CARBONIFEROUS FLUVIAL STRATA OF THE INVERNESS FORMATION AT FINLAY POINT, SOUTHWEST CAPE BRETON ISLAND

by

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A thesis submitted to the Department of Geology for partial fulfillment of the requirements for the Degree of Bachelor of Science (Honours)

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Abstract

A red bed unit of Westphalian C age at Finlay Point, Mabou Mines, Inverness County, Nova Scotia occurs stratigraphically near the base of the Inverness Formation and is correlated with offshore coal seams in the St. Lawrence Basin. A succession of sandstone and mudstone facies compose the measured section at Finlay Point and are indicative of a fluvial deposition environment. A sandstone facies assemblage represents in-channel deposits similar to those observed in braided streams. An alternating facies assemblage of sandstone and mudstone represents floodplain deposits which are deposited adjacent to the paleochannels.

The internal morphology and geometry of the sandstone bodies suggest that normal braiding did not develop and this enabled thick accumulation of floodplain deposits. Sandstone bodies are multi-storied and indicate vertical aggradation between banks and flood plain deposits are thick indicating they are remove from channels for extended periods. The fluvial environment which deposited these strata is interpreted as transitional between meandering and braided , possibly representing the early stages of development of the St. Lawrence Basin.

Chapter 1 Introduction

1.1 Purpose of Study

The strata at Finlay Point, and other strata of the Inverness Formation, have been studied stratigraphically, but never with the aim of understanding the detailed sedimentology of the area. It is the aim of this study to present the sedimentological data available at Finlay Point.

As a result of this description it is hoped that an understanding of the ancient fluvial system that deposited the strata of Finlay Point will be obtained. This will be done by comparison with models developed by other workers.

1.2 Location

The study area is located on the west coast of Cape Breton Island. Finlay Point is located at Mabou Mines, about 10 km northwest of the village of Mabou. The area is accessible by a gravel road in good repair. The outcrop studied was exposed in coastal cliff sections, easily accessible along the beach and headland that compose Finlay Point. The cliffs range from 5-30 m in height and are topped by several metres of overburden. Occasional slumps of these sediments obscure the cliff exposure. Extensive fracturing of some of the outcrop precluded climbing of the cliff as in some places faults altered the stratigraphic continuity along the cliffs.

1.3 Previous Work

In the 1880's studies of a regional nature were conducted in Nova Scotia by Fletcher. In the period between 1880 and 1927 various investigators studied the area of Mabou Mines and their work has been presented in private reports (Keating, 1950). In the late 1920's G.W.H. Norman of the Geological Survey of Canada did field studies in southwestern Cape Breton and his work resulted in the publication of a report in the Lake Ainslie Map Area in 1935, including a study of the

Mabou Mines area.

