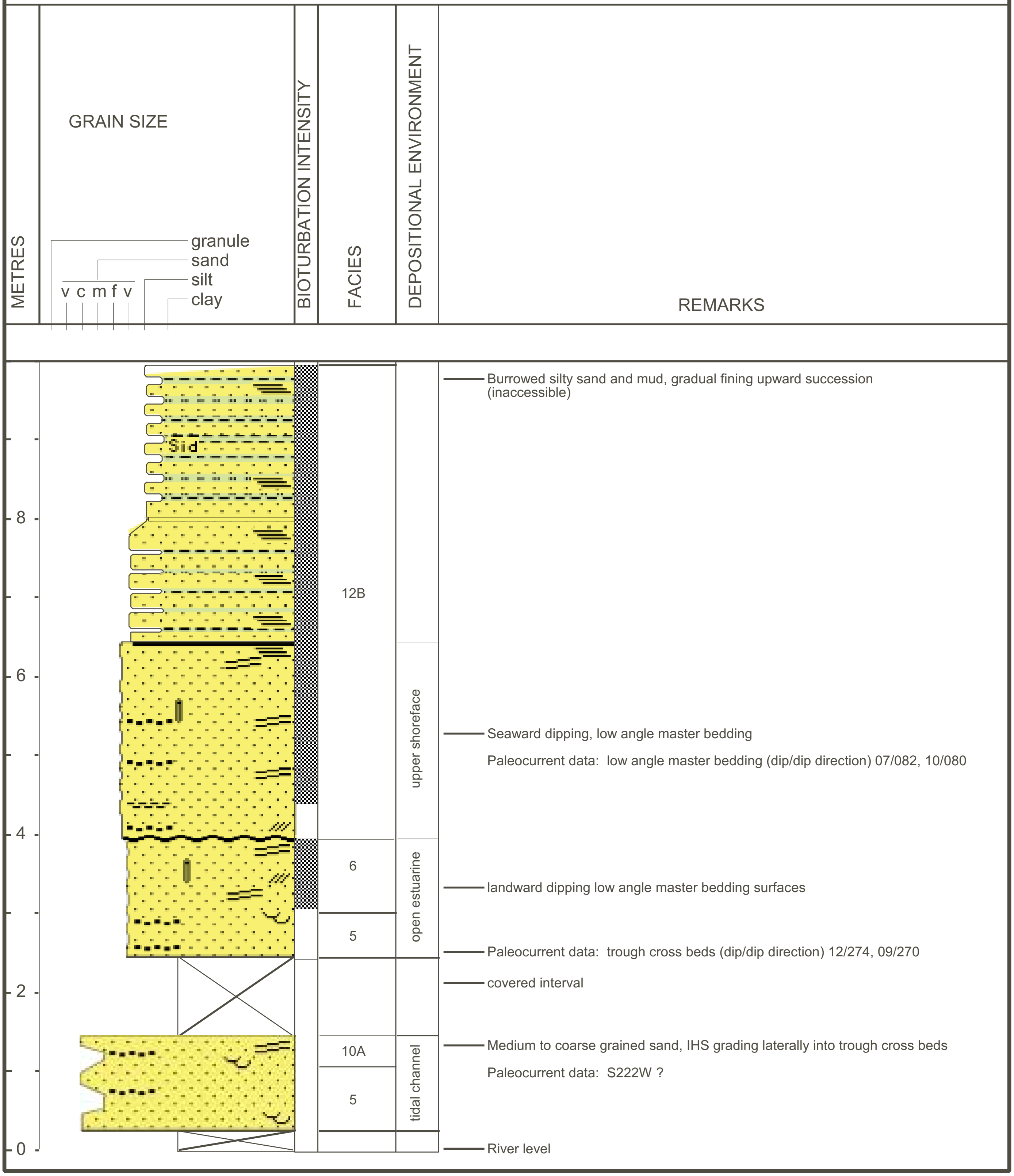
Daphne Island West #2 Section

UTM 0459640E 6349110N



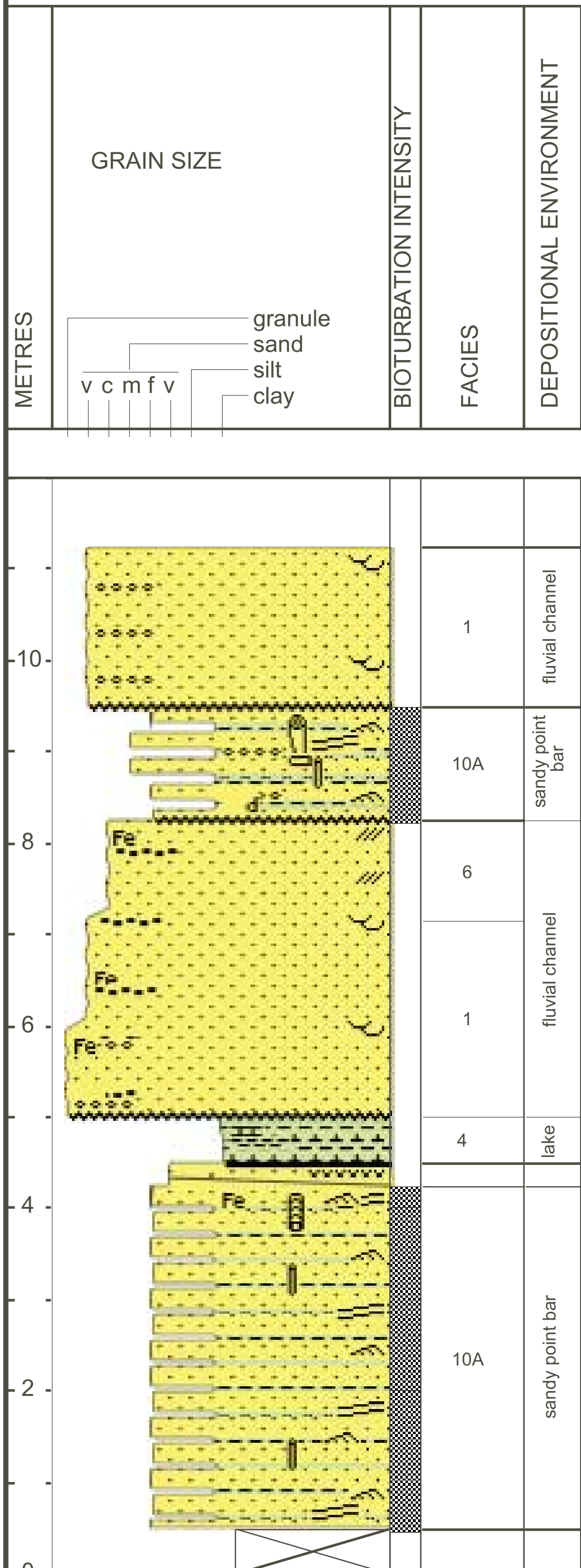
Daphne Island West #3 Section

UTM 0459650E 6349002N



Daphne Island East #1 Section

UTM 0460230E 6350120N



REMARKS

Trough cross bedded, very coarse grained sand, poorly sorted, angular erosion contact, local cut and fill to the north (cuts up to 0.5m deeper into underlying unit)

Paleocurrent data: trough axis bearing N062E

Burrowed, sand-dominated IHS (more argillaceous than basal unit), fine to medium grained with scattered granules

Paleocurrent data: lateral accretion bedding 04@134SE

Fining upward (granular to coarse grained sand within a fine grained matrix, abundant coaly debris trough cross bedded capped by unidirectional, high angle planar tabular cross beds (seaward dipping)

Paleocurrent data: High angle planar tabular bedding @N06E

White, friable marl, pinches out laterally

Sideritized contact, erosional, angular, internal unconformity

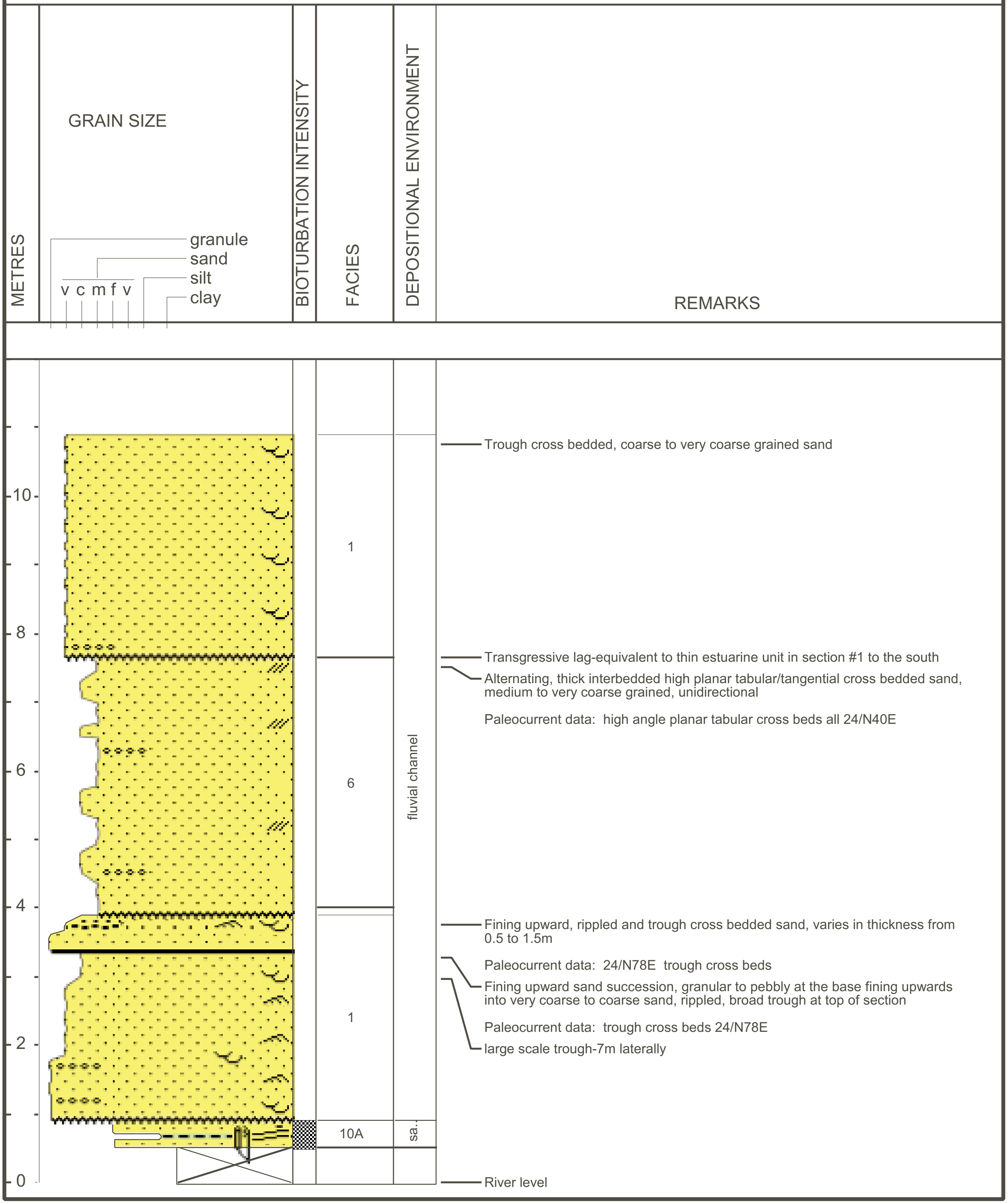
Thinly interbedded, fine grained sand and silty mudstone beds, sand beds (<25cm), mudstone beds (<5cm)

Paleocurrent data: Lateral accretion bed 10@ 120SE, ripples with lateral accretion @072NE

