The diversity of life in braided river systems during the Late Triassic at Burntcoat Head, Nova Scotia

Laura-Ann Broom

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Department of Earth Sciences

Dalhousie University, Halifax, Nova Scotia

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Abstract

Braided-fluvial deposits of the Late Triassic Wolfville Formation at Burntcoat Head have yielded important vertebrate bone material. The present study integrates fluvial sedimentology with paleobiology to gain a more complete understanding of the paleoenvironment and paleoecology. The Wolfville Formation was deposited within the extensional Fundy Basin during the break up of Pangaea. The 34 m studied section comprises channel bodies up to 5 m thick stacked to form three channel belt complexes with planar bases, up to 11 m thick. The channel deposits comprise thin lags of mudclast conglomerates, coarse- to fine-grained sandstones, interpreted as bedload deposits of bars and channel fills, and floodplain deposits that include pedogenically modified fine sandstones and claystones with carbonate nodules. Architectural elements include laminated sand sheets, lateral and downstream accretion macroforms, and sandy bedforms. Plane-bedded sandstones and trough cross-beds, formed by large dunes are prominent in the section. Paleoflow was near parallel to the cliff line with an average direction of 057°.

Reworked partial skeletons and bone and teeth fragments reveal a diversity of vertebrates. Collections at the NS Museum of Natural History yielded over 75 specimens from the area, some specific to the studied interval. Bone fragments of tetrapods range from a few mm to over 20 cm in length and were found as clasts within fine- to coarse-grained sandstone. Recent discoveries from the site include the partial skeleton of an archosauromorph reptile, *Teraterpeton hrynewichorum,* and procolophonid reptiles including *Acadiella psalidodon, Haligonia bolodon, and Scoloparia glyphanodon*. Trace fossils transitional between *Taenidium* and *Planolites* are locally abundant within channel sandstones and floodplain fine sandstones and claystones. Plant fossils were not observed, but possible vegetation-induced sedimentary structures were documented, and this along with the presence of herbivores suggests the presence of vegetation in the area.

The fluvial deposits formed near the paleoequator in a semi-arid climate with seasonal rainfall and high discharge, as indicated by thick plane-bedded sandstones, the abundance of scoured surfaces, and carbonate paleosols. Early calcite cements suggest a bicarbonate-charged groundwater system, and the angular nature of clasts indicates a proximal source and rapid deposition. Known localities of bone material are linked to the base of channel fills and in-channel dunes and the fragmentary and isolated nature of the specimens suggest considerable transport. Burrows indicate that invertebrates were active in channels during periods of abandonment and in floodplain deposits. The variety of specimens and biological material indicates that life flourished along these Triassic braided channels.

Keywords: Burntcoat Head, Wolfville Formation, braided rivers, taphonomy, paleoecology, diversity, semi-arid, reptile

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Chapter 1 Introduction

The excellent cliff exposures within the Minas Basin at Burntcoat Head, Nova Scotia reveal the braided-fluvial deposits of the Triassic Wolfville Formation and form a site where remarkable vertebrate bone material has been found. Previous studies have examined the sedimentology (Leleu *et al.,* 2010) and paleontology (Sues, 2003; Sues & Baird, 1998), however this information has not been integrated in any detail. Some of the vertebrate finds are precisely known, which provides a unique opportunity to investigate the whole terrestrial ecosystem at an important point in Earth's history, some 15 million years prior to the major extinction event of the Triassic-Jurassic boundary. It is of interest to combine information on the sedimentology and paleontology in order to gain an understanding of the paleoenvironment and paleoecology of organisms that existed in the Fundy Rift basin during the Late Triassic.

The Wolfville Formation consists of alluvial fan, fluvial, lacustrine, and minor eolian deposits which crop out along the coast of Nova Scotia and in New Brunswick (Leleu *et al.* 2010). The strata were deposited during the Carnian (Late Triassic) as a result of the initial continental rifting that formed the Fundy Basin during the break-up of Pangea (Wade *et al.* 1996). The cliff strata at Burntcoat Head were laid down by a sandy braided fluvial system, yielding stacked channel bodies that formed channel belts (Leleu *et al.,* 2010). The Wolfville Formation has yielded numerous vertebrate fossils (Sues, 2003) within sandstone and conglomerates, though bones and teeth are sparsely distributed and mostly occur as isolated fragments that are difficult to identify taxonomically. Over 75 partial specimens have been collected from the study site and surrounding area, and within the strata at Burntcoat Head several excellently preserved tetrapod fossils have been discovered and studied. Some of the more remarkable specimens include a partial skeleton of an archosauromorph reptile species, *Teraterpeton hrynewichorum* found by George P. Hrynewich in the 1990s, as well as three new taxa of Procolophonidae: *Acadiella psalidodon, Haligonia bolodon, and Scoloparia glyphanodon* (Sues, 2003; Sues & Baird 1998).

The numerous vertebrate fossils recovered at Burntcoat Head have yet to be considered within the braided-fluvial system that was present. Assessing how the bone material was preserved through studying the taphonomy provides evidence about how these animals were incorporated into the channels and provides insight into the ecosystem of which the vertebrates were a part during the Late Triassic. Other components of the ecosystem that have yet to be assessed at Burntcoat Head include trace fossils left by invertebrates and evidence for vegetation. Bringing together detailed information on the sedimentology of this fluvial system with the paleobiologic data reveals a diverse and thriving ecosystem in the Fundy Basin during the Late Triassic. This study assesses a 1 kilometer cliff section of strata in detail, aiming to link the stratigraphy and sedimentology of the cliffs at Burntcoat Head to the fossil material recovered from the site (Fig. 1.1).

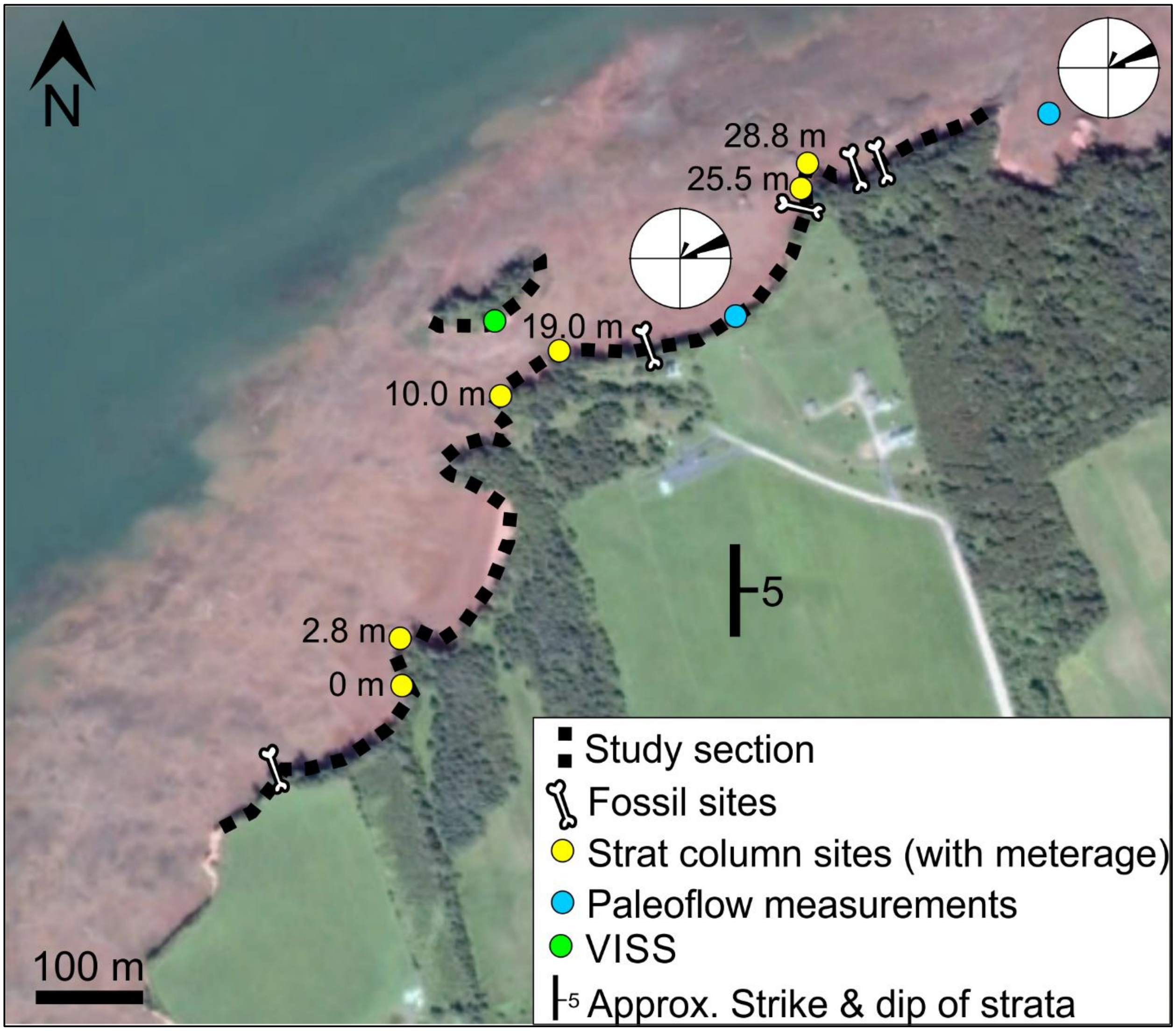


Figure 1.1 Areal image of study area (Google Earth) showing the cliff section denoted in black, the fossil sites, the stratigraphic column sites where measurements were taken and their corresponding meterage within the stratigraphic section, paleoflow measurements sites with rose diagrams, vegetation-induced sedimentary structure (VISS) locality, and approximate strike and dip of strata from Leleu *et al.* (2010).

Chapter 2 Geologic Setting and Previous Research

2.1 Fundy Rift Basin, Minas Subbasin, and Fundy Group

The Fundy Basin formed predominantly from extensional forces during the breakup of Pangaea along the eastern margin of North America during the Mid and Late Triassic (Wade *et al.*, 1996). The basin is composed of the Fundy, Chignecto, and Minas subbasins. Burntcoat Head is within the Minas subbasin, along the Minas fault zone (Fig. 1) (Olsen & Schlische, 1990). The Cobequid-Chedabucto fault zone represents the boundary between the Avalon and Meguma terranes and was dominated by right-slip movement during the assembly of Pangea during the Carboniferous. The fault zone was reactivated during extension in the early Mesozoic, and was dominated by left-oblique slip, transforming it into a transtensional rift subbasin. The Minas subbasin is composed of a series of synrift horsts, grabens, and half grabens and contains a condensed stratigraphic section of the Triassic (Olsen & Schlische, 1990), which has been estimated to be 2-3 km thick (Wade *et al.*, 1996) . The Fundy subbasin underwent different tectonic stresses than the Minas subbasin, forming along a dip-slip fault zone, and it contains a thicker stratigraphic section.

The Fundy Basin filled with continental sediments and basalts during the Middle Triassic to Early Jurassic (Wade *et al.*, 1996). The Minas sub-basin contains the Wolfville Formation and the Blomidon Formation which is capped by the North Mountain Basalt (Fig. 2.1) (Leleu & Hartley, 2010). These formations were deposited near the paleoequator (Witte *et al.*, 1991) in a hot and semi-arid climate as indicated by paleosols, and experienced periodic, seasonal rainfall and high fluvial discharge (Wade *et al.*, 1996).

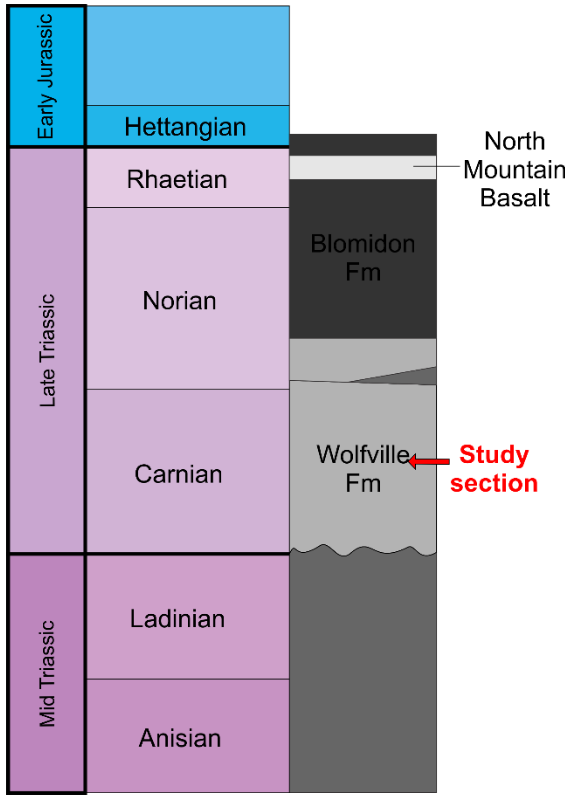


Figure 2.1. Stratigraphy of the Triassic section of the Minas Basin showing the from oldest to youngest: Wolfville Fm, Blomidon Fm, and North Mountain Basalt (modified from Leleu *et al.*, 2010).

The end of the Triassic is marked by a major extinction event, dated at 201.5 Ma (Schaltegger *et al.*, 2008). Archosauromorph reptiles, thecodont rhynchosaurs, placondonts, procolphonids, labyrinthodont amphibians, and most mammal-like reptiles went extinct around the globe at the end of the Late Triassic, which led to a change in tetrapod assemblages in the Early Jurassic to dinosaurs, crocodylomorphs, mammals, and modern reptiles and amphibians (Padian & Clemens, 1985).

2.2 Wolfville Formation

The Wolfville Formation is exposed in the Minas Basin and is unconformablly overlies Carboniferous strata and older metasedimentary rocks of the Meguma Terrane (Wade *et al.*, 1996). The deposits of the lower Wolfville Formation are exposed along the southern shore of the Minas subbasin, and the upper part of the succession can be seen along the southwestern shore of the Minas subbasin. The formation has been dated to be no older than Carnian (Olsen *et al.*, 1989) and comprises interbedded conglomerates and coarse- and medium-grained sandstones, and fine-grained deposits. These sediments are attributed to the initial phase of continental rift sedimentation (Wade *et al*., 1996), and have been interpreted as fluvial, alluvial fan, and eolian deposits (Klein 1962; Hubert & Mertz 1980) deposited under semiarid to subhumid conditions (Tanner, 1993) in an endorheic basin. The lower Wolfville Formation is dominated by fluvial sediments, whereas the upper Wolfville Formation is organised into a cyclical succession of channelized fluvial deposits, unconfined fluvial deposits, and playa lake claystones, with an upward increase in the proportion of playa, playa margin and splay deposits, taking the place of the fluvial sediments (Leleu & Hartley, 2010). This results in a transition from fluvial-dominated sedimentation of the Wolfville Formation to the playa-dominated sedimentation of the Blomidon Formation.

2.3 Burntcoat Head Section – Architecture and Fossil Discoveries

The section studied covers a 1 kilometre area along the cliffs at Burntcoat Head, Nova Scotia, within the Minas subbasin, and comprises a cliff section of braided-fluvial deposits of the Carnian Wolfville Formation gently dipping 5º to the East (Fig. 1.1 & 2.2) (Leleu *et al.*, 2010).

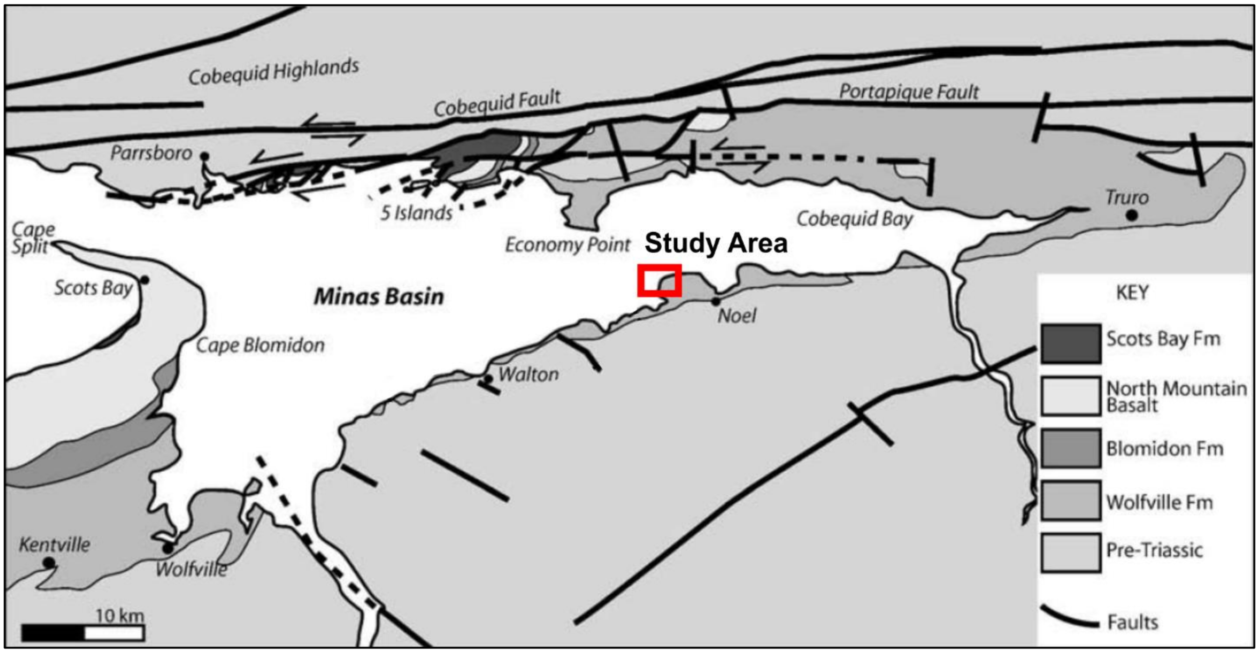


Figure 2.2 Location of study area at Burntcoat Head, Nova Scotia, Canada, within the Minas Basin showing the study site within the Wolfville Fm (Modified from Leleu *et al.*, 2009).

Previous studies of the Burntcoat Head section by Leleu *et al.* (2010) identified coarse-, medium-, and fine-grained sandstones, and claystones and minor conglomerates. The very coarse-granule and medium-grained sandstones were interpreted as bedload deposits of rivers, consisting of bar deposits and channel fill. The fine sandstones were attributed to waning flow in channels, abandoned channels, and overbank settings, and the claystone was interpreted to have settled out of suspension in floodplains. Major and minor surfaces were correlated across stratigraphic sections to understand the fluvial architecture, which revealed the stacking patterns of the fluvial system at Burntcoat Head and nearby Halfmoon Cove. The fluvial deposits consist of channel bodies that stack to form channel belts intercalated with floodplain deposits, and regional paleoflow direction has a mean of N031º (Leleu *et al.*, 2010).

