Sedimentology of Fluvial Red Beds at Waddens Cove, Cape Breton County, Nova Scotia

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I would like to acknowledge the guidance and assistance of Dr. Martin Gibling who acted as supervisor for this thesis. Field work and photographic materials were subsidised under a grant from ...., Grant number..............
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Abstract

A red bed unit in the Late Pennsylvanian Morien Group at Waddens Cove, Cape Breton County, Nova Scotia, occurs stratigraphically between the fine upper Morien Group and the coarse lower Morien Group. A succession of sandstone and mudstone facies makes up the measured section at Waddens Cove and are indicative of a meandering-fluvial depositional environment and the characteristic sub-environments of that setting. A sandstone facies assemblage represents in-channel deposits which tend to occur within distinct paleochannels. An alternating facies assemblage of sandstones and mudstones represents overbank deposits which occur on the perimeter of paleochannels.

The internal shape and geometry of some sandstone bodies indicates that normal lateral migration of meander bends was inhibited by resistant bank material, hard layers of early-cemented, rooted siltstone. The sandstone bodies contain up to six storeys which indicate vertical aggradation between the stable banks, and each storey contains epsilon cross-stratification which represents lateral accretion of point bars within the channel. The lateral wings of the channel complex show that during the final stage the river flowed in a broad, shallow channel cut into less-resistant material. Large-scale slump blocks of bank material occur at the

base of the largest paleochannel at Waddens Cove. One possible explaination for the occurrence of the red bed unit within the generally grey Morien Group sediments is that tributaries from different source areas fed into one major fluvial system.

CHAPTER 1. INTRODUCTION

1.1 Purpose

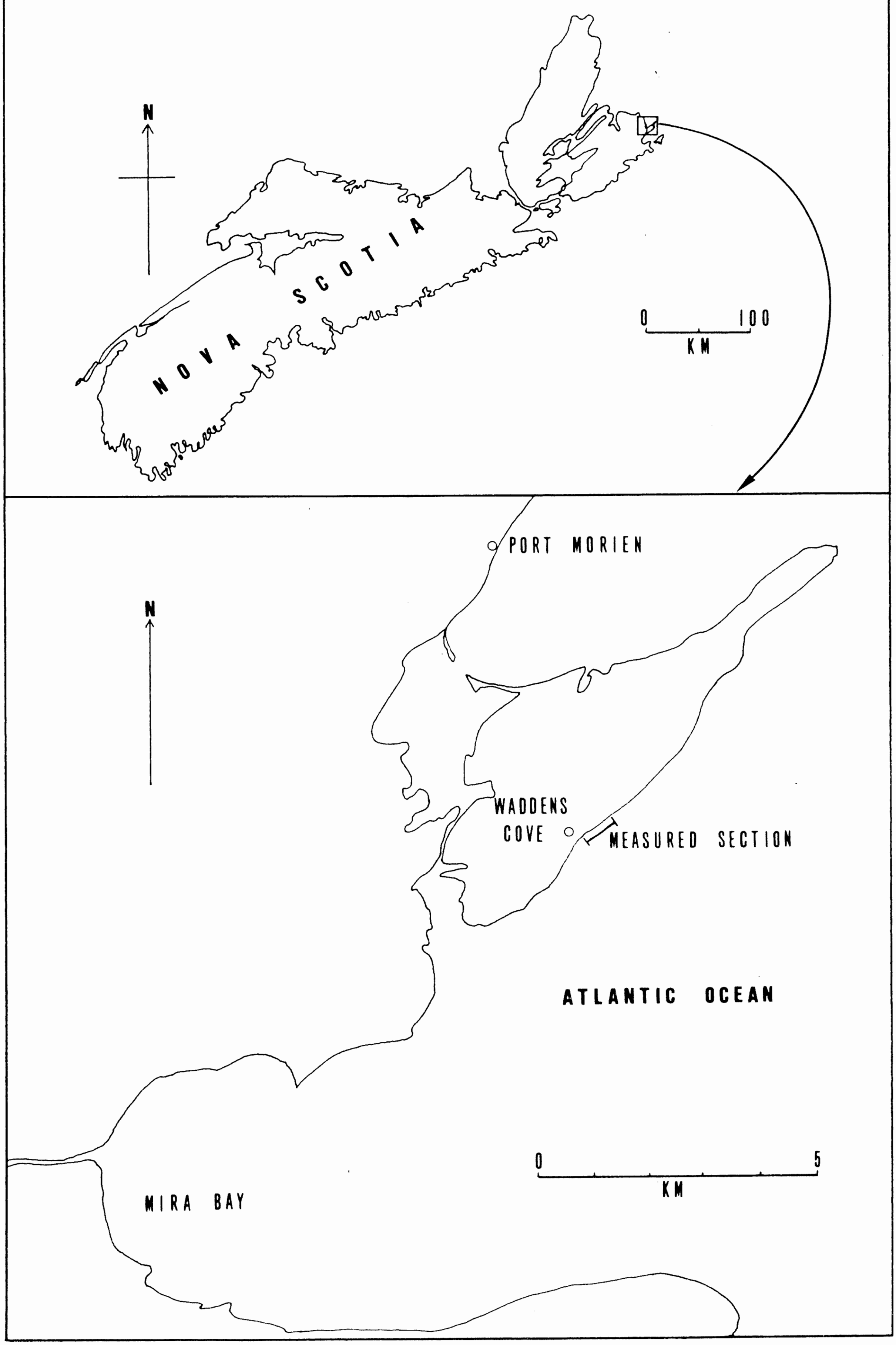
The sub-vertical cliffs of Waddens Cove, Cape Breton County, offer magnificent two-dimensional exposure of strata of the Pennsylvanian Morien Group. The purpose of this thesis is to examine the sedimentology of the ancient fluvial deposits exposed at Waddens Cove in order to propose an interpretation of the depositional environment in this area.

1.2 Location, Topography, and Physiography

Waddens Cove is located on the eastern coast of Cape Breton Island, on the northern head of Mira Bay. The community is 25 km east of Sydney and 15 km southeast of Glace Bay. The site of the section measured for this study is given in Figure 1.

Near Waddens Cove, a gently curving cliff section stretches for about 1.5 km. At the approximate center of the cove is an abandoned jetty, bordered on the northeast side by a sandy, rocky beach. In the area behind the beach, the bedrock is covered with overburden, but the cliffs rise to the northeast of the beach and southwest of the jetty. The maximum height

Figure 1. Study area map, Waddens Cove, Cape Breton County.



observed is about 15 m , and the mean height of the cliffs away from the beach is about 6 m above low tide level. Access to the cliffs is restricted to about 3 hours around low tide in the northeastern part of the section, the study area. Where steep cliffs are exposed, overburden varies from 0 - 0.5 m. The cliffs dip steeply beneath the sea and it is possible to make a close approach to the section in a Cape Island type of boat, except where resistant rocks form wave-cut platforms which extend seaward for several metres and are often just below water level.

1.3 Previous Work

The Sydney Basin, of which the Waddens Cove area is part, has been extensively studied since the first coal mine was started by French sailors during construction of the Fortress of Louisburg, circa 1720 (Hacquebard, 1980). Work dealing with the general geology, stratigraphy, paleontology, sedimentology, and coal geology of the Sydney Basin is presented in reports (and contained references) by Bell (1938), Forgeron (1980), Zodrow and McCandlish (1980), Duff et al. (1982), Dilles and Rust (1983), Hacquebard (1983), Rust et al. (1983), Boehner (1984), and Gibling and Rust (1984).

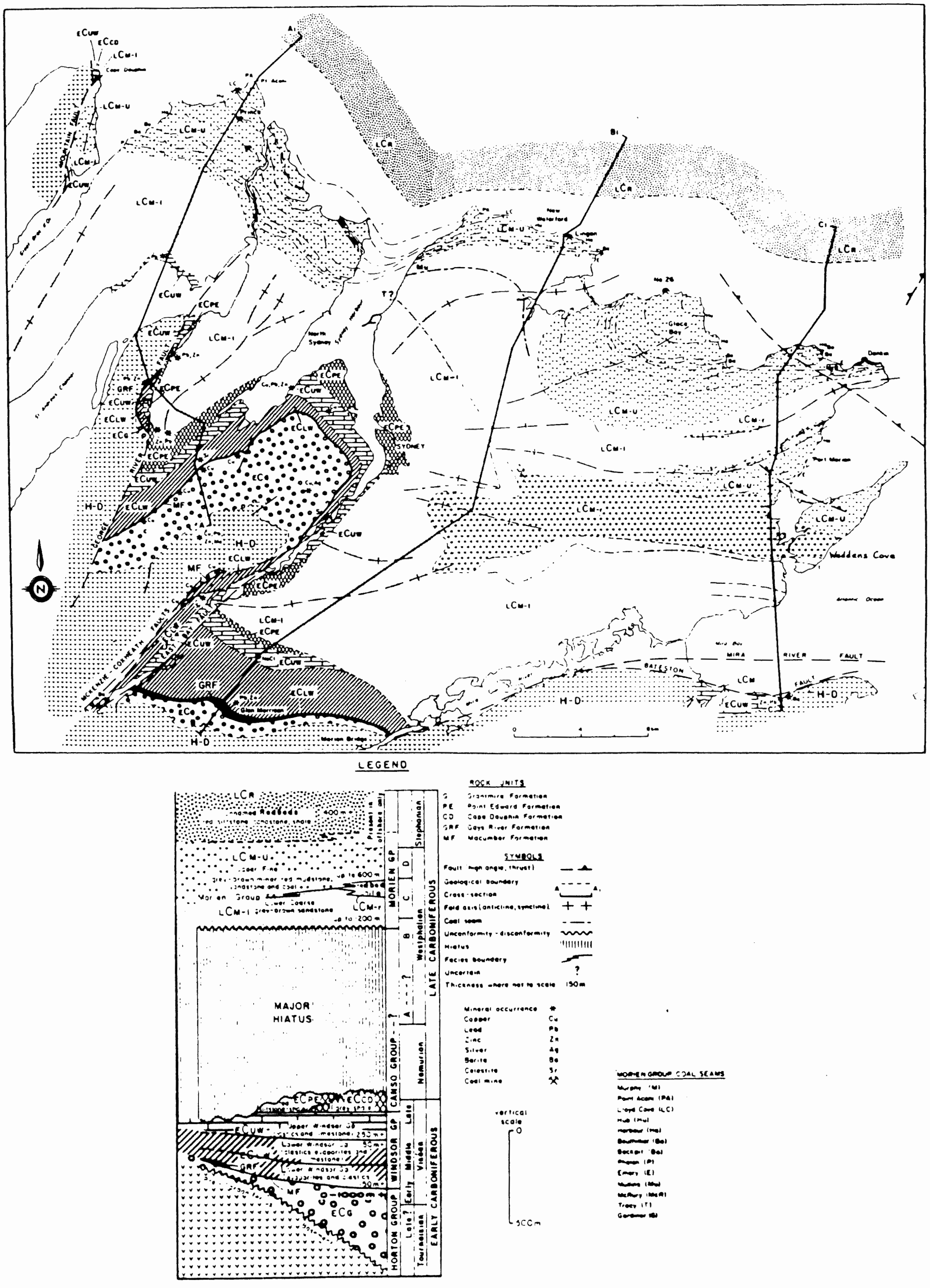
1.4 Tectonic Framework

The Carboniferous rocks of eastern Canada are part of the Appalachian mountain chain, which extends from Alabama to Newfoundland along the Atlantic seaboard (Hacquebard, 1972). Late Paleozoic evolution of the northern Appalachians included development of a wide zone of suturing after continental collision in the Devonian Acadian Orogeny. Movement along this suture zone was predominantly dextral strike-slip and a series of subbasins and intervening basement massifs was produced (Bradley, 1982). Tectonism was diachronous and variable along the strike of the suture zone and some of the subbasins have been interpreted as pull-apart basins (ibid.). Blocks of basement rock rose and subsided episodically, the uplifted blocks supplying sediments to the adjacent basins. As a result of lithospheric stretching following the orogenic event, the northern Appalachians became a site of widespread regional subsidence. The first expression of this subsidence in Maritime Canada was the deposition of the Horton Group continental clastics in fault-bounded basins. Later stages of the subsidence are represented by Middle to Upper Carboniferous blanket sands which onlap the earlier basement material.

