THE STRATIGRAPHY AND PALEONTOLOGY OF THE EASTEND FORMATION IN SASKATCHEWAN, CANADA

A Thesis

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By

Richard John Lawson Boulding

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FACULTY OF GRADUATE STUDIES AND RESEARCH

SUPERVISORY AND EXAMINING COMMITTEE

Richard John Lawson Boulding, candidate for the degree of Master of Science in Geology**,** has presented a thesis titled, ***The Stratigraphy and Paleontology of the Eastend Formation in Saskatchewan, Canada,*** in an oral examination held on January 29, 2019. The following committee members have found the thesis acceptable in form and content, and that the candidate demonstrated satisfactory knowledge of the subject material.

External Examiner:	Dr. Emily Bamforth, Royal Saskatchewn Museum
Co-Supervisor:	Dr. Janis Dale, Department of Geology
Co-Supervisor:	Dr. Tim Tokaryk, Adjunct
Committee Member:	Dr. Osman Salad Hersi, Department of Geology
Chair of Defense:	Dr. Kerri Finlay, Department of Biology

Abstract:

The purpose of this thesis is to examine the stratigraphy and fossil content of the Eastend Formation across Saskatchewan and examine its ill-defined boundaries to determine their impact on the stratigraphy of the Late Cretaceous in the province. The primary objective of this research was to create stratigraphic sections of the Eastend Formation from surface exposures across the southern part of the province by examining changes in lithology, stratigraphy, and stratigraphic boundaries. A secondary objective of this research was to create an updated faunal list for the Eastend Formation through paleontological excavations, surface collections, and bulk sampling of select sites to inspect for micro-vertebrate fossil content. Three dominant lithological facies were identified in the Eastend Formation including planar laminated and massive sands, cross-bedded and rippled sands, and interbedded silts and clays. The lower Eastend Formation depicts a prograding delta front in a low energy sheltered estuary where the upper Eastend Formation layers are interpreted as being a delta plain type environment related to shallow channels and overbank deposits. A total of 67 fossil specimens were collected and classified based on the preservation quality and completeness of each specimen including the first vertebrate and scaphopod material from the formation. Additionally, five ichnotaxa were identified from the Eastend Formation material from the Skolithos and Cruziana ichnofacies. The overall evidence derived from the geology, paleontology, and ichnology of the Eastend Formation points towards an estuarine depositional environment. These indicators could be the key to differentiating the gradational boundary at the base of the Eastend Formation and re-visiting the argument of the

Whitemud Formation as an altered horizon of the upper Eastend Formation, both of which would have profound impacts on the Late Cretaceous stratigraphy in Saskatchewan.

Acknowledgements:

Firstly, I would like to thank my thesis advisors Janis Dale and Tim Tokaryk for assisting with my research and never giving up on me, their support and encouragement was crucial throughout the course of this program. I want to thank the Royal Saskatchewan Museum's Fossil Research Station for the use of their equipment and facilities along with Tim Tokaryk and Wes Long for their instruction of current fossil excavation and preparation techniques. A deep thanks goes out to the landowners of the study sites for allowing me to prospect and excavate on their land. Lastly, I must thank my field assistants over the years including Farron Ager, Evan Thorson, Willie Birss, Dustin Ormiston, Shane Westphal, Bernt Hanson, Ian Goulet, and especially Daylene Boulding for all their help.

Dedication:

I would like to dedicate this thesis to my loving wife Yvonne Boulding and my family for being a constant source of strength and comfort through some of the most trying years in my life.

Table of Contents:

List of Tables and Figures:

Chapter 1: Introduction

1.1 Introduction

The Cretaceous Period in the Western Interior of North America is demarcated by a series of inundations by shallow epicontinental seas that at points in time linked the Arctic Ocean to the Gulf of Mexico (Broughan, 1984). These periods of inundation are attributed to tectonic loading phases from the Cordilleran Orogeny producing a retroarc foreland basin. The basin allowed for clastic material to accumulate forming a series of westward thinning marine sediments and eastward thinning terrestrial sediments (Broughan, 1984). The last among these transgressions resulted in the Bearpaw Sea depositing the marine shales of the Bearpaw Formation. Subsequently, the retreat of this sea resulted in the deposition of the Eastend formation which marks the transition from marine Bearpaw shales to non-marine Whitemud clay sediments (Broughan 1984).

The Eastend Formation was first named and its type locality chosen in the vicinity of Eastend, Saskatchewan by LS Russell in 1932. Since the initial examination of the formation, it has been the subject of controversy in terms of its exact age. This dating issue is due to the fact that fossils in the formation are scarce hence faunal evidence for its age is not conclusive since as of yet no diagnostic fossils have been found (Byers, 1968). However the formation's position in the stratigraphic column shows it to be of Late Cretaceous age. It consistently occurs between the Bearpaw and Whitemud Formations and since the Campanian-Maastrichtian time boundary has been placed within the upper part of the Bearpaw Formation, the Eastend Formation is thus

Maastrichtian in age (Byers, 1968). This means that the Eastend Formation itself is defined only by its relationships with the overlying Whitemud and underlying Bearpaw units. The problem that stems from this relationship is that the boundary between the Eastend and Bearpaw Formations is gradational and a point of division between the two in geologic sections is arbitrarily chosen. Likewise, the boundary between the Eastend and Whitemud Formations is another topic of interest since the sediments appear the same between the two formations with the only difference being the presence of kaolinite in the Whitemud.

In terms of radiometric dating no methods have been used on the Eastend Formation. However, radiometric dates applied to formations surrounding the Eastend can help to constrain the time range. The regressive upper boundary of the Bearpaw Formation (also the lower boundary of the Eastend Formation) is set at 68 million years in the westernmost plains and at 66 million years farther east in the Cypress Hills region (Folinsbee et al., 1964). The other radiometric date that can be used to constrain the age of the Eastend Formation comes from the Battle Formation which overlies the Eastend and Whitemud Formations. In the Battle Formation is a volcanic layer known as the Kneehills Tuff that has been dated to 66 mya (Folinsbee et al., 1961).

1.2 Purpose of Thesis

The purpose of this thesis is to determine the stratigraphy and paleontological content of the Eastend Formation across Saskatchewan (Figure 1).

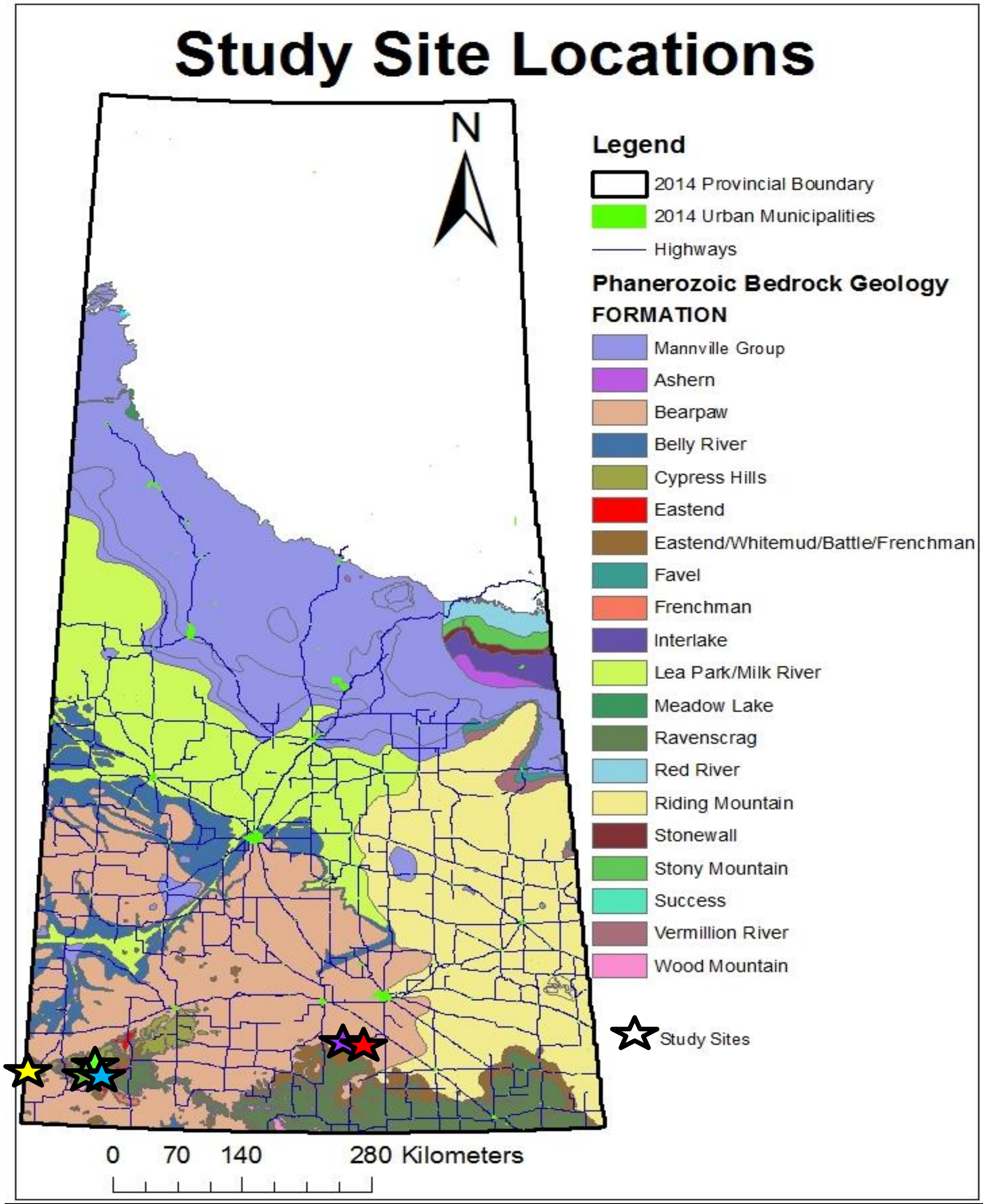


Figure 1.1: Map depicting the province of Saskatchewan showing relevant Phanerozoic bedrock geology and the locations of the study sites used in this investigation (stars).

1.3 Objectives

The primary objective of this thesis is to create a series of stratigraphic sections of the Eastend Formation from exposures that can be accessed across the southern portion of the province. The sections will be used to note any changes in lithology, stratigraphy, and the stratigraphic boundaries of the formation across the province.

A second objective of the thesis is to update the faunal list for the Eastend Formation with new taxonomic groups discovered over the process of this study. This will be accomplished through paleontological excavations to collect and preserve fossil specimens as well as bulk sampling of sites to inspect for micro-vertebrate fossil content. The selection of these excavation sites is based on extensive prospecting of Eastend Formation exposures across the province.

The third objective of the thesis is to investigate the ill-defined boundaries of the Eastend Formation to better differentiate it from surrounding geologic formations.

1.4 Rationale

The rationale behind this thesis is to expand the body of knowledge pertaining to the Late Cretaceous of Saskatchewan relating to both its geological and paleontological history. This type of work helps draw attention to the fossil content of Saskatchewan deposits in hopes of stimulating public interest in this financially neglected field of research. Finally, this project is a personal challenge for its researcher in order to expand their knowledgebase and experience in the fields of geology and paleontology.

1.5 Thesis Outline

The thesis is divided into seven chapters including this first introductory chapter. Chapter 2 covers details of the study sites and Chapter 3 is a review of previously written literature on the Eastend Formation. Chapter 4 explains the methods used within this research both in field and laboratory settings, Chapter 5 contains the stratigraphic results obtained in this study and discussions of these results, and Chapter 6 contains the paleontology results and discussions. Lastly, Chapter 7 outlines the conclusions that have been drawn from this research as well as some venues of future research pertaining to the Eastend Formation.

Chapter 2: Site Description

2.1 Introduction

This chapter covers the locations of the six sites selected for detailed study and sectioning, based on the surficial exposure of the Eastend Formation, as well as the surrounding terrain. The locations of these sites stretch across the southern portion of the province of Saskatchewan (Figure 1.1). The sites owe their current exposure to a complex glacial history that will be examined for each location.

2.2 Cypress Hills Site

The first of these sites is located in the West Block of Cypress Hills Interprovincial Park behind the West Block Campground, 5.5 km from the Alberta border and 67 km from the Montana border. The Cypress Hills owe their origin to uplift experienced during the initial stages of the formation of the Rocky Mountains that created a plateau of sediments. The areas of highest elevation in the Cypress Hills formed a glacial nunatak, which remained uncovered by ice sheets during the glaciations of the Pleistocene. The region now forms a major drainage divide in North America whose streams serve as tributaries for larger rivers flowing southward into the Gulf of Mexico, and northward into Hudson and James bays. The subsequent erosion from these streams allowed for the down-cutting and exposure of older strata from the Cypress Hills Formation down to the Eastend and Bearpaw formations (Thraves et al., 2007).

Study of the strata in the Cypress Hills can be hindered by the vegetative cover of the region limiting true exposures. In other areas, slopes are too steep to be vegetated or recently uncovered by geomorphologic processes. The study site in this region, known as the Battle Creek site, is a steep, approximately 15 m high exposure located on the North side of Battle Creek Road just before the La Barge Trail turnoff (49°36.222', 109°55.632'). The site was recently exposed by erosion along an outside bend of the Battle Creek removing the outermost layer of valley wall (Figure 2.1). The exposed sediments appear to be those of the Lower Eastend and Upper Bearpaw formations with abundant grey clays and silts, but still sizeable beds of yellowish tan sands present. Despite its large size, the area exposed, is only a small portion of a strongly vegetated valley wall covered in grasses, shrubs, bushes, and trees. A clear difference in this site from the others is the lack of glacially deposited sediments due to the site's unglaciated nature.

Figure 2.1: Cypress Hills Site exposure with the Battle Creek at its base. (Photo by R. Boulding)

2.3 Frenchman River Valley Sites

The next four sites are located in the Frenchman River Valley near the locality of Eastend, Saskatchewan. Eastend is situated in southwestern Saskatchewan approximately 80 km from the Montana border and 100 km from the Alberta border (Fig. 2.1). The town is best known for the nearby discovery of a *Tyrannosaurus rex* skeleton nicknamed "Scotty" in 1994. The town originated as a Northwest Mounted Police (NWMP) post that moved to the area in 1887 from the nearby Chimney Coulee. The post was the most eastern detachment from Fort Walsh and was located on the east end of their patrol, hence the post earned the name Eastend. In 1914 the CPR laid track into the ranching community around the NWMP detachment and as a result, on March 30, 1914, Eastend was incorporated as a village. On May 1, 1920, Eastend became a town that continues to this day (Jones, 1955).

The Frenchman River Valley, in which Eastend is situated, provides numerous exposures of Late Cretaceous sediments including those associated with the Eastend Formation which is the focus of this thesis. The river valley originated as a glacial spillway which down-cut into the sediments exposing from the top, the uppermost Cypress Hills Formation down to the Bearpaw Formation at the base of the valley. The sites studied were chosen primarily due to their undisturbed nature, which is in contrast to much of the Frenchman River Valley walls in the vicinity. Most of the valley walls appear to be down-dropped or slumped due to mass wasting processes, thus making the selected sites the most pristine examples.

The first of the four sites is a 30 m high road cut referred to as the Road Cut Site. This site is located on the southeast side of highway 13 (49°29.958' North by 108°50.761' West) where the site exits the Frenchman River Valley southwest of the Town of Eastend. The second site is referred to as the Humphrey Site, named after the local land owner who graciously gave access to the property. This site is on the northwest part of a section of valley wall that has become separated from the North side of the valley by erosion producing a hill-like feature. The site is located at 49°31.589' N latitude by 108°49.288' W longitude, just northeast of the *T. rex* Discovery Centre. The third site is called the Hanson Site, named after the landowner who kindly provided access to his property. The site is located approximately 18 km southeast of Eastend, Saskatchewan about 1 km off of Flatbed Road (49°27.295' Nlat.by 108°40.192' Wlong.). The exposure is situated in a draw formed by down-cutting by water flow draining from the higher surrounding elevations into the Frenchman River Valley. Historically this site was used as a buffalo jump by early First Nations inhabitants of the region.

The fourth study location in the Frenchman Valley is called the Vansandt Sites after yet another private landowner who gave access to outcrops on his land. These three sites are located 0.4 km northeast of the Road Cut Site and were bulk sampled to be processed for micro-vertebrates. The three sample sites are at varying stratigraphic levels within the Eastend Formation to be representative of the microfauna at different transitional zones in the stratigraphy. The Vansandt Sites area was perfect for this sampling process due to its various exposures, that revealed sediments from the upper to lower Eastend Formation and found during the prospecting process to contain shell material. The first sample site was taken from upper Eastend Formation sediments (49° 30.021' N latitude, 108° 50.48682' W longitude) whereas the other two were from the lowermost exposed portion of the formation (49° 30.00054' North by 108° 50.49714' West) and just below the sharp transition between the upper and lower formation (49° 29.99802' North by 108° 50.47782' West).

2.3.1 Road Cut Site

The road cut site is thought to exhibit a portion of the lower Whitemud Formation overlying the Eastend Formation. The Whitemud Formation is characterized by its white colouration which grades down-section into the yellowish tan sands of the Eastend Formation. The top surface of the section and surrounding area is quite barren with sparse shrubby vegetation and glacially deposited rocks approximately 0.5 cm to 30 cm in size (Figure 2.2). The glacial deposits on the surface are mostly subangular and subrounded with faceted sides and vary in lithology from metasedimentary to volcanics and intrusives. Many clasts have white mud material attached to them along with a white precipitate. The surface shows evidence of rill and gulley erosion, burrowing by gophers and covered with desiccation cracks (Figure 2.3). The upper portion of the road cut is very steep, reaching a 90° vertical in areas, with the slope angle decreasing to a more manageable 60° angle in the lower section (Figure 2.4). Also, variable iron staining and gypsum accumulations were noted throughout the road cut.

Figure 2.2: Top surface of the Road Cut Site. Larger clasts are glacial in origin. (Photo by R. Boulding)

Figure 2.3: Rill and gulley erosion on the top surface of Road Cut Site. (Photo by R. Boulding)

Figure 2.4: Photo of Road Cut Site taken facing southeast from the Eastend Dam. Note the steep relief of the uppermost material (Green Line) followed by a gentler relief farther down the road cut (Yellow Line). (Photo by R. Boulding)

2.3.2 Humphrey Site

The Humphrey site is thought to only exhibit sediments from the Eastend Formation due to the lack of white material which would characterize the Whitemud Formation (Fig. 2.1). It appears that the top surface of the Humphrey Site is below the boundary between the Eastend and Whitemud Formations, but is further complicated by the fact that the valley walls at lower elevations around the hill exhibit the Whitemud. This suggests that the surrounding valley walls have slumped downslope over time, leaving the hill site the best indicator of the original state and elevation of these units (Figure 2.5). Like the Road Cut Site, the vegetative cover consists of sparse grass and shrubs; however, the glacial dropstones have a larger size range from centimeters to meters in size (Figure 2.6). The boulders in some areas were so large that the section was oriented to avoid situations that would require moving them. Clasts range in composition from metasedimentary to igneous with some large blocks of limestone present. As well, this site exhibits variable iron staining throughout with gypsum deposits.

Figure 2.5: Photo of the Humphrey Site taken facing northwest from the fence line of the property. The sectioning line is illustrated (green line) along with where the Humphrey Quarry would be later dug (yellow rectangle). (Photo by R. Boulding)

Figure 2.6: Top surface and down-hill view of Humphrey Site (T.rex Discovery Centre in top right with yellow arrow). (Photo by R. Boulding)

2.3.3 Hanson Site

The Hanson site exhibits an undisturbed section of the Eastend Formation and unlike the other observed exposures along the Frenchman Valley is still attached to the undisturbed valley side wall.Its exposure due to the natural drainage and subsequent erosion of the face (Figure 2.7). Despite the appearanceof the Whitemud Formation along the top fringes of the valley in this area, the top portion of this section comes close but does not reach up into the Whitemud. The section is dominated by the yellowish tan sands of the Eastend Formation that appear to decrease down-section giving way to increased clay and silt contents. The top surface of the section and surrounding area has a distinctive grasslands vegetation punctuated with sparse shrubby vegetation and glacially deposited rocks approximately 0.5 cm to 3 m in size. These rocks are primarily sub-angular to sub-rounded with faceted sides and vary in lithology from metasedimentary to volcanics and intrusives. The Hanson Site is dangerously steep requiring climbing gear and ropes to undertake sectioning of this former buffalo jump. The exposed stratigraphic layers at this location are due to the steep nature of the slope, since most faces in the surrounding valley and draws are shallower and vegetated over by grasses.


Figure 2.7: View from top of Hanson Site looking northward back into the draw away from the Frenchman River Valley. (Photo by R. Boulding)

2.4 Vansandt Sites

The Vandsandt Sites are located in a large draw branching off from the main portion of the Frenchman Valley (Figure 2.8). The area exhibits sections from the lower Whitemud Formation down through the Eastend Formation to what is believed to be the Bearpaw Formation at the very base of the valley. The Whitemud Formation is defined by its white colouration which grades moving down-section into the classic yellowish tan sands of the Eastend Formation and continue into the increasing silt- and clay- rich portions of the lower Eastend Formation. The top surface of the section is covered with grassy vegetation at shallower slopes with exposure of the sediments occurring in steep sections where erosional gullies have formed cutting into the valley walls. There are a few exposed surfaces on slopes that are barren with a few sparse shrubs and accumulations of precipitated gypsum on the outer surface. A few glacial clasts were visible on the surface ranging from 5 to 50 cm in size, mainly sub-angular and sub-rounded in shape and varying in lithology including metasedimentary, volcanics and intrusive granites.

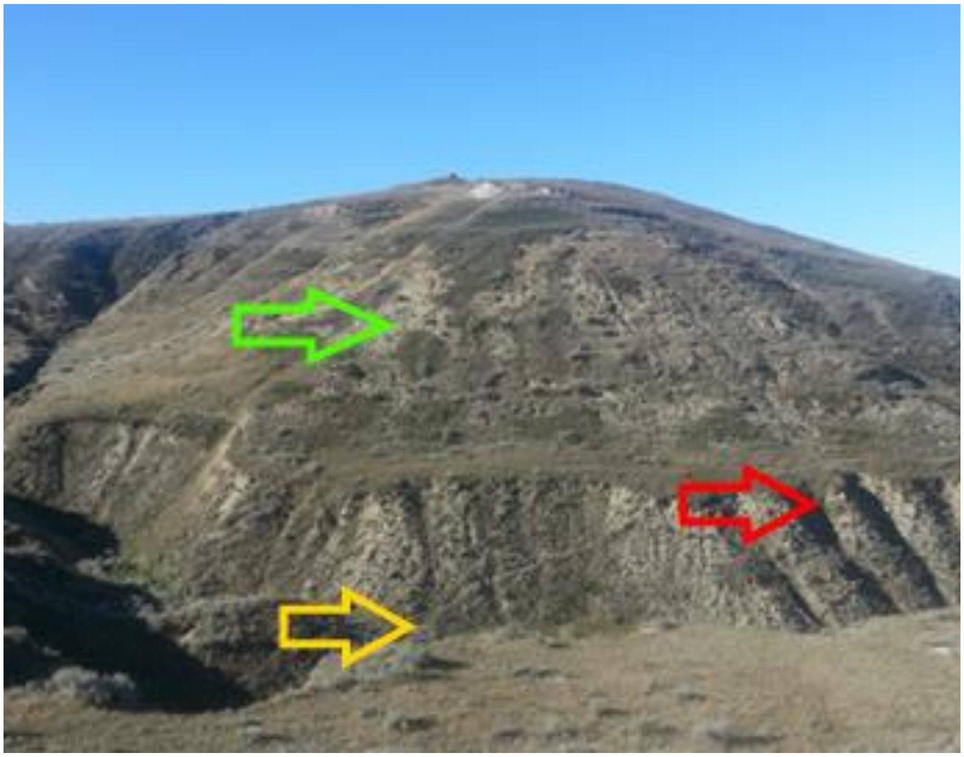


Figure 2.8: View looking downward towards Vandsandt Sites. The three sites chosen for sampling exhibited sediments from the Upper (green arrow) and Lower (yellow arrow) Eastend Formation as well as near the transition between the two (red arrow). (Photo by R. Boulding)

2.5 Claybank Site

The Claybank site is approximately 2 km southeast of Claybank, Saskatchewan on the Claybank Brick Plant National Historic Site (50° 1.30494" North by 105° 13.11108" West). The site is at the foot of the Dirt Hills along the Missouri Coteau which is a northeast-facing bedrock escarpment extending from eastern South Dakota across North Dakota and Saskatchewan into eastern Alberta. The Dirt Hills formed from glacial ice push of the southeast facing slope of the coteau. Blocks of bedrock and glacial debris were thrust upslope to form hills like the Dirt Hills along nearly all of the coteau’s 1000 km length. The section is about 200 m southeast of Mining Pit 3 where both the kaolinite and low-grade lignite of the Whitemud Formation were extracted to make fire brick. The sectioning itself was done on an immense slump block that had rotated almost onto its side but was large enough to show the complete stratigraphy from the Lower to Upper Eastend Formation with a small gap up near the Eastend to Whitemud transition (Figure 2.9). The area around the block was covered with prairie grasses and shrubs except in areas that the Whitemud material had collected from recent weathering processes. There are no large glacial erratics like those at the Frenchman Valley sites, but instead there are massive hills formed from blocks of Late Cretaceous material that exhibit various levels of stratigraphy from the Eastend and Whitemud formations.

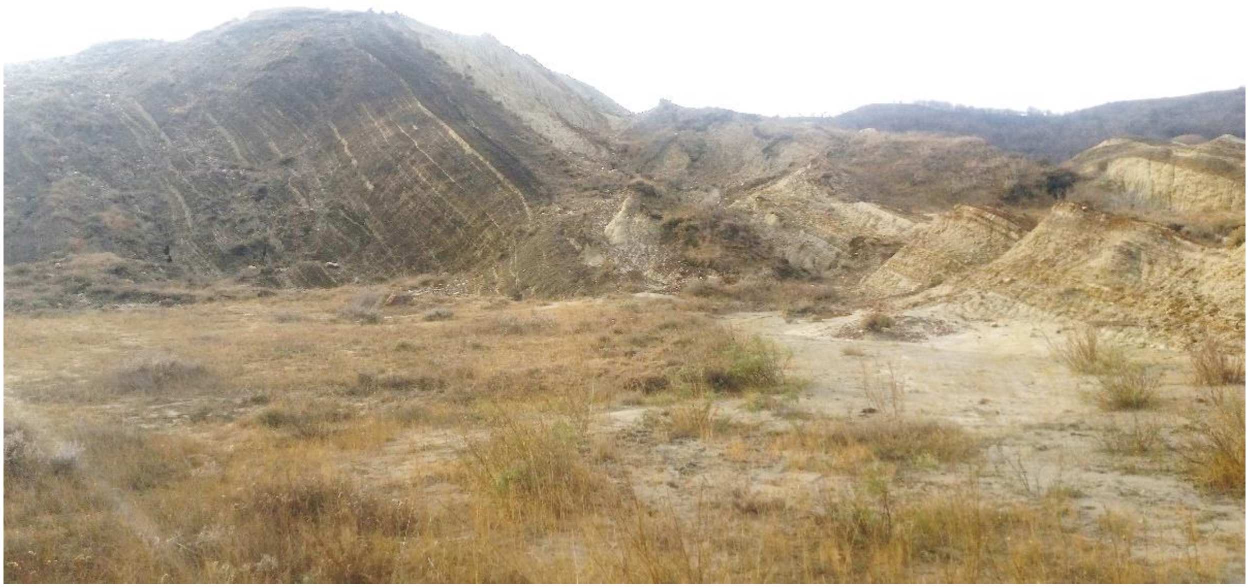


Figure 2.9: Rotated block containing a complete section of the Eastend Formation at the Claybank Site. (Photo by R. Boulding)

2.6 Avonlea Badlands Site

The Avonlea Badlands Site is found some 5 km northeast of Avonlea, Saskatchewan (50° 1.39008' N 104° 59.00694' W) north of Long Creek Golf & Country Club which also has exposures. These badlands are believed to have been excavated by glacial meltwaters and precipitation events today that result in surface erosion, downcutting into the Maastrichtian sediments forming the large valley area. The eroded parts of the badlands themselves are devoid of most vegetation with exception of a few hearty shrubs; but surrounding them are native prairie grasslands that owe their pristine state to the private landowners. The stratigraphy of this section of the badlands reveals upper Eastend Formation sediments with only a few meters of lower Eastend material near the base of the valley (Figure 2.10). Hoodoos are a common site within the badlands, where thin resistant deposits of clay/silt and iron precipitated layers cap pillars of fluvial sands (Figure 2.11). Also, the area features some of the largest glacial erratics that were encountered in this study. The rocks ranged from 4 cm to 6 m in size and metasedimentary to large intrusive granites in composition.

Figure 2.10: One of the areas looked at in the Avonlea Badlands Site. (Photo by R. Boulding)

Figure 2.11: A hoodoo from the Avonlea Badlands. (Photo by R. Boulding)

2.7 Glacial History

Late Cretaceous formations, including the Eastend Formation, are normally overlain by more recent sediments making their examination difficult. As a result of glacial processes, features like the Frenchman River Valley, Avonlea Badlands, and Dirt Hills allow for the exposure of Late Cretaceous formations. Saskatchewan has been subjected to multiple advances and retreats of ice sheets; however, the present landscape is primarily a result of the last major glacial event during the Late Wisconsinan (Fig. 2.12). During this last glacial event, the Laurentide Ice Sheet reached its maximum extent just south of the border between Saskatchewan and the United States around 20 to 23 ka BP. It is believed that the final deglaciation of Saskatchewan began around 17 to 18 ka BP with the province essentially ice free around 8.5 to 8 ka BP (Saskatchewan Geological Survey, 2003).

During deglaciation large volumes of meltwater drained from the ice sheet as it retreated towards the northeast. The meltwater drained the ice sheet through large channels that carved downward into the underlying material and exposing lower formations. Such spillway channels include the Frenchman River Valley which contains four of this study's sites. The Frenchman spillway formed around 18 ka BP effectively down-cutting into Tertiary and Late Cretaceous sediments and exposing the Eastend Formation, hence making major parts of this study possible (Figure 2.11). The Eastend area is thought to have been fully deglaciated by 13 ka BP. Around this time it is believed the Dirt Hills were formed from ice push helping to expose surfaces studied at the

Claybank Site. Likely a a combination of glacial scouring and meltwater actions exposed the sediments at the Avonlea Badlands Site (Saskatchewan Geological Survey, 2003).

The site in the Cypress Hills is not directly linked to Saskatchewan's glacial history. The hills were part of a glacial nunatak which remained uncovered by any glacial ice and today exhibit unique features due to their elevation and previously unglaciated state. The exposure studied at the Cypress Hills Site owes its origin to fluvial processes from Battle Creek and mass wasting processes.This site is the most recently exposed by erosion by the creek which caused a rotational landslide that exposed the sediments within the last five years.