Important vertebrate assemblages of the early Late Triassic have been found within the Wolfville Formation, and bones and teeth of vertebrates are found as clasts within sandstones and conglomerates (Sues, 2003). A recent vertebrate find from the Wolfville Formation at

Burntcoat Head was the partial skeleton of an archosauromorph reptile, *Teraterpeton hrynewichorum* (Sues, 2003). Other finds from Burntcoat Head include procolophonid reptiles including *Acadiella psalidodon*, *Haligonia bolodon,* and *Scoloparia glyphanodon* (Sues & Baird, 1998). These specimens reveal a diversity of tetrapods at Burntcoat Head during the Late Triassic. The medium-grained sandstones at Burntcoat Head have also been found to contain trace fossils and are thought to represent periods of bar abandonment, which allowed for colonization (Leleu *et al.*, 2010).

Chapter 3 Methodology

3.1 Field Analysis

3.1.1 Schematic Diagrams

Schematic diagrams of the channel belts were completed along the study site. Photos of the cliff were merged using Microsoft ICE and these photo pans were used to illustrate the architectural elements of the channel belts and their bounding surfaces, which were traced and interpreted in accord with the orientation of the cliff face in relation to paleoflow. Prominent surfaces and contacts visible in the photo pans were then digitized in CorelDraw® and the photo pans were taken back into the field to check the tracings. The observed lithofacies were interpreted based on the lithofacies set out by Leleu *et al* (2010) and more detailed subfacies were assigned based on the system of Miall (1978). Interpretations of the small-scale lithofacies have long been well understood the interpretations set out by Miall have been listed in Table 3.1. The capital letter represents the predominant grain size and the lower-case represents the characteristic texture or structure of the lithofacies. Architectural elements of the channel belts (Table 3.2) were classified and the depositional units and their bounding surfaces were then assigned hierarchies (Table 3.3) based on the system of Miall (1978, 1985, 1996). Paleoflow measurements were taken from trough-cross bed axis directions for visible trough forms on bedding surfaces and measurement locations are denoted in Figure 1.1. Accuracy of paleoflow measurements is within ten degrees. A rose diagram was then constructed to illustrate paleoflow. Localities of fossils within fallen blocks were recorded and traced back to their source layer, and locations of fossil discoveries from earlier work by others were recorded.

Table 3.1 Lithofacies Classification (Modified from Miall, 1978).

Facies Code	Lithofacies	Sedimentary Structures	Interpretation
St	Sand, fine to v. coarse, may be pebbly	Solitary or grouped trough cross beds	Sinuous-crested and linguoid (3-D) dunes
Sh	Sand, v. fine to coarse, may be pebbly	Horizontal lamination, parting or streaming lineation	Plane-bed flow
Sp	Sand, fine to v. coarse, may be pebbly	Solitary or grouped planar cross beds	Transverse or linguoid (2-D) dunes
Sm	Sand, fine to coarse	Massive or faint lamination	Variable
Fm	Mud, silt	Massive	Overbank or abandoned channel deposits
P	Paleosol carbonate	Pedogenic features – nodules	Soil with chemical precipitation

Table 3.2 Architectural elements in fluvial and abandoned channel and overbank deposits (modified from Miall, 1996).

Element	Symbol	Principal facies assemblage	Geometry and relationships
Sandy bedforms	SB	St, Sh	Lens, sheet, blanket, wedge
Downstream-accretion macroform	DA	St, Sh	Lens resting on flat or channelized base and an upper bounding surface. Accretion surfaces orientated downstream
Lateral-accretion macroform	LA	Sp, Sh	Wedge, sheet, lobe: accretion surfaces oriented across channel. Downlaps onto a basal erosion surface.
Laminated sand sheet	LS	Sh,	Sheet, blanket
Abandoned channel & floodplain fines	FF	Sm, Fm	Extensive lateral dimensions. Up to 4 m thick.

Table 3.3 Hierarchy of depositional units in alluvial deposits (Modified from Miall, 1996).

Rank	Characteristic of bounding surfaces
1st order	Bedding sets of same lithofacies
2nd order	Simple contacts between different lithofacies
3rd order	Internal minor erosion surfaces and reactivation surfaces
4th order	In channel architectural elements including bars
5th order	Major channels
6th order	Contacts between channel belt-complexes

3.1.2 Stratigraphic Sections

Three individual representative stratigraphic sections were measured and combined into a single log. Sites were chosen based on accessibility of outcrop. Bed-by-bed descriptions were completed for each channel body including grain size, sedimentary structures, bed contacts, bioturbation and other components including redox features. Data were collected over a 34-meter interval and drafted into a composite section using CorelDraw®. Locations were recorded and two samples were taken from each channel belt for thin section descriptions. The locations can be seen in Figure 1.1 with the meterage corresponding to the stratigraphic section for each site. The stratigraphic column was used to document the major facies based on lithofacies assigned by Leleu *et al* (2010) representing the depositional settings within the channel belts.

3.2 Microscopic Analysis

Six rock samples were taken from the study area and thin sections were made in the Dalhousie Earth Sciences Department. These thin sections were observed under a Nikon 50i transmitted light microscope and descriptions of the samples were completed, including mineralogy, grain shape, cement and alteration. These descriptions lead to interpretations on burial history. Point counting was completed at Saint Mary's University using Nikon Eclipse E 400 Pol polarising microscope equipped with a Coolpix digital camera, and an automated Stepping Stage and Petrog software from Conwy Valley Systems. Six slides were analyzed and 300 points were counted per slide, assigning a mineral to each point and photomicrographs were recorded for each point. The minerals counted were monocrystalline and polycrystalline quartz, plagioclase, orthoclase, microcline, biotite, muscovite, clays, calcite cement, iron oxide cement, oxides, and lithic fragments.

3.3 Museum Specimens

Vertebrate fossils previously collected from the cliffs along Burntcoat Head were observed at the Nova Scotia Natural History Museum. Detailed descriptions of the sediment they were enclosed in were completed including colour, grain size, sorting and clast lithology, size and roundness (Appendix C). If known, taxonomic information was recorded, and types of bone were identified when possible and the size of the specimens was measured. Taphonomy of the specimens was assessed looking for fractures and breaks in the material, hematite coats, abrasion, and internal or external bone features. The morphologies of the bones and their durability was assessed and the isolated or grouped nature of the bones was recorded along with whether the bones were articulated or disarticulated (Appendix D). Photographs of each specimen were taken, and any GPS locations in the specimen notes were recorded. Only a few of the specimens with GPS coordinates were located within the study area and the others were at higher levels in the upper Wolfville Formation. Other samples were used to gauge the facies associations and taphonomy of the bone material more widely.

Chapter 4 Sedimentology and Fluvial Architecture

4.1 Sedimentology and Stratigraphy

4.1.1 Facies Overview

The 34 m continuous stratigraphic section comprises three lithofacies that were distinguished and adapted from an earlier large-scale study of the site by Leleu *et al.* (2010). These lithofacies are based broadly on grain-size and are coarse-grained-granule grade sandstone, medium-grained sandstone, fine-grained sandstone, and claystone (Fig. 4.1). Miall's (1978) facies classification (Table 3.1) was used in the field as subfacies to provide more detail of bedforms contained within each lithofacies.

For the strata at Burntcoat Head, St subfacies is medium-coarse grained sandstones with stacked trough cross-beds that represent 3D dunes. Sp subfacies is medium-coarse gained sandstones with solitary or stacked planar cross-beds that represent 2D dunes. Sh subfacies is medium-coarse grained sandstones with horizontal laminae that stack to form plane-bedded sandstones. Sm subfacies is medium-coarse grained sandstones with a massive texture; in some cases, the beds may have been structureless at the time of deposition, but other beds may have lacked the grain-size variation to display sedimentary structures or have been weathered and thus may be cryptic representations of other facies. Fm subfacies consists of massive mudstones and fine-grained sandstones, the beds of which stack to form thick deposits. P subfacies represents paleosols with pedogenic features including carbonate nodules.

4.1.2 Facies 1: Coarse-Grained-Granule Grade Sandstone

This lithofacies comprises approximately 15% of the section (Fig. 4.2) and contains beds that vary in thickness from 0.3-2 m and stack to form units 4 m thick. It is composed of red-brown, coarse-grained-granule grade sandstone dominated by subangular to subrounded grains, and contains few extrabasinal pebbles and mudstone clasts (Fig. 4.1). The bases of beds are erosional and are commonly lined with locally abundant angular mudstone clasts that range in size from granules and pebbles (2-5 cm) to boulders up to 1 m in diameter. Facies 1 contains St subfacies composed of trough-cross beds which stack to form 3D dune sets from 60 cm to 1 m in thickness, and Sp subfacies is also present with planar cross-beds stacked to form 2D dunes sets 2 m thick. Intervals of Sm occur where massive beds were observed, stacking to form units 3 m thick.

4.1.3 Facies 2: Medium-grained Sandstone

This lithofacies represents the majority of the strata, and makes up 62 % of the stratigraphic section (Fig. 4.2). Beds are up to 3 m thick and form units up to 6 m thick. Facies 2 consists of red-brown, medium-grained sandstone with common coarse-grained sand and granule clasts and locally abundant mudstone clasts at erosional surfaces, with rare bone fragments (Fig. 4.1). Grains are subangular to subrounded, and mudstone clasts are angular and range in size from 2-20 cm, reaching boulder-sized clasts with diameters up to 70 cm. Facies 2 contains St and Sp subfacies composed of trough and planar cross-beds, attributed to 2D and 3D dunes, with similar set thicknesses to those in Facies 1. Intervals of Sm are present where massive bedding was observed which could be indicative of structureless fill or could be the result of a lack of grain-size differentiation or weathering. Beds of Sm formed units 2 m thick. Numerous scour fills were observed in facies 2, and this facies also contains locally abundant sand-filled burrows.

4.1.4 Facies 3: Fine-grained Sandstone

Facies 3 makes up 21% of the section (Fig. 4.2) and forms units up to 4 m thick. This facies is composed of very fine- to fine-grained sandstone with locally abundant carbonate nodules and minor lenses of medium-grained, clay-rich sandstone (Fig. 4.1). This facies is dominated by subfacies Sm with minor amounts of Fm and is composed of massive beds of fine-grained sandstone and minor mudstone with no obvious structure or bedforms, which stack to form units up to 4 m thick. The massive nature of this facies could imply that stratification was difficult to see, perhaps due to the lack of grain-size differentiation or due to weathering. Burrows are locally very abundant within this facies. P subfacies was present as units up to 0.5 m thick containing pedogenic features including carbonate nodules which range in diameter from a few mm to 3 cm. The nodules are scattered in the upper beds of fine-grained units and locally occur as vertical columns of nodules up to 25 cm in length.

4.1.5 Facies 4: Claystone

Lithofacies 4 comprises 2% of the section (Fig 4.2) and forms thin, discontinuous lenses and pebble- to boulder-sized angular mudstone clasts that line prominent erosion surfaces (Fig. 4.1). No bedding was observed, and sand-filled burrows were documented in some mud clasts. The facies is composed of Fm subfacies, consisting of massive mudstones that were generally observed as mudstone clasts ranging from 2 cm to 1 m in diameter, with most being within the pebble-cobble size range.

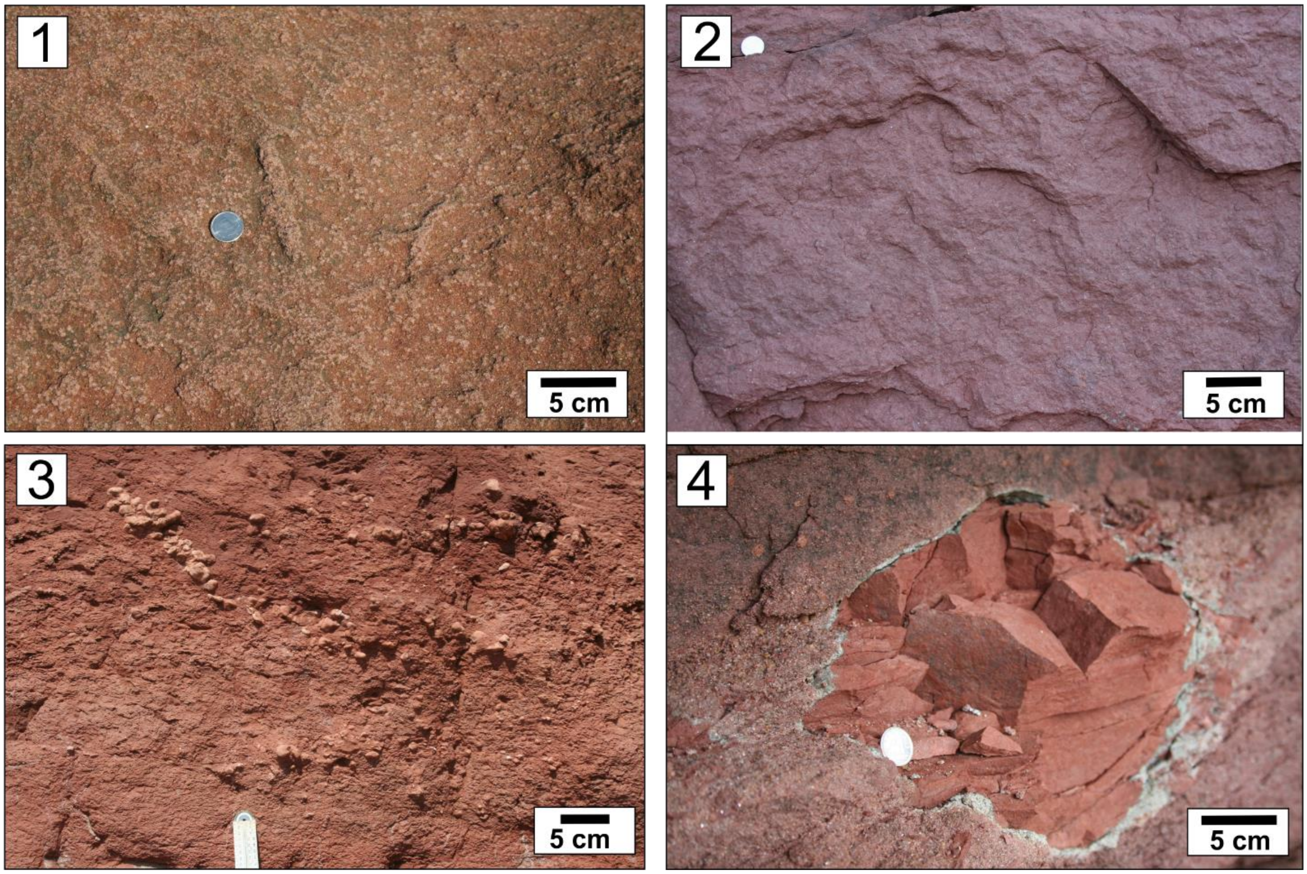


Figure 4.1 Facies observed at Burntcoat Head, Nova Scotia. Facies 1: Coarse-granule grade sandstone, Facies 2: Medium-grained sandstone, Facies 3: Fine grained sandstone, & Facies 4: Claystone represented by a mudstone clasts within a medium grained sandstone.

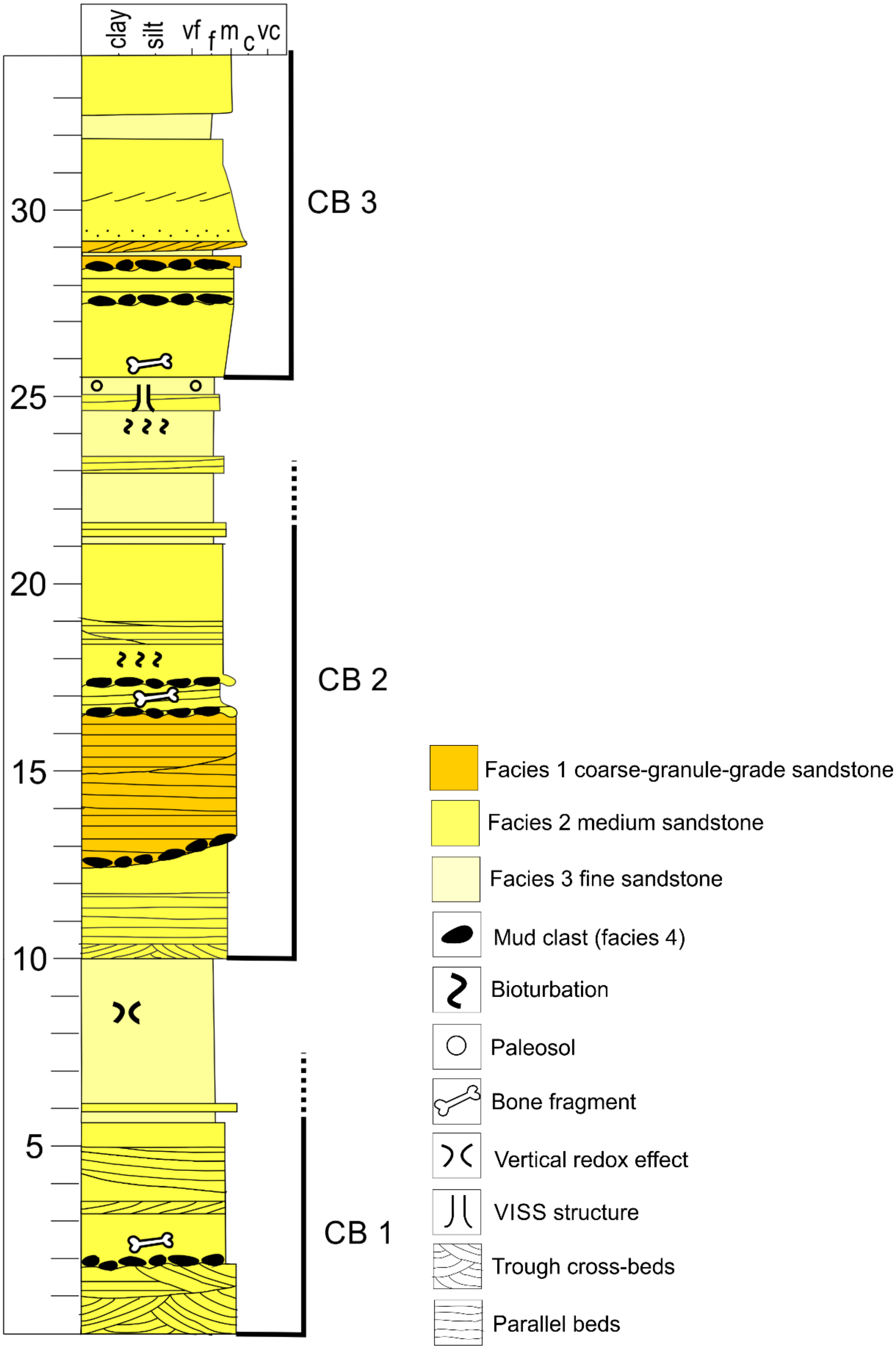


Figure 4.2 Stratigraphic section of the three channel belts (CB) at Burntcoat Head, Nova Scotia showing the four facies making up the channel fill, abandoned channel and floodplain deposits. Stratigraphic section also marks the presence of bioturbation, paleosols, bone fragments, VISS structures, and vertical redox effects. .

4.2 Fluvial Architecture and Paleoflow

4.2.1 Paleoflow

Paleoflow is important to consider when discussing the context of architectural elements and surfaces. Five paleoflow measurements were taken from trough cross-strata and were nearly parallel to the cliff line, with azimuths ranging from 025º-075º NE, and a mean paleoflow direction of 057º NE (Figure 4.3). The majority of paleoflow measurements ranged from 060-075º. These measurements are similar to paleoflow measurements of Leleu *et al.* (2010) from this area, which had two mean directions of N40º and N65º in the upper Burntcoat Head section, with a mean paleoflow direction of N44º (Fig. 4.3).