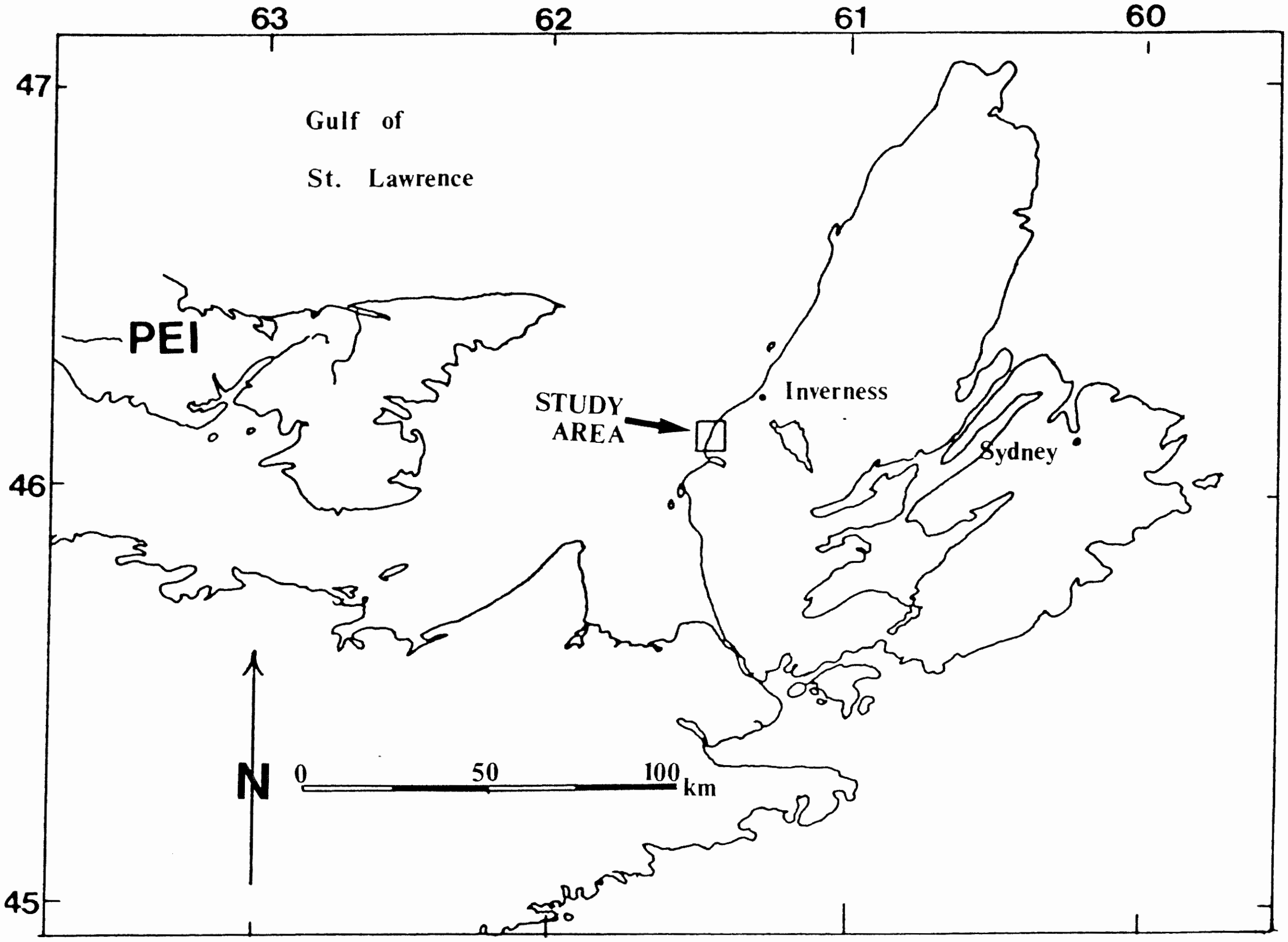


Figure 1 **LOCATION MAP**

In 1944 G.V. Douglas of the Nova Scotia Department of Mines completed a report on the Mabou Mines area. Douglas was unable to determine the stratigraphic relationship between Coal Mine Point and Finlay Point. He believed that the Finlay Point section overlies the Coal Mine Point section, but how far above he could not say. Douglas named the sandstone units at Finlay Point. The sandstone body between the Five-foot and Two-foot Seam is called the Point Sandstone and above the Two-foot Seam the sandstone body is called the Finlay Sandstone.

In 1949 Macdonald Coal Mines Ltd. of Sydney ran a small underground operation on the five-foot seam at Finlay Point. Keating (1950) quoted the mine reports which noted that the five-foot seam thinned to zero thickness in the north-east and due to this erratic nature of the seam mining was soon discontinued. This mining operation accounts for the disturbed appearance of the five-foot seam in the cliff and is represented in the graphic log.

In 1950 B.J. Keating of the Nova Scotia Research Foundation, in an unpublished report, described the Mabou Mines area. Keating found no lithological evidence of a correlation of strata between Finlay Point and Coal-mine Point. T.B. Haites of the Dominion Steel and Coal Co. compared the seams within the Inverness coal field, with those of the Sydney Basin. His was the first attempt to correlate the coal seams within the Mabou Mine area. He also used the term "shale member" to describe the finer grained sequences with intercalated coal seams. The shale members were named after the predominant coal seam contained in them, for example, the five-foot shale member at Finlay Point contains the Five-foot coal seam. These names were used in later reports by Hacqubard and the practice is continued in this report.