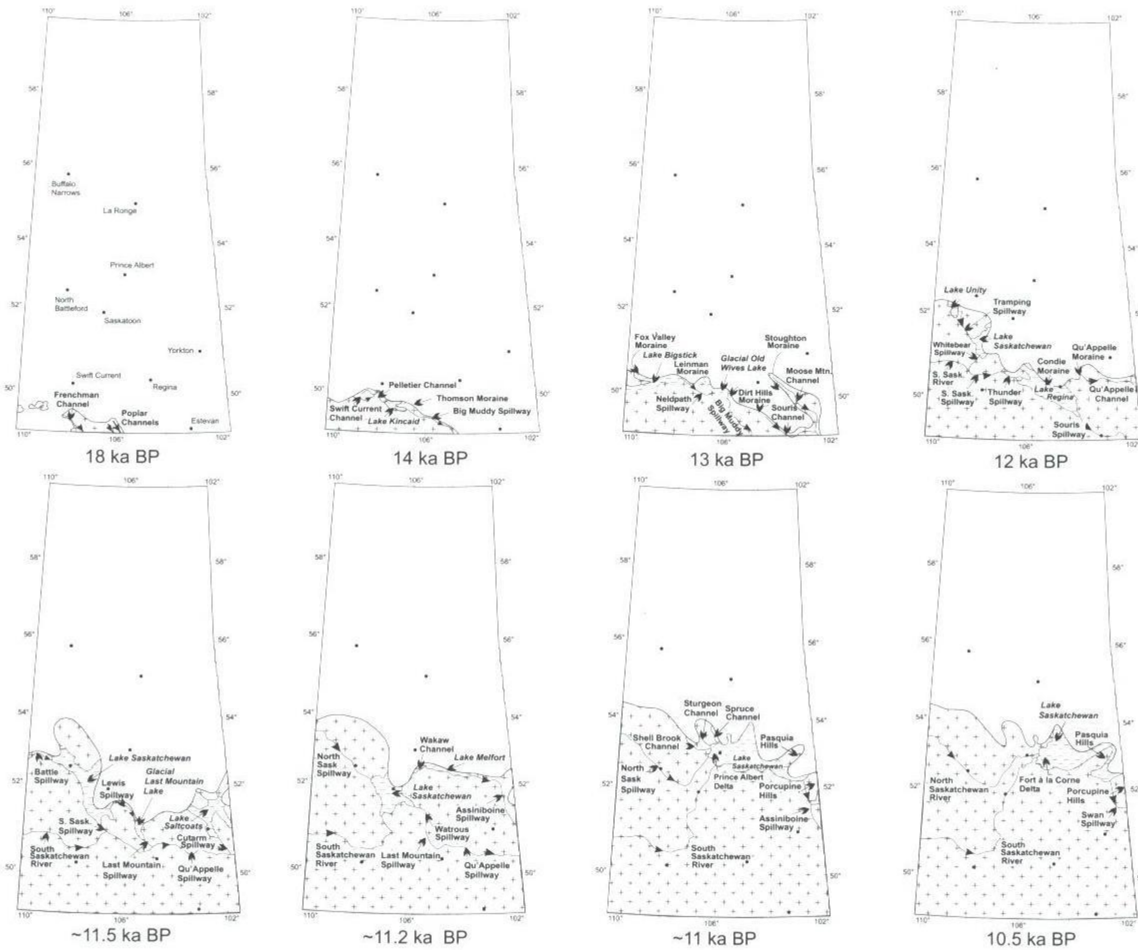


Figure 2.12: Late Wisconsinan deglaciation history of Saskatchewan from 18 to 10.5 ka BP (Modified from Saskatchewan Geological Survey, 2003).

Chapter 3: Literature Review

3.1 Introduction

The literature review presents previous research on the Eastend Formation. The first part of the review looks at the relationship between the Eastend Formation and the Williston Basin. This is followed by the tectonic and depositional settings of the Formation, and finally the rocks associated with the last Cretaceous transgressive/regressive cycle. The second part of the review looks at the Eastend Formation itself in terms of its history, distribution, type section, and previously recorded fossil content.

3.2 Geology of the Williston Basin

Exposures of the Eastend Formation examined in this study are located in the northwestern reaches of the ellipsoidal Williston Basin which covers parts of eastern Montana, western North and South Dakota, and southern Saskatchewan (Figure 3.1). The basin played a significant role in the deposition of Phanerozoic rocks in southern Saskatchewan including the Eastend Formation. The Williston Basin itself formed as a result of the metamorphic transformation of sublithospheric rocks attributed to crustal thickening. This thickening likely resulted from the Trans-Hudson Orogen convergence 1.8 to 1.9 Ga (Kent and Christopher, 1994). This caused densification of the rocks to occur resulting in loading and downward warping of the crustal rocks creating the basinal depression in which Phanerozoic rocks were deposited. Over time the Williston Basin underwent a number of episodes of subsidence in the Ordovician, Mississippian, and

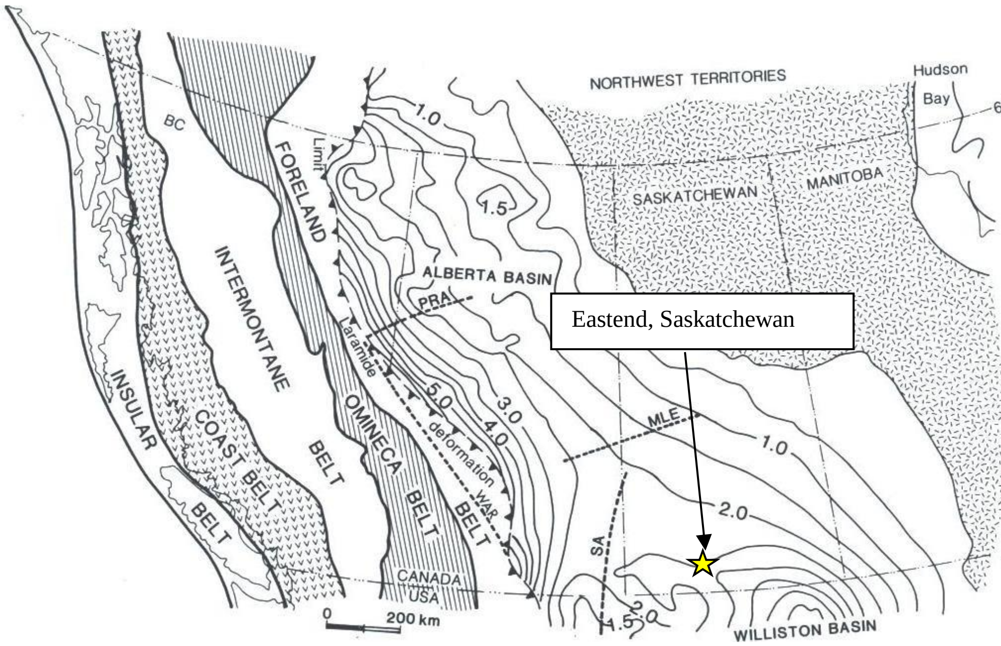


Figure 3.1: Map of Western Canadian Sedimentary Basin showing Eastend SK. The surrounding areas show the important tectonic elements (including Alberta and Williston basins). (Osadetz, 2010)

Jurassic. These periods of subsidence were attributed to a number of causes including stresses related to orogenies and by phase changes in basal lithospheric minerals over time (Kent and Christopher, 1994). In turn, these subsidence events provided the accommodation space for the deposition of both continental and marine sediments throughout the complex history of Phanerozoic inundations of western North America. The Williston Basin does have some effect on the deposition of the Late Cretaceous rocks but it is limited. This influence on the Late Cretaceous sediments is due to several of the basement structures of the Williston Basin rejuvenated towards the end of the Cretaceous (Kent and Christopher, 1994).

3.3 Tectonic and Depositional Settings of the Western Interior Basin

It is important to be acquainted with the tectonic and depositional settings associated with southern Saskatchewan's Late Cretaceous rocks. Instead of being linked with the Williston Basin, these rocks are associated with the Western Interior Basin. The basin extends more than 3,000 km north to south over about 35° of latitude from Texas to the Northwest Territories. The Western Interior Basin developed as a result of crustal loading during the western migration of the North American Plate and the subduction of Panthalassan Oceanic Plate. Initiation of the basin is traditionally associated with the deposition of the Upper Jurassic Morrison Formation in the United States, and the Fernie and Kootenay formations in Canada (Miall et al., 2008).

Throughout its history, the basin underwent a number of inundations that at one point linked the Arctic Ocean to the Gulf of Mexico through the Late Cretaceous Western Interior Seaway. These transgressions established a marine environment in the basin during both orogenic loading and quiescent stages in parts of the basin. One issue with these basin rocks is whether the transgressive and regressive sequences are actually related to eustatic rise and fall. The possibility does exist that sedimentation outpaced tectonics producing sediment supply driven regressions which may explain the eastward retreat of the Western Interior seaways (Catuneanu and Sweet, 1999).

3.4 Rocks Associated with the Last Cretaceous Transgressive/Regressive Cycle

The last invasion of the sea into the interior of North America was by the Bearpaw Sea. Rocks deposited during this final transgression (Figure 3.2) and associated regressions are exposed in the locality of Eastend, Saskatchewan. The Bearpaw shale marks the presence of the sea whose upper contact is gradational representing transition into the non-marine Eastend Formation. In this transitional zone, the shales become silty, greenish and carbonaceous, with sandstone beds increasing in number and thickness upwards (Crockford and Clow, 1965). The Eastend Formation consists of buff to pale yellow sands that register as 5y7/4d according to the Munsell colour chart and light grey silty shales that are categorized as 5y7/2d. The sands are poorly cemented and are interbedded with greenish grey, grey and brown shales. The Eastend Formation is defined as beds deposited in almost entirely brackish and fresh water environments with rare marine beds (Crockford and Clow, 1965). The nonmarine upper Eastend and Whitemud Formations were derived from Upper Cretaceous volcanic rocks, Precambrian and Paleozoic metamorphic rocks, and Paleozonic carbonates originating in Montana (Byers, 1968).

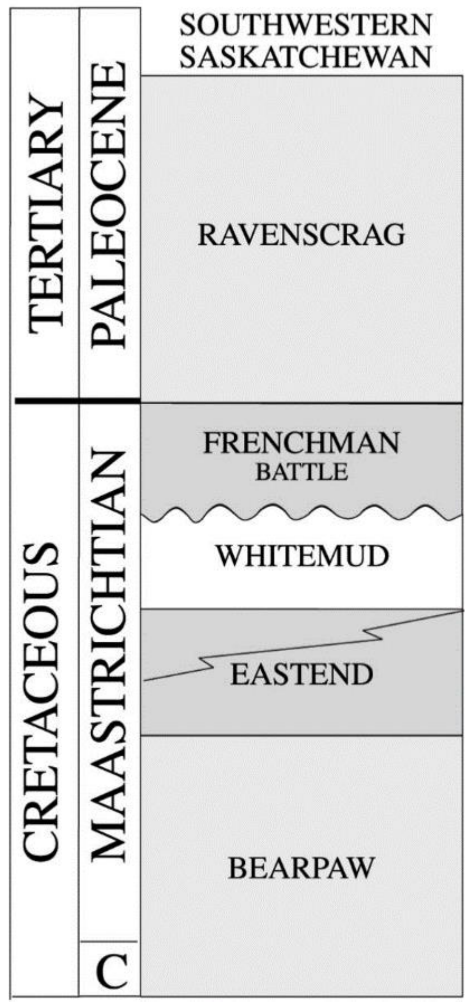


Figure 3.2: Late Cretaceous and Paleocene stratigraphy of southwestern Saskatchewan. (McIver, 2002)

The gradational contact between the Whitemud and Eastend Formations have been previously distinguished mainly on the basis of colour change, where the green and browns of the Eastend Formation are succeeded by the light grey and white of the Whitemud Formation (Crockford and Clow, 1965). At this contact, there is an abrupt decrease in volcanic lithic grains, an increase in metamorphic lithic grains and the appearance of kaolin and disappearance of biotite and apatite (Byers, 1968). The Whitemud sediments represent slow chemical weathering and leaching of aluminosilicate minerals to produce kaolinite which produces the white colouration that makes the formation visibly identifiable (Byers, 1968). The Whitemud Formation is interpreted as fluvial sediments deposited under continental conditions along with the overlying Battle shales and the uppermost Cretaceous sandstones of the Frenchman Formation (Crockford and Clow, 1965).

3.5 Geology of the Eastend Formation

The Eastend Formation in Saskatchewan was referenced by a number of different names (Figure 3.3). In early descriptions, these rocks were called Division Y of the Fox Hills or simply the Fox Hills Formation (Dawson, 1875 in Broughan, 1984). In later years McLearn (1930) referred to the rocks as Basal Sandstones which he later changed to Sandstone A, D, or E depending on the locality. The name Eastend was first assigned to the formation by L. S. Russell (1933) due to its exposure in the vicinity of the Town of Eastend in southwestern Saskatchewan. The formation was correlated with the Fox Hills

Formation in Montana and North Dakota along with the St. Mary River and Horseshoe Canyon formations in Alberta (Broughan, 1984, Figure 3.4).

Historically, the formation has been a source of confusion, at times having portions of its lithology misclassified with under or overlying formations and vice versa. In works by McLearn (1928), Bearpaw sands have been included with Eastend sands in what he referred to as the Yellow Sandstone. Likewise, Fraser et al., (1935) mapped Frenchman Formation sands as belonging to the Eastend Formation. This difficulty with pinning down the exact boundaries of the Eastend Formation is due to both the gradational boundaries it shares with its surrounding formations and the erosional unconformity at the top with the Frenchman Formation. This in turn poses a problem for the Eastend Formation which is primarily defined by its stratigraphic relationships with surrounding units.

DAWSON (1875)	McCONNELL (1885)	ROSE (1916)	DAVIS (1918)	McLEARN (1930)	RUSSELL (1933)	FRASER et al. (1935)	FURNIVAL (1946)	KUPSCH (1956)	PRESENT STUDY	Series	System
Lignite Tertiary	Fort Union	Laramie	Ravenscrag	Upper Ravenscrag	Upper Ravenscrag	(Buff facies) Upper Ravenscrag (Grey facies)	Ravenscrag	(Buff facies) Ravenscrag (Grey facies)	(Buff beds) Ravenscrag (Grey - beds)	PALAEOCENE	TERTIARY
?	Laramie			Lower Ravenscrag	Lower Ravenscrag	Lower Ravenscrag	Frenchman	Frenchman	Frenchman	UPPER CRETACEOUS	CRETACEOUS
						4	Battle	Battle	Battle		
Division y of Fox hills		Lance	Whitemud	Whitemud	Whitemud	Whitemud 3 2 1	Whitemud	Whitemud	Whitemud		
	Fox Hill	Fox Hills	?	Sandstone A / D / E	Eastend	Eastend	Eastend	Eastend	Eastend		

Figure 3.3: History of stratigraphical nomenclature in the Cypress Hills of Saskatchewan. (Broughan, 1984)

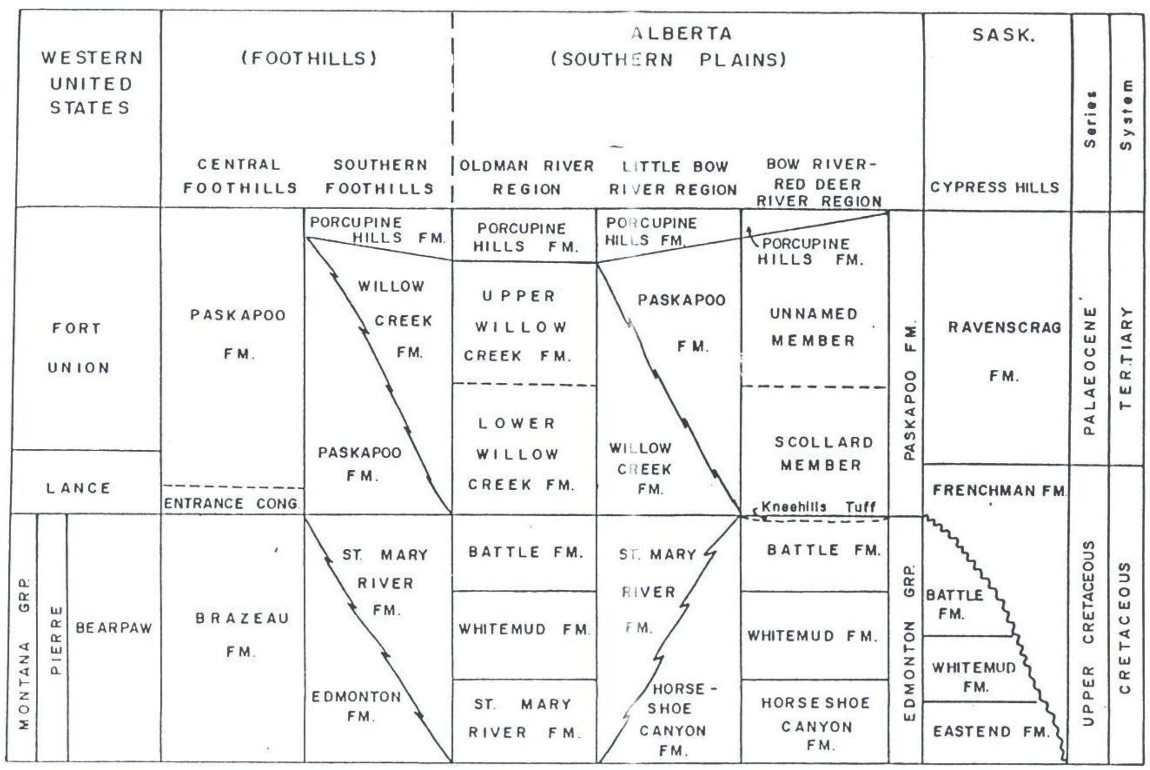


Figure 3.4: Correlatives of the Maastrichtian-Paleocene sediments in Saskatchewan, Alberta, and the U.S.A. (Broughan, 1984)

3.6 Distribution of Eastend Exposures

Exposures of the Eastend Formation are documented at a number of sites in southwest Saskatchewan, not limited to those near the type locality of Eastend. Other exposures are found in the Frenchman River Valley system from western exposures like Ravenscrag Butte and Table Butte to eastern ones following Flat Road that shift stratigraphically upward into Frenchman Formation deposits towards Shaunavon. Other limited exposures occur along Adams and Battle Creeks, along the south side of Old Man on His Back Plateau, and in the vicinity of Boundary Plateau. A few small exposures are documented along the north slopes of the Cypress Hills and within the exposed strata along Bear Creek (Furnival, 1950).

In addition to the documented exposures of the Eastend Formation, further exposures had been reported? at sites in the Dirt Hills, Avonlea Badlands, and Cypress Hills along Battle Creek and were examined in this study. Exposures of the formation in the Big Muddy Badlands were sought but not found and only the Whitemud Formation was found exposed at the base of the valley.

3.7 Type Section

Despite being defined in 1933 by Russell, a type section was not prepared for the Eastend Formation until 1956 by Kupsch (Appendix I). Kupsch described the formation as consisting primarily of greyish yellow to dusky yellow very fine sand with a high silt and clay content. He noted that the formation was typically thinly bedded with uncommon zones of small-scale cross-stratification. The carbonaceous material within the formation was referred to as small and scattered throughout the sediment but he noted that Russell had found a thick lignite seam in the formation in southeastern Alberta. Kupsch identified the Eastend sands as primarily quartz with about 40 per cent feldspar along with other minerals including chert, mica, and hornblende. The sands of the formation have a common calcareous nature that seemed to increase with depth. Lastly, Kupsch remarked that the gradational transitions between the Eastend Formation and its surrounding formations were ill defined. In fact, Kupsch chose an arbitrary point near the bottom of his section to mark the boundary between the Bearpaw and Eastend Formations. The upper transition into the Whitemud Formation occurred over approximately a metre (Kupsch, 1956).

3.8 Fossil Content

The documentation of the fossil content within the Eastend Formation had been undertaken primarily by L. S. Russell (1943) in the form of a faunal list (Appendix II). After spending a field season on the plains of western Canada in 1940, Russell identified numerous species within the formation both in Saskatchewan and Alberta. Russell (1943) documented eight species of bivalves within the formation near Eastend, Saskatchewan, along with the abundance and the levels of preservation for each species. The work performed by Russell (1943) is the most extensive research in regards to the fossil content of the Eastend Formation to date. In addition to his work in Saskatchewan, Russell examined the fauna of the Eastend Formation in Alberta with the help of R. W. Landes. In their work Russell and Landes (1940) noted twenty-one species of Pelecypoda, four species of Cephalopoda, and one species of Gastropoda present within the formation. Further searches through the literature in both Saskatchewan and Alberta shows no mention of any changes to the taxonomic classification of these specimens hence it is assumed that the identification of specimens by Russell and Landes are still valid.

Other occurrences where fossil content was found in the formation varies from a bivalve and gastropod shell by Broughan (1984) to a tooth from a carnivorous dinosaur that Furnival (1950) notes was unearthed by C.M. Sternberg. An important note, is that the tooth found by Sternberg was never documented and the specimen has since disappeared. This means that to date, no fossil vertebrate material has been documented within the Eastend Formation.

Chapter 4: Methods

4.1 Introduction

The field and laboratory methods involved in this study included: sectioning; sediment sampling; fossil prospecting; quarrying fossil material; and laboratory preparation of the fossil material. The field portion of this study consisted of digging and logging the sections, prospecting for fossil material, and extracting that material via a quarry. The field work was performed during the 2013 and 2015 field seasons. The preparation and identification of the fossil material in a laboratory setting was conducted in 2013 and 2014 with the processing of the bulk samples and micro-vertebrates taking place in 2014 in laboratories at the Royal Saskatchewan Museum, University of Regina, T. rex Discovery Centre, and Peace Region Paleontology Research Centre.

4.2 Sectioning and Logging

An objective of this thesis was to determine the stratigraphy and faunal content of the Eastend Formation. Stratigraphic charts with biohorizons were produced from six sites across Saskatchewan. The sites selected to be sectioned were chosen based on their relatively undisturbed nature and how complete the section was exposed. The sites that met these criteria were often steep sections of exposure where vegetation was unable to take root and grow on the surface. This in turn meant that many of the sites were quite perilous and required the use of ropes, anchors, and a climbing harness to perform the sectioning and documentation to mitigate the risks posed by the very steep faces reaching 90° in some cases (Figure 4.1). Additionally, the clay/silt layers were found to contain bentonite which has a soapy texture and is extremely slippery when wet creating another risk during fieldwork. At other locations, large boulders or patches of vegetation were encountered in the proposed sectioning path. To deal with this, units in the section were followed across-section to a better part of the exposure to avoid the obstacle. This correlation helped to maintain accuracy and ensured the continuity of the section.

During sectioning, a portion of the face was cleared so the true representative nature of the units could be examined free of any overlying material that might have wasted onto the face. The cleared portion of section was approximately 45 to 75 cm in width. Final exposure of the face was cleared carefully with a trowel and brush to ensure any delicate features of the face were not destroyed while clearing material away. The section was examined both close up and further away to permit a broader view for larger features that might not be apparent close up. The preparation of the section varied from simply cleaning an outcrop face to digging up to 80 cm back through wasted material into the section to expose a pristine example of the rock layers. At locations with portions of exposure that had too shallow a slope to properly examine the units, a series of steps were dug into the section to view the layers without removing large amounts of material (Figure 4.2). The data recorded from each of the layers in these sections included the thickness of each layer, its primary lithology and grain size, sedimentary structures, and any other sedimentological features. In addition, each layer was tested with dilute 5% hydrochloric acid to note the presence of any calcium carbonate, examined for fossil content and its colour determined with the use of the Munsell color system.

Figure 4.1: The view from the top of Road Cut Site looking down-section (Note the steep relief). (Photo by R. Boulding)

Figure 4.2: Up section view of part of the Road Cut Site. The step method was used here due to the gentle slope and apparent mass wasting of upper sediments over the outermost surface. Each step is approximately 30 cm in height). (Photo by R. Boulding)

4.3 Fossil Prospecting

As part of the field work phase of this investigation, several days were taken at each site to carefully prospect for any evidence of fossil material. During this process any fossil material located on the surface was noted and collected. Often small fragments of shell material were found along with the odd shark tooth, fish vertebra or pieces of larger vertebrate elements strewn down a slope. On finding these signs, the immediate vicinity was scoured closely to trace the material back to its source layer, in an upslope direction. On a few occasions, possible source areas were located and the outermost material above each layer was removed.

4.4 Fossil Quarrying and Extraction

A large accumulation of fossil material was found at the Humphrey Site, prompting the site to be quarried and its fossil material extracted and prepared for identification. A 2.4 m by 1.8 m area was staked out and the overburden was removed down to just above the fossil layer. After removing the overburden, starting from the outside, the material was removed delicately with brushes and precision hand tools to expose the top of the fossil content (Figure 4.3). Due to its extremely fragile nature, extraction of the fossil content was attempted in different ways in order to determine the best method.

The method that worked best was to clean the top surface of a select cluster of fossil material and then dig a narrow trench around it to isolate it from the rest of the quarry (Figure 4.4). The sides of the isolated block were sprayed with adhesive to stabilize the material and avoid catastrophic collapses of the block during the rest of the extraction process. The sides at the base of the block were then dug out gently to taper the base and create a pedestal with the exposed fossils on top (Figure 4.5). Next the fossils and block were covered with tissue paper and plaster over the top and sides of the block which hardened to form a jacket protecting the material. Once hardened, the jacket covered pedestal was broken free at the base and gently flipped onto its top surface while the bottom of the jacket was plastered to stabilize the entire block (Figure 4.6).

The jackets made of gypsona bandages or burlap and plaster allowed for the material to be stabilized externally until they could be opened and the internal fossil content prepared in a lab. The jackets were labeled, photographed, drawn onto the quarry map, and transported to the RSM fossil research station for safe keeping until they could be transported back to the main preparatory lab in Regina.

The success of the first quarrying technique prompted an expansion of the quarry another 0.5 m back into the hillside, widening it another 1.5 m toward the south. Further expansions of the quarry were halted when fossil material was absent in each direction.

Figure 4.3: Tim Tokaryk of the RSM demonstrating how to gently expose the uppermost fossil surface. This photo was taken in the quarry at the Humphrey Site. (Photo by R. Boulding)

Figure 4.4: The Humphrey Site quarry. In the photo a cluster of fossil material has been exposed and trenched around to begin the extraction process. (Photo by R. Boulding)

Figure 4.5: The top of an isolated fossil pedestal soon to be covered in tissue and wrapped in gypsona bandages or burlap and plaster which hardens. This hard outer shell (called a jacket) helps to stabilize the material for transport. (Photo by R. Boulding)

Figure 4.6: A hardened jacket still attached to the pedestal being carefully detached at the base. The jacket will then be flipped and its underside plastered as well. The author of this thesis, Richard Boulding, is on the left with his helpful friend Evan Thorson on the right. (Photo by R. Boulding)

4.5 Fossil Preparation and Identification

During the preparation stage fossil jackets were cut carefully open at the top and a combination of scalpels and brushes were used to remove the sediment from around the fossils (Figure 4.7). Often during this process, the removal of sediment from around one specimen would expose part of another, resulting in large clusters of layered fossil material. Once exposed the fossil clusters were coated with a mixture of acetone and dissolved paraloid plastic pellets referred to as B-72. The solution is designed for the acetone to evaporate when exposed to air leaving behind the plastics to harden and stabilize the material. Due to the highly frail nature of the fossils, B-72 was applied periodically as small portions of the fossil surface became exposed. Originally each specimen was sought to be individually extracted once stabilized and prepared on all sides. However, during the final preparation stages the decision was made to leave large clusters of the material within the jackets rather than put the fragile fossils at risk by extracting them. Basic identification of the fossils was done visually in the field based on previous knowledge and the help of RSM staff. Final identification was made using previous taxonomic papers on the select fauna, treatises like the Geological Society of America Treatise on Invertebrate Paleontology (1953), and the expertise of Tim Tokaryk (pers. comm.) from the paleontological unit at the RSM.

Figure 4.7: An opened jacket in the laboratory Note the broken and fragile nature of the fossil content and the shell fragments throughout the jacket. (Photo by R. Boulding)

4.6 Bulk Sampling

While prospecting the Vansandt Site, several locations were found with tiny fragments of shell material on the surface of the slope at varying stratigraphic levels within the Eastend Formation. Each of the levels with shell fragments were excavated further to find the origin of the fossils. These fragments were traced back to find only sizeable accumulations of tiny pieces of shell. It was thought the same process that concentrated these shell fragments may have formed accumulations of micro-vertebrate material at these areas making them prime candidates for bulk sampling. A total of three sites were chosen for bulk sampling at the Vansandt site to check for micro-vertebrate material. The sites were selected to be representative of different stratigraphic levels in the Eastend Formation, one site chosen from the upper formation, the lower formation and the transition zone between the upper and lower formation. In total 15 gallons of sediment were taken from each site totaling 45 gallons of sediment to be processed later.

4.7 Sieving and Processing Micro-Vertebrates

The nature of the clays and silts in the Eastend Formation make it a poor candidate for dry sieving since these sediments remain adhered together in fissile to blocky clasts. The upper formation material faces a similar problem with its clay/silts but to a lesser degree with its increased sand content. The decision was reached to use a wet sieving method that would help to disseminate the clays and silts to allow for their separation from any fossil material. It was decided not to use any chemical additives to disperse the clay sediments and prevent flocculation that could occur during the wet sieving process. This decision was based on the unknown nature of the micro-fossil preservation and whether the use of chemicals could damage the specimens.

First, the bulk samples were immersed in water for several days to soften the clay/silt clasts and make them easier to break apart during sieving. Each bulk sample was then sieved separately by taking half gallon manageable samples and working them with slowly running water through a sieve stack. The stack was comprised of a series of finer sieves of 4.75 mm, 2 mm, 1 mm, and 0.5 mm (Figure 4.8). At the base of each stack was a sieve pan used to collect the finest material. During sieving the pans had seven small magnets placed in them in the event any metallic microtektites were present in the samples (Figure 4.9).

Figure 4.8: A sieve stack used in the wet sieving process. (Photo by R. Boulding)

Figure 4.9: Magnets placed in bottom sieve pan with the purpose of collecting magnetic microtektites. (Photo by R. Boulding)

Once the wet sieving process was complete, the contents of each sieve was transferred to a large flat tray for air drying. The trays permitted for the contents to be spread out evenly for careful examination for any micro material using an Olympus SZ61 dissecting microscope. Any vertebrate microfossils or fragments of invertebrate shells were collected with fine tweezers and gently placed in a labeled sample vial. The specimens were described and classified using various texts and treatises to the most precise taxonomic level possible given the state of the fragment.

4.8 Fossil Specimen Photography

Fossil macro-specimen photography was conducted using Canon EOS 1000D DSLR camera and a diffuse lighting stage. Photography of micro-vertebrate specimens was conducted using a Visionary Digital photography station at the RSM, consisting of a Canon EOS 5D DSLR camera equipped with a Canon MP-E 65 mm Macro Photo Lens and tube extensions (Figure 4.10). Extended depth of field at high magnifications was achieved by combining multiple images from a range of focal planes using Helicon Focus 5.3.14 software.

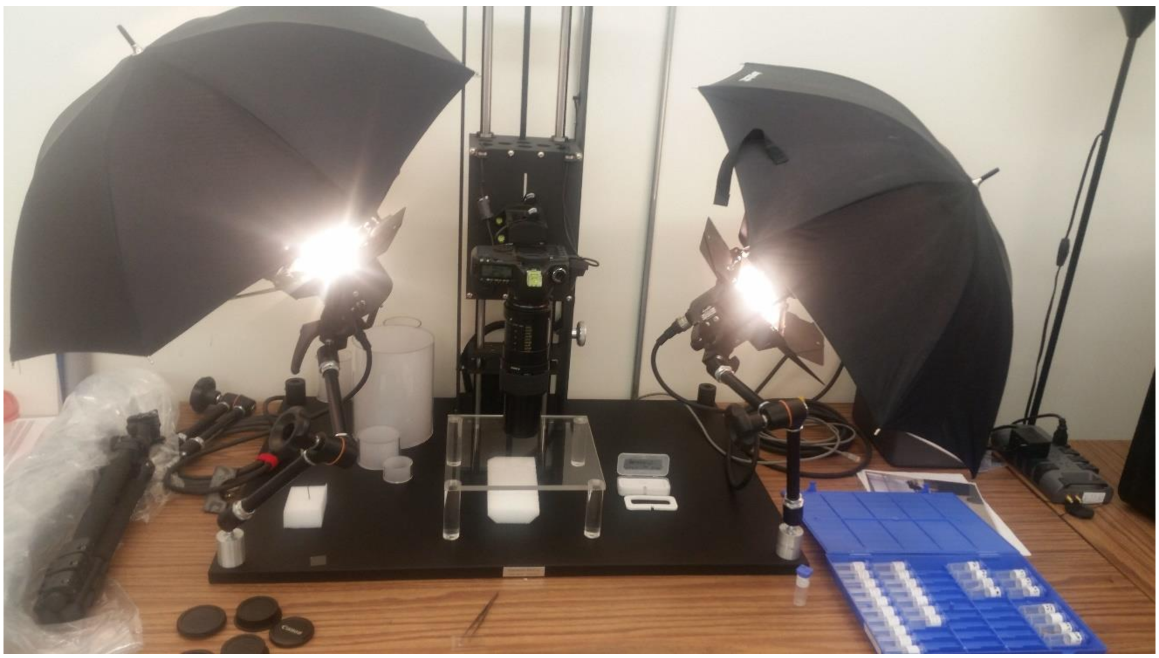


Figure 4.10: Visionary Digital Photography station used at the RSM in Regina to photograph micro-vertebrate specimens. (Photo by R. Boulding)

Chapter 5: Stratigraphic Results and Discussion

5.1 Introduction

This chapter presents the findings of this investigation including descriptions of the stratigraphic sections made at each study site (Figure 5.1) and the identification of three facies. Descriptions of sections include Cypress Hills, Road Cut, Humphrey, Hanson, Vansandt, Claybank, and Avonlea Badlands sites. This is followed by a discussion about the three facies, identified as planar laminated and massive sands, cross bedded, rippled sands and interbedded silts and clays. The chapter ends with an interpretation of the geology of the Eastend Formation from the sections in this study. All colours were determined using a Munsell 2010 colour chart.