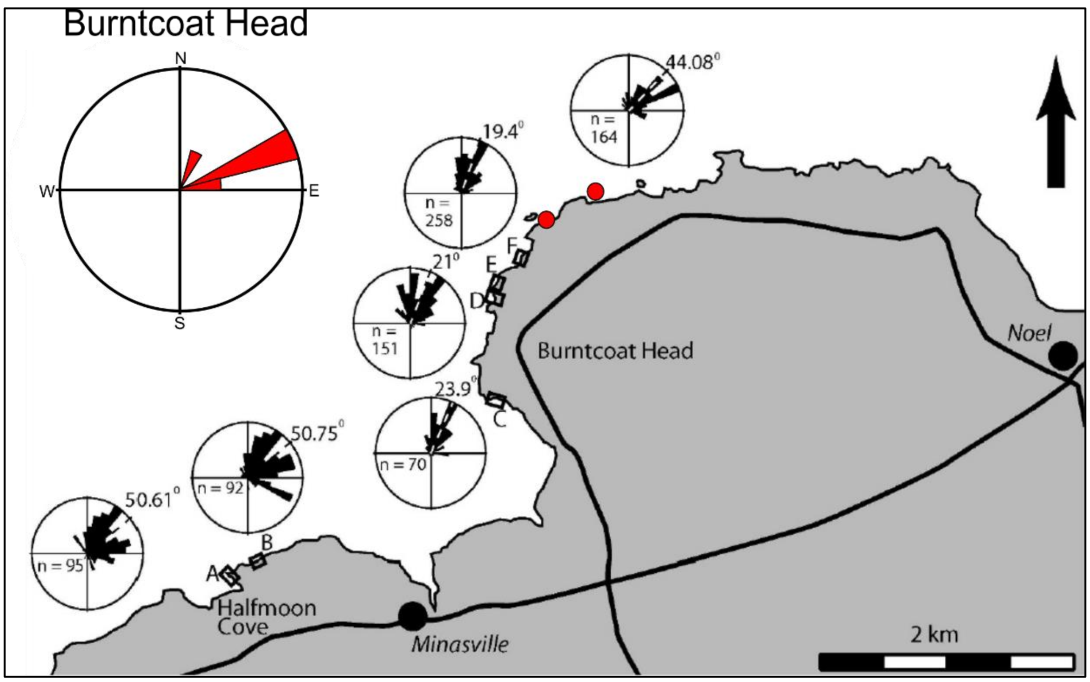


Figure 4.3 Paleoflow orientation measured at Burntcoat Head, Nova Scotia (denoted in red). Measurement locations represented with red circles. Other measurements (denoted in black) completed by Leleu *et al* (2010). Figure modified from Leleu *et al*. 2010

4.2.2 Architectural Elements

Architectural elements were assigned based on classifications by Miall *et al.* (1985, 1996). Braided river deposits, as inferred for this section by Leleu *et al*. (2010), are composed of channel bodies containing two main components: in-channel fill, typically cross-beds generated by the downstream migration of dune trains or, in places, plane beds; and distinctive, large-scale accumulations or bars that result from deposition along the sides of channels or in mid-channel positions and include a variety of bedforms. Bars along the side of channels accrete laterally, whereas mid-channel bars can accrete both downstream and laterally. Channel bodies are overlain by floodplain facies, and similar beds may also be present in abandoned-channel fills. These situations recur repeatedly in fluvial systems through time, leading to a characteristic set of “elements”.

Architectural elements represented by Miall (1985) within channel bodies, representing channel-fill and bar elements, include laminated sand sheets (LS), lateral accretion macroforms (LA), downstream-accretion macroforms (DA), and sandy bedforms (SB). Bedforms associated with LS elements are plane-bedded sandstones and SB elements include large cross-sets attributed to dunes. Overbank architectural elements include abandoned channel and floodplain fines (FF). In some cases at Burntcoat Head, thick units of massive sandstone in Facies 1-3, with only cryptic stratification visible, could not readily be attributed to any element. These architectural elements are visualized within annotated photo pans of the cliff section through Figures 4.5-4.8

At Burntcoat Head, laminated sand sheets (LS) are dominated by medium-grained sandstone (facies 2) and comprise Sh. LS elements are deposited parallel to paleoflow and the dominant bedform is plane-bedding (Fig. 4.4). Measurements from four LS elements in the cliff section show that the bedsets range in thickness from 1.5 to 3 m and are laterally discontinuous, ranging from 10-24 m in lateral extent. They form sheets that have gradational lower-bounding surfaces and erosive or gradational upper-bounding surfaces. They are bounded by channel cuts and within-channel bars, and occur within the lower, middle, and upper parts of channel belts. Thick sections of LS are denoted in Figures 4.6 and 4.7.

Sandy bedforms (SB) are predominantly composed of coarse-grained sandstone and medium grained sandstone (facies 1 and 2) which contain St and Sp. SB elements are deposited parallel to paleoflow and are made up of trough and planar cross-beds, representing large dunes (Fig. 4.4). Measurements from three occurrences of the SB element range in thickness from 1.5-2 m and are laterally discontinuous reaching extents of 4.5 to over 25 m. SB elements occur throughout channel belts and form lenses and sheets, occurring as channel-fill and probably building up in places to contribute to in-channel bars. Lower-bounding surfaces are generally erosional, and occurrences of SB infill the base of channel cuts and scours, whereas the upper-bounding surfaces tend to be gradational, grading into LS elements and massive sandstones. The most extensive section of SB occurs at the base of the cliff section in Figure 4.5.

Downstream-accretion macroforms (DA) are dominated by medium-grained sandstone (facies 2) and contain St, Sp, and Sh. They are interpreted as the deposits of large downstream-accreting bars that occur parallel to paleoflow and, from three measured elements, have thicknesses of approximately 1.5 m and lateral extents from 6.5-9 m in the downstream direction. They have erosive lower bounding surfaces with beds gently dipping downstream and fine upwards with their upper bounding surfaces curved downstream (Fig. 4.4). Preserved DA elements occur as lenses resting on flat or channelized bases and are located near the top of channel belts, forming in-channel bars (Fig. 4.4). The more obvious DA elements occur within the middle of the cliff section in Figure 4.5.

Lateral-accretion macroforms are composed of medium-grained sandstone (facies 2), and contain Sp and Sh. They represent laterally accreting bars which gently dip perpendicular to flow. The orientation of the outcrop being roughly parallel to paleoflow makes distinguishing LA elements more difficult, though a channel cut, oblique to paleoflow reveals one LA element that is 1.5 m thick, with a lateral extent of 3 m (Fig. 4.4). The lower bounding surface is erosive, at the base of a channel cut, and the upper-bounding surface is gradational, grading into a massive sandstone near the top of the channel belt. LA elements form wedges at the side of channel cuts with accretion surfaces orientated across the channel, and beds downlap onto a flat basal erosion surface.

Abandoned channel and floodplain deposits (FF) are dominated by medium-grained and fine-grained sandstones (facies 2 and 3) with few deposits of claystone (facies 4) (Fig. 4.4). Abandoned channel sediments are deposited parallel to paleoflow, while overbank deposits can spread widely in various directions during deposition. The transition from abandoned channel to floodplain deposits is gradational and difficult to distinguish in the field. Some floodplain deposits can be distinguished from abandoned channel deposits by the presence of carbonate nodules, implying prolonged soil formation. Combined thickness of abandoned channel and floodplain deposits is typically 2.5-4 m. Where carbonate nodules are visible, thus allowing the two types of deposit to be distinguished, abandoned channel deposits have thicknesses of approximately 2 m, and floodplains deposits are up to 1 m thick. FF elements are deposited over the in-channel and bar elements and can be traced laterally for over 170 m. The most laterally extensive deposit of FF can be seen in Figure 4.6 within the middle of the cliff section.

Overall, the strata are composed of laterally discontinuous elements dominated by LS and SB. SB deposits were laid down by large dunes and LS packages commonly form thick sets. DA and LA elements represent large accreting bars and these elements are overlain by abandoned channel and floodplain deposits.

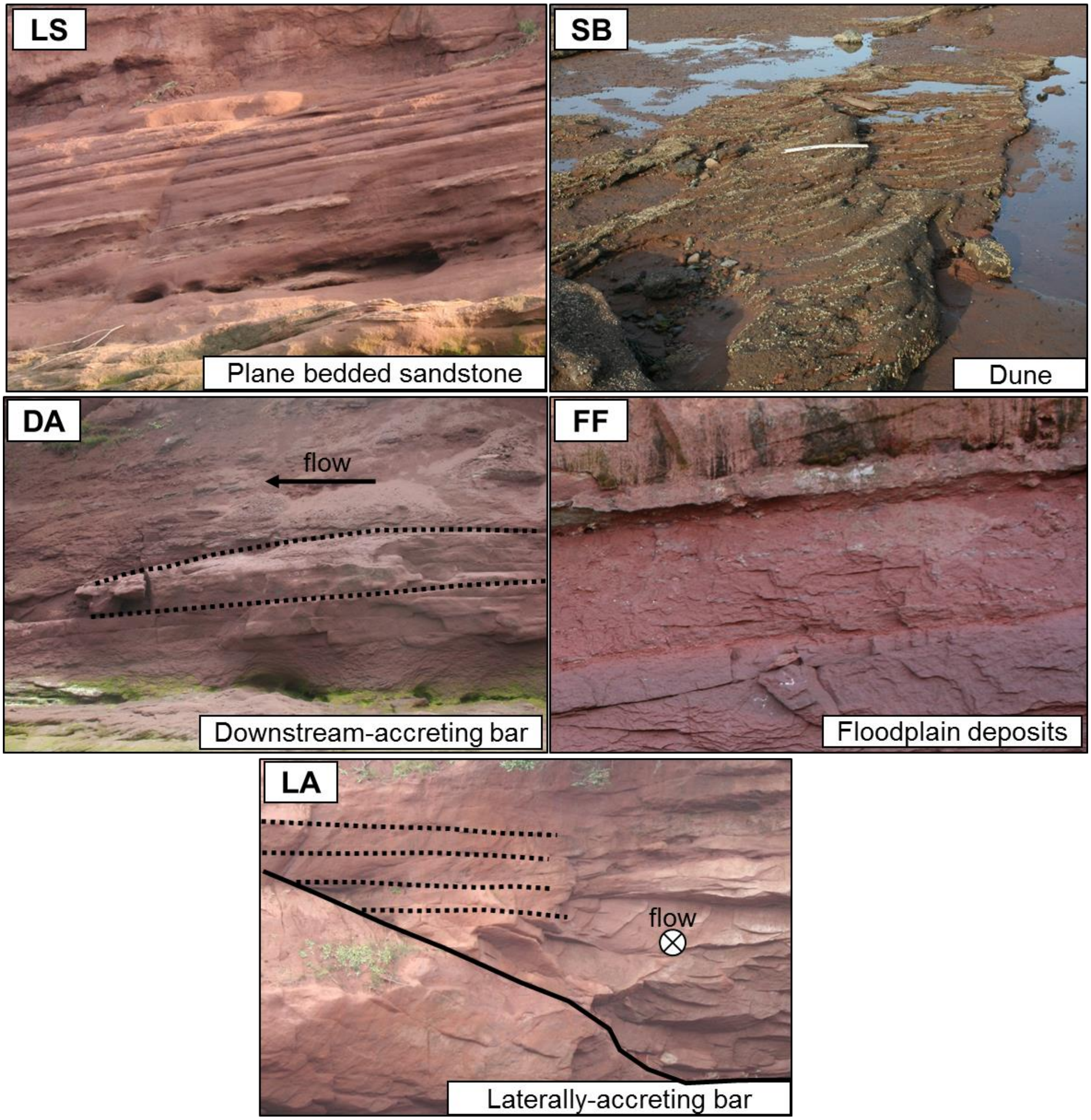


Figure 4.4 Architectural elements and their bedforms observed within the channel belts at Burntcoat Head, Nova Scotia. These include: Laminated sand sheets (LS) composed of plane-bedded sandstone, sandy bedforms (SB) composed of dunes, downstream-accretion macroforms (DA) composed of downstream-accreting bars, abandoned channel and floodplain fines (FF), and lateral-accretion macroforms (LA) composed of laterally accreting bars.

4.2.3 Surfaces

A hierarchy of surfaces was assigned based on the classification from Miall *et al.* (1996), and five ranks of surfaces were recognized within the three channel belts. Bounding surfaces between individual beds of the same lithofacies are classified as rank 1 bounding surfaces and simple contacts between different lithofacies are rank 2. Architectural elements including bars are bounded by rank 4 surfaces, and internal minor erosion surfaces and reactivation surfaces are rank 3. Major channel surfaces are classified as rank 5. Surfaces marking contacts between the three major channel belts are rank 6. These surfaces are illustrated through Figure 4.5-4.8 showing their position, geometries and extents through the cliff section.

In the Burntcoat Head outcrop belt, rank 6 surfaces are the most extensive and represent the contact between channel belts. They are near-horizontal with respect to the stratification, are visible parallel to paleoflow in the cliff section, and can be traced over distances greater than 170 m. These surfaces are sharp and erosive with up to 2 m of relief, and are laterally continuous contacts where medium- to coarse-grained sandstone of in-channel facies overlies fine-to medium-grained sandstone of abandoned channel and floodplain facies (Figs. 4.6-4.8). Surface 6-1 marks the start of channel belt 1 and is an erosive surface with about 20 cm of fine-grained floodplain facies below. It is laterally extensive, though the entire horizontal extent was not measured in the field. The thin nature of floodplain facies below suggests significant erosion beneath this surface. Surface 6-2 marks the base of channel belt 2 and is also an erosive surface with 4 m thick deposits of fine-grained floodplain facies below it. Surface 6-3 is a sharp, erosive surface with up to 2 m of relief which marks the beginning of channel belt 3; it can be seen in Figures 4.6-4.8 and can be traced over 170 m laterally and overlies up to 3 m of fine-grained floodplain facies.

Rank 5 surfaces represent channel cuts and occur at the base of channel bodies. They occur within channel belts and are variable in scale. Where viewed parallel to flow these surfaces run horizontal, and are curved when seen in outcrop views perpendicular to flow. Some rank 5 surfaces can be traced laterally over 150 m when parallel to paleoflow (Fig. 4.6). Rank 5 surfaces oblique to paleoflow are more discontinuous, and two measured channel cuts have basal surfaces of rank 5 that fade out laterally and have extents of 18-27 m and vertical relief of 2-4 m. A clear rank 5 channel cut surface that is oblique to paleoflow can be seen in the middle of the cliff section in Figure 4.7, represented by a non-parallel curved surface with a vertical relief of approximately 4 m. These surfaces bounding the base of channel bodies are overlain by laterally and vertically stacked bar elements and channel fill with some fine-grained deposits, and the channel bodies range from 2 to 5 m in thickness.

Rank 4 surfaces bound architectural elements. These surfaces are variable in their continuity. Rank 4 surfaces seen in sections parallel to paleoflow and bounding the base of abandoned channel and floodplain fine deposits can be traced laterally over 170 m (Figs. 4.5 & 4.6). Rank 4 surfaces bounding bedforms, laminated sand sheets, and downstream-accretion macroforms are more discontinuous and variable in their extent, which is controlled by the size of the architectural elements as discussed in 4.2.2. These surfaces are prominent in Figure 4.5 running on top of downstream-accreting bars in the middle of the cliff section. Rank 3 surfaces, representing minor erosion and reactivation surfaces, have limited lateral extent and are seen as small scours with relief up to 0.5 m; reactivation surfaces that cut the upper parts of bar forms extend laterally for up to 12 m. Rank 2 and rank 1 surfaces representing contacts between lithofacies and bedding sets of the same lithofacies have the most limited horizontal extents and are difficult to follow laterally for more than a few meters. These are the most abundant surfaces within the cliff section denoted in grey in Figures 4.5-4.8.

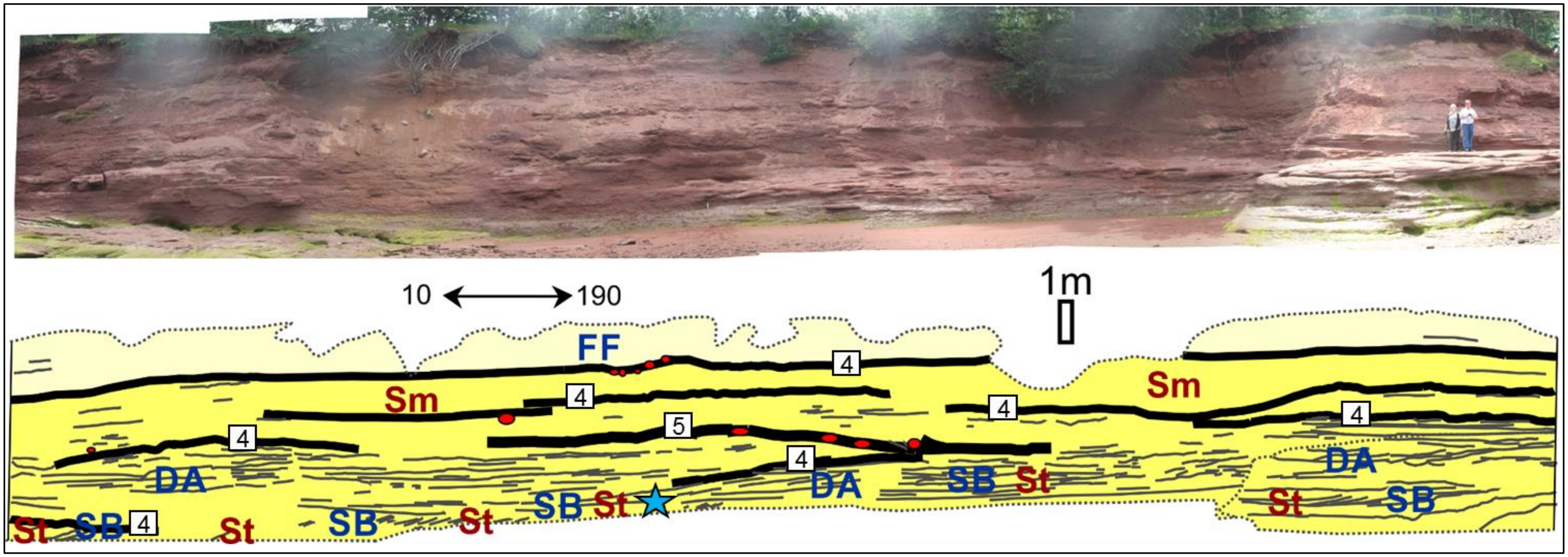
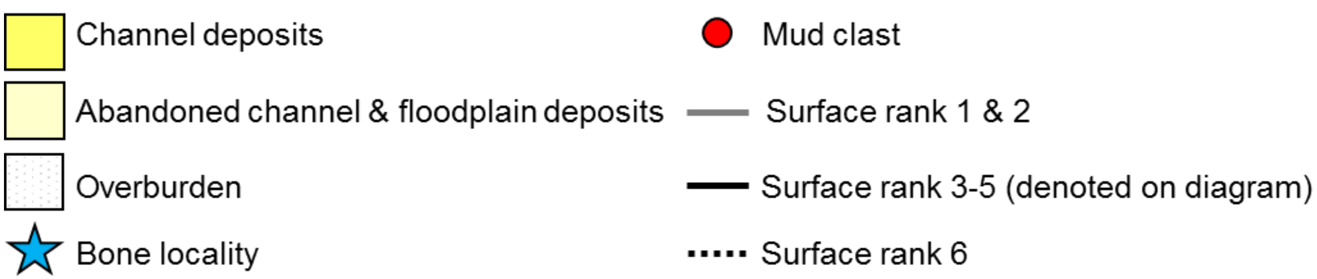


Figure 4.5 Schematic diagram of the top of channel belt 2 and the overlying abandoned channel and floodplain fines (FF). The channel belt section is predominantly composed of downstream-accreting bars (DA elements) and dunes forming trough-cross beds (St). Interpretation is limited by quality of outcrop and due to the moderately weathered upper section of cliff, the strata assigned the subfacies Sm. Location of *Stahleckeria* bone site is within the base of the cliff section within trough-cross beds.