In 1956 a report by P.A. Hacquebard of the Geological Survey of Canada provided a good correlation among the coal seams at Mabou Mines and an understanding of the lateral variation of coal seams and shale members in the area. Hacquebard's correlations were based on palynomorph population distributions from samples collected from both outcrops and boreholes. These boreholes were drilled by the Nova Scotia Department of Mines and Macdonald Coal Mines Ltd. Interest in the area terminated after these reports indicated the limited extent of onshore

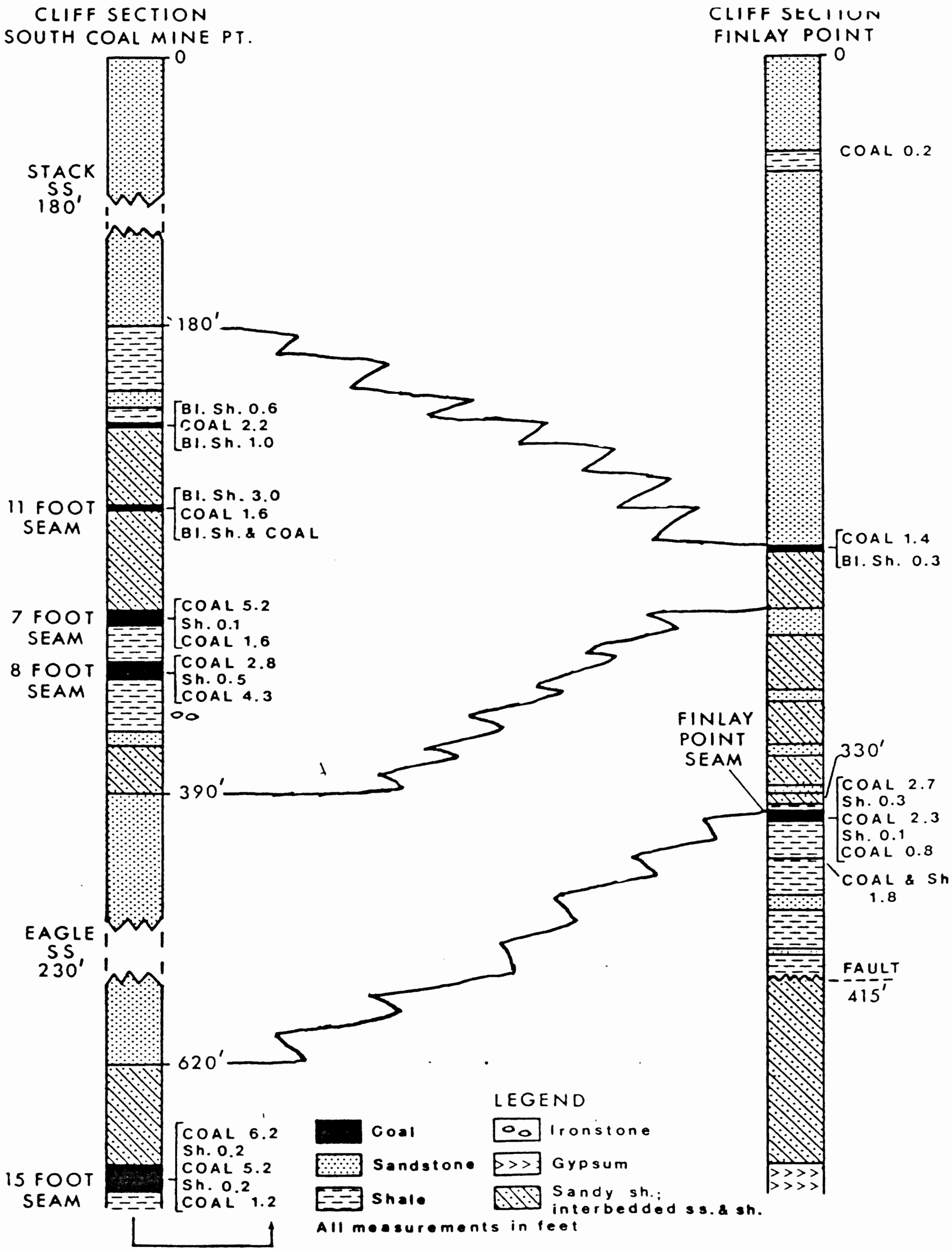


Figure 2 Coal Mine Point - Finlay Point Correlation (from Hacquebard 1980).

coal reserves. Hacquebard's correlations are summarized in Figure 2. He correlated the 7 foot and 8 foot coal seams interval at Coal-mine Point with the two foot seam at Finlay Point and the Fifteen-foot seam of Coal-mine Point with the five foot seam at Finlay Point.

Hacquebard (in press) recently completed a report on the offshore strata off the Inverness Formation. Data from offshore bore holes and seismic work were correlated with onshore outcrops, such as Finlay Point. The results of this work indicate that the largest coal basin in Atlantic Canada, the St. Laurence Basin, is located to the west of Finlay Point underlying the Gulf of St. Lawrence. These coal seams are presently below the limit of economic mining (1000m) but may in the future become an economic resource.