5.2 Section Descriptions

5.2.1 Cypress Hills Site

The base of the Cypress Hills Site (Figure 5.2) is dominated by alternating layers of clays and silts ranging from 3 cm to 80 cm in thickness. The clays exhibit an olive grey colouration, 5y4/2d, that disappears within the first eight meters from the base of the section. Variable staining is present throughout these clay and silt layers with the heaviest staining occurring around 1136 and 1140.3 meters elevation asl (above sea level). Among the clay and silt layers are sparse centimeter scale layers of very fine sand containing substantial amounts of silt.

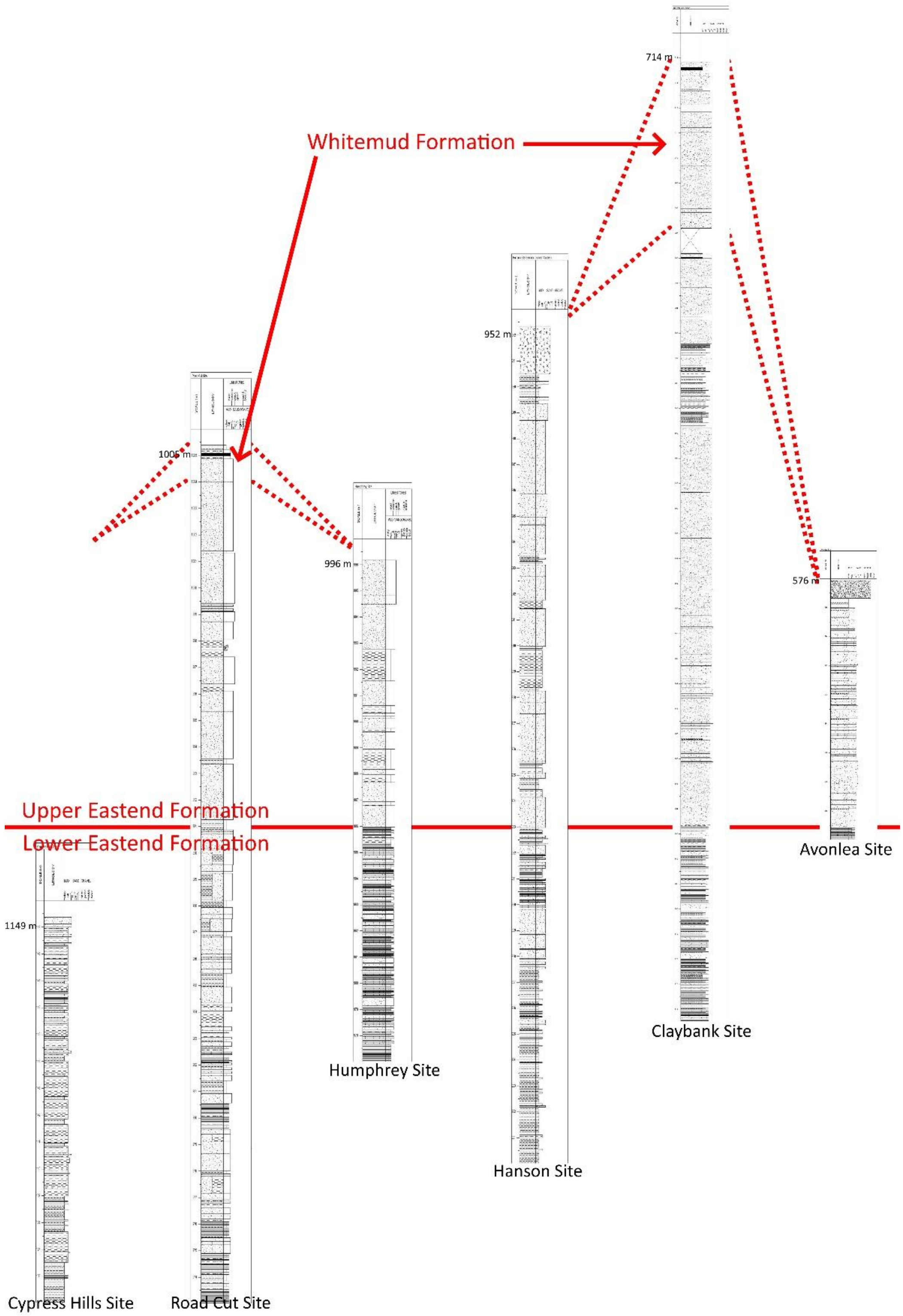
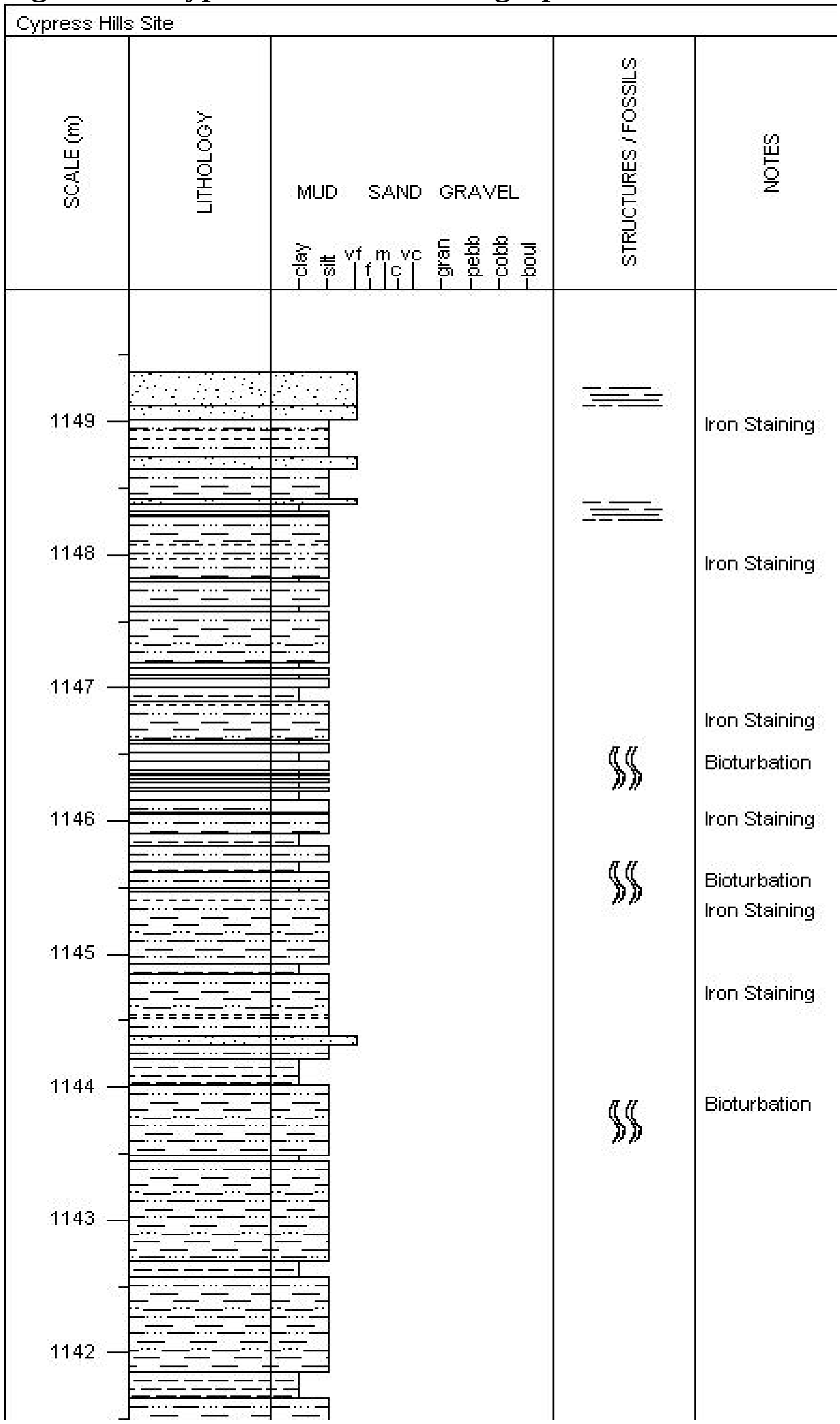
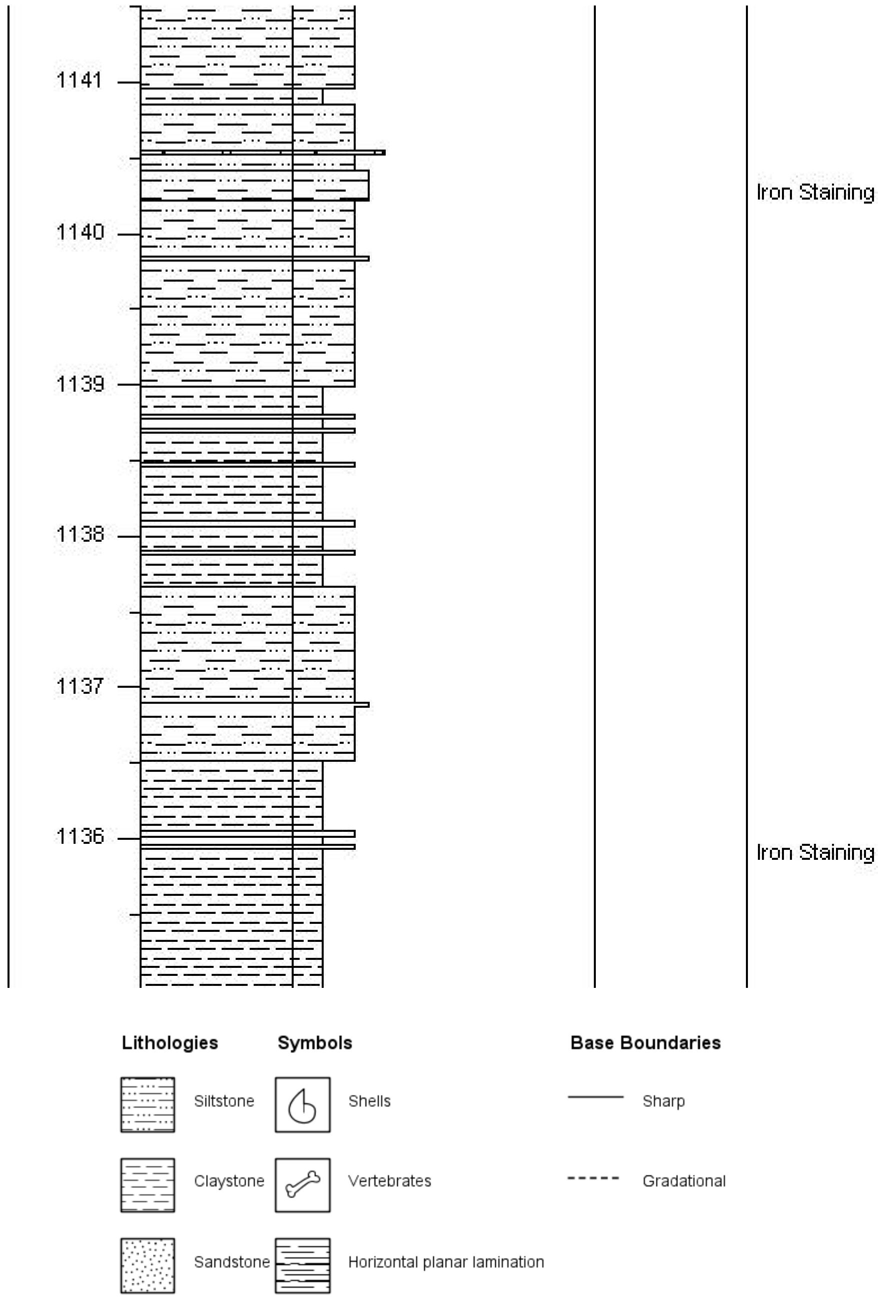


Figure 5.1: Correlation of the six stratigraphic sections made in this study across Saskatchewan.

Figure 5.2: Cypress Hills Site Stratigraphic Section




1141
1140
1139
1138
1137
1136
Iron Staining
Iron Staining
Lithologies
Symbols
Base Boundaries
Siltstone
Shells
Sharp
Claystone
Vertebrates
Gradational
Sandstone
Horizontal planar lamination

Around 1143 m asl the greenish colouration in the clays gives way to the more classic light grey, 5y7/2d, observed in other sections. The colour change is followed by the presence of obvious bioturbation within the clay and silt layers. These clay and silt layers begin to decrease in thickness moving up section and instead of the meters thick beds of clays and silts observed lower in the section, they now range from 2 cm to 50 cm in scale. The top two meters of the section show an increase in sands including very fine planar laminated sands that are more prevalent in other sections. Also, the appearance and increase in iron staining was noted within the upper five meters of the section. Above this, the section becomes discontinuous with occasional small patches of exposure exhibiting pale yellow sands, 5y7/4d, representing the upper Eastend Formation (Russell, 1933).

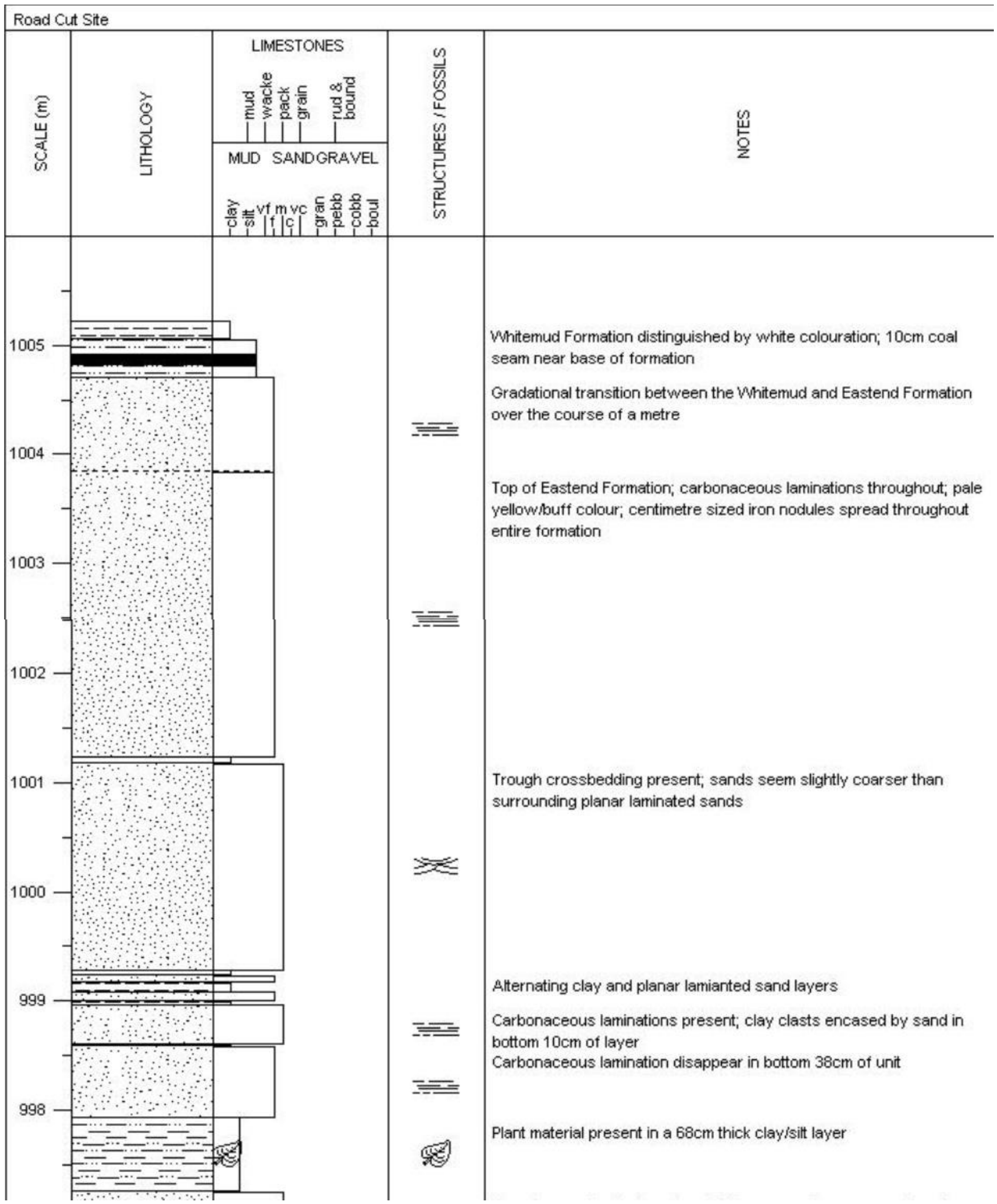
No fossil material was recovered from the Cypress Hills Site although given the unconsolidated nature of the sediments, if any material were present it would be extremely delicate. The bioturbation present in the upper portion of the section, was readily apparent with the colour change in the clays. But the extremely fissile nature of these clays in the lower part of the section could have resulted in the poor preservation of any traces.

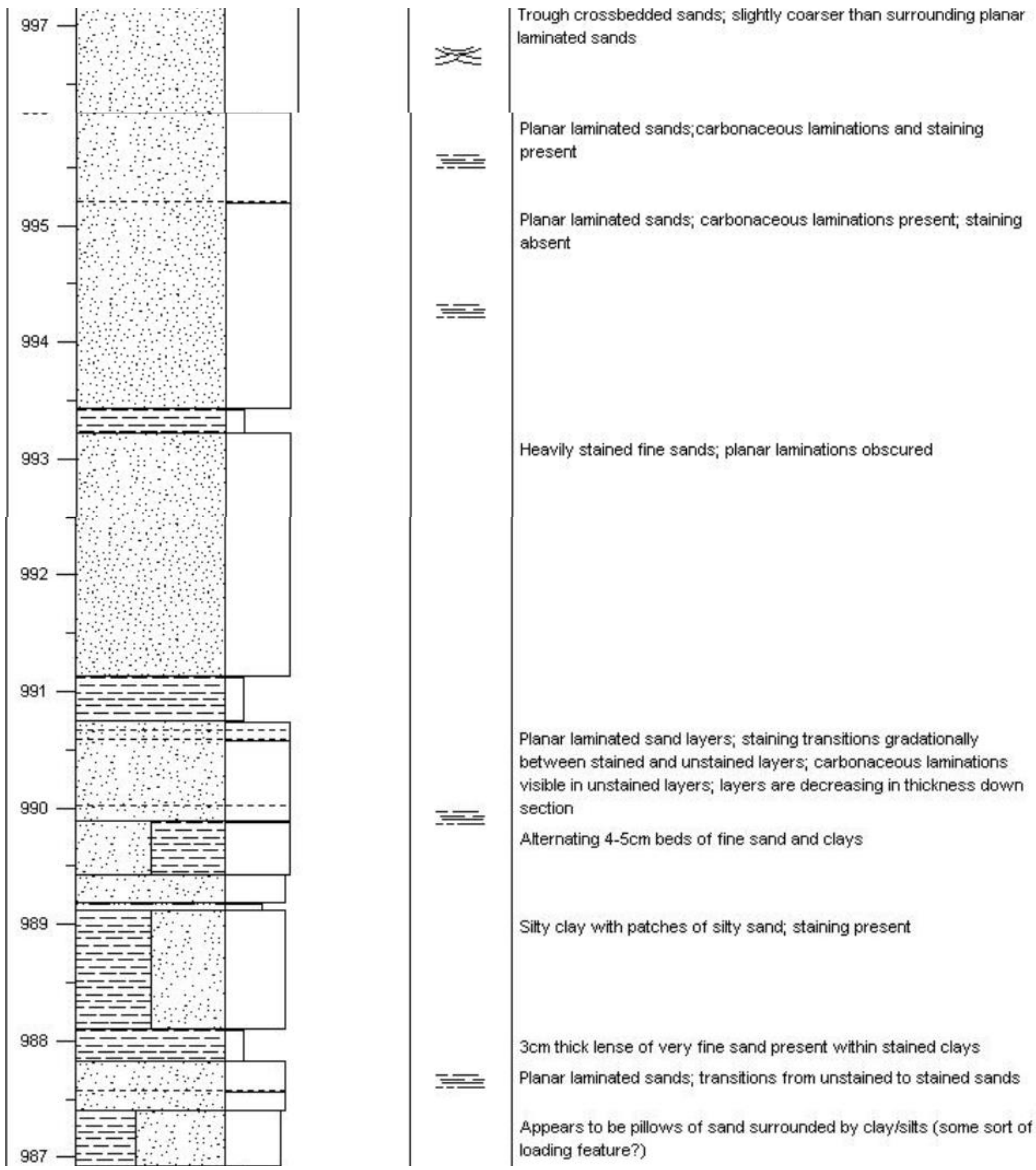
The fissile clays and presence of planar laminated sands associated with the Eastend Formation higher in the section suggest that the exposure represents the very gradual transition from the upper Bearpaw Formation sediments into the lowest reaches of the Eastend Formation.

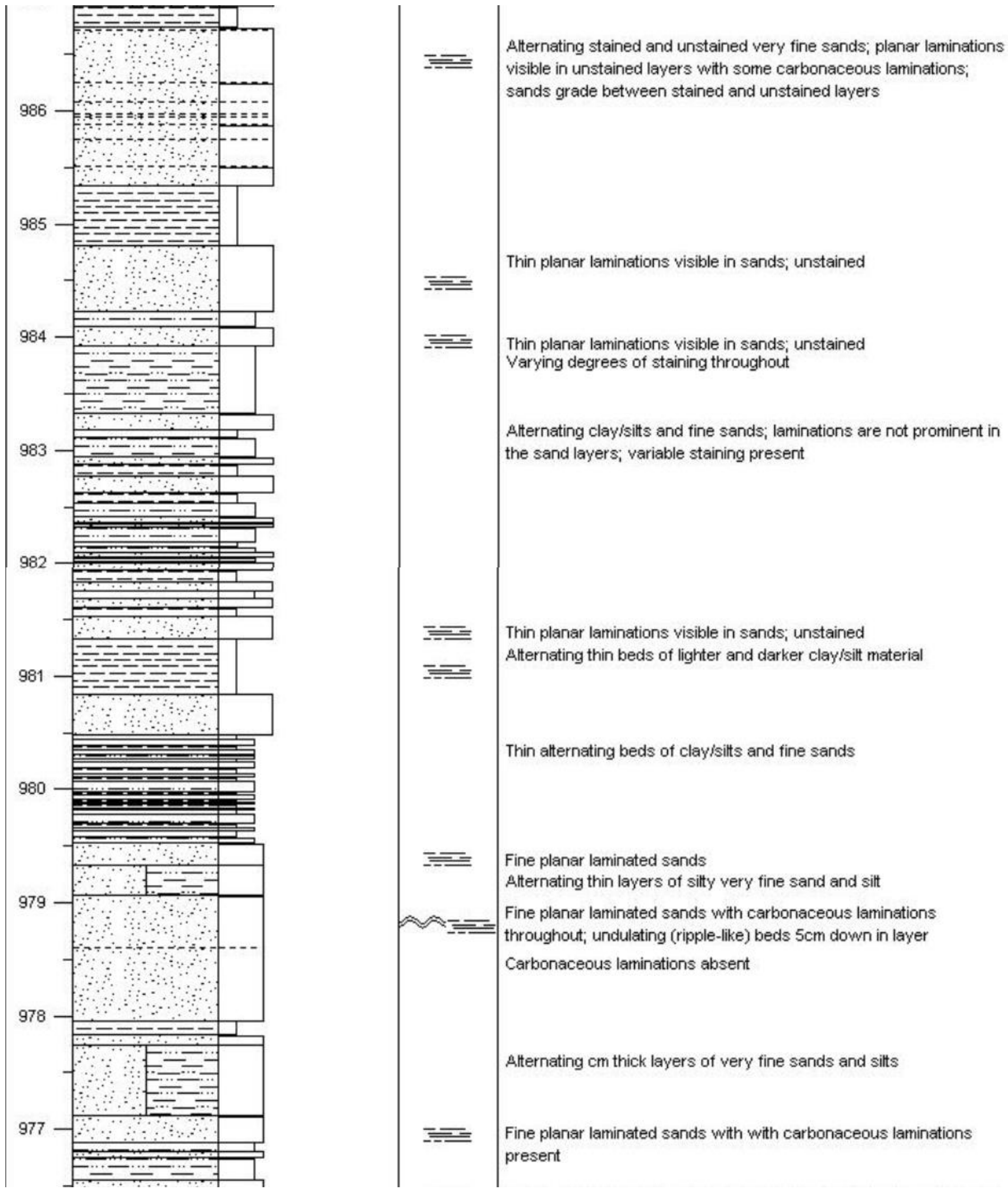
5.2.2 Road Cut Site

There is an obvious decrease in the number of clay and silt layers and an increase in the thickness of sand layers moving up section at the Road Cut site (Figure 5.3). This transition is most apparent in the sediments at elevations between 983 and 991 meters asl, which exhibit a large increase in sand material. The formation below the transition consists primarily of 1 to 25 centimeters thick beds of alternating clay/silt and very fine sand layers. It is noteable that the sands in the lower portion of the section are finer than those above the transition and that near the base of the section sediments approach silt/very fine sand size. These very fine sands at the base are planar laminated with carbonaceous laminations (Figure 5.4) unless they are visibly obscured by staining. Also in the lower portion of the section are a few thicker sand layers, one of which exhibits an undulating pattern around 979 meters asl where trough cross bedding is also visible within the sands (Figure 5.5).

Figure 5.3: Road Cut Site Stratigraphic Section




997
995
994
993
992
991
990
989
988
987
Trough crossbedded sands; slightly coarser than surrounding planar laminated sands
Planar laminated sands;carbonaceous laminations and staining present
Planar laminated sands; carbonaceous laminations present; staining absent
Heavily stained fine sands; planar laminations obscured
Planar laminated sand layers; staining transitions gradationally between stained and unstained layers; carbonaceous laminations visible in unstained layers; layers are decreasing in thickness down section
Alternating 4-5cm beds of fine sand and clays
Silty clay with patches of silty sand; staining present
3cm thick lense of very fine sand present within stained clays
Planar laminated sands; transitions from unstained to stained sands
Appears to be pillows of sand surrounded by clay/silts (some sort of loading feature?)



986
985
984
983
982
981
980
979
978
977
Alternating stained and unstained very fine sands; planar laminations visible in unstained layers with some carbonaceous laminations; sands grade between stained and unstained layers
Thin planar laminations visible in sands; unstained
Thin planar laminations visible in sands; unstained
Varying degrees of staining throughout
Alternating clay/silts and fine sands; laminations are not prominent in the sand layers; variable staining present
Thin planar laminations visible in sands; unstained
Alternating thin beds of lighter and darker clay/silt material
Thin alternating beds of clay/silts and fine sands
Fine planar laminated sands
Alternating thin layers of silty very fine sand and silt
Fine planar laminated sands with carbonaceous laminations throughout; undulating (ripple-like) beds 5cm down in layer
Carbonaceous laminations absent
Alternating cm thick layers of very fine sands and silts
Fine planar laminated sands with with carbonaceous laminations present

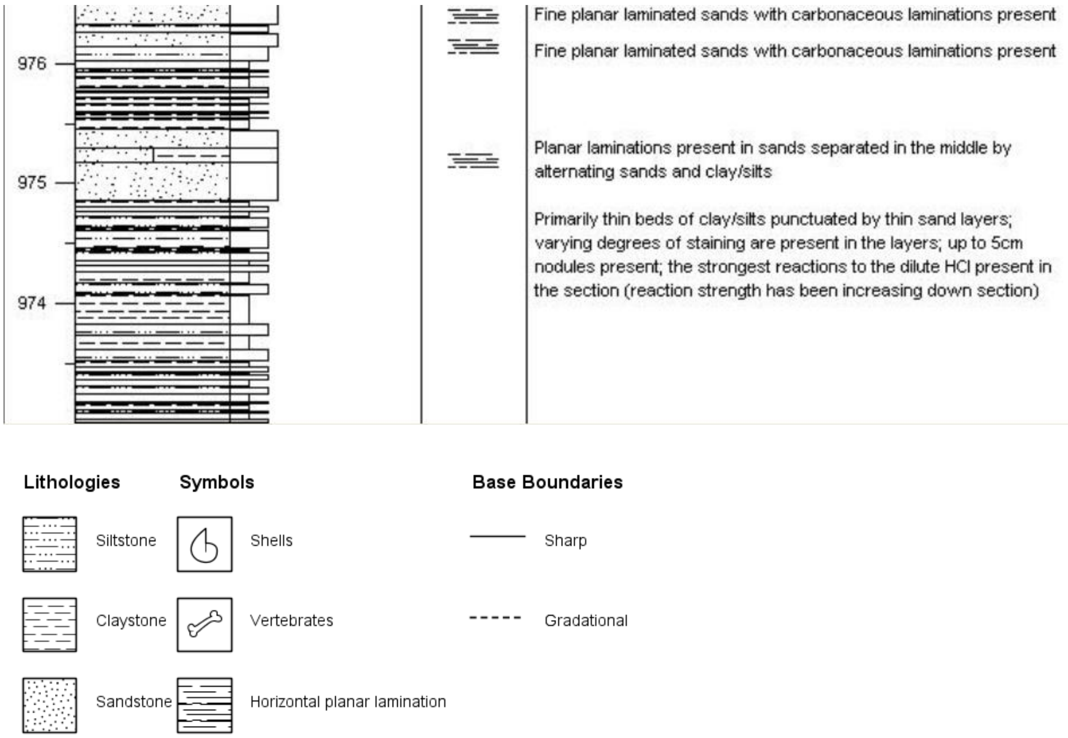

976
975
974
Fine planar laminated sands with carbonaceous laminations present
Fine planar laminated sands with carbonaceous laminations present
Planar laminations present in sands separated in the middle by alternating sands and clay/silts
Primarily thin beds of clay/silts punctuated by thin sand layers; varying degrees of staining are present in the layers; up to 5cm nodules present; the strongest reactions to the dilute HCl present in the section (reaction strength has been increasing down section)
Lithologies
Siltstone
Claystone
Sandstone
Symbols
Shells
Vertebrates
Horizontal planar lamination
Base Boundaries
Sharp
Gradational

Figure 5.4: Planar laminated sands with carbonaceous laminations from Road Cut Site around 1003 m asl. (Photo by R. Boulding)

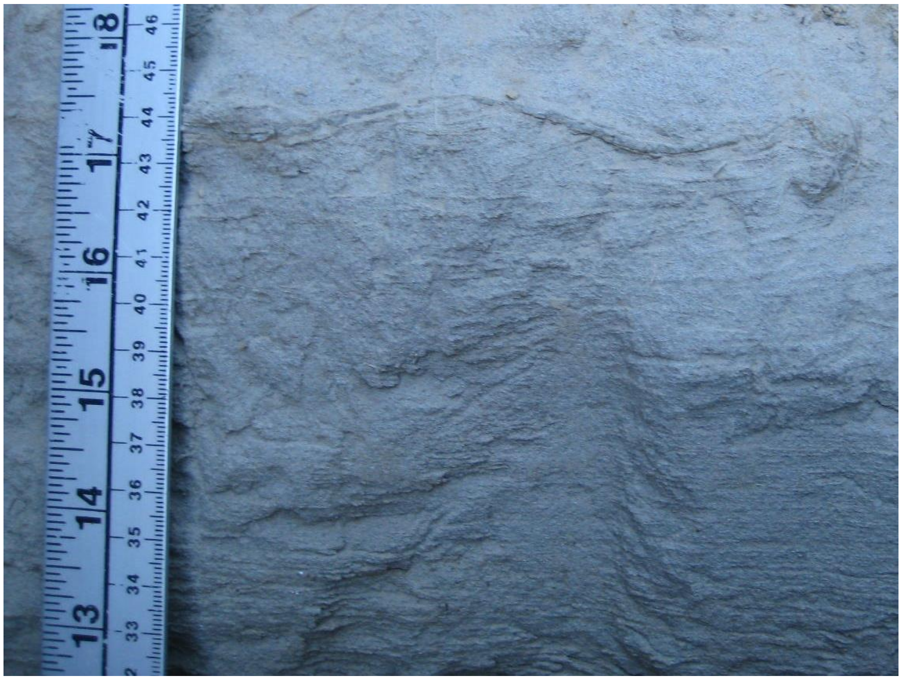


Figure 5.5: Undulating ripple pattern found in a sand layer at 979 m asl at the Road Cut Site. (Photo by R. Boulding)

The Eastend Formation above the transition zone is dominated by layers of fine sands 4 centimeters to 3.5 meters in thickness with carbonaceous laminations increasing in thickness up-section and are separated by clay/silt layers ranging in thickness from 0.5 to 68 cm. Two other layers in the upper Eastend Formation that diverge from the dominant laminar sands noted above are trough cross bedded sands located at approximately 1001.25 and 997.25 meters asl. The higher of the two layers is around two meters in thickness where the other is only about one meter thick. The sands present in the cross bedded layers seem to be slightly coarser than those of the surrounding sand units and lack the carbonaceous laminations. One noteworthy clay/silt layer in the upper Eastend Formation is located at around 998 meters asl which contains visible pieces of plant material throughout the 68 cm layer. Upon closer examination, it was determined that the plant material cannot be classified due to its fragmented nature and poor preservation (Tim Tokaryk, pers. comm., July 16, 2010).