River level

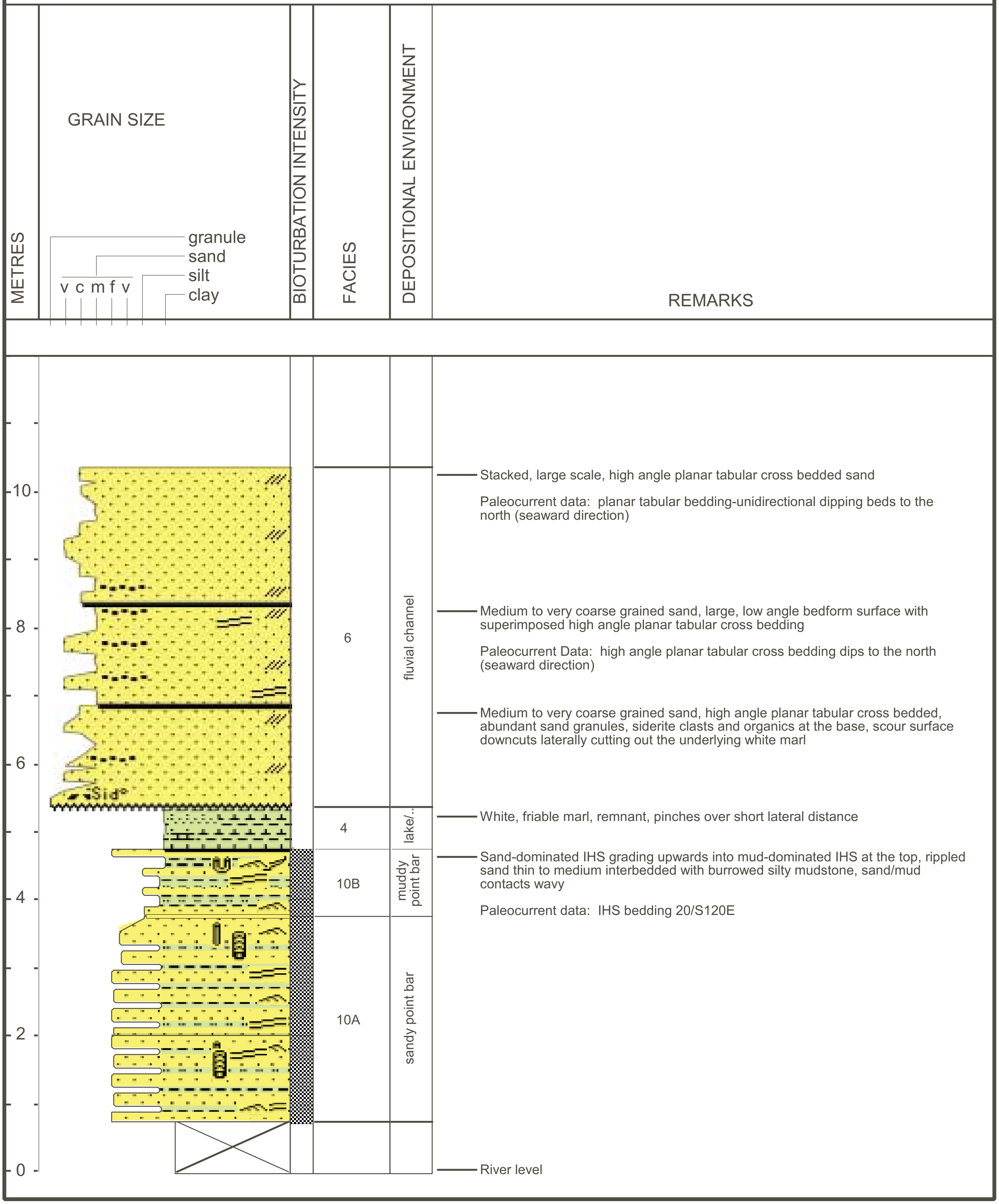
Daphne Island East #2 Section

UTM 0460220E 6350200N



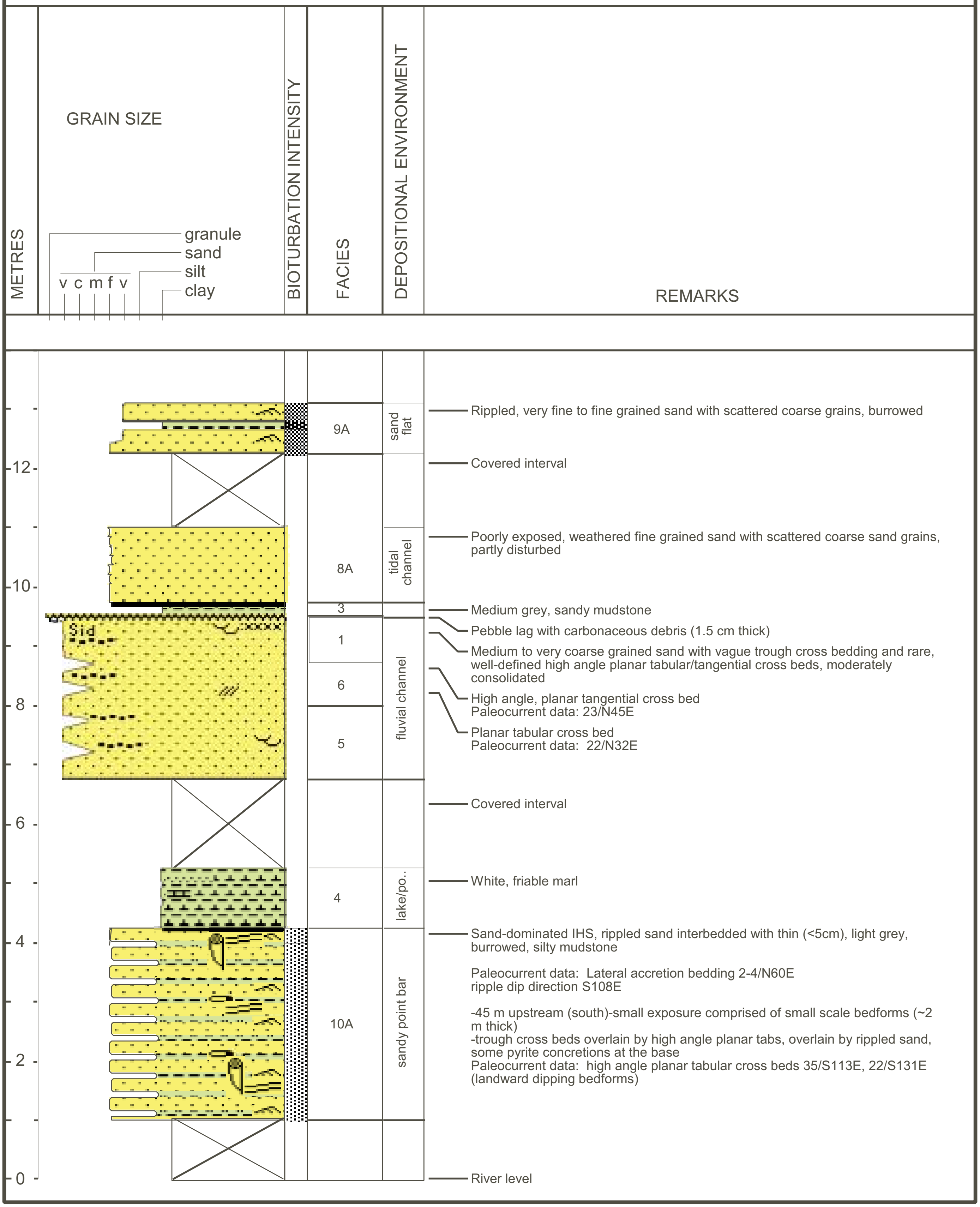
Daphne Island East #3 Section

UTM 0460250E 6350300N



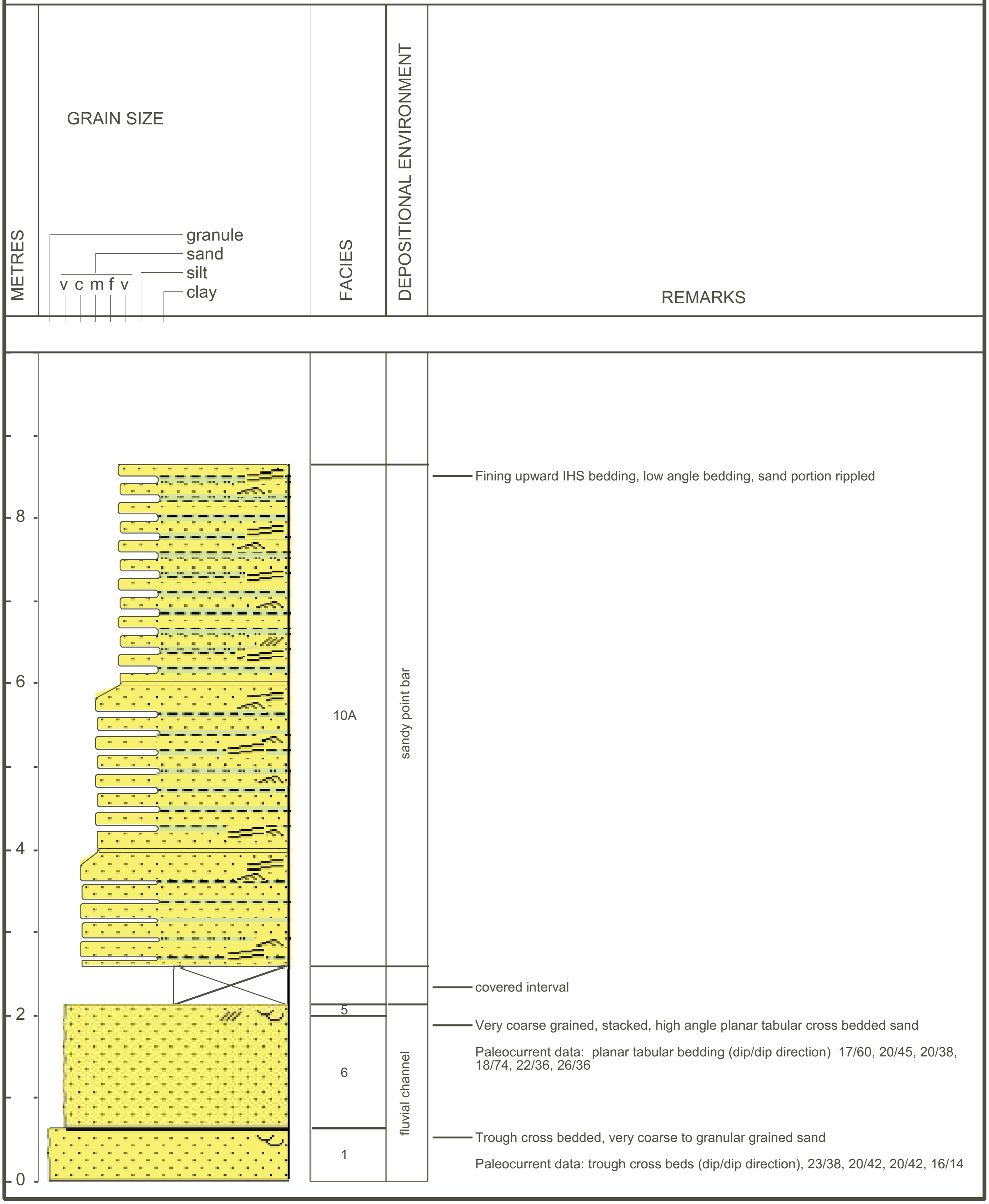
Daphne Island East #4 Section

UTM 0460230E 6350370N

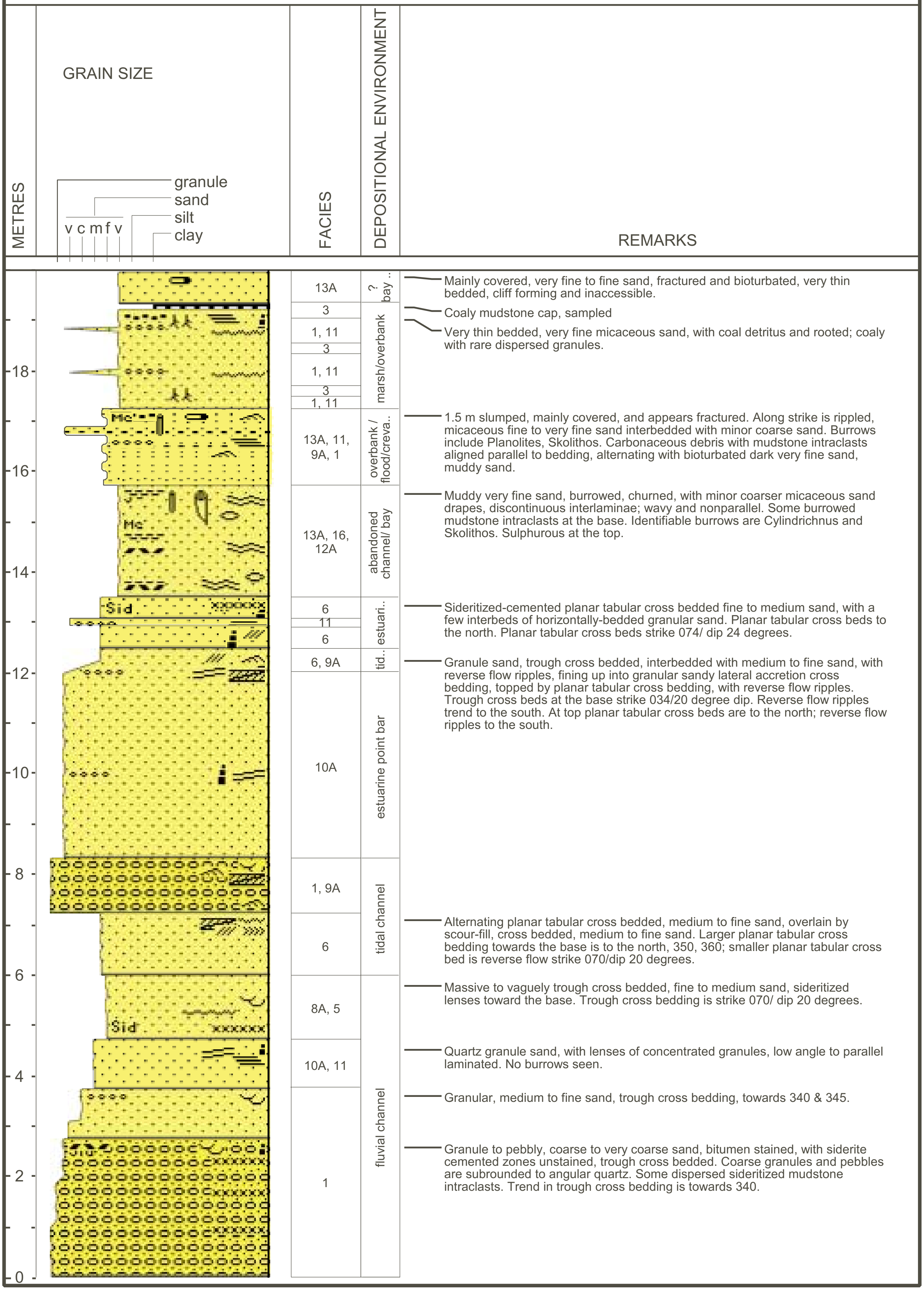


Daphne Island East #5 Section

UTM 0460210E 6350433N

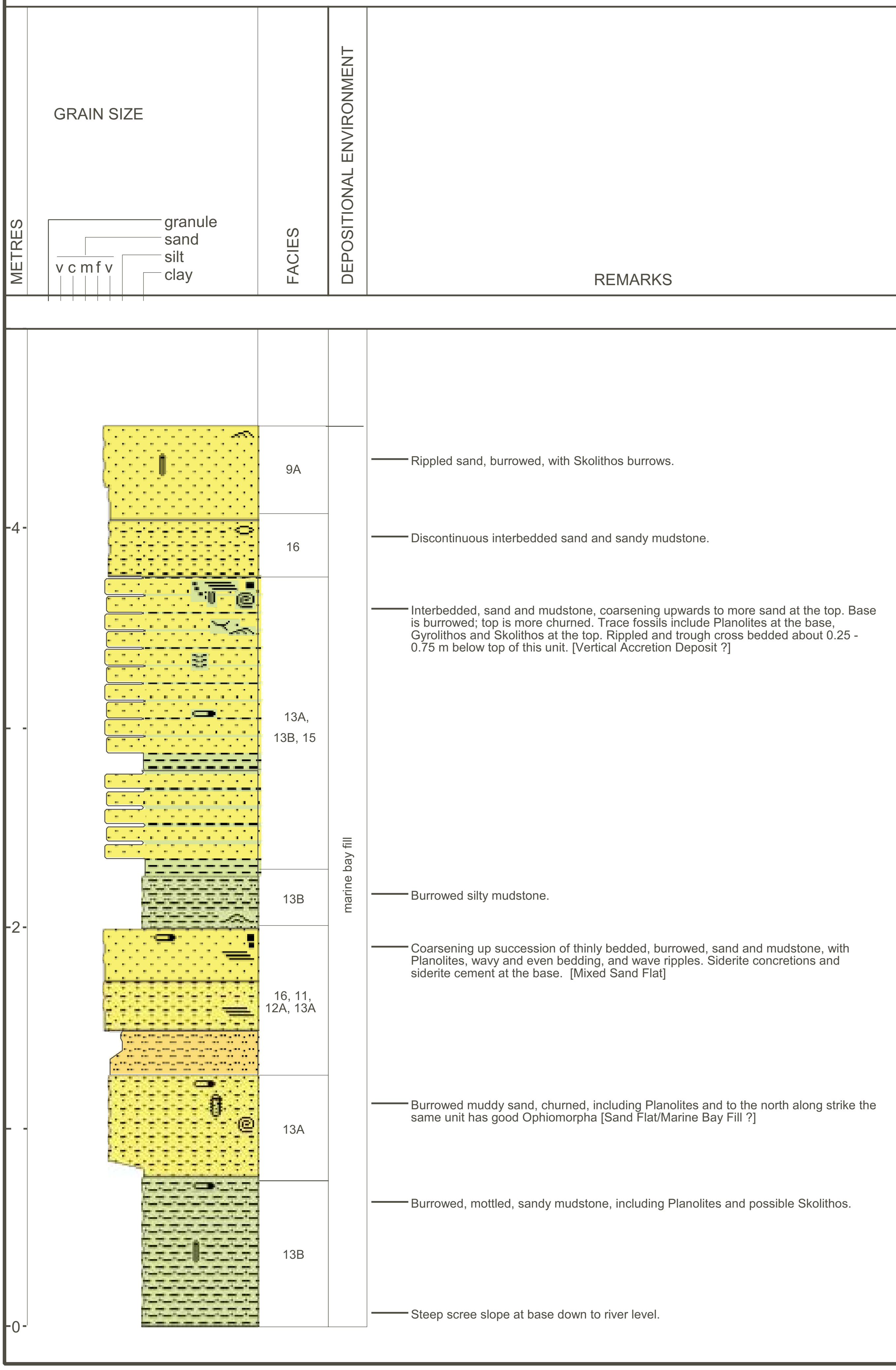


Pierre River Mouth (Lower) Section
UTM 0462150E 6367150N



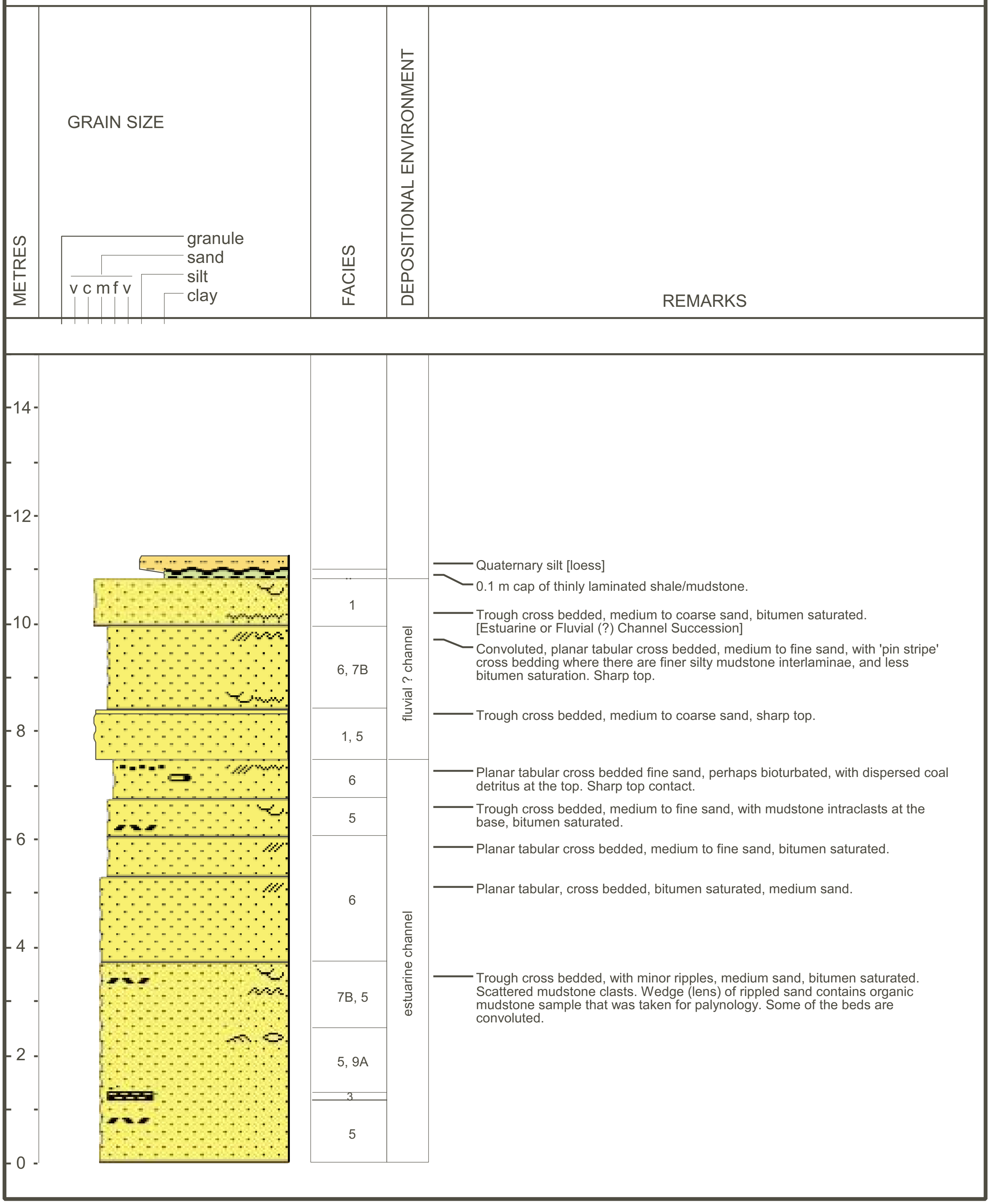
Pierre River Mouth (Upper) Section

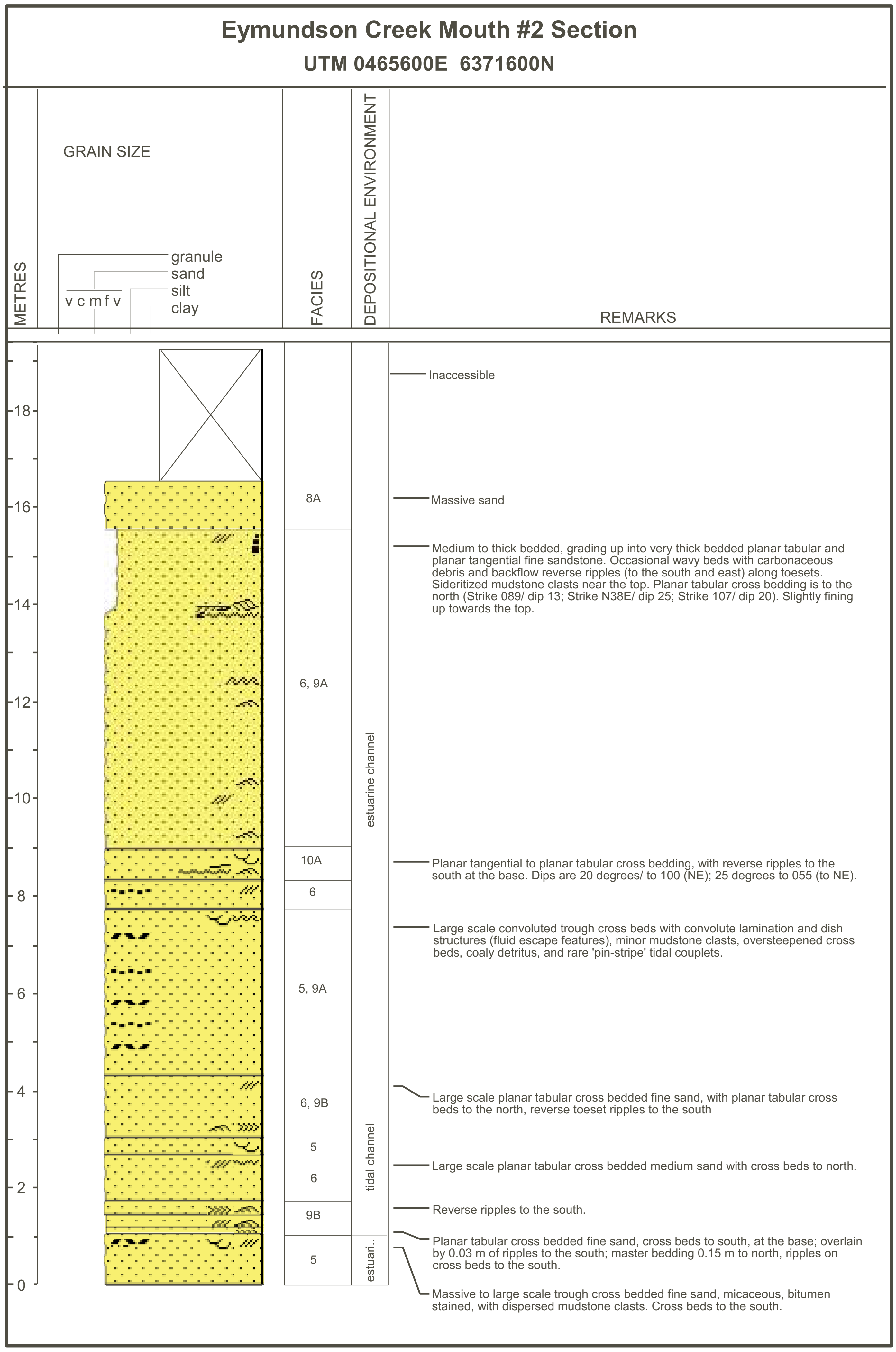
UTM 0462230E 6367250N



Eymundson Creek Mouth #1 Section

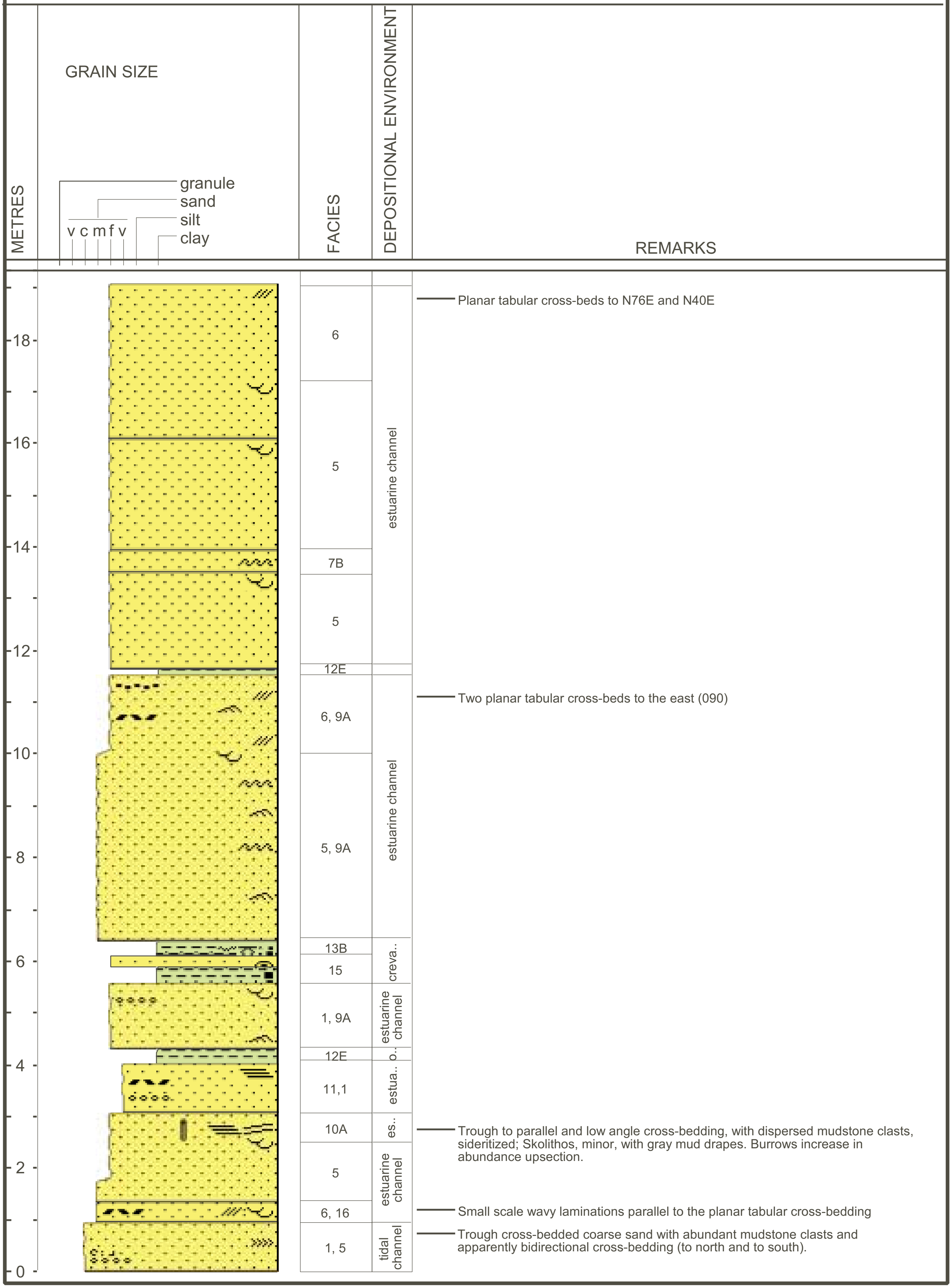
UTM 0465500E 6371500N




Eymundson Creek Mouth #2 Section
UTM 0465600E 6371600N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
18
16
14
12
10
8
6
4
2
0
8A
6, 9A
10A
6
5, 9A
6, 9B
5
6
9B
5
estuarine channel
tidal channel
estuari..
Inaccessible
Massive sand
Medium to thick bedded, grading up into very thick bedded planar tabular and planar tangential fine sandstone. Occasional wavy beds with carbonaceous debris and backflow reverse ripples (to the south and east) along toesets. Sideritized mudstone clasts near the top. Planar tabular cross bedding is to the north (Strike 089/ dip 13; Strike N38E/ dip 25; Strike 107/ dip 20). Slightly fining up towards the top.
Planar tangential to planar tabular cross bedding, with reverse ripples to the south at the base. Dips are 20 degrees/ to 100 (NE); 25 degrees to 055 (to NE).
Large scale convoluted trough cross beds with convolute lamination and dish structures (fluid escape features), minor mudstone clasts, oversteepened cross beds, coaly detritus, and rare 'pin-stripe' tidal couplets.
Large scale planar tabular cross bedded fine sand, with planar tabular cross beds to the north, reverse toeset ripples to the south
Large scale planar tabular cross bedded medium sand with cross beds to north.
Reverse ripples to the south.
Planar tabular cross bedded fine sand, cross beds to south, at the base; overlain by 0.03 m of ripples to the south; master bedding 0.15 m to north, ripples on cross beds to the south.
Massive to large scale trough cross bedded fine sand, micaceous, bitumen stained, with dispersed mudstone clasts. Cross beds to the south.

