The Joggins and Springhill Mines Formations

Facies Model and Interpretation of the Paleo-Environment

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Abstract

The type section of the Joggins Formation is located along the eastern shore of Chignecto Bay, Nova Scotia. A bed-by-bed measurement of the Carboniferous strata within a 200m stratigraphic zone encompassing the Joggins and Springhill Mines boundary is performed and classified into lithological units and facies types and finally, a conceptual model of the depositional paleo-environment is suggested. Facies types observed within the study area include large, moderate and minor-scale sandstone channel-fill facies; undulating, thin sheet, and tabular planar sandstone facies; grey friable, grey platy, red friable, and red platy mudstone facies; a coarsening-upwards bay-fill facies; and limestone, shale and coal organic facies.

A prominent feature of the lithology found in the stratigraphic section, is a repetative cyclicity. Cyclicity can be observed as small-scale coarsening-upward or fining-upward packages (<10m) and as larger-scale grey and red assemblages (<40m). The smaller-scale cycles are divided by sharp erosional boundary layers, designated as flooding surfaces, while larger-scale cycles generally have gradational boundaries. Grey assemblages reflect wetland environments, whereas, red assemblages reflect arid environments.

Both these trends can be used to synthesize facies types by association. Successive environments, resulting as a response to variations in base-level, can then be classified as either belonging to a progradational or retrogradational parasequence set. This establishes a contemporaneous link between facies types, and allows for modeling of paleo-environmental cyclical trends.

Keywords: Carboniferous, progradational parasequence sets, retrogradational parasequence sets, base-level, and facies types, sequences, and associations

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1.0 Introduction

1.1 General Statement

1.1.1 Area

The Joggins and Springhill Mines Formations are exposed, near Joggins village, at the mouth of the Bay of Fundy along the eastern shore of Chignecto Bay, Cumberland County, northwestern Nova Scotia (figure 1.1). The cliff exposure along the shoreline is being eroded away by a 12 to 15m diurnal tidal range, exposing a near continuous 24.3km suite of seven formations from the mouth of the Shulie River to a point 1km southwest of the mouth of Mills Creek (Ryan et al., 1994). The seven formations all form parts of the Cumberland and Mabou Groups. The Ragged Reef Formation, Springhill Mines Formation, Joggins Formation, Boss Point Formation and Claremont Formation are part of the Cumberland Group, whereas the Shepody Formation and Middleborough Formation are within the older Mabou Group (Ryan et al. 1994). The Joggins and Springhill Mines Formations are within the Cumberland Basin, the largest onshore coal basin in eastern Canada (Archer et al. 1995), along the northern limb of the Athol syncline (Ryan et al. 1994). The coals at Joggins are mid to late Westphalian A through B in age (Gibling et. al., 1992; Calder 1994, 1991; Ryan et. al. 1991). The Carboniferous strata in the Cumberland Basin are approximately 8km thick and they form one of the thickest basin-fill sequences in the Euramerican Coal Province (Calder, 1994).

1.1.2 Background points of Interest

The Joggins Formation is 'exceptionally' interesting. Historically, it is the birthplace of modern-day geology, with the first bed by bed measurement of a coal-

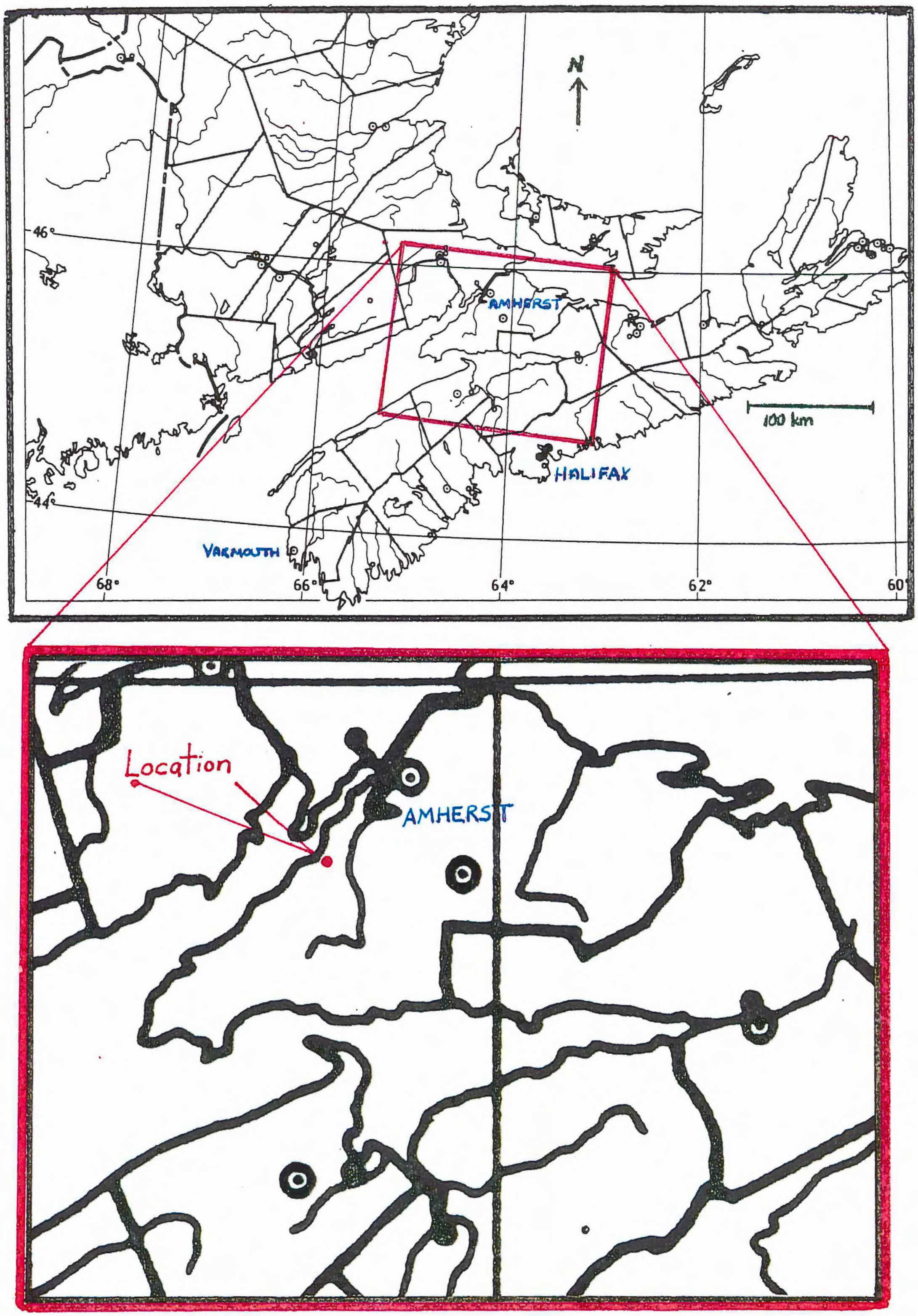


Figure 1.1 Location Map, Nova Scotia

bearing sequence performed by Logan in 1845. Logan measured a 2750m section and erected four divisions (Rust et. al. 1984). Following Logan's work, Dawson (1855) commented on the cyclical nature of the sequence, and upon recognizing this aspect, advanced some fundamental theories on geological dynamics. He explained the presence of in situ tree and root fossils, including *Calamites* and *Stigmaria*, in which some of the earliest vertebrate fossils can be found (Carroll et. al., 1972).

The limestones contain a fauna rich in bivalves and ostracods, comparable to European Coal Measures (Ryan et al. 1984). The Amphibian Order Microsauria, was originally based on the data collected from Joggins and trackways of the giant terrestrial arthropod (*Arthropleura*?) are also found (Ferguson 1966). Moreover, the 24.3 km cliff-face is among the largest continuous Carboniferous exposures in the world, and allows for a detailed insight into a period of time in which a significant proportion of coal, oil, and natural gas was sourced.

1.1.3 General Lithology

The lowest of four lithofacies of the Cumberland Group are within the Joggins section (Ferguson 1972). Logan's original divisions are still in use, although minor revisions have been made. The rocks consist of a vertically continuous and repetitive series of red to grey mudstone and brown sandstone, interbedded with minor coal, dark limestone, and ferruginous carbonate nodules (Gibling 1987). The sandstone bodies comprise grey erosional channel bodies and planar sandstones. The mudstones are grey or red to mottled in appearance and form predominantly friable beds with ferruginous concretions and clay root seams. The coal seams are thin (centimeter scale to 1m in thickness) and some gradationally overlie seat earth horizons. The entire section is 900m thick (Ryan et al. 1984); however, the section covered in this study focuses on the last two divisions of the Joggins Formation and continues through the boundary and into the base of the Springhill Mines Formation. The Springhill Mines Formation (MacCarrons Brook Member) is 80m thick and contains poorly developed coal seams, red mudstone increasing in both thickness and frequency up section, numerous thin (2m) sandstones, and common rhythmic sandstone and mudstone interstratification (Ryan et al. 1984).

1.1.4 Previous Work

The Joggins area has attracted a lot of attention since the arrival of Logan in 1845. Further work by Dawson and Lyell (1854) only added to the questions, which many have asked. Copeland (1958) discussed the Joggins section in his work on the Cumberland Coalfield. Hacquebard & Donaldson (1964) discussed the stratigraphy and palynology. Rogers (1965) revised some of Dawson's faunal work and suggested that the Cumberland Group was equivalent to Westphalian zones in Europe. Belt (1968) and Schenk (1969) discussed the paleogeography of the Fundy area during the Carboniferous era. Way (1968) conducted a sedimentological investigation on a section of the Joggins Formation. Rust et al. (1984) studied part of the Springhill Mines Formation in terms of facies sequences. The fossils present at Joggins have been mentioned and studied by many authors. In short, there has been a long tradition of geological interest in this area with current work still in progress.

1.2 Study Area

1.2.1 Significance of Facies Association

Gressly introduced the geological term 'facies' in 1838. Walker (1992) defined the term as, "a body of rock characterized by a particular combination of lithology, physical and biological structures that bestow an aspect different from the bodies of rock above, below and laterally adjacent." The term 'facies' is commonly used in both descriptive (e.g. sandstone facies) and genetic (e.g. meandering fluvial facies) applications. It is a practical way of classifying units in terms of lithology and characteristics. Furthermore, it is a useful tool in synthesizing data, helping relate larger scale cycles through 'associations' and forming 'sequences'.

Models, which can be produced from facies sequences, are termed 'facies models'. These are working models which can be applied to both modern-day environments and the stratigraphic record. In theory, the construction of these models would enable us to recognize paleo-environments preserved within the rock record by a set of distinctive and relative characteristics, which would still be relevant within comparable modern environments. Unfortunately, most models available lack the detail necessary to apply them without uncertainty. There are a complex and infinite number of elements working within each system, and variations within any one of these elements could produce any number of depositional results (Coleman 1966). A higher understanding of these elements in relation with each other objectively defines paleo-environments of specific interest (e.g. coal fields and hydrocarbon reservoirs).

The Joggins and Springhill Mines Formations are not only of geological interest, but also of economic significance. The occurrence of coal seams, which were mined during the colonial period and through to the 1970's, has had a great impact on the local and surrounding area. A better understanding of coal occurrence could be of economic value, if a detailed model can be constructed and then applied.

An important feature of the lithology of the cliffs is the cyclical patterns in which the deposits occur. The mechanisms, which promote environmental changes, are allocated to either allocyclic or autocyclic effects (Beerbower 1964). The former mechanism comprises tectonic, eustatic and climatic events, which influence the local stratigraphy. The latter mechanism comprises intrabasinal events such as channel switching. It is understood that the two mechanisms do not operate independently of each other and that, more than likely, the two work in conjunction resulting in a new depositional realm. Furthermore, it is usually quite difficult to separate the two mechanisms from the resulting deposits alone, as both mechanisms operate to change the relative-base-level with respect to the local environment, consequently re-establishing a new base-level.

This study was unable to classify any absolute 'Maximum Flooding Surfaces' (MFS), and therefore, the established 'system tract models' cannot be applied. The application of relevant information from other sources is difficult to apply in the unraveling of the environmental history of the study area. The Joggins and Springhill Mines Formations have been a source of both economic and educational interest ever since discovery. The synthesis of the study area is still not completed with any detail, but further study within the vertical cliff exposure overlying the study area would provide a more complete understanding.

1.2.2 Purpose and Thesis Structure

The study area begins in the uppermost part of the Joggins Formation and continues through the boundary between the Joggins and Springhill Mines Formations, concluding at MacCarrons Creek. In total, approximately 190m of vertical cliff section will be focused upon, including a 25m concealed interval. The purpose of this investigation is to construct a stratigraphic column for this section, then to apply facies analysis and associations to the column, and finally, to reconstruct the local environmental history, or the mechanism of deposition.

Although it is acknowledged that the general mode of deposition surrounding the Joggins Formation is associated with an extensive alluvial fan system (Calder, in press; Gibling 1994), no direct study has been conducted in order to disprove or model the environment.

This paper will first segregate lithological-types and classifying them into units, presented in chapter 2. Secondly, chapter 3 will draw upon a stratigraphic column to put into context the spatial relationship of the units in regards to underlying and overlying units, small coarsening-upward and fining-upward packages, flooding surfaces, maximum flooding surfaces and highstand system tract, and finally grey and red assemblages. Chapter 4 will discuss the surrounding macro-environment around the Joggins Formation, specifically the Cumberland Basin, relate the unit divisions to facies sequences, and draw upon a stratigraphic model to express a progradational environment related to the deposits within the study area. Finally, chapter 5 will present a discussion and conclusion.

1.3 Method

Fellow colleague Paul Teniere and I, Jeremy Tonelli, measured the cliff together. Unit divisions were based mainly on lithological variations and bed characteristics. Specific features recorded for each bed include: lithology, thickness, colour, bed style, sedimentary features, fossils, and concretions. Additional information was recorded where significant and sketches made of important units. Samples collected of each sandstone channel-fill body and two other planar sandstone bodies were used to compare texture and mineralogy. Channel samples were retrieved from the center of each channel. The measured section was then divided into two study sections across a major limestone body to constitute the boundary.

Stratigraphic thickness across concealed sections was estimated by pacing along dip direction. This method is illustrated within Fig. 1.2 and is an estimate at best considering the variability in pace caused by the rocky terrain, but nonetheless, produces a reasonable result.

A series of cliff-face photographs were then taken. The photographs are useful in correlating data to location. The photographs were scanned and pieced together using Corel Draw and Corel Photo Paint to form a seamless and continuous series of the cliff. This allowed for certain sections of the cliff to be highlighted, or for the tracing of units directly into the computer. This was mainly an experiment and was not further expanded on within this paper due to limitations of the equipment.

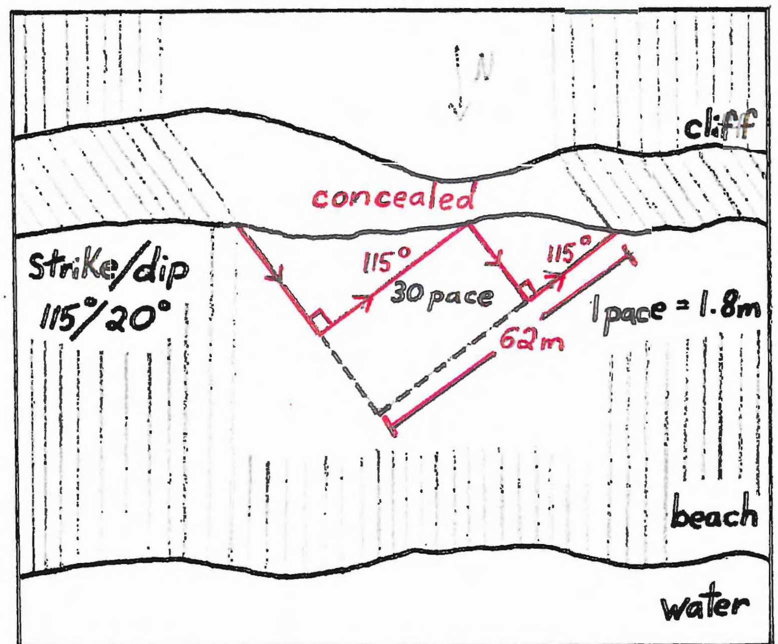


Fig. 1.2 Diagram of concealed interval measurement

1.4 Limitations

As mentioned previously, the cliffs near Joggins are being substantially eroded, which makes it hard to obtain detailed information for some intervals. Furthermore, there is a glacial till deposit overlying the section, and concealment of certain parts of the cliff caused by slumping is locally common. A century worth of coal mining, has eradicated small, but geologically significant areas of the cliff. Fossil fauna and flora and mineralogy were not studied in depth for this project in order to limit the scope of this paper; however, these are significant elements in fully developing a complete understanding and model of the paleo-environment. Importantly, especially with the introduction of elementary technology and programs, there should be a standard form in which geological research and presentation is done. The present mosaic of formats, not only makes it hard to relate similar aspects from unrelated studies, but also from previous related studies. Finally, the study area comprises a small proportion of the entire section, which limits conclusions related to large-scale cycles and events.

2.0 Facies Description

The following facies types are genetic classifications, dividing the smaller scale cycles in terms of lithological and depositional characteristics. The sandstone units have been divided into two groups, 1) sandstone channel units and 2) planar sandstone units (refer to Table 2.1). The sandstone channel units have been further broken down in terms of relative thickness and width as 1a) large, 1b) moderate, and 1c) minor sandstone channel-fill units, while the planar sandstone units have been sub-classified as, 2a) undulate, 2b) thin sheet, and 2c) tabular planar sandstone units. Mudstone units have also been sub-divided into, 3a) grey and friable, 3b) grey and platy, 3c) red and friable, and 3d) red and platy mudstone units. Finally, beds containing abundant organic matter have been grouped. The organic units have been divided into 4a) limestone, 4b) carbonaceous shale, and 4c) coal units.

Within the stratigraphic column presented, a larger cycle is represented in the 'grey' and 'red 'assemblages. Within these assemblages are facies sequences, which will later be linked as a series of progressive paleo-environmental changes, and will be shown to conform to the rise or fall of relative-base-level. These trends can be classified as forming part of progradational and retrogradational parasequence sets.

2.1 Sandstone Channel Units

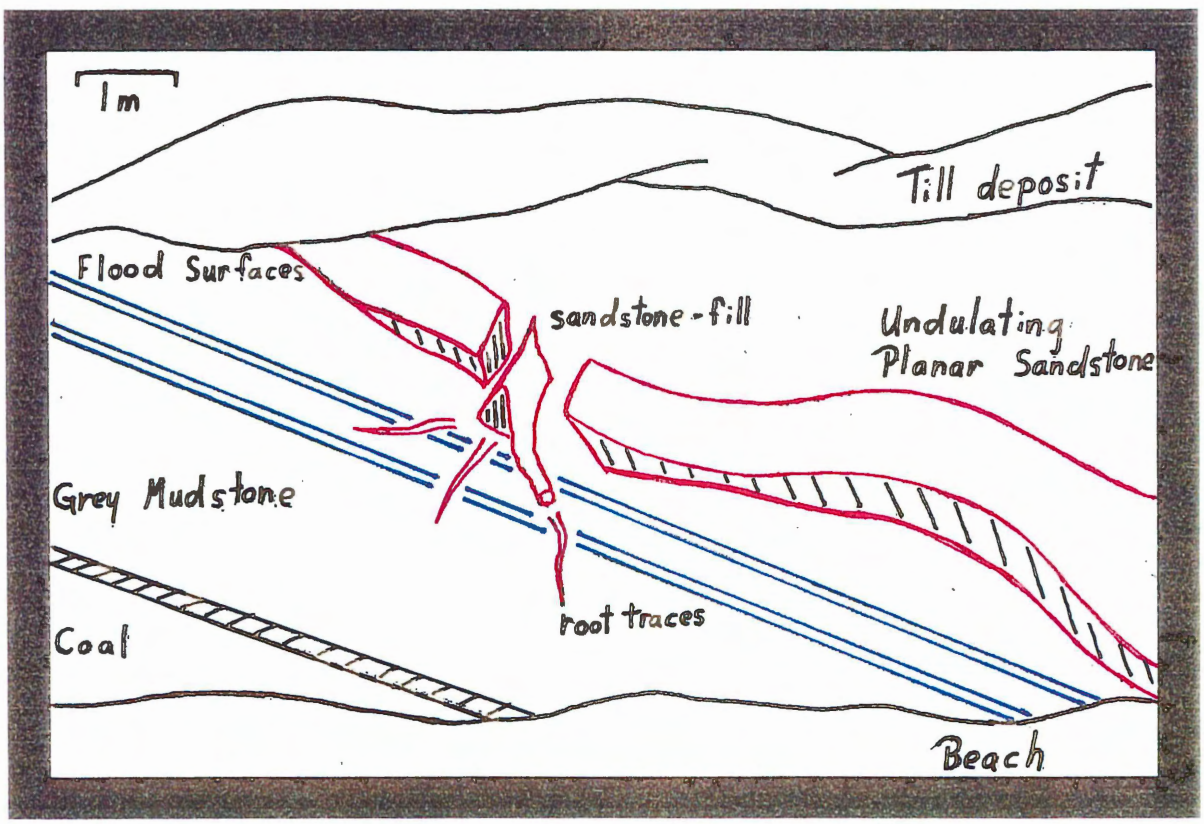
The sandstone channel-fill beds are light-grey in colour, have sharp undulating erosional basal contacts, a low thickness to width ratio in 2D sections, and extend laterally or erode into continuous undulating and tabular planar sandstone units (refer to planar sandstone units). There are three distinguishable channel sandstone types, 1a) large sandstone channel-fills, 1b) moderate sandstone channel-fills, and 1c) other minor sandstone channel-fills.

2.1.1 Large sandstone channel-fill units (1a)

The large sandstone channel units (6 to 8m width by 3 to 5m depth) contain prominent cross- and parallel- laminae. Relatively large cross stratification sets, < 0.6m thick, are present. Tool marks, including prods, skips and flute casts, scours, current lineation, ripple marks, and ridge and furrow marks are all present on exposed bedding surfaces. Paleo-flow measurements can be ascertained from ridge and furrow marks, found predominantly along the sandstone wave cut platforms, and flute casts. There is an indication of a general paleoflow direction of northeast to northwest (Appendix A). Larger bed forms, including stratification surfaces indicative of scroll bars and point bars, are also observed within the wave cut platforms.

These units contain the most abundance of plant fossil material. The most striking of these fossils are the large in situ (*lycopsid*) tree stumps (< 1m in diameter and 3m in height), *Calamites* stems (< 0.12m in diameter), and *stigmarian* roots (0.08m in thickness and < 7m in length), present within the channel bodies and surrounding planar sandstone beds. Figure 2.1 illustrates in situ *lycopsid* tree stump located within the underlying section. These fossilized trees have stigmarian root systems that can be traced into underlying mudstone units (figure 2.1). Abundant plant fossil fragments are present within these units. Along two bedding surfaces, large traces (*Diplichnites*) made by the arthropod *Arthropleura* and small traces of the ancestral kingcrab (*cf. Belinurus*) are present. Found in abundance locally are coalified tree fragments, some as large as 0.6m

Figure 2.1 Photograph (above) and diagram (below) of in situ *lycopsid* tree stump



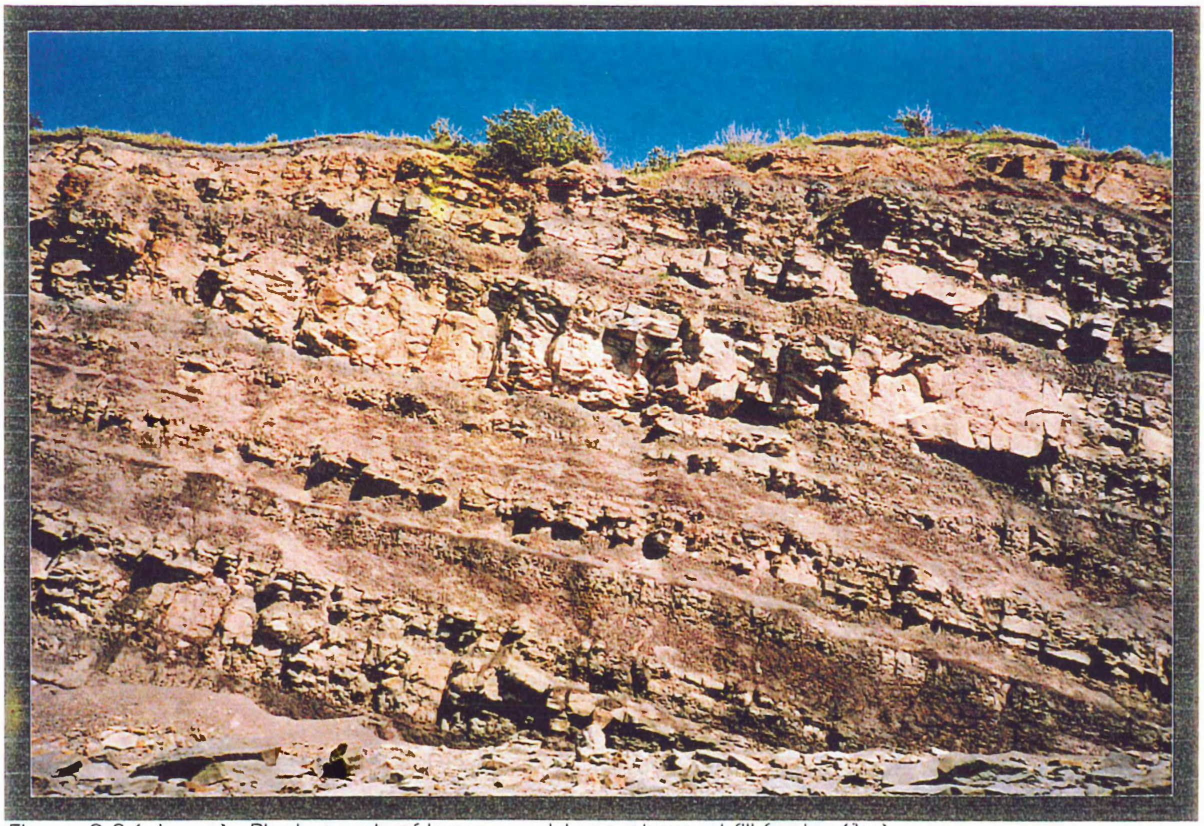


Figure 2.2 (above) Photograph of large sandstone channel-fill facies (1a)

Figure 2.3 (below) Photograph of multiple moderate sandstone channel-fil facies (1b)

wide and 1.2m long. These coalified tree fragments are positioned sub-vertically to horizontally; therefore, their presence is most likely caused by transportation. Sideritic and calcareous nodular concretions occur with spherical shapes within these units but are uncommon.