Geophysical surveying of the extensive offshore part of the Sydney Basin has shown that the structure of the basin is saucer shaped, with beds dipping toward the center of the basin (King and MacLean, 1976). In the onshore portion of the Sydney coalfield, however, the rocks have been mildly folded into broad synclines and anticlines (Hacquebard and Donaldson, 1970). A geological map of the Sydney Basin is given in Figure 2. The folds trend easterly to northeasterly with dips generally from 4° to 15° in the flanking beds.

The rank of coal is directly related to the degree of organic metamorphism which the coal has undergone (ibid.). Coal rank can be very accurately determined by the reflectance of vitrinite, a major constituent of coal. Since major and minor coal seams are widely distributed in the Sydney Basin, it is possible to make good estimates of the coal ranks and conditions of metamorphism which existed throughout the basin. Rank changes are found to be parallel to the present surface, not to the strata, indicating that deformation and tilting occurred very early, soon after deposition of the coal-bearing rocks. Further, some coal seams are slightly thicker in the synclines than in the anticlines (Forgeron, pers. comm.), more evidence that the folding began at the same time as deposition of the Morien Group rocks. The scarcity of thrust faulting in the Sydney coalfield supports the probability that the regional structure is the result of differential

FIG. 2 GEOLOGICAL MAP OF SYDNEY BASIN (BOEHNER, 1984).



compaction of the three main sediment types: sand, mud, and peat. Under the regime of a rapid subsidence rate and high sediment load, typical of pull-apart basins (Bradley, 1982), this differential compaction caused variable subsidence in different parts of the basin (Hacquebard, 1983). Thus, the structure and deformation seen in the rocks of the Sydney coalfield are primarily caused by gravitational forces.

1.5 Stratigraphic Framework

In mainland Nova Scotia and Cape Breton Island, the Pictou Group is the most recent of the Paleozoic rock units, with a time span from Upper Pennsylvanian to Lower Permian. The Morien Group of the Sydney Basin is stratigraphically equivalent to the Pictou Group - "Morien Group" being a local name firmly established in the geological literature.

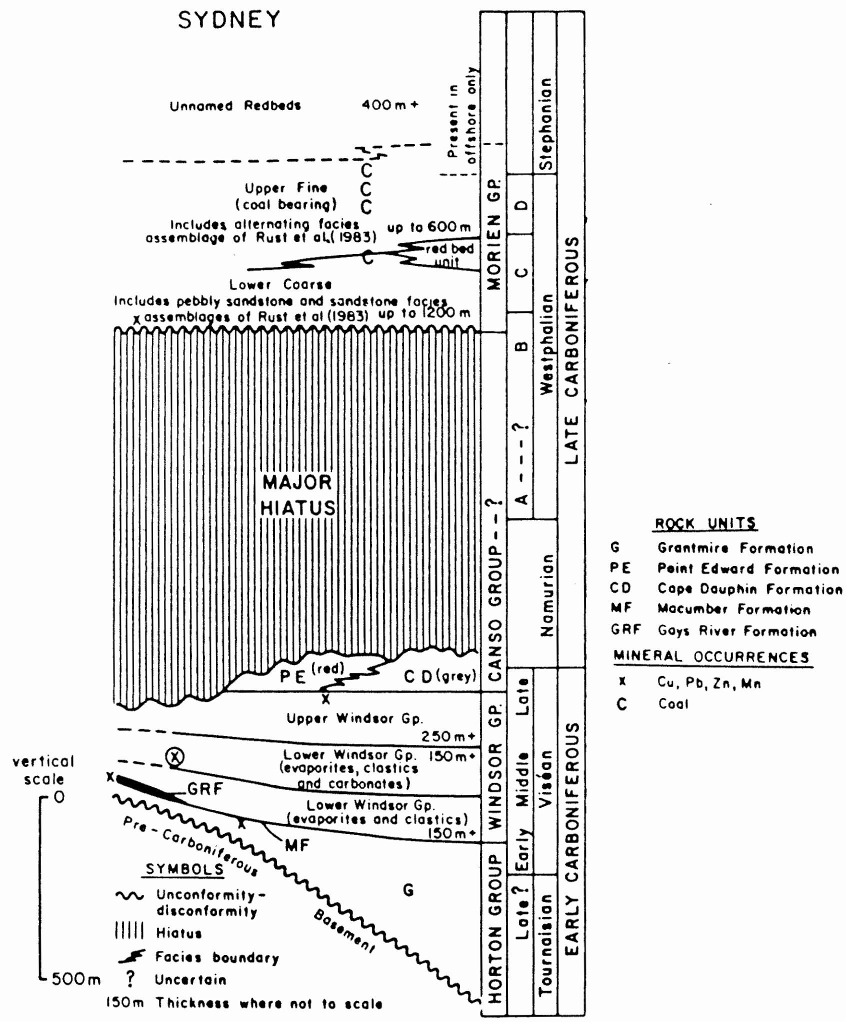
As a result of extensive work carried out in the Sydney Basin by the Nova Scotia Department of Mines and Energy and the Geological Survey of Canada during the years 1981-1984, the stratigraphy of the Sydney Basin is better known than was previously the case. The stratigraphic succession in the western part of the basin was outlined by Giles (1983). The stratigraphic sequence in the eastern part of the basin, including Waddens Cove, matches that of the western portion with the following exceptions (Boehner, 1984):

> "(1) an unnamed redbed unit is present above the upper (fine) Morien Group in the offshore parts of the Basin, and (2) a red calcareous (pedogenic) facies occurs in the Morien Group in the Wadden Cove area on Mira Bay."

A stratigraphic summary of the Sydney Basin is given in Figure 3. It is noted that all map units shown in Figures 2 and 3 will be defined as formal lithostratigraphic units upon completion of the maps and report on the area (ibid.).

The stratigraphic picture of the Morien Group is currently based on lithology and not biostratigraphy, as was the case prior to the 1980's. The Late Carboniferous Morien Group overlies a regional unconformity which marks a major erosional period in the history of the Sydney Basin. The Morien Group is a grey alluvial succession of continental clastics with no apparent marine incursions. The Group reaches a maximum thickness of 1800 m and has been subdivided into three stratigraphic units: (1) The lower unit is a coarse succession which includes the sandstone and pebbly sandstone facies assemblages outlined by Rust _et al_. (1983). (2) The upper, fine unit contains sandstones and mudstones of the alternating facies assemblage of Rust _et al_. (1983). (3) A third unit of

Figure 3. Stratigraphic chart of the Sydney Basin. (Boehner, 1984, p. 56).



Note: age assignments were compiled from various sources including palynology by Hacquebard (1983, 1972) and Barass (written communication, 1983) and megaflora by Zodrow and McCandlish (1978, 1980).

Figure 3. Stratigraphic summary of Sydney Basin.

limited extent occurs between the upper and lower divisions at Waddens Cove on the eastern side of the basin. This unit is a highly calcareous redbed unit of presumed pedogenic origin. Since this unit will be proposed as a formal lithostratigraphic unit in the near future, it is presumed that Waddens Cove will be the type section.

1.6 Economic Importance

The major economic impact of the Morien Group rocks is due to the thirteen major coal seams which extend throughout the Sydney Basin, not to the sandstones and mudstones exposed at Waddens Cove. However, the clastic units are intercalated with coals and are very important factors in the continuity of seams and the safety of exploiting them. It has been a recent innovation to relate sedimentological work on the patterns of sediment dispersal and paleoenvironment indicators in coal-bearing rocks to the modern exploitation of the coal resource (Duff et al. 1982). Paleochannels are of particular interest in coal geology because these sedimentary features are the cause of "washout" - the stone partings that destroy the continuity of a coal seam, and make floor and roof conditions unsound. Thus, the sedimentology, orientation, and frequency of occurrence of paleochannels within the coal-bearing sequence are important details to the coal geologist as well as the sedimentologist.

CHAPTER 2. METHODS

Three days of field work were conducted at Waddens Cove on July 13 - 15, 1984. After analysis of the data collected during this initial trip, a further three days of field work were conducted from October 6 - 8, 1984. On the first trip, the section was observed at close range and some preliminary sketches of the sedimentary features were made. The rock types were sampled and a systematic description of the sequence was made in part of the section. A local fisherman agreed to take his boat along the section so that the entire stretch of cliffs could be photographed at right angles to the shoreline. On the second trip, more photographs were taken from the sea in order to include a larger extent of the cove, which was examined by another Honours student. The description of the sedimentary sequence was completed during this second trip. Paleocurrent measurements were taken during both trips, as well as measurements of planar features such as lateral accretion surfaces, preserved channel banks, and rock unit contacts.

The sequence of photographs taken from the sea was enlarged and a mosaic was prepared by fitting the photographs together. Mylar overlays were used to trace features of sedimentary significance such as bedding planes, unit contacts, sedimentary structures, and slump blocks. Using this technique a sketch of about 500 m of cliff exposure was made. This sketch was then photographically reduced to a scale that permitted printing on a standard page. A photo-mosaic of part of the section studied is given in Figure 4.

In addition to this graphic work, a stratigraphic section of the strata examined was drawn up. Eleven thin sections were cut from the samples obtained, and subjected to petrographic analysis.

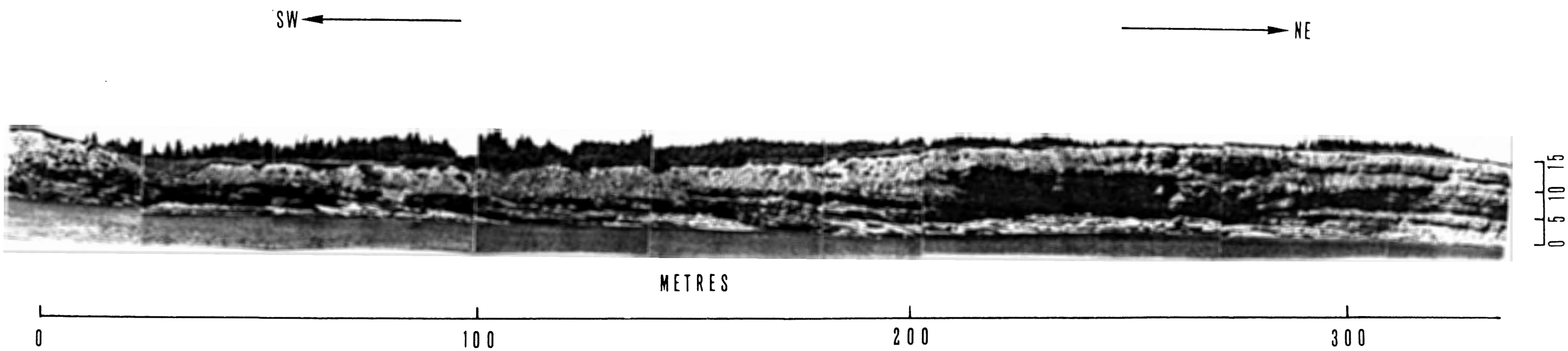


Figure 4. Photo - mosaic of part of the Waddens Cove section studied. Note major channel complex from 230 - 320 m. The stratigraphic section (Figure 9) was measured from about 50 m southwest of 0 m to about 150 m northeast of 300 m mark.