Two features present intermittently throughout the Eastend Formation are variable staining and iron nodules ranging in diameter from a few millimeters to almost ten centimeters. Both features are post-depositional and originated from water percolating down through the formation and precipitating the iron material leached out from the upper layers.

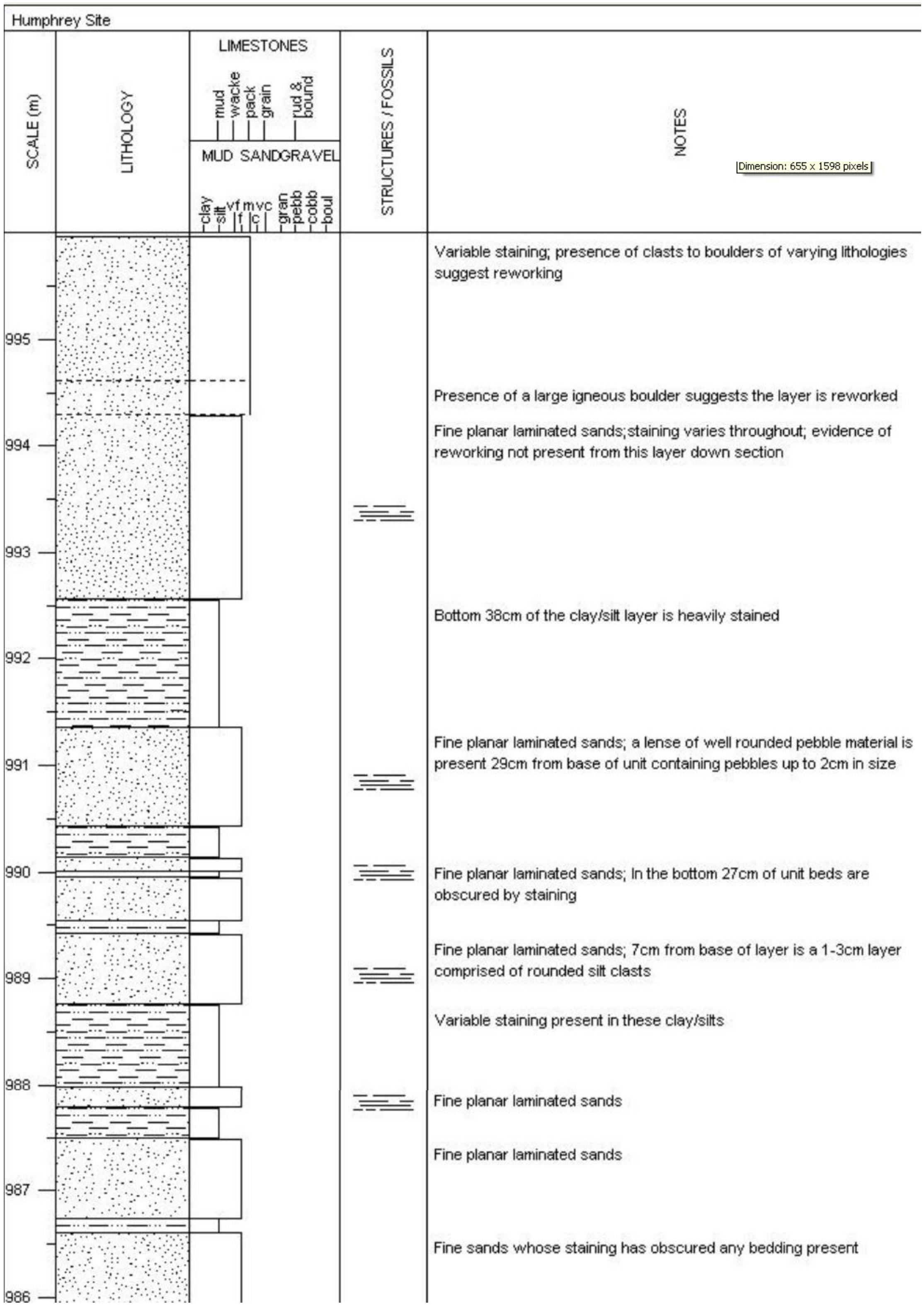
At the top of the Road Cut Site section there is approximately a half a meter of Whitemud Formation material consisting of horizontally bedded very fine sands and silts. Ten centimeters from the base of the Whitemud is a ten centimeter thick coal seam above which several infilled burrows from modern fauna were observed. The Whitemud material is distinguished by its white colouration, 2.5y8/1d on the Munsell colour chart, resulting from the presence of kaolinite which appears over a meter-thick transition zone from the buff coloured sands of the Eastend Formation below. The sands of the upper Eastend Formation exhibit some of the same characteristics as the Whitemud material. Like the lower Whitemud material, the upper Eastend sands are planar laminated, fine to very fine-grained sands with silt layered between them. The main differences between these two are that the Eastend Formation lacks the kaolinite present in the Whitemud and the Eastend sands exhibit parallel carbonaceous laminations.

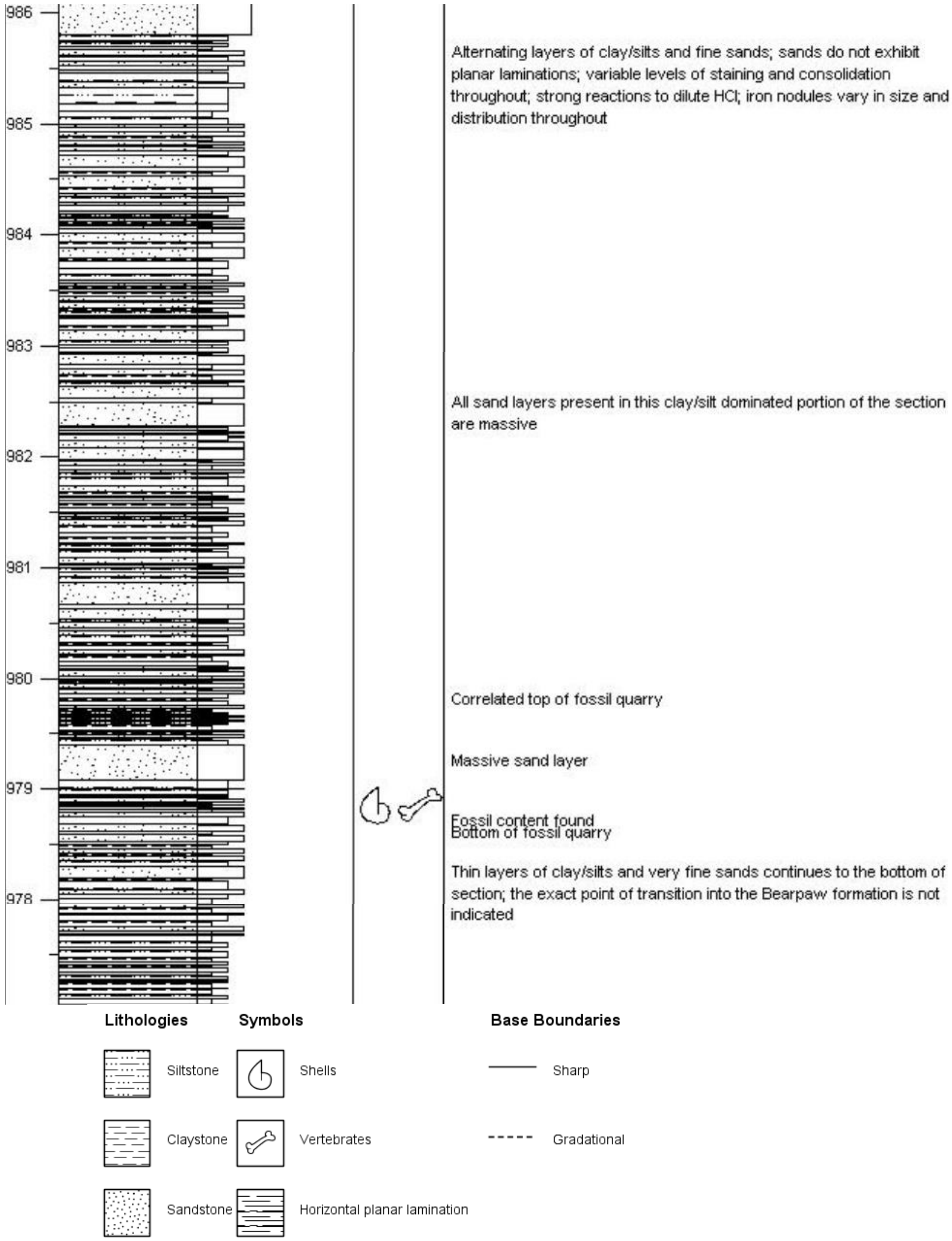
In terms of fossil content, no accumulations of fossil material were found in situ at this site. However, fossil material was present on the slopes of the Road Cut Site below 984 – 985 meters asl in a surface deposit of clay/silt dominated sediments that had been eroded out of the face of the road cut and washed down slope. Attempts were made to trace the washed out fossils up slope to find its original source with no success.

5.2.3 Humphrey Site

The lower portion of the Humphrey Site section (Figure 5.6) exhibits similar characteristics observed in the Road Cut section with thin alternating 0.5cm to 4cm layers of clay/silts and very fine sands. There are a few thicker sand units up to 35cm thick in the lower portion of the Humphrey Site section, although not as many as were observed in the Road Cut Section. These sand units appear to be massive and lack any planar laminated bedding.

Figure 5.6: Humphrey Site Stratigraphic Section




986
985
984
983
982
981
980
979
978
Alternating layers of clay/silts and fine sands; sands do not exhibit planar laminations; variable levels of staining and consolidation throughout; strong reactions to dilute HCl; iron nodules vary in size and distribution throughout
All sand layers present in this clay/silt dominated portion of the section are massive
Correlated top of fossil quarry
Massive sand layer
Fossil content found
Bottom of fossil quarry
Thin layers of clay/silts and very fine sands continues to the bottom of section; the exact point of transition into the Bearpaw formation is not indicated
Lithologies
Siltstone
Claystone
Sandstone
Symbols
Shells
Vertebrates
Horizontal planar lamination
Base Boundaries
Sharp
Gradational

The Humphrey Site exhibits a change in the nature of sediments as it transitions from thin alternating clay/silt and sand layers in the lower portion to thick sand units separated by clay/silts in the upper portion. In the Humphrey Site section, there is some thinning of the upper sand units prior to the transition at approximately 985.75 meters asl. The key difference between the Road Cut Site section and the Humphrey Site is that the transition between the lower and upper portions is much more abrupt in the latter. At the Road Cut Site the transition occurred over an 8 meter interval where at the Humphrey Site it happened over only one meter.

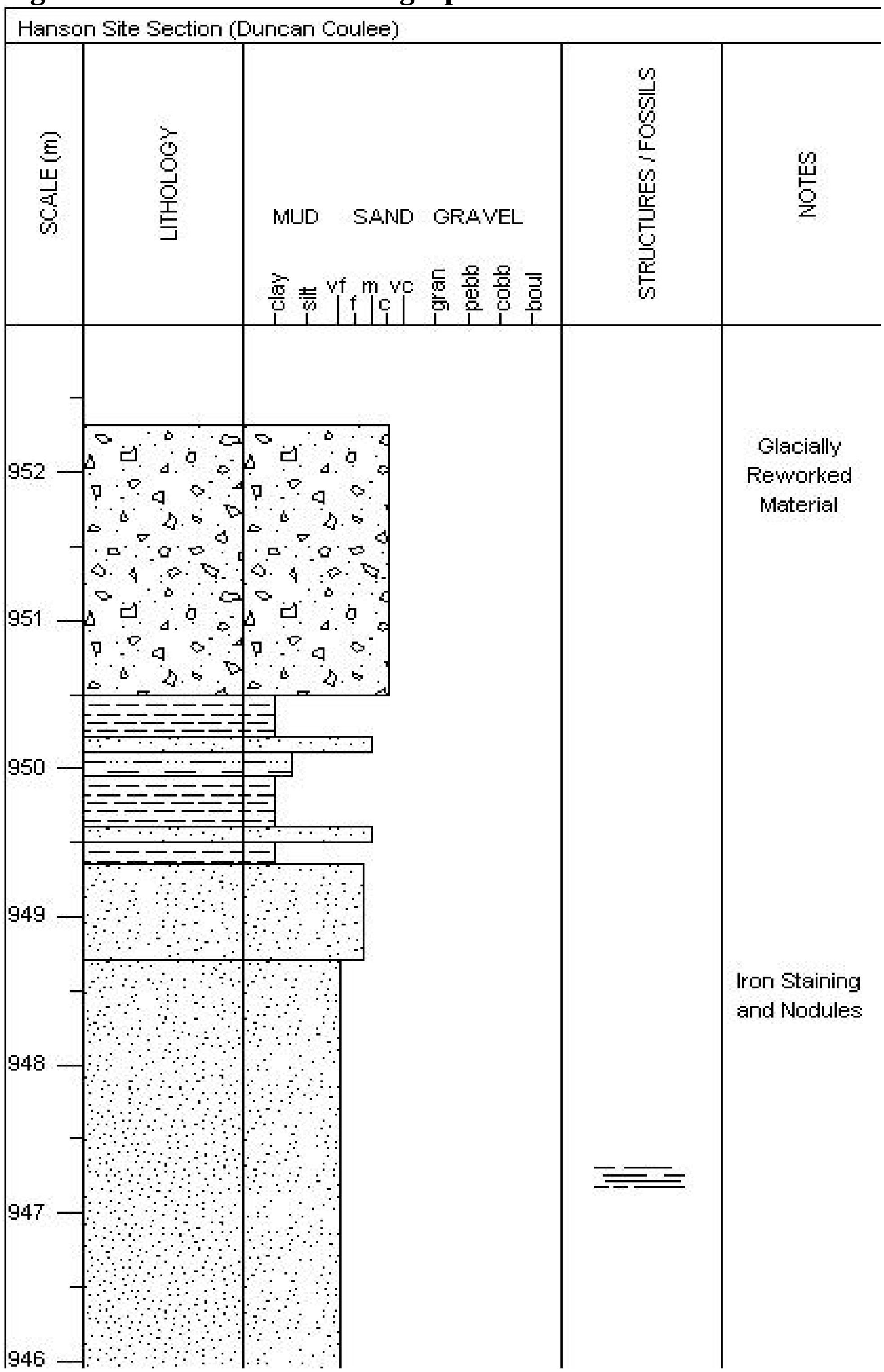
For the most part, the upper portion of the Humphrey Site section is similar to that of the Road Cut Site with sand units that range from 10 to 100 centimeters at max thickness. These sand units are separated by clay/silt layers ranging from 2 to 115 centimeters thickness. The Humphrey Site section contains variable levels of staining and intermittent iron nodules ranging in diameter from 0.5 to 5 cm. In contrast to the Road Cut Site, the Whitemud Formation is absent at the top of the Humphrey Site. Instead the top of the Humphrey Site section is reworked upper Eastend Formation sands. The reworked sands are filled with convoluted structures surrounding numerous clasts and boulders constituting about 20% of the material and ranging in lithology from meta-igneous to metasedimentary. Approximately one and a half meters from the top of the section the reworked material gives way to the classic planar laminated sands seen in the Road Cut Site with one key difference, the Humphrey Site sands contained no evidence of carbonaceous laminations.

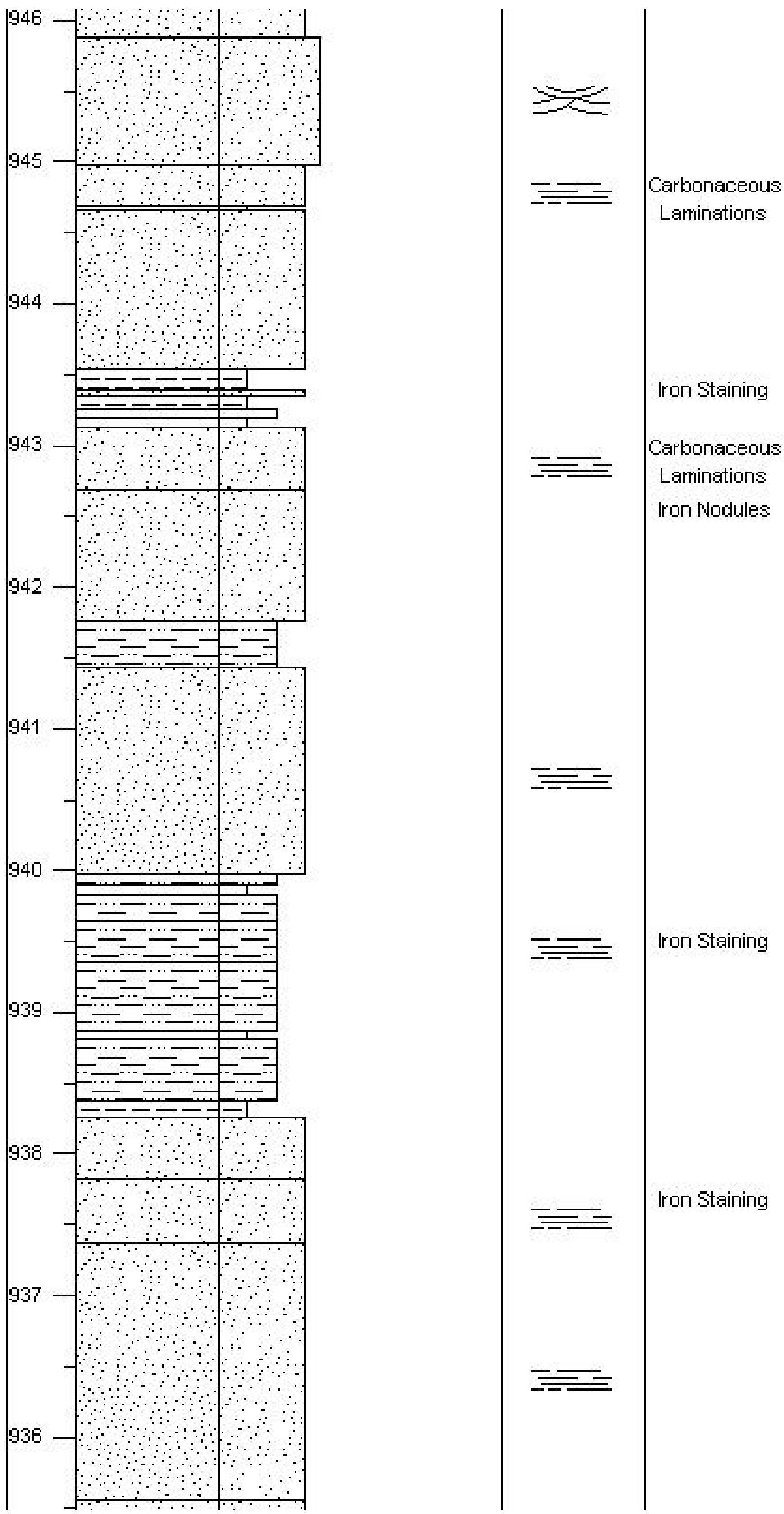
A stratigraphic layer containing fossil content was found at the Humphrey Site at 979.85 meters asl. The 10 cm thick layer was comprised of medium to coarse sands and yielded an abundance of fossil material that appeared to be in situ. Any washed out fossil material on the surface was collected. A two by three meter quarry was dug to examine the stratigraphy and extract the in situ fossil material from the site. The quarry was extended another 2 m into the hillside and 2.5 m on the south side of the quarry, unfortunately the expansion did not yield any additional fossil material or stratigraphic features.

5.2.4 Hanson Site

The base of the Hanson Site section (Figure 5.7) and first eight meters are dominated by clays ranging in thickness from 10 to 100 cm in thickness. These clay layers are punctuated with centimeter thick layers of silt and rare very fine sand silty layers. The clays and silts are fissile in nature and crumble away when trying to clear a smooth face for the section. Above 928 meters asl there is a noticeable increase in the presence of sands in the section and by 940 meters asl sands dominate the upper portion of the section. These 3 cm to 2.8 m thick sands are very fine in texture with planar carbonaceous laminations present within them.

Figure 5.7: Hanson Site Stratigraphic Section




946
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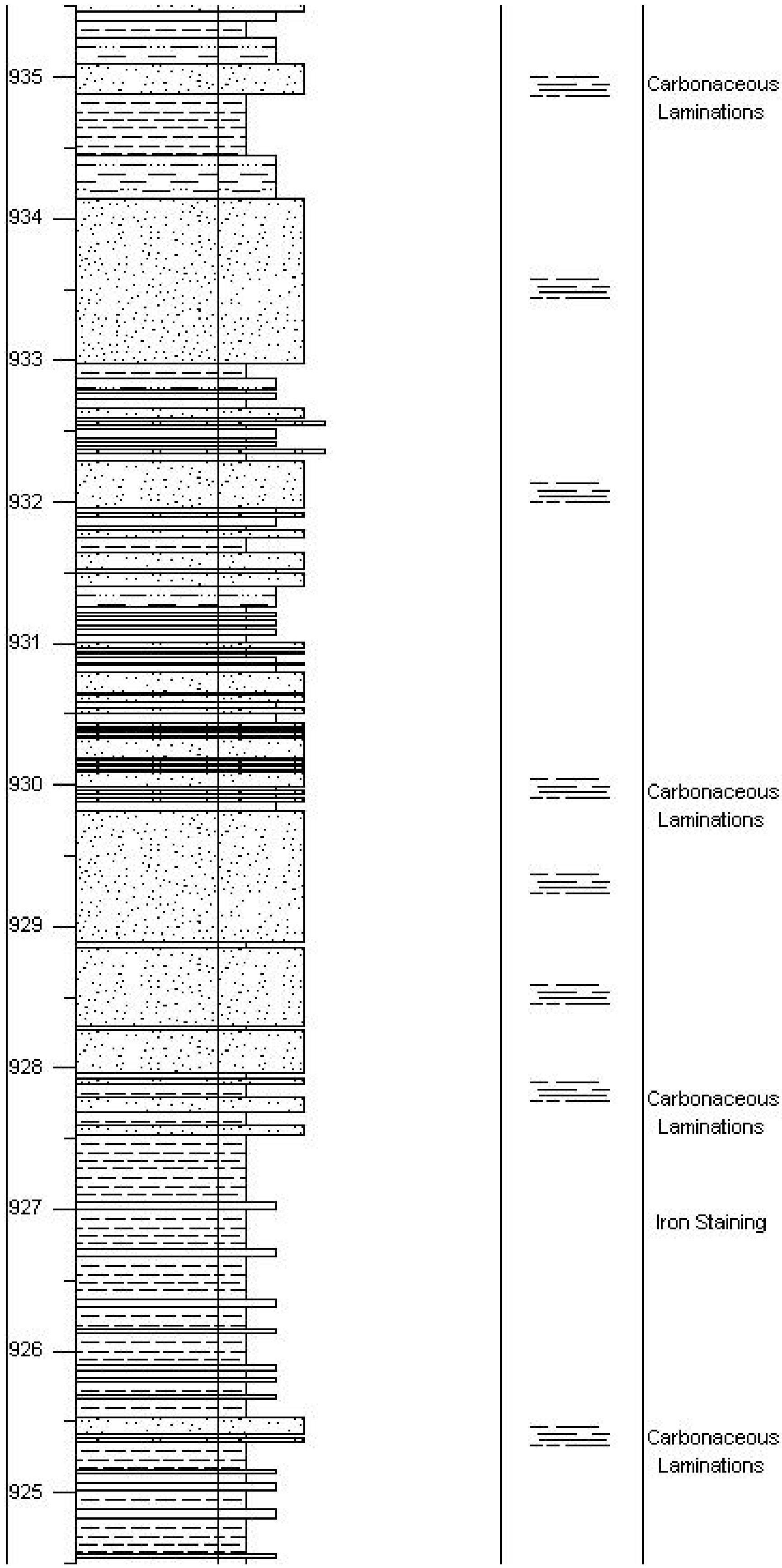
944
943
942
941
940
939
938
937
936
Carbonaceous Laminations
Iron Staining
Carbonaceous Laminations
Iron Nodules
Iron Staining
Iron Staining


935
934
933
932
931
930
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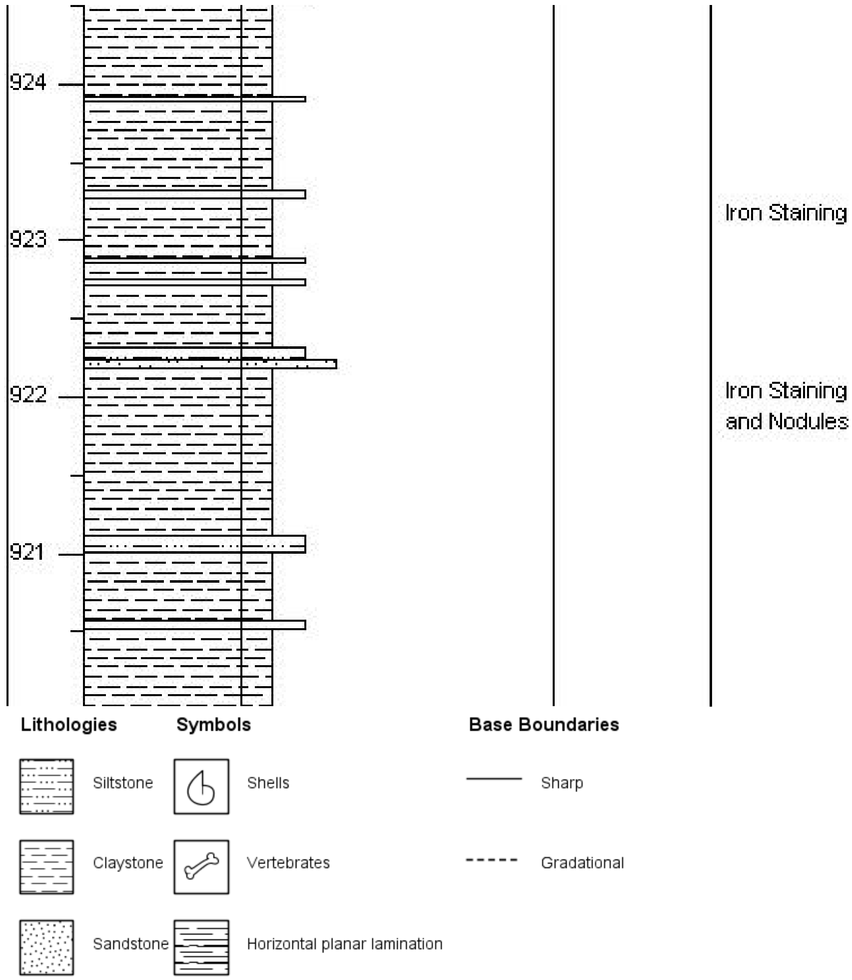
928
927
926
925
Carbonaceous Laminations
Carbonaceous Laminations
Carbonaceous Laminations
Iron Staining
Carbonaceous Laminations


924
923
922
921
Iron Staining
Iron Staining and Nodules
Lithologies
Symbols
Base Boundaries
Siltstone
Shells
Sharp
Claystone
Vertebrates
Gradational
Sandstone
Horizontal planar lamination

The massive or planar laminated sands are broken up from 930 to 933 m asl by 1 to 40cm scale beds of clays, silts, and very fine to fine sands. The planar laminated sands return above 933 m asl and are characterized by meter thick beds split up by clay layers up to 15 cm in thickness and silt layers reaching 50 cm in thickness. A noted exception to the usual planar sands are a 90cm layer of trough cross bedded fine sands at 945 meters asl. Above this are thick layers of very fine sands without carbonaceous laminations, that are punctuated with clay and silt layers 10 to 30 centimeters in thickness. The top two meters of the section are glacially reworked sediments with large rounded clasts up to 20 cm in dimension incorporated into the sands associated with the upper Eastend Formation. The metasedimentary to igneous in composition of these clasts coupled with a lack of any sedimentary structures associated with the sands in other areas of the section suggests reworking by glacial activities.

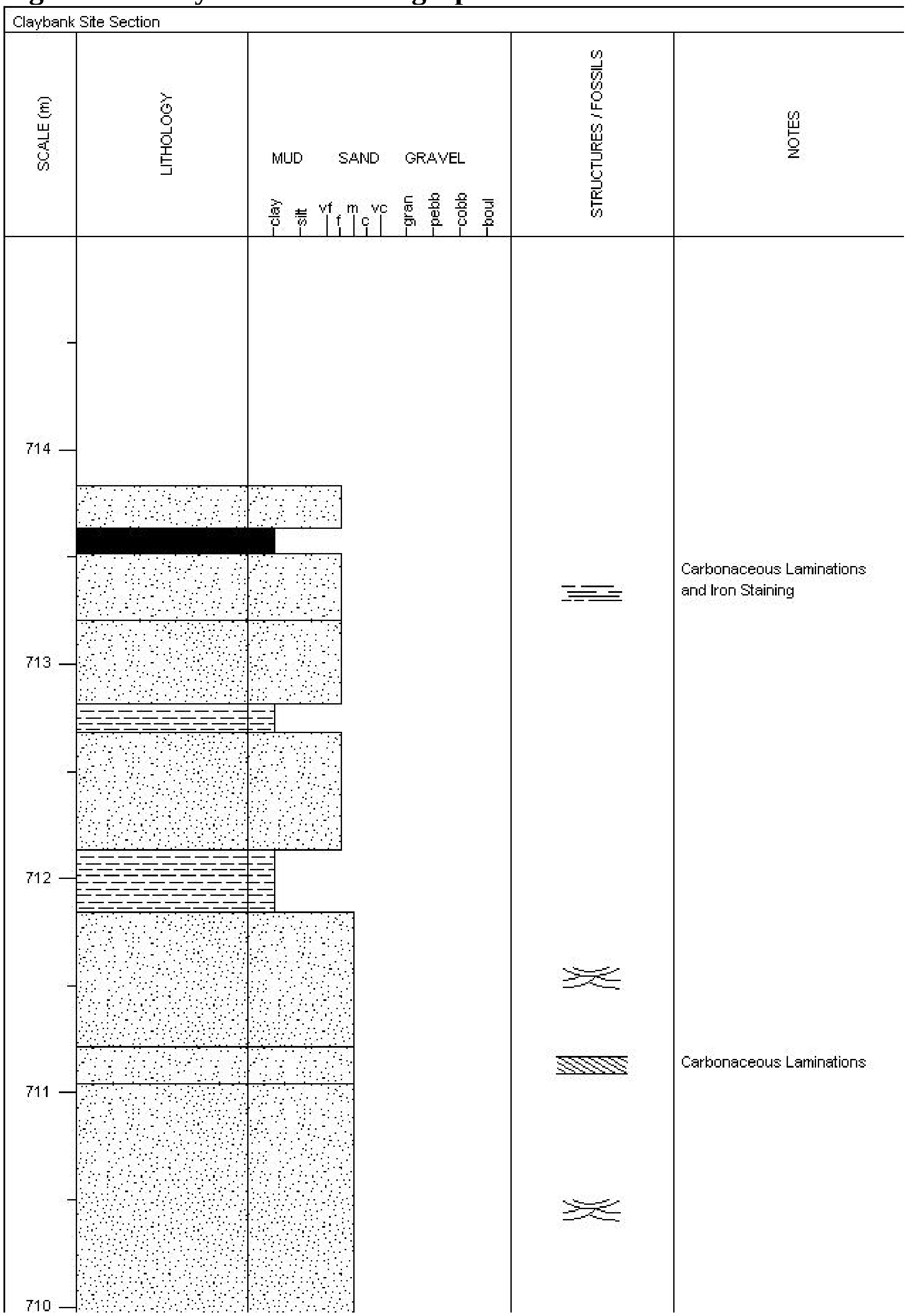
The section exhibited variable staining throughout accompanied by iron nodules, typically 1cm in diameter, with a few up to 3cm in diameter found around 948 meters asl. The site was also noted for its archaeological richness, containing both artifacts and bones buried from its historical use as a buffalo jump. However, the unconsolidated nature of these sediments combined with the steep nature of the buffalo jump and need for repelling equipment made the prospecting for fossils and the identification of any bioturbation in the section extremely difficult. Further prospecting and excavation of the section was not conducted to follow the personal wishes of the landowner, who did not want any further disturbance to the site.