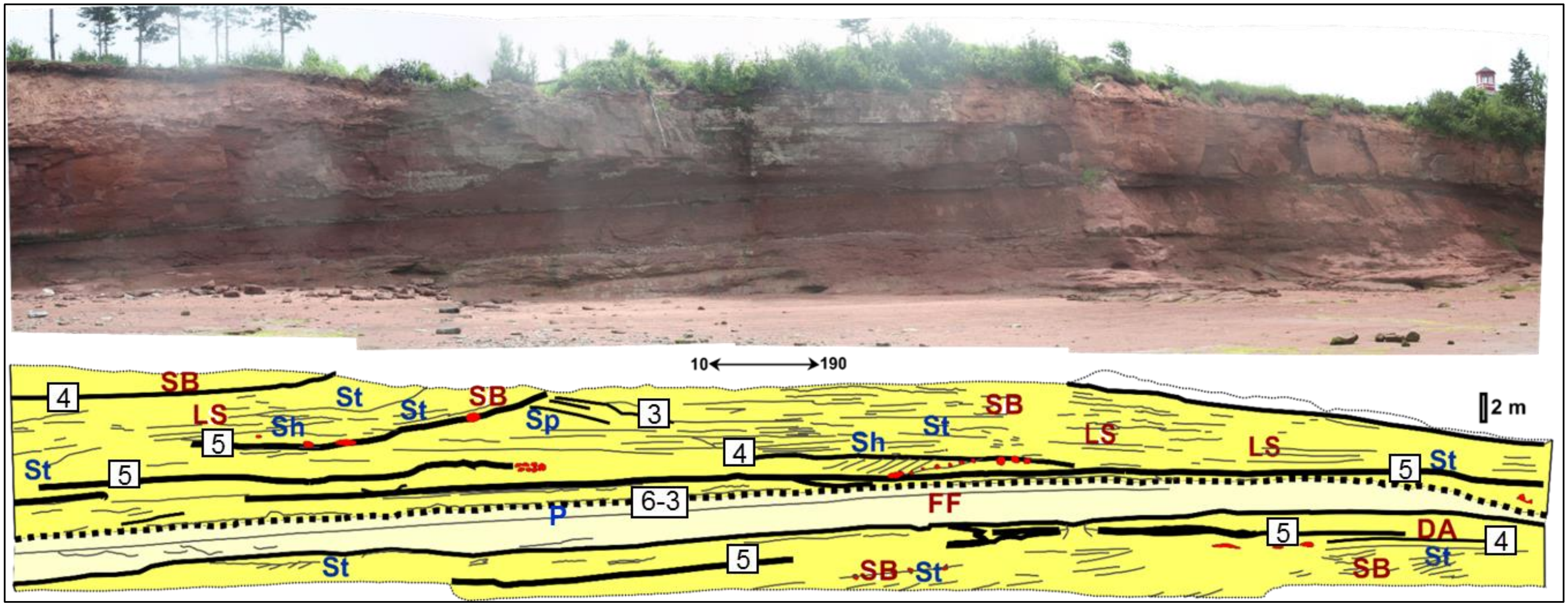


Figure 4.6 Schematic diagram of the top of channel belt 2 and the base of channel belt 3 with abandoned channel and floodplain fines (FF) in between. The channel belt section is predominantly composed of thick deposits of LS, and SB elements. Large channel cuts represented by rank 5 surfaces have up to 4 m of relief and are also seen running parallel to paleoflow with large lateral. The base of channel belt 3 is illustrated by the erosive 6-3 surface. Full interpretation limited by quality of outcrop.

Channel deposits
Abandoned channel & floodplain deposits
Overburden
Mud clast
Surface rank 1 & 2
Surface rank 3-5 (denoted on diagram)
Surface rank 6

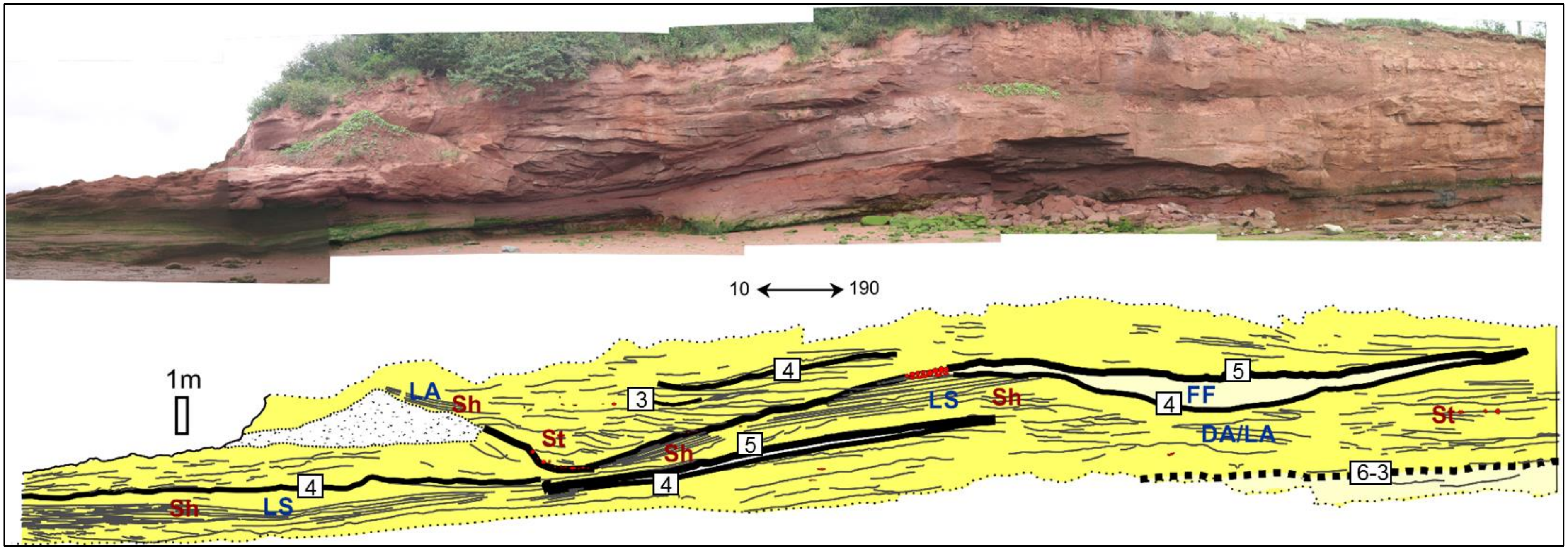
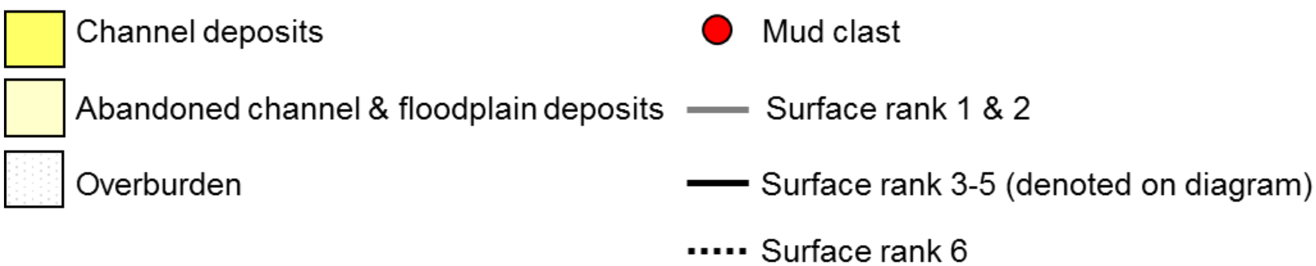


Figure 4.7 Schematic diagram of channel belt 3 and underlying abandoned channel and floodplain fines (FF). Within this channel belt section a large channel cut non-parallel to paleoflow is represented by a rank 5 surface cutting though the middle of the diagram. This channel belt is composed of DA/LA, and LS elements as well as plane-bedded sandstones and trough-cross beds (St). Interpretation limited by quality of outcrop.



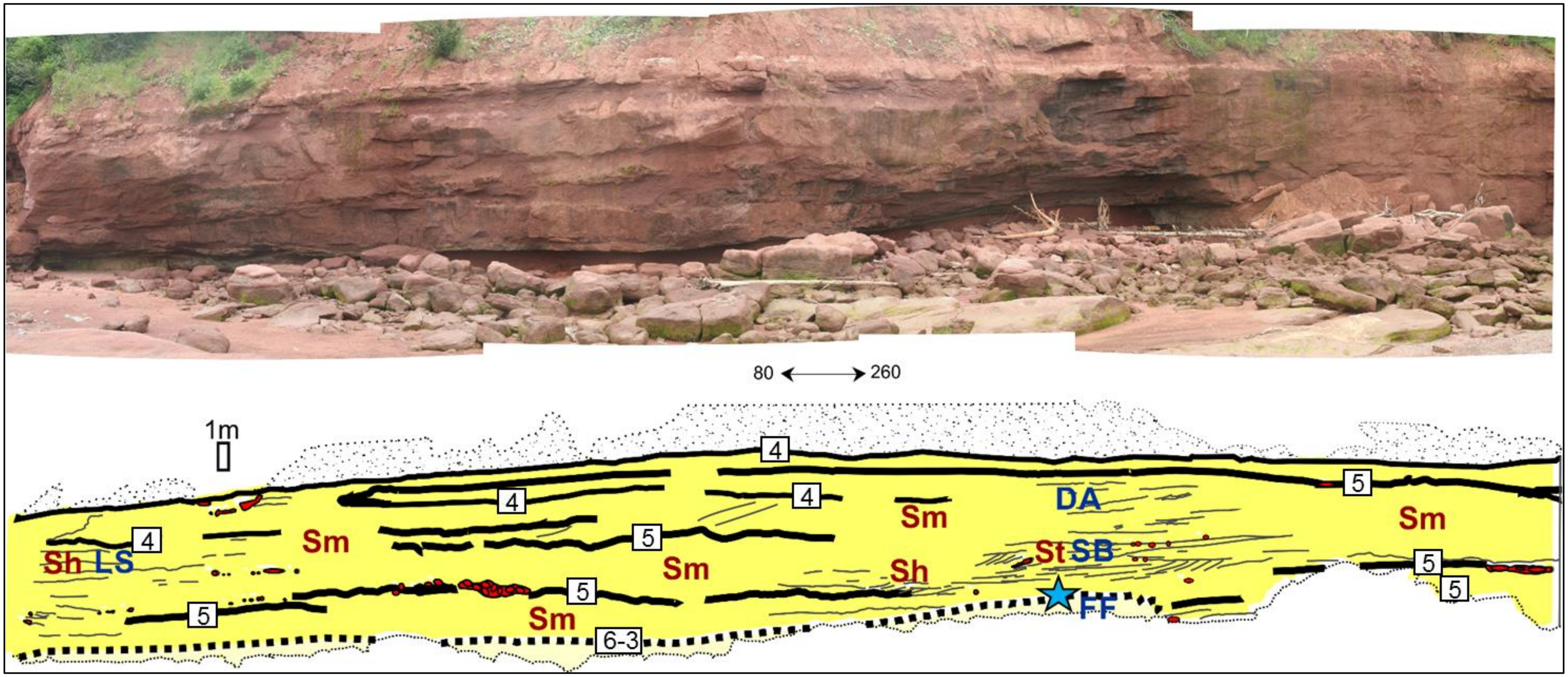
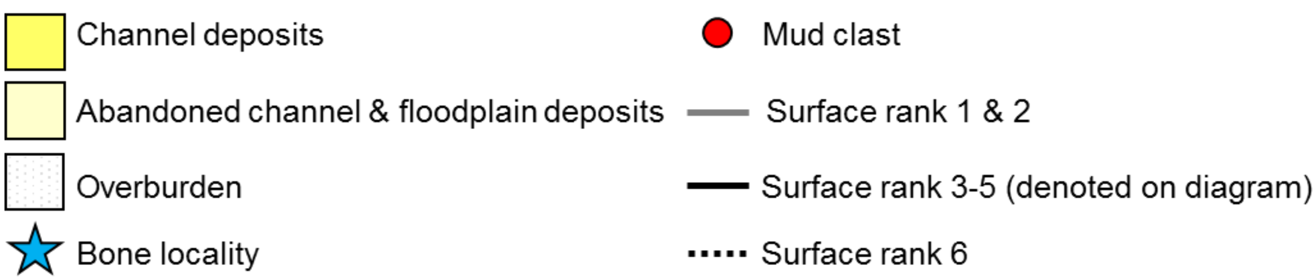


Figure 4.8 Schematic diagram of the top of channel belt 3 above the 6b surface. The cliff section is predominantly composed of Sm due to the quality of the outcrop with few visible DA, LS, and SB elements as well as abundant mud clasts. Interpretation limited by quality of outcrop. Location of isolated bone fragment is marked at the base of channel belt 3.



4.2.4 Channel Bodies and Channel Belts

Overall the study section is composed of packages of stacked channel bodies, forming three channel belts, which are overlain by abandoned channel and floodplain deposits. These three channel belts can be seen in the stratigraphic column (Figure 4.2), denoted CB1, CB2, and CB3, and the gradual transition from abandoned-channel fill to floodplain deposits is denoted by the hashed line. Channel bodies are composed of laterally and vertically stacked channel-fill and bar elements (LS, SB, DA and LA) with a few fine-grained deposits (FF). Individual channel bodies denoted by rank 5 surfaces range in thickness from 2-5 m; in most cases channel widths could not be determined due to the cliff line being near parallel to paleoflow, though one oblique cut revealed a minimum channel width of about 12 m. These packages of stacked channel bodies are overlain by abandoned channel and floodplain deposits which range in thickness from 0.2-4 m. Packages of stacked channel bodies are considered channel belts. The start of a new channel belt is denoted by erosive rank 6 surfaces, and three of these can be identified in the studied section as seen in Figure 4.2 with channel belts ranging in thickness from 5.5-11 m in thickness.

Chapter 5 Biological Evidence

5.1 Vertebrates

Recently studied specimens recovered from the section include the partial skeleton of an archosauromorph reptile, *Teraterpeton hrynewichorum* (Sues, 2003) and procolophonid reptiles including *Acadiella psalidodon*, *Haligonia bolodon*, and *Scoloparia glyphanodon* (Sues & Baird, 1998). A currently studied specimen has been provisionally identified as the genus *Stahleckeria* (MacRae written communication, 2015), and rare unidentified bone fragments and teeth of tetrapods occur as clasts within sandstones.

Over 75 specimens have been recovered from the Burntcoat Head area. Most of these specimens have no location data recorded, making exact channel associations impossible to determine. The five known bone localities are shown in Figure 1.1, though only three of these can be traced to their source beds. Bones and teeth occur predominantly as isolated fragments, essentially clasts, within sandstones. Based on the grain size of sediment enclosing specimens from the museum, most of the bone material occurs in facies 2 and 3. Approximately 40% of the specimens were found within sediments dominated by facies 2 and 55% of the samples were located in sediments dominated by facies 3 (Fig. 5.1). Only 5% of the samples were found within facies 1 sediments, and none were observed in facies 4 sediments (Fig. 5.1). Approximately 36% of the samples were associated with angular mudstone clasts (Fig 5.2), which were generally in the granule-pebble size range, though the amount of sediment surrounding each specimen was limited.

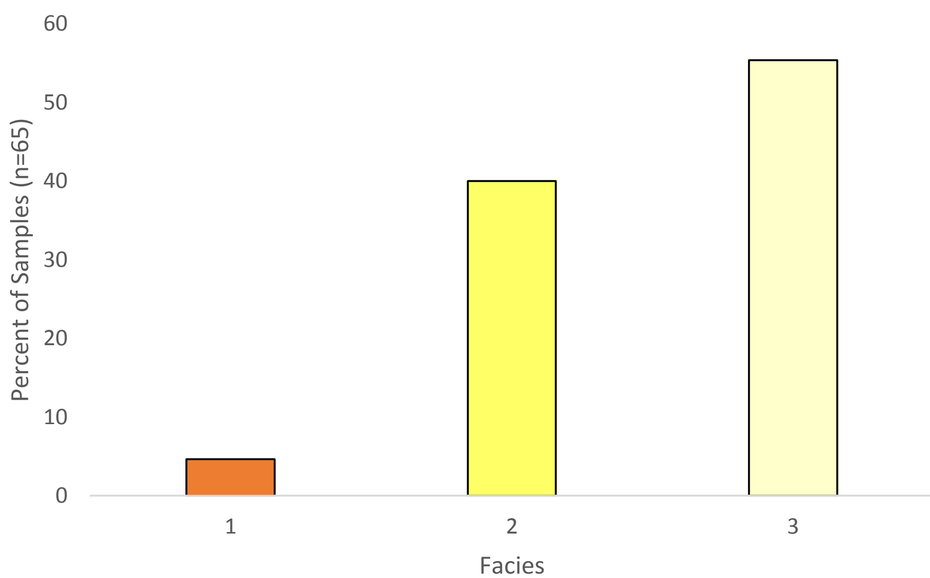


Figure 5.1 Percent of bone fragment specimens occurring in sediments belonging to facies 1, facies 2 and facies 3.

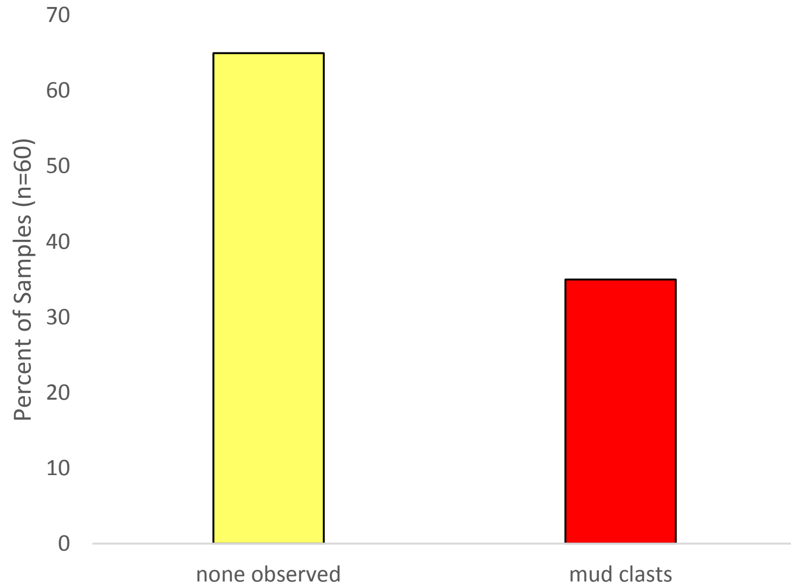


Figure 5.2 Percent of bone fragment specimens occurring in sediments with mud clasts and where no mud clasts were observed.