On a larger architectural scale, the sandstone channel bodies all share a similar characteristic bed style. Channel units are massive to internally stratified. Discrete channel scour surfaces are shallow, < 3m in depth, and narrow, < 8m in width. In well exposed areas, the sandstone channel bodies erode into sandstone splays (refer to planar sandstone units, below), illustrated in Figure 2.2. Within the larger scale channel units, channel deposits are present as stacked sets eroding into underlying channel deposits (Figure 2.4).

Laterally, within separate channel sets, and vertically, on separate bedding planes, paleoflow measurements show a general direction, but features indicating a wider variation in direction are also present. These variations in flow direction are commonly found within modern environments and are caused by various elements which may produce flows within virtually 180° radius. Factors contributing to this include variable flow rates, turbulent flow, channel sinuosity, bed forms and obstacles (Miall 1994). Vertical occurrences of multiple channel sandstone bodies are a result of a reactivation of abandoned channel bodies, a cause of channel migration, channel cut-off, and channel switching (Miall 1994).

2.1.2 Moderate sandstone channel-fill units (1b)

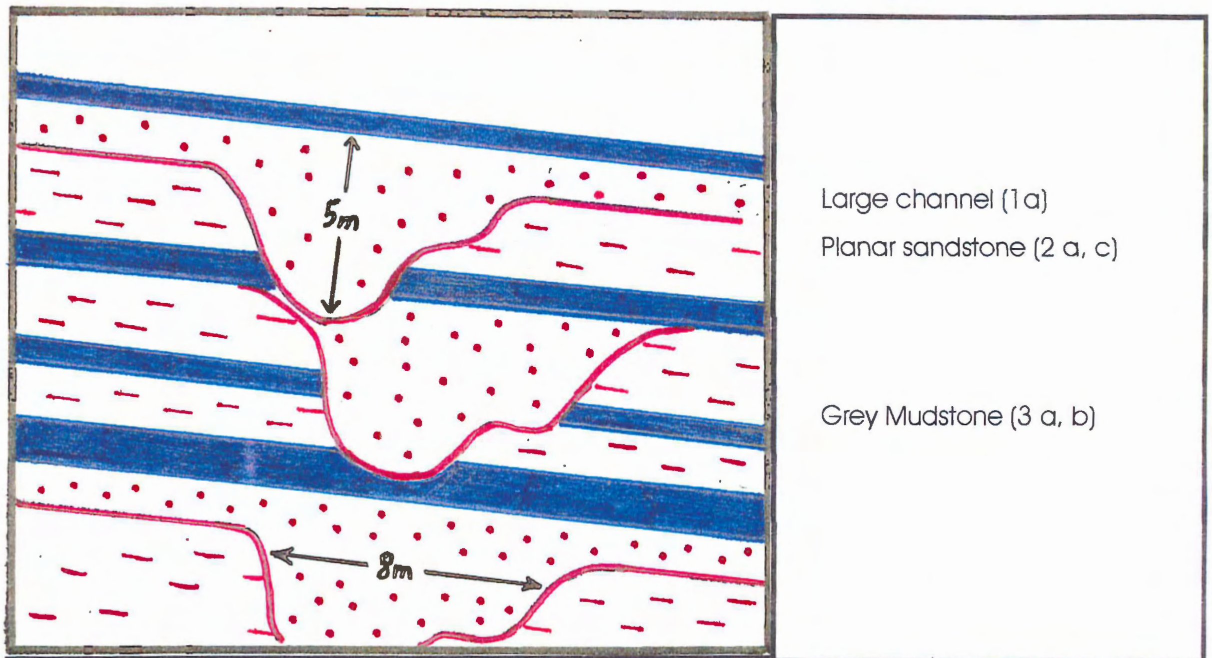


Fig. 2.4 Diagram of vertically stacked large sandstone channel units

The moderate sandstone channel-fill bodies (3 to 7m wide by 1 to 3m thick) are similar to the large channel bodies in respect to bed style, sedimentary structures, and fossil content. The contrast, however, in their lack of any large bar forms, the lower frequency of larger sedimentary structures, and the presence of several bodies positioned laterally with respect to each other, rather than stacked vertically. Moderate channel bodies occur in greater abundance than the large bodies. It is possible that some of the larger channels classified within this section do contain bar forms which are either concealed due to the orientation of the cliff section with respect to their form, or have been eroded (figure 2.3).

Although the presence of plant fossils is characteristic of both large and moderate channel sandstone bodies, the fossil density is greater in the latter. The majority of fossils are fragmented (<1mm) and unidentifiable. Fossil-rich laminae are common within this unit. Sideritic and calcareous nodular concretions are rare.

The moderate channel bodies are found within multiple channel systems. Groups of up to four individual channel bodies are present within the same stratigraphic level (Figure 2.5). They are separated by planar sandstone bodies, which grade into or are eroded by the moderate channel bodies (refer to planar sandstone units).

This unit is interpreted as being an anastomosing fluvial system. This type of fluvial system is characterized by several low width to depth ratio channels that are interconnected and separated by large vegetated islands (Miall 1978). Individually, each shallow channel contains the characteristics of a smaller scale meandering channel, reinforced here by the similarities in bed marks and sedimentary structures with the absence of larger scale structures, such as, large cross-sets, mega-ripples, and scroll bars.

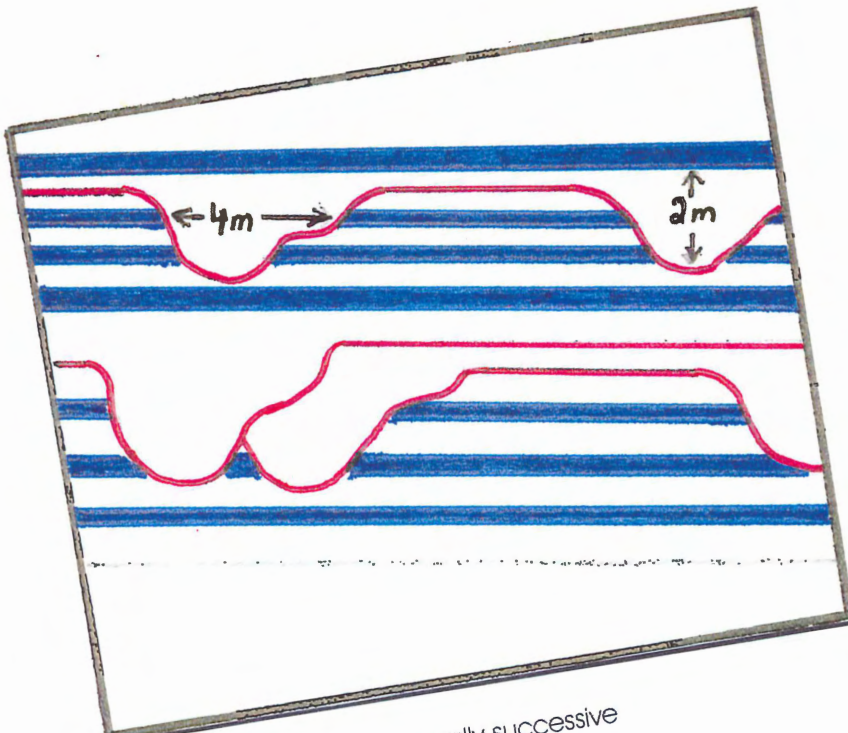


Fig. 2.5 Diagram of laterally successive moderate sandstone channel units

The absence of these larger scale structures, which are present within modern-day anastomosing systems, could be due to erosional processes, posing a greater effect on the shallower moderate channel bodies, or poor exposure.

2.1.3 Minor sandstone channel-fill units (1c)

The minor sandstone channel-fills are the most common of the channel sandstone facies present along the cliff section. They occur within the majority of undulating planar sandstone beds (refer below) and are found as discrete laterally successive systems within individual beds, or within undulating planar sandstone beds that extend laterally from moderate and large channel sets (Figure 2.3).

These channel bodies are less than 1m in thickness and in width. They are consolidated sandstone bodies containing weak to strong parallel and cross-laminae. Fossils are commonly fragmented; however, rare *Calamites* and in situ stigmarian fossils can be identified. The presence of tool marks (refer to large sandstone channel-fill unit) along the bedding surfaces indicates that these minor channels received a relatively strong periodic current, presumably in a fluctuating flow regime.

The minor channel sandstones are similar to modern feeder channels, which feed into crevasse splays and floodplains (Miall, 1978). These channel types are activated only during high run-off periods (e.g. seasonal). During this time, water levels rise above the channel levees causing breaks in the levees and concentrated spillovers into the surrounding floodplains. This facies type results fom a moderately high-energy regime in sporadic episodes.

2.2 Planar Sandstone Units

Planar sandstone bodies contain flat to moderately undulating beds with sharp erosional basal contacts. They occur as both massive tabular sets and thinly bedded planar sheets that are heterolithic. Additionally, they are found in cyclical sets cut by channel sandstone bodies. The planar sandstone bodies presently appear in the cliff as flat lying, continuous to discontinuous beds protruding from the cliff up to 0.5m. Planar beds found as heterolithic units interstratified with mudstone in the lower section of the study area, are stratigraphically positioned within proximity to the organic units, contain *lycopsid* trees (Calder, personal communication).

Divisions between units were based on bed form and thickness. There are three distinguishable planar sandstone types, i) undulating-planar sandstone units, ii) thin sheet planar sandstone units, and iii) tabular-planar sandstone deposits.

2.2.1 Undulating planar sandstone units (2a)

The undulating sandstone units contain continuous to discontinuous beds, >0.05 to 0.9m thick, and locally interstratified with siltstones and mudstones. Characteristic of all the sandstones, they contain erosional basal contacts, which are flat to moderately undulating. The undulating sandstone units occur as both discrete beds across the cliff and as laterally 'enclosed' sets eroded by channel sandstone bodies (Figure 2.6). The beds contain planar laminae and cross-laminae. Along bedding surfaces, tool marks, scours, flute casts, and load structures are common features.

Plant fossils are abundant within these units. In situ *Stigmarian* roots can be traced laterally for more than 10m in certain areas, with vertical root traces extend into the underlying units. *Calamites* is present in situ and locally in abundance (0.1m average spacing) and up to 1m in height. Indeterminate plant fragments are also common, either scattered or concentrated along bedding surfaces.

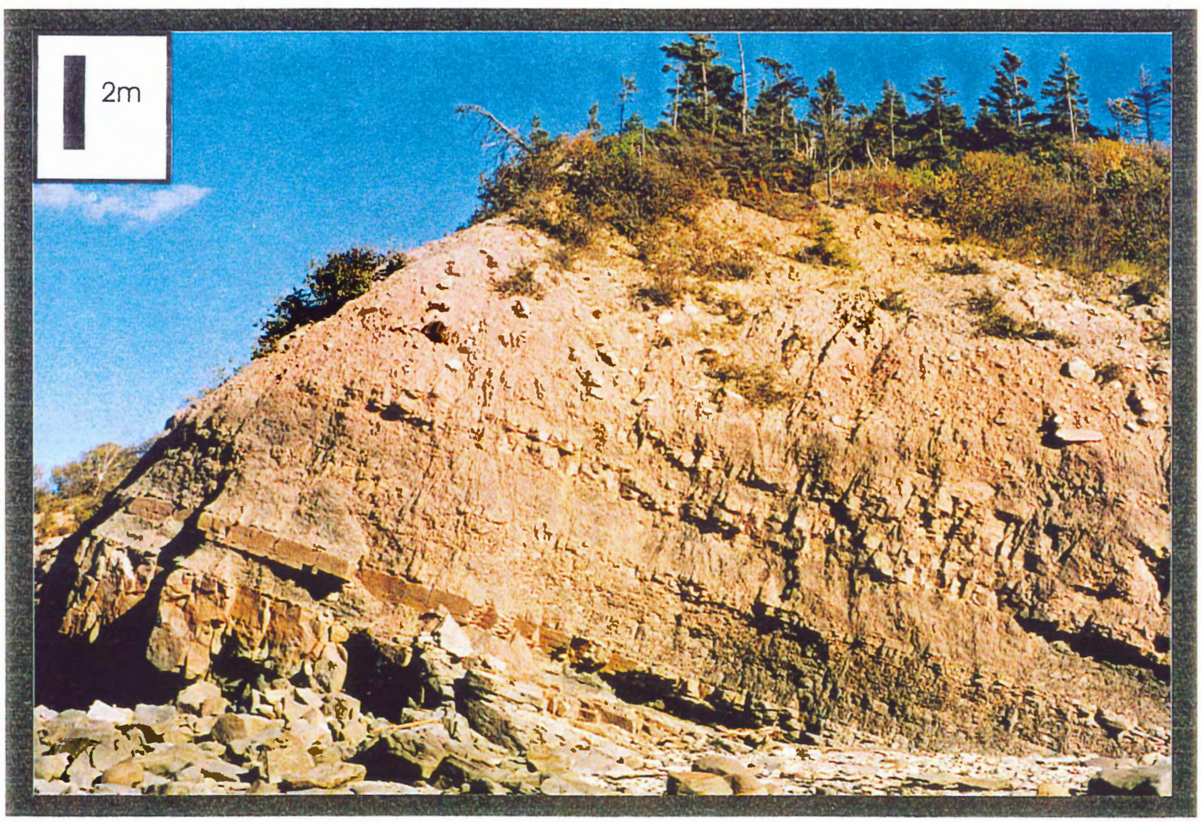
The undulating sandstone units are interpreted as crevasse splays and are associated with overbank deposits. The abundance of specific vegetative fossil types is an indication of the paleo-environment, whether or not it was locally prone to constant inundation (Calder, personal communication). Since they are associated with channel bodies, it is reasonable to suggest an alluvial setting. The tabular sandstone bodies incised by channels would have been transformed into small-scale vegetated island bar forms, separating the interconnecting anastomosing fluvial channels. Cross-beds show the accretionary direction of these splay forms. Muddy interbeds indicate separate flood events and represent inactive periods.

2.2.2 Thin sheet planar sandstone units (2b)

This type of unit is rare within the study section. The thin sheet planar beds are flat, thin (< 0.1m), and featureless. These units are, however, distinguishable from other planar sandstone beds in thickness. Laterally, these units extend as continuous even sheets. Vertically, they have both erosional basal contacts and gradational contacts with planar tabular, undulating and channel beds. They occur with and without minor platy siltstone and mudstone interbeds.

These planar sandstone deposits are flood deposits, produced by the complete, yet shallow, inundation of the local area. Flood episodes reflected by these deposits were rapid and short in duration, a possible explanation for the thin beds. Both autocyclic and

Figure 2.6 (above) Photograph of heterolithic undulating planar sandstone facies (2a)
Figure 2.7 (below) Photograph of tabular planar sandstone facies (2c), overlying channel-fill



allocyclic changes may contribute to a short period of enhanced sediment movement. Shallow waters would inundate existing channel systems and vegetative flat-lying lands.

2.2.3 Tabular planar sandstone units (2c)

This facies comprises continuous tabular planar beds of sandstone. These beds are individually 0.1 to 0.45m in thickness and are common only locally within the study section. Grain size is medium grained. Most beds within this unit are massive, although parallel and cross-laminae are present within specific stratigraphic horizons. Bedding surfaces lack any sedimentary features. The fossil content within these beds is low, and concretions were not observed.

These units are concentrated in areas overlying limestone deposits (refer to stratigraphic column, (chapter 3, and organic units below). The majority of these units are interstratified with red mudstones within the study area. The tabular sandstone beds differ from the undulating beds in structure and form (Figure 2.7).

These deposits are submerged flood deposits, the result of similar processes producing the thin sheet planar sandstone deposits. The thickness of this unit is the main distinguishing feature between the thin sheet and tabular sandstone deposits. This variation may be a result of flood duration, local topography, or increased sediment load.

2.3 Coarsening-Upward Bay-fill Units (5)

The bay-fill units consist of gradational coarsening-upward packages of mudstone passing into sandstone. These units are approximately 1m thick. They are comprised of grey friable to platy mudstone deposits (0.4 to 0.7m thick) underlying discontinuous tabular planar sandstone deposits (0.2 to 0.4m thick). Larger sedimentary bedforms (e.g. hummocky cross-stratification) are not observed, possibly a result of poor exposure or poor preservational effects. The sandstone deposits locally contain minor plant fragments and root traces. The mudstone deposits contain spherical and irregular sideritic and calcitic concretions (<0.07m in length). Parallel laminae are present. These units generally occur within close proximity with major and minor flooding surfaces.

These units have been classified as inland bay-fills. These deposits can be generated when channel bodies feed into open standing bodies of water or topographical restricted areas (Kosters 1989; Tye & Coleman 1989). Pre-existing mudstone deposits are overlain by fine sediment, which grade into coarser-grain deposits as accumulation progresses.

2.4 Mudstone Units

Mudstone units are thin horizons to thick beds (up to 10m). These units are poorly consolidated and undergoing a high degree of erosion. These beds are red, grey and mottled in colour, while friable or platy in appearance. The mudstone beds are soft, crumbly and very fine in grain size, implying a significant clay content. They also lack preserved sedimentary structures.

Horizontal and vertical clay seams within these units appear to be root traces. Sideritic and calcareous concretions, commonly present in spheroidal, elongate, and root cast forms, occur in abundance within certain beds. Sand-filled root casts are also present and can be traced into overlying sandstone units containing tree stumps.

There are four identifiable mudstone facies, i) grey friable, ii) grey platy, iii) red friable, and iv) red platy mudstones. Since grey and red variations in colour are the result of reducing or oxidative processes the four units will be treated as two units within the text. They are, a) friable mudstone and b) platy mudstone.

2.4.1 Friable mudstone units (3a & c)

The friable mudstone units comprise the majority of the cliff. Although red, grey, and mottled friable mudstone beds are interbedded, they typically occur with one colour form in greater abundance. Bed thickness varies from 0.05 to ~10m. Beds are very fine grained, soft, and crumbly, resulting in heavy erosion of the cliffs. Most of the mudstone beds are partially concealed by the till overburden. Grey beds differ from red beds in sedimentary features present. Whereas, grey beds commonly contain clay seams, root traces, and sideritic spherical and elongated nodular concretions, red beds contain desiccation cracks and few concretions; however, this is a generalization, and exceptions are present.

These characteristics are interpreted to result from soil formation, locally in marsh and swamp environments. These are low energy environments with high biological productivity. Very fine sediment is transported and left stagnant, forming a soil horizon with a high biological capacity. Bioturbation by roots and underground organisms destroys all stratification, producing a friable deposit. Raised water table levels would bog the local area and within these waterlogged environments the preservation of fossil fragments and root traces would be high. Anaerobic conditions are also favourable in the cultivation of microbes or physiochemical processes, resulting in the presence of sideritic and calcareous concretions. Modern observations within anoxic organic-rich black mud environments effected by flood tides and sustaining a dense flora have yielded irregular and spheroidal siderite-calcite-iron monosulphide nodules (Coleman 1993).

The colour variation between grey and red mudstone deposits is a variation in reducing or oxidizing processes. Hot and arid conditions arise when the water table drops, causing oxidative processes to alter the grey friable mudstone deposits to red friable mudstone beds. Biological matter breaks down, and fossil fragments and traces are poorly preserved. Within sustained arid environments desiccation cracks form.

2.4.2 Platy mudstone (3b & d)

Platy mudstone beds occur throughout the cliff and are locally abundant. This facies is, however, uncommon within the cliff section generally, but is still quite distinguishable from the friable mudstone beds. Bed thickness ranges from 0.01m to 4.0m. The platy mudstone beds, similar to the friable mudstone beds, are very fine grained (implying a clay rich content), soft, and crumbly. The platy mudstone beds weather recessively; however they weather into small discoidal fragments rather than irregular pieces, implying that much of the original stratification has been preserved. The platy mudstone beds are found both as independent beds with sharp contacts, and as vertically graded beds passing into and out of friable mudstone units. Within these units, only discoidal sideritic nodular concretions have been observed.

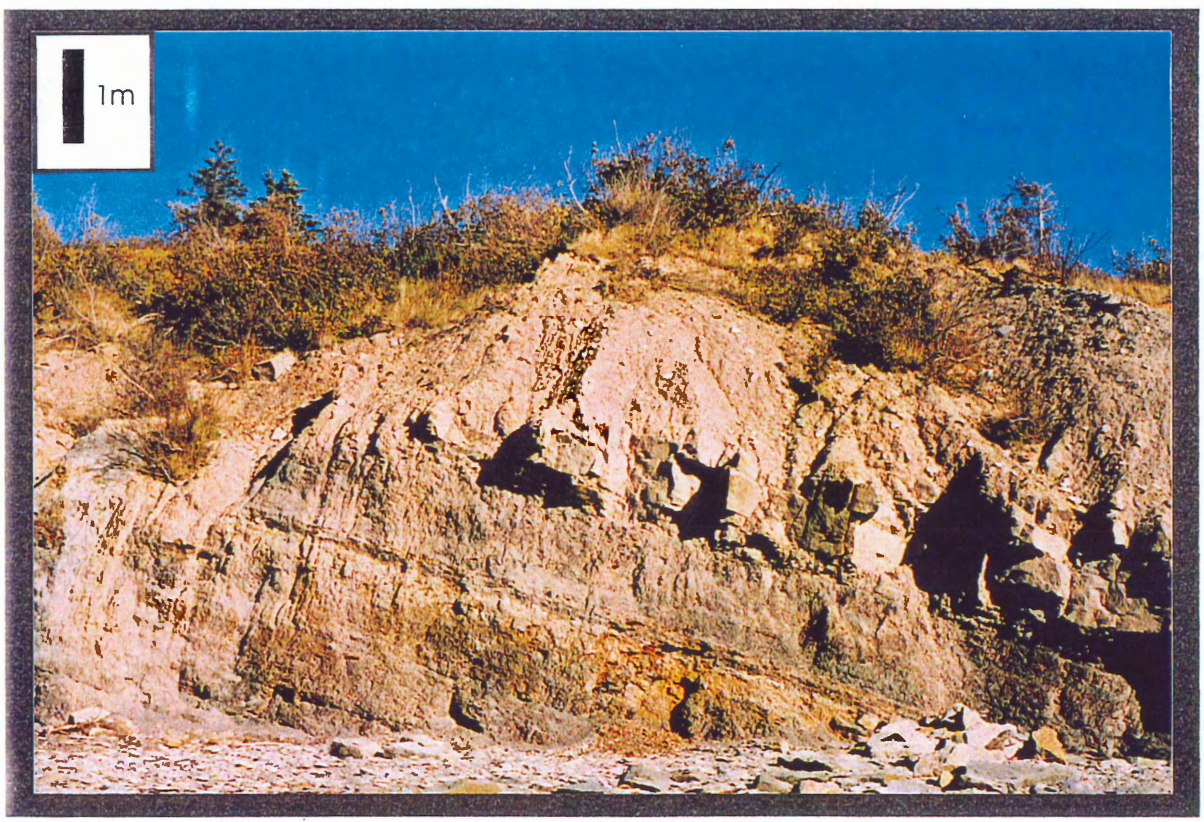
Deposits of this nature must occur within restrictive environments, protecting the stratification from biological and weathering processes. The close proximity of these units with overlying and underlying fluvial and flood deposits suggests that the platy mudstones were deposited in sub-aqueous environments. This environmental model would be within a low energy system, transporting only very fine sediment. A possible explanation could be a rise in the water table, drowning the terrestrial flat lying area with a shallow standing body of water (i.e. allocyclic).

2.5 Organic Units

The organic units are, in most respects, the most interesting units and the most distinguishable features of the cliff. The Joggins Formation and surrounding local geology is of historical value because early mining exploration concentrated on extracting the coal from the Joggins Seam. There still remain several lesser coal seams, however, unfortunately the Joggins Seam is not one of these. In addition, limestone and carbonaceous shale units are present.

The limestone deposits (4a) are significant units within the Joggins Formation as they are representative of an environmental change. These units were used to divide the cliff into working sections and used as markers during measurement. The carbonaceous shale units (4b) are thin continuous black beds found overlying and underlying coal seams (4c) and stringers. These units are primarily concentrated within the lower section of the study area. Fossils, including bony fish, bivalves, spirorbid, eocarid, ray-like fish, and tetrapod footprints have been documented within this lower section.