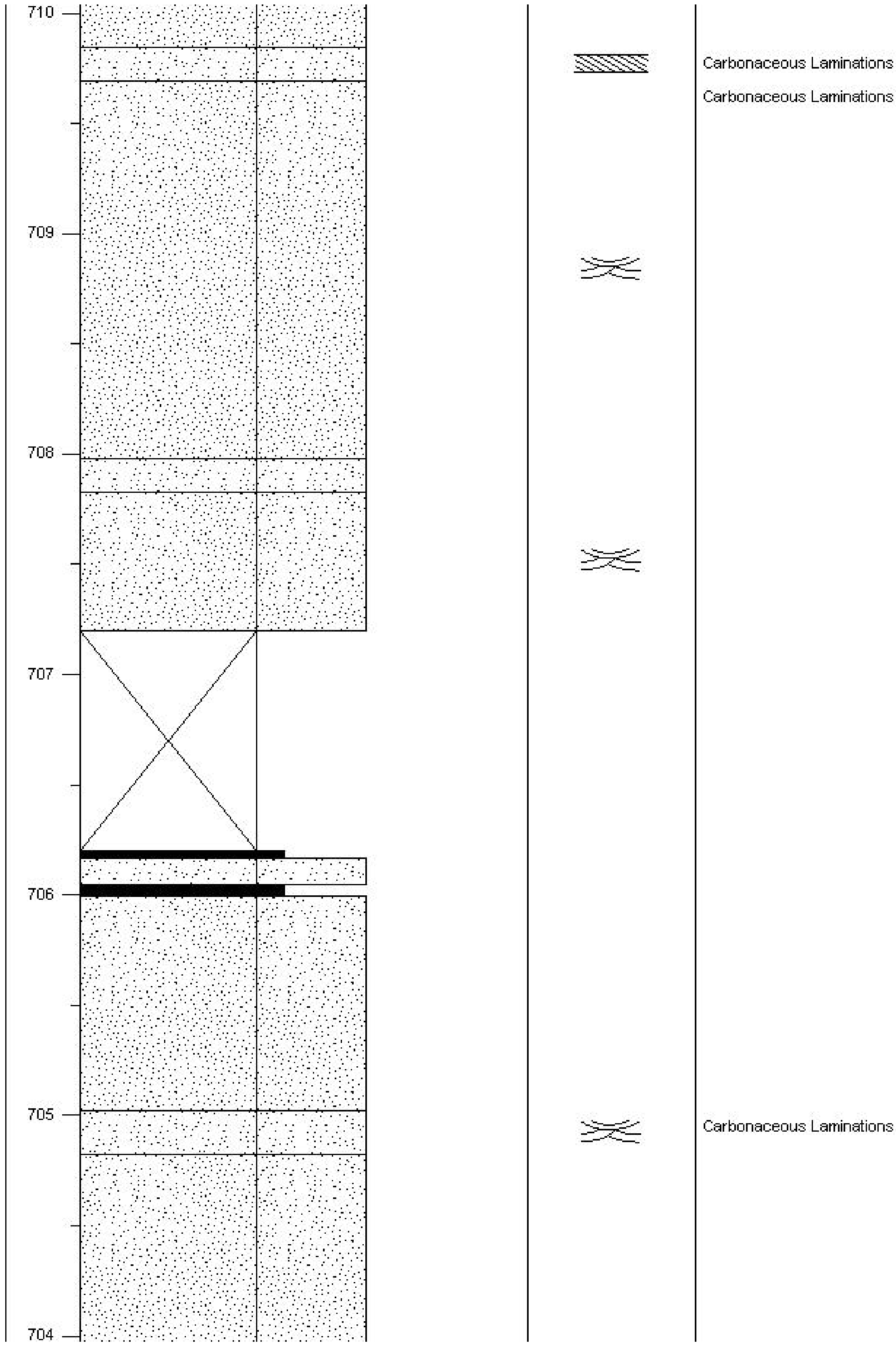
5.2.5 Claybank Site

The best exposure of the Eastend formation at the Claybank Site (Figure 5.8) is a rotated block. The beds of the block are at a 40° angle from horizontal making it difficult to refer to exact elevations. To address this issue, specific elevations of beds in the section were measured as though the section were vertical, with the actual basal elevation of the section set at approximately 675 meters asl.

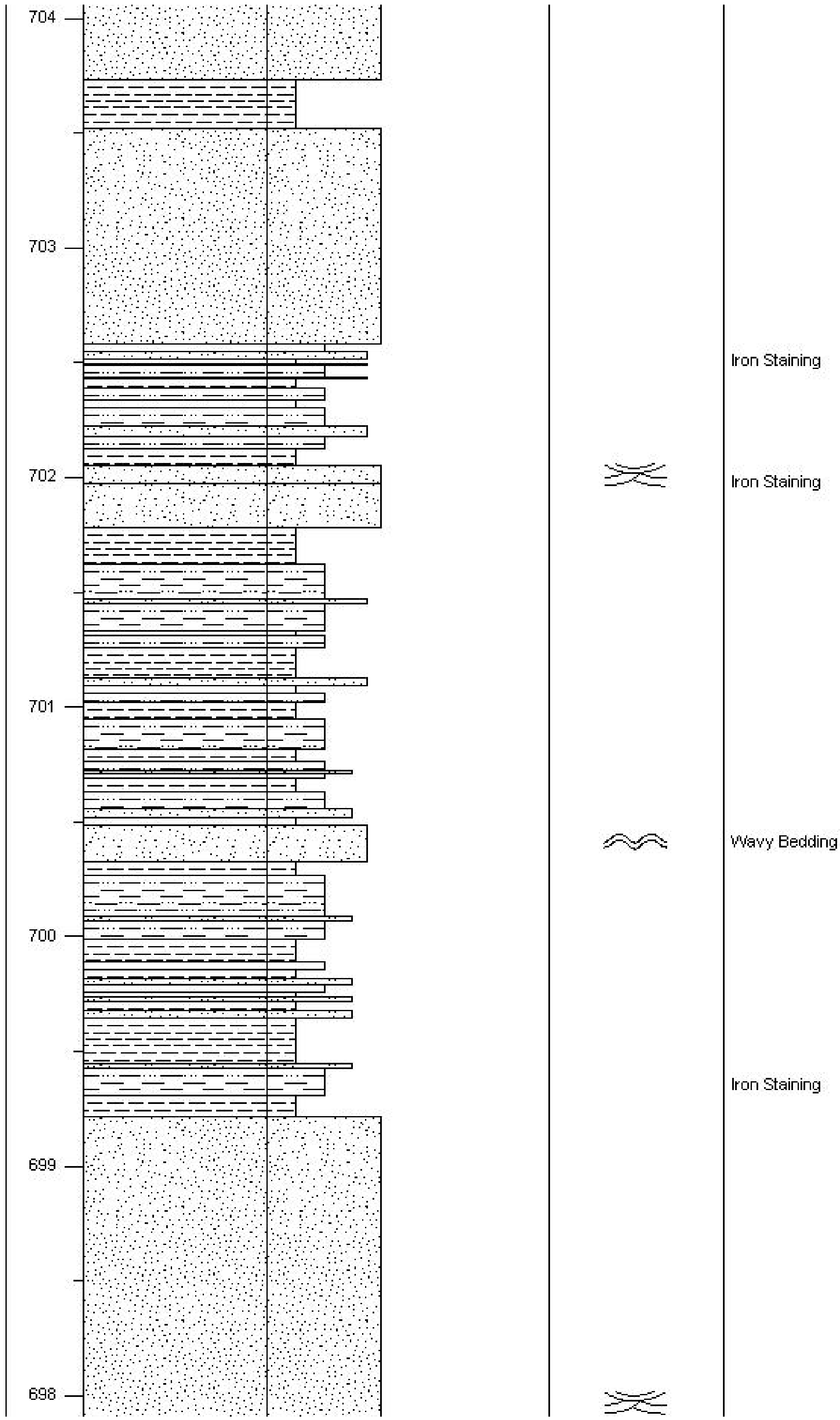
Like the Road Cut and Humphrey Sites, the lower portion of the Claybank Site section from 675 to 683.4 meters asl was dominated by 0.5 cm to 20 cm thick beds of alternating clay and silt layers along with layers of very fine sands. These silty sands were planar laminated with the exception of two sand layers at approximately 678.1 and 680.1 meters asl that were both approximately 20 cm in thickness. These two sand layers were coarser grained than other sands in this part of the section and exhibited planar cross bedding. The sediments of the lower section exhibited variable staining often associated with the sandy layers. The lower section was devoid of any carbonaceous material or evidence of bioturbation which could have been obscured by how wet the sediments were during the logging process due to constant rain.

Figure 5.8: Claybank Site Stratigraphic Section

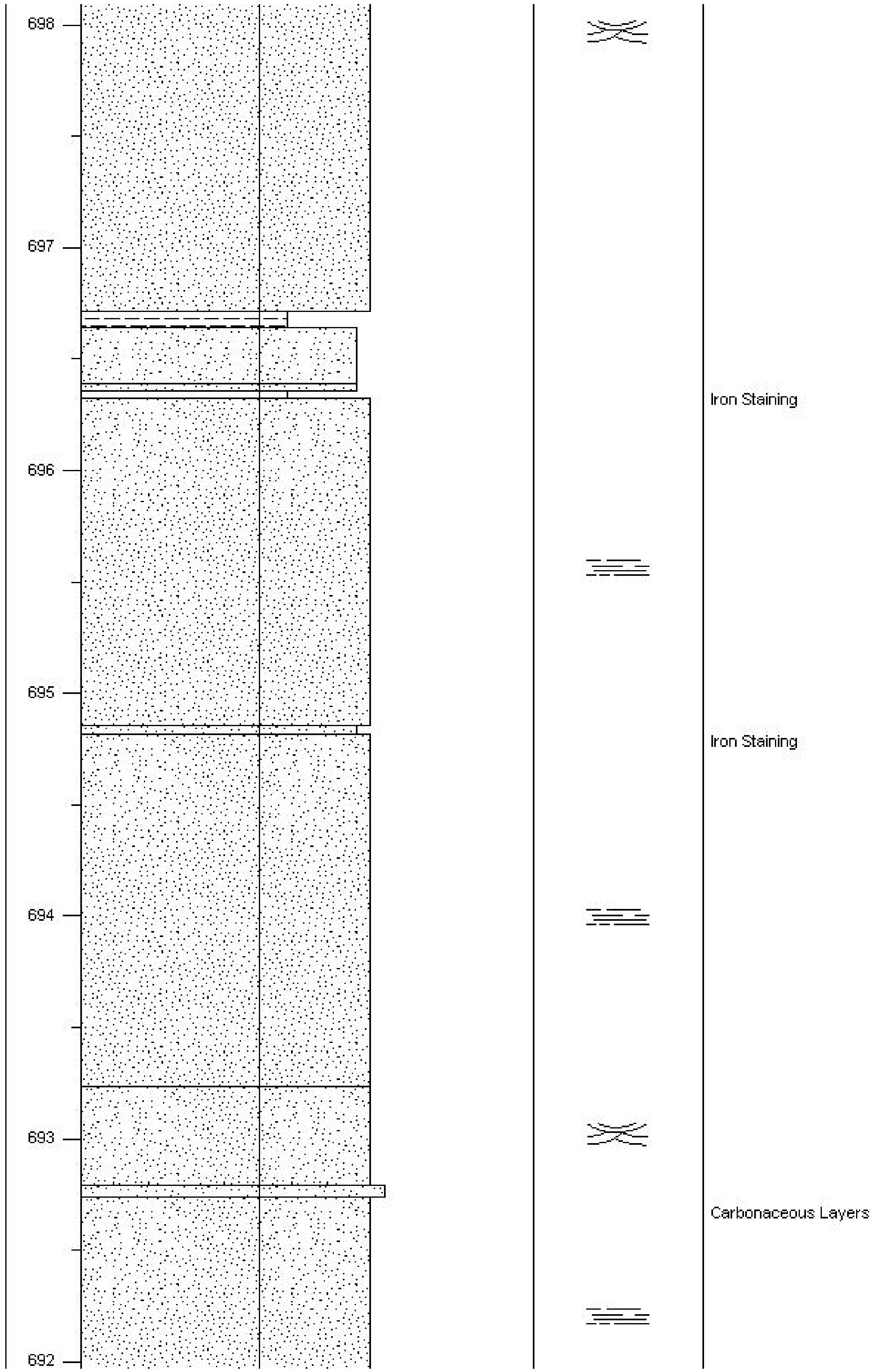


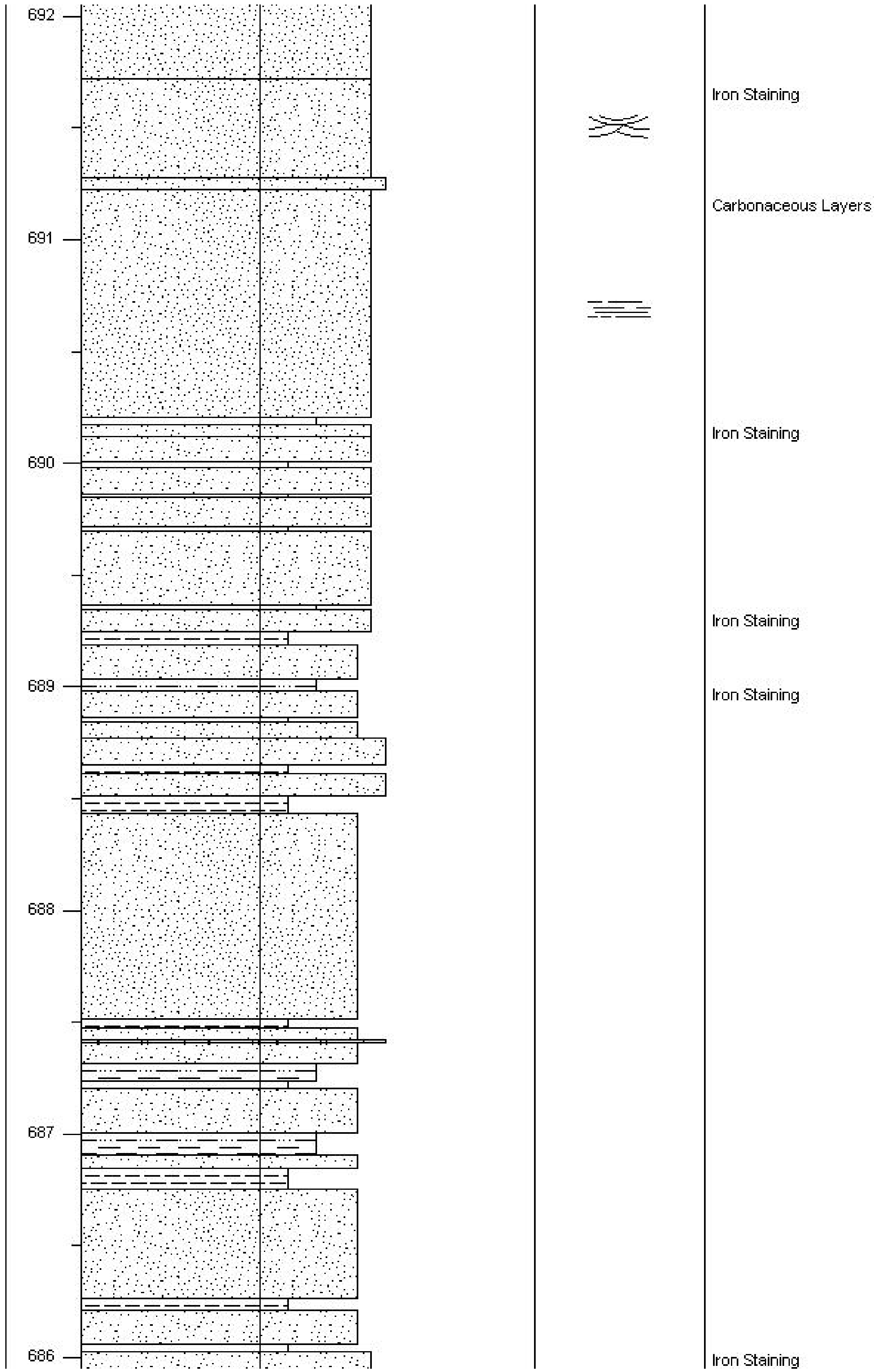


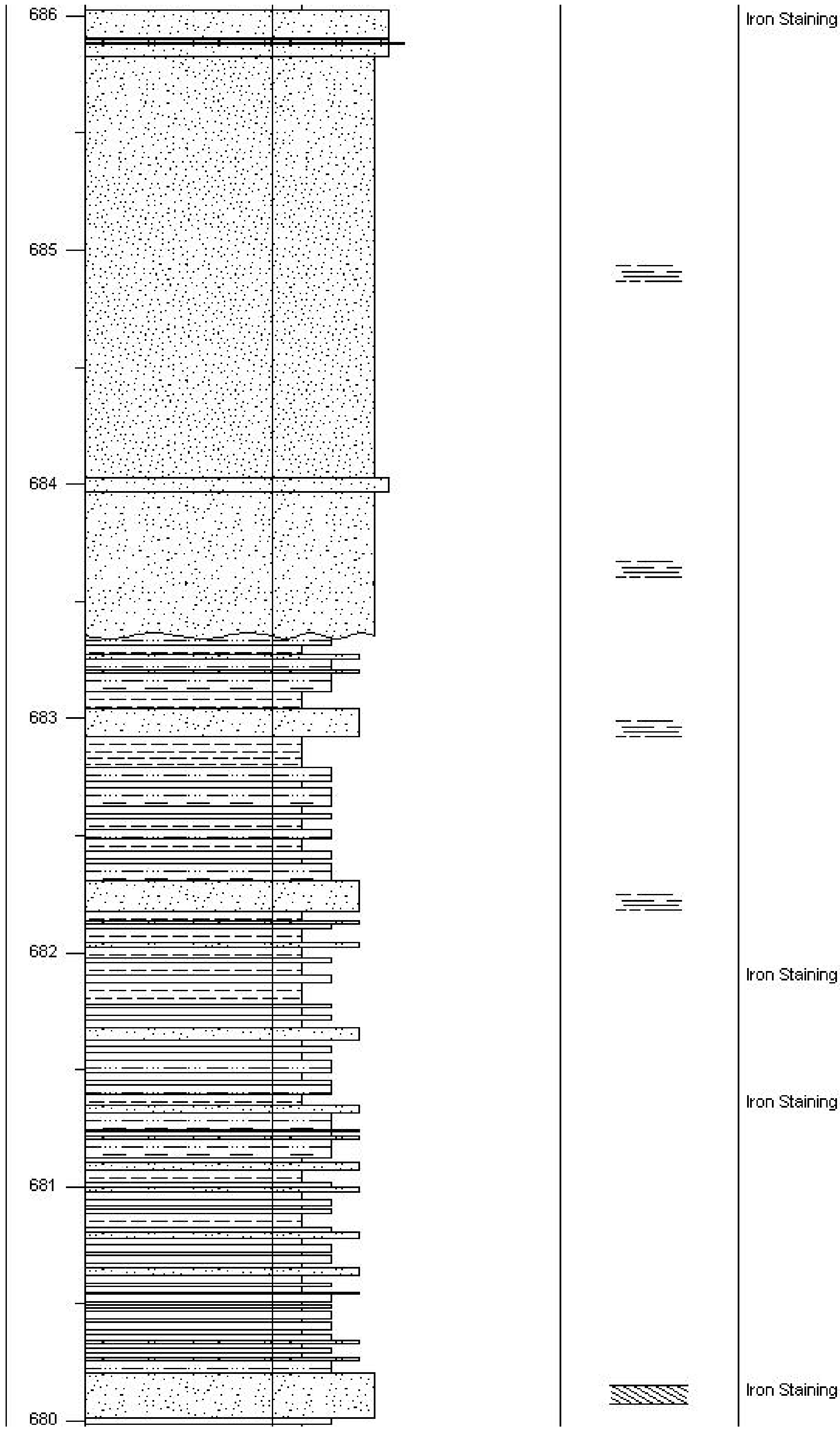
710
Carbonaceous Laminations
Carbonaceous Laminations
709
708
707
706
705
Carbonaceous Laminations
704



704
703
Iron Staining
702
Iron Staining
701
Wavy Bedding
700
Iron Staining
699
698


698
697
696
695
694
693
692
Iron Staining
Iron Staining
Carbonaceous Layers


692
Iron Staining
691
Carbonaceous Layers
Iron Staining
690
Iron Staining
689
Iron Staining
688
687
686
Iron Staining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685
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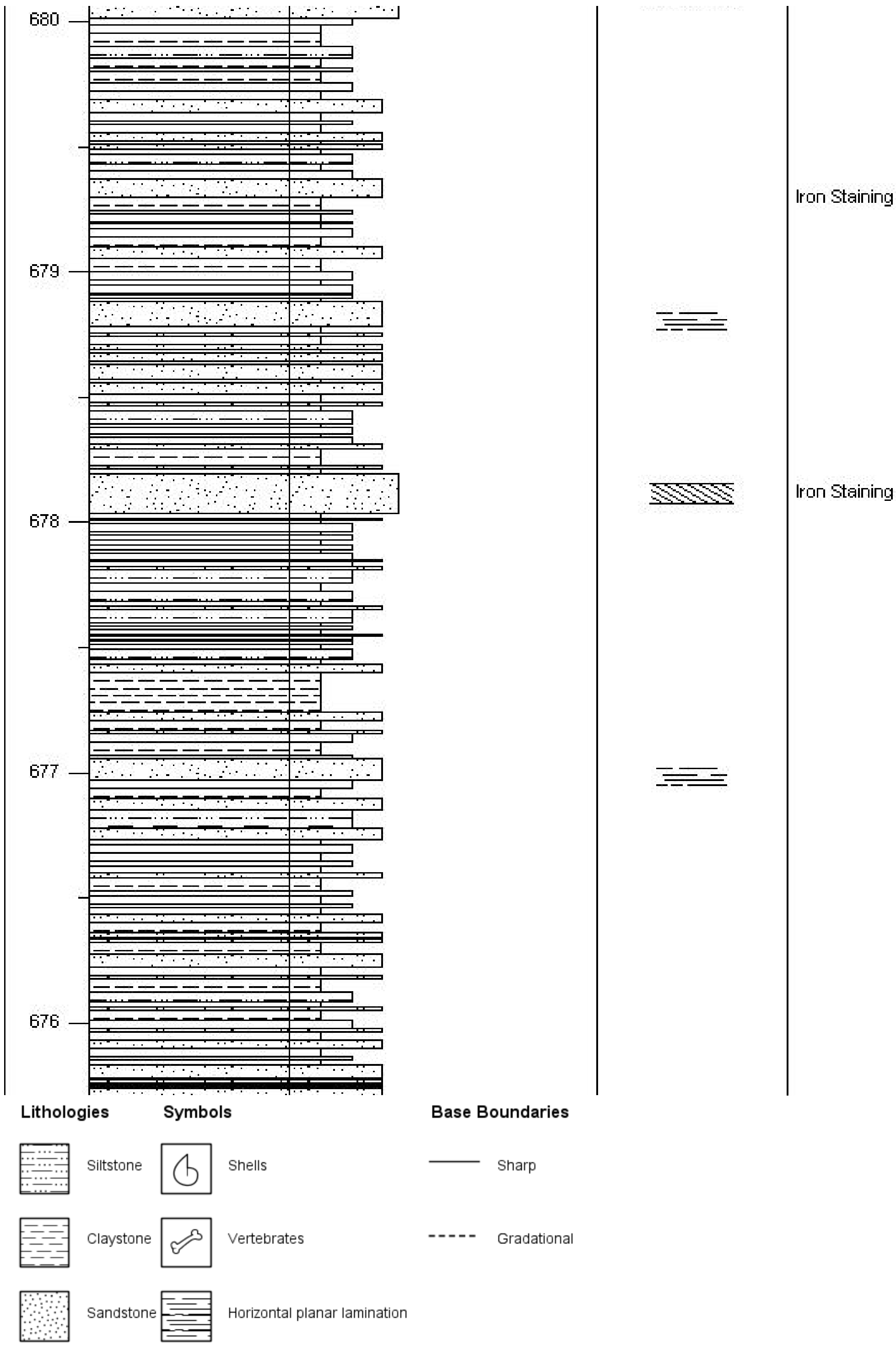
680
Iron Staining
Iron Staining
Iron Staining
Iron Staining


680
679
678
677
676
Iron Staining
Iron Staining
Lithologies
Symbols
Base Boundaries
Siltstone
Shells
Sharp
Claystone
Vertebrates
Gradational
Sandstone
Horizontal planar lamination

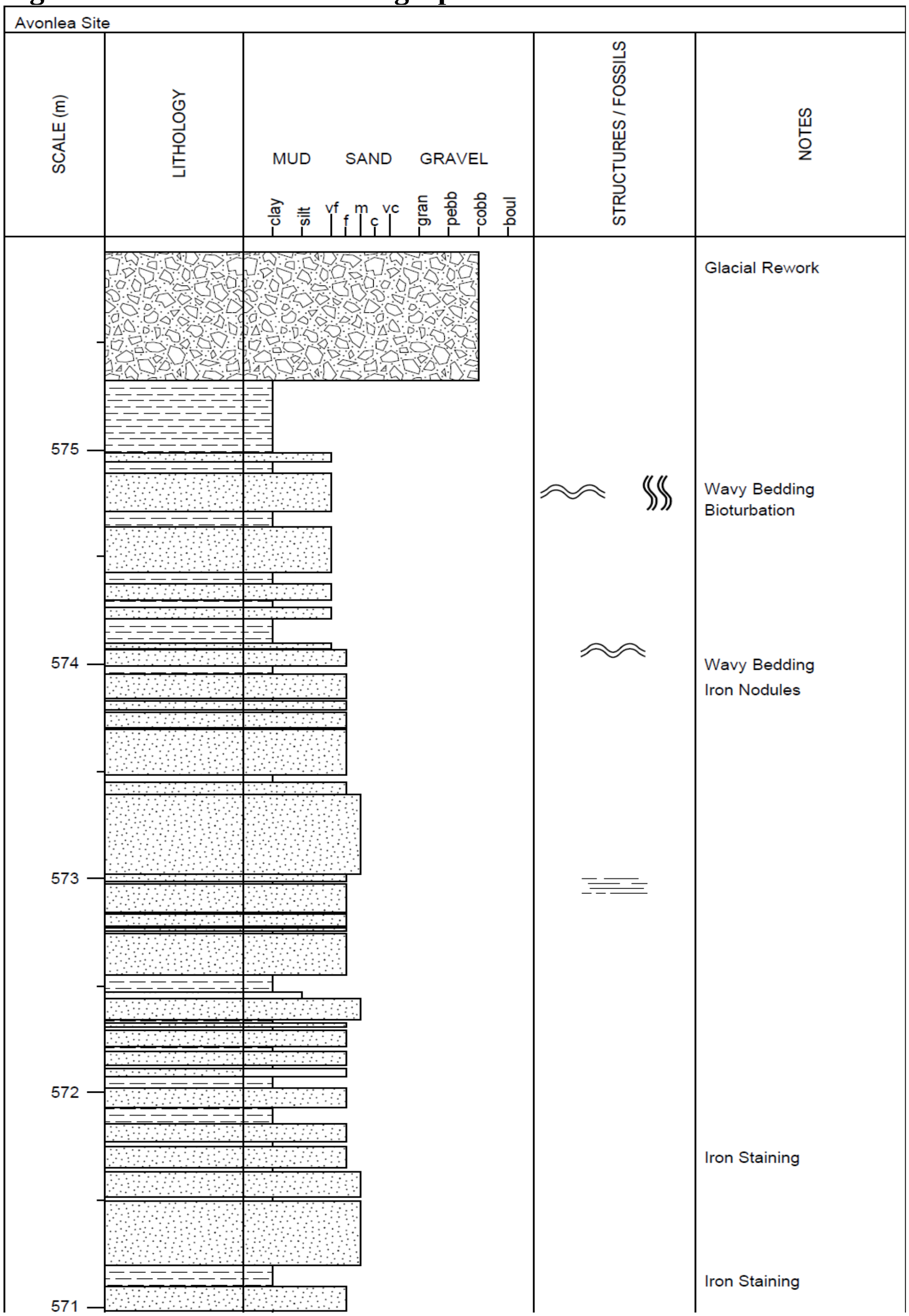
The nature of the sediments shifts rapidly around 683.4 meters asl transitioning into sand dominated layers reaching up to 2.5 meters in thickness. These sand units are separated by 0.5 to 10 cm thick clay and silt layers. Several bed forms are found following the transition including planar laminated sands that are slightly coarser than those farther down the section. These planar sands can be 60 centimeters to 2.4 meters in thickness and may contain carbonaceous laminations. Massive sands up to a meter in thickness are found in the upper section that are primarily fine-grained but do exhibit medium and even coarse-grained textures in a few layers up to 15 cm in thickness. Represented as well above the transition are trough cross bedded sands at 691.35 m, 692.85 m, 696.7 m, 701.95 m, 704.85 m, 707.25 m, 707.99 m, 709.85 m, and 711.25 m asl. The trough cross bedded sands are medium grained and range from 20 cm to 2.5 m in thickness with some layers exhibiting carbonaceous laminations. There is an overall coarsening of the sands in the upper Eastend Formation around 689.25 m asl where the fine-grained sands give way to medium grained ones. The dominance of sand in the upper Eastend Formation diminishes from 699.3m to 702.6 m asl. At this transition elevation there is an increase in the presence and thickness of both clay and silt layers that reach up to 25 cm and 20 cm in thickness for the silts and clays respectively while the sand layers in this zone reach a maximum of 16 cm thick. This zone is reminiscent of part of the section between 675 and 683.4 meters asl with the key difference that trough cross bedding is present in one layer of sands and wavy bedding in another.

Topping off the upper portion of the Eastend Formation in this section at 706 m asl are two coal seams 5 and 3 centimeters thick and separated by a 12cm unit of medium massive sand. Above the coal seams, exposure of the formation disappears under vegetation for about 1 m. Directly above the interval of vegetative cover, the exposure begins again revealing the kaolinized sands of the Whitemud Formation. Similar to the Road Cut Site, the sedimentary features of the Whitemud are almost exactly the same as those seen in the upper Eastend Formation, with the exception of the presence of kaolinite. The Whitemud sediments consist of medium grained sands with planar laminated, trough cross bedded, and tabular cross bedded sedimentary structures. Iron staining and carbonaceous laminations are present within these sands along with the rare clay layer up to 20 centimeters in thickness.

5.2.6 Avonlea Site

The Avonlea Site section (Figure 5.9) consists primarily of sediments of the upper Eastend Formation with only about 0.4m of the lower formation exposed. The lower formation sediments (below 567.4m asl) consisted of iron stained centimeter scale layers of clays, silts, and very fine silty sands that in parts of the valley exhibited soft sediment deformation structures such as flame structures (Figure 5.10). At about 567.40m asl sediments quickly transition to those associated with the upper Eastend Formation with sands becoming dominant.