1.4 Tectonic Setting

During the Carboniferous and Permian, sedimentation occurred throughout the Fundy Basin in environments of tectonic extension, compression and strike-slip deformation. The deformation was never continuous at any locality and was associated with shifting depositional centres, although sedimentation was widespread and probably continuous on a regional scale (Howie and Barss, 1975).

Early Carboniferous sedimentation included continental sedimentation of the Horton Group, a marine incursion represented by the Windsor Group and a return to continental clastic sedimentation during the deposition of the Canso, Cumberland and Riversdale Groups. All of these groups include conglomerates associated with faults which controlled sedimentation (Bradley, 1982) and resulted in rapid subsidence. The deposition of these stratigraphic groups within interconnected fault-bounded basins is related to a stage of local crustal extension.

During a phase of declining thermal subsidence large areas of continental fluvial coal measures were deposited as the Pictou Group. These Pictou strata unconformably blanket older Carboniferous rocks and onlap basement areas. By this time the Fundy Basin was a stable craton with few active faults and low subsidence rates. Pictou sediments are exclusively fluvial and lacustrine, and sedimentation was not fault controlled.

Bradley (1982) developed a regional tectonic history of the Late Paleozoic Appalachian region. After Mid-Late Devonian continental collision the Acadian suture zone and part of the Avalon basement became the site of a major intracontinental transform system. Eventually several hundred kilometers of right-lateral offset accumulated within a wide fault zone. Sediment source areas included stable platforms in south-west Nova Scotia, north-central New Brunswick and eastern Newfoundland. Extensional basins developed adjacent to these source areas as a response to lithospheric stretching.

Widespread regional subsidence followed the extension, the timing of which is not certain. It is, however, definitely associated with the basement onlap of the Pictou sediments.

Continued late Carboniferous strike-slip fault motion has obscured basin onlapping to the south and east of the St. Lawrence Basin. This major pull-apart basin (25,000 km^2) is located offshore adjacent to Finlay Point. The strata at Finlay Point have been disturbed by a complex tectonic history involving renewed strike-slip deformation, as seen in Figure 4.

1.5 Stratigraphy

The strata exposed at Finlay Point are of the Pictou Group, and in particular the Inverness Formation. Bell (1944) included the Inverness Formation in the Pictou Group because of macrofossil assemblages. Hacquebard and Barss (1967) confirmed this assignment using palynological dating techniques. An age of Westphalian D to Stephanian was assigned to the Inverness Formation as a result of the work.

The Pictou Group rests uncomfortably on Upper Carboniferous and older basement rocks. Thickness of the Group ranges from 100-2400 metres with the possibility of 4-5 kilometres of Westphalian to Permian sedimentary rocks in the centre of the St. Lawrence Basin. The coal measures of the Pictou Group in southwestern Cape Breton are stratigraphically equivalent to the Upper Carboniferous Stellarton and Morien Groups elsewhere in the province. (Lexicon of Canadian Stratigraphy, in press). The stratigraphy of the Mabou Mines area is shown in Table 1.

The environment of deposition of the Pictou Group and its equivalents is generally interpreted as a low-lying, low-slope alluvial floodplain with meandering streams and interchannel swamps where vegetation flourished (Rust et. al., 1983). Other environments and fluvial styles include braided streams in the Morien Group (Gibling and Rust, 1984) and fluvial-lacustrine coals of the Pictou Group on the northern mainland of Nova Scotia (Hacquebard and Donaldson, 1969).

1.6 Economic Importance

The coal seams exposed at Finlay Point and other onshore coal seams of the Inverness Formation have been correlated with offshore bore holes and seismic sections. The strata at Finlay Point represent an onshore exposure of this largely submarine basin, the largest coal basin in Eastern Canada (Hacquebard, in press). The coal seams at Finlay Point cannot be considered economic because of their poor quality and limited extent. Understanding the sedimentological relationships of the coal seams and the sand bodies intercalated with them is important if large offshore reserves are ever to be exploited.