Figure 2.8 (above) Beginning of the Stratigraphic Column, Limestone facies (4a)
Figure 2.9 (below) Photograph of Coal facies (4c), overlying a thin seat earth layer



2.5.1 Limestone (4a)

The limestone units are thin, black, fissile, and almost shaly beds. The fossil content includes an abundance of bivalves and ostracods. The limestone is black, laterally continuous, and occurs as planar tabular beds, 0.1 to 0.4m in thickness.

These units are present as thin and sparsely occurring deposits, and are therefore not a common feature of the section under examination. There are two limestone beds within the section, and the main limestone bed was used as a marker to begin measurements (Figure 2.8). The abundant fauna shows high levels of localized aquatic biological activity. Fossils include, from the phylum *Arthropoda,* class *Ostracoda: Carbonita alilis, C. elongata, C. fabulina, C. pungens, C. rankiniana, C. secan, Hilboldtina rugulosa, Candona bairdiodes*, and *Candona salteriana*; from the class *Malacostraca: Pygocephalus (Anthrapalaemon) dubius*. From the phylum *Mollusca*, class *Pelecypoda: Naiadites carbonarius, N. longus, and Curvirmula sp.* Also present, from the phylum *Chordata*, class *Acanthodii: Gyracanthus duplicatus* (Dawson 1855; Calder, in press).

Although the limestone deposits within the Joggins Formation have been interpreted as being non-marine, it has been recently argued that this may be an over generalization (Calder, in press). Problems exist in that the terms marine and non-marine do not represent the full spectrum of aquatic fauna (Calder, in press). The limestone deposits reflect a brackish? water basin environment, recently suggested by Calder as possibly having an open water-way with the sea. In order to support the dense biological fauna, water would have had to be constantly circulated and relatively persistent in comparison with the shorter cyclical flood events. The large content of fossils remaining

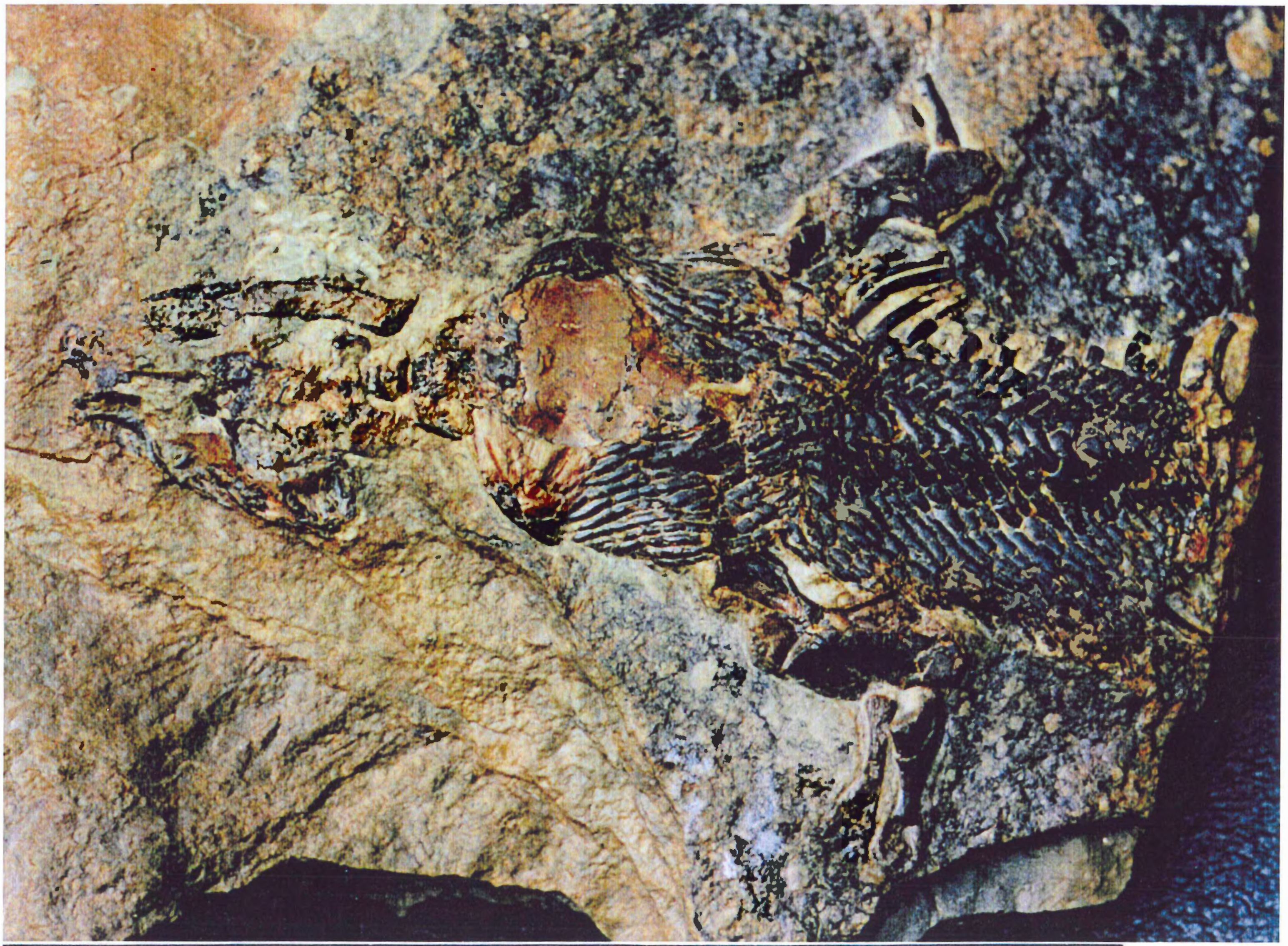


Fig. 2.10 Fossil of reptiliomorph from planar? Sandstone unit (Calder, 1998)

relatively intact demonstrates that the fauna is derived locally. Organisms associated elsewhere with marine environments and found within the limestone fossil record have been treated in the past as specialized adaptations to a freshwater environment, but they may have been anadramous instead (Calder, in press), suggesting an open waterway with the marine environment.

2.5.2 Carbonaceous shale units (4b)

The carbonaceous shales are thin (<0.25m) beds, commonly occurring with minor coal laminae. They are rare, but lithologically distinct. They occur as individual and stacked laminar beds within the mudstone units. The shales are fissile and black, which result from a high fossil carbonaceous content; however, pant fossils commonly are fragmented and indeterminate.

Shale deposits are exclusive to aquatic environments. They occur in both marine and freshwater environments, resulting from the low energy submerged deposition of highly stratified mudstone. The shale units observed at Joggins are carbonaceous. In situations of rapid inundation, there would be a high impact on the fauna and flora. These fragments could deposit within the aqueous environment, gradually breaking down within the shale deposit.

2.5.3 Coal units (4c)

The coal facies are centimeter scale coal laminae, which may occur in association with clay and shale laminae (figure 2.9). There are no major seams, such as the Queen

Seam and Joggins Seam, within the study section. The coals indicate minor peat accumulation in wetlands with consistently waterlogged substrates.

Table 3.1 Facies Types

Facies	Grain Size	Colour	Bed Style	Sedimentary Structure	Interpretation
1a) Large Sandstone channel-fill body	Medium/ fine sand with pebble-sized clastic horizon.	Light grey	Massive and hard to planar bedded with mud interbeds. Sharp erosional basal contact, narrow (7m) lensoidal (3m) bodies extending to sheet sandstones laterally, and vertically re-occurring.	Strong cross-laminar and parallel laminar features. Cross-stratification (0.6m) and scroll bar features. Tool marks, ripple marks, ridge and furrow structures, and parting lineation features present along bedding surfaces. Large fossilized in situ tree stumps rooting into underlying unit, calamites stems, and stigmarian roots present within channel, as well as fish scales, plant stems, leaf fragments, and Arthropleura trackways.	High energy sediment transportation environment. Small meandering fluvial system related or independent to a larger anastomosing fluvial system. Seasonal flow variations would favour re-activation of the channel after lag periods and would continue as multiple vertical sets eroding into underlying channels.
1b) Moderate sandstone channel-fill	Fine to medium sand	Light grey	Massive and hard to planar bedded with mud interbeds. Sharp erosional basal contact, narrow (6m), and concave-upward (1m) bodies extending laterally to multiple channel sand-fills with similar characteristics divided by sheet sandstone bodies.	Strong cross-laminar and parallel laminar features. No bar structures noted. Tool marks, ripple marks, ridge and furrow structures, and parting lineation features present along bedding surfaces. In situ tree stumps rooting into underlying unit, calamites stems, and stigmarian roots present within channel, as well as fish scales, plant stems, and leaf fragments.	High energy sediment transportation environment in which channel migration, cut-off, and switching produces multiple lateral systems which can be seasonally activated and re-activated. Small fluvial set related to a larger anastomosing fluvial system.
1c) Minor sandstone channel sand-fill	Fine to medium sand	Light grey	Massive and hard. Sharp erosional basal contact, narrow (4m), and concave-upward (<1m) bodies extending laterally to multiple channel sand-fills with similar characteristics divided by sheet sandstone bodies.	Cross-laminar and parallel laminar features. Tool marks are present along bedding surfaces. Calamites stems, and stigmarian roots present within channel, as well as plant, leaf, and root fragments.	High and fluctuating energy sedient transportation environment. Small feeder channels deriving sediment from larger fluvial bodies during seasonally high flow rates and supplying crevasse splays.

Channel Sandstone Bodies

2a) Undulate planar sandstone deposit	Fine/ medium grain	Light grey	Continuous to discontinuous planar to undulating sand beds (>0.4m). Sharp contacts.	Parallel and cross-laminar features. Tool marks and flute casts present on bedding planes. Plant fossil fragments are abundant and Calamites stems are locally common.	High and fluctuating energy depositional environment. Overbank sand flat deposit or crevasse splay.	Planar Sandstone Bodies
2b) Thin sheet planar sandstone deposit	Fine/ medium grain	Light grey	Continuous fissile planar to moderately undulating sandbodies (< 0.1m). Sharp to gradational contacts.	Strong parallel laminae with featureless bedding surfaces.	Moderate energy depositional environment. Flood and subaqueous deposition.	
2c) Tabular planar sandstone deposits	Fine/ medium grain	Light grey	Continuous massive and hard planar sandbodies (>0.5m). Sharp contacts.	Parallel laminae with featureless bedding surfaces.	Moderate energy depositional environment. Submerged flood deposit.	
3a) Grey friable mudstone	Clay to silt	Grey and mottled.	Friable to poorly developed platy features, poorly consolidated, and poorly weathered.	Spherical to elongated sideritic and calcitic nodular concretions and abundant clay seams are common to abundant within beds.	Low energy sediment environment. Various stages of developing paleosoil horizons with high levels of biological activity; ie. wetland, marsh, or salt marsh environment.	Mudstone D
3b) Grey platy mudstone	Clay to silt	Grey to purple-grey and mottled.	Platy beds extending laterally and vertically grading to poorly developed platy and/or friable beds. Poorly consolidated, and poorly weathered.	Beds are well stratified. Sideritic nodular concretions are rare. Clay seams are common.	Low energy sediment environment lacking bioturbation. Flood event and rise in the water table level. Silt and mud deposited within a submerged environment; ie. shallow basin, drowned valley. Result of a relative rise in base level.	

3c) Red friable mudstone	Clay to silt	Red and mottled.	Friable to poorly developed platy features, poorly consolidated, and highly weathered.	Sideritic nodular concretions and clay seams are rare within beds. Desiccation cracks (sandstone-fill) are common locally.	Low energy sediment environment. Paleosoil horizons with high levels of biological activity. Oxidational processes have occurred, the result of either a change in environment to arid, or chemical processes in the development of a red paleosoil. Wetland, marsh, or salt marsh environment.	
3d) Red platy mudstone	Clay to silt	Red to mottled.	Platy weathered beds extending vertically and grading to poorly developed platy and/or friable beds. Poorly consolidated, and highly weathered.	Beds are well stratified and contain no sedimentary structures or features.	Low energy sediment environment lacking bioturbation. Flood event and rise in the water table level. Silt and mud deposited within a submerged environment. Result of a relative rise in base.	
4a) Limestone	Very fine	Black	Continuous fossiliferous fissile planar beds.	Abundant re-mineralized bivalves, ostracods, and other fossil fragments.	Large body of circulating water (brackish?), either lake or lagoon system. Local inundation as a result of a change in base level.	Organic Deposits
4b) Shale	Very fine	Purple grey to black.	Thin fossiliferous fissile beds occurring within mudstone beds.	Thin, cm scale, featureless fissile beds. Fossil content is fragmented and unidentifiable.	Impure peat accumulation, arising from excessive sedimentation. Result of subsidence or a rise in base-level. A 'clastic' swamp.	
4c) Coal	Very fine	Black	Immature coal seams and 'stringer' on a millimeter scale. Commonly occur within shale units.	Lustrous to semi-lustrous blocky seams. Plant and leaf fossil fragments.	High vegetative drowning event, peat swamp/mire environment established. Shallow burial and chemical infiltration from overlying environment.	

3.0 Stratigraphic Column

The stratigraphic column for the Joggins and Springhill Mines Formations in the study area (fig.3.1) represents approximately 190m of section measured along the near-vertical cliff. The column begins at a limestone bed, which follows a large concealed interval. This limestone bed is located within the upper part of the Joggins Formation. The stratigraphic column continues through the boundary and into the lower part of the Springhill Mines Formation, ending at MacCarrons Creek.

A legend is provided in order to relate the bed by bed observations to the location. Each page represents approximately 10m of cliff, while a synopsis of the column has also been provided (fig. 3.2). Facies numbers have been assigned in order to relate facies sequences to the column. Smaller scale coarsening-upward (CU) and fining-upward (FU) intervals, on the order of 1 to 10m, have also been outlined by blue and red arrows respectively. Boundaries between these packages are, for the most part, sharp and erosional.

Larger scale cycles are noted within the adjacent bar as either 'grey assemblages' or 'red assemblages'. These larger cycles may consist of up to 40m of strata and can be identified as wetland and dryland environments. Boundaries between these large-scale cycles are gradational and the cycles can be associated with 'highstand' and 'lowstand' conditions. Successive occurring environments can be classified as Progradational and Retrogradational parasequence sets.

Progradational parasequences are designated by successive deposits indicating a progressive rise in the water table (i.e. mudstone -> sandstone channel -> coarsening-upward bay-fill). This parasequence set may occur in conjunction with either grey or red preserving the stratification within the upper part of the unit. This environment was then eroded by multiple moderate channel systems, possibly an anastomosing fluvial system. Crevasse splaying, caused by sediment spilling over the channel levees, would further erode the surrounding floodplain environment. Channel systems encountering a restricted basin, would inundate the environment and create an inland bay (Kosters 1989; Tye & Coleman 1989). A catastrophic flood event would deposit stratified mud along with decaying vegetation, producing the highstand horizon marked by the carbonaceous shale facies (Koster 1989; Kosters & Suter 1993).

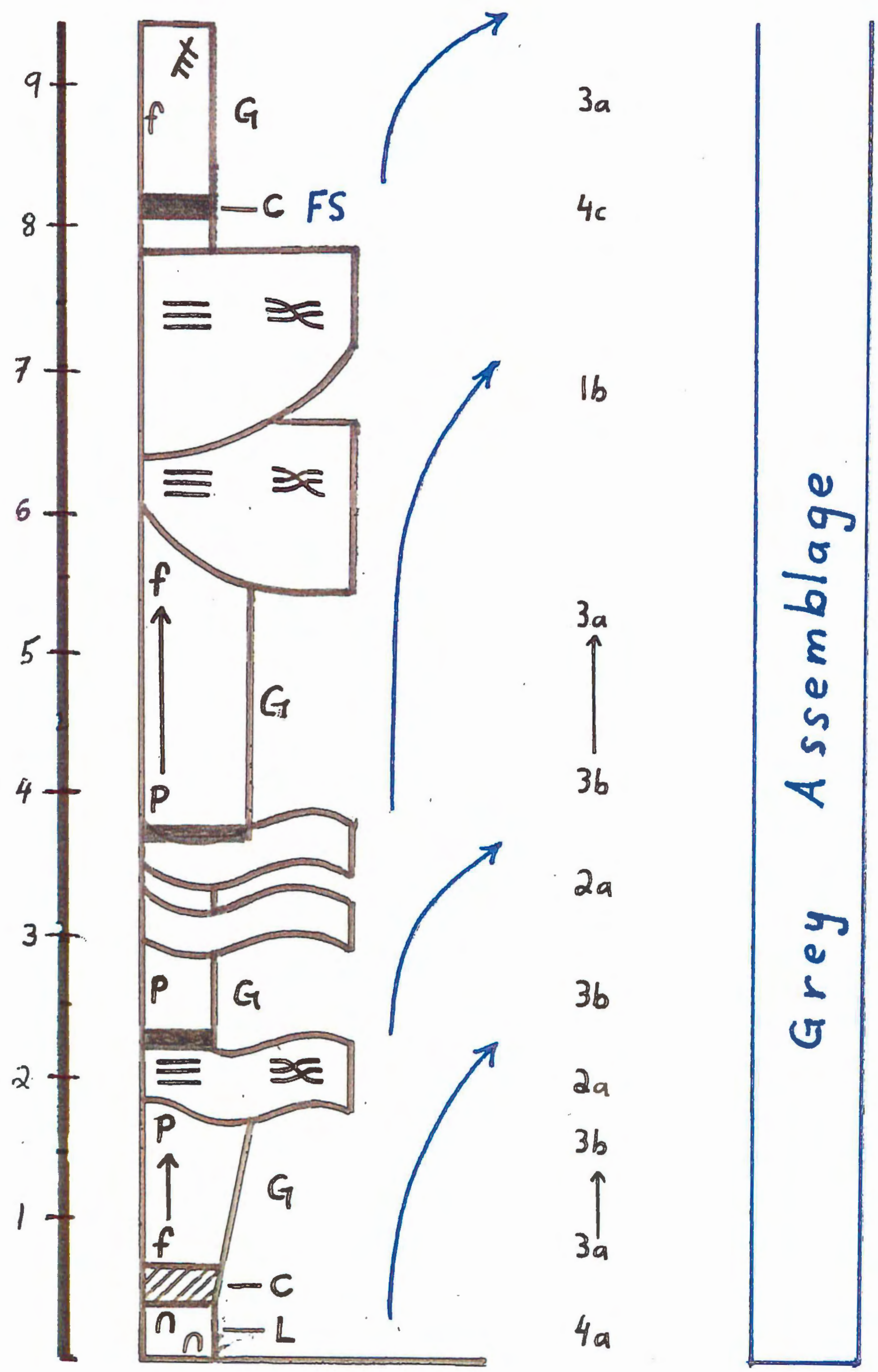
Generally, fining-upward packages, illustrated by the red arrows, are indications of a retrogradational parasequence set. These parasequence sets are broadly defined within the stratigraphic column as vertically occurring beds indicative of a reduction in energy. Basal contacts can be observed as sharp and conformable. An example within the stratigraphic column of a retrogradational parasequence can be found within the 55 to 59m area.

Within this sequence, a high-energy environment comprising a large sandstone channel-fill facies containing thin sheet planar sandstone flood facies, is followed by a fining-upward package containing a minor sandstone channel-fill facies. The lowstand period, defining this parasequence, is an overlying red friable mudstone facies. This sequence illustrates a progressive reduction in energy. A mass sediment transportation environment is succeeded by an arid or well-drained paleosol environment. This parasequence occurs within the upper boundary between a red assemblage grading into a grey assemblage.