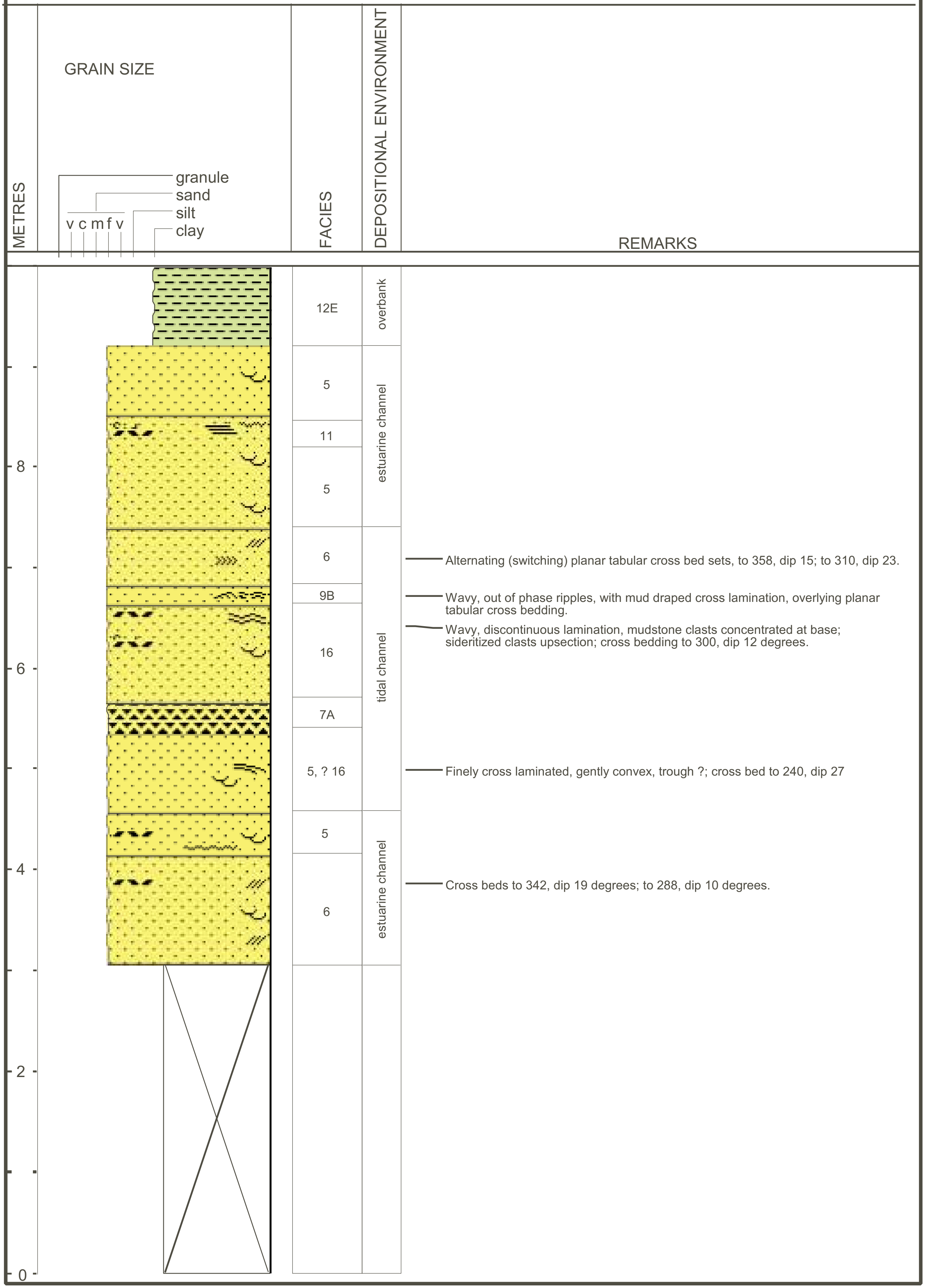
Eymundson Creek Mouth #3 Section

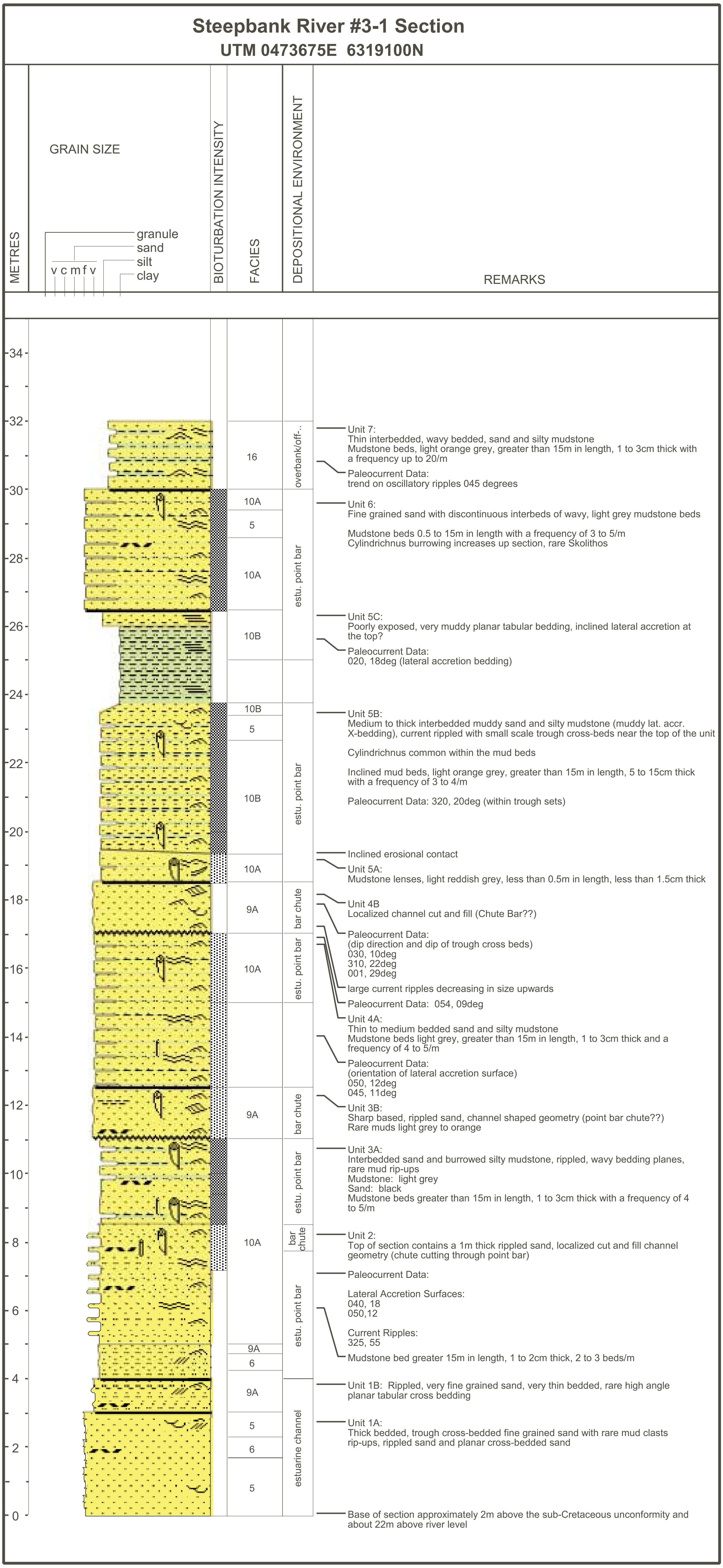
UTM 0465700E 6371800N



Eymundson Creek Mouth #4 Section

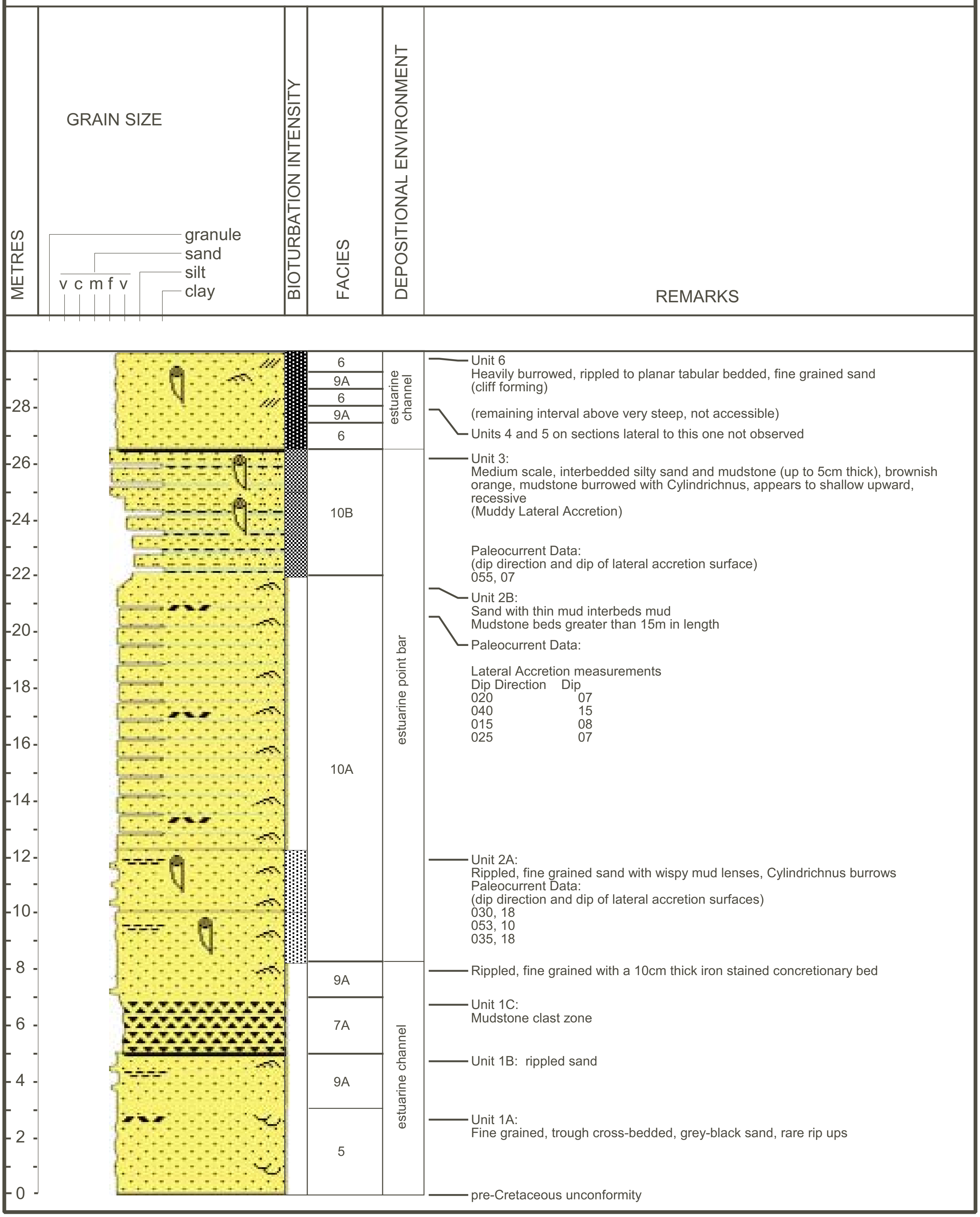
UTM 0465959E 6371974N




Steepbank River #3-1 Section
UTM 0473675E 6319100N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
16
10A
5
10A
10B
10B
5
10B
10A
9A
10A
9A
10A
9A
6
9A
5
6
5
overbank/off-..
estu. point bar
estu. point bar
bar chute
estu. point bar
bar chute
estu. point bar
bar chute
estu. point bar
estuarine channel
Unit 7:
Thin interbedded, wavy bedded, sand and silty mudstone
Mudstone beds, light orange grey, greater than 15m in length, 1 to 3cm thick with a frequency up to 20/m
Paleocurrent Data:
trend on oscillatory ripples 045 degrees
Unit 6:
Fine grained sand with discontinuous interbeds of wavy, light grey mudstone beds
Mudstone beds 0.5 to 15m in length with a frequency of 3 to 5/m
Cylindrichnus burrowing increases up section, rare Skolithos
Unit 5C:
Poorly exposed, very muddy planar tabular bedding, inclined lateral accretion at the top?
Paleocurrent Data:
020, 18deg (lateral accretion bedding)
Unit 5B:
Medium to thick interbedded muddy sand and silty mudstone (muddy lat. accr. X-bedding), current rippled with small scale trough cross-beds near the top of the unit
Cylindrichnus common within the mud beds
Inclined mud beds, light orange grey, greater than 15m in length, 5 to 15cm thick with a frequency of 3 to 4/m
Paleocurrent Data: 320, 20deg (within trough sets)
Inclined erosional contact
Unit 5A:
Mudstone lenses, light reddish grey, less than 0.5m in length, less than 1.5cm thick
Unit 4B
Localized channel cut and fill (Chute Bar??)
Paleocurrent Data:
(dip direction and dip of trough cross beds)
030, 10deg
310, 22deg
001, 29deg
large current ripples decreasing in size upwards
Paleocurrent Data: 054, 09deg
Unit 4A:
Thin to medium bedded sand and silty mudstone
Mudstone beds light grey, greater than 15m in length, 1 to 3cm thick and a frequency of 4 to 5/m
Paleocurrent Data:
(orientation of lateral accretion surface)
050, 12deg
045, 11deg
Unit 3B:
Sharp based, rippled sand, channel shaped geometry (point bar chute??)
Rare muds light grey to orange
Unit 3A:
Interbedded sand and burrowed silty mudstone, rippled, wavy bedding planes, rare mud rip-ups
Mudstone: light grey
Sand: black
Mudstone beds greater than 15m in length, 1 to 3cm thick with a frequency of 4 to 5/m
Unit 2:
Top of section contains a 1m thick rippled sand, localized cut and fill channel geometry (chute cutting through point bar)
Paleocurrent Data:
Lateral Accretion Surfaces:
040, 18
050,12
Current Ripples:
325, 55
Mudstone bed greater 15m in length, 1 to 2cm thick, 2 to 3 beds/m
Unit 1B: Rippled, very fine grained sand, very thin bedded, rare high angle planar tabular cross bedding
Unit 1A:
Thick bedded, trough cross-bedded fine grained sand with rare mud clasts rip-ups, rippled sand and planar cross-bedded sand
Base of section approximately 2m above the sub-Cretaceous unconformity and about 22m above river level