Only three bones have exact known field localities to the source layer. Two bone fragments were found occurring as isolated pieces in sandstone blocks. One bone fragment was located in the middle of channel belt 1 surrounded by facies 1 sediments and occurred near the base of a channel cut (Fig. 5.3). Its approximate position within the stratigraphic column can be seen in Figure 4.2. The other bone fragment was located at the erosive base of channel belt 3 within a medium-grained sandstone, associated with angular mudstone clasts (Fig. 5.3). Its location can be seen in in the schematic diagram of channel belt 3 (Fig. 4.7) and its approximate location within the stratigraphic column is seen in Figure 4.2. The third known locality was a partial *Stahleckeria* specimen located within the middle of channel belt 2 within trough-cross beds attributed to dunes (Fig. 5.3). This bone site is located within base of the cliff section in Figure 4.5 and its approximate location within the stratigraphic column can be seen in Figure 4.2.

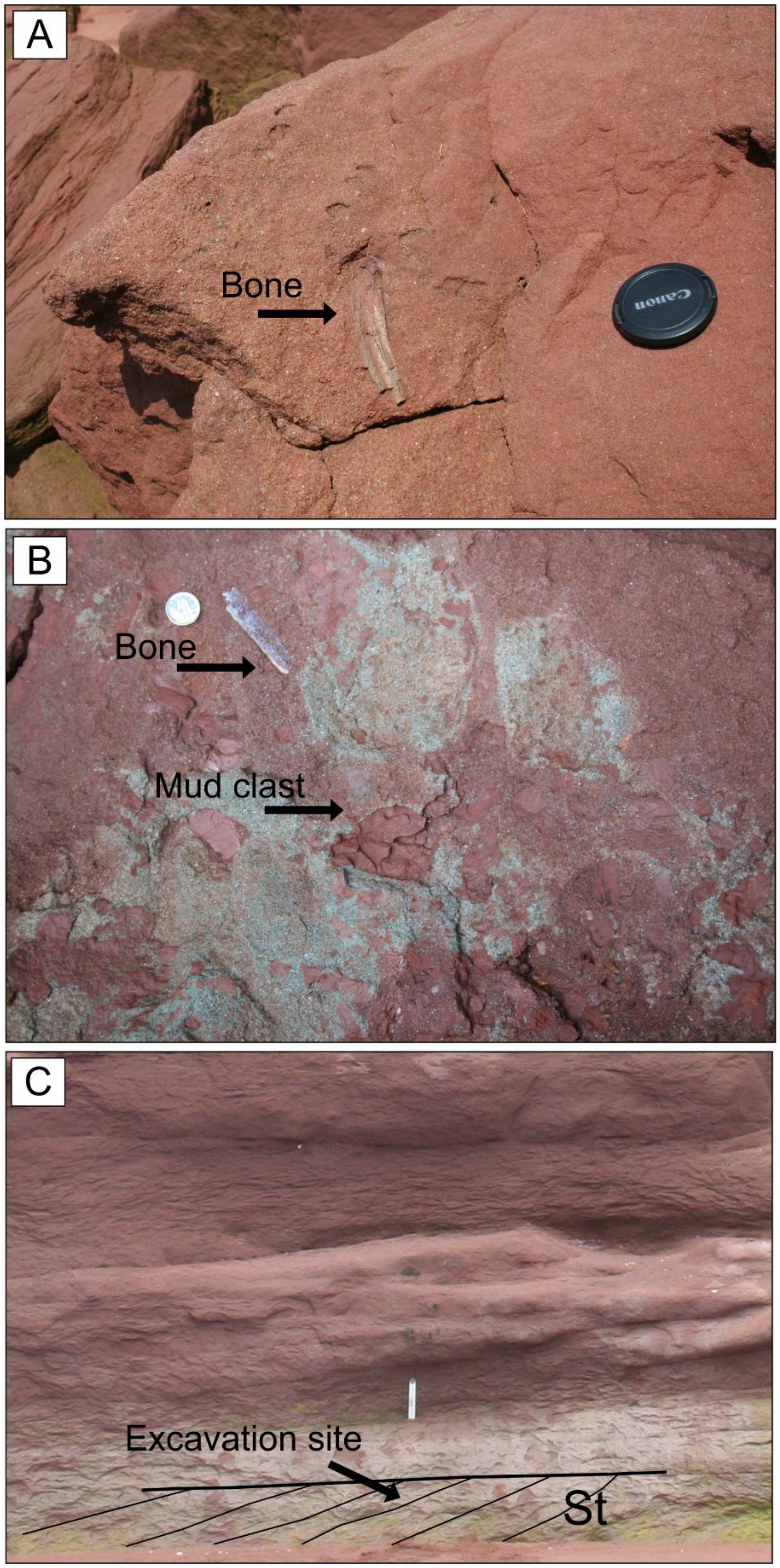


Figure 5.3 A) Bone fragment within sandstone block from a channel cut in channel belt 1. B) Bone fragment with angular mud clasts at the base of channel belt 3. C) Approximate excavation site of *Stahleckeria* bone from channel belt two within trough-cross bedded sandstone.

Bones in the museum collection and at known field sites range in length from 0.2-20 cm and in width from 0.1-8 cm and some examples of the variety of specimens can be seen in Figures 5.5 and 5.6. The median length of bone material is 1.5 cm and the median width is 0.6 cm. Most of the specimens occur as isolated pieces of disarticulated bone, and less than 1% of these occur as partially articulated specimens. Around 24 specimens were small jaw fragments, ranging in lengths from 0.2-3.7 cm and with widths from 0.3-1.5 cm and these made up 34% of the specimens (Fig. 5.4). Other bone material included four isolated specimens of individual vertebrae with lengths from 1.6-8 cm and widths of 0.3-5.5 cm, nine specimens of isolated and mostly partial limb bones with lengths from 0.9-1.4 cm and widths of 0.15-1 cm, six small teeth, and two scute impressions with lengths of 2.5-3 cm and widths of 1.4-2 cm (Fig. 5.4). Many of the other bones (about 45 % of the specimens) were too fragmentary to identify.

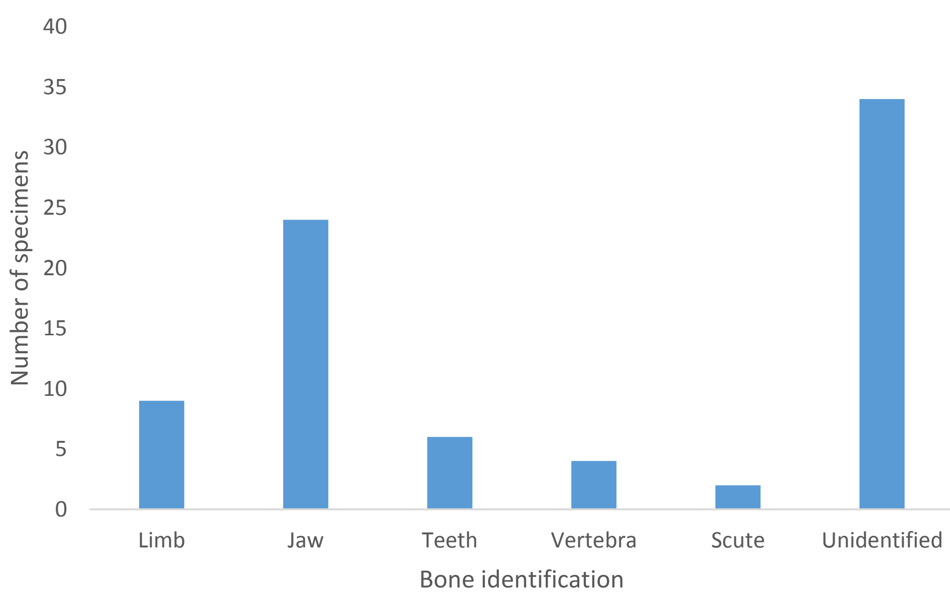


Figure 5.4 Bone identifications for specimens recovered from Burntcoat Head Nova Scotia including limbs, jaw fragments, teeth, individual vertebrae, scute impressions, and unidentified fragments.

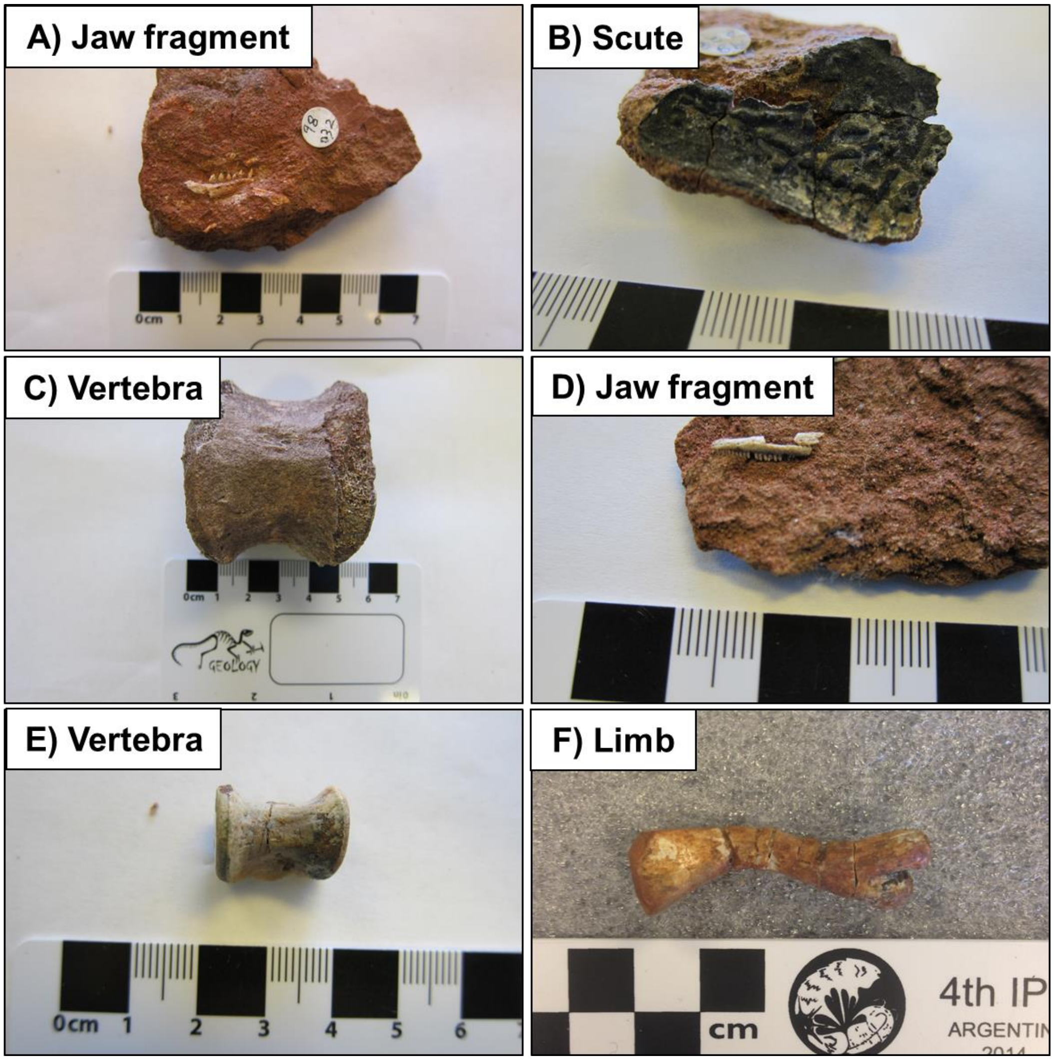


Figure 5.5 Examples of museum specimens collected from the Burntcoat Head Area showing the variety of morphologies observed including A) Jaw fragment (NSM98032), B) Scute impression (NSM98028) C) Vertebra (NSM94065), D) Jaw fragment (NSM98001), E) Vertebra (NSM94067), and D) Limb bone (NSM000GF023.3).

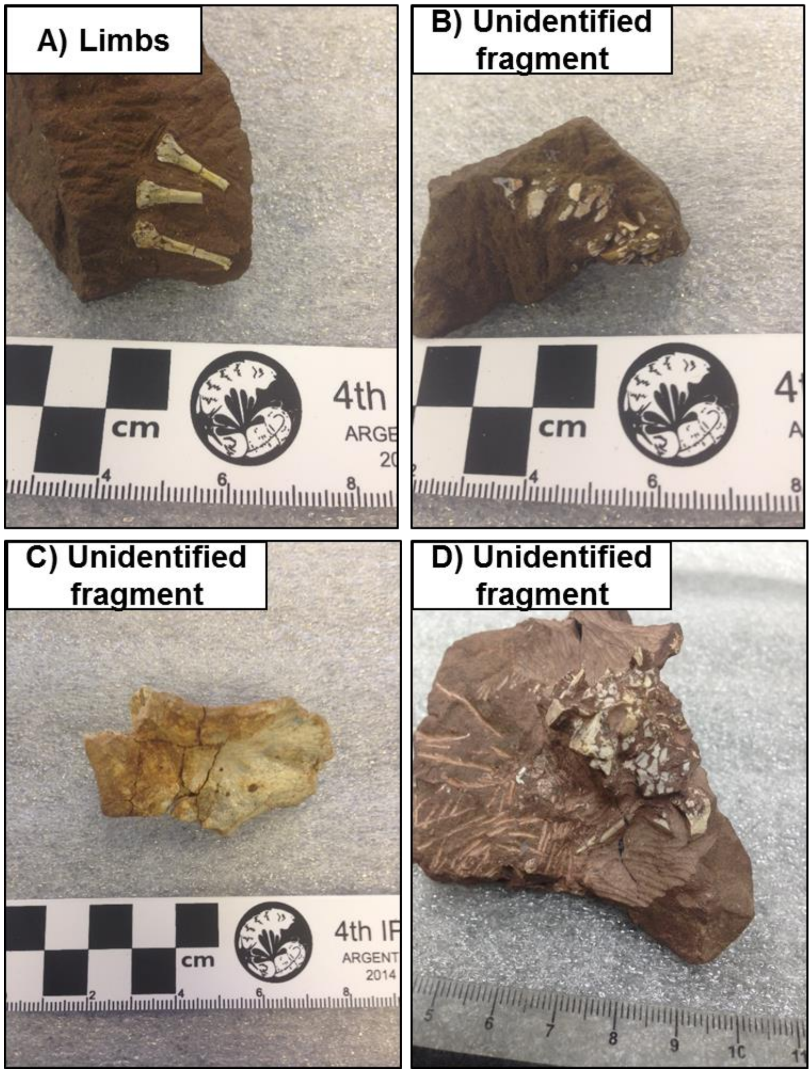


Figure 5.6 Examples of museum specimens from the Burntcoat Head area including A) limb bones (NSMM23), B) unidentified bone fragments (NSM66-1), C) unidentified bone fragment (NSM96052) & D) unidentified bone fragments (NSMM-12)

Most of the bones were somewhat abraded and had broken edges where the internal bone could be observed. Bone fractures were often filled with sediment, and in cases where the soft parts of specimens were absent, (the inside of large teeth, inside of bones) this was filled with sediment. Bones also commonly had hematite coats.

Provisional taxonomic identifications of specimens are limited due to the broken and isolated nature of most bone fragments. Some provisional identifications of specimens, provided in the museum information sheets, were completed by Sues and Hrynewich, and include one maxilla belonging to a the genus *Rhyncosauria* of archosaruomorph reptiles, one jaw attributed to the Traversodontidae family, seven fragments belonging to procolephonid reptiles, one jaw attributed to *Scoloparia* genus of this family, and six fragments of *Protosuchus* jaws and teeth (Fig. 5.6). One fish fragment composed of amalgamated scales was also observed (Fig. 5.6), and a *Stahleckeria* specimen was recently found within the study area (MacRae, written communication, 2015). The taxonomic groups of vertebrates found around Burntcoat Head are listed in Table 5.1 and some examples of artistic reconstructions of these taxa can be seen in Figure 5.7.

Table 5.1 Taxonomic groups of vertebrates found around Burntcoat Head, listing the number of specimens assigned to each family. Note, only one of the 7 Procolophonia reptiles has been provisionally identified as *Scoloparia.*

Phylum	Class	Order	Family	Genus	# of specimens
Chordata	Reptilia	Anapsida	Procolephonia	*Scoloparia* (1)	7
Chordata	Reptilia	Diapsida	Archosauromorpha	*Rhyncosauria*	1
Chordata	Reptilia	Crocodylomorpha	Prodosuidae	*Protosuchus*	6
Chordata	Synapsida	Cynodontia	Traversodontidae	*?Arctotraversodon*	1
Chordata	Synapsida	Dicynodontia	Stahleckeriidae	*Stahleckeria*	1
Chordata	?Fish fragment				1

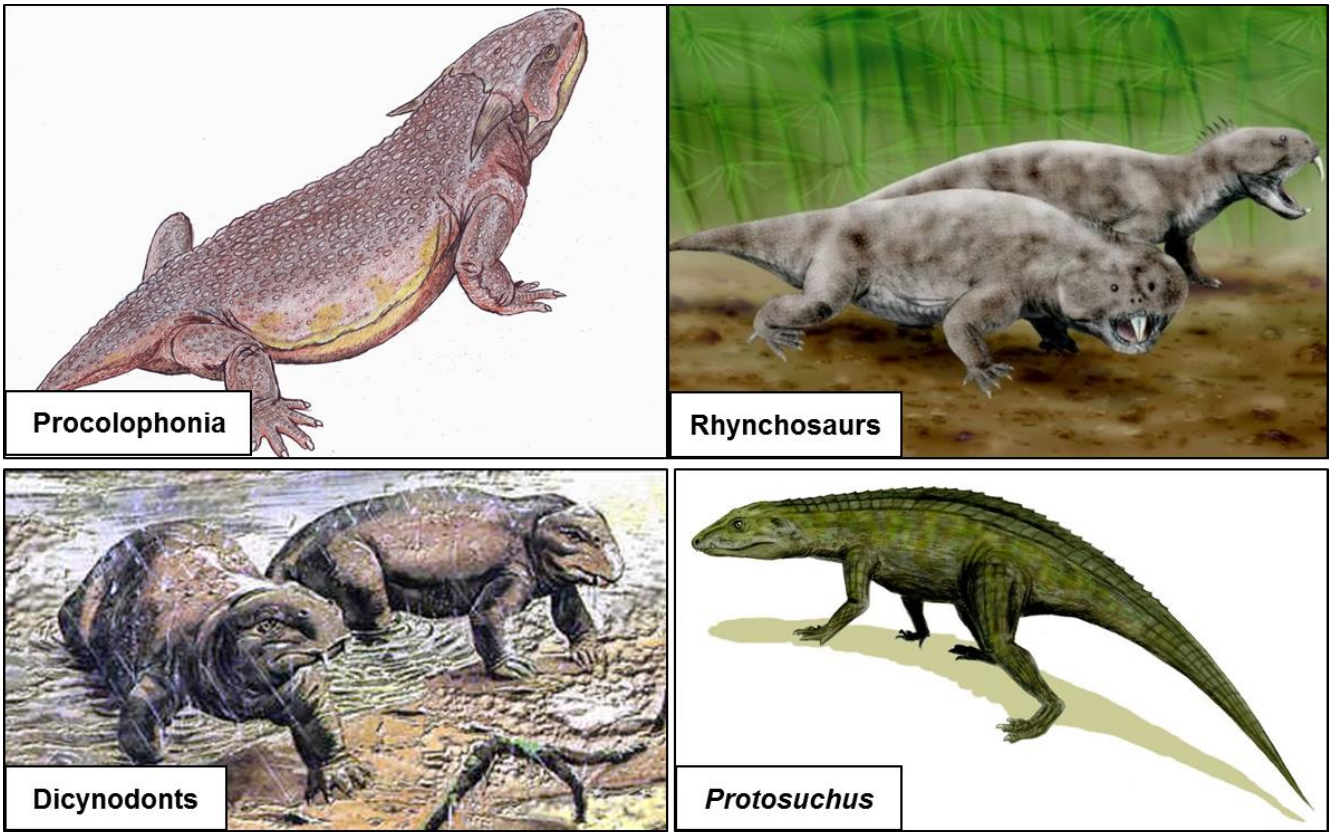


Figure 5.7 Artistic reconstructions of various taxa observed at the study site. Procolophonia image (en.academic.ru), Rhynchosaurs image (palaeos.com), Dycynodonts image (palaeos.com), and *Protosuchus* image (carnivoraforum.com).