Figure 3.1
Stratigraphic Column for the Joggins and Springhill Mines Formations

Legend

C ----- coal
L ----- limestone
S ----- carbonaceous shale
∩ ----- brachiopods, bivalves, and ostrocods
f ----- friable / bioturbated
P ----- platy / stratification or inundation
↑ ----- grading
≡ ----- planar-lamination
≈ ----- cross-lamination
≋ ----- ripple marks
----- cross-stratification
°o°o ----- conglomerate
↗ ----- tool marks
----- vegetative fossils (root traces, plant fragments)
☰ ----- in situ tree trunks
↓ ----- traced into underlying unit
n ----- sideritic nodular concretions
G ----- grey colouration
R ----- red colouration
M ----- mottled colouration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G
C
L
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4c
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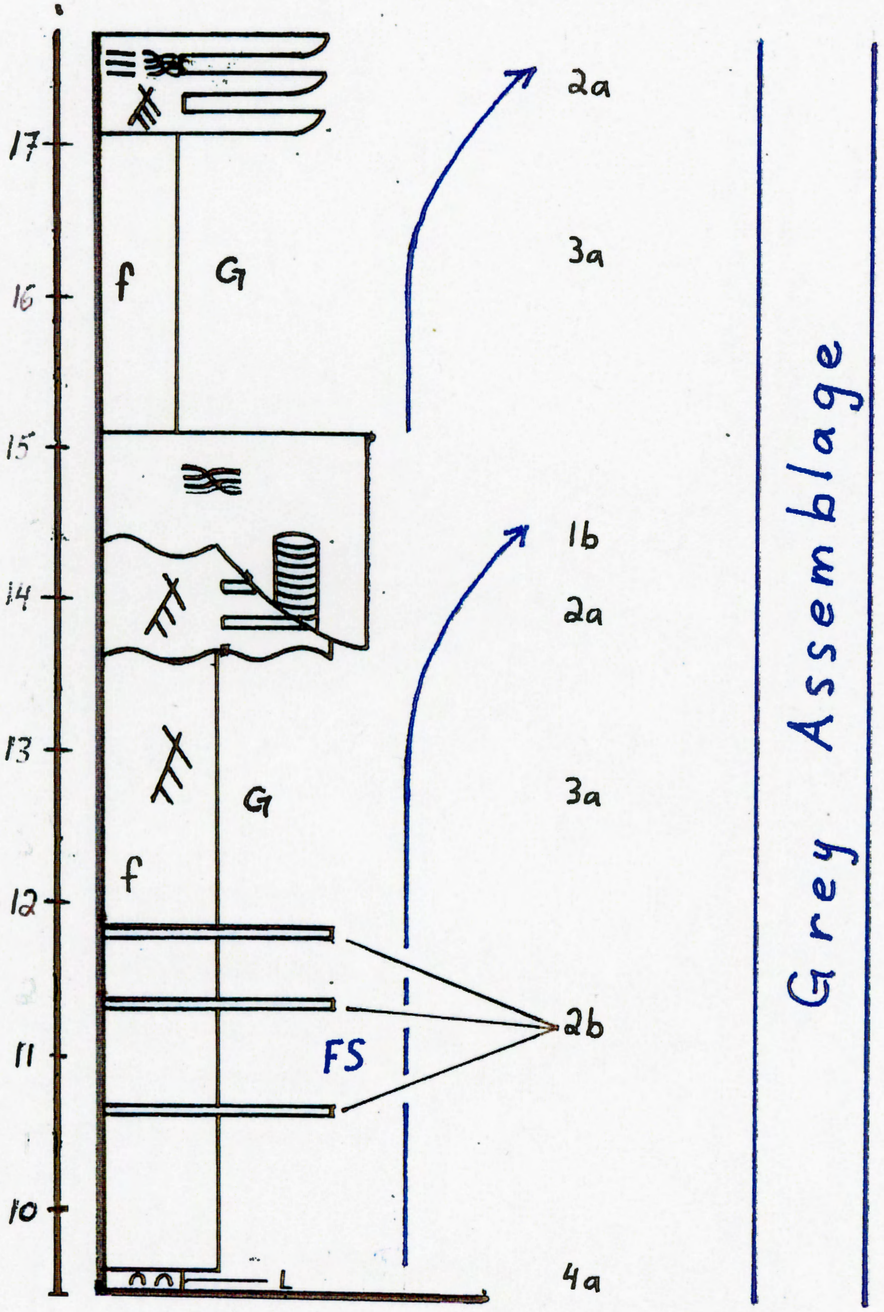
4a
Grey Assemblage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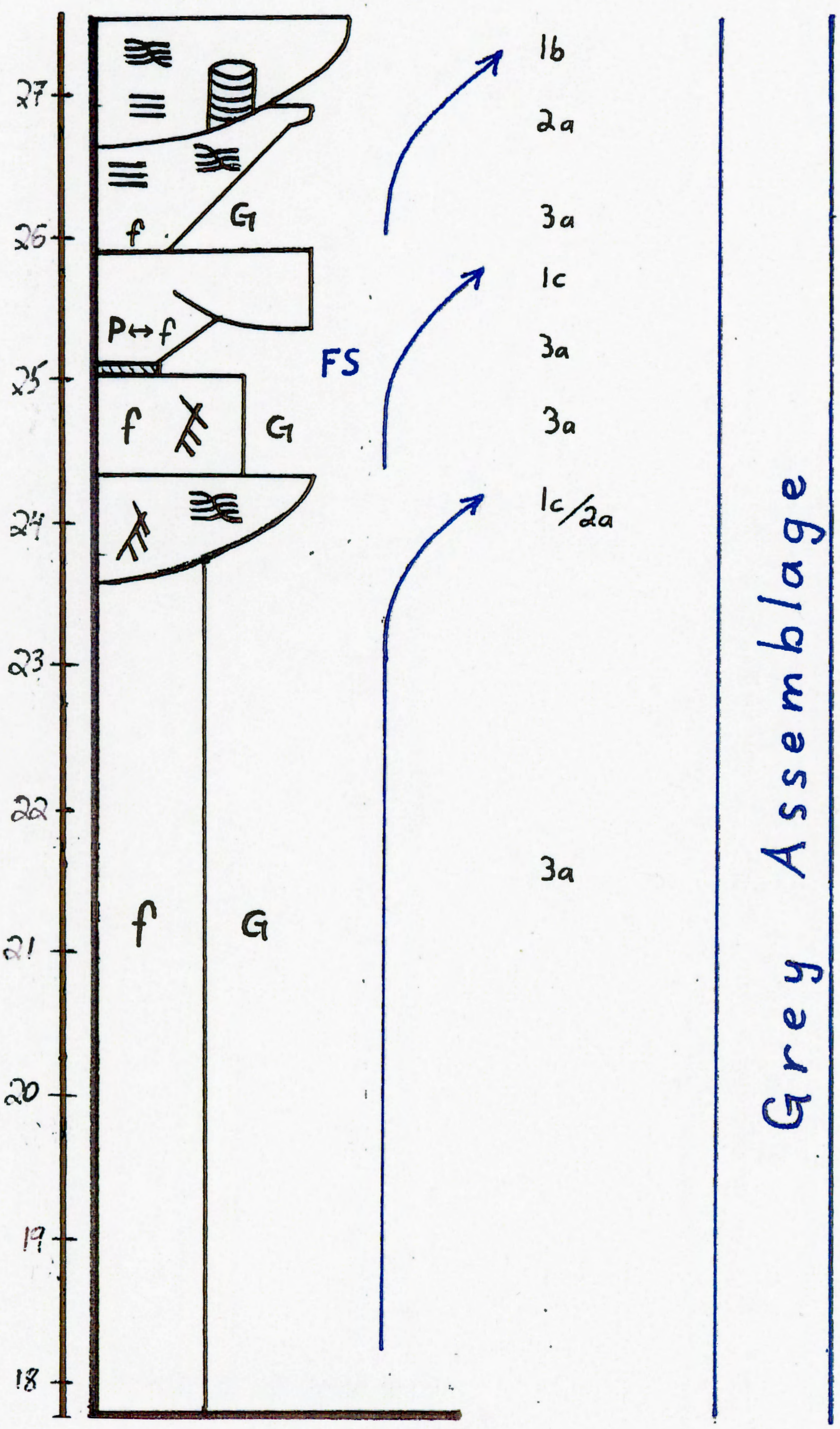
Grey Assemblage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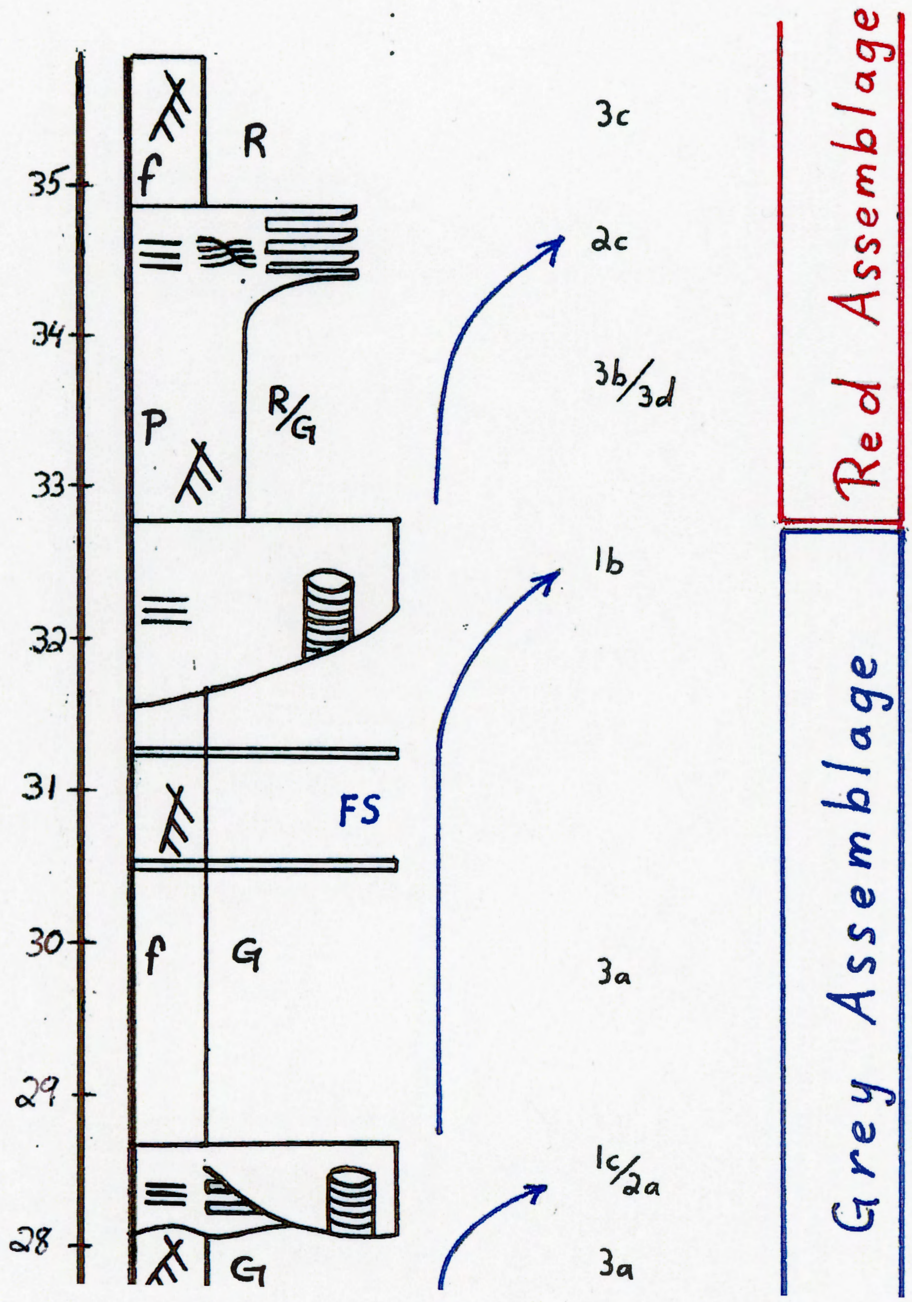
Grey Assemblage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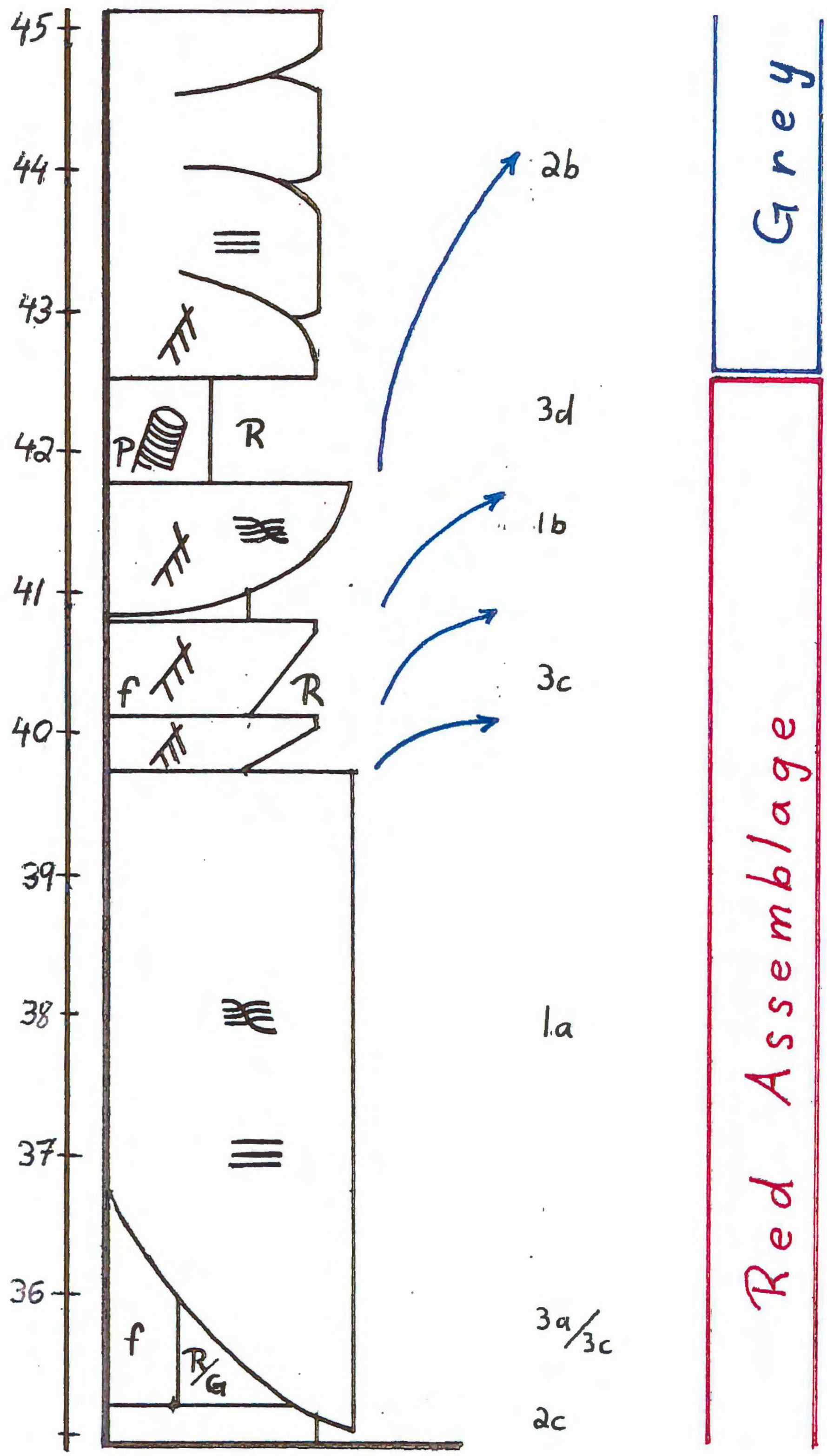
Red Assemblage
Grey Assemblage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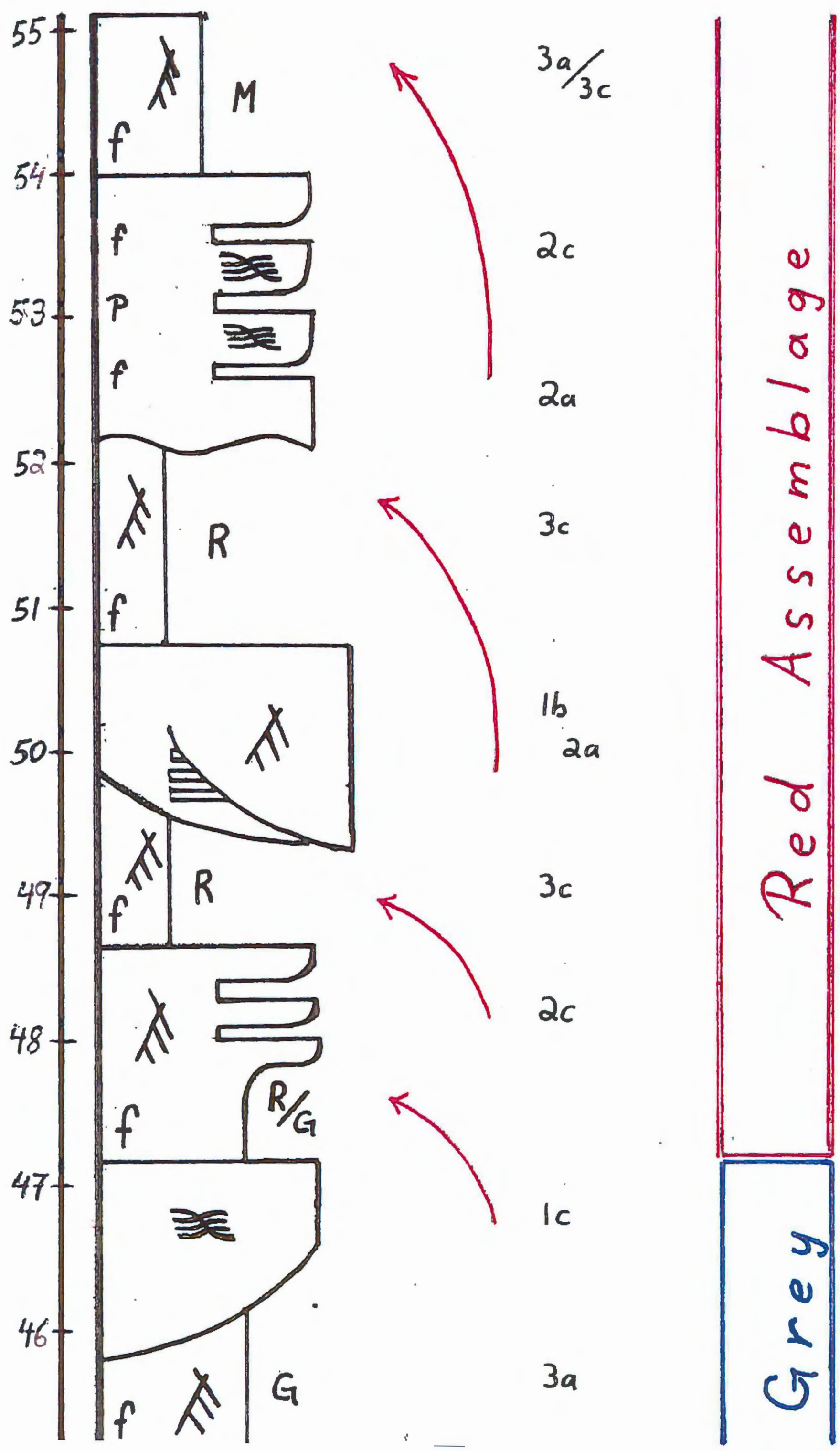