Figure 5.9: Avonlea Site Stratigraphic Section



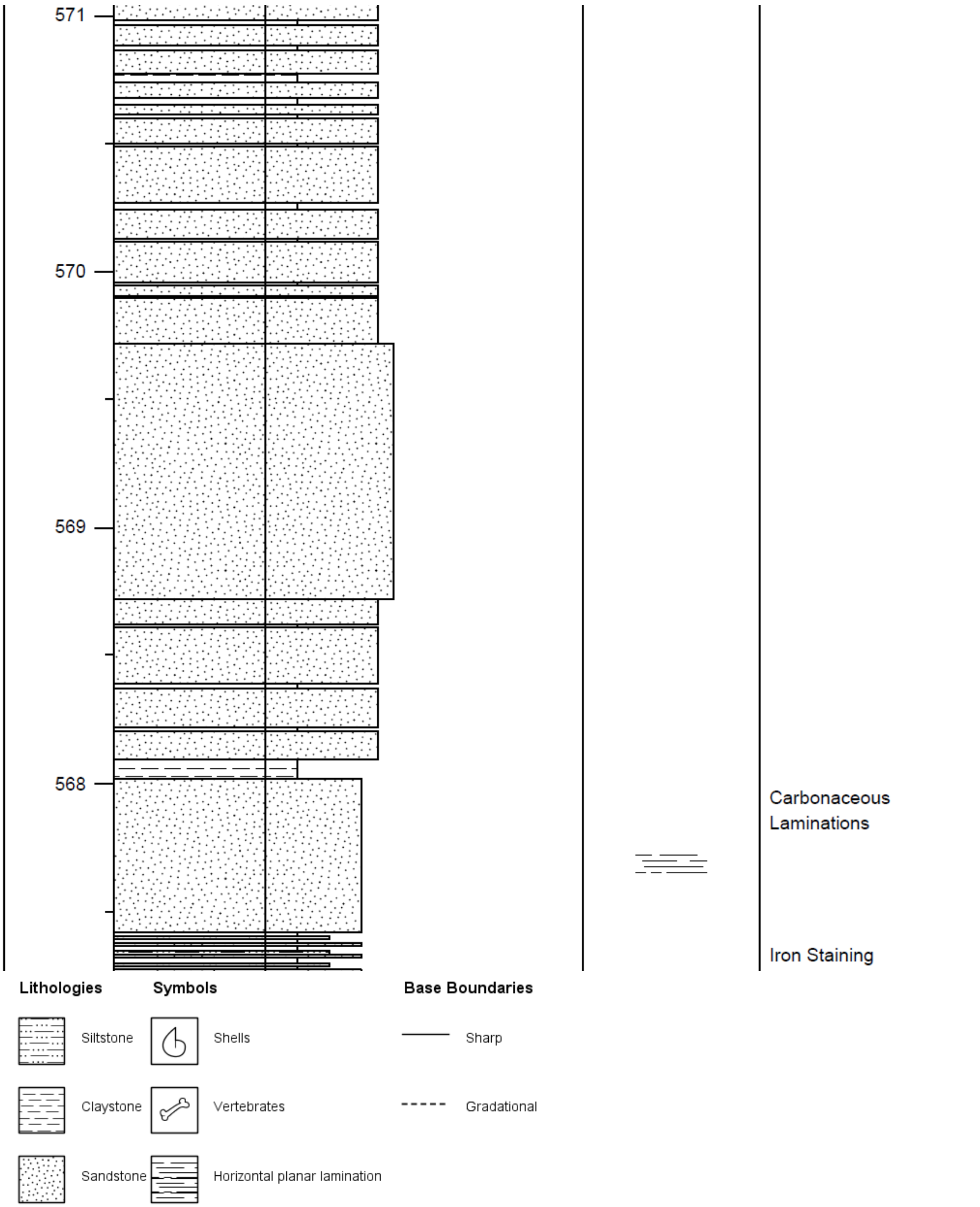

571
570
569
568
Carbonaceous Laminations
Iron Staining
Lithologies
Siltstone
Claystone
Sandstone
Symbols
Shells
Vertebrates
Horizontal planar lamination
Base Boundaries
Sharp
Gradational

Figure 5.10: Flame structure soft sediment deformation in the lower Eastend Formation at the Avonlea Site. (Photo by R. Boulding)

The sands in the upper Eastend Formation are fine-grained with a few layers exhibiting very fine and even medium grained textures. Structurally, the sands appeared mostly massive with a few layers displaying planar laminations at 567.40 and 573 m asl. Wavy bedding was observed within the sands around 574.75 m asl along with apparent bioturbation. In between these thick sand layers are clay/silt layers ranging from barely 1cm up to 30cm in thickness. The clay/silts are very fissile in nature making the identification of structures or bioturbation difficult, Despite this, a layer of wavy bedded clays was identified at 574.20 m asl with some iron nodules 0.5 to 2cm in diameter. The section is topped by a thick layer of glacially reworked Eastend Formation material with sub-rounded to rounded clasts up to 30 cm in diameter incorporated into the formation sands. The area was scouted extensively to find an upper transition into Whitemud Formation sediments with no success.

5.3 Facies Descriptions

Three main facies are identified within the Eastend Formation sections and include planar laminated and massive sands, cross bedded and rippled sands, and interbedded clays and silts.

5.3.1 Planar laminated and massive sands

The first facies is the planar laminated sands (Figure 5.4) which are found in the upper portions of the sections at the Road Cut, Humphrey, Hanson, Claybank, and Avonlea sites and intermittently in the lower portions of the sections. These units range from 0.5 centimeters to 1.8 meters in thickness and are characterized by fine to very fine-grained sands with a pale yellow 5y7/4d colouration. The planar laminations in these sands are 1-5mm in thickness and often interbedded with carbonaceous laminae composed of compressed layers of plant debris. The laminations in some sand units are much fainter than in others. The possibility exists that the laminated sandstones are linked to the massive ones because in the Road Cut, Humphrey, Claybank, and Avonlea sections the laminated sands grade into massive sandstones and vice versa. This could indicate that the laminations are present but not always visible in some sand layers and their presence might not indicate a difference in depositional environment. One possibility is that the lack of structure in certain massive sands could be due to staining which visually obscures the presence of laminations in portions the sections.

In the lower Eastend Formation, the planar laminated sands have a finer grain size than that of the planar laminated sands in the upper parts of the sections representing a coarsening upward sequence in the sections. The planar laminations also signify deposition within a low energy environment whose sheltered nature would allow this type of sedimentary structure to form. The presence of carbonaceous material the laminations suggest a proximity to a continental setting where an existing supply of plant material would exist. The absence of the carbonaceous laminations in some sections could be related to a low supply of plant material in that area or other factors like a low preservation potential for the laminations. A faster sedimentation rate that did not allow for the plant material to accumulate into laminations could also be a plausible explanation for their absence.

5.3.2 Cross-bedded and rippled sands

The second major facies is recognized by the sands featuring low angle trough cross bedding (Figure 5.11) and tabular cross bedding (Figure 5.12). These sand units are found only in the upper Eastend sands and range between 10cm to 2m in thickness with the individual beds being 2 to 5cm in thickness. The base of the trough cross bedded units are erosional in places and devoid of any visible fossil content but exhibit rip-up clasts at the Avonlea and Road Cut Sites (Figure 5.13). The trough cross bedded sands at the Road Cut Site also indicated an east to west (270º) paleoflow direction. Occurrences of tabular cross bedded and rippled sands were documented at the Avonlea Site in addition to the trough cross beds. The tabular cross beds were observed in vertical outcrops conformably on top of planar laminated sands where ripples were documented as exposed horizontal surfaces making them much more visible than in cross section. Despite ripples being found at other sites in the study, the Avonlea Site was the only kilometer-wide scale exposure that allowed for more features to be visible, including the tops of these unidirectional rippled sand surfaces (Figure 5.14). The fine to medium grained pale yellow sands associated with the Upper Eastend Formation also exhibited an apparent increase in mica and feldspar content (Figure 5.15) versus those in the lower formation (Figure 5.16).

Sedimentary structures like cross bedding and unidirectional ripples are most commonly associated with fluvial processes (Visher, 1972). The stratigraphic limitation of these features to the Upper Eastend Formation and their extension upward into the Whitemud Formation allows for the association of their depositional environments. The

Figure 5.11: Facies 2 - Trough cross-bedded sands from Road Cut Site. (Photo by R. Boulding)

Figure 5.12: Facies 2 - Tabular cross-bedded sands from Avonlea Site. (Photo by R. Boulding)

Figure 5.13: Rip-up clasts at base of a trough cross-bedded layer from Road Cut Site. Glove is 10cm across for scale. (Photo by R. Boulding)

Figure 5.14: Surface ripples on an exposed face parallel to bedding from Avonlea Site. (Photo by R. Boulding)

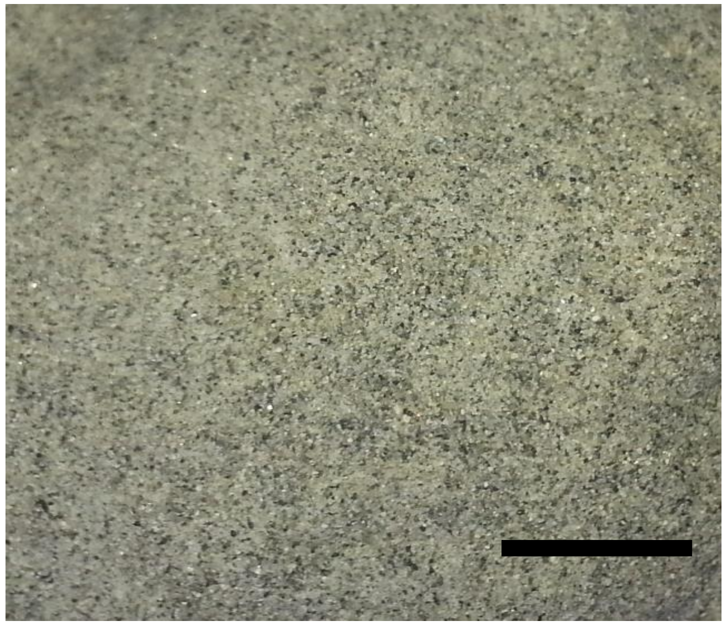


Figure 5.15: Upper Eastend Formation Massive Sands from Claybank Site. Scale bar is 1 cm. (Photo by R. Boulding)

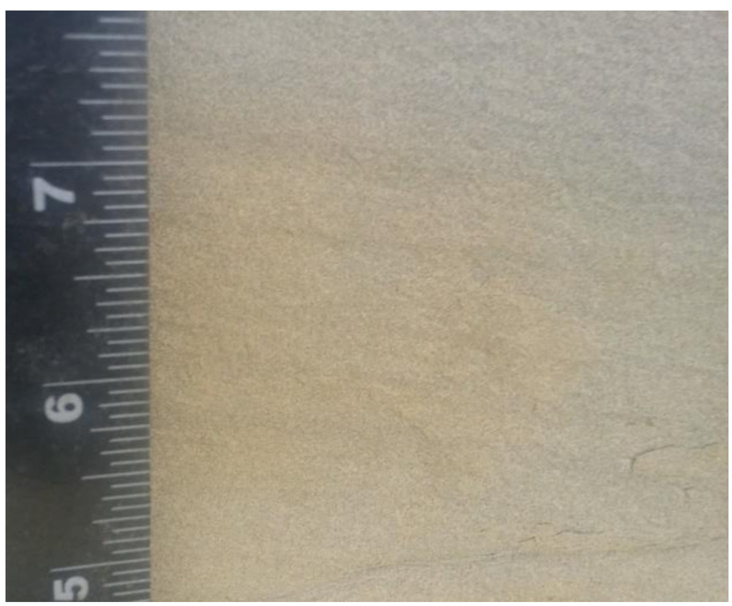


Figure 5.16: Lower Eastend Formation Sands from Road Cut Site with carbonaceous material in layers. (Photo by R. Boulding)

Whitemud Formation represents non-marine deposition in a low lying coastal plain setting (Byers, 1968). Given the marine influence on the sediments of the Lower

Eastend Formation, it is likely that the Upper Eastend Formation characterizes the transition between transitional marine and fully terrestrial fluvial deposits.

5.3.3 Interbedded Silts and Clays

Clays and silts present within the sections are typically grey and brown but can appear yellowish red, 5yr4/6d on the Munsell colour chart, due to iron-oxide staining. In the lower portion of the Eastend Formation these sediments are represented as very well sorted interbedded silts and clays interrupted by fine sand layers. The clay/silt layers are often fissile in nature and show evidence of burrowing that decreases at higher stratigraphic levels in the formation until they are completely absent from the Upper Eastend Formation. The sand layers within the interbedded clay/silts could indicate times of slightly higher energy and increase in occurrence and thickness upwards in the formation results in an overall coarsening. This could indicate an increasing fluvial influence on near shore deposits in a progradational system. These alternating silts, clays, and silty clays can be interpreted as the lowermost bay fill of a lower delta plain deposit. The distributary system advancing farther into the bay would deliver coarser grained clastics accounting for the appearance of the sand layers and their increase in occurrence, coarseness, and thickness farther up the formation.

In the upper portion of the Eastend Formation clay/silt beds occur in two ways, one of which is at the top of massive and cross-bedded sand units that represent fluvial influence (Figure 5.17). These clay/silts vary in thickness from 2-3 cm up to 50 cm and in some layers contain pieces of plant matter suggesting proximity to terrestrial environments. The proximity of these clay/silts to the cross bedded sands suggests they are also related to fluvial transport. The second occurrence of clay/silts in the Upper Eastend Formation denotes them as encased in sand units as clay rip-up clasts noted in Figure 5.13. The clay clasts were documented at the Humphrey Site Section around 998.7m asl. The clasts are 2 to 8mm in size and are dispersed within the bottom 10 cm of the sand layer where it contacts the clay/silt layer below. The dispersal of these clasts randomly through the lower portion of the sand layer suggests previously deposited clays from the layer below were picked up and redeposited among the sands.

An interpretation of the clay layers in the Upper Eastend Formation is overbank and floodplain deposits related to the series of shallow channels. This is based on their stratigraphic position directly overlying or incorporation as rip up clasts in fluvial deposits represented by cross bedded and coarser sands.

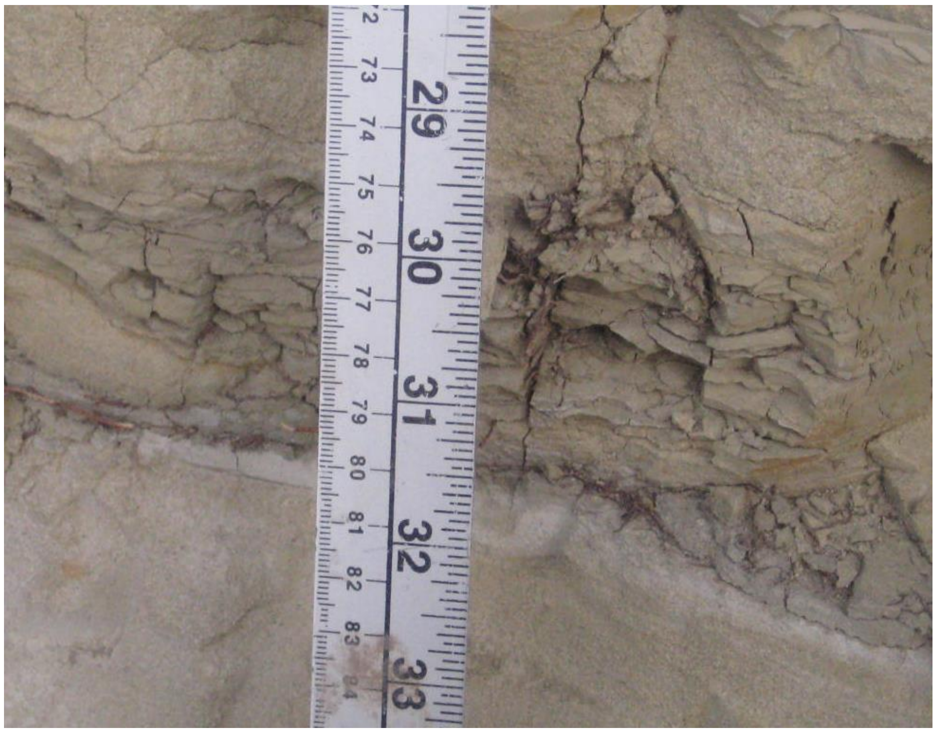


Figure 5.17: A clay and silt layer between Eastend Formation Sands from Road Cut Site. (Photo by R. Boulding)

When beds of the Eastend Formation are exposed to weathering, the bentonitic content is revealed. In the Avonlea Site, differential weathering causes resistant clays to cap off layers of sands producing hoodoos (Figure 5.18) in areas. When subjected to wetting and drying the bentonite in the clays produces a distinctive popcorn-like texture (Figure 5.19) on the surface. These bentonitic clays have a soapy texture and are very slippery when wet and were only encountered on this scale at the Avonlea Site. It should be noted that all the other sites examined were vertical exposures where the Avonlea Site was a much larger region of outcrop allowing for the bentonite in the clays to be openly exposed and experience wetting and drying to form the distinctive popcorn texture.

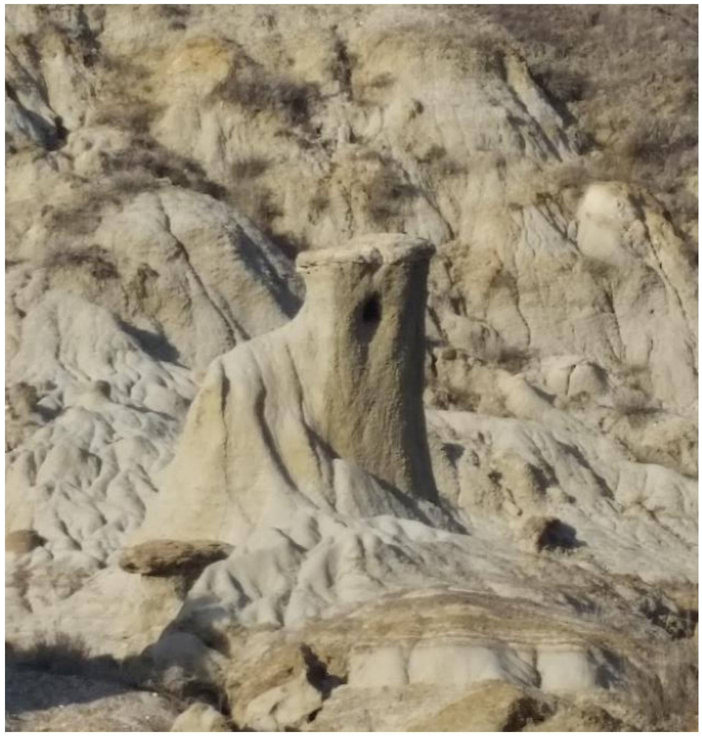


Figure 5.18: A 2m tall hoodoo capped with a sand layer from the Avonlea Site. (Photo by R. Boulding)

Figure 5.19: Popcorn texture due to bentonite content in clay/silt layers from Avonlea Site. (Photo by R. Boulding)

5.4 Interpretation of Geology

The geologic sections depicting the lower Eastend Formation suggest a prograding delta front consisting primarily of bentonite rich clays, silts, and intermittent very fine sands. The observed fine grain and planar laminated nature of the sediments suggest a low energy sheltered environment like that of an estuary. In some cases, underlying layers of soft sediment were subjected to deformation forming convoluted bedding structures like the flame structures observed in the Avonlea Site section from sediment loading. Moving higher in the sections and essentially farther inland as the delta front would have progressed forward, the number and thickness of sand layers started to increase. The shallowing of the depositional environment also marked a decrease in the thickness of the clay and silt layers leading up to the eventual transition between lower and upper Eastend Formation and the onset of the delta plain type environment (Figure 5.20).

The sediments of the lower delta plain environment featured an increase in both sand content and grain size. The planar laminated nature of the sands still persisted, reflecting the low energy of the environment but now with the addition of plant material being incorporated and observed as the carbonaceous laminations. The plant material illustrates the increasing subaerial influences introducing the material into the coastal depositional environment. The ascent into the upper Eastend Formation is marked by an increase in a fluvial influence on the sedimentary depositional structures by the presence of trough and tabular cross bedding in addition to ripples and wavy bedding structures. It

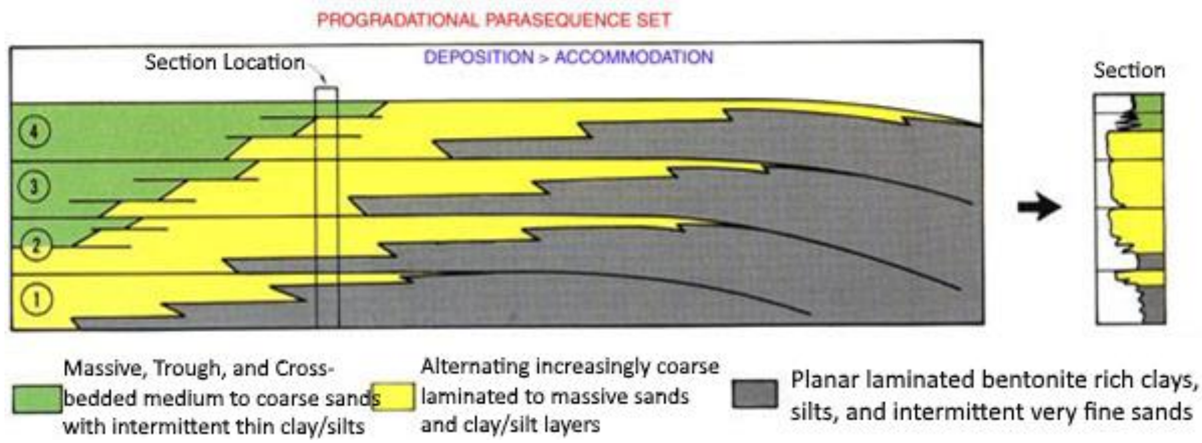


Figure 5.20: Representation of prograding delta front sediments as related to the Eastend Formation stratigraphic sections. (modified from Wagoner et al., 1988).

is likely, that some of these fluvial features like the wide low angle trough cross beds may have overprinted or reworked sediments previously laid down in the delta front environment producing a sharp transition between the lower and upper formation. The fluvial influence increases up section with increasing dominance of medium textured sands. This evidence supports a prograding coastline of the delta plain environment. The clay and silt layers in the upper Eastend Formation are now attributed to overbank and floodplain deposits along with the few thin coal seams attributed to back-swamp environments.

At the top of the Eastend Formation in the Road Cut and Claybank sections the same sediments and sedimentary structures persist upwards into the Whitemud Formation with the only apparent difference being the bright white colour of the formation. Some authors suggest that the white kaolinite is the result of the weathering of the fluvial sediments found in the upper Eastend Formation that are rich in feldspars and micas (Byers, 1968). The time needed for these minerals to weather would mean that the Whitemud sediments would have to be exposed for a lengthy period of time. This suggests that the weathering of the aluminosilicates to produce the diagnostic kaolinite and white color of the Whitemud Formation could be the result of pedological processes over a long period of subaerial exposure. This would mean that kaolinite in the Whitemud is a secondary post-depositional weathering feature and does not denote a change in sedimentation or the sedimentary environment from that of the upper Eastend Formation. This in turn suggests that the Whitemud Formation is not a formation but rather a horizon of altered Eastend Formation material. The idea of the Whitemud

Formation being assigned to the formation below has been suggested in studies of the Horseshoe Canyon Formation in Alberta, an analogue of the Eastend Formation in Saskatchewan. In this work, the Whitemud is interpreted as a sub-unconformity paleosol alteration horizon rather than a formation (Hamblin, 2004).

Chapter 6: Paleontological Results and Discussion

6.1 Introduction

This chapter examines the paleontological material collected over the course of this study defined by systematic paleontology (Table 6.1). The chapter starts with the invertebrate specimens in ascending taxonomic order of scaphopods, gastropods, and bivalves (Table 6.2). The second group of specimens are the more complex vertebrates ordered by taxonomic order as sharks, fish, turtles, and mosasaur material (Table 6.3). The plant material group is third and has been kept separate from the other specimens which includes amber and fossilized wood samples. Ichnologic trace fossils have been identified during this study with several forms of burrows. Most of the fossils were excavated at the Humphrey Site quarry with other specimens recovered from surface picking at the Road Cut Site and sieving of sediment from the Vansandt Site. The fossils provide an additional line of evidence to the sedimentological and environmental conditions at the time of deposition. The taxonomic classifications are provided for the fossil specimens along with information about their geological and environmental significance.

Table 6.1: **Summary Table of Fauna and Flora Identified in Study**		
Taxonomic Classification	No. of Specimens	Study Sites
Kingdom Plantae………………………………………………	7	H, V
Kingdom Animalia		
Phylum MOLLUSCA		
Class SCAPHOPODA…………………………………….	9	H
Class GASTROPODA…………………………………….	2	H
Class BIVALVIA		
Order VENEROIDA		
Family CARDIIDAE		
Genus *LAEVICARDIUM*……………………….	2	H
Order CARDIIDA		
Family TANCREDIIDAE		
Genus *TANCREDIA*…………………………….	3	H
Phylum CHORDATA		
Class CHONDRICHTHYES		
Subclass ELASMOBRANCHII		
Cohort EUSELACHII		
Subcohort NEOSELACHII		

Order LAMNIFORMES……………………… Family ODONTASPIDIDAE	4	H, RC
Genus *CARCHARIAS* *Carcharias, cf. C. samhammeri*………	3	H, RC
Class ACTINOPTERYGII Infraclass TELEOSTEI…………………………………	10	H, RC, V
Class REPTILIA Order TESTUDINES Suborder CRYPTODIRA Family CHELYDRIDAE………………………...	1	H
Superorder LEPIDOSAURIA Order SQUAMATA Clade PLATYNOTA Superfamily MOSASAUROIDEA……………	2	H

6.2 Invertebrate Paleontology

Table 6.2:
Summary Table of Invertebrate Specimens Identified

Taxonomic Classification	Specimens	
Kingdom Animalia		
Phylum MOLLUSCA		
Class SCAPHOPODA………………………………	RSM P3171.3	RSM P3171.39
	RSM P3171.18	RSM P3171.44
	RSM P3171.28	RSM P3172.3
	RSM P3171.29	RSM P3172.4
	RSM P3171.30	
Class GASTROPODA……………………………...	RSM P3171.11	RSM P3171.27
Class BIVALVIA		
Order VENEROIDA		
Family CARDIIDAE		
Genus *Laevicardium*………………………..	RSM P3171.36	RSM P3171.31
Order CARDIIDA		
Family TANCREDIIDAE		
Genus *Tancredia*………………………….	RSM P3171.34	RSM P3171.21
	RSM P3171.35	

SYSTEMATIC PALEONTOLOGY

Class SCAPHOPODA (Bronn, 1862)

gen. et sp. indet.

Figures 6.1-6.9

Referred specimens: RSM P3171.3, portion of a scaphopod; RSM P3171.18, scaphopod fragment; RSM P3171.28, scaphopod fragment; RSM P3171.29, scaphopod fragment; RSM P3171.30, scaphopod fragment; RSM P3171.39, portion of a scaphopod; RSM P3171.44, scaphopod fragment; RSM P3172.3, scaphopod fragment; RSM P3172.4, scaphopod fragment.

Description and Discussion

The shell of scaphopods is a conical tube, curved and open at both ends contributing to their common name of tuck shells. Ornamentation, when present, consists of longitudinal or, in a few species, annular ribbing (Reynolds and Steiner, 2008). Scaphopods have not been identified previously in the literature of Late Cretaceous deposits of Saskatchewan or Alberta. This appears to be their first documentation in these deposits.

All scaphopod samples were collected at the Humphrey site from various jackets listed in Table 6.2 and in the figure captions. The exception is two scaphopods RSM P3172.3, and RSM P3172.4, from the Road Cut Site.

RSM P3171.3 (Figure 6.1), a partial scaphopod shell, that measures 2 cm in length and 3 mm in cross section. The specimen has fine longitudinal striations and infilled with a fine silty clay different from the coarser medium sands from which the fossil was excavated. The small fragment of scaphopod shell, RSM P3171.18 (Figure 6.2), measured 2 mm in length by 1.5 mm in cross section with no apparent longitudinal striations. Scaphopod fragment RSM P3171.28 (Figure 6.3) is 3 mm in length by 1.5 mm in cross section and has well defined striations. RSM P3171.29 (Figure 6.4) also from the Humphrey Site quarry. measures 3 mm in length by 1.5 mm in cross section and exhibits faint striations. RSM P3171.30 (Figure 6.5) is a scaphopod fragment that measures 4 mm in length by 1.5 mm in cross section with no visible striations. The scaphopod RSM P3171.39 (Figure 6.6) measures 4 cm in length by 3 mm in cross section and tapers towards one end. This specimen is partially eroded and crushed but does exhibit longitudinal striations on intact portions. This portion of scaphopod RSM P3171.44 (Figure 6.7) measures 8 mm in length by 1.5 mm in cross section and has no discernable longitudinal striations.

Figure 6.1: RSM P3171.3: Partial scaphopod shell from jacket RB-10-001 with very faint striations and a clay infill. Scale in mm. (Photo by R. Boulding)

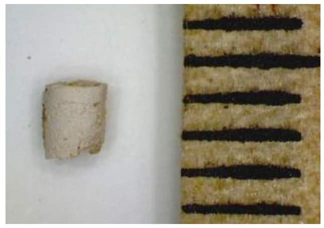


Figure 6.2: RSM P3171.18: Scaphopod fragment from jacket RB-10-002. Scale in mm. (Photo by R. Boulding)

Figure 6.3: RSM P3171.28: Scaphopod fragment with defined striations from jacket RB-10-004. Scale in mm. (Photo by R. Boulding)

Figure 6.4: RSM P3171.29: Scaphopod fragment with faint striations from jacket RB-10-004. Scale in mm. (Photo by R. Boulding)

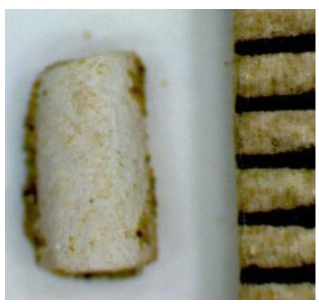


Figure 6.5: RSM P3171.30: Scaphopod fragment from jacket RB-10-004. Scale in mm. (Photo by R. Boulding)

Figure 6.6: RSM P3171.39: Partial scaphopod from jacket RB-10-005 with visible longitudinal striations. Scale in mm. (Photo by R. Boulding)

Figure 6.7: RSM P3171.44: Partial scaphopod from jacket RB-10-007. Scale in mm. (Photo by R. Boulding)

Both RSM P3172.3 (Figure 6.8) and RSM P3172.4 (Figure 6.9) were found among the surface material of the Road Cut Site. RSM P3172.3 (Figure 6.8) is a scaphopod shell fragment 6mm in length and 2mm in cross section with faint longitudinal striations. The second scaphopod specimen RSM P3172.4 (Figure 6.9) measured 6 mm in length and 3 mm in cross section. This fragment appears to have some very faint longitudinal striations.

The classification of fossil scaphopods is difficult since the radula, shell, and foot are required when subdividing the taxa. The fact that soft tissue morphological features are used in the identification of the sub-taxa means that these specimens cannot be classified beyond their tusk-shaped class.

Commonly known as tusk shells, modern scaphopods are found in marine environments, buried in substrates of soft sediment from shallow depths down to 2000 m. Tusk shells appear in the fossil record in the Mississippian period and still exist today (Reynolds and Steiner, 2008).

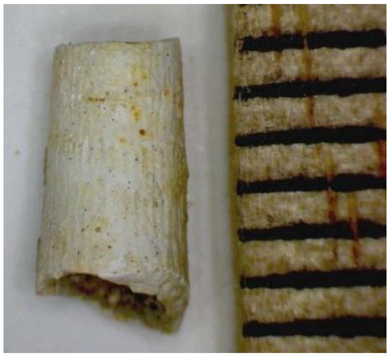


Figure 6.8: RSM P3172.3: Scaphopod fragment with faint longitudinal striations from Road Cut Site. Scale in mm. (Photo by R. Boulding)

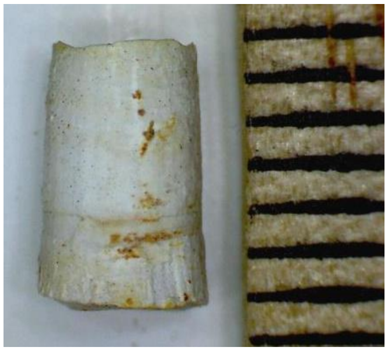


Figure 6.9: RSM P3172.4: Scaphopod fragment with very faint longitudinal striations from Road Cut Site. Scale in mm. (Photo by R. Boulding)

Class GASTROPODA (Cuvier, 1795)

gen. et sp. indet.

Figures 6.10-6.11

Referred specimens: RSM P3171.11, gastropod shell fragment; RSM P3171.27, gastropod shell fragment.

Description and Discussion

Gastropods are distinguished from all other molluscs by undergoing torsion during development. The adult body is generally covered with a single shell, which is often coiled and torted but may also be conical or even tubular or bivalved (Aktipis et al., 2008). Gastropods have previously been identified in the Eastend Formation (Russell, 1933) in the vicinity of Eastend, Saskatchewan. Gastropod species have also been identified in the underlying Bearpaw Formation and Belly River Group in Alberta (Johnston and Hendy, 2005).

RSM P3171.11 (Figure 6.10) was excavated from the Humphrey Site quarry in jacket RB-10-001 and RSM P3171.27 (Figure 6.11) from the same site, but jacket RB-10-004. Both specimens are fragments of gastropod shells with only the top whorl of the shell remaining. The whorl is the only visible diagnostic feature present with these specimens, but it is still enough to place them in class Gastropoda. RSM P3171.11 exhibits a raised almost conical upper whorl tapering towards the apex where RSM P3171.27 has a flat whorl that is smooth like the rest of the fragment's surface. RSM P3171.11 measures 5 mm in diameter and the upper apex is 1 mm in diameter (Figure 6.25). RSM P3171.27 consists of three upper whorls, the largest of which is 10 mm in diameter and an apex measuring 1.5 mm in diameter (Figure 6.26).

Gastropods exist from the Late Cambrian to the present and found in a large variety of marine and terrestrial environments. The fragile and incomplete condition of gastropod shells from Eastend make it impossible to classify them further and thus nothing more concise can be stated about their environment.