CHAPTER 3. FACIES DESCRIPTION

3.1 Introduction

The first use of the term "facies" has been attributed to the Swiss geologist, Amanz Gressley (1838), who used this term to indicate rock units which are characterized by similar lithological and paleontological criteria (Selley, 1977). Through time, "facies" has been used in many contexts - for example, "fluvial facies" has been used to indicate the broad range of stream deposits, but "point bar facies" has also been used to indicate a much more restricted sedimentary environment within the "fluvial facies" (Davis, 1983). To limit the broader use of this term, and inherent genetic implications, it seems best to restrict "facies" to rock units ranging in thickness from centimetres to metres, recognized by geometry, lithology, sedimentary structures, and fossil content, representative of a distinct process of sedimentation (Gibling and Rust, 1984).

Ten facies have been recognized in the Morien Group by Gibling and Rust (1984), following the classification scheme of Miall (1978). The Waddens Cove strata are consistent with these facies types, and a list is given in Table 1. Photographs of the eight major facies forming continuous beds in the area are shown in Figure 5 and Figure 6.

Table 1. Lithofacies in the Waddens Cove Study Area. (After Miall, 1978, and Gibling and Rust, 1984.)

Facies Code	Description	Interpretation
Gm	Massive to poorly stratified pebble to granule conglomerate, with vascular plant fragments and intraclasts of mudstone and carbonate.	Longitudinal bars, lag deposits.
St	Trough cross-stratified sandstone, mainly medium- to coarse-grained. Sets are usually grouped and up to 70 cm thick.	Dunes (lower flow regime)
Sp	Planar-tabular cross-stratified sandstone, mainly medium- to coarse-grained. Sets are usually solitary and a few dm thick, locally up to 2.6 m thick.	Linguoid, transverse bars, sand waves (lower flow regime)
Sh	Horizontally stratified sandstone, fine-to coarse-grained. Current lineation is common, and the strata may dip at low angles (transitional to facies St).	Planar bed flow (lower and upper flow regime)
Sr	Small-scale crosslaminated sandstone, fine-to very-fine grained.	Ripples (lower flow regime)
Fl	Interlaminated shale, siltstone, and very fine-grained sandstone. Small-scale crosslamination, burrows, and roots are common. Colour is grey-green or red.	Overbank or waning flood deposits
Fm	Massive mudstone, red or grey-green.	Overbank or drape deposits
Fv	Cemented fine-grained sandstone to siltstone, variegated in appearance. Units are laterally continuous for hundreds of metres.	Overbank deposits, soil deposits
P	Nodules of siderite, calcite, or silica. Unbedded concretions.	Soil deposits
C	Coal or carbonaceous shale.	Swamp deposits

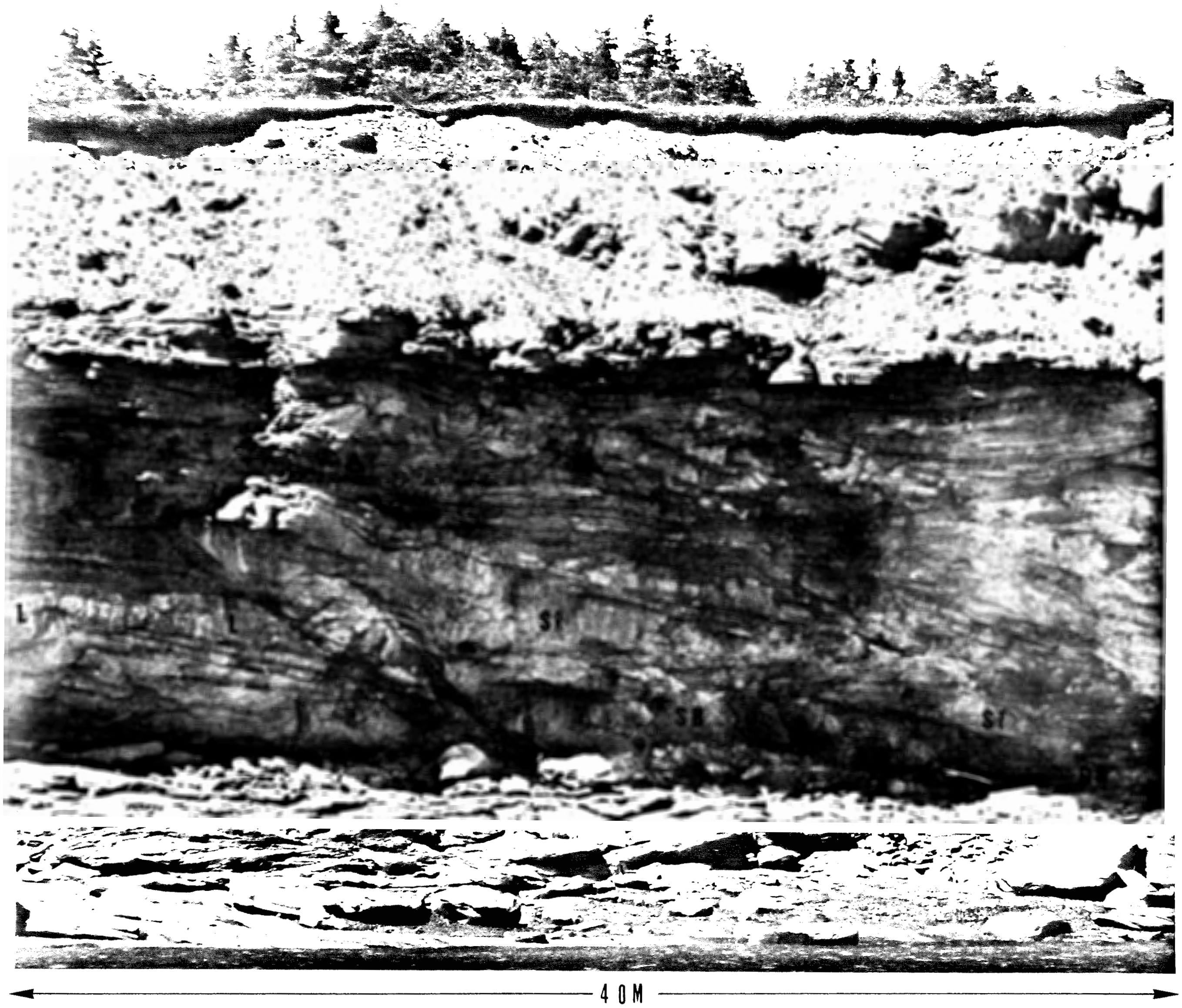


Figure 5. Photograph of cliff section at Waddens Cove.

Facies Types: L - Paleosol bed.
Sr- Ripple-marked sandstone.
St- Trough cross-stratified sandstone.
Sh- Horizontally stratified sandstone.
Gm- Massive conglomerate.

SB - Slump Blocks

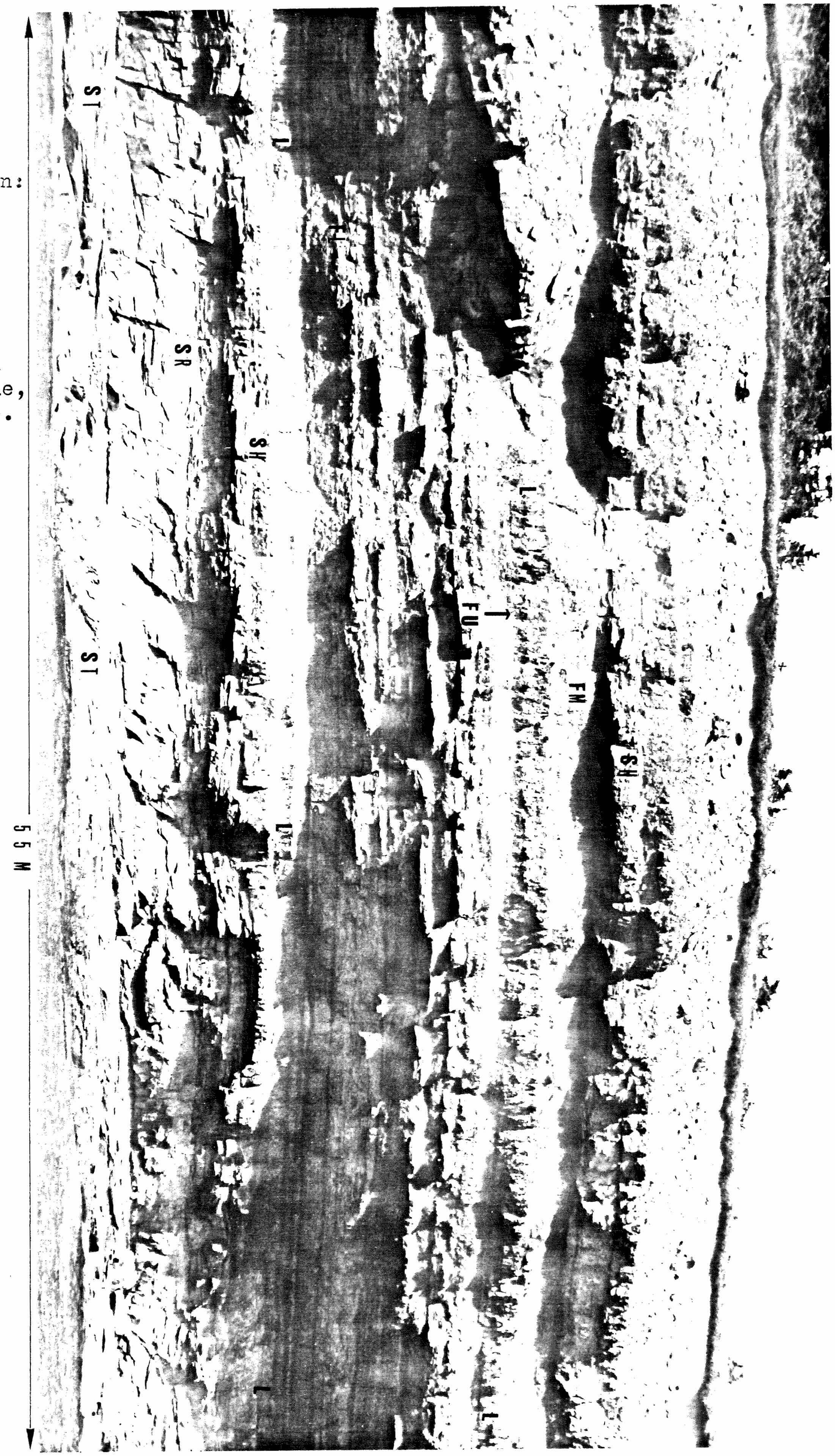
Figure 6.

Photograph of cliff section at Waddens Cove.

Facies types shown:

Sh-Horizontally stratified sandstone.
Fm-Massive mudstone.
L -Paleosol bed.
Fl-Interlaminated shale,siltstone, fine sandstone.
Sr-Ripple-marked sandstone.
St-Trough cross-stratified sandstone.

FU - Fining-up sequence.



3.2 Facies Gm

This lithofacies is a massive conglomerate which is limited in occurrence at Waddens Cove, but which occurs in small-scale, irregular, or lensoid units. The matrix of the conglomerate is medium- to coarse-grained sandstone, according to the Wentworth Scale of Grain Sizes (Table 2). Granule-sized particles occur in abundance. Beds of this facies typically have an undulating base, which is erosional upon the underlying unit, and a gradation to facies St at the top. The conglomerates contain intraclasts of floodplain origin: reddish-brown to greenish-grey mudstone, and carbonized plant stems. The mean thickness of this facies is about 15 cm, with no lateral continuity beyond about 1 m.