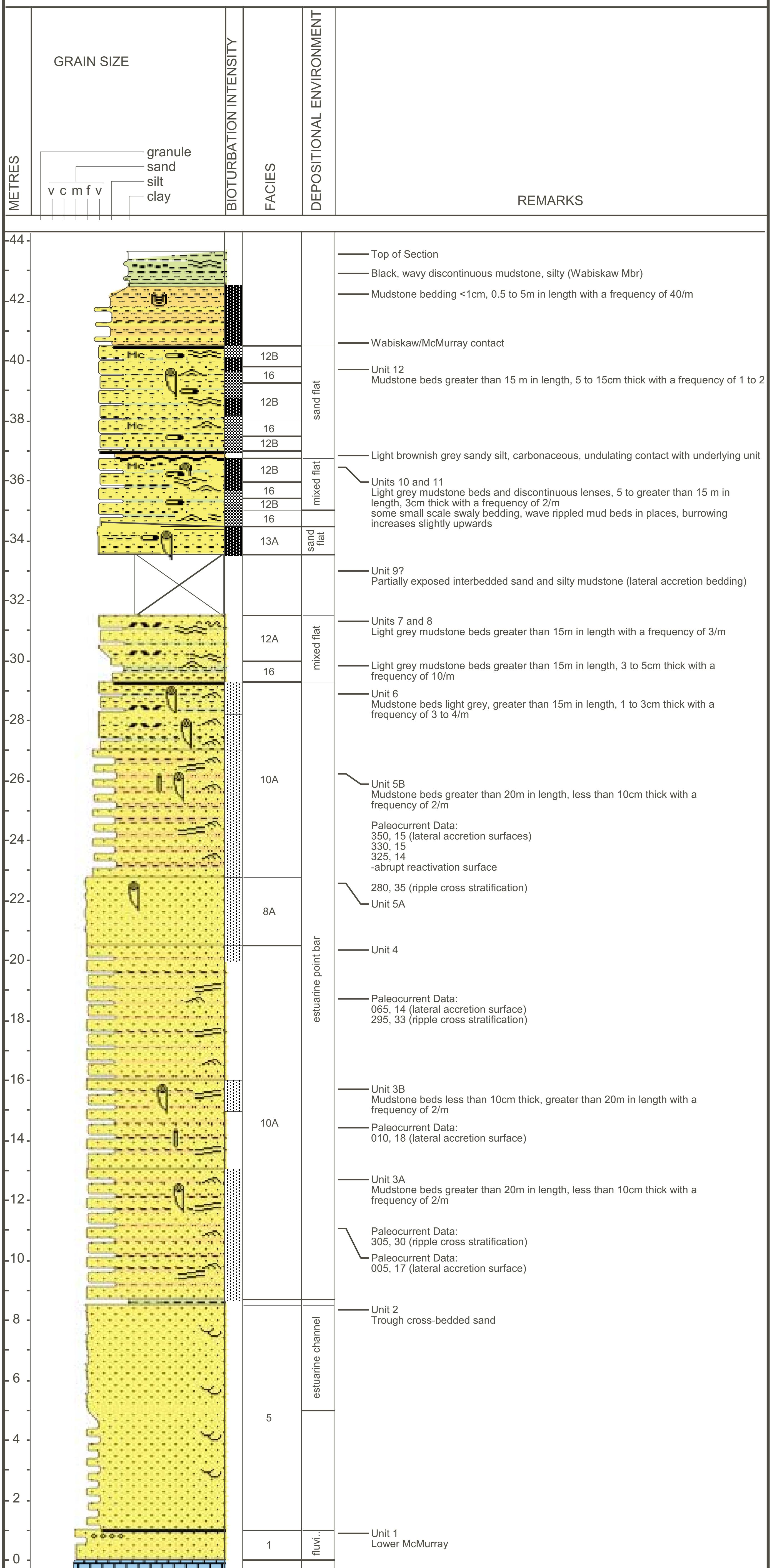
Steepbank River #3-2 Section

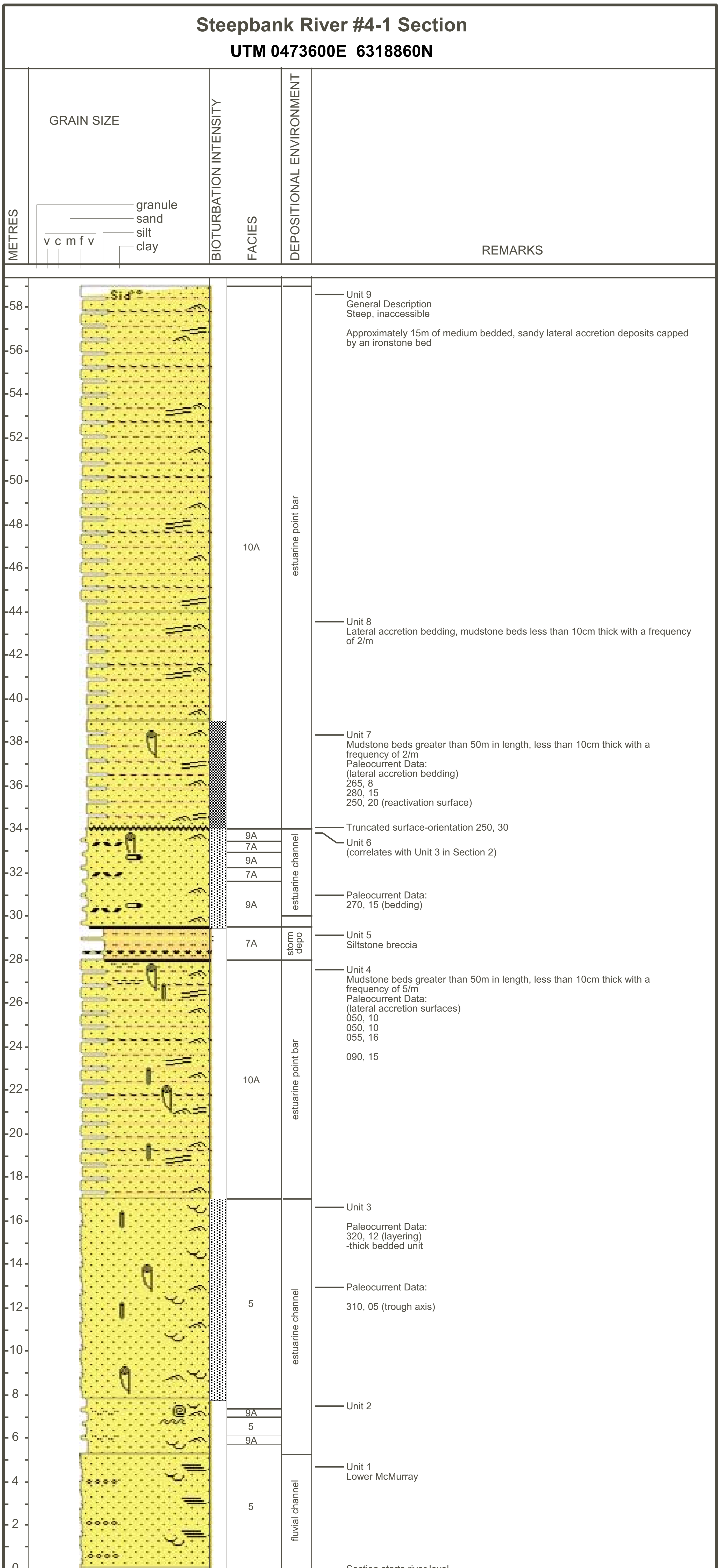
UTM 0473700E 6319070N



Steepbank River #3-3 Section

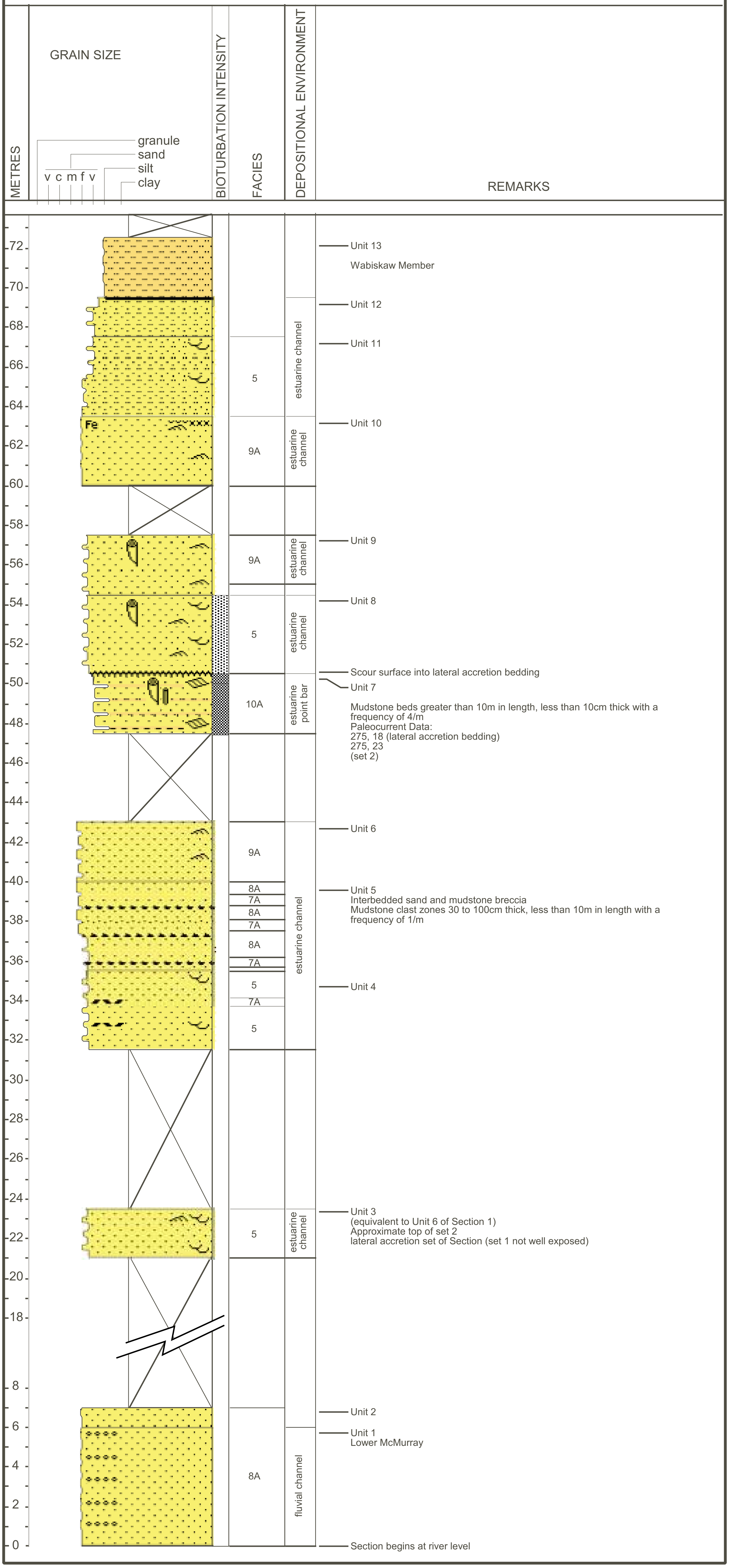
UTM 0473725E 6319050N




Steepbank River #4-1 Section
UTM 0473600E 6318860N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
Sid
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
10A
9A
7A
9A
7A
9A
7A
10A
5
9A
5
9A
5
estuarine point bar
estuarine channel
storm depo
estuarine point bar
estuarine channel
fluvial channel
Unit 9
General Description
Steep, inaccessible
Approximately 15m of medium bedded, sandy lateral accretion deposits capped by an ironstone bed
Unit 8
Lateral accretion bedding, mudstone beds less than 10cm thick with a frequency of 2/m
Unit 7
Mudstone beds greater than 50m in length, less than 10cm thick with a frequency of 2/m
Paleocurrent Data:
(lateral accretion bedding)
265, 8
280, 15
250, 20 (reactivation surface)
Truncated surface-orientation 250, 30
Unit 6
(correlates with Unit 3 in Section 2)
Paleocurrent Data:
270, 15 (bedding)
Unit 5
Siltstone breccia
Unit 4
Mudstone beds greater than 50m in length, less than 10cm thick with a frequency of 5/m
Paleocurrent Data:
(lateral accretion surfaces)
050, 10
050, 10
055, 16
090, 15
Unit 3
Paleocurrent Data:
320, 12 (layering)
-thick bedded unit
Paleocurrent Data:
310, 05 (trough axis)
Unit 2
Unit 1
Lower McMurray
Section starts river level