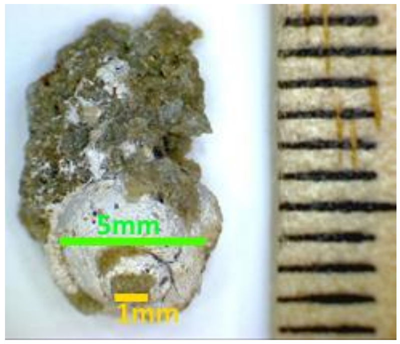


Figure 6.10: RSM P3171.11: Fragment of gastropod shell with only the apex and upper whorls present. The specimen was found in jacket RB-10-001 from the Humphrey Site quarry. Scale in mm. (Photo by R. Boulding)

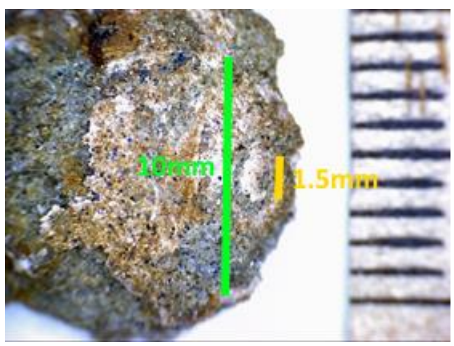


Figure 6.11: RSM P3171.27: Fragment of gastropod shell with only the apex and upper whorls present. The specimen was found in jacket RB-10-004 from the Humphrey Site quarry. Scale in mm. (Photo by R. Boulding)

Class BIVALVIA (Linnaeus, 1758)

Subclass HETERODONTA (Bieler et al., 2010)

Order VENEROIDA (Bieler et al., 2010)

Family CARDIIDAE (Lamarck, 1809)

Laevicardium (Swainson, 1840)

sp. indet.

Figures 6.12-6.13

Referred specimens: RSM P3171.36, almost complete bivalve; RSM P3171.31, partial bivalve.

Description and Discussion

A total of 24 bivalve specimens were collected during this study. The specimens ranged in preservation, from moderately preserved valves to loosely related accumulations of shell fragments. Though the fragments are able to give an indication of the number of bivalves in the fossil community, they lack any major features for identification and cannot be identified further. For the purposes of narrowing down sedimentary and depositional environments in this thesis, only the bivalves able to be identified will be considered.

Five moderately complete bivalves had enough visible characteristics to warrant further classification. The fragility and orientation of the specimens with their commissure lines parallel to bedding greatly limited the examinable surface of the specimens to the uppermost exposed valve. This orientation of the bivalves suggests they had been moved, however this transportation must not have been very far considering the valves are only about 2 mm in thickness and would abrade easily. The orientation and closed nature of the valves restricted the examination of the hinge zone, teeth, and internal features.

Bivalves are characterized as having a bilateral symmetry, a laterally compressed body enclosed in a bivalved shell that articulates dorsally via a hinge or ligament (Giribet, 2008). In the work of Loris Russell, the same bivalves were identified from the Eastend Formation in Saskatchewan as were found in the Hoseshoe Canyon Formation of Alberta (Russell, 1943).

Specimens RSM P3171.36 (Figure 6.12) and RSM P3171.31 (Figure 6.13) were excavated from the Humphrey Site quarry in jacket RB-10-005. Both exhibit smooth rounded valves with a bilateral symmetry. The valves have a distinctive heart shape with an orbiculate outline at the ventral end and tapering slightly towards the dorsal end. Faint growth lines are visible near the edges of the specimens and closer towards the beak that occupies an equilateral position. They measure around 5 cm in shell length (anterior to posterior), 4.5 cm in shell height (dorsal to ventral) and 0.75 cm in width.

The identification of these bivalves is based on valve bilateral symmetry and heart shape which places them in the family Cardiidae. When those features are coupled with the smooth rounded surface of the valves it aligns them into the genus *Laevicardium* which is the only genus in the family Cardiidae with smooth valves (Russell, 1933). In the 1930's, Loris Russell identified a new species, *Laevicardium holmesi* based on tooth and socket morphology. Unfortunately, these structures are not visible in the specimens collected in this study.

Known commonly as modern “egg cockles,” living bivalves of genus *Laevicardium* are known to be shallowly infaunal or epifaunal filter-feeding bivalves. They inhabit sandy, sheltered marine beaches throughout the world (Pechenik, 2005).

These bivalve specimens were infilled with a fine clay/silt material that differed from the sandy matrix that surrounded them. The clay silt appears to be similar to the stratigraphic layer directly below the sands containing the fossil accumulation. This evidence suggests that these bivalves, *Laevicardium* likely died and were infilled with the clay silt prior to being exhumed, transported by a later marine event and deposited in the sands.

Figure 6.12: RSM P3171.36: Bivalve of genus *Laevicardium* found in jacket RB-10-005 from the Humphrey Site quarry. (Photo by R. Boulding)

Figure 6.13: RSM P3171.31: Bivalve of genus *Laevicardium* found in jacket RB-10-005 from the Humphrey Site quarry. Scale in cm. (Photo by R. Boulding)

Class BIVALVIA (Linnaeus, 1758)

Order CARDIIDA (Ferussac, 1822)

Family TANCREDIIDAE (Meek, 1864)

Tancredia (Lycett, 1850)

sp. indet.

Figures 6.14-6.15

Referred specimens: RSM P3171.34, bivalve; RSM P3171.35, bivalve; RSM P3171.21, bivalve.

Description and Discussion

All three of the bivalve specimens came from the Humphrey Site quarry. RSM P3171.34 and RSM P3171.35 (Figure 6.14) were found in jacket RB-10-005 RSM P3171.21 (Figure 6.15) was discovered in jacket RB-10-004. The bivalves are ovate to subtrigonal in outline with a moderate protuberance of the umbo. The posterior of the valve is more oval in shape where the anterior is slightly rostrate. The valves are smooth with no surface ornamentation but do exhibit growth lines. The valves measure 5 cm in shell length (anterior to posterior) and 3.5 cm in shell height (dorsal to ventral) by 0.75 cm in width. The shells are thick and measure about 2 mm in cross-section.

The narrowing of the valve towards the anterior margin and lack of surface characteristics with the exception of growth lines, suggests the genus *Tancredia*. Russel (1943) used the tooth and socket structure of the bivalves to classify them as *Tancredia americana cupressensis*. The lack of access to these distinguishing parts of the bivalves due to their orientation and their fragility makes further classification to species infeasible.

Skogstrom (1958) went into detail about genus *Tancredia* and their indication of warm marine environments. Paleo-temperatures can be established by the oxygen isotopes in the calcium carbonate of the shell to indicate uniform temperatures of about 15°-16° C. These bivalves were warm water, shallow burrowers that occupied flat sandy bottoms devoid of extreme conditions (Skogstrom, 1958).

All the valves examined of *Tancredia* were found to contain medium grained sand sediments that matched the matrix surrounding the outside of the shell. This suggests that the bivalves likely did not undergo transport after their death or were only transported a short distance. In addition, the bivalves could feasibly have lived in environmental conditions similar to the depositional environment of the sediments surrounding them and if transport of these valves had occurred, it would not have been over a long distance.

Figure 6.14: RSM P3171.34 and RSM P3171.35: Bivalve of genus *Tancredia* found in jacket RB-10-005 from the Humphrey Site quarry. Scale in cm. (Photo by R. Boulding)

Figure 6.15: RSM P3171.21: Bivalve of genus *Tancredia* found in jacket RB-10-004 from the Humphrey Site quarry. Scale in cm. (Photo by R. Boulding)

6.3 Vertebrate Paleontology

Table 6.3: Summary Table of Vertebrate Specimens Identified		
Taxonomic Classification	Specimens	
Kingdom Animalia		
Phylum CHORDATA		
Class CHONDRICHTHYES		
Subclass ELASMOBRANCHII		
Cohort EUSELACHII		
Subcohort NEOSELACHII		
Order LAMNIFORMES…………………..	RSM P3171.12	RSM P3171.46
	RSM P3171.45	RSM P3171.47
Family ODONTASPIDIDAE		
Genus *Carcharias*		
Carcharias, cf. C. samhammeri…	RSM P3171.40	RSM 3172.5
	RSM P3171.20	
Class ACTINOPTERYGII		
Infraclass TELEOSTEI……………………………..	RSM P3171.7	RSM P3171.17
	RSM P3171.8	RSM P3171.42
	RSM P3171.9	RSM P3172.2
	Temporary	Catalogue #s:

	13-1-3-002	13-1-1-002
Class REPTILIA	13-2-4-001	13-2-4-003
Order TESTUDINES		
Suborder CRYPTODIRA		
Family CHELYDRIDAE…………………….....		
Superorder LEPIDOSAURIA	RSM P3171.13	
Order SQUAMATA		
Clade PLATYNOTA		
Superfamily MOSASAUROIDEA……….....		
	RSM P3171.41	RSM P3171.10

SYSTEMATIC PALEONTOLOGY

Class CHONDRICHTHYES (Huxley, 1880)

Subclass ELASMOBRANCHII (Bonaparte, 1838)

Cohort EUSELACHII (Hay, 1902)

Subcohort NEOSELACHII (Compagno, 1977)

Order LAMNIFORMES (Berg, 1958)

Family ODONTASPIDIDAE (Muller and Henle, 1837)

Carcharias (Rafinesque, 1810)

Carcharias, cf. C. samhammeri (Cappetta and Case, 1975)

(Figures 6.16-6.18)

Referred specimens: RSM P3171.40, tooth; RSM P3171.20, tooth; RSM 3172.5, tooth.

Description and Discussion

Teeth of selachians consist of an enameloid covered crown and a well-developed basal root. In sharks the crown generally forms a sharp point known as the cusp with labial (external) and lingual (internal) faces limited by cutting edges. The cutting edges are normally sharp but may be blunt or can disappear on some anterior teeth. The enameloid may be smooth or folded on either face of the crown or both. On each side of the cusp there are often one to several pairs of varying developed lateral cusplets that can be smooth or folded. The root may have long and well separated branches or lobes with a distinct centro-lingual protuberance with a more or less pronounced axial groove or it may be massive with a flat basal face of cordiform outline. The base of the labial face of the crown can overhang the root by a labial bulge that sometimes bears short vertical folds (Cappetta, 1987).

Shark teeth have been documented in Late Cretaceous formations that are analogs to the marginal marine deposits of the Eastend Formation. The identified specimens were found in micro vertebrate assemblages of the Horseshoe Canyon Formation in Alberta (Lavigne, 1999) and the Fox Hills Formation in North Dakota (Feldman and Palubniak, 1975).

Specimen RSM P3171.40 (Figure 6.16) was found in Jacket RB-10-005, and. RSM P3171.20, (Figure 6.17) in jacket RB-103 at the Humphrey Site quarry. Sample (RSM 3172.5, Figure 6.18) was the only shark tooth found in the surface material of the Road Cut Site and not in situ.

RSM P3171.40 (Figure 6.16) is a complete shark tooth with a definite asymmetry. The crown of the tooth has a broad base tapering in the distal direction toward a wide and flattened cusp. The crown face is smooth on both sides with some faint longitudinal ridges (green arrow). There is a partial dental band on the specimen (yellow arrow), but the crown is surrounded by a pair of triangular cusplets (red arrows) that are separate and unattached from the crown. The base of the root has a U-shaped arch between the two root lobes with a short nutrient groove (purple arrow) at the center of the root. It measures 10 mm from the outside of the root lobes and 12 mm from the base of the root lobes to the tip of the crown.

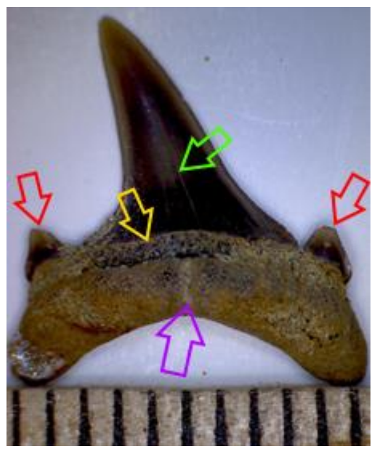


Figure 6.16: RSM P3171.40 (labial view): Shark tooth with faint longitudinal ridges (green arrow), a partial dental band (yellow arrow), a pair of triangular cusplets (red arrows), and a prominent nutrient groove (purple arrow). Scale in mm. (Photo by R. Boulding)

Another shark tooth RSM P3171.20, (Figure 6.17) is almost a complete tooth with a pronounced asymmetry. Broad based crown with a wide, flattened, cusp. The crown face is smooth on both sides with a few, slightly visible, longitudinal ridges (green arrow). The base of the crown has a well-defined dental band (yellow arrow). The mesial portion of the root is absent but on the distal side is a triangular shaped cusplet (red arrow) that is not attached to the crown along a continuous surface. The absence of one of the root lobes makes it difficult to determine the shape of the arch between them and further the identification. RSM 3171.20 measures 9 mm from the tip of the existing root lobe to the front of the tooth where the other lobe is absent. From the base of the root lobe to the tip of the crown measures 10 mm.

Sample (RSM 3172.5, Figure 6.18) has a complete crown and a partially complete root. It measures 7 mm from the tip of the existing root lobe at the front of the tooth to behind the crown where the other lobe is absent. From the base of the root lobe to the tip of the crown is 8 mm. The tooth has a pronounced asymmetry with a broad-based crown and a wide, flattened, cusp. The crown face is smooth on both sides with no well-defined longitudinal faces or a dental band. The distal portion of the root is absent, but on the mesial side is a triangular shaped cusplet. The base of the root appears flat but without both root lobes the exact root morphology can only be inferred.

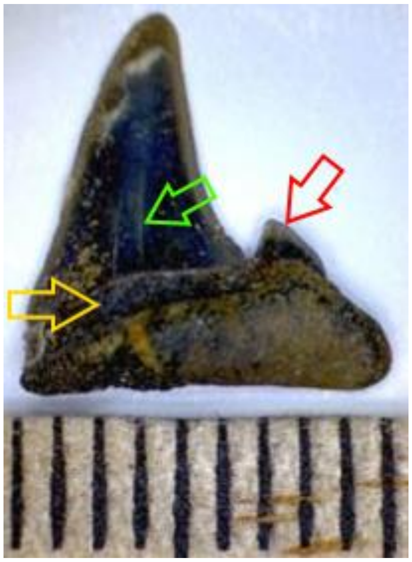


Figure 6.17: RSM P3171.20 (labial view): Shark took with mesial portion of root missing. The specimen has faint longitudinal ridges (green arrow), a visible dental band (yellow arrow), and one triangular distal cusplet present (red arrow). Scale in mm. (Photo by R. Boulding)

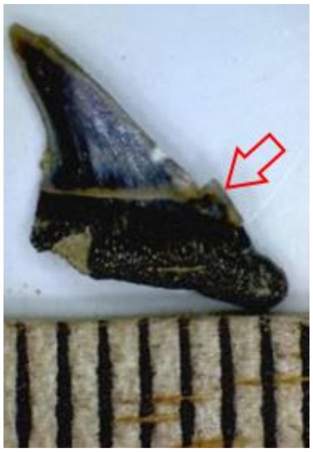


Figure 6.18: RSM P3172.5 (labial view): Shark tooth with distal portion of root missing and a single triangular mesial cusplet (red arrow). Scale in mm. (Photo by R. Boulding)

The dentition of *Carcharias* is known for roots with well-separated lobes and a sharp nutrient groove. The lateral teeth seen in these specimens, are shorter, broader and more blade-like. The cutting-edge of the crown leads down to one or two pairs of lateral cusplets depending on the species. The specimens are identified as *Carcharias samhammeri* due to their smooth enamel, widening of the tooth base, and a single pair of lateral cusplets. Their roots are bilobate and always possess a relatively deep nutrient groove. The specimens do not identify with *Carcharias holmdelensis* or *Carcharias amonesis* due to a lack of two pairs of lateral denticles. Also, *Carcharias teuiplactus* can be ruled out due to the lack of irregular, discontinuous creases in the crown almost reaching the apex (Cappetta and Case, 1975).

6.2.4.2 Implications

Carcharias, known as sand tiger sharks, are found from the Lower Cretaceous to present. Living sand tiger sharks are reported in temperate to tropical waters of the Atlantic and Indo-West Pacific shelf from the surf to depths of 191 m.

Class CHONDRICHTHYES (Huxley, 1880)
Subclass ELASMOBRANCHII (Bonaparte, 1838)
Cohort EUSELACHII (Hay, 1902)
Subcohort NEOSELACHII (Compagno, 1977)
Order LAMNIFORMES (Berg, 1958)
gen. et sp. indet.

Figures 6.19-6.22

Referred specimens: RSM P3171.12, tooth crown fragment; RSM P3171.45, tooth missing most of root; RSM P3171.46, tooth missing most of root; RSM P3171.47, tooth missing most of root.

Description and Discussion

The best identification that can be made for these specimens, given their state of preservation, is to place them under the order Lamniformes. Admittedly, with more visible characteristics these specimens potentially could all represent separate taxa or minimally one. Teeth of this order are generally slender with sharp cusps that taper towards a point at the apex of the crown. Roots of teeth under this order tend to be arched, but given that most or all of the roots are missing from these specimens this feature cannot be applied (Nelson, 2006). If the roots and any evidence of cusplets or denticles survived then further identifications could be made.

The following four shark tooth fragments were collected at the Humphrey Site RSM 3171.12 (Figure 6.19) in jacket RB-10-001, RSM P3171.45 (Figure 6.20) and RSM P3171.46, (Figure 6.21) in jacket RB-10-007. RSM P3171.47 (Figure 6.22) was discovered in the surface material of the Humphrey Site just downhill from the quarry site.

RSM 3171.12 (Figure 6.19) consists of a portion of the crown of a tooth with no root present. The crown appears to be symmetrical based on how much of the specimen is present. The crown face is flat and broadened with smooth sides. Approaching the base of the crown is a series of prominent longitudinal ridges (green arrow). The absence of the root of the tooth greatly impedes its identification.

Figure 6.19: RSM P3171.12 (labial view): Crown fragment of shark tooth with longitudinal ridges present near the base of the crown (green arrow). (Photo by R. Boulding)

RSM P3171.45 (Figure 6.20) consists of the crown and part of the root of a tooth that was found in jacket RB-10-007 from the Humphrey Site quarry. The crown is symmetrical, tapering from base to cusp. The cusp of the tooth is flat and narrow with smooth crown faces and faint longitudinal ridges (green arrow). The root of the tooth is not complete, greatly limiting the identification of this specimen.

Another shark tooth fragment from the Humphrey Site quarry RSM P3171.46 (Figure 6.21) consists of the crown and part of the root of a tooth. The crown is mostly symmetrical, bulging more on one side. The cusp of the tooth is flat and narrow with smooth crown faces and no longitudinal ridges or a dental band. The incomplete root and a lack of any other indicative features makes further identification of this specimen difficult.

Specimen RSM P3171.47 consists of the crown and part of the root of a tooth. The crown is symmetrical with a flat, broad cusp. The crown faces are smooth with faint longitudinal ridges (green arrow) and a partial dental band (yellow arrow). Further identification cannot be accomplished without the entire root of the tooth.

Figure 6.20: RSM P3171.45 (labial view): Crown and partial root of a shark tooth. Some faint longitudinal ridges are visible running almost the length of the crown (green arrow). (Photo by R. Boulding)

Figure 6.21: RSM P3171.46 (labial view): Crown and partial root of shark tooth. (Photo by R. Boulding)

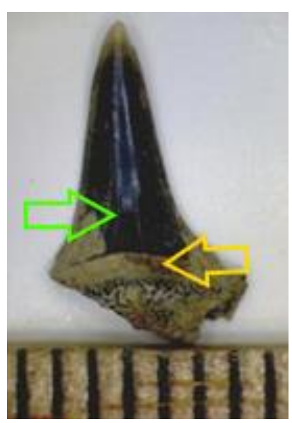


Figure 6.22: RSM P3171.47 (labial view): Crown and partial root of shark tooth with faint longitudinal ridges (green arrow) and a partial dental band visible (yellow arrow). (Photo by R. Boulding)

Superclass OSTEICHTHYES (Huxley, 1880)

Class ACTINOPTERYGII (Klein, 1885)

Infraclass TELEOSTEI (Müller, 1845)

gen. et sp. indet.

Figures 6.23-6.32

Referred specimens: RSM P3171.7, vertebra; RSM P3171.8, incomplete vertebra; RSM P3171.9, vertebra; RSM P3171.17, fragments of vertebra; RSM P3171.42, vertebra fragment; RSM P3172.2 vertebra fragment; 13-1-3-002 (temporary catalogue number), vertebra fragment; 13-2-4-001 (temporary catalogue number), vertebra; 13-1-1-002 (temporary catalogue number), dentary; 13-2-4-003 (temporary catalogue number), tooth?

Description and Discussion

Isolated elements from fish remains can be identified only at high taxonomic levels with the entire specimen often needed for more accurate classifications. Distinctive elements such as dentaries and centra, when in large sample sizes, are important paleoecologically for identifying distribution patterns and estimating minimum levels of diversity and size-frequency distribution (Neuman and Brinkman, 2005). Fish fossils have been identified throughout the Late Cretaceous formations of the Western Canadian Sedimentary from the Belly River Group to the Frenchman Formation (Neuman and Brinkman, 2005).

RSM P3171.7 (Figure 6.23) was excavated from the Humphrey Site quarry in jacket RB-10-001. The vertebra centrum has concave anterior and posterior cotyles with a notochordal foramen in the center of the circular shaped cotyle (green arrows). The sides of the centrum exhibit deep pits between thin branching support ridges along with remnants on the dorsal side of where the neural spine would have attached (yellow arrows). Towards the ventral side of the centrum are remnants of haemapophyses on each side towards the posterior of the centrum (red arrows). RSM P3171.7 measures 6 mm from dorsal to ventral and 5 mm from anterior to posterior.

The fossil, RSM P3171.8 (Figure 6.24) was found in jacket RB-10-001 from the Humphrey Site quarry and measures 3.5 mm from dorsal to ventral and 5 mm from anterior to posterior. The vertebra centrum exhibits concave anterior and posterior cotyles but due to the fragility of the specimen the last of the sediment was not removed from the circular shaped cotyle. The sides of the centrum are smooth with a few pieces missing near the anterior and posterior ends. For now the centrum is being identified as a fish vertebra but the smooth nature of the sides of the centrum differ greatly from the rest of the fish vertebra found in the quarry. There has been suggestions that the vertebra could be from a snake or even an amphibian like a salamander but to this point there is not enough of the specimen to fully make that conclusion. The specimen shows no evidence of remnant attachment points on the sides of the centrum.

RSM P3171.9 (Figure 6.25) was extracted from jacket RB-10-001 from the Humphrey Site quarry and measures 3 mm from dorsal to ventral and 3.5 mm from anterior to posterior. The vertebra centrum exhibits concave anterior and posterior cotyles with a notochordal foramen in the center of the cotyle (green arrow). The centrum is slightly wider in anterior view than it is tall. The sides of the centrum have shallow pits separated by thick ridges running parallel to one another from anterior to posterior. The dorsal side of the centrum shows heavily eroded remnants of a

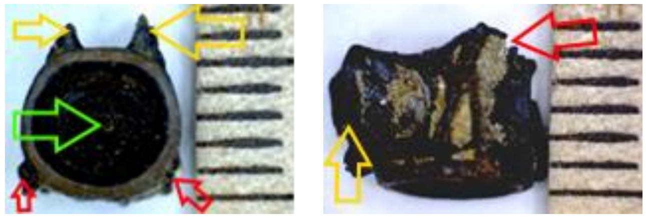


Figure 6.23: RSM P3171.7 (anterior and side view): Fist vertebra showing notochordal foramen (green arrow), neural spine attachment points (yellow arrows), and remnants of haemapophyses (red arrows). Scale in mm. (Photo by R. Boulding)

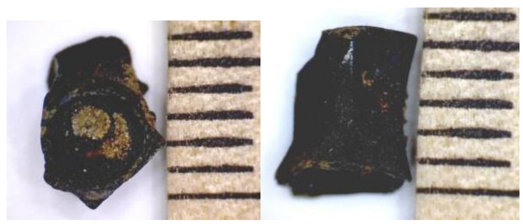


Figure 6.24: RSM P3171.8 (anterior and side view): Fish vertebra? Scale in mm. (Photo by R. Boulding)

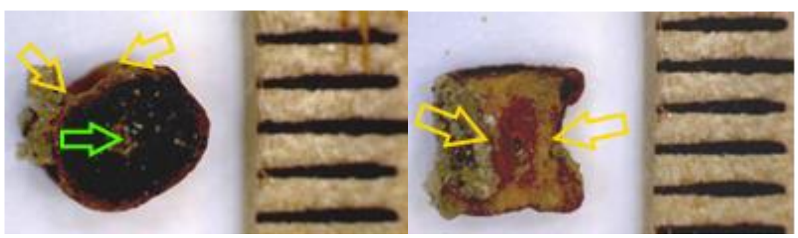


Figure 6.25: RSM P3171.9 (anterior and dorsal view): Fish vertebra with a visible notochordal foramen (green arrow) and eroded connection points for a neural spine (yellow arrows). Scale in mm. (Photo by R. Boulding)

connection point for a neural spine (yellow arrows).

RSM P3171.17 (Figure 6.26) was found in jacket RB-10-002 from the Humphrey Site quarry. The specimen consists of fragments of a centrum from a fish vertebra found concentrated in the jacket. The fragments from the centrum sides appear smooth like RSM P3171.8. One fragment from the side centrum, is about 4 mm from anterior to posterior.

RSM P3171.42 (Figure 6.27) was recovered from jacket RB-10-007 from the Humphrey Site quarry. The specimen is a fragment of a cotyle from the centrum of a fish vertebra and measures 8 mm from dorsal to ventral. The cotyle exhibits growth rings and a notochordal foramen in the center of the cotyle (green arrow) that would be circular if it were complete.

A cotyle fragment RSM P3172.2 (Figure 6.28) was collected from the surface material at the Road Cut Site. The cotyle is from the centrum of a fish vertebra. The fragment exhibits growth rings but lacks enough of the centrum to comment on its shape. The maximum diameter of measures 7 mm by 8 mm.

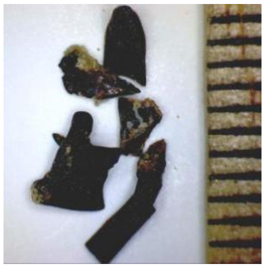


Figure 6.26: RSM P3171.17: Fish vertebra fragments. Scale in mm. (Photo by R. Boulding)

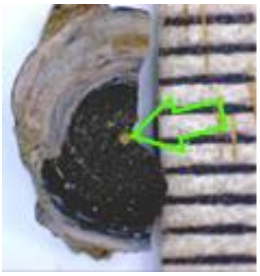


Figure 6.27: RSM P3171.42: Fragment of fist vertebra cotyle with visible notochordal foramen (green arrow). Scale in mm. (Photo by R. Boulding)

Figure 6.28: RSM P3172.2: Fragment of fish vertebra cotyle. Scale in mm. (Photo by R. Boulding)

The following four recognized elements, all with temporary catalogue numbers 13-1-3-002, 13-2-4-001, 13-1-1-002, and 13-2-4-003, were all collected from bulk sampling. The specimens come from the transition zone from lower to upper Eastend Formation of the Vansandt Site. Despite having gross morphology and texture of osteichthyian centra, further characteristics are not available.

Temporary catalogue number 13-1-3-002 (Figure 6.29) is a fragment of a cotyle from the centrum of a fish vertebra which is 3.5 mm by 3 mm across. The fragment exhibits growth rings but lacks enough of the centrum to comment on its shape.

Temporary catalogue number 13-2-4-001 (Figure 6.30) is a fish vertebra centrum with concave anterior and posterior cotyles, that measure 1 mm from dorsal to ventral and 1.5 mm from anterior to posterior. Due to the fragility of the specimen, sediment was not cleared from the cotyles to identify the presence of the notochordal foramen. The cotyle is slightly oval, being wider across than in the dorsal/ventral direction. The sides of the centrum exhibit deep pits between thin branching support ridges, along with remnants on the dorsal and ventral sides of where the neural and hemial spines would have attached (yellow arrows).

Temporary catalogue number 13-1-1-002 (Figure 6.31) appears to be a weathered part of the right dentary of a fish that is overall robust and in good shape. The top of the dentary reveals where the teeth were consolidated with the summit of the alveolar ridge of the jaw without sockets (green arrow). The dentary measures

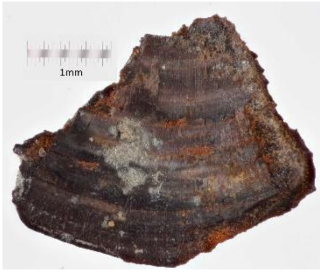


Figure 6.29: 13-1-3-002: Fragment of fish vertebra cotyle. (Photo by R. Boulding)

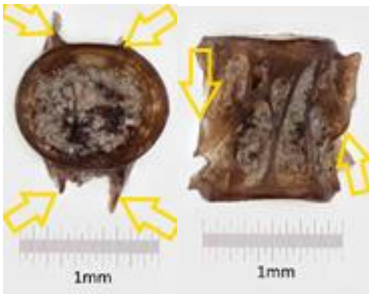


Figure 6.30: 13-2-4-001 (anterior and side view): Fish vertebra with visible neural and hemial spine attachment points (yellow arrows). (Photo by R. Boulding)

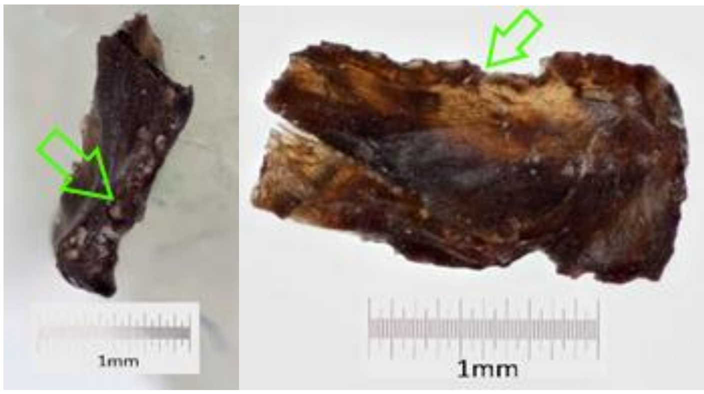


Figure 6.31: 13-1-1-002 (dorsal and side view): Right dentary of a fish with a visible alveolar ridge without sockets (green arrow). (Photo by R. Boulding)

1.75 mm from anterior to posterior and 1.25 mm from dorsal to ventral and is by no means a complete element.

13-2-4-003 (Figure 6.32) is a fragment of what looks like could be the cusp of a tooth or even a shark denticle. The fragment has a conical shape, almost caninform, with raised striations (green arrow) following the length of the specimen to its apex. It measures 2.75 mm from base to apex and 2 mm across its base. Further identification of this material beyond infraclass Teleostei is exceedingly difficult due to the poor preservation quality and low number of other l specimens from which to draw conclusions.

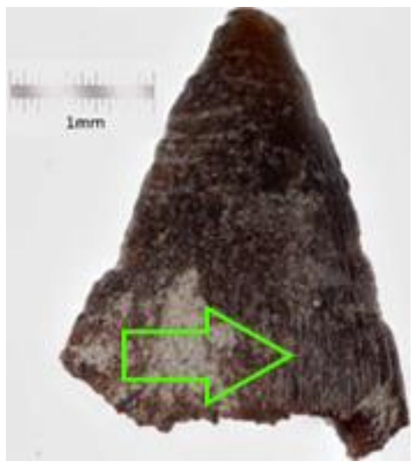


Figure 6.32: 13-2-4-003: Fish cusp of a tooth? Shark denticle? with a conical shape and raised striations (green arrow) running the length of the specimen towards the apex of the cusp. (Photo by R. Boulding)

Order TESTUDINES (Batsch, 1788)

Suborder CRYPTODIRA (Cope, 1868)

Family CHELYDRIDAE (Gray, 1831)

gen. et sp. indet.

Figure 6.33

Referred specimen: RSM P3171.13, costal scute fragment of turtle carapace.

Description and Discussion

RSM P3171.13 (Figure 6.33) was found at the Humphrey Site quarry in jacket RD-10-001 oriented upside down and overlain by a cluster of bivalve shells. This turtle sample measures 9 cm by 6 cm and is about 1 cm in thickness. The shape of the fragment suggests it is a costal plate scute that would have been located between vertebral and marginal scutes of the carapace. The specimen has visible ornamentation on its upper surface that aid in its identification. The outer surface of the fragment is strongly weathered, but overall it appears to be well preserved. The fact that the scute was found as an isolated element suggests it underwent transport to the location it was discovered.