Facies Gm is interpreted as a fluvial lag deposit primarily because of the coarse grain size relative to the other local beds. Other evidence for this interpretation includes the massive bedding, floodplain origin of intraclasts, and the association within paleochannels. Since the main clast type of the Waddens Cove section is mudstone, of the sort seen locally, it can be concluded that these conglomerates resulted from erosion and subsequent deposition of local floodplain material.

3.3 Facies St

Trough cross-stratified sandstone is one of the major

Table 2. Wentworth Scale of Grain Size Ranges.

Name		Size(mm)
Boulder		256
Cobble		64-256
Pebble		4-64
Granule		2-4
Sand	very coarse	1-2
	coarse	0.5-1
	medium	0.25-0.5
	fine	0.125-0.25
	very fine	0.063-0.125
Silt	coarse	0.032-0.063
	medium	0.016-0.032
	fine	0.004-0.016
Clay		less than 0.004

facies types seen within paleochannels and forming wave-cut platforms. The grain size ranges from coarse- to medium-grained sandstone, but very coarse-grained sandstone is common near the base of this facies. The troughs are grouped, frequently in lensoid sandstone bodies up to 1 m thick. Individual troughs vary from 5 to 30 cm thickness and from 15 to 50 cm width. The intersection of two troughs defines a line which indicates the paleocurrent azimuth. The color of this facies is predominantly grey, but coarser material near the base is often red as a result of common mudstone and carbonate nodules as intraclasts. The facies generally shows a transitional base to facies Gm and a transitional top into other sandstone facies. The average thickness of St layers is about 10 - 20 cm.

Trough cross-stratification is formed by the migration of dunes, more or less along the flow direction of a channelized stream. For this reason, facies St is the best source of paleocurrent data. Such migrating dunes may be produced within a channel, or in a levee, or a crevasse splay. These environments are sketched in Figure 7.

3.4 Facies Sp

Planar cross-stratified sandstone is very rare in the study

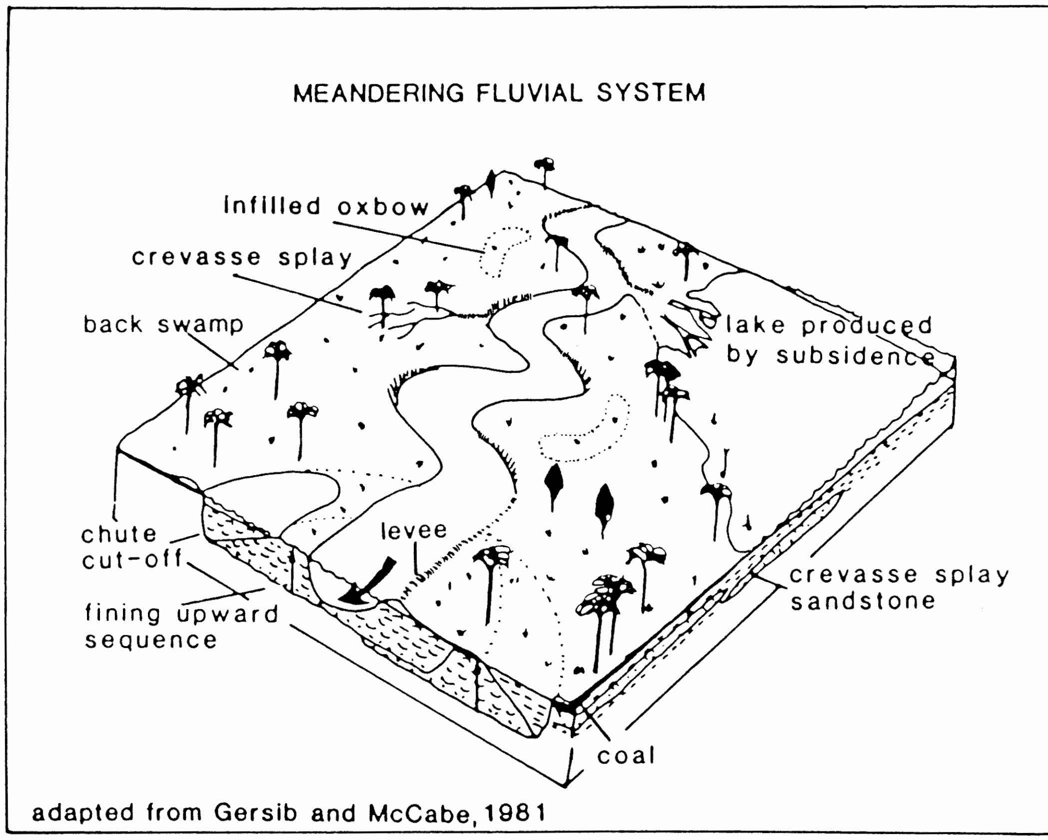


Figure 7. Characteristic environments of the meandering fluvial system. After Best, 1984.

area, and was observed only twice in units with predominant trough cross-stratification. Where observed, the unit was about 20 cm in thickness with planar stratification about 5 cm in spacing. This sandstone was typically medium-grained.

Due to the association of this facies with facies St, it is interpreted as representitive of the migration of straight-crested dunes under the same general flow conditions as facies St.

3.5 Facies Sh

Horizontally stratified sandstone is a very common facies in the Waddens Cove area. The laminations are defined by fine dark layers separating sandstone beds of varying thickness, generally thickening upward. The grain size ranges from medium- to fine-grained sandstone. The thickness of stratification varies from 1 or 2 mm to 20 cm, but a typical unit has layers of about 2 cm near the base and about 10 cm near the top. Units of facies Sh range from 10 cm to 60 cm in thickness. The facies generally has an abrupt base, often overlying a mudstone, and an abrupt top contact as well. Carbonate-nodule intraclasts from 2 - 5 cm in diameter are locally found in this facies. It is noted that laminae are often laterally variable, with one thick lamina splitting into dozens of finer laminae only 1 - 2 mm thick.

Horizontal lamination is formed by planar bed flow, most commonly high velocity flows where water depth is limited. This could occur in a crevasse splay or levee environment.

3.6 Facies Sr

Rippled sandstone is the most common sandstone facies in the study area. The units are either regularly bedded, or lensoid in shape, and tend to show a sheer, blocky face with ripples only visible upon close examination. The ripple marks are formed by alternating, inclined layers of greyish-green and reddish-brown sandstone. The ripples are small-scale, ranging from 2 - 5 mm in thickness of cross-strata with wavelengths from 5 - 15 cm. The units are commonly thick-bedded, forming layers up to 2 m thick. The base of these units is typically undulating, but not scoured. Unit contacts tend to be abrupt both at base and top.

Ripples are ubiquitous in fluvial settings, and this ripple-marked facies could be produced in many depositional conditions within the lower flow regime. Rippled sandstone may be found in deposits from crevasse splays, levees, overbank areas, and within paleochannels.

3.7 Facies Fl

This laminated mudstone unit is very common in the study area, forming beds up to 3m in thickness. The mudstone is composed of silt- or very fine sand-sized particles and contains a large proportion of organic material. The rock is very fissile and strata are complex, splitting laterally or contorted by compaction. The colour of this unit is mainly red with local green mottles. The laminae range from 1 or 2 mm to 1 cm in thickness and are usually caused by a thin layer of slightly coarser silt or very fine sand. Fossilized molds of ostracods or bivalves are common throughout this facies.

This fine facies represents overbank deposits where the sediment load was carried by suspension and deposited with waning flow. As such, it may occur in any overbank setting. However, the fossilized faunal remains and the preservation of laminae, without the bioturbation of roots, probably indicates a swamp or quiet lowland area back from the vegetated levees.

3.8 Facies Fm

This facies is similar in many ways to facies Fl, but no laminae have been preserved and the influence of root systems is very obvious in facies Fm. Rooting is thought to be the cause of bioturbation in facies Fm, destroying lamination which may initially have been present. Fm occurs in thinner beds than Fl in the study area, but beds from 5 cm to 50 cm were seen.

As was the case with facies Fl, facies Fm is considered an overbank deposit. The presence of root systems up to 30 cm long, however, indicates that the deposits were stable in the depositional environment for some time, and were colonized by vegetation. A further indication of this subaerial exposure is the presence of desiccation cracks which appear polygonal in outline and narrow with penetration into the mudstone. The desiccation cracks are generally green in contrast to the reddish-brown colour of the mudstone. Carbonate nodules are common in this unit as well, and further support the pedogenic interpretation.

3.9 Facies Fv

This facies is not volumetrically abundant in the study area, but two distinct and laterally continuous layers of this facies are present and seem to be structurally important in the formation of paleochannels. Facies Fv is a massive fine sandstone to siltstone which has a distinctive variegated appearance due to red and green mottles, being about 60% red and 40% green.

Although some of the green coloration occurs around long stringers which appear to be caused by rooting, the main green coloration occurs in irregular blotches. This rock is extremely hard while other rocks of similar grain size in the area are quite friable. Facies Fv commonly has an undulating top, indicative of an erosional surface. A large slump block of this material occurs at the base of a very large paleochannel, indicating that this facies was cemented and internally cohesive before the main incision of the channel took place. This unit occurs in beds which are laterally continuous for hundreds of metres, and vary in thickness from 50 cm to 1.25 m.

The grain size of this facies is fine sand to silt, indicating overbank deposition. The cementation and mottling of this unit further indicate that the beds were subaerially exposed for a relatively long period, as such conditions would encourage the diagenetic cementation observed. Similar rock types have been called "calcrete" by other authors (Gibling and Rust, 1984, and Best, 1984), but that term is really not applicable to the facies seen at Waddens Cove."Calcrete" is a term which generally describes a solidly, usually nodular, carbonate-rich bed. In the case of facies Fv, the rock is a cemented clastic unit with very little evidence of carbonate nodules. In fact, the rock shows only minor carbonate in nodules and is not reactive when treated with HCl. It is not known if the nodular carbonate is siderite or dolomite.

3.10 Facies P

Carbonate nodules are common in facies Fl, Fm, St, and Sr but do not form bedded units on their own. Individual nodules are common as intraclasts in the coarser facies, while groups of nodules occur around roots in the finer facies. The nodules range in size from 2 - 5 cm in diameter, but some nodules smaller than this, about 0.5 - 1 cm, occur in rooted horizons. Some rimming of root material by carbonate is apparent in rooted beds. It is probable that the carbonate growth and formation of concretions was an early diagenetic process promoted by subaerial exposure.

3.11 Facies C

There is no coal in the Waddens Cove section measured, although carbonized plant fragments are common as intraclasts in some of the coarser facies. Some mudstone layers, however, are highly carbonaceous, but the high concentration of organic matter is not laterally continuous. These organic-rich areas are marked by yellow staining of the rock, due to the weathering of pyrite in the carbonaceous material to form the yellow mineral, jarosite, $KFe_3(SO_4)_2(OH)_6$.

3.12 Petrographic Data

3.12.1 Major Grain Types - Thin Section Analysis

In thin sections taken from sandstone samples, quartz is by far the most common grain type, making up 70% - 80% of the thin sections. Lithic fragments make up from 5% - 20% of grains, and all samples contain about 5% - 10% mica. Some lithic grains are schistose in texture, showing an alignment of material within the grain. Polycrystalline quartz is found as a small percentage of the total quartz content, and these grains often show sutured contacts. The presence of schistose lithic fragments and sutured polycrystalline quartz is indicative of a metamorphic source for these clasts. No feldspars were observed in the sandstone thin sections.

In siltstones, quartz is again the dominant grain type, making up 60% - 70% of the rock. As was the case for sandstones, lithic fragments and micas are also common, each making up 5% - 10% of the samples. A substantial proportion of the siltstone samples is made up of matrix material, and the grains are mostly matrix supported. Again, feldspars were not observed in the siltstone samples.