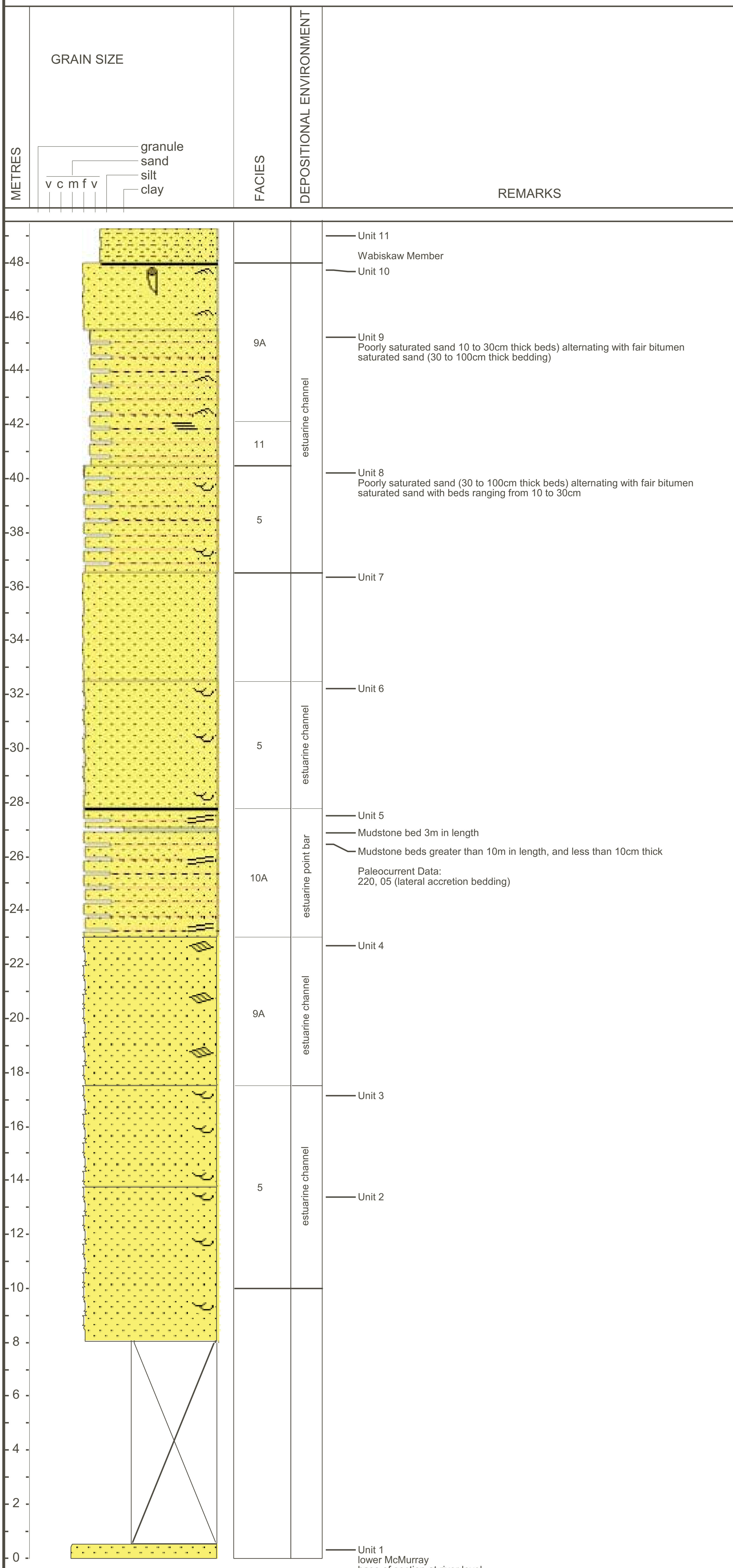
Steepbank River #4-2 Section

UTM 0473550E 6318800N



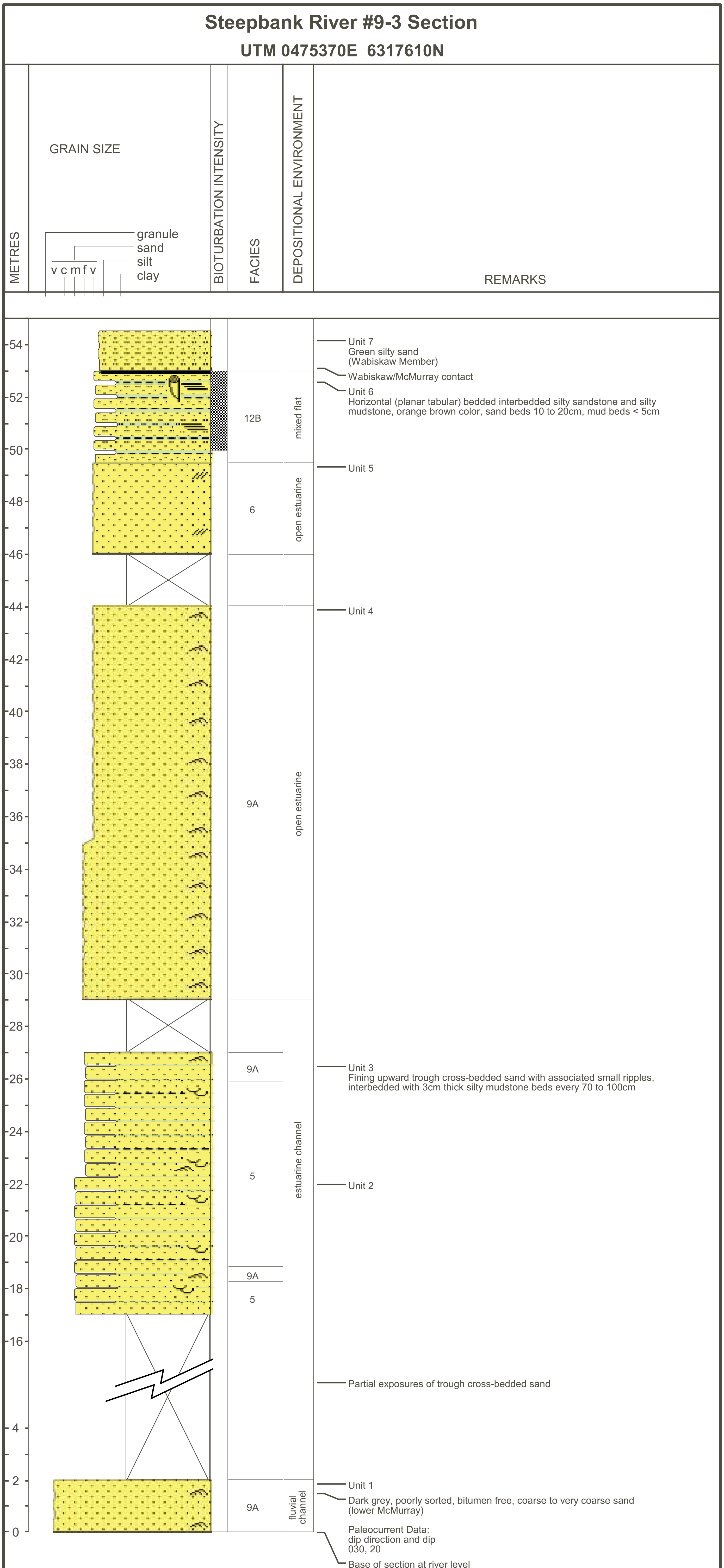
Steepbank River #9-1 Section

UTM 0475300E 6317760N



Steepbank River #9-2 Section

UTM 0475400E 6317700N


Steepbank River #9-3 Section
UTM 0475370E 6317610N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
4
2
0
12B
6
9A
9A
5
9A
5
9A
mixed flat
open estuarine
open estuarine
estuarine channel
fluvial channel
Unit 7
Green silty sand
(Wabiskaw Member)
Wabiskaw/McMurray contact
Unit 6
Horizontal (planar tabular) bedded interbedded silty sandstone and silty mudstone, orange brown color, sand beds 10 to 20cm, mud beds < 5cm
Unit 5
Unit 4
Unit 3
Fining upward trough cross-bedded sand with associated small ripples, interbedded with 3cm thick silty mudstone beds every 70 to 100cm
Unit 2
Partial exposures of trough cross-bedded sand
Unit 1
Dark grey, poorly sorted, bitumen free, coarse to very coarse sand (lower McMurray)
Paleocurrent Data:
dip direction and dip
030, 20
Base of section at river level

Christina River #1 Section

UTM 0498075E 6278050N

REMARKS

Unit 1: Quaternary sand, brown-tan; 1 m, rooted at top

Inaccessible, covered interval; about 7 m thick.

Unit 2: (3.0m) Medium gray, planar tabular cross-bedded, coarse and granule grained sand (some pebbles); NW paleoflow. Crossbed sets range 15 - 35 cm thick. Extends upward into covered interval comprised of the same material.

Unit 3: (3.5m) Medium gray, trough cross-bedded sand; NW paleoflow. Cross-bed sets range 35 - 50 cm thick. In the lower 1/3 of this unit, Fe-stained sideritic and limonitic intraclasts are concentrated within the base of the trough cross-beds. Fe-stained clasts are up to 12 cm long.

Unit 4: (0.50m) Medium gray, trough cross-bedded, fine grained sand; uniform paleoflows to NW. Ripples at the base of trough cross-bed toesets. NW paleoflow.

Unit 5: (0.25m) Medium gray, ripple cross-bedded fine grained sand; uniform paleoflows to NW. Small scale trough crossbeds at top. Paleoflows also uniformly to the NW.

Unit 6: (0.25m) Medium gray, planar tabular cross-bedded fine grained sand; uniform paleoflows to NW. Small scale ripple-drift cross-beds at base with paleoflows to the SE, marching up toesets of the planar tabular cross-beds.

Unit 7: (1.0m) Medium gray, extensively rippled, fine grained sand; uniform paleoflows to NW.

Unit 8: (0.25m) Medium gray, massive --> rippled, fine grained sand; uniform paleoflows to NW.

Unit 9: (0.25m) Medium gray, rippled, fine grained sand; uniform paleoflows to NW. Dispersed Fe-stone ripup clasts within small troughs.

Unit 10: Medium gray, parallel-laminated fine grained sand. Beds are each about 5 cm thick, upper flow regime deposits.

Unit 11: Medium gray, rippled quartz fine sand. Unit is about 0.3 m thick. ? Fluvial overbank deposits.

Unit 12: (1.0m) Medium gray, massive --> parallel laminated quartz fine sand. Fe-cemented Fe-stone cap.

Unit 12: (1.5m) Medium gray, massive --> parallel laminated, fine grained sand. Fe-cemented Fe-stone cap. At base are a few dispersed Fe-stone, sideritic and limonitic intraclasts within massive lower part of bed.

Unit 13: (1.0m) Medium gray, rippled, fine grained sand. Base becomes covered along strike.

Unit 14: Medium gray, planar tabular cross-bedded fine grained sand. Covered along strike. Paleoflows uniformly to the NW.

Unit 15: (4-5M) Medium gray, mainly massive, with some vague parallel lamination within fine to medium grained sand. Unit is 4 - 5 m thick. Covered along strike.

Unit 16: Medium gray, planar tabular crossbedded (single set 0.75m thick), quartz-rich, fine grained sand. Along strike this becomes covered. Paleoflows uniformly to the NW.

Unit 17: (3-4m) Medium gray, mainly massive, with some vague parallel lamination within quartz-rich, fine to medium grained sand. Covered along strike.

Unit 18: Medium gray, fine to medium grained, quartz sand. Unit is 3-4 m thick. Along strike unit is scoured out 1.5 m of underlying section, about 20 ft upstream. Swaley-bedded fine to medium sand at the base, with large-scale scours and sigmoidal lateral accretion cross-beds. Paleoflows mainly directed to the NW, a few flow reversals in small scale planar tabular cross-beds to SE as reverse-flows up the forsets.

Unit 19: (1-2m)Medium gray, fine to medium and coarse grained, quartz sand. Along strike unit scoured out from above. Small-scale rippled fine sand, medium to coarse sand fining up into fine sand, burrowed near the top.

Unit 20: (1.5m) Medium gray, fine to medium and coarse grained sand. Small-scale rippled fine sand, medium to coarse sand fining up into fine sand, burrowed near the top; underlain by massive sand, with pinch and swells of lenticular coarse sand and granules. Paleoflows mainly directed to the NW, a few flow reversals to SE.

Unit 21: (2m) Medium gray, fine grained sand. Thin-bedded and burrowed, with vague relict ripple cross-beds. Well-pronounced Cylindrichnus and small Skolithos burrows.

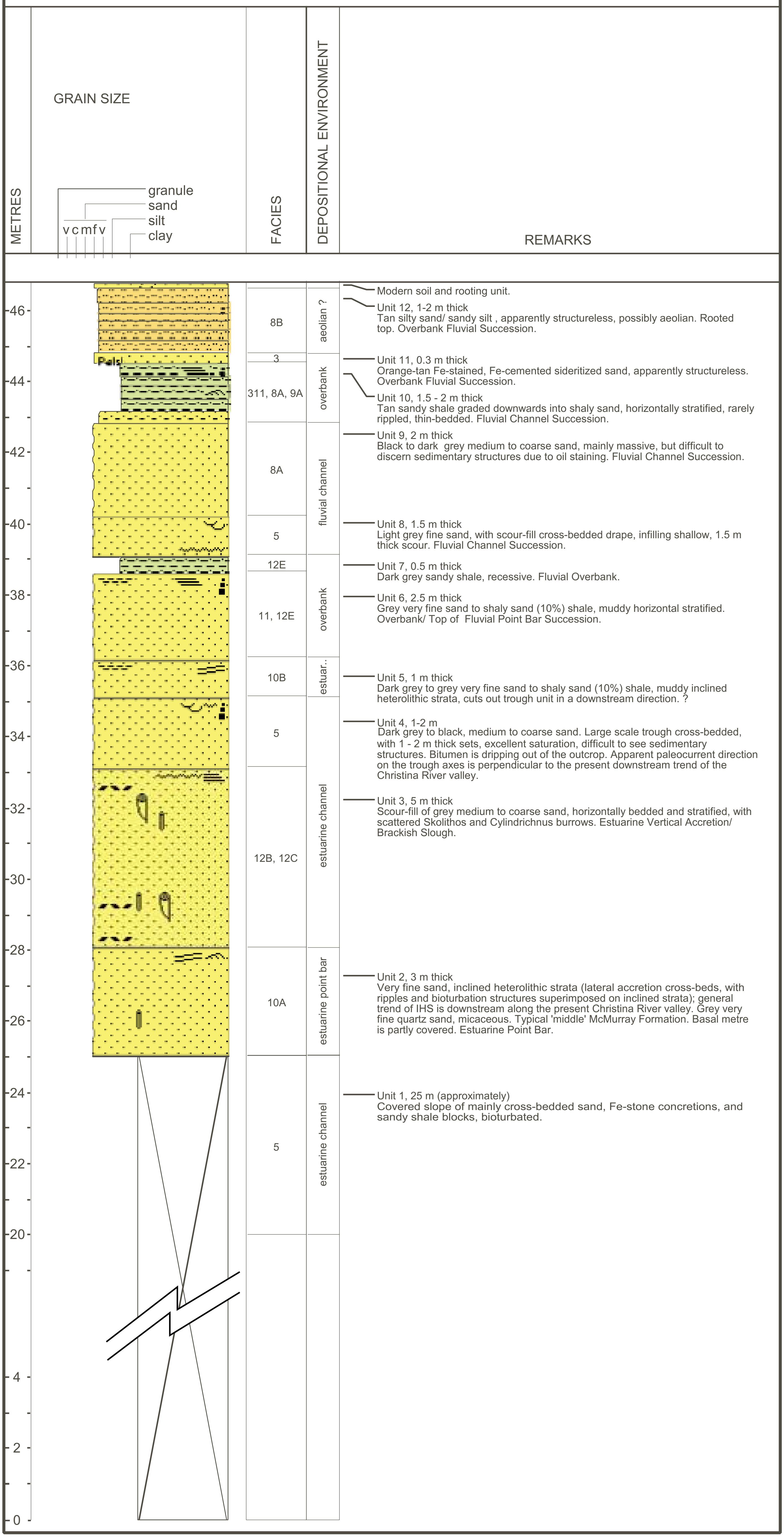
Unit 21: Medium gray, quartz granule, medium to coarse grained sand. Unit is 0.5m thick. Prominent planar tabular cross-beds. In float quartz clasts are up to 2 cm in length and well rounded.

Unit 22: Red, Fe-stone drape. Unit is 0.15 m thick.
pre-Cretaceous unconfomrity

Unit 23: Buff-tan, banded, wavy bedded argillaceous lime mudstone and limestone
Devonian-Christina Member/Waterways Formation.