Turtles are reptiles of the order Testudines characterized by a special bony cartilaginous shell developed from their ribs and acting as a shield (Hutchinson, 1996). In some instances, ornamentation patterns on the carapace of fossil turtles can be used as a diagnostic feature of a particular taxonomic group (Holroyd and Hutchinson, 2002). The textures of several common turtles from the Late Cretaceous of North America that possess distinctive shell textures were compared with the sample. RSM P3171.13 (Fig. 6.33) has a shell texture of deep interconnected furrows creating irregularly shaped raised ornamentation between the furrows. This type of texture is associated with the family Chelydridae, a group that contains modern snapping turtles. The texture does not fit with the densely-packed, small, rounded and flat bumps of genus *Compsemys* or rows of low triangular pits associated with genus *Basilemys*. The specimen does not exhibit rounded pits that merge to form long parallel rows of grooves and ridges that would suggest family Trionychidae and does not have gentle undulating pits and bumps associated with genus *Adocus*. Likewise, the shell lacks the irregularly pitted texture of family Baenidae (Holroyd and Hutchinson, 2002).

Family Chelydridae ranges from the Late Cretaceous to recent, with modern extant genera endemic to the western hemisphere. Fossil specimens of this family have a much larger range and are found in North America, Europe, and Asia. Chelydrid are well documented in Upper and Middle Cretaceous formations in Alberta analogous to the Bearpaw through Frenchman Formations in Saskatchewan. Studies of vertebrate microfossil assemblages in the Dinosaur Park area have shown distinct inland and coastal communities of Chelydrids present (Brinkman, 2005).

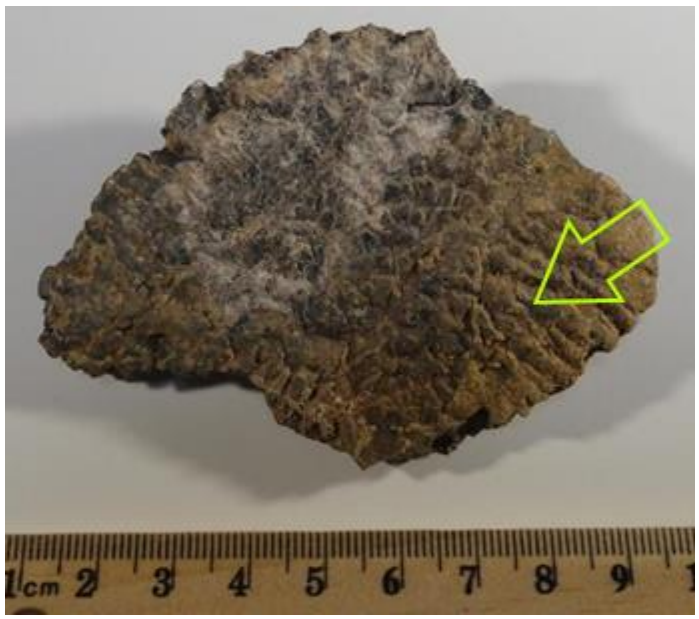


Figure 6.33: RSM P3171.13: Costal turtle scute fragment of turtle carapace. Note the shell texture of deep interconnected furrows creating irregularly shaped raised ornamentation between the furrows (green arrow). (Photo by R. Boulding)

Class REPTILIA (Laurenti, 1768)

Superorder LEPIDOSAURIA (Haeckel, 1866)

Order SQUAMATA (Oppel, 1811)

Clade PLATYNOTA (Duméril and Bibron, 1839)

Superfamily MOSASAUROIDEA (Gervais, 1853)

gen. et sp. indet.

Figures 6.34-6.35

Referred specimens: RSM P3171.41, vertebra; RSM P3171.10, vertebra.

Description and Discussion

Vertebrae RSM P3171.41 (Figure 6.34) and RSM P3171.10 (Figure 6.35) were excavated from the Humphrey Site quarry in jacket RB-10-001. RSM P3171.41 is a mosasaur vertebra that has been reduced to a centrum with diagnostic concave and convex faces. This centrum is the more robust of the two samples and measuring 3.5 cm between its concave and convex faces and 2 cm in cross section. The specimen is fairly well preserved but does exhibit some breakage with minor fragments missing. The dorsal side of the vertebra features the beginning of the connection to the neural spine and which is absent from the specimen.

The second mosasaur vertebra collected, RSM P3171.10, exhibits concave and convex articulating faces measuring 2.3 cm between them. The centrum of this vertebra measures only 1 cm in cross section making it appear more elongate compared to the other mosasaur vertebra that looks more robust. RSM P3171.10 is essentially the centrum of a vertebra whose concave end had become detached and fragmented. The dorsal side of the centrum has a raised portion that likely attached to a now absent neural spine. Despite the morphological differences between the two vertebrae, their concave and convex endings identify them as both belonging to mosasaur. The significance of the mosasaur material to the quarry site is that each vertebra is isolated and hence some geological process has separated them from the rest of the skeleton. It is undetermined if both vertebrae belong to an individual in which case they would be from different parts of the vertebral series.

The identification of these individual vertebrae belonging to the superfamily Mosasauroidea is done by examining the characteristic cotyle of the centrum. In this case, both specimens exhibit a concave posterior cotyle and convex anterior cotyle on each centrum which is known as the opisthocoelous. Other large vertebrate marine animals associated with the Campanian-Maastrichtian Western Interior Seaway can be ruled out since their vertebrae exhibit different characteristics. Plesiosaur vertebrae centrum have flat to slightly concave cotyles making them acoelous to slightly amphicoelous. Another diagnostic feature of champsosaur centrum concerns the portion between rib attachments which forms an hourglass shape and has a thin midline ridge (Carroll, 1988).

Mosasaurs first appear near the Middle Cretaceous and disappear from the fossil record at the end of the Cretaceous period. Despite only existing for about 26 million years, mosasaurs were very successful around the globe with material found on every continent in both marine and deep-water deposits (Carroll, 1988). Mosasaurs are well known in the Late Cretaceous sediments in Western Canada with specimens documented in the Bearpaw Formation in Alberta, Saskatchewan, and Manitoba (Caldwell, 2005). Mosasaur material has also been found in estuarine deposits in the Oldman Formation of Alberta (Caldwell, 2005) but have not previously been identified in similar environments of the Eastend Formation.

Figure 6.34: RSM P3171.41: Centrum of mosasaur vertebra with a concave posterior cotyle (red arrow) and a convex anterior cotyle (greed arrow). A raised portion is visible on the dorsal side where the neural spine would have attached (yellow arrow). (Photo by R. Boulding)

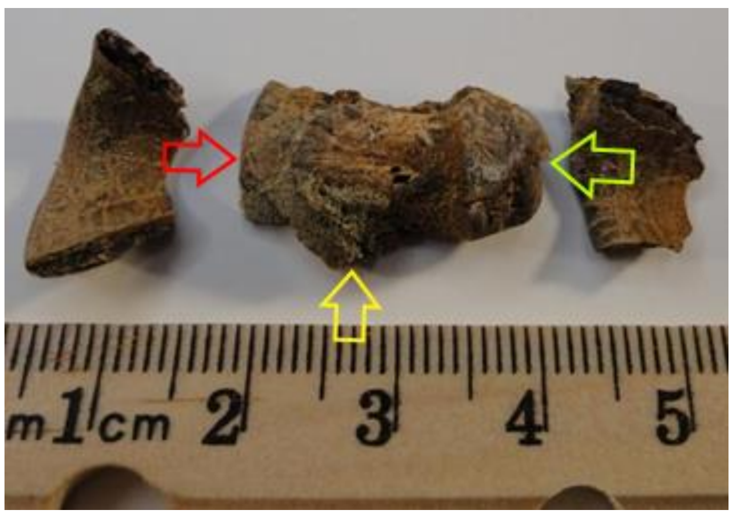


Figure 6.35: RSM P3171.10: Centrum of mosasaur vertebra with a concave posterior cotyle (red arrow) and a convex anterior cotyle (greed arrow). A raised portion is visible on the dorsal side where the neural spine would have attached (yellow arrow). (Photo by R. Boulding)

6.4 Plant Material

Kingdom PLANTAE

gen. et sp. indet.

Figures 6.36-6.42

Referred specimens: RSM P3171.14, fossilized wood material; 13-1-4-001 (temporary catalogue number), amber; 13-2-1-001, amber; 13-2-1-002, amber; 13-2-2-001, amber; 13-2-2-002, amber; 13-2-2-003, amber.

Description and Discussion

Throughout the sectioning and fossil collection portions of this study, plant material was encountered on many occasions both within carbonaceous laminations and as separate small elements. Though there are no diagnostic characteristics to warrant classification, the presence of the plant material still has important paleoenvironmental implications. One large specimen of plant material was found in the Humphrey Site Quarry in jacket RB-10-001. Specimen RSM P3171.14 (Figure 6.36) is a piece of wood approximately 10.5 cm long and 4 cm in width; however, the poor preservation quality of the wood severely limits further classification.

While processing the bulk samples from the Vansandt Site, amber material was encountered at two of the three stratigraphic levels. Specimen 13-1-4-001 (Figure 6.37) was found in the material sampled from a stratigraphic height near the transition between the lower and upper Eastend Formation. In addition, amber samples were found in the micro material from the site sampled below this Eastend Formation transition with samples 13-2-1-001 (Figure 6.38), 13-2-1-002 (Figure 6.39), 13-2-2-001 (Figure 6.40), 13-2-2-002 (Figure 6.41), and 13-2-2-003 (Figure 6.42).

Macrofloral material would suggest like the amber, coastal deposition rather than deep water. The Western Interior Seaway, within Saskatchewan, has rare occurrences of wood material in the Bearpaw Formation that was interpreted to have been transported no great distance from the shoreline (Caldwell, 1968).

Figure 6.36: RSM P3171.14: Fossilized wood recovered from jacket RB-10-001 from the Humphrey Site quarry. (Photo by R. Boulding)

Amber Material

(Photos by R. Boulding)

Figure 6.37: 13-1-4-001

Figure 6.38: 13-2-1-001

Figure 6.39: 13-2-1-002

Figure 6.40: 13-2-2-001

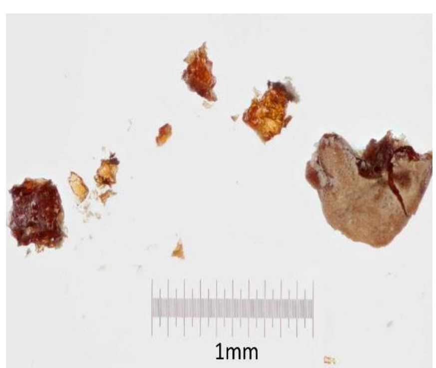


Figure 6.41: 13-2-2-002

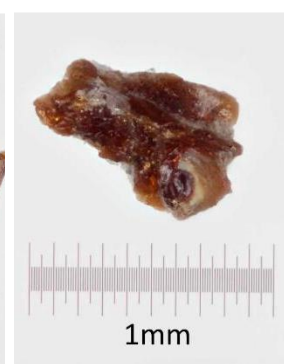


Figure 6.42: 13-2-2-003

6.5 Trace Fossils

During the field studies, numerous occurrences of bioturbation were observed mainly associated with clay/silt and planar laminated sand layers. This suggests the bioturbation in the Eastend Formation is related to sediments representing lower energy conditions and possibly even low sedimentation rates. In a few instances, some ichnological features were noted in coarser sands, but overall the presence of bioturbation seemed to decrease as energy levels went up as denoted by evidence of increasing fluvial energy, coarsening textures and bedforms. Additionally, variable iron staining of the formation likely obscured evidence of bioturbation in some areas. Traces found in the Eastend sections include, *Skolithos* ichnofacies with ichnogenus *Monocraterion* and *Skolithos*, and the *Cruziana* ichnofacies.

SYSTEMATIC ICHNOLOGY

MONOCRATERION? igen. (Torell, 1870)
gen. et sp. indet.

Figure 6.43

Description and Discussion

Occurrences of this trace (Figure 6.43) were found as concentric circles in cross section, normally along the tops of very fine sand layers and measure 4 cm in diameter. Samples were initially thought to be some sort of depositional feature, but upon closer scrutiny were determined to be a trace fossil. There are numerous ichnotaxa that can exhibit a concentric cross section, thus these traces are tentatively identified as cf. *Monocraterion*, which belongs to the Skolithos ichnofacies.

Monocraterion are described as a series of concentric rings in transverse section usually 1-4 cm in diameter (Frey and Howard, 1985). This type of trace is similar to the ichnogenus *Rosselia* which has a circular transverse section and a central cylindrical pencil like tube which was not observed in the samples collected. Similarly, transverse sections of the ichnogenus *Skolithos* can have a concentric shape making identifications difficult. *Monocraterion* are interpreted as dwelling structures and associated with deposit feeding behaviours in shallow marine water settings. The traces are attributed to marine worms (polychaetes) and worm-like organisms (Frey and Howard, 1985).

SKOLITHOS igen. (Haldemann, 1840)

Skolithos sp.

Figure 6.44

Description and Discussion

Occurrences of this trace identified as *Skolithos* (Figure 6.44) were observed as small concentric holes in cross section in the upper surface of a ripple marked, medium sand layer at the Avonlea Site. The holes have smooth edges and measured about 1cm in diameter and are similar to holes found in fine sand surfaces at the Humphrey Site.

Descriptions of ichnogenus *Skolithos* define the traces as parallel cylindrical tube burrows that are smooth and do not branch. *Skolithos* is often associated with high-energy marine conditions including nearshore shallow marine facies and are attributed to several organisms including polychaetes, phoronids, arthropods, and small vertebrates (Bromley, 1996).

Figure 6.43: Possible *Monocraterion?* trace from Humphrey Site. (Photo by R. Boulding)

Figure 6.44: Note the circular tube burrows of ichnogenus *Skolithos* in a rippled surface found at the Avonlea Site. (Photo by R. Boulding)

CHONDRITES igen. (von Strenberg, 1833)

Chondrites sp.

Figure 6.45

Description and Discussion

Occurrences of this trace (Figure 6.45) were found as tiny burrows in very fine sand and clay/silts at the Road Cut, Vansandt, Claybank, and Humphrey Site. The traces were less than 1 mm in diameter with smooth edges and almost root-like with their branching nature.

Descriptions of ichnogenus *Chrondrites* traces consist of complexes of small shafts in dentritic patterns. These traces normally never cross, form along bedding planes, and are attributed to feeding traces of deposit feeding worm organisms and found in a multitude of marine conditions (Bromley, 1996).

THALASSINOIDES igen. (Ehrenberg, 1944)

Thalassinoides sp.

Figure 6.46

Description and Discussion

These traces (Figure 6.46) appear as branching interconnected cylindrical burrows in very fine to fine sands at the Road Cut, Humphrey, Hanson, Claybank, and Vansandt Sites. The traces were about 1 cm in diameter with smooth edges. *Thalassinoides* traces are described as branched cylindrical burrows interconnected with shafts. The traces are attributed to deposit feeding behaviours and dwellings of crustaceans in shallow marine settings and occasionally in deep marine turbidite sequences (Bromley, 1996).

Figure 6.45: Burrow traces of ichnogenus *Chondrites* from the Humphrey Site. (Photo by R. Boulding)

Figure 6.46: *Thalassinoides* traces from the Vansandt Site. The black bar represents 5cm. (Photo by R. Boulding)

OPHIOMORPHA igen. (Lundgren, 1891)

Ophiomopha sp.

Figure 6.47

Description and Discussion

Ophiomorpha (Figure 6.47) were found as both horizontal and vertical cylindrical burrows. The burrows had a branching structure with a bumpy, uneven outer surfaces that looked like they were lined with fecal pellets. These traces were found in layers of very fine to medium grained sands. The burrows were about 2 cm in diameter up to 10 cm or more in length.

The burrows are dwelling burrows of decapod crustaceans and found in prolific number along marine shoreface environments with brackish water as well as sandy substrates including estuaries and tidal shoals (Andersson, 1981).

Figure 6.47: *Ophiomorpha* traces from the Humphrey Site. (Photo by R. Boulding)

6.6 Interpretation of Ichnology and Fossil Material

6.6.1 Ichnology

A total of five ichnotaxa were identified from the Eastend Formation material made up primarily from the Skolithos and Cruziana ichnofacies. The Skolithos ichnofacies identified as cf. *Monocraterion* and *Skolithos* indicate a shallow, nearshore marine water. The Cruziana ichnofacies including *Chrondrites, Thalassinoides,* and *Ophiomorpha* indicate a shallow nearshore marine shore face environment including estuaries and tidal shoals.

The combination of Skolithos and Cruziana ichnofacies in the same deposits are a strong indicator of an estuarine environment. The ichnotaxa exhibit a low overall diversity and diminished concentrations suggesting the Eastend Formation is an estuary influenced by brackish water. Where river and seawater mix there is a stressing effect on the burrowing organisms. Fewer organisms are adapted to fluctuating salinity conditions, this results in reduced bioturbation and less ichnological traces being preserved (Buatois and Mángano, 2007).

6.6.2 Fossil Material

A total of 67 specimens were collected and classified to varying taxonomic levels from surface collections at the Road Cut Site, micro material sampled form the Vansandt Sites, and a combination of surface picking and quarrying from the Humphrey Site. Once taxonomic classifications are made of the fossils, known information about these taxonomic groups can be used to infer the type of paleo-environment in which they lived. Thus far, interpretation from the paleontological material has been kept separate from those based on the geology and ichnology to test if separate lines of data point towards the same conclusions regarding the environment.

The taxonomic classifications for the vertebrate specimens include mosasaurs, turtles of family Chelydridae, teleost fish, and sand sharks. Deposits in which most mosasaurs are found indicate that particular species likely occupied different parts of the water column with some preferring shallow, near-shore, marine waters while others lived in deep water (Carroll, 1988). It should be noted that in a separate study a paddle bone from a juvenile plesiosaur has been found from the Eastend Formation near the Vansandt Site, strongly linking the sediments to a coastal environment (Tokaryk et al., In Press). Chelydridae turtles vary greatly in their range of habitats and occupy near shore freshwater to inland terrestrial environments. Likewise, teleost fish occupy a wide variety of environments, spanning marine to freshwater environments. The sand shark material offers information used to narrow down the paleo-environmental conditions, since they are restricted to temperate to tropical waters from the surf zone down to 191 m water depths. A marine shoreline environment with freshwater input is an environment where all these vertebrate groups cross and could conceivably be found together.

More detail can be added to the paleo-environmental interpretation from the taxonomic classifications of the invertebrate fossil material. The identification of the bivalves offers the most information about environment due to the specific habitats they occupy. Bivalves of genus *Laevicardium* are identified as living in sandy, sheltered beaches throughout the world (Schneider, 1995). Similarly, the bivalves of genus *Tancredia* prefer living in low energy sandy substrates in warm shallow waters (Skogstrom, 1958). These bivalves offer additional information about the environment through measurements of isotopic oxygen from calcium carbonate of their shells, suggesting they thrived in temperatures around 15°-16°C (Skogstrom, 1958). Gastropod material does not help to narrow down the paleo-environment, since they are widely distributed across marine to terrestrial realms. Scaphopods, live in marine environments buried in soft sediments ranging from shallow water to 2000 m depths. One environment where all these invertebrate taxa could exist are a warm, shallow nearshore environment with a sandy substrate and sheltered low energy conditions.

Lastly, the plant material recovered in the form of fossilized wood and amber samples helps underline the nearshore relationship of the fossil material. This plant material in addition to the carbonaceous matter found in laminations in the Eastend Formation could be possible only with a nearby supply of plant material readily incorporated in the sediments. The presence of the plant material indicates the close proximity of the vegetation to the zone of deposition and hence a shoreline where the vegetation would be present is a viable option.

The overall environmental picture painted by the information known about the taxonomic groups classified among the fossil material is a temperate, low energy nearshore environment. An estuary should be considered due to the mixing of fresh and marine waters, a sheltered environment that would be prone to higher energy events like storms. The effect of these high-energy events would help to concentrate fossil material into isolated accumulations like that observed at the Humphrey Site.

Chapter 7: Conclusions

7.1 Summary

The purpose of this thesis is to examine the stratigraphy and fossil content of the Eastend Formation across Saskatchewan. This detailed stratigraphic assessment will help delineate ill-defined stratigraphic boundaries of the Eastend Formation impacting the stratigraphy of the Late Cretaceous in the province. The primary objective of this research was to create stratigraphic sections from six surface exposures across the southern portion of the province. From these sections examinations were undertaken of the changes in lithology, stratigraphy, and stratigraphic boundaries of the Eastend Formation. A secondary objective of this research was to update the faunal list for the Eastend Formation. This was accomplished through paleontological excavations and surface collection to gather and preserve fossil specimens in conjunction with bulking sampling of sites to inspect for micro-vertebrate fossil content. The sites were selected based on extensive prospecting of Eastend Formation exposures across the province. The sites yielding fossil material in this study came from the Frenchman River Valley near Eastend, Saskatchewan.

The geologic sections point to three dominant lithological facies found in the Eastend Formation including planar laminated and massive sands, cross-bedded and rippled sands, and interbedded silts and clays. The lower Eastend Formation has been interpreted as a prograding delta front consisting primarily of bentonite rich clays, silts, and intermittent very fine sands. The observed fine grain and planar laminated nature of the sediments suggest a low energy sheltered environment like that of an estuary. Moving higher in the sections and essentially farther inland as the delta front would have progressed eastward, the number and thickness of sand layers started to increase. The shallowing of the depositional environment also marked a decrease in the thickness of the clay and silt layers leading up to the eventual transition between lower and upper Eastend Formation and the onset of the delta plain type environment.

The upper Eastend Formation layers are interpreted as being related to shallow channels producing laminated and cross-bedded sands with thin clay/silt layers representing overbank deposits from the channels when they flood. These same sediments and sedimentary structures persisted upwards into the Whitemud Formation with the only real difference being the white coloration of the formation. The white kaolinite has resulted from the weathering of the fluvial sediments similar to the upper Eastend Formation that are rich in feldspars and micas. The weathering of the aluminosilicates to produce to the diagnostic kaolinite or is the result of pedological processes as a soil profile began to develop meaning the kaolinite in the Whitemud is a secondary post-depositional pedological feature. Since the Whitemud would not denote a change in sedimentation or the sedimentary environment from the upper Eastend Formation, it could be possible to conclude that the Whitemud Formation is not a formation but rather a horizon of altered Eastend Formation material.

In total 67 fossil specimens were collected from surface prospecting, quarrying, and sieving bulk samples of sediment for micro fossils (Table 6.1). The preparation of these specimens proved to be extremely difficult due to their fragility and the unstable nature of their surrounding substrate. As a result, the degree to which these specimens could be classified was highly varied based on the quality of the material and the number of specimens found. In the future, as specimens from the Eastend Formation continue to be found it is very likely that classification of fauna in the formation will improve in detail.

The fossil specimens were classified to varying degrees based on the preservation quality and completeness of each specimen. Among the vertebrate elements identified were mosasaur vertebrae, turtle carapace, fish vertebrae and cranial elements, and numerous shark teeth. This handful of specimens represents the first vertebrate material found in the Eastend Formation many of which were found concentrated within the Humphrey Site quarry. Invertebrate specimens collected during this study included bivalves, gastropods, and scaphopods that varied in completeness from partial to whole specimens. Additionally, fossilized wood material was recovered from the Humphrey Site quarry along with fragments of amber found among the micro material from the Vansandt Sites. The depositional environment indicated by the fossil material is a temperate, low energy, nearshore environment like that of an estuary. This type of sheltered environment would be prone to higher energy events like storms which would account for the concentration of the fossil material into isolated accumulations like that observed at the Humphrey Site. These high energy events would account for the isolated fossil elements that had been separated from the rest of the specimen.

A total of five ichnotaxa were identified from the Eastend Formation material from the Skolithos and Cruziana ichnofacies. The Skolithos ichnofacies identified as

Monocraterion (tentatively) and *Skolithos* indicate a nearshore marine shallow environment. The Cruziana ichnofacies identified as *Chondrites*, *Thalassinoides*, and *Ophiomorpha* indicate a shallow nearshore marine shore face environment including estuaries and tidal shoals. This combination of Skolithos and Cruziana ichnofacies in the same deposits support the interpretation of an estuarine environment.

The overall evidence derived from the geology, paleontology, and ichnology of the Eastend Formation points towards an estuarine depositional environment. This combination of indicators could be the key to differentiating the gradational boundary between the lower Eastend Formation and the upper Bearpaw Formation. Likewise, the suggestion can be made that the Whitemud Formation is a subaerially altered horizon of the upper Eastend Formation by pedological processes would have a profound impact on the Late Cretaceous stratigraphy in Saskatchewan and deserves further study.

7.2 Future Research

The conclusions derived from the objectives of this research have helped to develop a better understanding of the stratigraphy and paleontological significance of the Eastend Formation. However, this same research uncovered other research opportunities that could be examined in the future. The first of the research topics pertains to further defining the boundaries of the Eastend Formations. The gradational boundary with the Bearpaw Formation can be narrowed down using geologic, fossil, and bioturbation evidence but there may be other lines of evidence that could be explored such as geochemical analysis. Similarly, geochemical evidence may help to further determine if the Whitemud Formation is an altered horizon of the upper Eastend Formation by subaerial exposure and pedological processes.

The second major research topic that could be addressed in the future would be to continually expand on the fauna and floral list for the formation and result in further refining the classification of taxa from the formation. This could be achieved through further prospecting for exposures of the Eastend Formation to find fossil material including mass accumulations like that of the Humphrey Site.

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Appendix I: Eastend Formation Type Section

SECTION 1 (MURPHY'S CLAY PIT EAST)

Location: Southwest of Eastend, Saskatchewan. North of Highway 13 in large gully east of Murphy's clay pit. In Lsd. 6-25-6-22w3.

Elevation: Base of Eastend at approximately 3,140 feet.

Section: Measured with tape and handlevel by W. O. Kupsch and S. P. Jordan, June 18, 1953. Sample description by W. O. Kupsch and N. Frost.

Note: Section 1 can be regarded as the type section of the Eastend formation.

Unit	Description	Thickness in feet-inches
	Upper Cretaceous	
	WHITEMUD	
	(Lower member)	
Overlying	Sand, very light grey, fine to medium grained, well sorted. Stratification indistinct, small scale crossbedding in places, massive, cliff-forming. Thickness of lower member of Whitemud, measured from Eastend-Whitemud contact to the lowest brown carbonaceous shale layer of the middle member of the Whitemud	19'7"

7

Unit	Description	Thickness in feet-inches
21	Sand, dusky yellow, fine grained, well sorted, laminated with some of the laminae caused by thin films of carbonaceous material. Micaceous, impure, brown lignite layer of two inches maximum thickness in the upper two feet of unit 21. This lignite layer is non-persistent and grades laterally into grey clay. The contact between unit 21 of the Eastend formation and the overlying lower member of the Whitemud is gradational. The sands differ slightly in colour (Eastend dusky yellow, Whitemud light grey), grain size (Eastend finer grained), and presence of grey clay lenses in the Eastend........	5'4"
20	Sand, dusky yellow, similar to unit 18, but with some irregular lenses of grey clay....................	3'1"
19	Silt, yellowish grey, very fine grained, grades into coarse clay	11"
18	Sand, dusky yellow, fine grained, generally well sorted but with some coarser grained laminae. Cherty, feldspathic. Brown to black carbonaceous fragments and micaceous material visible on the lamination planes....................	3'5"
17	Clay, light greenish grey with high silt content, in places silt or very fine grained sand, light olive grey, well sorted. Chert, mica, and carbonaceous material visible locally. Unit 17 forms a distinctive grey band above the underlying coarser grained orange grey units....................	8"
16	Siltstone, dark yellowish orange, slightly calcareous, fine to medium grained, some small carbonaceous fragments, well indurated, with shaly structure. Unit 16 is distinctive (grain size, colour, induration, and structure) and appears to be persistent in the Eastend area. The gradational contact between the Eastend and the Whitemud as placed in this section is thirteen feet five inches above unit 16, which certainly belongs to the Eastend formation and which occurs near its upper limit....................	6'3"
15	Sand, similar to unit 14, but distinctly laminated. Dusky yellow laminae alternate with light olive brown laminae....................	2'1"
14	Sand, greenish grey, fine grained, grains angular, chert and feldspar visible. Unit 14 contains two clay beds, dusky yellow, one inch in thickness each....................	1'9"

13	Sand and clay interbedded. Sand, pale olive, slightly calcareous, fine to very fine grained, well sorted, feldspathic, micaceous, black carbonaceous fragments in places. Clay, light olive grey, slightly calcareous. Unit 13 contains small (up to two inches in diameter) accretionary bodies of crumbly sand and iron oxide, dark yellowish orange	10"
12	Clay, yellowish grey to light olive grey, slightly calcareous, coarse grained grading into silt, some poorly preserved plant fragments	9"
11	Silt, yellowish grey to light olive grey, similar to unit 10	1'9"
10	Silt, light olive grey, slightly calcareous, coarse grained. Grades into very fine grained sand, feldspathic, micaceous. Abundant brown and black carbonaceous material in small fragments, a few millimetres in diameter	3'2"
9	Sand, light olive grey, calcareous, very fine grained, grains subangular, feldspathic, micaceous, and carbonaceous. In the sand occur irregular lenses of silt and clay, dark yellowish orange, calcareous. Unit 9 is distinguished from unit 8 by the more intense and generally browner colour of its finer grain sizes	2'11"
8	Silt, similar to unit 1	3'4"
7	Siltstone, yellowish grey, calcareous, medium grained. In places grading into very fine grained sandstone. Contains black carbonaceous material of silt size. Except for slightly coarser grain size and distinct shaly structure unit 7 is similar to the underlying unit 6. Units 4 to 7 form a conspicuous hard band, cliff forming, which can be traced laterally through the gully, but which is in places nonpersistent	5"
6	Siltstone, yellowish grey, calcareous, very fine grained, grading into claystone with conchoidal fracture. Some parts are of coarser grain and form sandstones. Brown to black carbonaceous material scattered throughout, but especially prominent in the coarser parts. A few larger (up to one-half inch in length), poorly preserved plant fragments. Distinct jointing in places, with joint planes coloured dark brown by iron oxides. Two strata make up unit 6: the lower is about five inches thick and breaks up into small blocky fragments, the upper is about ten inches thick and breaks into large massive blocks	1'3"
5	Sand, yellowish grey, fine to very fine grained, calcareous, laminated. The laminae are especially visible on weathered surface. In places they exhibit small scale cross-stratification. Unit 5 is less resistant than either unit 4 or unit 6 and forms a recess in the hard band of units 4 to 7, which forms a small cliff	11"
4	Siltstone, greyish yellow, calcareous, fine grained to very fine grained grading into claystone in places; black carbonaceous material of silt size. Unit 4 is fairly well indurated and is the lowest unit of a conspicuous, hard, cliff forming band	6"
3	Clay and silt, similar to unit 1	16'5"
2	Clay to very fine silt, moderate yellowish brown, calcareous, dark clay stringers in places, small black carbonaceous fragments	5"
1	Clay interbedded with silt. Clay, yellowish grey. Silt, light olive grey, calcareous, medium grained, grading into very fine sand, finely laminated (about five laminae to one inch), locally small scale cross stratification. Very thin (up to 0.3 inch) layers of black carbonaceous plant material in places. Nests of selenite crystals on the surface of the finer grained sediments. Some small accretionary bodies of very fine grained sand, noncalcareous, cemented by pale and dark yellowish orange iron oxide. Thickness of individual clay and silt strata is irregular, varying from a few inches to several feet and causing a wavy contact between the two	23'6"
	Total thickness of Eastend formation:	80'6"

Bearpaw

Underlying	Limonite-rich layer consisting of sand and clay, noncalcareous, moderate yellow and light brown due to iron oxides	2"

Appendix II: Eastend Formation Faunal List

Pelecypoda (Bivalvia):

Species (or indicated genus)	Location (province)	
	Saskatchewan	Alberta
Anomia sp.		X
Corbula sp.		X
Corbula spherioides	x	
Corbula sprouli		X
Cybophora gratiae	x	
Gervillia Birugata	x	
Inoceramus fibrosus		X
Inoceramus sp.		X
Laevicardium Holmesi	x	
Mactra sp.		X
Mactra warrenana		X
Nucula cancellata		X
Nucula planimarginata		X
Ostrea glabra		X
Oxytoma nebrascana	x	
Panope mclearni		X
Pholadomya cupressensis	x	X
Protocardia borealis		X
Protocardia subquadrata		X
Pteria linguiformia		X
Pteria nebrascana		X
Saxicava levis	x	
Tancredia americana cupressensis	x	X
Tellina cupressensis		X
Thracia ? sp.		X
Yoldia cupressensis		X
Yoldia mcconnelli		X

Gastropoda:

Species (or indicated genus)	Location (province)	
	Saskatchewan	Alberta

Polinices sp.		X

Cephalopoda:

Species (or indicated genus)	Location (province)	
	Saskatchewan	Alberta
Discoscaphites abyssinus		X
Ponteixites gracilis		X
Acanthoscaphites quadrangularis		X
Acanthoscaphites sp.		X