5.2 Invertebrates

Trace fossils occur within coarse-, medium-, and fine-grained sandstones, and claystones (Fig. 5.8). They occur within channel deposits and within abandoned channel and floodplain fines. They are also present within mudstone clasts that have been incorporated into channel fill deposits. Burrows range in length from 2-30 cm, with an average length of 7 cm ± 4 cm and widths range from 0.2-1.5 cm with an average width of 0.7 cm ± 0.4 cm. Traces preserved in mudstone clasts are filled with a contrasting grain size of fine-medium sand (Fig. 5.8). Within the sandstone of channel belt 1, the burrows have been identified as probably *Taenidium* and *Planolites* traces produced by the same animal (L.Dafoe, written communication, 2015). *Planolites* contain unstructured fills and *Taenidium* is composed of backfilled traces with no lining, and well preserved specimens have tightly backed menisci (Fig. 5.8 & 5.9) (Baucon *et al*. 2014). Trace fossils within channel belts 2 and 3 with poorer preservation are also attributed provisionally to animals, though their ichnology is not clear (Fig. 5.8).

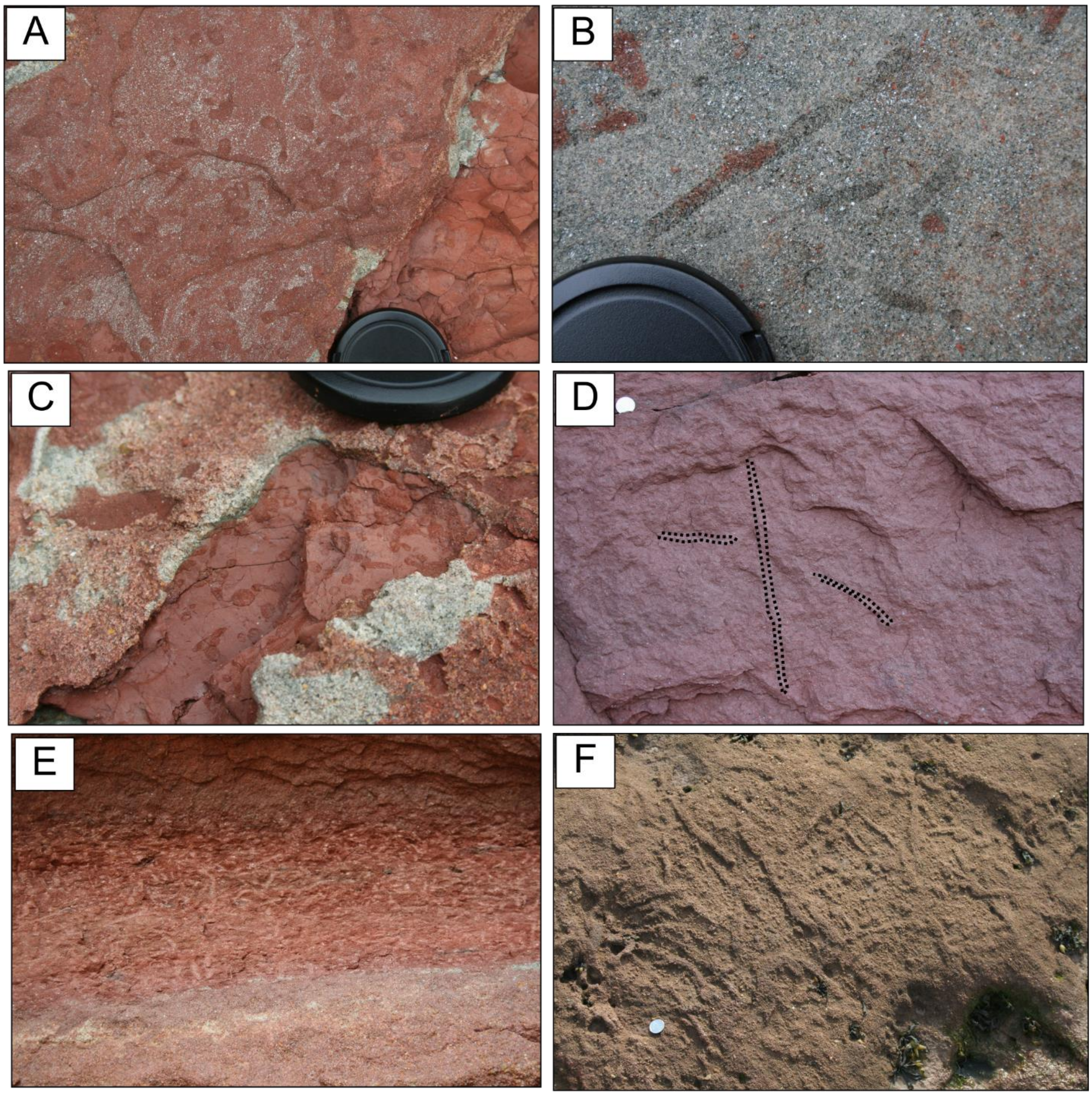


Figure 5.8 Traces from sediments at Burntcoat Head, Nova Scotia. A) Traces in facies 2 B) *Taenidium* backfilled traces in facies 2 C) Sand-filled traces in a mud stone clast within a facies 2 block. D) Traces in facies 2 E) Abundant traces in Facies 3 F) Traces in Facies 1.

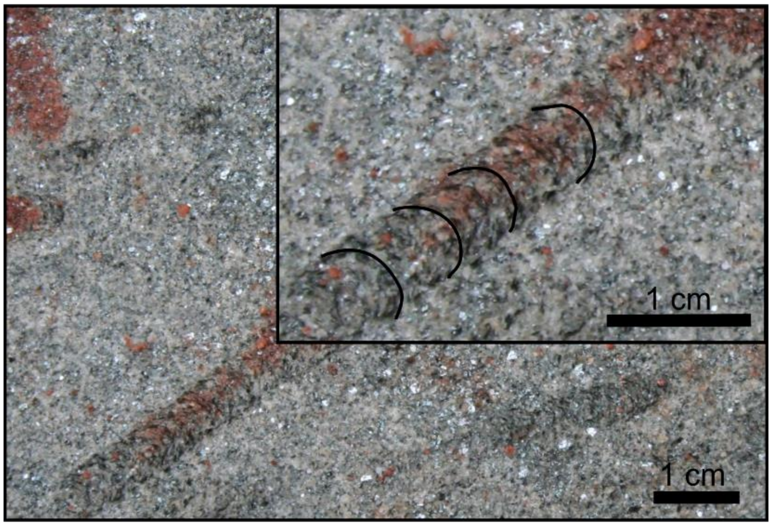


Figure 5.9 Closer view of *Taenidium* backfilled traces within facies 2 with tightly packed menisci denoted in black.

5.3 Plant Evidence

No plant fossils were observed within the channel sediments at Burntcoat Head. However, evidence of possible vegetation-induced sedimentary structures was documented (Fig. 5.9). Vegetation-induced sedimentary structures are structures which form by the interaction of detrital sediment with plants *in situ* (Rygel *et al.* 2004). These structures comprise hollows filled with fine-grained sandstone. Two structures were documented, which range in height from 0.3 to 0.9 m and have widths of 0.1 to 0.2 m. The fills are composed of massive reddish-brown fine-grained sandstone with carbonate nodules, with reddish-brown medium-grained sandstone beds terminating against them. The fills form near-vertical areas of finer grained material abruptly juxtaposed against coarser material, which are presumed to be forming cylinders, though none were observed in planview, which have sharp, erosional bases or gradual bases with coarser grained material below (Fig. 5.10).These structures were observed within the base of channel belt 3 and their location within the study area is denoted in Figure 1.1 and their approximate position within the stratigraphic section can be seen in Figure 4.2.

Another possible biologic effect is prominent vertical zones with redox features (Fig. 5.11. They occur in areas where reddish-brown medium-grained sandstone layers are overlain by reddish-brown fine-grained sandstones and claystones. Between these contacts there are greyish-blue redox layers that downturn into the medium-grained sandstones. Dimensions of these features are in the decimeter scale, though precise measurements were not taken in the field. These features were seen within Channel belt 1 and an approximate location of one of these features within the stratigraphic section can be seen in Figure 4.2.

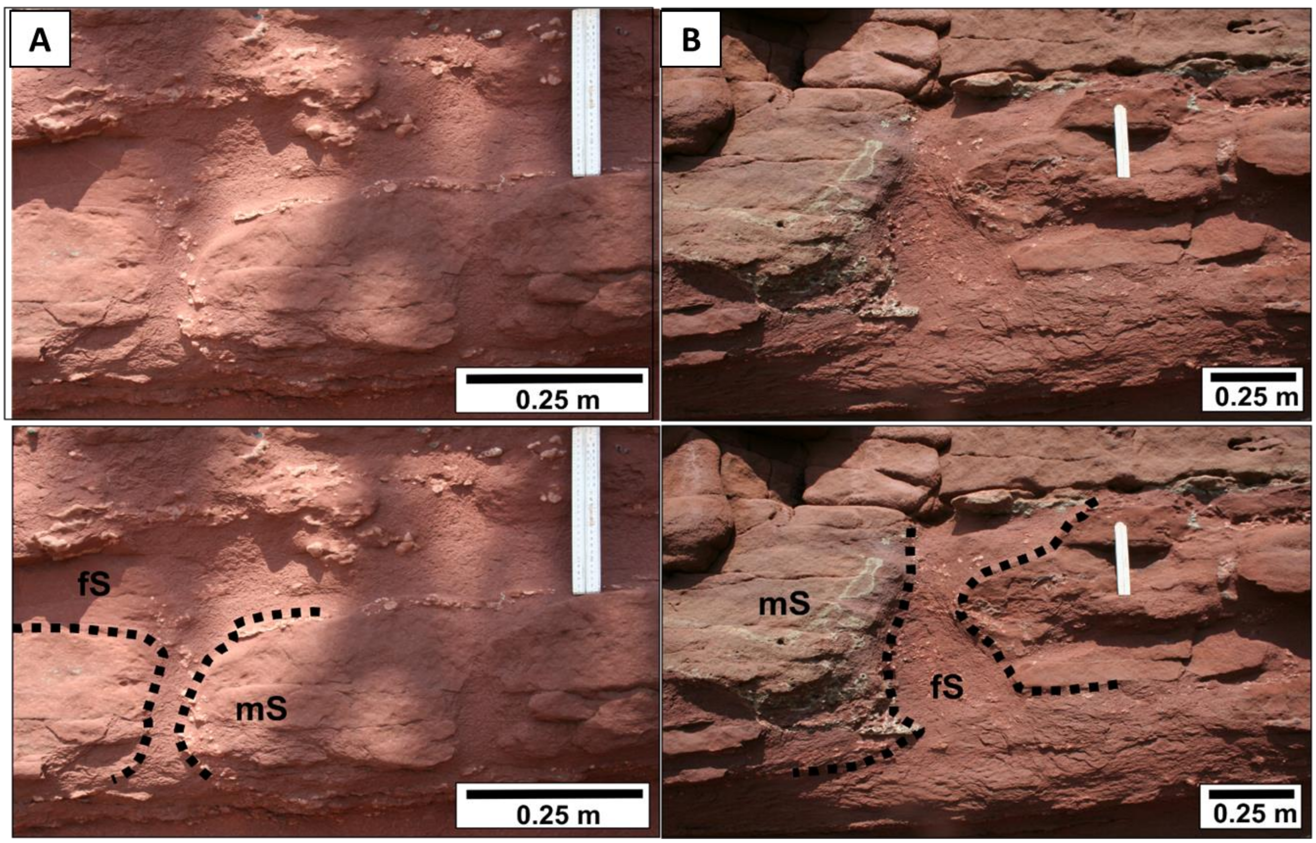


Figure 5.10 Possible vegetative-induced sedimentary structures. A) Symmetrical hollow of fine-grained sandstone with terminating beds of medium-grained sandstone on either side. B) Asymmetrical hollow of fine-grained sandstone with terminating beds of medium-grained sandstone.

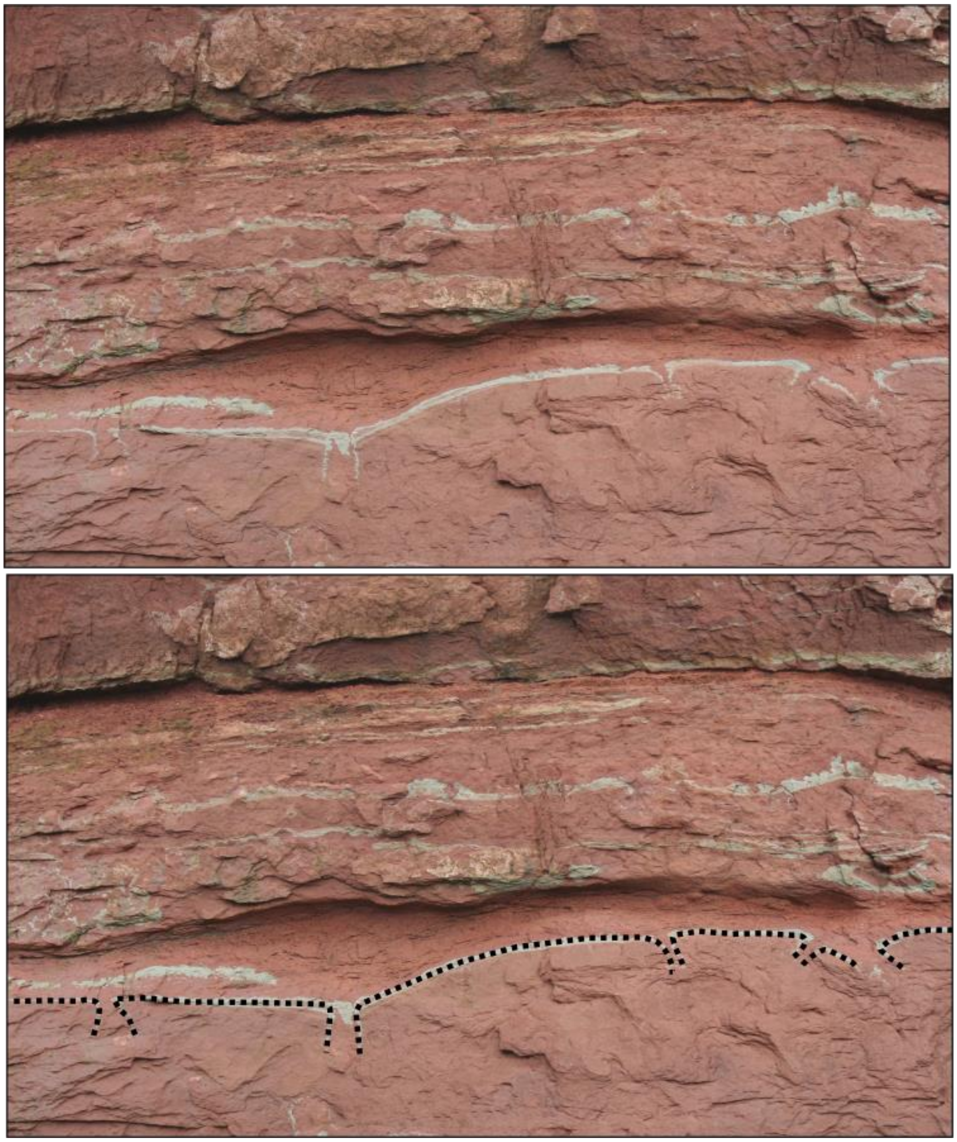


Figure 5.11 Vertical redox reactions within fines terminating into a medium-grained sandstone. Scale of the vertical features is in the decimetre scale.

Chapter 6 Petrography

Point counting revealed details of the composition of six samples from the three channel belts. The samples plot within the subarkose and arkose fields on a quartz-feldspar-lithic ternary diagram (Fig. 6.1). Detrital grains include quartz, orthoclase, microcline, plagioclase, biotite, muscovite, oxides, and lithic fragments, and examples can be seen in Figure 6.2. Grains are predominantly angular-subangular and lithic fragments are generally rounded and include siltstone and slate. Important distinctions can be seen in thin section between the coarser grained (facies 1) and finer grained (facies 2) samples. Coarse sandstones (LB05, LB04, LB07) contain abundant calcite cement, which reached up to 29% in samples (Fig. 7.2). Iron-oxide cements were also observed, though in low abundance (<1%). Medium-grained sandstones had more grains with iron oxide coatings and had a more clay-rich matrix, though the coatings were very fine-grained, making identification difficult.

Grains appear floating in cemented areas, and kinked micas are present between grains where grains are in contact outside cemented areas. Some feldspars have been heavily altered to sericite and etching of quartz grains was observed. There are visible fractured grains, some fractures infilled with calcite, and a few areas of kaolinite cement were observed. There are also some instances of dissolution of feldspars.