Grey
Red Assemblage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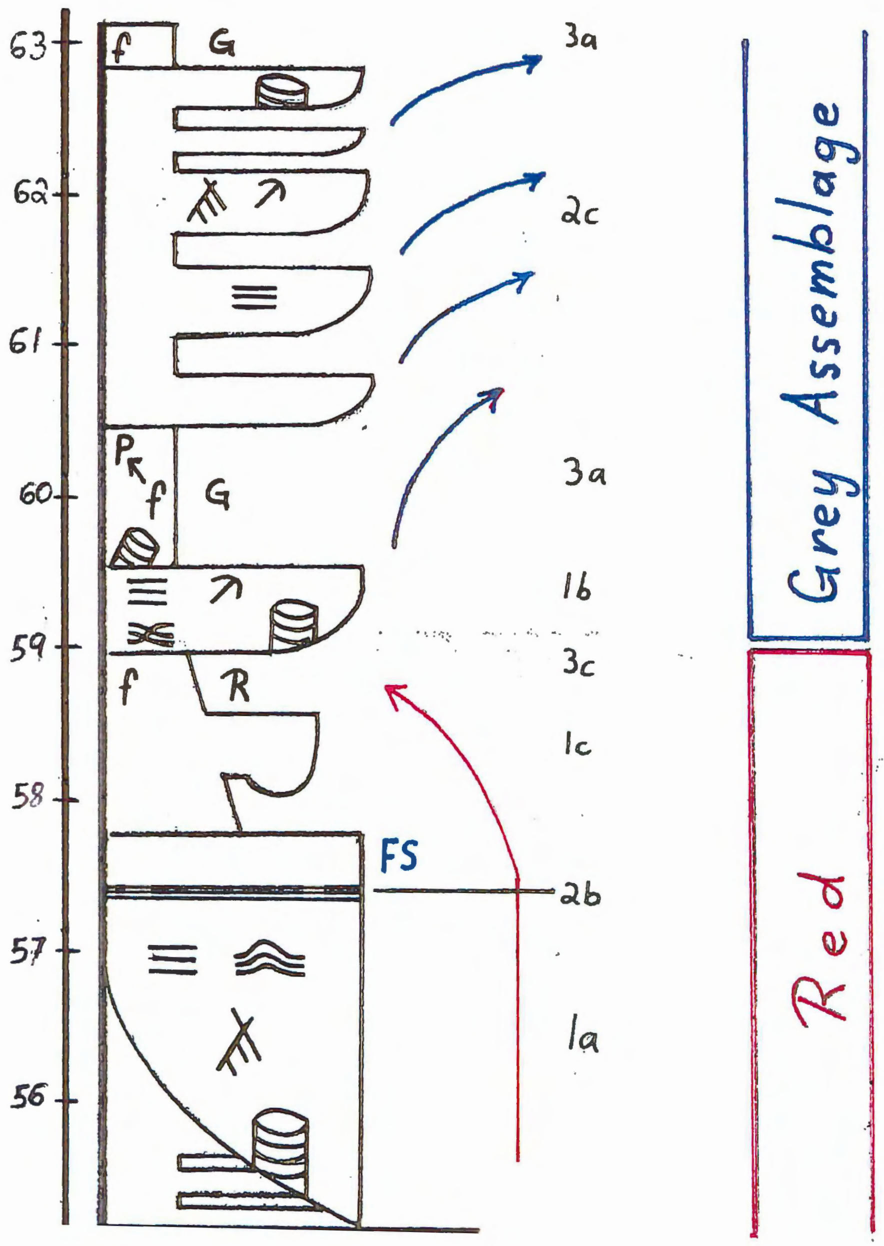
Red Assemblage
Grey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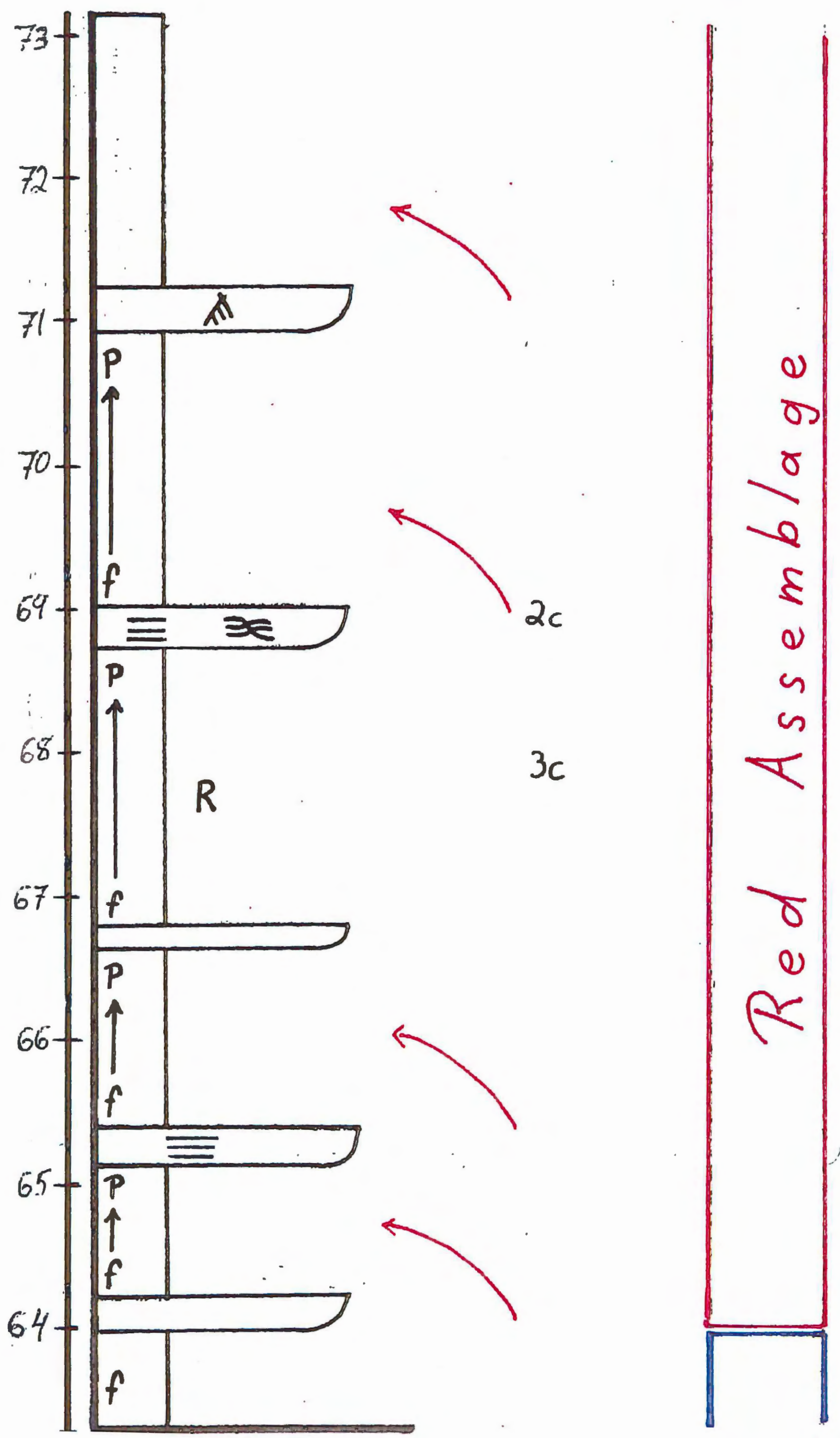
Grey Assemblage
Red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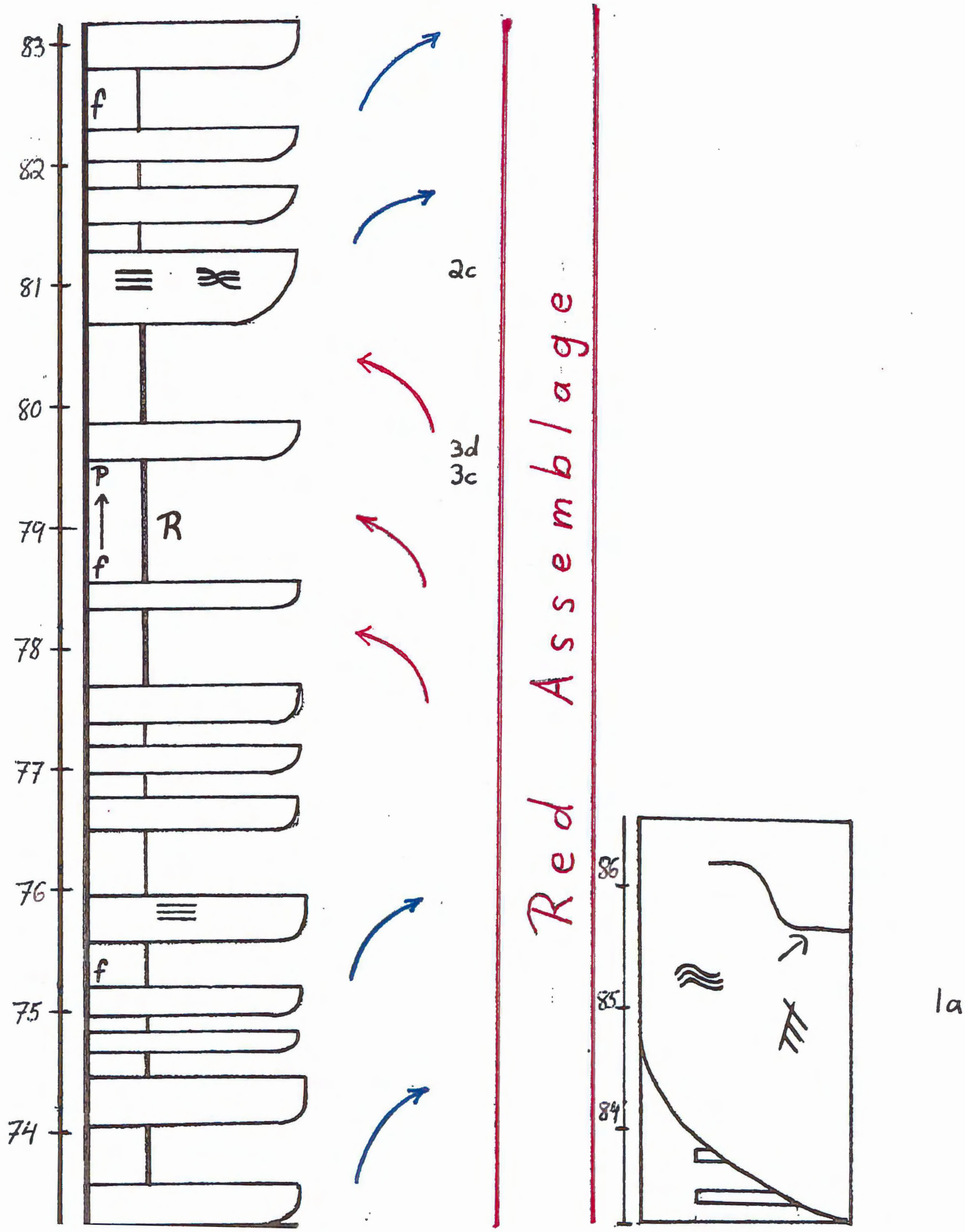
Red Assemblage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Red Assemblage
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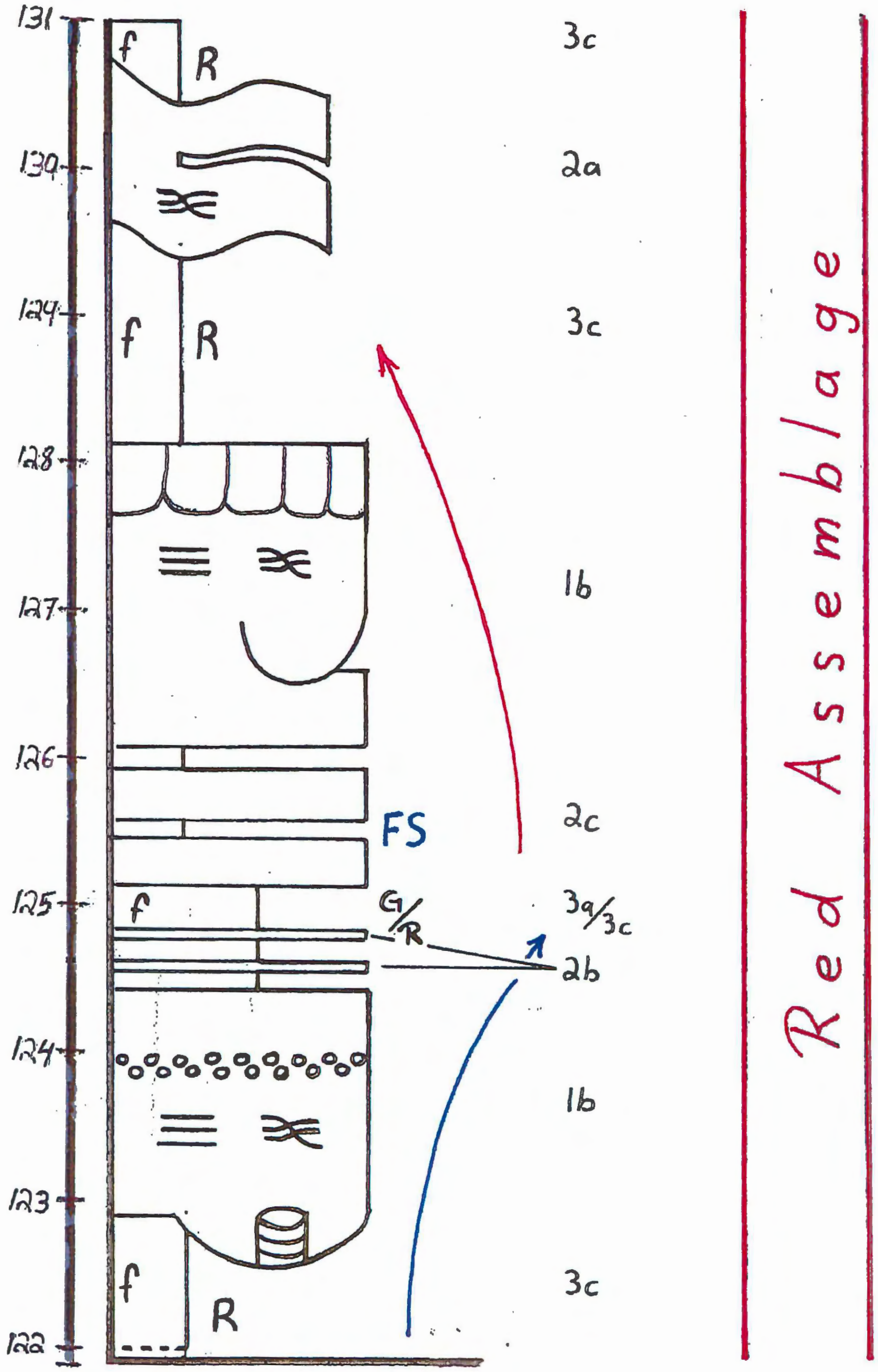
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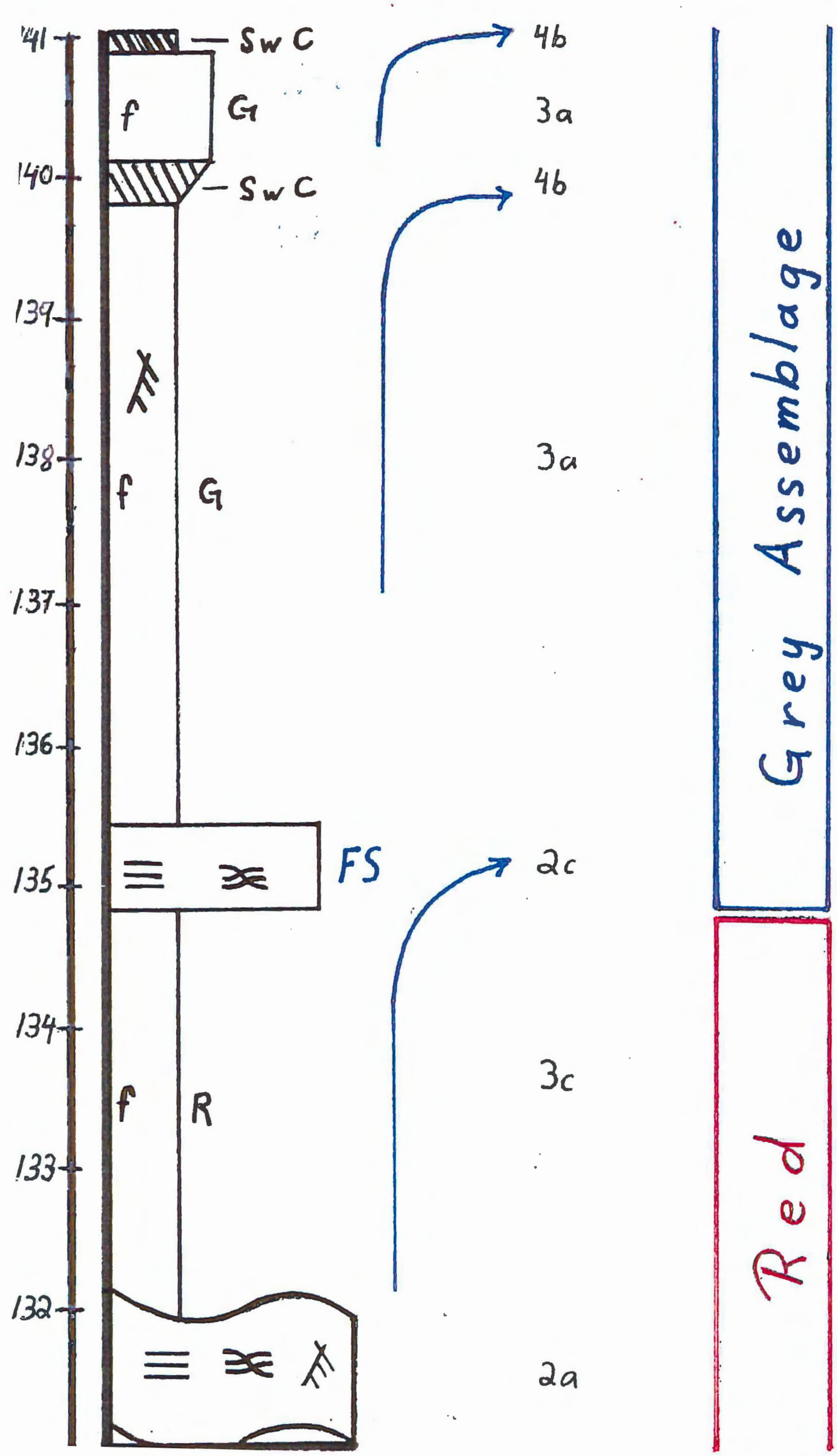
Red Assemblage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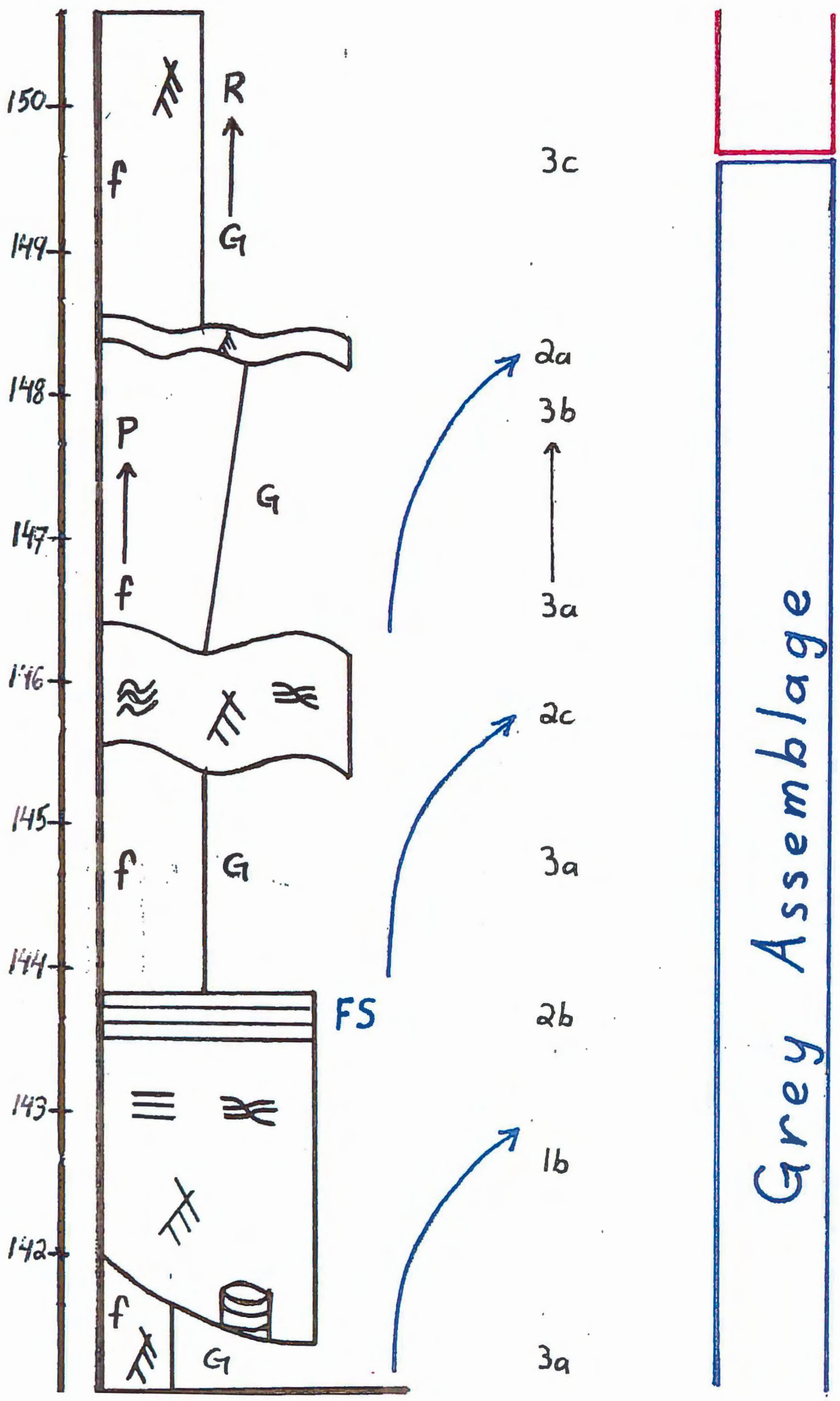
Grey Assemblage
Red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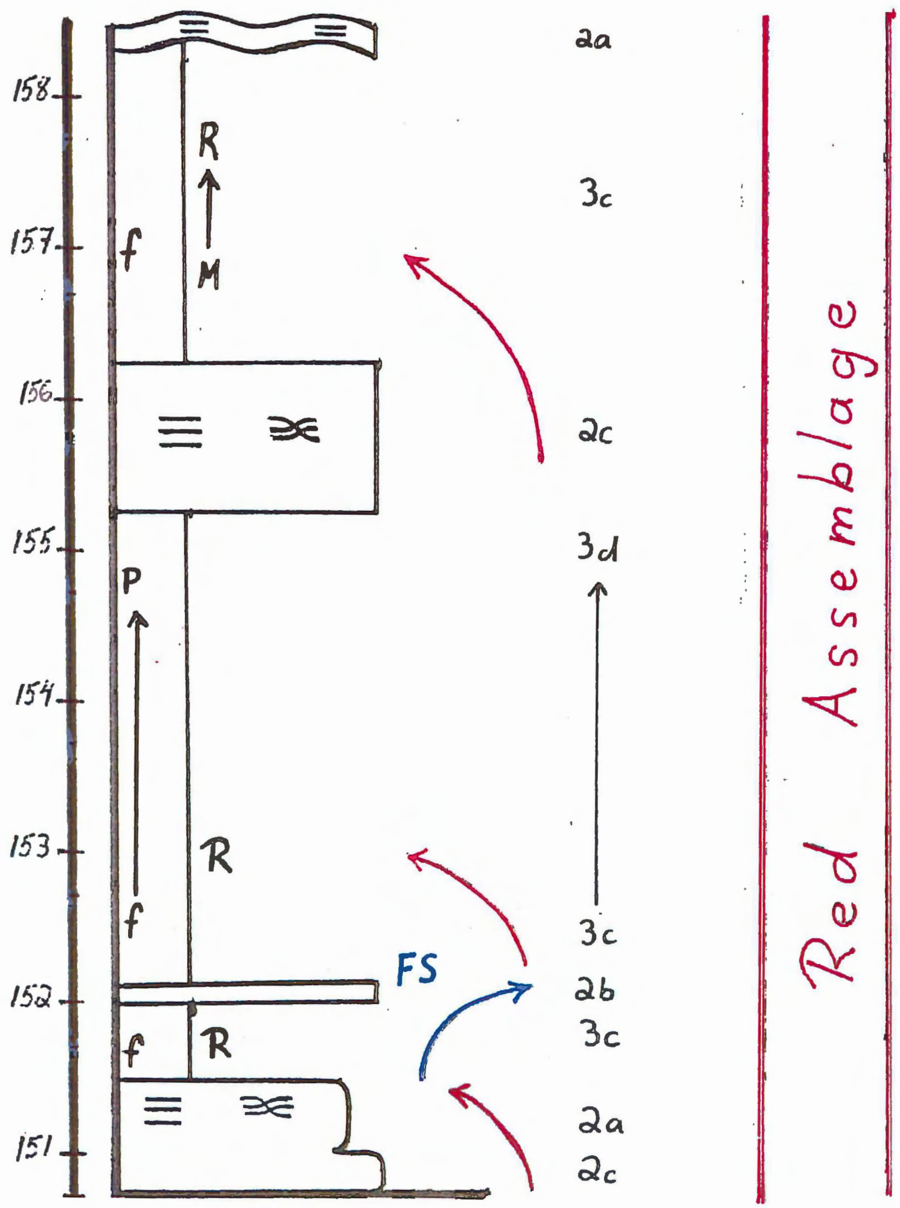
Grey Assemblage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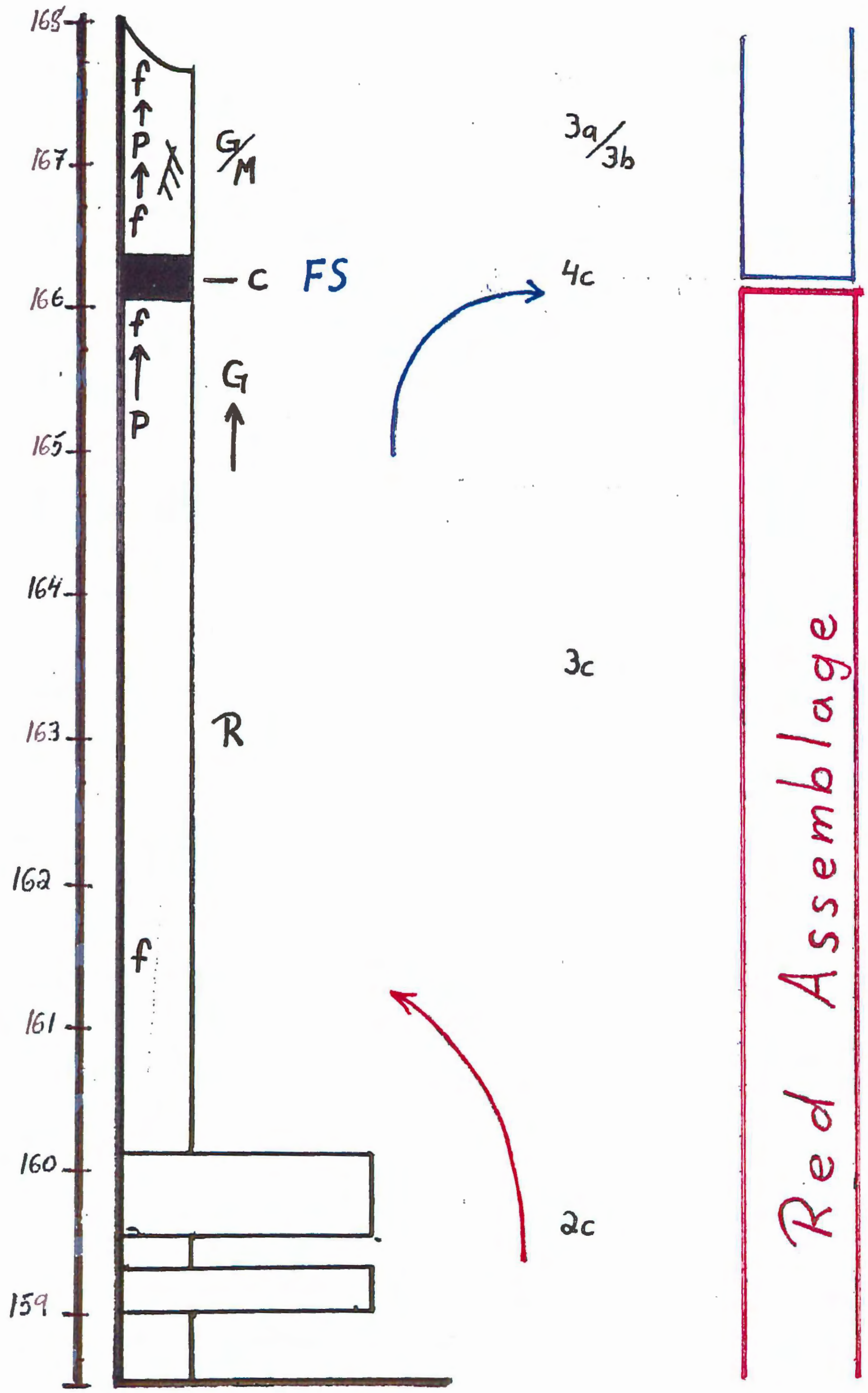
Red Assemblage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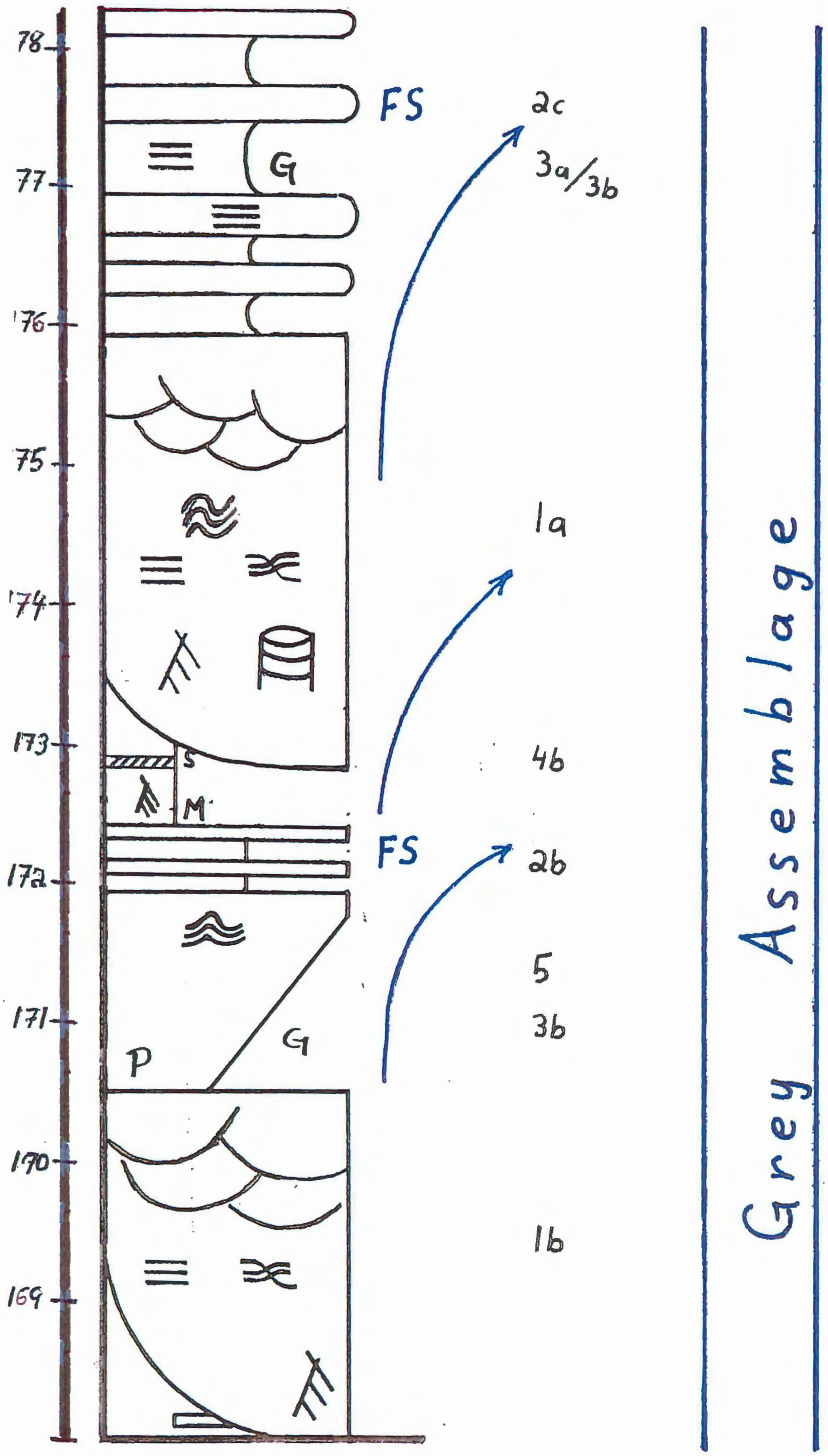
Red Assemblage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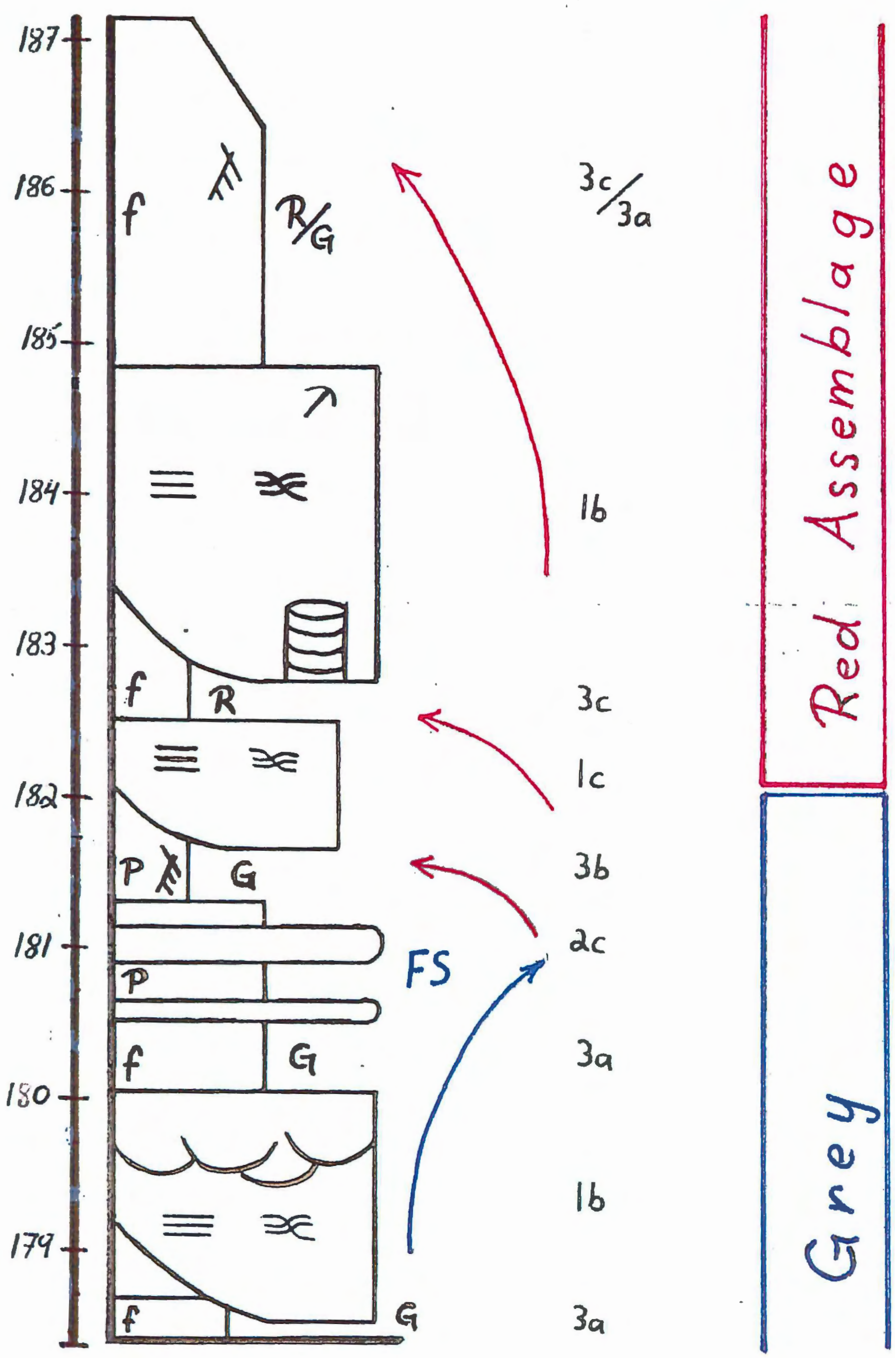
Grey Assemblage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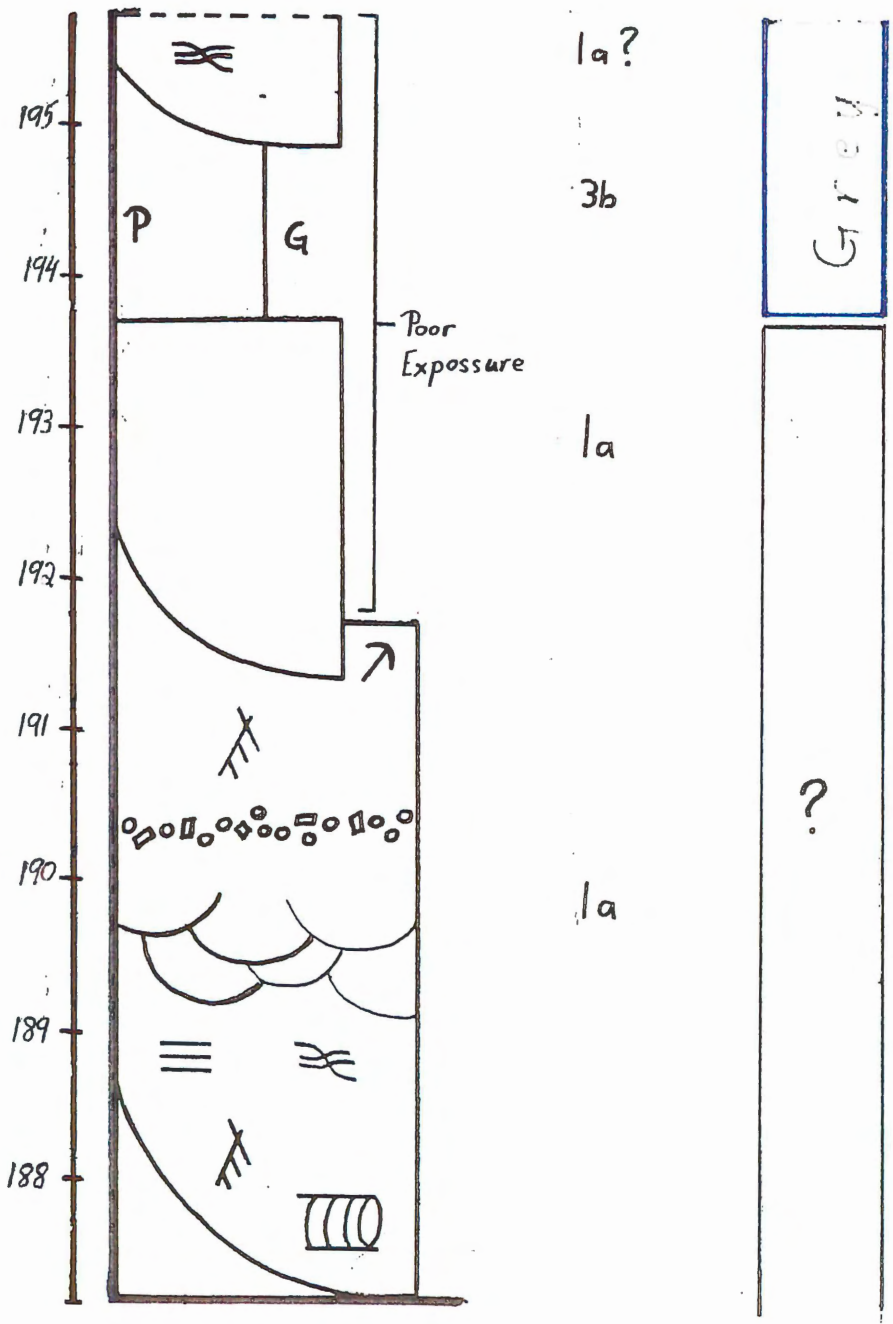
Red Assemblage
Grey