Well-cemented siltstone units were also primarily quartz (about 70%), lithic fragments (about 5%), and mica (about 5%) and these grain proportions were similar to those found in the poorly-cemented sandstones.

It is noteworthy that the sandstones, both well- and poorly-cemented types, are quite porous. Voids make up some 5% - 15% of the total rock volume, but it is not known if these are primary or are caused by weathering effects.

3.12.2 Matrix

In a sedimentary rock, the matrix is microgranular material which occurs in the pore spaces of the rock, and which is syn-depositional in origin (Selley, 1976). The main matrix material seen in the thin sections observed was clay. Clays made up about 5% - 15% of the sandstones and about 25% - 40% of the mudstone samples. X-Ray Diffraction was not used to determine the clay species, but Dilles (1983) reported that red beds contained roughly equal proportions of kaolinite and illite in samples collected in this general area. The clays are colorless or slightly yellowish and have low relief but can be distinguished by a weak birefringence.

3.12.3 Cements

A cement is a crystalline substance precipitated into the void spaces of a sedimentary rock after deposition of the sediments (Selley, 1976). Cementation of siltstone beds is an important aspect of bank stabilization in a fluvial setting, and two extensive cemented beds at Waddens Cove were seen to be related to the depth of incision of paleochannels. The major cementing substance in these clastic units was hematite, forming 15% - 20% of the thin sections taken from 3 samples of this rock. The hematite cement is deep red-brown to opaque in transmitted light and occurs in masses which fill most of the intergranular space. The hematite also tends to rim quartz grains, even those in close contact, suggesting an early diagenetic origin. Porosity is about 5% in these cemented beds and these low porosity values are related to the occurrence of pore-filling hematite cement. The proportion of hematite varies within one thin section, as some patches occur where porosity is greater and the hematite content is only about 5%. It is probable that this is related to the red - green mottling of these cemented beds. No carbonate was seen in thin sections, but carbonate nodules occur locally in the cemented beds.

CHAPTER 4 STRATIGRAPHIC DATA

4.1 Measured Section

The location of the measured section is outlined in Figure 1, and encompasses a substantial portion of the transitional red-bed unit which outcrops at Waddens Cove, as mapped by Boehner (1984). A sketch of the cliff section studied is given in Figures 8A and 8B.

4.2 Facies Assemblages

4.2.1 Introduction

A "facies assemblage" is a group of facies which tend to occur together in consistent proportions in vertical sequence. Taken together, these assemblages can be used to interpret the depositional environment of a succession of sedimentary rocks. In the Waddens Cone section, there are two facies assemblages. An association of sandstone facies St, Sr, and Sh make up the sandstone facies assemblage, which is generally found within paleochannels. Paleochannels are large-scale erosional surfaces which cut through the regularly-dipping strata, are concave-upward and may be filled with a complex of sedimentary rock

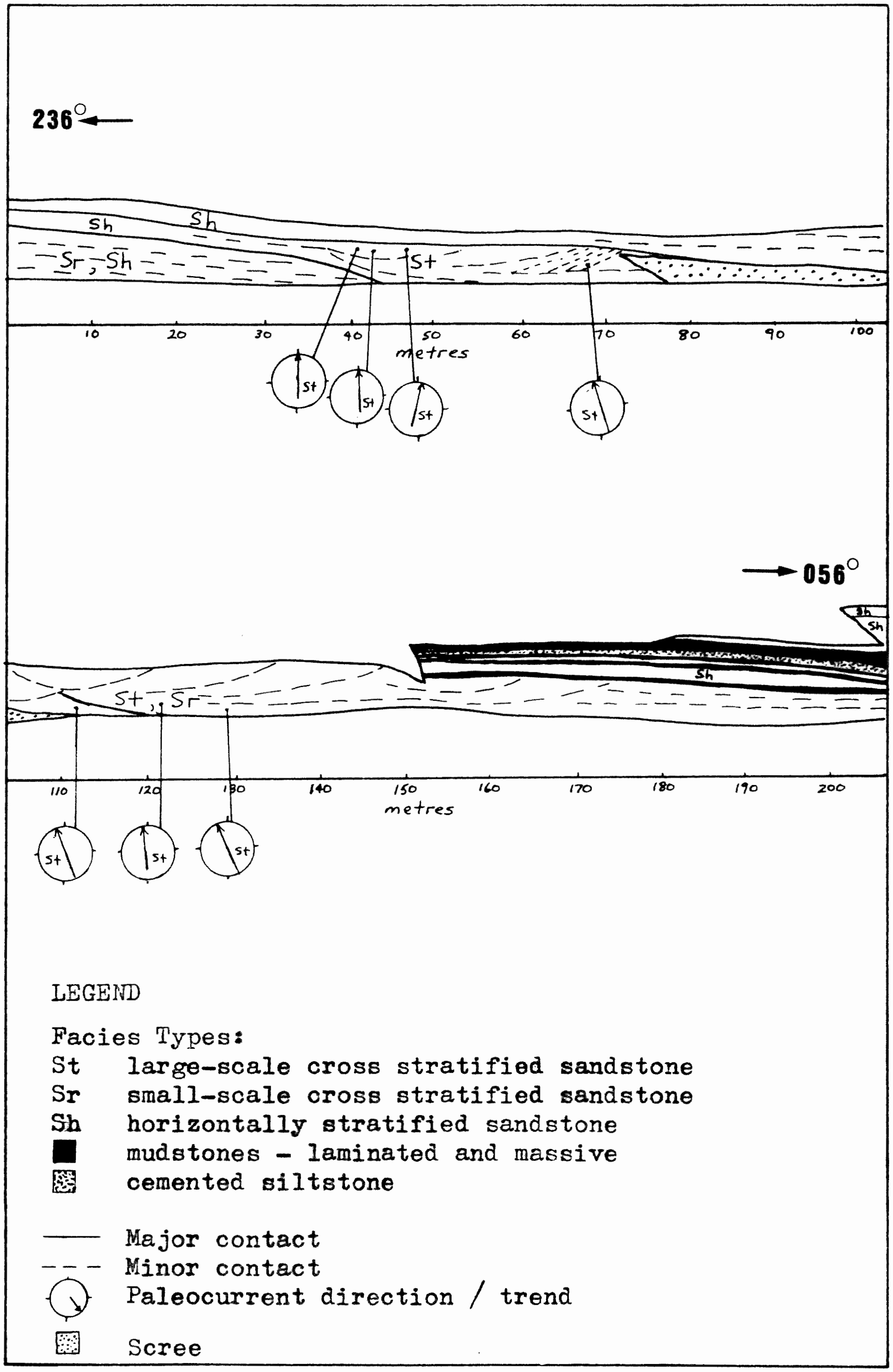


Figure 8A. Sketch of the cliff section studied, Waddens Cove. Continued on next page. No vertical exaggeration.

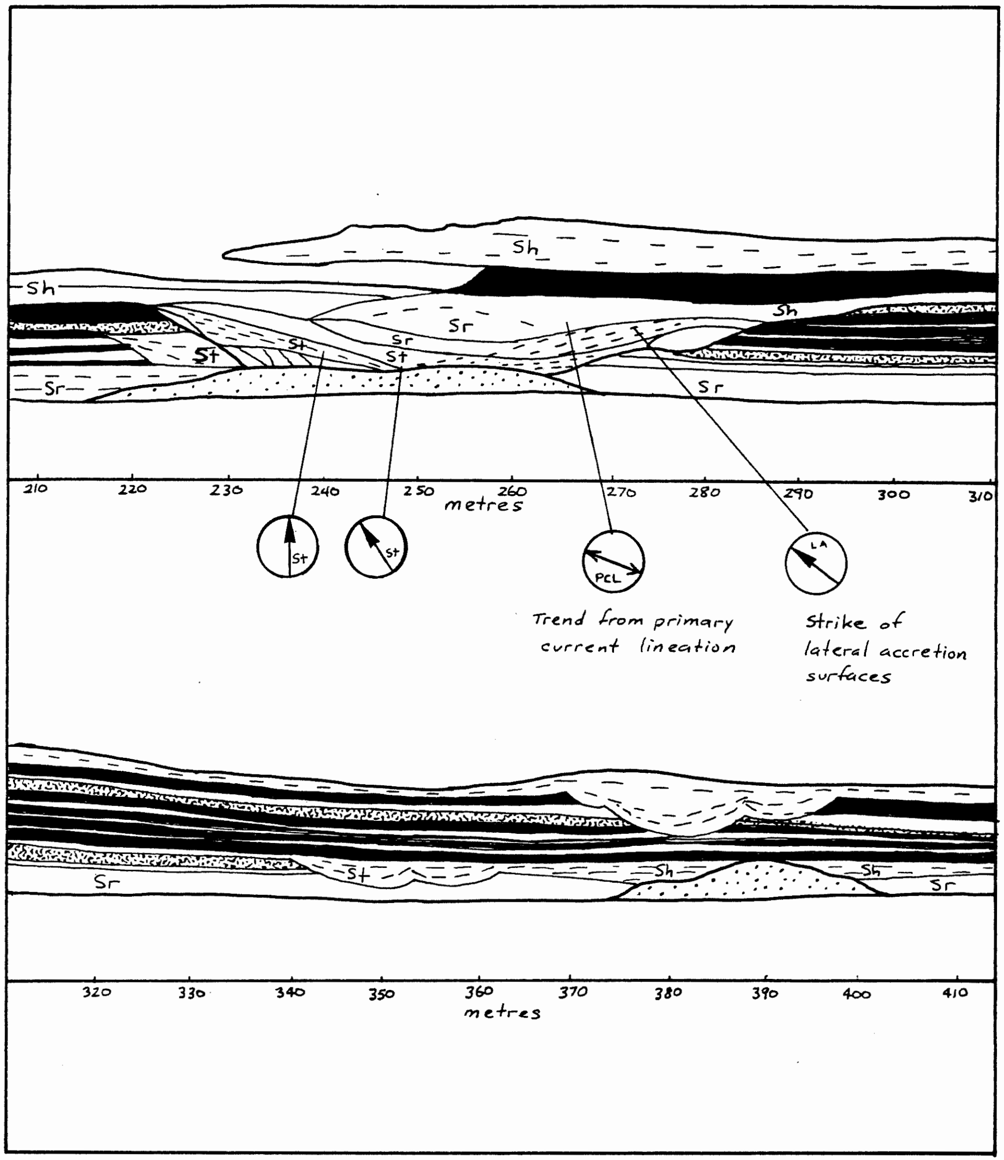


Figure 8B. Sketch of the cliff section studied, Waddens Cove. Legend as 8A, orientation of cliff as 8A.

layers representing the infilling of this erosional channel. The fine sediments in the area make up the alternating facies assemblage. This assemblage consists of sequences of interbedded mudstone, thin-bedded, horizontally laminated sandstone, and cemented siltstones. A schematic summary of the stratigraphic succession in the measured section is given in Figure 9.

4.2.2 Sandstone Facies Assemblage

Within the erosional surface defining the banks of a paleochannel, a series of sandstone facies occur. The erosional base of the channel is typically overlain by facies Gm or St, representing the lag deposit and the bed-load sediments carried by channelized flow. Complex or lensoid units of facies Sr and St, in variable proportions, form the middle portions of channels. Units of horizontally laminated sandstone overlie these facies to cover the tops of paleochannels. This sandstone facies association has a thickness which may suggest the depth of the ancient stream and varies from 0.5 to 8 m. In the largest channel, repetitions of these channel facies, St, Sr, and Sh, occur within secondary erosional surfaces, confined by the larger banks.

A rare but interesting feature in the sandstone facies assemblage is the presence of epsilon cross-stratification.