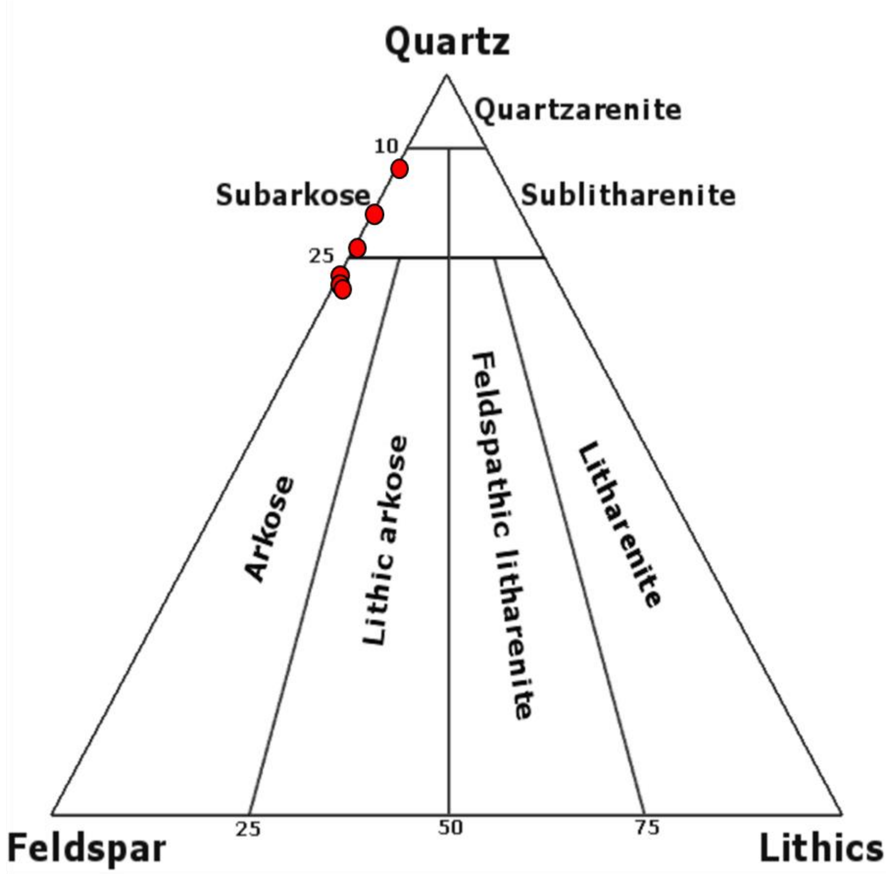


Figure 6.1 Quartz-feldspar-lithic ternary diagram showing plots of six samples from Burntcoat Head, Nova Scotia with samples plotting within the arkose-subarkose range.

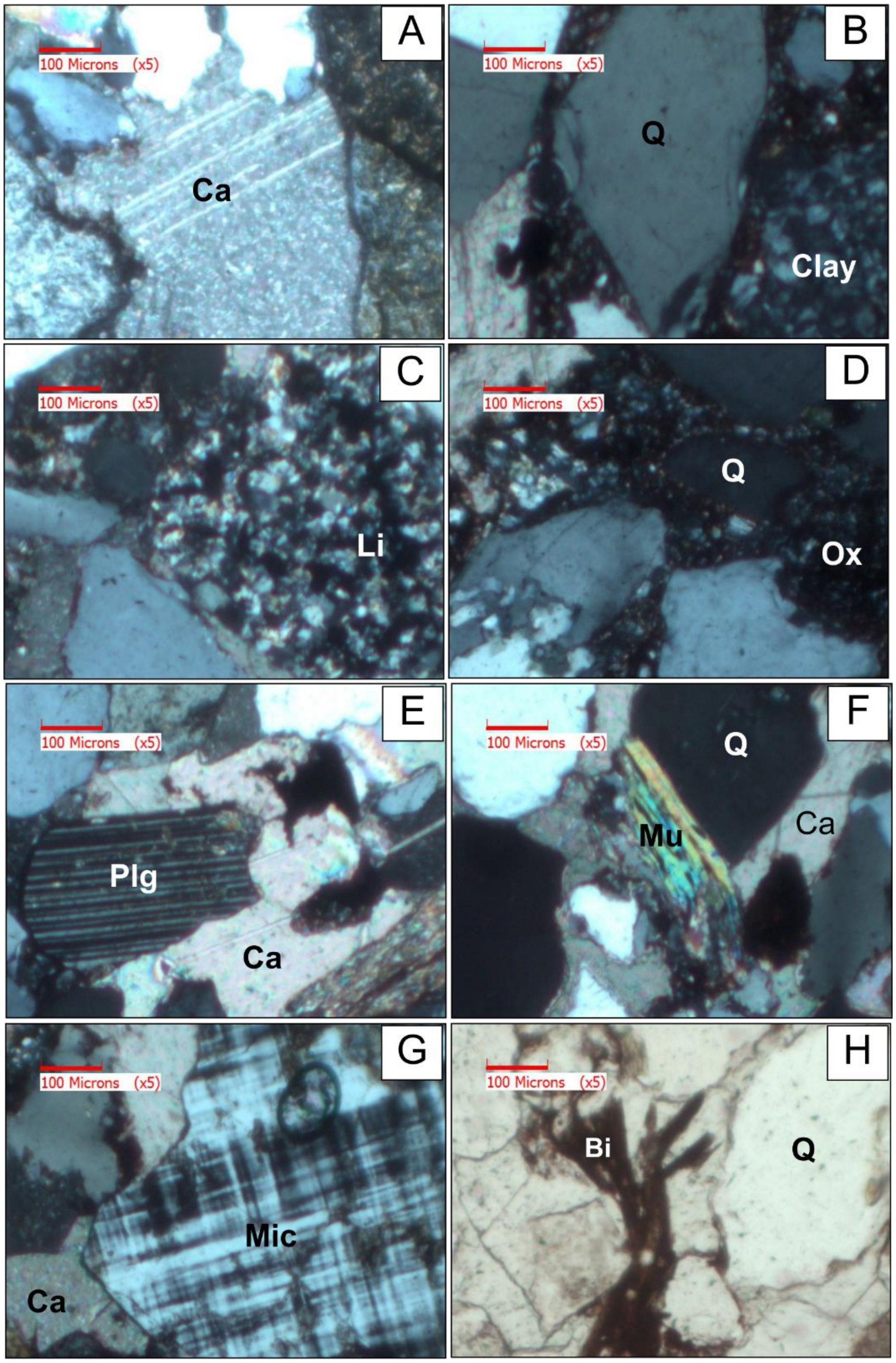


Figure 6.2 Petrographic images of thin sections including A) Calcite cement, B)Angular quartz and fine grained clay, C) Sedimentary lithic fragment, D)Quartz grains within iron oxide matrix, E) Plagioclase grain surrounded by calcite cement, F) Muscovite and quartz grains surrounded by calcite cement, G) Microcline grain surrounded by calcite cement, H) Biotite and quartz grain. Note all images were taken in cross-polarized light with the exception of image H which was taken in plane-polarized light. Q = quartz, Plg = plagioclase, Mu = muscovite, Ca = calcite, Bi = biotite, Mic = microcline, Li = lithics, Ox = iron oxides.

Chapter 7 Discussion

8.1 Nature of Fluvial System

The strata at Burntcoat Head are dominated by trough-cross bedded sandstones formed by 3-D dunes, and plane-bedded sandstones. These form prominent components of the fluvial system, forming under different flow conditions. Trough-cross beds would have formed during periods of steady flow in the lower flow regime, whereas plane-bedded sandstones would have been deposited over sustained periods of upper flow regime conditions. The abundance of Sh suggests that flow conditions were often in the upper flow regime. The presence of calcareous paleosols suggests strongly seasonal conditions with <760 mm of precipitation annually (Royer, 1999). Burntcoat Head likely experienced highly seasonal precipitation and flow within a semi-arid climate, resulting in the dominant bedforms observed.

Periods of peak flow resulted in erosional features and channel scours, as well as the accumulation of plane-beds. Thick deposits of plane-bedded sandstone occur at the base, middle and top of channels. Thick accumulations of plane-beds observed at the base of channels in the River Gash in Sudan are attributed to flow conditions having velocities high enough to encompass the entire channel within the upper flow regime (Abdullatif, 1989), and the occurrence of flashy-sheet flood sequences during channel initiation in upper flow regime conditions is supported by thick sets of plane-beds at channel bases (Abdullatif, 1989). It is likely that the fluvial system at Burntcoat Head experienced sustained periods with velocity/depth parameters within the upper flow regime, and the preservation of thick accumulations of plane-bedded sandstones suggests that the area had a strongly seasonal climate, experiencing seasonal peaks in precipitation (Fielding, 2006). When compared to less episodic braided-fluvial system like the South Saskatchewan River, distinct differences can be noted.

Burntcoat Head represents a more flashy system, experiencing rapid lateral facies change and generating thick sets of plane-beds throughout the channel. This contrasts with the local accumulation of plane beds in the South Saskatchewan River, which were found to be concentrated in the tops of bars, representing the local development of upper regime conditions when shallow water covered the bars (Cant & Walker, 1978).

Dunes migrating downstream within channels and across bars were active during times of reduced peak flow velocities, as observed within the Platte River (Horn *et al.*, 2012). The lateral change of Sh to St at Burntcoat Head has also been observed within the River Gash where it is interpreted as the interfingering of channel-fill and flood sequences (Abdullatif, 1989). Ripple cross-lamination was not observed, which is probably a function of grain size being dominated by medium sand and coarser (Southard & Boguchwal, 1990).

Large bars are represented by large-scale mounded forms with a gentle downstream dip of uppermost and internal surfaces. This morphology is likely a result of reworking the tops of bars within an upper flow regime river, likely experiencing partial modification due to subsequent floods and variations in flow conditions (Abdullatif, 1989). The erosive nature of the system is less likely to preserve bar surfaces high in the channel as they would be reworked or cut away by incision. The limited lateral extent of these bars (< 9 m) also suggest that these did not manage to build for any distance which could be another indicator of episodic flow. Scour surfaces are prominent within basal channel deposits and muds have been stripped off the banks by intense floods, resulting in the accumulation of mudstone clasts within channel fills and especially along erosional surfaces.

The channels eventually filled and were subsequently abandoned. Abandoned channel sediments indicate that, once channels had avulsed, they still experienced periodic waning flow.

Thick floodplain deposits with paleosols also suggest that the braided channels switched course for sustained periods before eroding into the floodplain sediments at an earlier channel site. The combination of preserved channel and floodplain deposits indicates that this was likely an unconfined system which was able to migrate and avulse freely on a broad plain and flowed to the northeast.

The braided-fluvial system at Burntcoat Head is not a unidimensional story. Channel belt 2 likely experienced fewer periods of upper-flow regime conditions when compared with channel belt 3, which resulted in channel belt 2 having more downstream accreting bars and in-channel dune sets. Channel belt 3 experienced sustained periods of upper-flow regime conditions as a large component of the channel belt is composed of plane-bedded sandstone. The braided-fluvial system was overall an aggrading system. The channel belts reach 11 m in thickness whereas channel bodies typically range from 2-5 m in thickness. Even though local erosion is prominent within the channel system, the system was aggradational overall, which suggests an abundant sediment supply coming from the Meguma platform from the south (Leleu *et al.*, 2009).

8.2 Taphonomy and Diversity of Life

8.21 Vertebrate Fauna

The most common vertebrates recovered from the Wolfville Formation are procolophonid parareptiles including the genus *Scoloparia*, archosaurian reptiles and cynodont therapsids including traversodont taxa (Sues & Fraser, 2010). Individual specimens recovered from Burntcoat Head strata have been provisionally linked to these families, revealing that the Burntcoat Head section represents the typical faunal assemblage of the Wolfville Formation. The isolated and fragmented nature of the specimens also restricts taxonomic interpretations, limiting a complete assessment of diversity. The large 20x8 cm dentary recovered from the study site belongs to a traversodont, which are large cynodonts from the Late Triassic (Fig. 5.7); examples from Argentina and India have been inferred to reach lengths up to 2 m (Sues, 2000). Procolophonid specimens represent small- to medium-sized lizard-like parareptiles (Fig. 5.7), which were distributed globally and span the entire Triassic period. Archosauromorph reptiles including *Rhyncosauria* (Fig. 5.7) have a global distribution and were the most abundant during the Middle-Late Triassic. To date, no confirmed dinosaurian remains have been recovered from the Wolfville Formation, and no specimens of semi-aquatic to aquatic phytosaurs, and very few metoposaur specimens, have been recovered. These are often found in Late Triassic assemblage in North America and Europe, though their absence is likely linked to the semi-arid climate of the Fundy Basin (Sues & Fraser, 2010).

8.22 Taphonomy

Preservation of vertebrate material is rare. The majority of vertebrate material recovered from Burntcoat Head is single, disarticulated bone fragments. Only three specimens can be traced to their source bed within the strata at Burntcoat Head, based on discoveries made during the present study or by McRae limiting interpretations on where vertebrate material was deposited within the fluvial system. One specimen has been linked to trough-cross beds attributed to dunes (Fig. 5.3), which can be seen in the middle of channel belt 2 (Figures 4.2 & 4.5) and the other two specimens were found as isolated fragments at the base of channel cuts (Fig. 5.3) in channel belt 1 and 3 surrounded by abundant angular mudstone clasts (Figs. 4.2 & 4.8).

From the 75 museum specimens that cannot be linked to specific beds, the presence of mudstone clasts within the matrix provides evidence that a significant proportion of the bone material was incorporated into the fluvial system as part of channel lags, representing material reworked from bank material during channel incision or from organisms that died in the channel. Taphonomic analysis suggests that bones underwent considerable transport. Most of the specimens are fragmentary and these would have been broken down and worn during transport. Large skeletal elements would require fast flow to be entrained and transported which, as suggested by the high abundance of plane-bedded sandstones in the cliff, was frequent. High-velocity flow also likely displaced carcasses, accounting for the isolated nature of bone localities. Taphonomy studies of the mid-Triassic fluvial succession of East Devon reveal similar findings, with most bones occurring as isolated fragments, which have disassociated from their skeleton, indicating the dynamic nature of the fluvial environment (Hart, 2014). The lack of fish material recovered from the site is likely in part because these bones are delicate and more likely to be disassociated in this high energy system, and partially due to the flashy nature of the system during low base flow and peak flow. Also, the bones and scales would likely occur as small isolated elements which would be hard to spot within the cliff section.

Bias has a significant impact on the diversity of specimens recovered from the study site. Preservation bias would impact the diversity and type of bones recovered from the site. The more commonly observed bones including jaw fragments, teeth, limb bones, and individual vertebrae, were probably preferentially preserved due to their higher durability and abundance in skeletal systems, while soft parts and fragile material would decompose or break apart before they had the chance to be buried. The majority of the samples were collected by a single collector. There is little to no information with the samples as to how the specimens were collected, which creates the possibility of sample bias if the collector was looking for specific fossils or concentrating on certain beds. This could have the effect of skewing the diversity and abundance of specimens in the collection and could also bias information on where the majority of these specimens were coming from within the braided river system.

8.23 Invertebrate Trace Makers

Taenidium barretti/Planolites montanus traces occur within abandoned bars and floodplain deposits. The high abundance and low diversity of traces suggest that the tracemakers were well adapted to the floodplain and bar environments and that conditions favoured their colonization. *Taenidium* and *Planolites* are easily confused as menisci within *Taenidium* traces are often poorly preserved (Baucon *et al.*, 2014). These burrows formed as the result of ingestion-and-excretion backfilling, more commonly associated with worm-like-organisms (Baucon *et al*. 2014). They backfill by consuming the sediment, resulting in dissimilar matrix and fill sediments of burrows, which was observed in traces in mudstone clasts, filled with medium sandstone. Excavation backfilling produces traces with the same sediments composing the fill and matrix and are generally formed by arthropods though they are not limited to these taxa. These excavation and backfilling traces were the most commonly observed traces within the section.

8.24 Plants

Vegetation-induced sedimentary structures (VISS) form from the interactions of sediment with *in situ* plants (Rygel *et al.* 2004), and the possible VISS structures at Burntcoat Head could have formed as a result of plant decay. The plant would have been entombed within the medium-grained sandstone before decaying and the empty space would have then been filled by fine sandstone. If the width of the VISS structure is taken to represent the approximate diameter of the plant stem, the plants would probably have been small shrubs with bases less than 20 cm in diameter. Vertical and branching root traces have been documented in the lower Wolfville

Formation in paleosols with carbonate nodules showing a local vertical fabric (Leleu *et al.*, 2009). Some of the carbonate nodules at Burntcoat Head display a weak vertical fabric, possibly the result of forming in places where roots were present. Vertical redox effects could also be the result of biological activity, though this would have to be investigated further. Other than root traces, no identifiable plant material has been recovered from the Wolfville Formation (Sues & Fraser, 2010). The absence of plant fossils is probably a result of the hot and dry climate readily oxidizing the plant material. The semi-arid climate also would have made water a limiting factor for plant growth (Dodson *et al.*, 1980).

Another method of interpreting the presence of plant life within the Burntcoat Head strata includes looking at the feeding strategies of the tetrapod families recovered from the site, as the presence of herbivores would suggest that plants were a part of the Late Triassic fluvial ecosystem. Herbivory has been inferred through studies on skull and dentition morphologies. The Traversodont family of Cynodonts has been interpreted to be omnivorous, feeding on high-fiber plant material, among other modes (Sues, 2000). It has also been suggested that smaller procolophonid taxa were insectivorous, though larger forms were mostly herbivorous, and archosauromorph reptiles have generally been considered herbivorous (Sues, 2000). Similarly, the presence of large herbivores in the Jurassic Morrison Formation suggested a large impact on supporting vegetation, indicating that there must have been high plant productivity (Dodson *et al.*, 1980) The presence of these taxa indicate the likelihood of plants growing along the braided-fluvial system for these tetrapods to consume, though these are general accounts for the families observed at the site and more specific information on the individual species from Burntcoat Head would have to be investigated further in order to confirm that these individuals would have consumed plant material.

8.3 Burial History

The sandstones of Burntcoat Head show evidence for cementation during shallow burial with minimal compaction of grains as indicated by grains apparently floating in carbonate cements. Clays including kaolinite fill the pore space and likely formed due to weathering and alteration of feldspars (Kettanah *et al*., 2014). During early diagenesis, iron oxides and carbonates would have precipitated before compaction of grains occurred, resulting in floating contacts in the coarser grained samples, suggesting shallow burial of the sandstones. Iron oxide cements would have formed in the earliest phase of diagenesis, as they form rims on the surface of detrital grains, surrounded by later calcite cements. Evidence of later compaction is seen through kinking of muscovite and biotite grains and the presence of fractures within brittle minerals like quartz. Early carbonate cements suggest a bicarbonate-charged ground water system, which is probably in accordance with the presence of carbonate nodules within paleosols. The angular nature of the detrital grains is in accord with the immature arkose-subarkose composition, suggesting proximity to the source and implying rapid transport and deposition, which is in accord to the thick deposits of plane bedded sandstones discussed earlier.

Partial dissolution of K-feldspars and plagioclase and sericite alteration of feldspars is common and occurred as a result of fluid interactions. The absence of quartz overgrowths suggests a lack of silica cementation during diagenesis. The majority of grains are not well rounded, suggesting that the sands are relatively immature, and a nearby source in the South Mountain Batholith granites was suggested by Kettanah *et al.* (2014). The majority of lithic grains are well rounded and are mostly siltstone and possibly slate, likely contributed by the Meguma Supergroup and Horton Group (Kettanah *et al*., 2014).