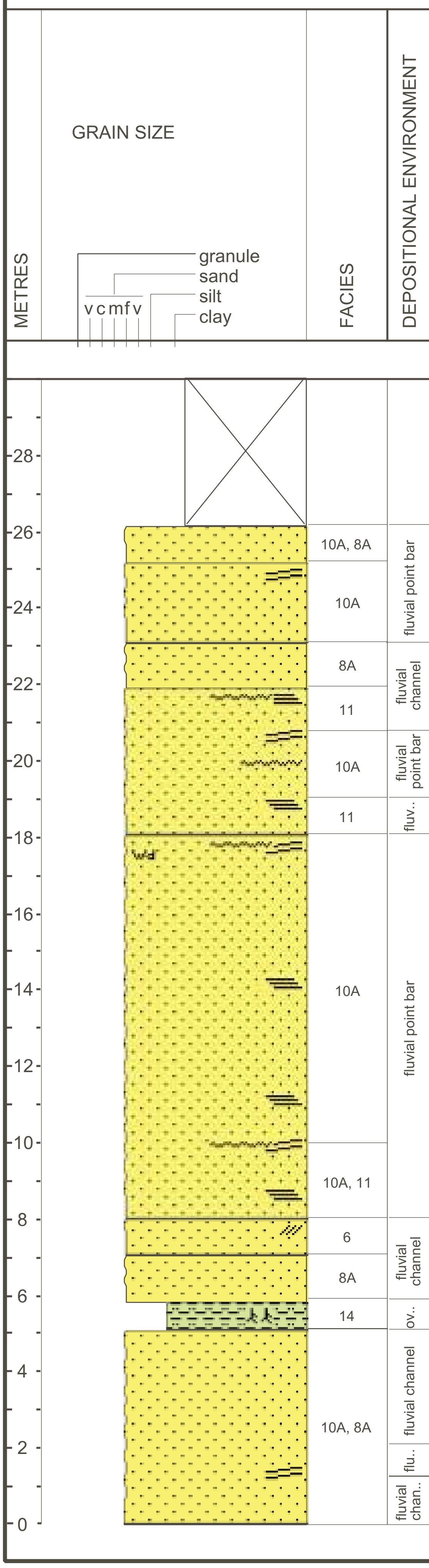
Christina River #2 Section

UTM 0498350E 6277620N



Christina River #3 Downstream Section

UTM 0499440E 6277180N



REMARKS

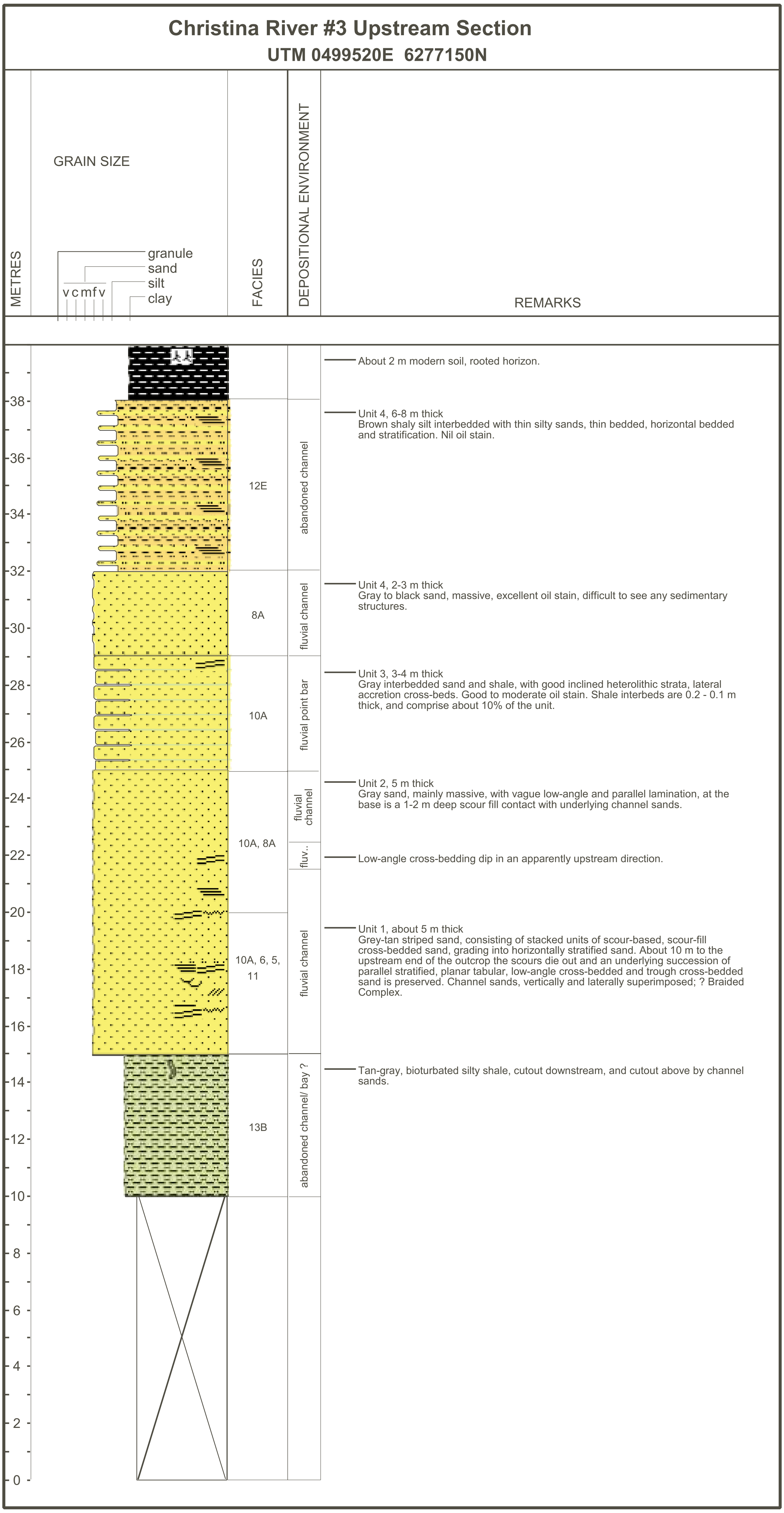
Inaccessible top.

Unit 4, 15 m thick
Low-angle and scour filled sands, overlain by interbedded massive channel sand, and low-angle inclined heterolithic point bar sands; smaller scale than below. Grey colouration, with less oil stain than below.

Unit 3, ~ 10 m thick
Massive channel oilsand, with vague parallel stratification, and cannonball siderite concretions at the top; cut out by a 10-m thick scour surface, infilled with scour-fill cross-bedding, about 1 - 2 m thick draping the scour surface, then the whole fill is inclined heterolithic strata, at a low angle, dipping downstream. Fluvial Channel Succession, cut and filled by Fluvial Channel to Point Bar Succession.

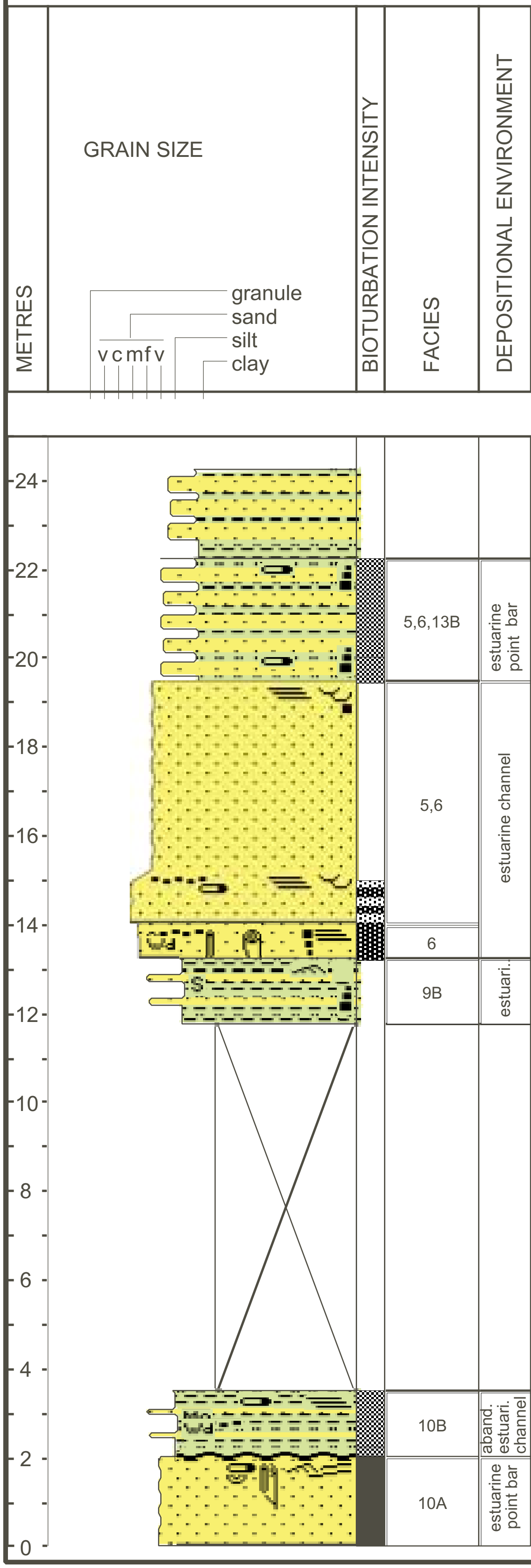
Unit 2, 3 m thick
Recessive dark gray silty shale, rooted, overlain by massive, ~ 1 m thick sand, topped by planar-tabular cross-bedded sand. Fluvial Channel Succession.

Unit 1, 4 - 5 m thick
Black - dark gray, massive, oilsand; becomes channelized upstream; vague low-angle cross-bedding, dipping upstream


Christina River #3 Upstream Section
UTM 0499520E 6277150N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
12E
8A
10A
10A, 8A
10A, 6, 5, 11
13B
abandoned channel
fluvial channel
fluvial point bar
fluvial channel
fluv..
fluvial channel
abandoned channel/ bay ?
About 2 m modern soil, rooted horizon.
Unit 4, 6-8 m thick
Brown shaly silt interbedded with thin silty sands, thin bedded, horizontal bedded and stratification. Nil oil stain.
Unit 4, 2-3 m thick
Gray to black sand, massive, excellent oil stain, difficult to see any sedimentary structures.
Unit 3, 3-4 m thick
Gray interbedded sand and shale, with good inclined heterolithic strata, lateral accretion cross-beds. Good to moderate oil stain. Shale interbeds are 0.2 - 0.1 m thick, and comprise about 10% of the unit.
Unit 2, 5 m thick
Gray sand, mainly massive, with vague low-angle and parallel lamination, at the base is a 1-2 m deep scour fill contact with underlying channel sands.
Low-angle cross-bedding dip in an apparently upstream direction.
Unit 1, about 5 m thick
Grey-tan striped sand, consisting of stacked units of scour-based, scour-fill cross-bedded sand, grading into horizontally stratified sand. About 10 m to the upstream end of the outcrop the scours die out and an underlying succession of parallel stratified, planar tabular, low-angle cross-bedded and trough cross-bedded sand is preserved. Channel sands, vertically and laterally superimposed; ? Braided Complex.
Tan-gray, bioturbated silty shale, cutout downstream, and cutout above by channel sands.

Christina River #4 Section

UTM 0512121E 6265989N



REMARKS

(2m thick) Wabiskaw D fill. Difficult to reach this section of outcrop.

(2.75m thick) Very fine grained sand. Small trough cross-beds and planar tabular beds with discontinuous sandy mudstone interbeds. Burrowed. The top contact of this unit is the contact between the Upper McMurray and the Wabiskaw.

(4.5m thick) Clean upper fine to lower fine grained sand. Large scale trough cross-beds with interbedded planar tabular bedding. Fines upwards.

(1m thick) Medium sand grained, excellent trough cross-bedding with coal. Planar tabular bedding alternating with bioturbated coaly sand in between.

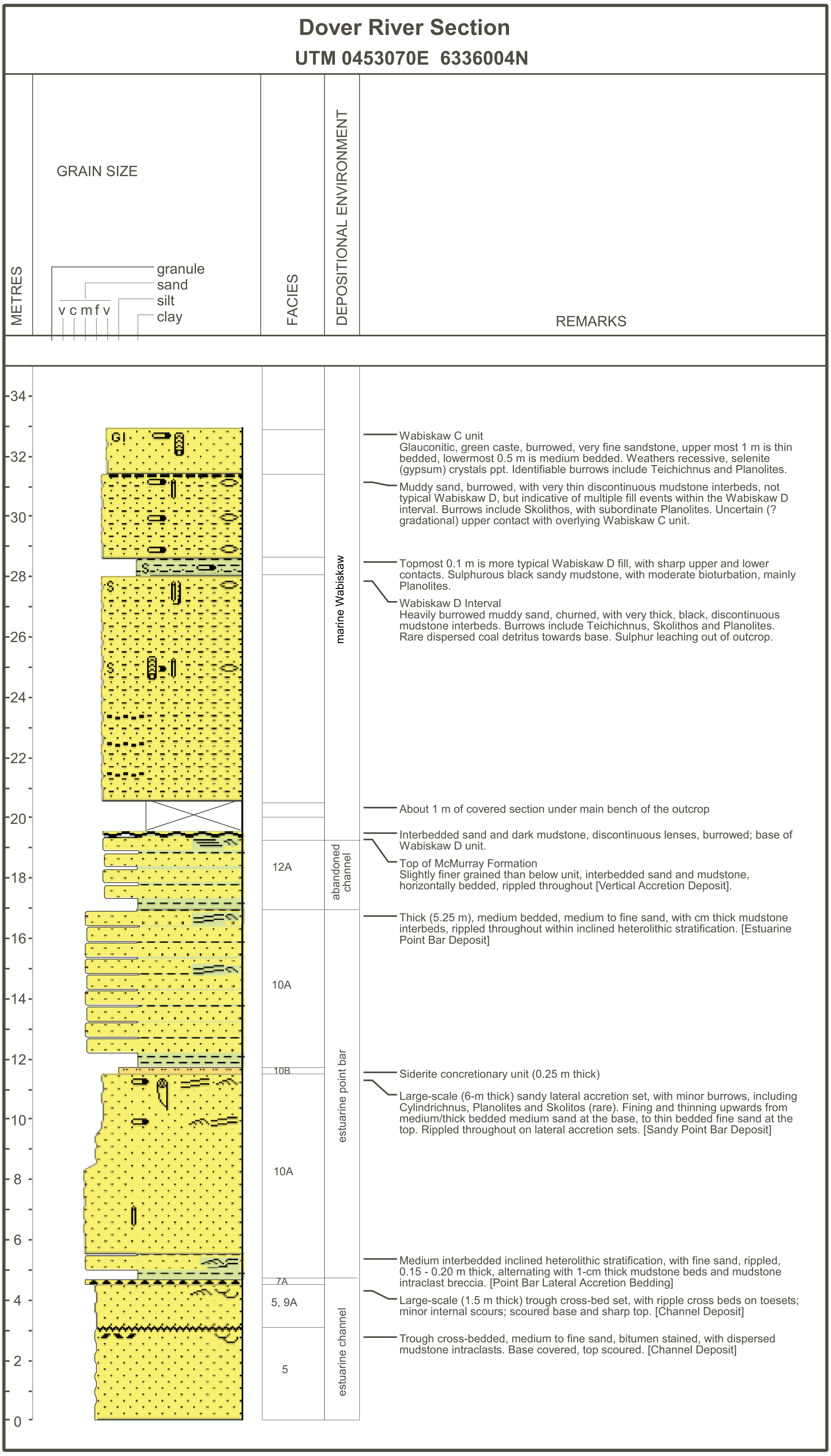
(0.75m thick) Medium sand grain size, planar tabular beds. Abundant coaly debris, wood fragments common. Sulphur is weathered out, as well as possible manganese. Skolithos and Cylindrichnus common. Coarsening upwards unit.