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Poor Exposure
1a?
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Grey
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3.1 Facies associations within the stratigraphic column

3.1.1 Parasequence characteristics and boundaries

Contacts between facies sequences are controlled by depositional factors. The small coarsening-upward packages, illustrated by the blue arrows, define increasing depositional energy levels. These cycles have been referred to as progradational parasequence sets. Increasing flow energy will transport and deposit a coarser and greater sediment load. A complete progradational parasequence cycle would consist, from lowstand conditions to highstand conditions, of a mudstone facies, tabular and sheet planar sandstone facies, sandstone channel facies occurring with undulating planar sandstone facies, and a possible coarsening-upwards bay-fill facies, or an organic rich facies sequence.

Basal contacts are sharp erosional divisions, resulting from the higher energy level in the stratigraphically successive environments. An example of a progradational parasequence set, albeit not an idealized one as suggested above, is found within the 167 to 173m area of the stratigraphic column. This set begins with a friable mottled mudstone facies eroded by a moderate sandstone channel-fill facies and undulating planar sandstone facies. Overlying the sandstone facies is a coarsening-upwards bay-fill facies, which is succeeded by a sheet planar sandstone horizon. The highstand period within this parasequence can be placed at the carbonaceous shale layer. The lower boundary of this parasequence is a gradational division of the red assemblage passing into the grey assemblage.

Successive vertical facies associations indicate a progradational period. The vegetated soil horizon can be described as experiencing first a minor flood episode, assemblages, however, are indicative of a shift towards wetland conditions. Flooding surfaces (FS) are designated as progradational highstand periods.

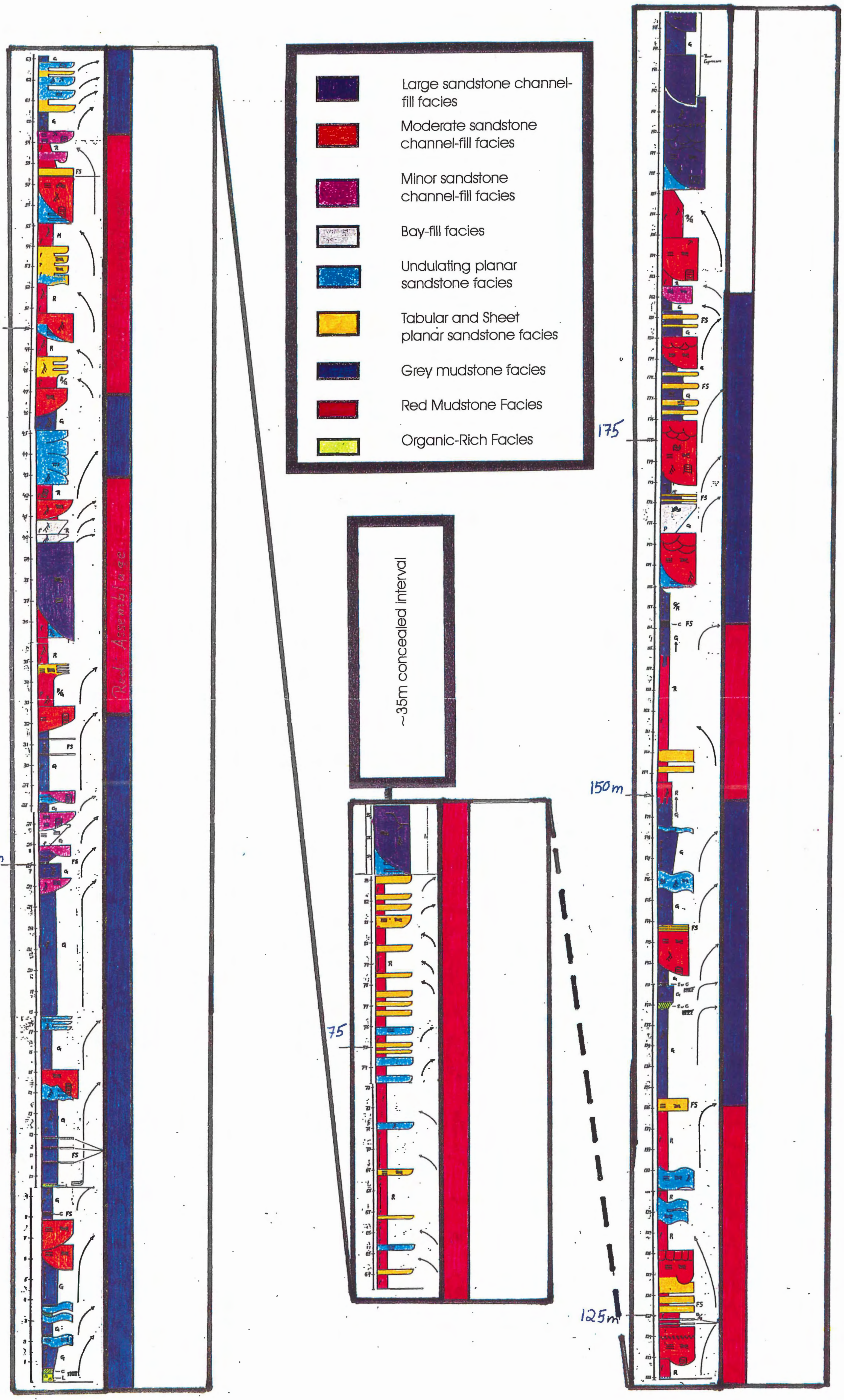


Figure 3.2

Condensed Stratigraphic Column for the Joggins and Springhill Mines Formations

4.0 Interpretation

4.1 Mechanism for Cyclicity in Deposition

Striking aspects of the Cumberland Basin exposure along Chignecto Bay are its continuous and repetitive sequences. In fact, this cyclical trend was striking enough to be mentioned by some of the earliest geologists. Dawson (1854), was able to put forth some of the most advanced geological theories of his time based upon the cyclicity present within the Joggins Formation. However, Dawson was concerned with the rich fossil fauna present within this section and, in theorizing about their occurrence, discussed the small-scale local environments, specifically the tropical and sub-tropical faunas. The cyclical mechanism of deposition is of special interest. By utilizing this cyclicity, we may build-up facies associations, taking the lithological sedimentary deposits a step further and creating a model of the local paleo-environment within the time depicted.

Cyclicity can be explained in terms of equilibrium (Miall 1978). Environments which are considered 'out of equilibrium', experience a stress caused by a net gain or loss of sediment (Beerbower 1964). Fluvial environments are the best example of such a state of flux (Miall 1978). Therefore, cyclicity within an area is the result of a shift from an environment in a state of disequilibrium through a succession of related environments until a state of equilibrium is attained with base-level. If an environment has reached a state of equilibrium, then there is no change in the rate of sediment accumulation or loss, and the environment may remain in a steady state. Steady state episodes can be regarded as environments experiencing 'highstand' or 'lowstand' conditions (Gibling, personal communication). Under such circumstances, this stagnant state will only be altered in response to allocyclic or autocyclic effects.

Table 4.1 Allocyclic Changes in an Alluvial Plain

Mechanism	Energy system changes	Morphological and sedimentary consequences
A. Discharge **1. Increase**	Current energy increase; frequency, extent and velocity of overbank flow may increase. Effects of biological and chemical systems diluted.	Channels deepened with erosion of substrate and deposition of coarse sand and gravel on bars; floodplain receives coarser sediment or may be eroded if velocity is relatively high or cohesiveness of substrate is relatively low. Large channel fills associated with sheets of interlaminated sand, silt and clay on floodplains. Little diversion until sand sheet is accumulated.
2. Decrease	Current energy decreases; frequency, extent, and velocity of overbank flow may decrease, but channel diversion may increase temporarily. Effects of biological and chemical systems concentrated.	Channels silted with deposition of fine sand on bars; floodplain receives sheet of clay with evidence of weathering, groundwater deposition, root action, etc. Shallow channel fills with frequent diversions over sandy substrate until accumulation of clay restricts such changes because of cohesiveness.
B. Load **1. Increase**	Current energy decreases; diversions increase; effects of biological and chemical systems diluted.	Channels silted; floodplain receives sheet of clay with interventions of crevasse sands and silts. Shallow channel fills with frequent diversions.
2. Decrease	Current energy increases; diversion decreases. Effects of biological and chemical systems concentrated.	Channels deepened; floodplain receives sheet of clay with few interventions of sand or silt – may be eroded if reduction of load is great or cohesiveness low; strong admixture of biological and chemical sediments.
C. Slope **1. Increase**	Current energy increases; diversions and overbank flow decrease; effects of biological and chemical systems concentrated	Channels deepened; floodplains receive little of no sediment and will show progressive erosion as tributary channels develop; increasing evidence of root action, dessication, weathering, and groundwater deposition.
2. Decrease	Current energy decreases; diversions and overbank flow increase; effects of biological and chemical systems diluted.	As in B. 1.

(Beerbower 1964)

Allocyclic effects include large-scale activity, specifically the rate of subsidence, eustacy, and climate; whereas, autocyclic effects are smaller scale changes, incorporating intrabasinal effects such as delta lobe switching and plant succession within mires. Table 4.1 is taken from Beerbower (1964), and outlines responses to allocyclic infuences. Regardless of the mechanism, both operate to change the relative base level with respect to a given area and result in imposing a stress on the local environment. The question then arises as to which mechanism is governing the cyclicity of deposition found within the Joggins Formation. Typically, it is impossible to answer this question with any degree of certainty, and most likely, the combination of the two factors would have influenced the final deposition. Within the surrounding area is evidence of tectonic influences (Ryan &Boehner 1994). I will briefly explore the surrounding geology of the Cumberland Basin.

4.2 The Cumberland Basin

The Joggins Formation is present along the northern limb of the Athol Syncline, which was an active but minor tectonic feature within the larger encompassing Cumberland Basin, and to the south of the Caledonian highland which bounds the Cumberland Basin. As well, the Cumberland Basin is a sub-basin within the regional Maritimes Basin. Bell defines the Cumberland basin as;

> "The two coalfields"...Joggins – River Hebert and Springhill... "belong to a single basin of deposition, the Cumberland basin, which lies within a larger geosynclinal area of Carboniferous sedimentation that may be designated the Fundy geosyncline. The Cumberland basin is bounded on the west by the crystalline rocks, mainly Precambrian, of the Caledonia upland of southern New Brunswick, and on the south by the crystalline rocks and

> altered sediments, Silurian and later, of the Cobequid upland of Nova Scotia. The eastern boundary is formed by the McLellan – Brown upland of Pictou and Antigonish Counties. The northern boundary of the basin cannot from present knowledge be defined, for it apparently lies beneath a cover of sediment of late Upper Carboniferous (Pennsylvanian) age".
>
> (Bell 1944; cited in Ryan and Boehner, 1994)

There are three major structural features present locally which influenced the Cumberland Basin development; 1) the Cobequid – Chedabucto Fault System (Minas Geofracture), 2) the North Fault along the northern margin of the Cobequid Highlands Massifs, and 3) the Cumberland Basin and its internal structures (Ryan and Boehner, 1994). Structural features within the basin can be classified as; "1) salt structures, including diapirs, domes, diapiric anticlines, and folds and faults related to salt flows; 2) basin development (growth) features unrelated or indirectly related to evaporite tectonics, including growth faults, strike-slip faults and major synclines; 3) structures related to buried uplift blocks (e.g. Hastings Uplift), including joints, and thrust faults (Ryan and Boehner, 1994).

The Cumberland Basin contains a series of synclinal forms; the Athol, Scotburn, Tatamagouche, Wallace and Amherst synclines, and two diapiric anticlines; the Minudie and Claremont anticlines (Ryan and Boehner, 1994). Schenk, 1971; Keppie, 1982; Donohoe and Wallace, 1985 – (from Ryan and Boehner, 1994) interpreted the fault displacement to have begun by the Middle Devonian or earlier and to have continued intermittently throughout the Carboniferous. Donohoe and Wallace, 1985 and Ryan et al. 1987 – (from Ryan and Boehner, 1994) estimated the net dip-slip movement occurred in the Namurian and early Westphalian, correlated to thick fanglomerate deposits which are present adjacent to the faults.

4.3 Environmental conditions and associated lithofacies

This section will briefly outline the basic conditions in which certain lithofacies are deposited. A model of a progradational parasequence set using deposits found within the study area as representative paleo-environments follows this section. As mentioned before, although the Cumberland Basin contains evidence of tectonic activity, climatic variations could have imposed equally significant influences (Beerbower 1964; Miall 1978).

4.3.1 The Sandstone Channel Facies

The sandstone channel facies are the most distinctive within the cliff. This is a result of the 2D architectural shape of these particular units in the cliff (they look like 'rock' rivers!). These environments require the flow of water to shape their structure. They are present within both progradational and retrogradational parasequences. This facies can be regarded as an environmental mechanism, which acts to achieve a balance between the current environment with respect to base-level.

Within modern environments, deeper and larger meandering fluvial bodies shape the landscape, constantly eroding and transporting a supply of sediment down gradient. Seasonal variations may increase the flow regime and inundate the surrounding floodplains. Sporadic channel switching, cut-off, and migration are responsible for changing the location and re-activating channel bodies. Regardless of progradational or retrogradational sequences, channel bodies act as the transport conduit, exporting terrestrial derived sediment seaward, or importing coastal sediment landward. Therefore, the channel facies can be found within both grey and red assemblages.

Generally, terrestrial gradients are commonly eroded by meandering channel bodies (Miall 1978; Miall 1988; Walker 1992). This is a generalized statement since factors including bedrock, vegetation, and topology influence the channel form (Walker 1992). The final deposition can be reflected as the large sandstone channel-fill facies (1a) found at the 38, 85, and190m intervals within the stratigraphic column.

Meandering fluvial systems undergo morphological changes while passing through varying environments, such as, in shallow gradient environments (i.e. rapidly subsiding troughs and broad cratonic basins) (Walker 1992). Anastomosing fluvial systems are common within stable positioned banks, which influences include vegetative abundance, bedrock characteristics, and sediment load. Presently, these environments experience a high seasonal flow variation, and occur as a broad system consisting of subordinate channels with relatively wide bodies in relation to depth (Walker 1992). The anastomosing alluvial system may be associated with the moderate sandstone channel-fill facies (1b). Stratigraphically, these deposits are located at 7, 14, 27, and 32m position within the first grey assemblage. This facies is a relatively common facies type within the study area (refer to Fig. 3.2).

The higher flow rates, associated with seasonal floods, impose a stress on the environment. If the rate of accumulation episodically increases to a rate greater than the rate of removal, then the sediment load would spill over the channel levees and deposit sediments within the floodplain. The floodplain is fed by small-scale feeder channels, which erode through the levees and adjacent sand forms. Therefore, these feeder channels may be associated with either large or moderate channel facies types and can be found within a stratigraphic column as either an independent unit, or within association with other channel bodies. The channel forms resemble the minor sandstone channel-fill facies (1c). This facies commonly occurs within undulating planar sandstone facies types (2a). An example of the minor channel facies is found at the 28.5m interval within the stratigraphic column.

4.3.2 The Planar Sandstone Units

The planar sandstone deposits are the most abundant sandstone deposits within the study area at the Joggins and Springhill Mines Formations. Distinguishing features between the three outlined facies-types can only be seen at close proximity to the cliff. These deposits reflect high energy flow episodes.

The overbank deposits mentioned within the previous channel environment, are termed crevasse splay deposits and can be compared with the undulating planar sandstone deposits (2a). Within the stratigraphic column, this facies occurs in association with the sandstone channel facies, seen within the 85, 14, and 28.5m levels. This is a common feature of modern fluvial systems (Miall 1978). The deposits are planar, and the grain size depends on the source and energy level (Beerbower 1968). These deposits may cause minor erosion, resulting in an undulating basal surface. Generally, these are inferred to result from high seasonal flood cycles; an example of these conditions could be drawn from the recent flooding of the Mississippi River, which left many of Americans homeless and damaged thousands of kilometers of farm land. During the interim, conditions are usually quite favourable for a dense flora.

Cyclical major flood events, statistically occurring in 50 and 100 year cycles within the modern environment, can cause widespread and rapid inundation. Deposition may occur within a sub-aqueous environment, probably accounting for the thin sheet and tabular planar sandstone facies (2b & c) found at Joggins. The two units may be related in depositional mechanism, and differ only on the basis of duration of the episodes depositing them.

4.3.3 The Mudstone Units

The mudstone deposits reflect low energy environments, such as marsh and swampland environments. A high biological productivity can be sustained within these 'wetland' environments. Very fine sediment is transported and left stagnant, resulting in high degrees of bioturbation, which destroys the original stratification, or grey platy mudstone facies (3b), and produces a grey friable bed deposit, represented by facies type (3a). The lower 10m of the stratigraphic column contain mudstone units grading from platy to friable in appearance. The colour appearance shows a variation in reducing or oxidizing processes.

A change in climate to a more arid condition would cause oxidation to occur, producing a red friable mudstone bed (3c) from the grey bed. The red beds are within homogeneous sets, implying that oxidation occurred syndepositionally. Within the long term, this environment would be unfavourable to sustaining a high level of biological activity or preservation. Desiccation cracks could form from the evaporation of water from the sediment.

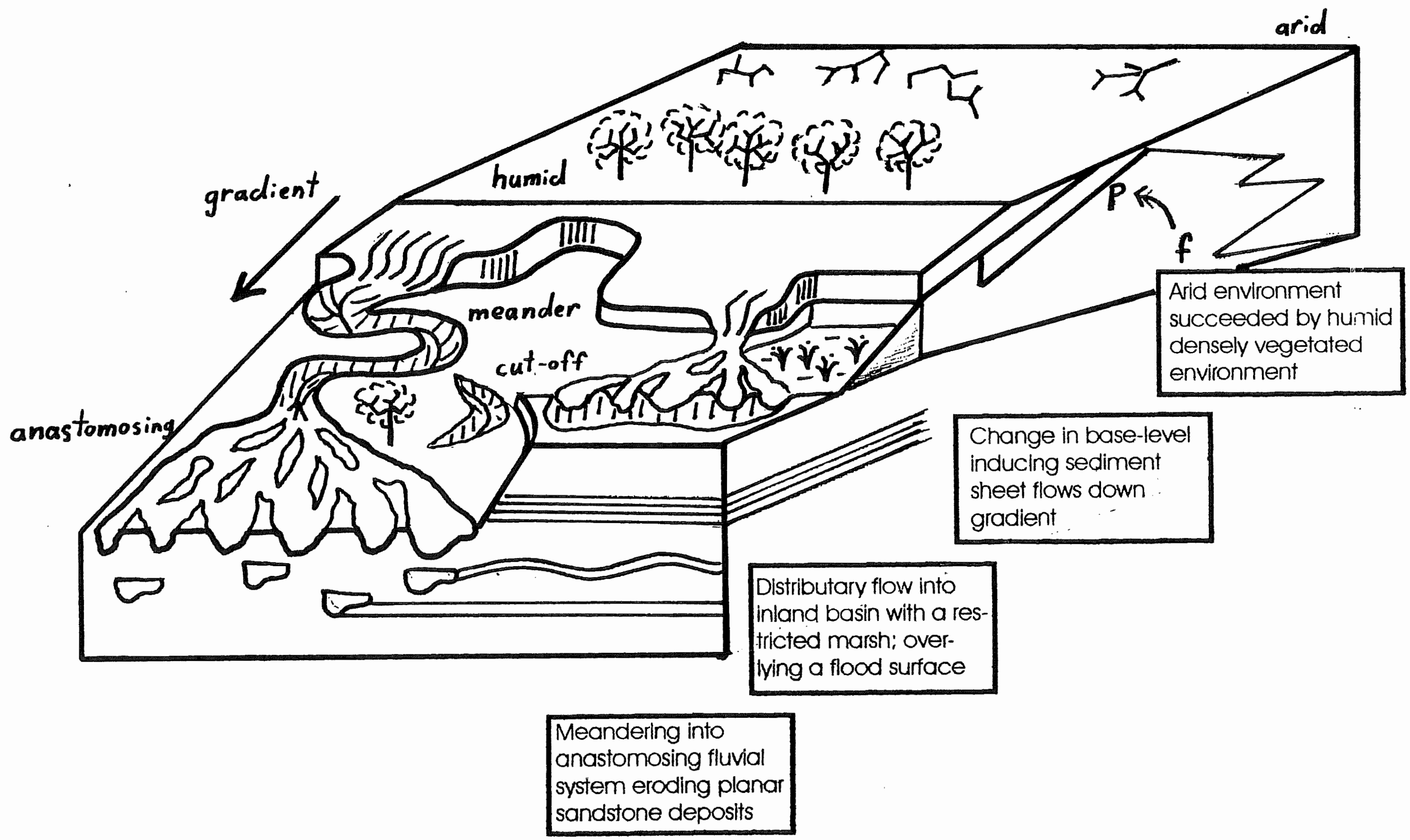
During progradational periods, the rise in the water table would inundate the local area and created anaerobic conditions favorable for the preservation of root traces, the cultivation of microbial processes resulting in the presence of sideritic concretions, and the grey mudstone colour. A continual rise in base level may result in stagnation and a marginal inundation of the area, and deposit a strongly stratified grey mudstone facies (3b). This environment, however, when shifted into a state of non-equilibrium contains the potential energy to initiate erosional processes.

The platy siltstones and mudstones appear as submerged deposits. These deposits are the result of short-term flood events, in which the water table would have risen and inundated the flat-lying vegetated environment. There are beds containing multiple platy mudstone horizons appearing as successive horizons within the stratigraphic column. This could be evidence for several cyclical short term flooding events. Within the cliff, these beds, regardless of thickness, are the easiest indication for marking the beginning of a flood cycle or event. A sudden drop in base level would, again, create an arid environment favouring oxidation of the platy grey mudstones, producing a red platy mudstone facies (3d). The red platy mudstone facies occurs within proximity to the friable red mudstone facies within the 34m red assemblage from the 64 to 98m stratigraphic interval.