Chapter 8 Conclusions

Integration of the sedimentology and biological materials reveals a diverse and thriving ecosystem at Burntcoat Head during the Late Triassic. The studied section is overall an aggradational system composed of channel bodies which stack to form three distinct channel belts overlain by floodplain deposits. Channel bodies are composed of laterally and vertically stacked channel-fill and bar elements including LS, SB, DA, and LA which are overlain by thick sets of abandoned channel and floodplain deposits (FF) with developed paleosols. The dominant bedforms in the strata include thick sets of plane-bedded sandstone and large dunes. The presence of paleosols suggests that the Fundy Basin was in a semi-arid climate where strongly seasonal temperatures and precipitation would have impacted the braided river system flowing through the area. This seasonal climate led to erosive, flashy rivers, which cut into the sides of banks and stripped away sediment resulting in large channel cuts with accumulations of mudstone clasts at the base. Periods of peak flow led to high discharge and resulted in the thick deposits of plane-bedded sandstone. The combination of channel and floodplain deposits and the accumulation of paleosols suggest that these braided rivers were unconstrained and could migrate and avulse on a broad plain. Paleoflow indicates these rivers were flowing to the northeast and poorly rounded material suggests that these sandstones were deposited proximal to their source from the Meguma Terrane to the south. After deposition, the sandstones show evidence for shallow burial in a bicarbonate-charged groundwater system.

The vertebrates recovered from Burntcoat Head suggest that this section represents a typical faunal assemblage of the Wolfville Formation. Recovered partial specimens and fragments reveal that small procolophonid reptiles, achosaurian reptiles, and large traversodont therapsids lived along these braided rivers, and evidence left behind by trace-makers suggests that abandoned bars and floodplain deposits made ideal habitats for small burrowing worm-like organisms and arthropods leaving behind *Taenidium* and *Planolite*s traces. Most of the specimens occur as isolated and fragmented bones and teeth, and the nature of the vertebrate material suggests that these bones underwent considerable transport within the channels and likely led to the preservation of the more durable and abundant bone material including jaw fragments, teeth, vertebrae, and limb bones. Small herbivores were likely consuming plants growing along the rivers and evidence for vegetation-induced sedimentary structures was observed. Overall, the braided-channels at Burntcoat Head were part of a diverse ecosystem where life was flourishing during the Late Triassic.

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Appendix A: Summary of point counting results for thin section data

Grain Type	LB005	LB004	LB007	LB001	LB006	LB003
Monocrystalline Qtz	182	125	118	170	157	170
Polycrystalline Qtz	18	12	10	10		8
Orthoclase	46	53	50	51	19	35
Microcline	10	3	3	7		
Plagioclase	3	6	2	9	4	
Biotite	1	2	3	12	20	14
Muscovite			2	3	5	6
Oxides	6	5	5	11	15	9
Lithic Fragment		2	8	1		5
Clay	2	4	5	22	37	37
Authigenic Calcite	32	88	83		2	1
Authigenic Oxides			11	4	41	15
Total Points	300	300	300	300	300	300

Appendix B: Summary of architectural element data

Element	Lateral extent (m)	Thickness (m)	Parallel or perpendicular to flow	Lithofacies and vertical succession	Nature of lower and upper bounding surface	External geometry (sheet, lens, wedge)	Relation to scours	What do they grade into	Position in channel belt	Other notes
LS	13, 17, 10, 12, 24	2, 1.5, 3, 2	Parallel	Sh, Sp	Base – gradational, upper- erosive or gradational	Sheet, blanket		St, bars. Topped by channel cuts.	Lower, middle and upper channel belt	
LA	3	1.5	Perpendicular. Accretion surfaces orientated across channel	St, sp, sh	Lower is an erosive channel cut upper is gradational, more massive, near top of channel (gradual transition)	Wedge. Accretion surfaces oriented across channel. Downlaps onto flat basal erosion surface	Formed at side/base of scour (side of channel cut)	The top of channel (limited by extent of outcrop)	Side of channel cut	Only 1 well preserved
DA	7, 9, 6.5	1.5, 1.5, 1.5	Parallel. Accretion surfaces orientated downstream	St, sp, sh	Curved downstream upper bounding surface. Lower is erosive.	Lens resting on a flat or channeled base with convex-up internal erosion surfaces bounding surfaces.		Fine upwards. Reworked upper bounding surfaces	Occur closer to top of channel belt	
SB	>25, 6, 4.5	1.5, 2, 1.5	Parallel	St, sp,	Upper is gradual, lower is erosional	Lens, sheet, blanked, wedge. Occurs as channel-fill and minor bars	Infills scours	Sh, St, bars	Throughout channel, near base, near top, at base of bars	
FF	>170	Floodplain fines (0.7 m) where carb nodules start. (below carbonate 1.8-2.2) total 2.5-4.0	Parallel	Fl, Fm	Transition is gradual, only marker is carbonate nodules. Lower is sharp (but more gradational) upper is erosional.	Sheet	Infills scours	Erosive contact with sands above. Grade into each other.	Above channel belt deposits.	

Appendix C: Summary of sediment descriptions for Nova Scotia Museum of Natural History specimens

Catalogue No	Dominant Grain Size	Sorting	Clasts	Roundness	Colour	Other Comments
NSM000GF022	removed from matrix					
NSM000GF023.2	vFU-fL	Moderate	none		red-brown	muscovite present
NSM000GF023.3	removed from matrix					
NSM000GF023.4	removed from matrix					
NSM000GF023.5	removed from matrix					
NSM000GF025	fL	Moderate	few lithics (quartz)	subangular	red-brown	muscovite present
NSM000GF023.1	vFU-fL	Well Sorted	none		red-brown	muscovite present
99003	cL	Poorly Sorted	few granules quartz	subrounded	red-brown	muscovite present
98001	vfU-fL	Moderate		subangular-subround	red-brown	muscovite present
98030	vcL	V. Poorly			red-brown	muscovite present
98029	mL	Poorly		subrounded	red-brown	muscovite present
98035	fU-fL	V. Poorly	common mudstone clasts granule size	angular	red-brown	muscovite present
99077	fL	Not enough matrix	none		red-brown	muscovite present
98006	mU-cL	V. Poorly	quartz and mud clasts	angular	red-brown	muscovite present
98002	fU	Moderate	mud clasts granules size. Quartz grains common	angular	red-brown	muscovite present
98041	fU-mL	V. Poorly	mud clasts vcs to granule sized	angular	red-brown	muscovite present
98027	mL	V. Poorly	mud clasts VCS-granule	angular	red-brown	muscovite present
99042A	cU-vcL	Moderate	few granule sized mud clasts	angular	red-brown	muscovite present
98032	fU	Moderate	few granule sized mud clasts	angular	red-brown	muscovite present
94074	mL	Moderate	few granule sized mud clasts	subrounded	red-brown	muscovite present
98011	fU-mL	Moderate-well	none		red-brown	
98028	fU-mL	Moderate-poorly	granule sized mud clasts	angular	red-brown	muscovite present
97041	fU-mL	Poorly	granule-pebble mud clasts	subangular-subround	red-brown	muscovite present
98026	mL	Moderate	some granule -pebble mud clasts	subangular	red-brown	muscovite present
97034	mL-mU	Moderate	1 pebble sized mud clast	subrounded	red-brown	muscovite present
95011	fU-mL	Moderate-poorly	granule-pebble mud clasts	subrounded	lighter red-brown	muscovite present
97001	fL-fU	Moderate-well	very few granule lithics. Note absence of mud clasts	subrounded	red-brown with mottling	muscovite present

96002	fU-mL	Moderate	vC sand sized mud clasts and quartz	subangular-subround	red-brown	muscovite present
97019	fU-mL	Very Poorly	many pebble sized clasts, mostly mud, few lithics	subrounded	mottled, reddish brown and white	muscovite present
97044	fU	Poorly	vC-granule mud clasts	subrounded	red-brown	muscovite present
08/11/90 block A	mL-mU	Very Poorly	granule-pebble sized mud clasts and lithics (mostly quartz)	subangular-subround	mottled, reddish brown and white	muscovite present
c.w. 08/07/90	fU	Moderate	few granule-pebble sized lithic clasts (absence of mud clasts)	subangular-subround	red-brown	muscovite present
12.2	fL-fU	Well	clasts are dominantly small pieces of bone (granule-peb size)		red-brown	muscovite present
No ID 1	fU-mL	Moderate	few granule sized clasts	subangular	red-brown	muscovite present
No ID 2	fL-fU	Moderate	clasts are dominantly small pieces of bone (granule-peb size)	bone frags are angular	rusty brown	
6:4c	fL-fU	Moderate	small granule size bone frags	angular	rusty brown	
No ID 3	fL-fU	Moderate	bone fragments granule to pebble sized	subangular-subround	rusty brown	
No ID 4	fU	Moderate	bone fragments granule to pebble sized	subangular	rusty brown	
149:1	fL-fU	Well	very few granule bone frags		rusty brown	
6:4b	fL-fU	Moderate	abundant gran-pebble sized bone fragments	subangular	rusty brown	
nsm988gf11.1 23:1	fL-fU	Well	few pebble sized bone frags	subangular	rusty brown	
No ID 5	fL-fU	Not enough matrix	none		rusty brown	
nsm988gf26.1	fL-fU	Well	few granule-pebble sized bone frags	subangular	rusty brown	
66-1 or99-1	fL-fU	Well	none		rusty brown	
No ID 6	fL-fU	Moderate	granule size bone frags		rusty brown	
6:88	fL-fU	Moderate	granule-pebble bone frags	subangular	rusty brown	
m-12	fL-fU	Moderate-well	granule-pebble bone frags	angular-subangular	rusty brown	
36:1	fL-fU	Moderate	granule size bone frags	subangular	rusty brown	
nsm988GF29.1	fU-mL	Moderate	granule size bone frags	suban-an	rusty brown	
No ID 7	fL-fU	Moderate	granule-pebble size bone frags	subangular	rusty brown	
6:8a	fL-fU	Moderate	granule-pebble size bone frags	ang-subang	rusty brown	
No ID 8	mL	Moderate	few gran-pebble sized clasts	subang	red-brown	muscovite present
misc fragments	mL	Moderate	few gran-pebble sized clasts	subrounded	red-brown	muscovite present
No ID 9	fL-fU	Well	none		rusty brown	

M23	fL-fU	Well	few granule bone frags	cant tell	rusty brown	
6:4a	fU	Moderate	granule-pebble bone frags	subround-suban	rusty brown	
40 or 115	fL-fU	Moderate	granule-pebble bone frags	subroun-suban	rusty brown	
M30	fL-fU	Well	few gran-pebble bone frags	subround-suban	rusty brown	
30:4	fL-fU	Moderate-well	none		rusty brown	
M32	fL-fU	Moderate	granule-pebble bone frags	subangular	rusty brown	muscovite present
No ID 10	mL	Well	few granule sized clasts	subrounded	red-brown	muscovite present
No ID 11	mL	Well	few granule sized clasts	subangular	red-brown	muscovite present
block N of C	mL	Moderate	few granule sized clasts	subangular	red-brown	muscovite present
No ID 12	mL -mU	Moderate	few granule sized clasts	subangular	red-brown	muscovite present
99041	mL	Well			red-brown	muscovite present
94066						
94065						
99043	mU					
98036						
98039	mU	Moderate	granule sized mud clasts	subangular	red-brown	
94067						
98015	mU		pebble sized mud clasts	subangular		
97042	mL-mU	Poorly	mud clasts	subangular	red-brown	
97045						
96052						
97023						
98024	mL-mU	Poorly	mud clasts	subangular	red-brown	
99076	removed from matrix					
99075	removed from matrix					

Appendix D: Summary of taphonomy and morphology descriptions for Nova Scotia Museum of Natural History specimens

Catalogue No	General Description	Bone dimensions (cm)	Taphonomy observations
NSM000GF022	Large Bone Fragment - lower jaw	20x8	teeth infilled with sand. Jaw has broken surfaces on either end. Back teeth missing
NSM000GF023.2	Small bone fragments		fragment. Broken edges reveal inside of bone.
NSM000GF023.3	limb bone (humorous?)	4x1	humorous? Moderately abraded. Hematite coating. Bent from original form. Broken surface
NSM000GF023.4	limb bone	2.5x0.6	Broken surfaces glued together. Some abrasion
NSM000GF023.5	partial limb bone	1.5x1.2	abraded and broken off from other portion of bone which no longer is present.
NSM000GF025	jaw (maxilla)	2.5x0.6	Broken edge on posterior end. Hard to see other end due to prep.
NSM000GF023.1	Articulated vertebrae and tailbone, and hand	spine: 9.6x2 hand: 4.8x3.6	many vertebrae and tail bone. Couple of ribs?, limb bones? Manus with fillangies
99003	6 small teeth likely were attached to jaw	0.9x0.2	
98001	Small jaw bone with teeth	1.3x.25	broken mandible with many small teeth. Broken on bottom surface and on on surface that would attach to skull. Only see outside of bone
98030	unknown fossil (scute?)	1.8x0.6	scute? not well preserved
98029	Scute? Black fossil	2.5x1.4	scute, almost complete. Partially broken on end - this break is likely due to prep.
98035	2 teeth and jaw fragment .	0.2x0.2	jaw broken on either end to reveal a section with only 2 teeth attached. Prep does not allow to see broken surfaces on either side of fragment. Top surface is outside of bone
99077	Fish Fragment - Scales	2x1.5	
98006	Individual tooth		removed during prep because impression is left behind.
98002	piece of jaw with 3 teeth	0.8x0.6	only section of 2 teeth, rest broken off
98041	tiny bone fragment	0.3x0.1	tiny partial piece of jaw. Mandible? with 3 teeth in place. Back end missing. Breaking likely from prep
98027	tiny piece of jaw with 2 small teeth. Mandible?	0.4x0.3	Broken on either end (missing most of jaw). Seeing outside surface of bone
99042A	piece of jaw with exposed teeth	2.5x1.5	very cracked, broken. Jaw fragment incomplete, with 3 teeth in place. Bone is broken. Hematite coating removed during prep
98032	Jaw fragment with 6 teeth. Mandible?	1.3x0.5	Broken on end that would attach to skull. Prep allows only to see surface
94074	jaw fragment (mandible?)	3x0.7	mostly broken away leaving impression
98011	jaw piece? Bone fallen out	1.5x0.6	bone fallen out
98028	scute - black, fragment	3x2	only a partial scute with broken surfaces.
97041	jaw fragment	2x0.7	partial lower jaw, broken, teeth in place
98026	small jaw fragment	0.4x0.2	broken piece of jaw with few teeth. Ends of jaw missing. Prep only allows to see outside surface.

97034	small jaw fragment	0.5x0.5	jaw gone, impression left behind
95011	jaw fragment	1.2x0.5	
97001	jaw fragment	1.1x0.4	lower jaw weathering not super prominent due to preparation of sample. Missing at least the back end of the jaw.
96002	2 sediment filled teeth	0.4x0.6	just teeth, no jaw bone
97019	jaw fragment with four teeth	1.8x0.5	jaw fragment removed, impression. Teeth are fractured
97044	jaw fragment (lower?)	1.8x0.3	partial jaw (lower?) broken , back and front end missing. Prep only reveals top surface where outer surface of bone is present
08/11/90 block A	bone fragments	7	
c.w. 08/07/90	bone fragments	5	
12.2	partial jaw fragment with few teeth	2	
No ID 1	bone fragment	3.5	
No ID 2	bone fragment	1.5	
6:4c	small bone fragments	0.3	
No ID 3	small bone fragments	2.2	
No ID 4	small jaw fragment along with other small bone fragments	0.5	
149:1	partial femur?	5x1.5	
6:4b	small bone fragments		
nsm988gf11.1 23:1	jaw fragment with teeth (lower?)	1.4x.7	jaw is fractured, thin cracks infilled with sediment
No ID 5	bone fragments	2	
nsm988gf26.1	limb bone fragment	3	
66-1 or99-1	small bone fragments and one tooth	0.4x0.4	likely part of jaw, very broken up
No ID 6	broken up jaw fragment with few teeth	0.6	
6:88	bone fragment	2.7x0.5	
m-12	broken up bone fragments	3.5x1.7	
36:1	jaw fragment with teeth	1.4x0,7	jaw is fractured, and fracture is infilled with sed. Ends are broken and teeth are missing. Bottom surface is broken
nsm988GF29.1	tooth	0.25x0.2	tooth is isolated
No ID 7	broken jaw fragment jaw with teeth	0.2	
6:8a	small broken granule-peb sized bone fragments		
No ID 8	bone fragment, partially removed	8	
misc fragments	bone fragments (cant measure)		

No ID 9	jaw fragment with 3 teeth	0.6x1.5	
M23	3 limb bones all aligned in a row	1.7x0.5	bones are partial, fractured, and abraded . Fractures infilled with sed. Brittle deformation. Only surface of bones are revealed in prep
6:4a	multiple small bone fragments	1.7x0.3	partial vertebra, abraded
40 or 115	multiple bone fragments		limb bone. Broken in half with sediment in between (broken surface)
M30	bone fragment	1.8x0.5	bone is fractured, abraded and isolated. Inside of bone is revealed where broken at ends of bone
30:4	2 bone fragments	1	
M32	bone fragments	1x1	broken, isolated bones, some with thin factures
No ID 10	blackish bone fragment	8.5	
No ID 11	2 bone fragments	4	
block N of C	bone fragments scattered	5	
No ID 12	bone fragment	3	
99041	jaw fragment	0.5x1.3	
94066	vertebra	8x3.5	broken on one end - exposes inside of bone. Incomplete piece.
94065	vertebra	4.5x5.5	some abrasion on either end of vertebra. Inside of bone exposed. Hematite coating.
99043	limb bone	0.9x0.15	end broken off. Very small limb bone. Prep only reveals outer surface
98036	tip of premaxillary "beak"? Rhyncosaur	5.4x1.9	partially broken off at larger end and infilled with sandstone. Tip still intact. Completed covered in hematite coat
98039	jaw fragment	0.3x0.3	3 teeth, only small portion of jaw. Broken at one end. Prep only reveals one side of specimen. Outside of bone
94067	vertebra	1.6x1.2	abrasion on side that attaches to spine reveals inside of bone. Broken on this side. Incomplete
98015	small unidentifiable bone fragments	0.7x0.6	very broken up
97042	lower jaw fragment	1.4x.4	broken. Mandible? End pieces of jaw missing
97045	partial femur?	3.7x1.1	missing end of bone (broken) parallel fractures present, rounded top of bone. Obvious hematite coating has been partially removed by prep. Can see inside of bone at fractured end.
96052	broken bone fragment (can't identify)	5.4x2.7	broken, partial bone piece, rounding of abraded edges. Radial flaking. Can't tell what bone is but has a socket. Hematite coating
97023	broken bone piece (too broken to identify)	1x0.6	broken, angular, sediment filled. Looks like piece of a limb bone. Incomplete. Removed from ss. Broken surfaces reveal inside of bone]
98024	tooth	1.1x0.3	tooth is broken and fractured, but likely this occurred during excavation because impression is present
99076	tooth	1.7x0.8	
99075	tooth	0.9x0.5	