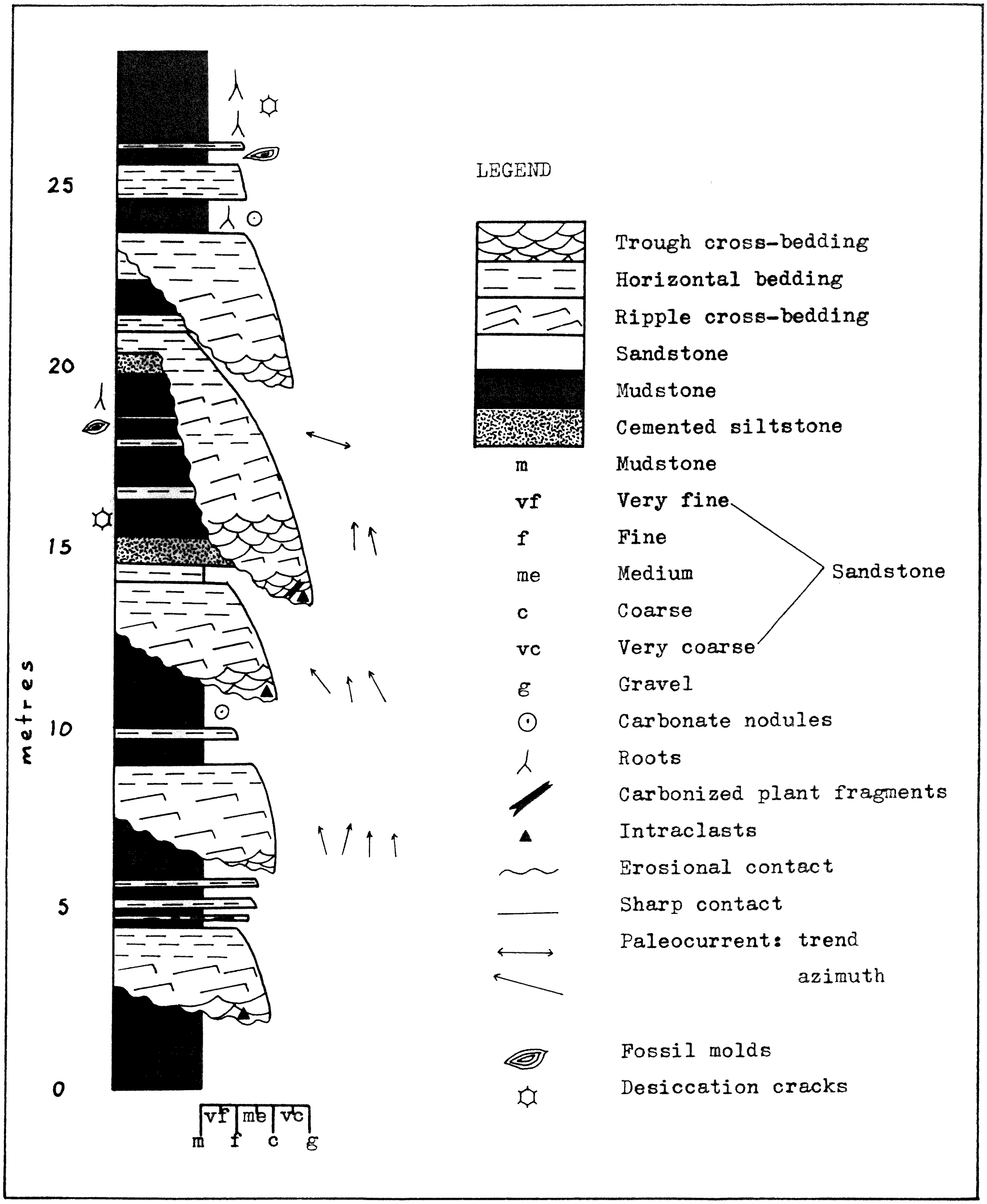


Figure 9. Summary of stratigraphic sequence in study area.

This sedimentary structure is a large-scale inclined bedding passing through the sequence within a sandstone unit. Accretion surfaces have low-angle dips, from 5° - 20°, and are marked by mud or silt drapes which can be traced down through a sand body, often to its base, from 1 - 3 m.

4.2.3 Alternating Facies Assemblage

A succession of interbedded mudstones, thin-bedded sandstones, and cemented siltstones comprise the alternating facies assemblage. This assemblage makes up about 55% of the measured section. The banks of paleochannels cut through this facies assemblage, and are overlain by it as well. The mudstones tend to occur in thick beds, with thin beds of horizontally-stratified sandstone interspersed between mudstone layers. The thin-bedded sandstones commonly occur at the base of fining-upward sandstone to mudstone sequences within the thicker beds of laminated and massive mudstone. Two beds of cemented siltstone are continuous through the northeast 250 m of the section, and occur near the top of the banks of the largest paleochannels.

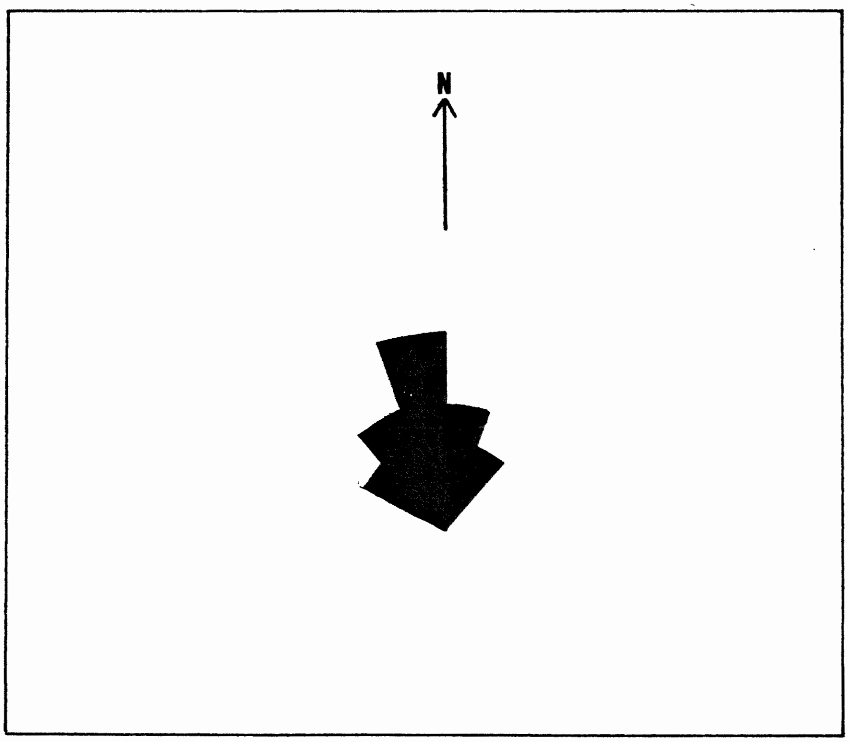
4.3 Paleocurrents

The paleocurrent measurements taken in the measured section are summarized in Figure 10, a paleocurrent rose diagram. These measurements show a drainage pattern to the north to northwest and a source area from the south to southeast. With the exception of one trend measurement from a primary current lineation, the variability was only about 90°, ranging from 285° - 008°. The paleocurrent azimuth measurements were taken within paleochannels and were defined by the intersection of trough cross-beds in facies St.

4.4 Paleochannels

As can be seen in Figures 8A and 8B, the scale of paleochannels preserved in the Waddens Cove strata is variable. In the southwest portion of the section, three small-scale paleochannels occur, cutting into thin-bedded sandstones. These channels have erosional bases which penetrate the bank material to a depth of about 0.5 - 1 m and are from 2 - 10 m in width. These sandstone-hosted channels do not show clear banks on both sides, but rather they tend to show one erosional bank on the southwest side and secondary contacts with regularly-dipping beds on the northeast side. These channels are filled with rippled and horizontally-stratified sandstones, with only minor trough cross-stratification. Epsilon cross-stratification was noted in one of these channels,

Figure 10. Paleocurrent Rose Diagram.
Data is taken from 9 azimuth measurements.



occurring on the northeast margin of the channel and dipping 15° to the southwest.

The presence of cemented beds and mudstones in the northeastern 250 m of the section seems to be the factor controlling the preservation of larger paleochannels. One very large paleochannel cuts through at least 8 m of dipping strata and has a width of about 75 m. The sandstone fill of this channel is complex and will be discussed in more detail in the next chapter. Further to the northeast, four other paleochannels cut into the same cemented beds and mudstones as the largest channel, and show preservation of two clearly defined banks. These latter paleochannels vary in size from 1 - 4 m in depth and from 8 - 20 m in width. The largest of these is high up in the cliff and could not be observed at close range. Those occurring at lower levels were infilled primarily by horizontally stratified sandstone.

There are nine paleochannels in the measured section, but one large channel occurs on a headland just to the southwest of the largest paleochannel and is inaccessible even at low tide. No detailed information could be obtained from this channel.

CHAPTER 5 INTERPRETATION OF FLUVIAL DEPOSITION

5.1 Introduction

The type of alluvial system responsible for fluvial deposits in ancient rocks may be interpreted from four basic properties which can be observed in the field (Collinson, 1978):

1) Ratio of thickness of coarse member to fine member in the overall succession.

2) Paleocurrent patterns.

3) Internal organization of the coarse member sand body.

4) Shape of the coarse member sand body.

The discussion in this chapter will focus on these four parameters in the order given above.

5.2 Coarse Member / Fine Member Thickness Ratio

One of the first things noticed in fluvial sedimentary rocks is the relative proportions of sandstone and mudstone, and this property may be immediately related to the nature of the channel systems active at the time of deposition. It has been argued (Schumm, 1963) that sinuosity increases with an increase in the proportion of cohesive material in the banks. Although this property alone neglects many of the variables essential to an understanding of channel behavior, it is a useful measure in combination with other information. The best graphic illustration of the fine to coarse member ratio is given in the stratigraphic column, Figure 9. Calculations of individual bed thickness show that mudrocks constitute about 40% of the overall succession. This high proportion of mudstones represents an abundance of muds of floodplain origin and strongly suggests a more sinuous type of channel system, probably of the meandering type.

5.3 Paleocurrent Patterns

The connection between a high dispersion of paleocurrent directions and a high sinuosity stream has long been assumed, however the picture is more complex than originally thought (Collinson, 1978). The fact that low sinuosity sandy braided streams may produce widely dispersed paleocurrents reduces the predictive value of this measurement, especially when considered alone. However, as with the coarse / fine member ratio, paleocurrents are a vital part of the description of alluvial deposits and are the best indicators of regional paleoslope and drainage patterns.

The paleocurrent data for the Waddens Cove section is given in the stratigraphic column (Figure 9) and summarized in a paleocurrent rose diagram (Figure 10). As previously mentioned, the variability is not great, and a source area to the south to southeast is indicated. This differs somewhat from the regional paleoslope for the Sydney Basin as a whole, which is from southwest to northeast (Duff et al. 1982).

Given the length of the section measured, the paleocurrent pattern shown in the rose diagram shows a fairly consistent flow direction, with a moderate degree of variability. It is probable that bank strength, in particular the strength of early-cemented siltstones, prevented many of the channels flowing through this area from meandering freely over the alluvial plain. Hence, sediments reflect a meandering stream environment while paleocurrents suggest that the meandering was restricted by physical factors, an apparent paradox.

5.4 Internal Organization of Coarse Member Sand Bodies

The traditional association of the fining-upward sequence with lateral accretion on point bars in a meandering river system is actually based on very little data from present point bars within meander systems (Collinson, 1978). The facts presented by modern research show that no single vertical sequence can be said to categorize a specific channel type. However, one feature seems to be fairly typical of meandering streams - that of epsilon cross-stratification. This sedimentary structure is a large-scale inclined bedding passing through the sequence and indicative of lateral accretion of the point bar, which is assumed to be the depositional bank of a meandering stream. For this reason, epsilon cross-stratification is also referred to as lateral accretion bedding.