4.3.4 The Organic Units

These units are present as thin and sparsely occurring deposits, and are therefore not a consistent feature of the section under examination. They do, however, represent significant time intervals. There are two limestone beds within the section, and the main limestone bed was used as a marker to begin the study area. The abundant fauna shows high levels of localized aquatic biological activity, possibly a lake or flooded basin

Figure 4.2 3D Model of the Joggins and Springhill Mines Formations' paleo-environment



environment. In order to support the biological life, water would have had to have been constantly circulated, implying a waterway to the sea, and relatively persistent in comparison with the short cyclical flood events.

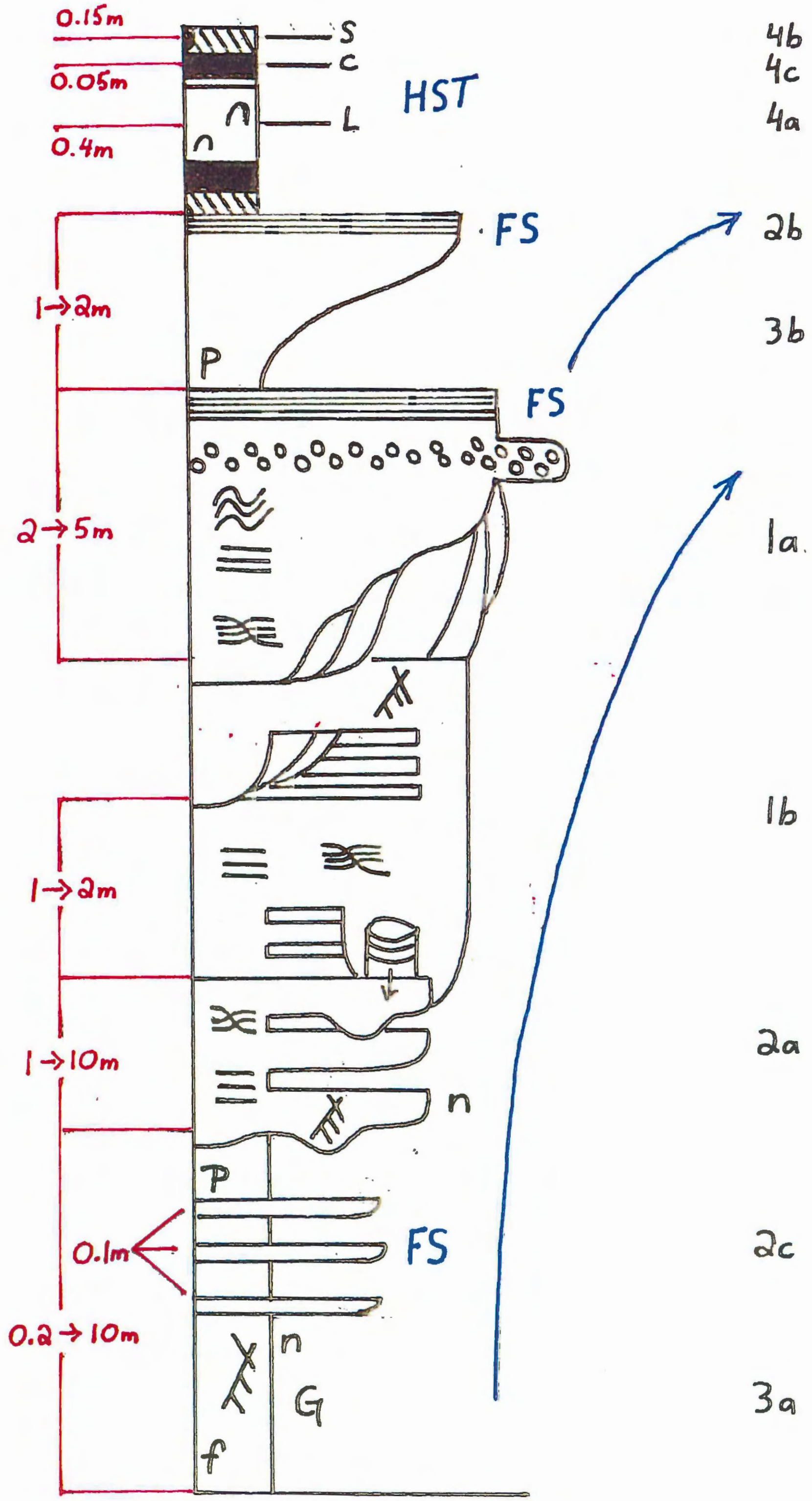
These beds mark peaks in highstand periods within progradational parasequence sets. The aquatic fauna indicates that local inundation was significant enough in duration to drown out the area. There is a large content of shell fossils, which remain intact, demonstrating that the fauna originated locally. Limestone deposits are indicative of open water environments, or swamp-like environment.

The coal deposits associated with the Joggins section are interpreted as peat mire deposits. Modern environments related to this are densely vegetated, water-logged wetland environments. During the Carboniferous, significant amounts of the world's coal as well as oil was forming.

4.4 Conclusion: A Paleo-Environmental Model for the Joggins study section

The paleo-environment depicted within the study area of the cliffs at Joggins cannot be explained with certainty unless viewed in context of the overall cyclical occurrence of the lithology. Within this context, Joggins depicts a story of periodic drowning and drying episodes. By observing the overlying and underlying units, a relationship can be established of a gradual variation caused by the fluctuation in base level.

A basic model for the local environment can be created and is represented in a stratigraphic column in figure 4.1, and 3D cross-section in figure 4.2. Figure 4.1 illustrates a schematic progradational parasequence set producing a stratigraphic


0.15m
0.05m
0.4m
S
C
L
HST
4b
4c
4a
FS
2b
1→2m
P
3b
FS
2→5m
1a
1b
1→2m
1→10m
2a
n
P
FS
0.1m
2c
0.2→10m
n
G
f
3a

succession of deposit-types observed within the study section. The scale has been condensed, but relative bed thickness ranges have been provided. This model section would belong to the grey assemblage, and consists of two main coarsening-upward packages.

During lowstand, an arid environment is in place. Deposits are oxidized, producing a red colouration (3c). Possibly scarce vegetation or biological life could be sustained or preserved within this environment. Desiccation cracks form as water retained in the sediment is evaporated (3d). As the base level begins to rise, a result of external allocyclic or autocyclic effects, a 'wetter' environment is established. The red colouration becomes mottled as biological or physico-chemical processes are more conducive to reducing effects.

A more tropical climate would further raise relative-base-level and gradually alter the environment. The initial wetter climate would produce a deposit, reflecting the low energy environment, such as, a strongly stratified mudstone (3b). Humid and wetter conditions would ultimately favour a higher diversity and density in the biologic population. This change would produce a stress on the environment, and animals and plant activity would destroy all stratification in the underlying paleosol (3a). This facies is the first unit represented within the model stratigraphic column (figure 4.1). Plant activity would establish dense root networks, which would act to consolidate the loose sediment.

The rise in base level would initially inundate underlying sediment and could result in thin silty parallel bed deposits. The terrestrial environment would be bogged and the sediment subjected to reducing processes. The resulting deposit would be grey and friable in appearance. Microbial and physico-chemical processes could produce calcareous and ferruginous nodular concretions, forming from the waterlogged vegetation.

The flow of water and sediment down gradient due to gravity, could result in a local inundation. This may result in the deposition of thin sheet (2b) or thicker tabular (2c) planar sandstone deposits containing abundant vegetative fossils. If this new environment stagnates, then the biotic environment would reactivate within the coarser sediment, producing friable sandstone, as well as mudstone, sediment containing nodular concretions.

However, continued flow would begin to scour around local obstacles, such as massive trees, creating minor depressions in the environment (1c). This would concentrate a stronger flow regime within scours. Further erosion caused by the increased energy would incise channels through the floodplain environment, producing moderate channel sandstone deposits (1b) with possibly in situ tree stumps preserved within them. Seasonal flow variations, channel migration, and channel cut-off would produce multiple lateral channel scours within a single horizon. During episodes of increased drainage, sediment would flood the channels and spill over the levees. These floods would shallowly inundate the local vegetation, which is consolidating the channels. These sediment deposits can be compared to crevasse sand splays (2a), which are fed by minor channels eroding through channel levees.

Larger meandering individual channels (1a) would also occur. The even higher energy regime would increase erosion, producing coarser sediment, and create sand bar forms. Minor rapid episodic floods would still inundate the channel and might produce very thin sheet-like sandstone deposits (2b). A further rise in base-level would inundate the environment. This could result in a variety of distinct environments. Over a gradual and slow process, environments such as bays and inlets could further form and result in brackish aquatic environments. This would result in tabular sandstone deposits followed by calcareous limestone deposits (4a).

Catastrophic inundation could result in major erosional stresses on the environment in a of the local fauna. This drowning event would deposit a carbonaceous shale bed (4b), a platy organic rich mudstone. These environments are conducive to peat mire accumulations. Burial of this environment would favour the processes producing coal.

The uppermost part of the section in figure 4.1 is representative of a maximum highstand condition, where rapid inundation would stabilize the environment, producing a depositional environment favourable to the preservation of organic material. Peat mires may form seat earth deposits. Swamp environments could deposit shale as well, a possibility for why coal laminae are associated with shale deposits. Continued and prolonged flooding periods can be interpreted as resulting in limestone or shale deposits, and mark transgressive maxima.

This model is a cyclical chain of events. Variations within this scheme, producing sub-cycles, are products of changes of relationship between allocyclic and autocyclic events.

Acknowledgements

This paper is the product of a continuing survey of the cliff exposure near Joggins. The project is being headed by Martin Gibling, professor of Earth Sciences at Dalhousie University, whose supervision and collaboration in most elements within this paper were invaluable. The extensive bed by bed measurements were done with the help of Paul Teniere. I would also like to extend my appreciation to John Calder, whose last minute insights into the fossil record and paleo-environment of the Joggins Formation greatly improved the detail in this paper. I am grateful for the efforts of Tom Duffett, who scanned the cliff-side photographs into the computer for me. Many thanks to my mother of course, Shirley Low, whose emotional and financial support helped to complete this study. Finally, I would like to acknowledge the help of Katie Dodson and Kathryn Dillon in reviewing text, assisting in figures, and lending constructive support.

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Appendix (A)

Unit Description

DATE: June 25, 1997 UNIT: 001

LITHOLOGY: limestone

THICKNESS: 0.4 m BASAL CONTACT: sharp erosional

COLOUR (fresh/weather): black

BED STYLE:
- planar beds with wavy (shell) laminae
- fissile

SEDIMENTARY STRUCTURES: calcareous shell fragments: brachiopods and bivalves

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DATE: June 26, 1997 UNIT: 002

LITHOLOGY: mudstone

THICKNESS: 1.3 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey

BED STYLE:
- coarsening up sequence (minor)
- friable at base grading to platy at top
- carbonaceous layer with minor coal stringer

SEDIMENTARY STRUCTURES: - root traces

DATE: June 26, 1997 UNIT: 003

LITHOLOGY: sandstone

THICKNESS: 2 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey/light purple grey

BED STYLE:
- continuous planar sand bed (0.5m)
- silty mudstone bed, platy and grey, (0.55m)
- heterolithic sand with siltstone near upper contact

SEDIMENTARY STRUCTURES:
- p// and x- lam (dark (org?) layers)
- NO scours

DATE: June 26, 1997 UNIT: 004

LITHOLOGY: silty mudstone

THICKNESS: 2.3 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey with pink grey

BED STYLE:
- platy at base with organic clay seams
- Grading vertically to elongated nodular layer and friable bed style
- nodular layer at top

SEDIMENTARY STRUCTURES: - root traces, nodular concretions

DATE: June 26, 1997 UNIT: 005

LITHOLOGY: channel sand unit

THICKNESS: 1.8 m BASAL CONTACT: sharp undulating erosional and planar

COLOUR (fresh/weather): grey/purple grey

BED STYLE:
- 2 continuous planar sands (0.6 m) with channel Grooves (0.8 m)
- friable to platy silty mudstone with nodules (0.15m)
- planar sand with minor channel grooves (0.8 m)

SEDIMENTARY STRUCTURES:
- x- and p// laminations
- nodular concretions in silty mudstones

DATE: June 26, 1997 UNIT: 006

LITHOLOGY: carbonaceous layer overlying seat earth

THICKNESS: 0.4 m BASAL CONTACT: planar sharp with planar mud horizon

COLOUR (fresh/weather): dark grey

BED STYLE:
- 0.25 m seat earth layer
- carbonaceous layer contains coalified thin beds

SEDIMENTARY STRUCTURES: - leaf fossil fragments

DATE: June 26, 1997 UNIT: 007

LITHOLOGY: mudstone

THICKNESS: 1.2 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey/org. grey

BED STYLE:
- friable mud
- 2 siderite nodular layers (0.05m thickness) 0.45 and 0.75 m from base
- carbonaceous shale layer (0.01 m thickness) 0.6 m from base

SEDIMENTARY STRUCTURES: - root fragments and traces

DATE: June 26, 1997 UNIT: 008

LITHOLOGY: limestone with silty mudstone horizons

THICKNESS: 0.15 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): dark grey and grey

BED STYLE:
- limestone (0.03m)
- friable silty mud (0.09m)
- limestone (0.02 m)

SEDIMENTARY STRUCTURES:
- hard planar beds
- calcareous brachiopods and bivalves

DATE: July 5, 1997 UNIT: 009

LITHOLOGY: muddy siltstone with silt beds

THICKNESS: ~4.0 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey/purple and pink grey

BED STYLE:
- friable mud silt with discontinuous platy beds
- silt beds (0.05m) at 1, 1.8 m from base
- sand bed at 2 m from basal contact
- strong laminations (platy) with organic rich bed surfaces

SEDIMENTARY STRUCTURES:
- nodular concretions (0.02m thickness) in mud silt
- root traces

DATE: July 5, 1997 UNIT: 010

LITHOLOGY: heterolithic sandstone unit with mud and siltstone horizons

THICKNESS: 0.8m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): light grey/ red and purple grey

BED STYLE: - planar sand (0.07m thickness) with friable silt interbeds

SEDIMENTARY STRUCTURES:
- elongated nodular concretions (0.08m) in silt
- in situ *stigmaria* (>4 m length) in silt continuous into sand sets

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DATE: July 5, 1997 UNIT: 011

LITHOLOGY: sandstone

THICKNESS: 0.8 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey/purple grey

BED STYLE:
- platy at basal contact (0.6m thickness), grading vertically to a friable mass
- thin sand (0.06m thickness) horizons within friable mass at 0.8, 0.9, 1.6 m from base

SEDIMENTARY STRUCTURES:
- sand contains cross-laminations
- sub-sphere nodular concretions (0.02m diameter) in mud
- organic rich bed surfaces within sand
- root traces within mud

DATE: July 5, 1997 UNIT: 012

LITHOLOGY: mudstone

THICKNESS: 2.0 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey/green grey

BED STYLE:
- platy bed style (0.6 m thickness)
- grades to friable mass with thin planar sandstone beds (0.01m thickness) at 0.8, 0.9, and 1.6m from basal contact

SEDIMENTARY STRUCTURES:
- cross laminations in sandstone
- sub-spherical nodules in mud (0.02m)
- org lam in sand
- root traces in sandstone

DATE: July 5, 1997 UNIT: 013

LITHOLOGY: heterolithic sandstone with mud

THICKNESS: 0.65 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): light grey/purple grey

BED STYLE:
- planar sands (0.01 to 0.07m thickness)
- friable mud horizons (0.03m thickness)

SEDIMENTARY STRUCTURES:
- undulating, planar and cross-laminations in sand
- discontinuous nodular bands (0.07m) in mud sand contact
- org rich bed surfaces in sand
- root traces? in mud

DATE: July 5, 1997 UNIT: 014

LITHOLOGY: muddy siltstone

THICKNESS: 6 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey/green to red grey

BED STYLE: - friable mass with grey friable silt bands (0.02m thickness)

SEDIMENTARY STRUCTURES: - common nodular concretions (0.04m) and along base of unit(0.07m)
- clay seam root traces

DATE: July 5, 1997 UNIT: 015

LITHOLOGY: sandstone

THICKNESS: 0.55m BASAL CONTACT: planar sharp with minor erosional grooves

COLOUR (fresh/weather): grey/purple grey

BED STYLE: - continuous planar bed with undulating grooves within bed
- undulating platy sand

SEDIMENTARY STRUCTURES: - undulating laminations
- round nodules (0.02m diameter)
- in situ root fragments

DATE: July 5, 1997 UNIT: 016

LITHOLOGY: siltstone

THICKNESS: 0.7 m BASAL CONTACT: sharp

COLOUR (fresh/weather): light grey/green grey

BED STYLE: - friable bed

SEDIMENTARY STRUCTURES: - elongated nodular concretions (0.040
- root traces, root fragments?

DATE: July 5, 1997 UNIT: 017

LITHOLOGY: coarsening up sequence: mud to silt to sand

THICKNESS: 0.9 m BASAL CONTACT: sharp organic rich layer

COLOUR (fresh/weather): light grey/purple grey

BED STYLE: - platy mud grading vertically to a friable mud, siltstone set, and then into sand (0.2m thickness)

SEDIMENTARY STRUCTURES: - small (cm scale) nodular concretions concentrated in mud and silt

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DATE: July 5, 1997 UNIT: 018

LITHOLOGY: coarsening up sequence; mud, silt to sand

THICKNESS: 1 m BASAL CONTACT: planar sharp with minor grading

COLOUR (fresh/weather): grey

BED STYLE: - friable mass with grading to sand (0.45 m)
- heterolithic planar sands

SEDIMENTARY STRUCTURES: - undulating laminations and planar laminations in sand
- nodular concretions in mud silt (0.07m length)

DATE: July 5, 1997 UNIT: 019

LITHOLOGY: sand channel unit

THICKNESS: 0.8 m BASAL CONTACT: sharp undulating erosional

COLOUR (fresh/weather): grey/green grey

BED STYLE: - continuous planar sets laterally into anticlinal grooves

SEDIMENTARY STRUCTURES: - planar-, cross, and undulating laminations
- nodules (0.01m)

DATE: July 5, 1997 UNIT: 020

LITHOLOGY: mudstone

THICKNESS: 0.45 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey/purple and red grey

BED STYLE: - friable mottled bed

SEDIMENTARY STRUCTURES: - common nodular concretions (0.02m)
- root traces

DATE: July 5, 1997 UNIT: 021

LITHOLOGY: sandstone

THICKNESS: 0.6 m BASAL CONTACT: planar with minor undulating sharp

COLOUR (fresh/weather): grey/green grey

BED STYLE:
- planar continuous to discontinuous sand (0.3m thickness)
- anticlinal grooves with minor mud horizons (0.1m thickness)

SEDIMENTARY STRUCTURES:
- planar laminations in sand
- nodular concretions in mud (0.04m)

DATE: July 5, 1997 UNIT: 022

LITHOLOGY: silty mudstone with sandstone horizons

THICKNESS: 3.0 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey sands and red silt/grey and red

BED STYLE:
- friable mottled bed with discontinuous 2m long sand wedges (0.5m)
- faint platy bedding overlying sand

SEDIMENTARY STRUCTURES:
- planar lam in sand
- nodular concretions (0.08m)
- root traces

DATE: July 5, 1997 UNIT: 023

LITHOLOGY: sandstone channel unit

THICKNESS: 1.1 m BASAL CONTACT: erosional sharp

COLOUR (fresh/weather): grey

BED STYLE:
- planar non-massive undulating sands (0.1m thick) with mottled silt horizons
- massive channel scours (1.2m depth and ~5m width)

SEDIMENTARY STRUCTURES:
- planar and undulating laminations
- spherical nodular concretions
- in situ tree fossils (0.2m), root fragments
- ridge and furrow paleocurrent reading: 134

DATE: July 5, 1997 UNIT: 024

LITHOLOGY: muddy siltstone

THICKNESS: 1.6 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey red

BED STYLE: - friable moderately mottled bed

SEDIMENTARY STRUCTURES: - root traces

DATE: July 5, 1997 UNIT: 025

LITHOLOGY: heterolithic sandstone with siltstone

THICKNESS: 0.5 m BASAL CONTACT: planar sharp with minor grading

COLOUR (fresh/weather): grey

BED STYLE: - discontinuous to continuous planar sand beds (0.05m thick)
- minor silt horizons (0.05m thick)

SEDIMENTARY STRUCTURES: - faint cross-, and planar laminations

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DATE: July 5, 1997 UNIT: 026

LITHOLOGY: mudstone

THICKNESS: 1 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE: - friable red bed
- minor grey bands (0.01m thick) close to basal contact

SEDIMENTARY STRUCTURES: - nodular concretions (0.04m)
- root traces?

DATE: July 5, 1997 UNIT: 027

LITHOLOGY: sandstone

THICKNESS: 0.25 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): grey/green grey

BED STYLE: - continuous planar with minor undulating (0.25m)

SEDIMENTARY STRUCTURES: - fossil fragments and impressions

DATE: July 5, 1997 UNIT: 028

LITHOLOGY: mudstone

THICKNESS: 1.6 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): mottled grey red/green grey red

BED STYLE:
- friable bed
- discontinuous sand wedges

SEDIMENTARY STRUCTURES:
- nodular concretions in mud (0.1m)
- root traces

DATE: July 6, 1997 UNIT: 029

LITHOLOGY: sandstone channel unit

THICKNESS: 2.94 m BASAL CONTACT: erosional sharp

COLOUR (fresh/weather): purple grey

BED STYLE:
- massive continuous planar sand beds
- one massive channel suite cutting underlying units 027 and 026
- five channel suites, platy at base and massive at top, cutting unit 027
- channels around 9m wide and 3 to 4m depth

SEDIMENTARY STRUCTURES:
- faint planar and undulating laminations
- x-lam
- organic fragments in channel suites (fish scales?)
- plant impressions in planar suite
- ridge and furrow paleocurrent 110, 116

DATE: July 6, 1997 UNIT: 030

LITHOLOGY: siltstone with clay seams

THICKNESS: 1.3 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE:
- friable bed with clay seams
- discontinuous planar sand bed (0.3mthick) with channel scours (0.4m deep)

SEDIMENTARY STRUCTURES:
- organic clay layer (0.08m thick) overlying sand
- nodular concretions in silt (0.09m length)
- root traces

DATE: July 6, 1997 UNIT: 031

LITHOLOGY: sandstone channel body

THICKNESS: 0.75 m BASAL CONTACT: erosional undulating sharp

COLOUR (fresh/weather): light grey/green grey

BED STYLE: - massive sand unit

SEDIMENTARY STRUCTURES: - cross- laminations
- in situ root fossils, plant impressions

DATE: July 6, 1997 UNIT: 032

LITHOLOGY: silty mudstone

THICKNESS: 0.8 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey/purple grey

BED STYLE: - poor platy bed
- discontinuous red layers (0.02m)

SEDIMENTARY STRUCTURES: - rare nodular concretion
- charcoalified tree, tilted, rooting into underlying unit

DATE: July 6, 1997 UNIT: 033

LITHOLOGY: heterolithic sandstone with siltstone

THICKNESS: 2.55 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey/purple grey

BED STYLE: - planar platy sand beds (mm to 0.15m)
- minor silt horizons (cm scale)

SEDIMENTARY STRUCTURES: - planar lamination
- common nodules (0.05m)
- root fragments rare with concentration at the top of the unit, in situ

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DATE: July 6, 1997 UNIT:034

LITHOLOGY: siltstone with minor sand channel sets

THICKNESS: 2.7 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): red grey/red purple grey

BED STYLE: - friable red bed

- minor sand channels (1.0m depth)

SEDIMENTARY STRUCTURES:
- x-lam in sand
- fossil fragments in sand
- spherical nodules (0.04m diameter) in silt, uncommon
- root traces in silt

DATE: July 6, 1997 UNIT: 035

LITHOLOGY: heterolithic sandstone with siltstone

THICKNESS: 0.8 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): light grey red/ green grey red

BED STYLE:
- planar sand beds (<0.2m)
- poor platy red silt horizons

SEDIMENTARY STRUCTURES:
- nodular concretions (0.02m length) in silt
- root fossils in sand
- root traces in silt

DATE: July 6, 1997 UNIT: 036

LITHOLOGY: mudstone

THICKNESS: 1.1 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE:
- friable red bed
- grey bands (cm) throughout with (0.07m) band 0.15m from top of unit

SEDIMENTARY STRUCTURES:
- nodular concretions (0.04m)
- root traces and org clay seams

DATE: July 6, 1997 UNIT: 037

LITHOLOGY: heterolithic channel sandstone unit with silty mudstone

THICKNESS: 1 m BASAL CONTACT: erosional undulating to planar sharp

COLOUR (fresh/weather): grey/purple grey

BED STYLE:
- continuous planar sand beds
- multiple (3?) massive channel bodies

SEDIMENTARY STRUCTURES:
- x-lam in channel set
- organic clay root traces

DATE: July 6, 1997 UNIT: 038

LITHOLOGY: mudstone

THICKNESS: 1.35 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE: - friable bed

SEDIMENTARY STRUCTURES: - org clay root traces

DATE: July 6, 1997 UNIT: 039

LITHOLOGY: shallow heterolithic channel sandstone with silt

THICKNESS: 1.9 m BASAL CONTACT: minor erosional undulations with planar sharp

COLOUR (fresh/weather): grey

BED STYLE:
- continuous planar sand
- few shallow channel grooves (0.45m)
- friable silt horizons (0.3m thick)

SEDIMENTARY STRUCTURES: - x-lam in sand

DATE: July 6, 1997 UNIT: 040

LITHOLOGY: silty mudstone

THICKNESS: 1.15 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): mottled to banded

BED STYLE: - friable bed with vertical platy sections (funneling)

SEDIMENTARY STRUCTURES: - root traces

DATE: November 11, 1997 UNIT: 041

LITHOLOGY: sandstone channel unit

THICKNESS: 2.7 m BASAL CONTACT: erosional undulating sharp

COLOUR (fresh/weather): light grey/purple grey

BED STYLE: - fine to med. grain
- platy and planar style (0.05m thick)
- channels are massive, 8 to 10m wide and 3m deep (erodes unit #40, 39?)