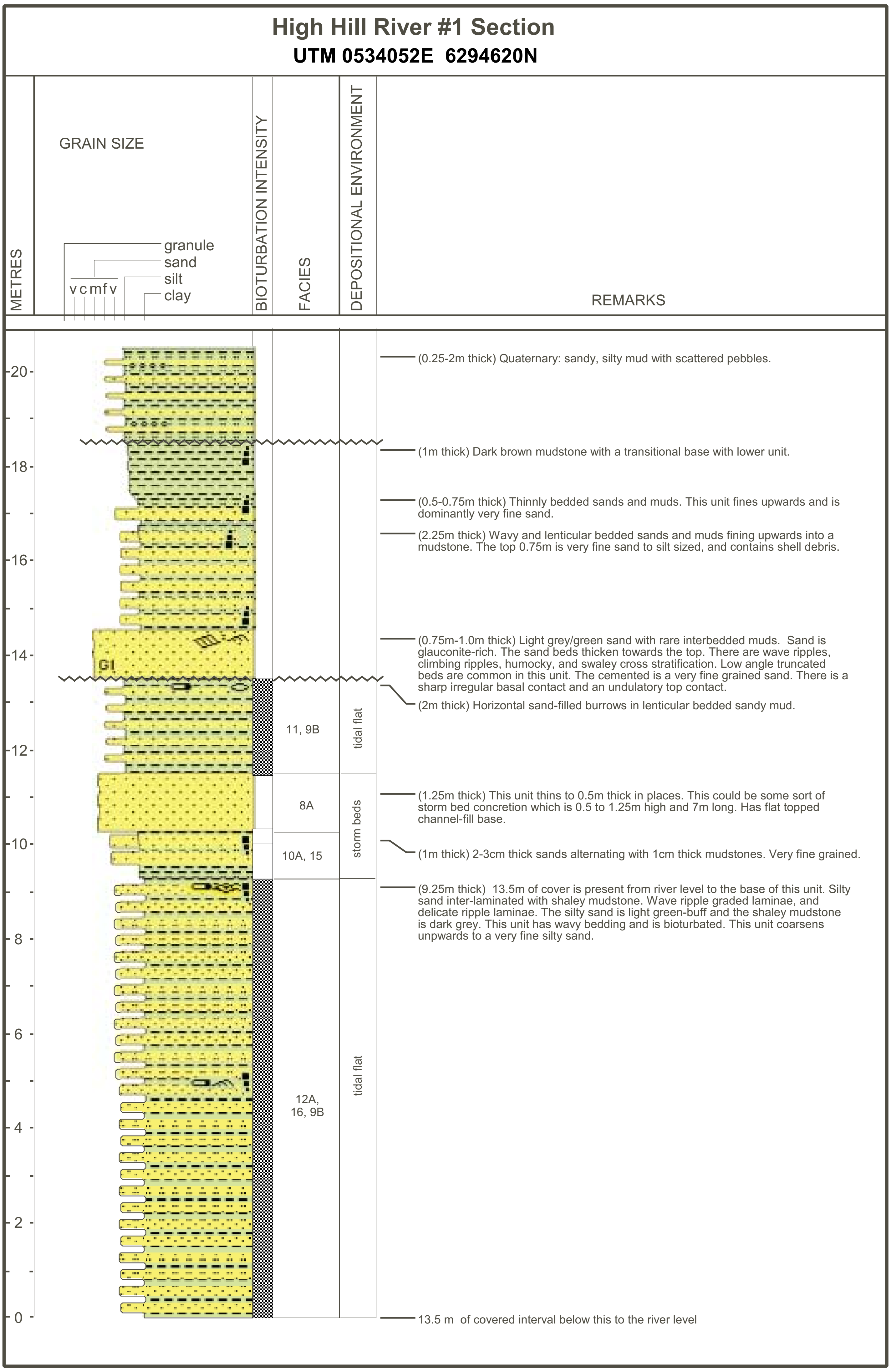
(1.5m thick) Laminated rippled, dark grey sandy mudstone. Fines upwards to a muddy siltly-sand. Partially covered at base and sulphur weathered out.

(8.25m thick) Covered interval

(1.5m thick) Dark grey brown burrowed silty micaceous mudstone with thin laminae of sand. Common coaly debris and wood fragments. There is a wavy burrowed contact with lower unit. Muddy vertical accretion. Took palynology sample.

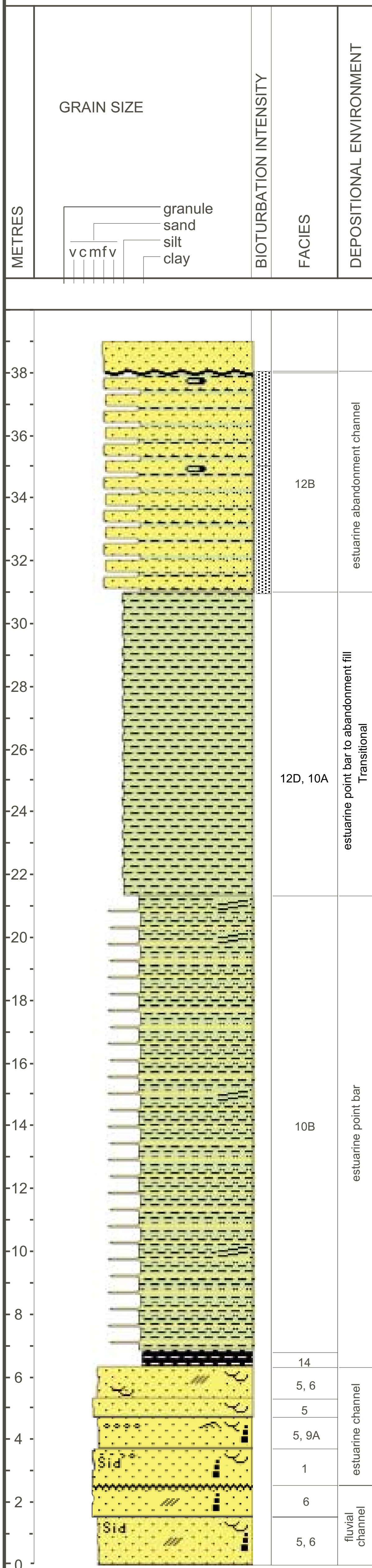
(2m thick) Consolidated very fine grained sand with abundant quartz and mica. Parallel bedded sand with ripples, sandy inclined heterolithic strata, very thickly bedded. Common traces are Arenicolites, Skolithos, Planolites, and rare Cylindrichnus. Lateral accretion.


Dover River Section
UTM 0453070E 6336004N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Gl
S
12A
10A
10B
10A
7A
5, 9A
5
marine Wabiskaw
abandoned channel
estuarine point bar
estuarine channel
Wabiskaw C unit
Glauconitic, green caste, burrowed, very fine sandstone, upper most 1 m is thin bedded, lowermost 0.5 m is medium bedded. Weathers recessive, selenite (gypsum) crystals ppt. Identifiable burrows include Teichichnus and Planolites.
Muddy sand, burrowed, with very thin discontinuous mudstone interbeds, not typical Wabiskaw D, but indicative of multiple fill events within the Wabiskaw D interval. Burrows include Skolithos, with subordinate Planolites. Uncertain (? gradational) upper contact with overlying Wabiskaw C unit.
Topmost 0.1 m is more typical Wabiskaw D fill, with sharp upper and lower contacts. Sulphurous black sandy mudstone, with moderate bioturbation, mainly Planolites.
Wabiskaw D Interval
Heavily burrowed muddy sand, churned, with very thick, black, discontinuous mudstone interbeds. Burrows include Teichichnus, Skolithos and Planolites. Rare dispersed coal detritus towards base. Sulphur leaching out of outcrop.
About 1 m of covered section under main bench of the outcrop
Interbedded sand and dark mudstone, discontinuous lenses, burrowed; base of Wabiskaw D unit.
Top of McMurray Formation
Slightly finer grained than below unit, interbedded sand and mudstone, horizontally bedded, rippled throughout [Vertical Accretion Deposit].
Thick (5.25 m), medium bedded, medium to fine sand, with cm thick mudstone interbeds, rippled throughout within inclined heterolithic stratification. [Estuarine Point Bar Deposit]
Siderite concretionary unit (0.25 m thick)
Large-scale (6-m thick) sandy lateral accretion set, with minor burrows, including Cylindrichnus, Planolites and Skolitos (rare). Fining and thinning upwards from medium/thick bedded medium sand at the base, to thin bedded fine sand at the top. Rippled throughout on lateral accretion sets. [Sandy Point Bar Deposit]
Medium interbedded inclined heterolithic stratification, with fine sand, rippled, 0.15 - 0.20 m thick, alternating with 1-cm thick mudstone beds and mudstone intraclast breccia. [Point Bar Lateral Accretion Bedding]
Large-scale (1.5 m thick) trough cross-bed set, with ripple cross beds on toesets; minor internal scours; scoured base and sharp top. [Channel Deposit]
Trough cross-bedded, medium to fine sand, bitumen stained, with dispersed mudstone intraclasts. Base covered, top scoured. [Channel Deposit]


High Hill River #1 Section
UTM 0534052E 6294620N
METRES
GRAIN SIZE
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
FACIES
DEPOSITIONAL ENVIRONMENT
REMARKS
20
18
16
14
12
10
8
6
4
2
0
Gl
11, 9B
8A
10A, 15
12A, 16, 9B
tidal flat
storm beds
tidal flat
(0.25-2m thick) Quaternary: sandy, silty mud with scattered pebbles.
(1m thick) Dark brown mudstone with a transitional base with lower unit.
(0.5-0.75m thick) Thinnly bedded sands and muds. This unit fines upwards and is dominantly very fine sand.
(2.25m thick) Wavy and lenticular bedded sands and muds fining upwards into a mudstone. The top 0.75m is very fine sand to silt sized, and contains shell debris.
(0.75m-1.0m thick) Light grey/green sand with rare interbedded muds. Sand is glauconite-rich. The sand beds thicken towards the top. There are wave ripples, climbing ripples, humocky, and swaley cross stratification. Low angle truncated beds are common in this unit. The cemented is a very fine grained sand. There is a sharp irregular basal contact and an undulatory top contact.
(2m thick) Horizontal sand-filled burrows in lenticular bedded sandy mud.
(1.25m thick) This unit thins to 0.5m thick in places. This could be some sort of storm bed concretion which is 0.5 to 1.25m high and 7m long. Has flat topped channel-fill base.
(1m thick) 2-3cm thick sands alternating with 1cm thick mudstones. Very fine grained.
(9.25m thick) 13.5m of cover is present from river level to the base of this unit. Silty sand inter-laminated with shaley mudstone. Wave ripple graded laminae, and delicate ripple laminae. The silty sand is light green-buff and the shaley mudstone is dark grey. This unit has wavy bedding and is bioturbated. This unit coarsens unpwards to a very fine silty sand.
13.5 m of covered interval below this to the river level

High Hill River #2 Section

UTM 0532600E 6290820N

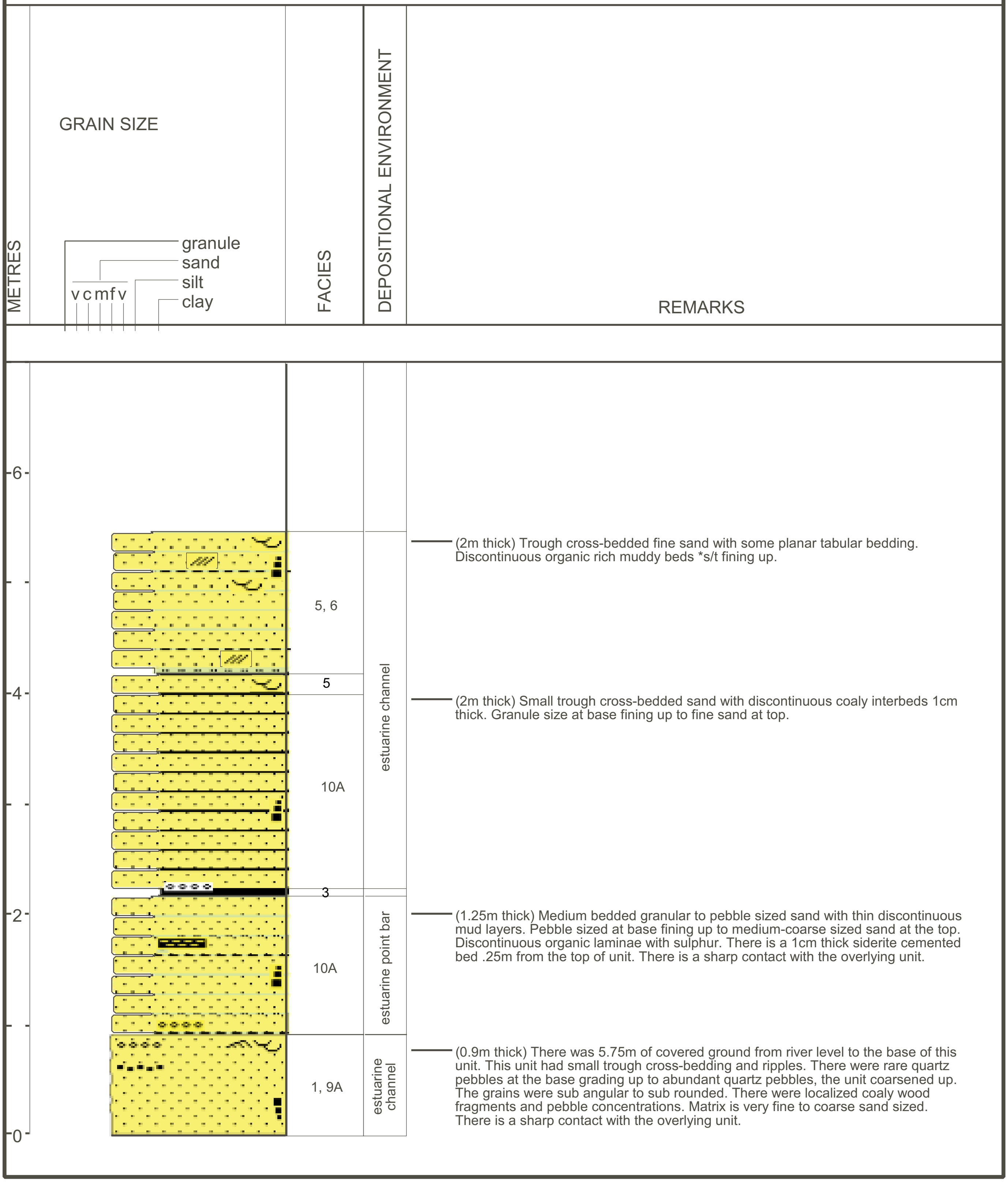


REMARKS

- Token thickness for the Wabiskaw sands which are glauconitic.
- Unconformable contact between the overlying Wabiskaw and McMurray.
- (~7m thick)Sandy vertical accretion fill, grading up to mud. Fining upward interbedded white sand and buff mudstone with planar tabular and trough (questionable) cross-stratification. Burrowed.
- (~10m thick) Inaccessible cliffs. Muddy looking, however downstream this unit becomes sandy.
- (~15m thick) Inaccessible. Muddy inclined heterolithic strata which becomes vertical accretion further along strike. At the bottom of the unit there is a dark grey-brown mudstone 0.5 m thick with organics at base.
- (~1m thick) Medium to coarse grained sand (inaccessible). Trough cross-stratification near bottom, planar tabular beds in the middle and more trough cross-stratification at the top. About 50 m downstream this unit becomes laterally accreting sandy cross beds. (IHS)
- (1.6m thick) Medium grained sand with trough cross-stratification.
- (1m thick) Trough and ripple cross stratified medium to fine grained sand. Some scattered pebble lenses. Unit fines upwards.
- (1.2m thick) Pebbly medium to coarse grained sand. Sideritized; trough cross-stratified. Quartz granules at top of bed, and dispersed coal fragments. Unit fines upwards. Base of unit is a scour surface.
- (1m thick) Planar tabular cross-stratified medium to coarse grained sand. Maximum dip direction on planar tabular cross-stratified beds is 290 degrees. Overall fining upward unit.
- (1.5m thick) There was 1.5m of covered ground from river level up to the base of this unit. This is fine to medium sand and has planar tabular sets with trough cross-stratification. High angle medium to coarse sand at base. Maximum dip direction on planar tabular beds is 310. Sideritized is prevalent. Overall unit is fining upwards.
- 1.5 m of covered interval below this point to the river level.

High Hill River #3 Section

UTM 0532600E 6290820N



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