Lateral accretion surfaces are very noticeable in the lensoid sandstone bodies seen at Waddens Cove. These units consist of lateral accretion sets in very fine- to medium- grained sandstone. The units range in thickness from 1 - 3 m and the average dip of the accretion surfaces is about 15°. The direction of dip is found to be roughly perpendicular to the paleocurrent indicators within the channels. It is probable, then, that these epsilon cross-strata represent inclined point bar surfaces with paleoflow along the strike of the surface.

5.5 Shape of the Coarse Member Sand Body

The cross-sectional shape of a preserved sandbody may be used to interpret the type of channel which deposited the sediment, and its behavior. The Waddens Cove section features one very large-scale paleochannel which occupies about 75 m of the measured section and allows a good chance to apply this relationship. In order to examine fluvial architecture, some introduction to terms is necessary. Figure 11 presents an illustration of some sand body shapes. Friend et al. (1979) provide a concise account of the relevant definitions. A "sand body" is defined as a single, interconnected mappable body of sand which may have the form of a sheet, or which may be elongate in form. The elongate bodies are called ribbons if they have a width / height ratio of less than 15. Within the ribbon sand body, units of rock which are separated by scour surfaces are called storeys. The term "multi-storey" may be used to describe the vertical sequence of storeys within a sand body, while undifferentiated sand bodies are called "simple". A ribbon sand body, further, is said to consist of a "central body" to which may be attached a pair of sub-horizontal "wings".

A major sand body, interpreted as a paleochannel complex, occurs in the measured section at Waddens Cove along with several smaller paleochannels. This large-scale channel complex is shown in a photo-mosaic in Figure 12. The width of this channel complex is about 75 m and the depth is about 8 m, giving a width / depth ratio of about 9 and thus fitting the definition of a ribbon sand body given above. This is a multi-storey ribbon with 6

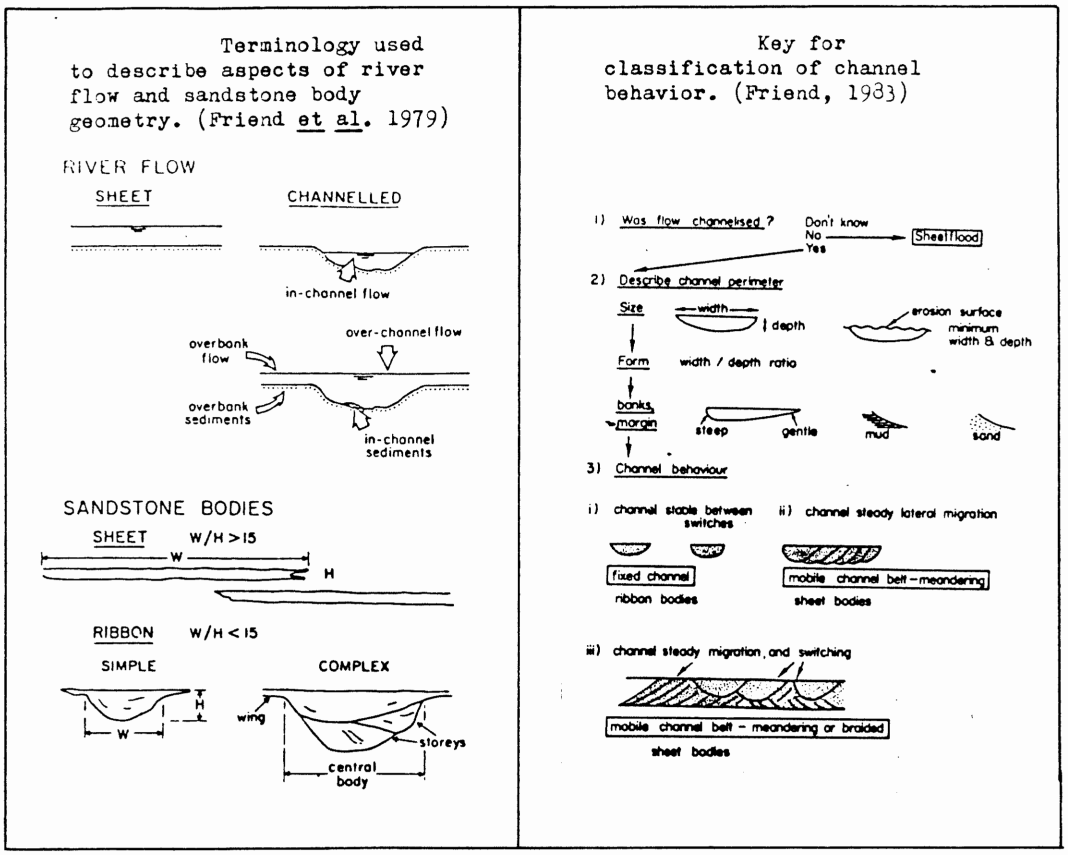


Figure 11. Terminology of fluvial architecture and classification of channel behavior.

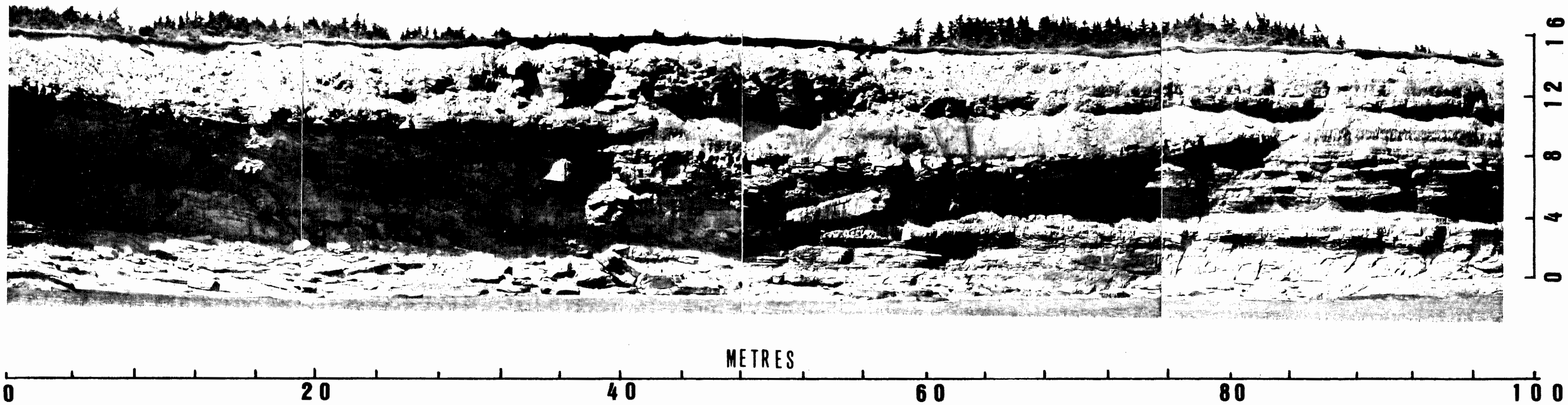


FIGURE 12 SANDSTONE FILLED CHANNEL, WADDENS COVE

main units within the sand body and sub-horizontal wings over each bank (Figure 13). Within storeys 3 and 4, lateral accretion sets dipping from 8 to 12 are defined by fine mud drapes cutting through the storeys. This pattern of stratification is interpreted as evidence of lateral migration of a channelized flow with step by step accretion of a sandy point bar. The smooth, undulating surface of the basal scour suggests that the channel outline was cut in one major event, rather than in the step by step scour events related to the accretion of the storeys. Slump blocks occur in the first storey, and are composed of bank material which may be matched with the beds at the perimeter of the channel. This indicates that the southwest bank of this channel was a cut-bank, or erosional surface.

The general separation of paleochannels in the measured section shows that channels were relatively stable between switches in position. The resulting ribbon sand bodies, then, reflect conditions of channel behavior. Four factors appear to be of controlling importance in the relationship between river flow and sediment building (Friend et al. 1979). The first factor is the river flow strength. High sinuosity is usually related to flow strengths of intermediate value, however the major channels seen at Waddens Cove appear to have been stable for relatively long periods without lateral migration of the overall

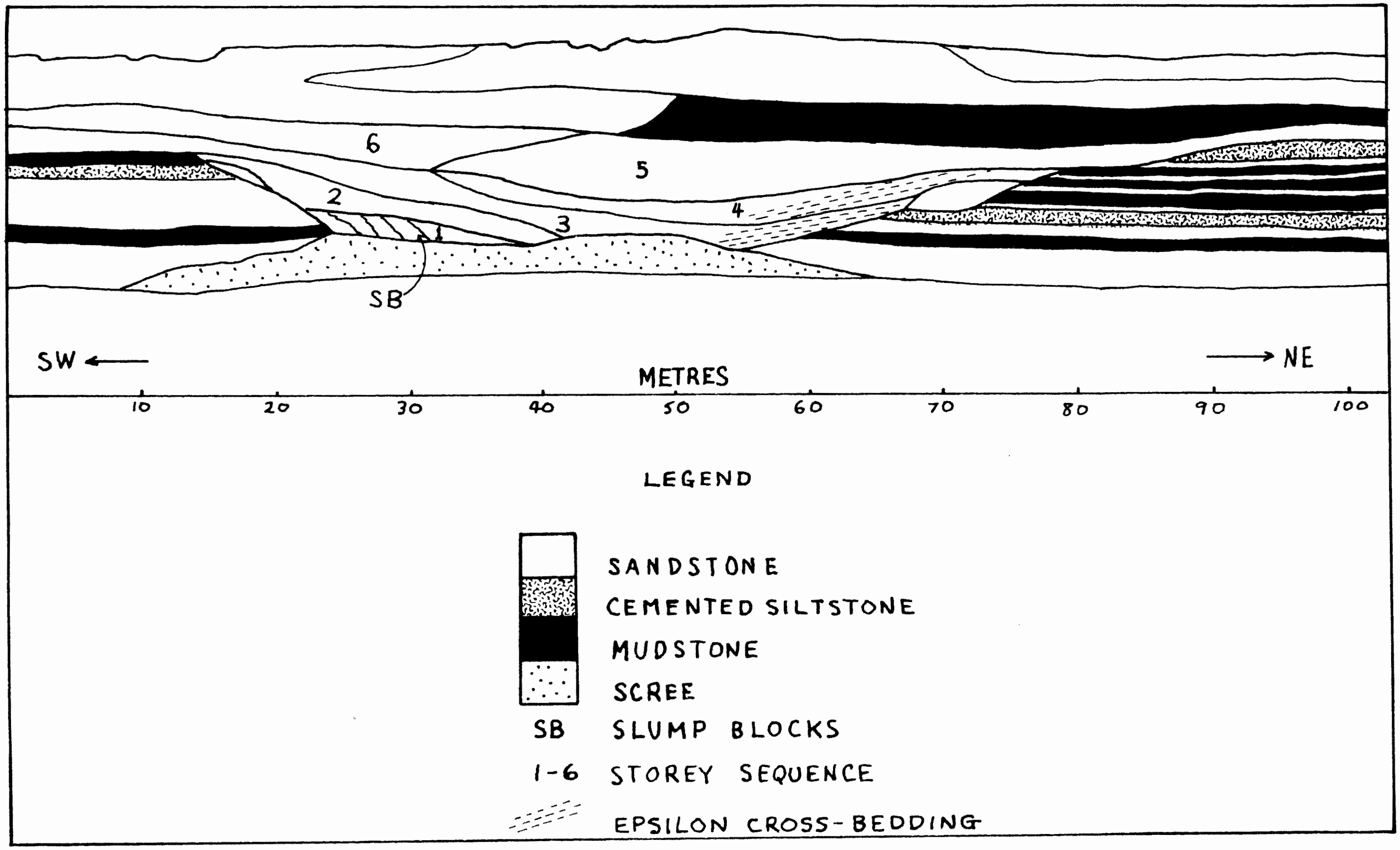


Figure 13. Internal geometry of ribbon sandstone body, Waddens Cove.

channel position. Migration within the channel has occurred, and is represented by lateral accretion within storeys 3 and 4. The second factor is probably more relevant to the position stability, namely the factor of bank strength. In general, banks formed from cohesive material produce narrower, deeper channels that those formed in sandy or gravelly banks. In the Waddens Cove area, distinct beds of cemented siltstone occur high in the channel banks. These resistant beds undoubtedly stabilized the channels between switches. Evidence for the early origin of these resistant, cemented beds are erosional tops, slumps into the channels, and widening of the channels over the tops of the cemented beds. The third factor is flood periodicity and duration of stream flow. It is expected that continuous lateral migration is the product of long-continued, steady flow. Conversely, floods with rapid onset followed by periods of low discharge will tend to produce major changes of channel pattern due to avulsion or cut-off (Friend *et al.* 1979). In the section studied, both processes seem to have contributed to the sediment distribution . The fourth factor is vertical movement of the channel area due to tectonic or morphological events. It is thought that deep incision of channels may be caused by local uplift, if other factors support this interpretation. The area studied did not supply enough evidence to support or reject this idea. However, deep incision of a channel, for whatever reason, will inhibit lateral sediment building. The multi-storied structure of the major channel at Waddens Cove indicates that both lateral and vertical sediment building occurred in this area.