SEDIMENTARY STRUCTURES: - planar lam common
- asymmetrical ripples, ridge and furrow
- in situ roots, vegetative fossil impressions and fragments
- paleoflow; 14, 118, 124

DATE: November 11, 1997 UNIT: 042

LITHOLOGY: siltstone finning to mudstone with planar sandstone body

THICKNESS: 1.2m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red (silt and mud)

BED STYLE: - friable mass grading vertically from silt (0.3m thick) to mud (0.5m thick) with platy planar sandstone unit (0.4m thick) dividing silt and mud
- clay seam overlying sandstone (mm)

SEDIMENTARY STRUCTURES: - elongated nodules in silt (0.08m), spherical nodules in mud (0.03m)
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DATE: November 11, 1997 UNIT: 043

LITHOLOGY: sandstone channel unit

THICKNESS: 0.5 to 0.95m BASAL CONTACT: sharp undulating erosional

COLOUR (fresh/weather): light grey/grey

BED STYLE: - fine to medium grain
- shallow channel sand, 4m wide and 1m deep
- platy with no interfingers
- undulating unit

SEDIMENTARY STRUCTURES: - x- and planar lam
- flute casts and tool marks on bed plane
- in situ *stigmarian* root fossil and abundant fossil fragments

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DATE: November 11, 1997 UNIT: 044

LITHOLOGY: mudstone

THICKNESS: 0.9m BASAL CONTACT: sharp

COLOUR (fresh/weather): grey

BED STYLE:
- friable to shaly both laterally and vertically
- minor mottling
- carbonaceous layers (mm scale)

SEDIMENTARY STRUCTURES: - charcoalified tree stump positioned sub-vertically and rooting into underlying unit

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DATE: November 11, 1997 UNIT: 045

LITHOLOGY: sandstone

THICKNESS: 2.4m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): grey

BED STYLE:
- fine to medium grain
- planar platy sandstone with mudstone horizons (90:10)
- one undulating sand bed (0.5m thick) protruding from cliff

SEDIMENTARY STRUCTURES:
- planar lam in planar sand beds
- large plant fossil fragments in undulating bed
- tool marks present on bed plane on undulating bed
- in situ *stigmarian* roots within upper sandstone beds, bioturbated?, spherical nodules (0.03m) rare

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DATE: November 11, 1997 UNIT: 046

LITHOLOGY: mudstone

THICKNESS: 0.3m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey

BED STYLE: - friable soft bed with overlying clay seam (0.1m)

SEDIMENTARY STRUCTURES: - none

DATE: November 11, 1997 UNIT: 047

LITHOLOGY: mudstone with planar sandstone beds

THICKNESS: ~10m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red and grey

BED STYLE:
- majority of the unit is red friable to platy mudstone
- two minor channel bodies (3m by 1m) at the top of the cliff laterally extending to sharp planar thin continuous to discontinuous beds (cm to 0.2m)
- minor sand channel at base of cliff along lateral line of the two channels

SEDIMENTARY STRUCTURES:
- root traces in sand
- base channel
- fossil fragments and root fragments at top of channel
- poor planar- and cross-laminations

DATE: November 11, 1997 UNIT: 048

LITHOLOGY: planar sand with mudstone

THICKNESS: 4.5m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): light green grey/purple grey and red

BED STYLE:
- fine grain
- fissile and massive sand beds
- friable red mudstone
- continuous planar beds

SEDIMENTARY STRUCTURES:
- strong planar laminations in sand
- tool marks on sand bed plane
- elongated and spherical nodules (cm) in mudstone

DATE: November 11, 1997 UNIT: 049

LITHOLOGY: mudstone with planar sand bed within

THICKNESS: 3m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): red and grey

BED STYLE:
- same as underlying unit with majority red mud
- planar sand bed (0.5mthick)

SEDIMENTARY STRUCTURES: - same as unit #48

DATE: November 11, 1997 UNIT: 050

LITHOLOGY: planar sand with friable mudstone beds

THICKNESS: 2.5m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey and red

BED STYLE: - same as unit #48

SEDIMENTARY STRUCTURES: - same as unit #48

DATE: November 11, 1997 UNIT: 051

LITHOLOGY: channel sandstone unit

THICKNESS: ~3m BASAL CONTACT: sharp erosional undulating

COLOUR (fresh/weather): grey

BED STYLE:
- massive channel unit at tip of point
- fine to medium grain
- channel 10m wide and 3m deep

SEDIMENTARY STRUCTURES:
- ripples and tool marks on bed plane
- fossil fragments

DATE: October 11, 1997 UNIT: 101

LITHOLOGY: mudstone

THICKNESS: ~1m of exposure BASAL CONTACT: *concealed*

COLOUR (fresh/weather): red

BED STYLE: - friable bed

SEDIMENTARY STRUCTURES: - none seen

DATE: October 11, 1997 UNIT: 102

LITHOLOGY: sandstone channel unit

THICKNESS: ~2.0 m BASAL CONTACT: sharp erosional undulating

COLOUR (fresh/weather): light grey/purple grey

BED STYLE:
- medium grain
- clastic layers
  - well sorted
  - clast to clast contact
  - sub-rounded
  - majority sandstone clasts (cm to 3 cm)
  - a-axis along bedding plane
- 6? Channel sets inter-erosional
- upper section contains platy sand layers (0.1m)

SEDIMENTARY STRUCTURES: - p// and x- lam
- paleocurrent; ridge and furrow off wave cut (130, 17, 67, 80, 52)
- (in situ in wave cut) fossil fragments (*Calamites*)
- coalified fragment (0.15m)
- concretions, rare, only exposed in wave cut, spherical (0.02m)

DATE: October 11, 1997 UNIT: 103

LITHOLOGY: siltstone with sand interbeds

THICKNESS: 0.7 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red and grey colour banding

BED STYLE:
- friable red siltstone (75% of unit)
- planar grey medium grained sand layers (0.04m thick)

SEDIMENTARY STRUCTURES: - planar laminations in sandstone

DATE: October 11, 1997 UNIT: 104

LITHOLOGY: planar sandstone to channel unit

THICKNESS: 3.5 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey with red (30%) banding

BED STYLE:
- medium grained
- massive channel sand body (1.2m deep)
- discontinuous blocky sand body (2 to 2.5m thick)
  - undulating body
- consolidated planar sand body (0.4m thick)

SEDIMENTARY STRUCTURES: - channel sand contains planar and cross- lam

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DATE: October 11, 1997 UNIT: 105

LITHOLOGY: mudstone

THICKNESS: 1.4 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE:
- friable bed
- siltstone lens present in mid section

SEDIMENTARY STRUCTURES: - concretions, common, sub-spherical to spherical (0.04m)

DATE: October 11, 1997 UNIT: 106

LITHOLOGY: sandstone

THICKNESS: 1 m BASAL CONTACT: undulating sharp, erosional

COLOUR (fresh/weather): light purple grey/ grey

BED STYLE: - consolidated massive bed (0.35m thick) to planar style beds (0.12m)

SEDIMENTARY STRUCTURES: - cross- laminations with minor planar lam

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DATE: October 11, 1997 UNIT: 107

LITHOLOGY: mudstone

THICKNESS: 0.5 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE: - friable

SEDIMENTARY STRUCTURES: - none

DATE: October 11, 1997 UNIT: 108

LITHOLOGY: sandstone

THICKNESS: 0.9 m BASAL CONTACT: sharp undulating, erosional

COLOUR (fresh/weather): grey/brown grey

BED STYLE: - fine to medium grained
- massive consolidated bed

SEDIMENTARY STRUCTURES: - planar and cross- laminations
- fossil fragments are present, but uncommon

DATE: October 11, 1997 UNIT: 109

LITHOLOGY: mudstone

THICKNESS: 2.9 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE: - friable bed
- dispersed grey muddy siltstone layers (0.03m thick)

SEDIMENTARY STRUCTURES: spherical concretions, common, (0.01m)

DATE: October 11, 1997 UNIT: 110

LITHOLOGY: sandstone

THICKNESS: 0.6 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): purple grey/grey

BED STYLE: - massive continuous planar body

SEDIMENTARY STRUCTURES: - poorly developed planar- and cross- lamination

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DATE: October 11, 1997 UNIT: 111

LITHOLOGY: mudstone

THICKNESS: 4.4 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): purple grey/ brown grey

BED STYLE:
- friable bed
- coarsening up sequence within 2.2 m from mud to silt
- sandstone lens, undulating, overlying siltstone (0.4m thick)
- minor thin carbonaceous shale layers between mud to silt
- friable mudstone bed for remaining unit

SEDIMENTARY STRUCTURES:
- root traces and fragments are common
- concretions abundant wt upper mudstone set
- cross- and planar laminations within sand

DATE: October 11, 1997 UNIT: 112

LITHOLOGY: immature shaly coal

THICKNESS: 0.3 m BASAL CONTACT: moderately sharp

COLOUR (fresh/weather): dark grey, black/ brown grey, black

BED STYLE:
- continuous planar bed
- coal stringers within carbonaceous shale

SEDIMENTARY STRUCTURES: - leaf and plant fragments

DATE: October 11, 1997 UNIT: 113

LITHOLOGY: silty mudstone

THICKNESS: 0.8 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey

BED STYLE: - friable bed

SEDIMENTARY STRUCTURES: - abundant root traces

DATE: October 11, 1997 UNIT: 114

LITHOLOGY: carbonaceous shale with coal stringers

THICKNESS: BASAL CONTACT: planar sharp

COLOUR (fresh/weather): black with brown staining

BED STYLE: - carbonaceous shale with abundant coal stringers

- minor seat earth overlying shale (0.05m)

SEDIMENTARY STRUCTURES: - none seen

DATE: October 11, 1997 UNIT: 115

LITHOLOGY: fossiliferous mudstone

THICKNESS: 0.8 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey brown

BED STYLE: - minor bedding in few areas

SEDIMENTARY STRUCTURES: - abundant plant fossils and root fragments
- root traces abundant

DATE: October 11, 1997 UNIT: 116

LITHOLOGY: sandstone channel unit

THICKNESS: 2 m BASAL CONTACT: sharp erosional undulating

COLOUR (fresh/weather): light grey

BED STYLE:
- massive and uniform in thickness, with cuts into underlying unit # 115
- fossiliferous
- strong bedding at top section
- fine to medium grained

SEDIMENTARY STRUCTURES:
- in situ tree trunk, *Calamites*, impressions (0.1m)
- planar- and cross- laminations
- abundant root fragments (0.05 to 0.1m length)
- other plant fragments

DATE: October 11, 1997 UNIT: 117

LITHOLOGY: silty mudstone

THICKNESS: 1.5 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey

BED STYLE:
- featureless friable silty mudstone near base of unit
- sand wedge in mid unit
- overlying silty mudstone is platy, bedded

SEDIMENTARY STRUCTURES: - planar laminations in mud, sand is featureless

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DATE: October 11, 1997 UNIT: 118

LITHOLOGY: sandstone

THICKNESS: 0.85 m BASAL CONTACT: sharp undulating, erosional

COLOUR (fresh/weather): light grey with minor red

BED STYLE: - planar undulating beds

SEDIMENTARY STRUCTURES:
- faint laminations
- minor ripple marks
- minor fossil fragments

DATE: October 11, 1997 UNIT: 119

LITHOLOGY: muddy siltstone coarsening to siltstone

THICKNESS: 2 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light to medium red grey

BED STYLE:
- friable at base
- minor sand lens within muddy siltstone
- stratified and blocky siltstone

SEDIMENTARY STRUCTURES: - faint laminations in sandstone

DATE: October 11, 1997 UNIT: 120

LITHOLOGY: sandstone

THICKNESS: 0.25 m BASAL CONTACT: undulating sharp, erosional

COLOUR (fresh/weather): light grey

BED STYLE:
- massive undulating bed
- fossiliferous

SEDIMENTARY STRUCTURES:
- leaf fragments
- abundant root traces

DATE: October 11, 1997 UNIT: 121

LITHOLOGY: silty mudstone

THICKNESS: 2.5 m BASAL CONTACT: sharp, nodular layer

COLOUR (fresh/weather): grey to red grading

BED STYLE:
- friable bed with minor bedded areas
- thin bands of carbonaceous shale within upper third of unit (0.05m thick)
- fossiliferous

SEDIMENTARY STRUCTURES:
- elongated concretions within lower section (0.05m)
- abundant root traces

DATE: October 11, 1997 UNIT: 122

LITHOLOGY: sandstone

THICKNESS: 0.25 m BASAL CONTACT: sharp undulating

COLOUR (fresh/weather): grey with red staining

BED STYLE: - main massive lens, which becomes non-massive laterally

SEDIMENTARY STRUCTURES: - none

DATE: October 11, 1997 UNIT: 123

LITHOLOGY: sandstone

THICKNESS: 0.5 m BASAL CONTACT: sharp undulating with gradational planar

COLOUR (fresh/weather): grey

BED STYLE:
- fine grained discontinuous sand
- massive

SEDIMENTARY STRUCTURES: - poor cross- and planar laminations

DATE: October 11, 1997 UNIT: 124

LITHOLOGY: mudstone

THICKNESS: 0.5 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE: - friable bed

SEDIMENTARY STRUCTURES: - none

DATE: October 11, 1997 UNIT: 125

LITHOLOGY: sandstone

THICKNESS: 0.15 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): grey

BED STYLE:
- fine to medium grained
- discontinuous beds

SEDIMENTARY STRUCTURES: - poor cross- and planar laminations

DATE: October 11, 1997 UNIT: 126

LITHOLOGY: mudstone

THICKNESS: 3.1 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE:
- faint platy bedding, mostly friable
- minor mottling at top 2 m of unit
- thin continuous planar sand beds (0.04 to 1.8 m thick)

SEDIMENTARY STRUCTURES: - concretions in mud (0.04 to 0.06 m)

DATE: October 11, 1997 UNIT: 127

LITHOLOGY: sandstone

THICKNESS: 1 m BASAL CONTACT: planar sharp, erosional

COLOUR (fresh/weather): grey

BED STYLE:
- massive planar bed
- fine to medium grain

SEDIMENTARY STRUCTURES: - strong planar and cross- laminations

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DATE: October 11, 1997 UNIT: 128

LITHOLOGY: mudstone

THICKNESS: 2.0 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE: - friable bed

- mottling wt bottom 1.2 m

SEDIMENTARY STRUCTURES: - elongated nodular concretions, horizontal, (0.3 to 0.4m)

DATE: October 11, 1997 UNIT: 129

LITHOLOGY: sandstone

THICKNESS: 0.25 m BASAL CONTACT: sharp undulating, erosional

COLOUR (fresh/weather): grey

BED STYLE: - massive body
- fine to medium grained

SEDIMENTARY STRUCTURES: - planar lamination

DATE: October 11, 1997 UNIT: 130

LITHOLOGY: mudstone

THICKNESS: 7.55 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE:
- friable bed
- minor planar sand beds (0.3m thick) and sand lenses (0.6m thick) within bottom 2m
- consolidated red siltstone beds (0.02m) spaced throughout
- top section grades? to platy to friable grey mudstone

SEDIMENTARY STRUCTURES: - nodular root layer (0.06m), 2m from top of unit

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DATE: October 11, 1997 UNIT: 131

LITHOLOGY: coal seam

THICKNESS: 0.3 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): black

BED STYLE: - three main seams with clay btw
  - first at 0m (0.05m from base)
  - second at 0.085m (0.04m)
  - third at 0.19m (0.6m)

SEDIMENTARY STRUCTURES: - none

DATE: October 11, 1997 UNIT: 132

LITHOLOGY: mudstone

THICKNESS: 1.65 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey

BED STYLE:
- friable bed with faint platy sections grading laterally and vertically
- minor mottling

SEDIMENTARY STRUCTURES:
- root traces
- root concretions

DATE: October 11, 1997 UNIT: 133

LITHOLOGY: sandstone channel unit

THICKNESS: 2.5 m BASAL CONTACT: sharp erosional undulating

COLOUR (fresh/weather): light grey

BED STYLE:
- fine to medium grained
- planar bedded base with minor siltstone grades
- massive channel fills and beds within remaining unit

SEDIMENTARY STRUCTURES:
- strong planar and cross- lamination
- fossiliferous lam
- large scale ripples (0.6m cross-beds)
- root fragments and traces, common
- paleoflow from wave cut, ridge and furrow; 190, 183, 342, 162

DATE: October 11, 1997 UNIT: 134

LITHOLOGY: muddy siltstone to sandstone

THICKNESS: 2 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): light grey

BED STYLE:
- partly concealed
- platy mud silt bed
- grading to fine/medium grained sand with silt interbeds

SEDIMENTARY STRUCTURES: - ripples within sand

DATE: October 11, 1997 UNIT: 135

LITHOLOGY: mudstone

THICKNESS: 0.75 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): mottled

BED STYLE: - minor org rich shaly layers

SEDIMENTARY STRUCTURES: - abundant root traces

DATE: October 11, 1997 UNIT: 136

LITHOLOGY: sandstone channel unit

THICKNESS: 2.7 m BASAL CONTACT: sharp undulating erosional

COLOUR (fresh/weather): light grey

BED STYLE:
- fine to medium grained
- thick massive packages
- upper third of unit highly fossiliferous
- thin org shale bed 1m below top (01m)
- top third contains siltstone interbeds

SEDIMENTARY STRUCTURES:
- abundant strong planar and cross- lamination
- rippling
- large cross beds (0.05 to 0.3m wide)
- plant material, root fragments (in situ *stigmaria*, 0.2m), root traces
- concretions within siltstone
- paleocurrent, ridge and furrow; 324, 180, 174

DATE: October 11, 1997 UNIT: 137

LITHOLOGY: heterolithic sandstone with siltstone

THICKNESS: 2.35 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): sand light grey/grey; silt purple red

BED STYLE:
- siltstone platy to consolidated beds
- interlayered planar to mod. undulating sand beds (minor pinch-offs)

SEDIMENTARY STRUCTURES:
- planar lam in both silt and sand
- horizontal and vertical Oriented nodular concretions within silt (0.6m)

DATE: October 11, 1997 UNIT: 138

LITHOLOGY: muddy siltstone

THICKNESS: 0.3 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): purple grey

BED STYLE: - friable

SEDIMENTARY STRUCTURES:
- elongated nodular concretions near base (0.7m)
- 0.2m from base and up contains no concretions
- elongated nodular concretions at top contact (0.2 to 0.3m)

DATE: October 11, 1997 UNIT: 139

LITHOLOGY: sandstone channel unit

THICKNESS: 1.35 m BASAL CONTACT: sharp undulating erosional

COLOUR (fresh/weather): light grey/grey

BED STYLE:
- continuous planar massive sand beds with channel grooves (1m) 3.5 m wide
- minor, 5%, mudstone interfingering
  - dark. purple grey
  - friable to platy
  - conformable with sand

SEDIMENTARY STRUCTURES:
- planar and cross- laminations in sand
- cross beds (large) in sand
- organic fragments in sand

DATE: October 11, 1997 UNIT: 140

LITHOLOGY: siltstone with sandstone interbeds

THICKNESS: 1.25 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey

BED STYLE:
- sand to sand contact divided by mm scale shale siltstone
- platy to friable siltstone bed
- conforms with sandstone
- grey to red
- dips into underlying unit #139
- continuous to discontinuous thin sand beds (0.1 to 1m)
- minor channel grooves (1m) 1.7m wide
- minor thin clay seams

SEDIMENTARY STRUCTURES: - none seen

DATE: October 11, 1997 UNIT: 141

LITHOLOGY: mudstone

THICKNESS: 0.47 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): dark purple grey and sharp change to red

BED STYLE: - poorly developed platy mud bed
- grey sub unit is 0.21m, with a sharp change to red to top
- no change in bed characteristic

SEDIMENTARY STRUCTURES: - root concretions in grey section

DATE: October 11, 1997 UNIT: 142

LITHOLOGY: sandstone channel body

THICKNESS: 0.67 m BASAL CONTACT: sharp erosional undulating

COLOUR (fresh/weather): light grey sand, purple grey silt

BED STYLE:
- discontinuous to continuous sand channel body with minor muddy siltstone interfingers
- thick planar sandstone beds (0.3m) to platy style
- channel sets (0.8m) 2.5m wide
- fine grain sandstone

SEDIMENTARY STRUCTURES: - strong planar and cross- laminations

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DATE: October 11, 1997 UNIT: 143

LITHOLOGY: mudstone

THICKNESS: 0.59 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): red

BED STYLE:
- friable bed with thin (cm) grey mud bands
- clay seams present
- carbonaceous shale layer at basal contact

SEDIMENTARY STRUCTURES: - poor root traces, rare

DATE: October 11, 1997 UNIT: 144

LITHOLOGY: sandstone channel unit

THICKNESS: 1.74 m BASAL CONTACT: sharp erosional undulating

COLOUR (fresh/weather): light grey

BED STYLE:
- fine to medium grained
- massive to non-massive sand body
- minor red banding near base, uncommon
- clastic layers, uncommon, rounded

SEDIMENTARY STRUCTURES:
- planar and cross- lamination
- in situ tree impression (0.45 to 0.5m), root traces into underlying unit
- tool marks on bedding surfaces
- paleoflow, ridge and furrow from wave cut; 324, 346, 121, 144, 140, 146 165, 160, 180

DATE: October 11, 1997 UNIT: 145

LITHOLOGY: siltstone fining up to mudstone

THICKNESS: 2.3 m BASAL CONTACT: planar sharp

COLOUR (fresh/weather): 70% red, 30% grey

BED STYLE:
- *poorly exposed*
- consolidated friable siltstone bed (1.6 m)
- contains fine sandstone interbeds
- thin (mm) clay separating gradational change to friable and crumbly mudstone
- several clay seams present within upper part of the unit

SEDIMENTARY STRUCTURES:
- siltstone
- spherical concretions (0.02m), common
  - root traces
- mudstone
  - nodular concretions present at red/grey band contacts
  - root concretions (0.08m)

DATE: October 11, 1997 UNIT: 146

LITHOLOGY: sandstone channel unit

THICKNESS: 4.5 m BASAL CONTACT: sharp undulating erosional

COLOUR (fresh/weather): light grey

BED STYLE:
- medium grained (at base)
- massive (at base 2.5m) to non-massive interbedded channel sand
- channel sets (7 m)
- organic rich layers and coalified tree fragments
- Clastic beds, poorly sorted (0.05m)

SEDIMENTARY STRUCTURES:
- poor to strong p// and x- lam
- massive cross beds (2.5m)
- fossil fragments on bedding surfaces
- in situ root and tree, *Calamites*, (0.7m)
- coalified plant debris and large *Calamites* trees (excavated)

- nodular concretions, elongated to spherical, (0.09m)
- wave cut
- asymmetrical ripples
- ridge and furrow (1.5m)
- horizontal large tree stumps (0.5m)
- in situ roots
- paleoflow; parting lineation and ridge and furrow; 123, 90, 86, 88, 82, 102, 90, 96, 110, 93, 100

DATE: October 11, 1997 UNIT: 147

LITHOLOGY: sandstone channel unit

THICKNESS: 2.0 m BASAL CONTACT: sharp undulating erosional

COLOUR (fresh/weather): light grey

BED STYLE:
- poorly exposed
- fine grained
- platy sand beds interbedded with mud and silt, friable and grey
- massive channel body

SEDIMENTARY STRUCTURES: - nodular concretions, elongated, in friable mud and silt

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DATE: October 11, 1997 UNIT: 148

LITHOLOGY: siltstone bed overlain by sandstone channel body

THICKNESS: ~2 m (to overburden) BASAL CONTACT: planar sharp

COLOUR (fresh/weather): grey

BED STYLE:
- very poorly exposed and high up in cliff
- massive to discontinuous platy sand beds
- grading? In and out of silt
- underlying overburden

SEDIMENTARY STRUCTURES:
- cross- laminations
- fossils are rare
- spherical concretions present along bedding surfaces
- no organics

Progradational Parasequence for the Joggins and Springhill Mines Formation Type

Progradational Parasequence for the Joggins and Springhill Mines Formation Type

- High organic content
- Coarsening-up, Platy mudstone
- Accretionary bars, Vertically stacked, Visible sand bars
- Shallow channels, Laterally extensive, Abundant veg. Matter
- Vegetated planar sandstone, shallow inundation
- Soil horizon, Rise in water table, Minor flood events

Progradational Parasequence for the Joggins and Springhill Mines Formation Type

Complete inundation

Bay environment

Large channel body with accretionary bar forms

Laterally extensive channel bodies (anastomosing)

Flood event

Densely vegetated environment