The main points which outline the history of the major channel complex at Waddens Cove may be summarized as follows. Some catastrophic event, probably a strong flood, carved out a distinct channel cut, relatively deep and narrow and stabilized by cemented siltstones. Slumping of bank material into this erosional cut occurred just after it was formed. The erosional surface was then infilled by a series of units, some showing lateral accretion surfaces indicative of lateral migration within the channel. These units form storeys within the paleochannel and were probably caused by periodic floods and major modification of the pre-existing sediments. The storeys built up vertically within the main banks as a result of stream aggradation. A widening of the channel occurred in the topmost storeys as the resistant beds were covered by sediment fill and the stream could overflow the earlier banks. This was the cause of the wings seen atop this channel. Eventually, overflowing of banks led to channel abandonment and the deposition of overbank mudstones on top of channel sandstones.

5.6 Depositional Environment

5.6.1 Introduction

From the data discussed in Chapters 3, 4, and 5, the environment of deposition in the Waddens Cove area is interpreted as a meandering fluvial system which deposited sandy and muddy red beds in a terrestrial setting. The facies present at Waddens Cove are similar to the Alternating Facies Assemblage of Rust et al. (1983) with respect to the proportion of mudstone in the sequence, but dissimilar with respect to coal, which is absent in the measured section. Meandering rivers are characterized by a number of sub-environments with distinct processes of sedimentation, and which occur in an ordered spatial arrangement (Gibling and Rust, 1984).

5.6.2 Sandstone Facies Assemblage

The sandstones and minor gravels are interpreted as fluvial channel and point bar deposits. Gravels overlying erosional scour surfaces represent the coarse lag deposits from base level of an active stream. Epsilon cross-stratification in the sandstone units represents lateral accretion on point bar surfaces. Fining upward is commonly observed in sandstone facies, conforming to the classical idea of the internal organization within a meandering stream deposit. It should be noted, however, that the grain size range within any storey is as great as that within the entire sand body complex.

Channel depths in the study area varied from about 0.5 to 8m, on the evidence of preserved channel banks and in-channel deposits. The smaller channels tend to be filled with facies Sr and Sh and probably represent crevasse splays or small feeder channels which cut through levee systems. A high sinuosity is suggested by the high proportion of fine sediment in the sequence, but resistant beds in the bank material have limited the lateral migration of most channels.

5.6.2 Alternating Facies Assemblage

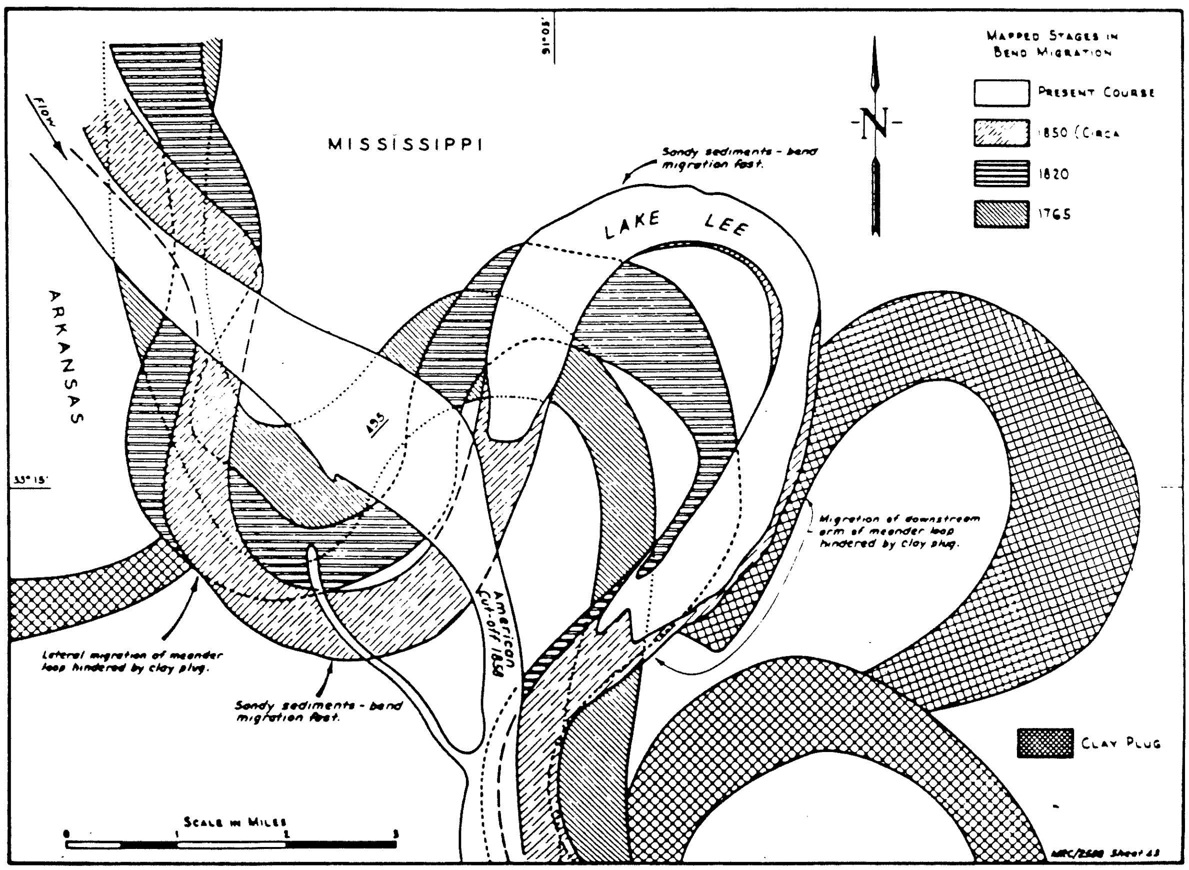
Mudstones are interpreted as floodplain deposits, and form about 40% of the strata in the study area. Two laterally extensive beds of cemented siltstone show secondary hematite and indicate a low water table and subaerial exposure of the overbank material. This exposure caused oxidation of iron and resulted in the red-brown colour of the fine beds at Waddens Cove. This oxidizing environment also caused inhibition of organic sedimentation in the area, resulting in a lack of coal. Rhizoliths, the preserved remains of roots in mineral matter, are products of pedodiagenesis (soil-forming processes) (Klappa, 1980). These features of the fine facies are further indication of subaerial environments unsaturated in groudwater, and are found in post-Silurian successions.

Such extensive development of root and soil horizons suggests a subhumid environment which is compatible with discontinuous discharge and deep incision of channels during heavy floods (Puigdefabras and Van Vliet, 1978). Layers of thin-bedded fine sandstone are also considered part of the overbank material. These layers are too laterally extensive to be crevasse splays and probably represent fast-flowing discharge of water over the tops of channels as sheet flow.

5.6.3 Modern Analogue

The Mississippi River is one modern analogue for meandering fluvial sedimentation. In this system, a stream flowing in uniform bed materials exhibits a regular outline and pattern of migration (Fisk, 1943). Most migrating river bends, however, encounter locally resistant beds in the bank sediment which slow the rate of bank recession. Such a change in the regularity of migration often results in the formation of abnormal meanders and leads to the cut-off of the meander loop. The control which is exerted by clay plugs on the migration of meander bends is shown in Figure 14. In the vicinity of Lake Lee, Mississippi, a channel bank stabilized by clay plugs remained in place for about 100 years, leading to the cut-off of the meander loop.

Figure 14. Mississippi River - Control of bend migration by clay plugs in the vicinity of Lake Lee, Mississippi. (Fisk, 1943, Fig. 57)



CHAPTER 6 CONCLUSIONS

6.1 Importance of Cemented Layers in Channel Incision

Large-scale paleochannels are preserved in the Waddens Cove area as a result of early cementation of overbank material which then formed stable banks for the deep incision of streams. Once carved, these stable channels could not migrate freely over the alluvial plain and abnormal meander bends occurred, which eventually contributed to cut-off and infilling of the channels.

6.2 Vertical Aggradation Within Channels Due to Incision

As a result of deep incision, normal lateral accretion of fluvial deposits could not occur, and vertical aggradation of sediments occurred within channels. Although epsilon cross-stratification indicates that lateral accretion did occur within storeys of sand body complexes, vertical aggradation was the main factor in sediment building within channels.

6.3 Classification Problem

A difficulty arises in defining the type of fluvial system responsible for the deposits at Waddens Cove because the geometric form of the deposits is modified by bank stabilization. Thus, the sedimentary facies are indicative of a meandering stream environment, but the paleocurrent and sand body data are not typical of a meandering fluvial system.

6.4 Slumps of Hard Material

Slump blocks have been described from ancient meandering-fluvial deposits (Gersib and McCabe, 1981; Dilles, 1983), but seem to be absent from literature dealing with braided-fluvial deposits. Braided streams lack cohesive muds in thick units and are hence unlikely to produce slump blocks. The presence of distinct, large slump blocks in the major paleochannel in the study area is further support for a meandering depositional model.

6.5 Relation of This Study to Hydrocarbon Reservoirs

The type of narrow, ribbon sandstone bodies preserved at Waddens Cove would be excellent resevoir rocks in a favourable environment for hydrocarbons. The channel fill sequences consist of porous sandstones surrounded by mudstones, cemented siltstones, and thin-bedded sandstones. Such a setting is similar to some of the productive reservoirs in clastic units of the Alberta Basin (Putnam and Oliver, 1980), where hydrocarbon traps are created by lateral and vertical facies changes.

6.6 Grey vs. Red Lateral Equivalents in the Sydney Basin

The Mississippi River system is a modern analogue applicable to the problem of the origin of the transitional red bed unit exposed at Waddens Cove and stratigraphically between the lower and upper Morien Group, which are grey sediments. In the Mississippi valley, tributaries contribute sediments from two major sources: red-brown, weathered sediments from the mid-western plains, and grey-green sediments from the Appalachians. Tributaries emptying into the main trunk of the Mississippi thus have two different sediment types, and a given deposit may contain interfingering sediments of both types, with roughly parallel paleocurrents. In this way, the source area as well as the environmental conditions are important in the occurrence of red beds (Fisk, 1943).

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