TABLE OF FORMATIONS

ERA	PERIOD	AGE	GROUP	LITHOLOGY
CENOZOIC	Recent and Pliestocene		------	Till, gravel and sand
UNCONFORMITY				
PALEOZOIC	Pennsylvanian	Westphalian D to Stephanian	Pictou (Inverness Fm.)	Grey sand-stone, grey shale, coal, cong.
	UNCONFORMITY			
	Mississippian	Visean C to E	Upper Windsor	Sandstone, conglomerate, black shale, limestone
		UNCONFORMITY		
		Visean A to C	Lower Windsor	Gypsum and anhydrite
		UNCONFORMITY		
		Tournaisian	Horton	Conglomerate, and sandstone
		UNCONFORMITY		
			Horton (Fisset Brook Fm.)	Rhyolite, andesite, tuff and volcanics

Table 1 (after Keating, 1950)

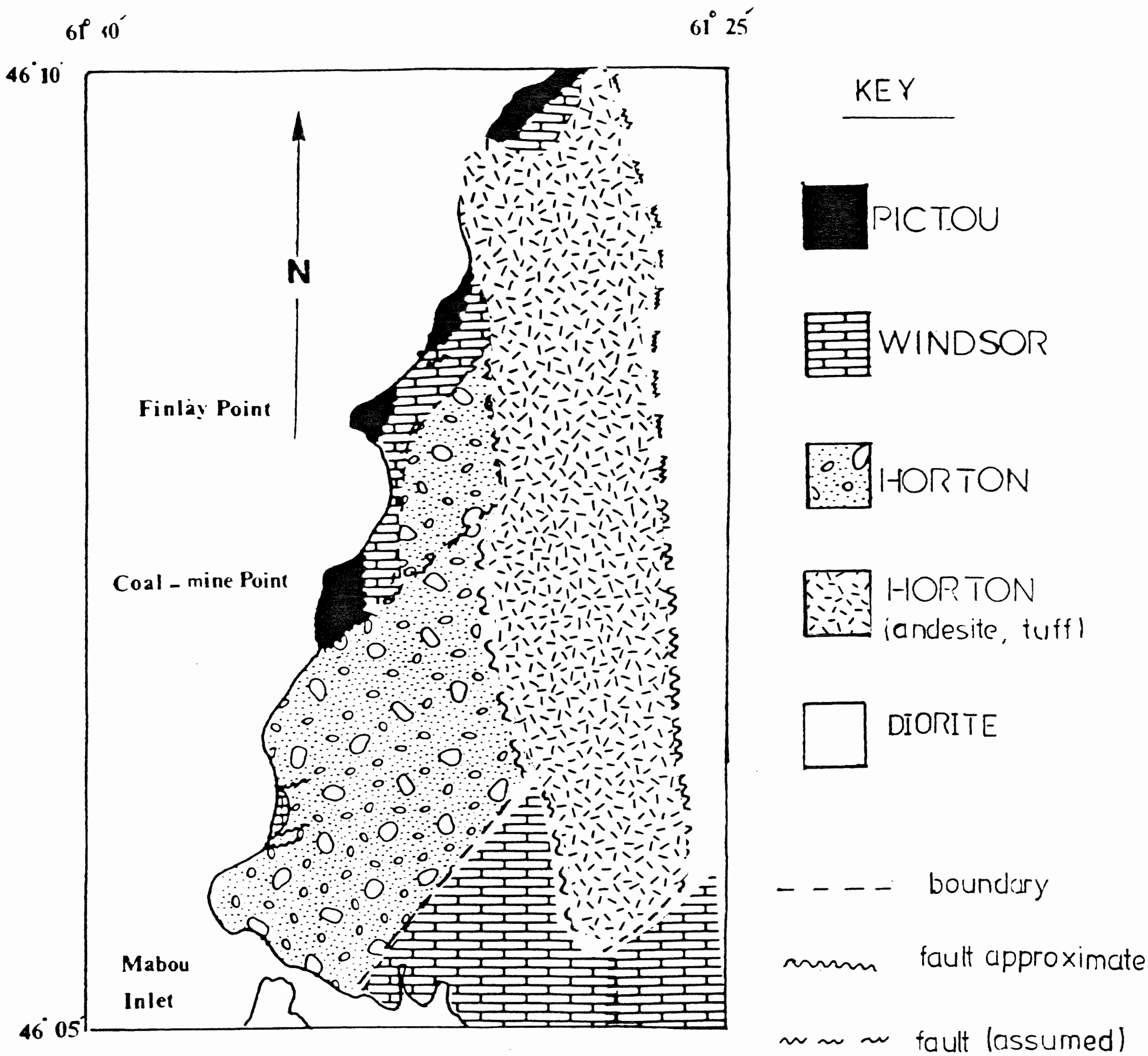


Figure 3 MABOU MINES, INVERNESS CO. N.S.

(after Norman, 1935)

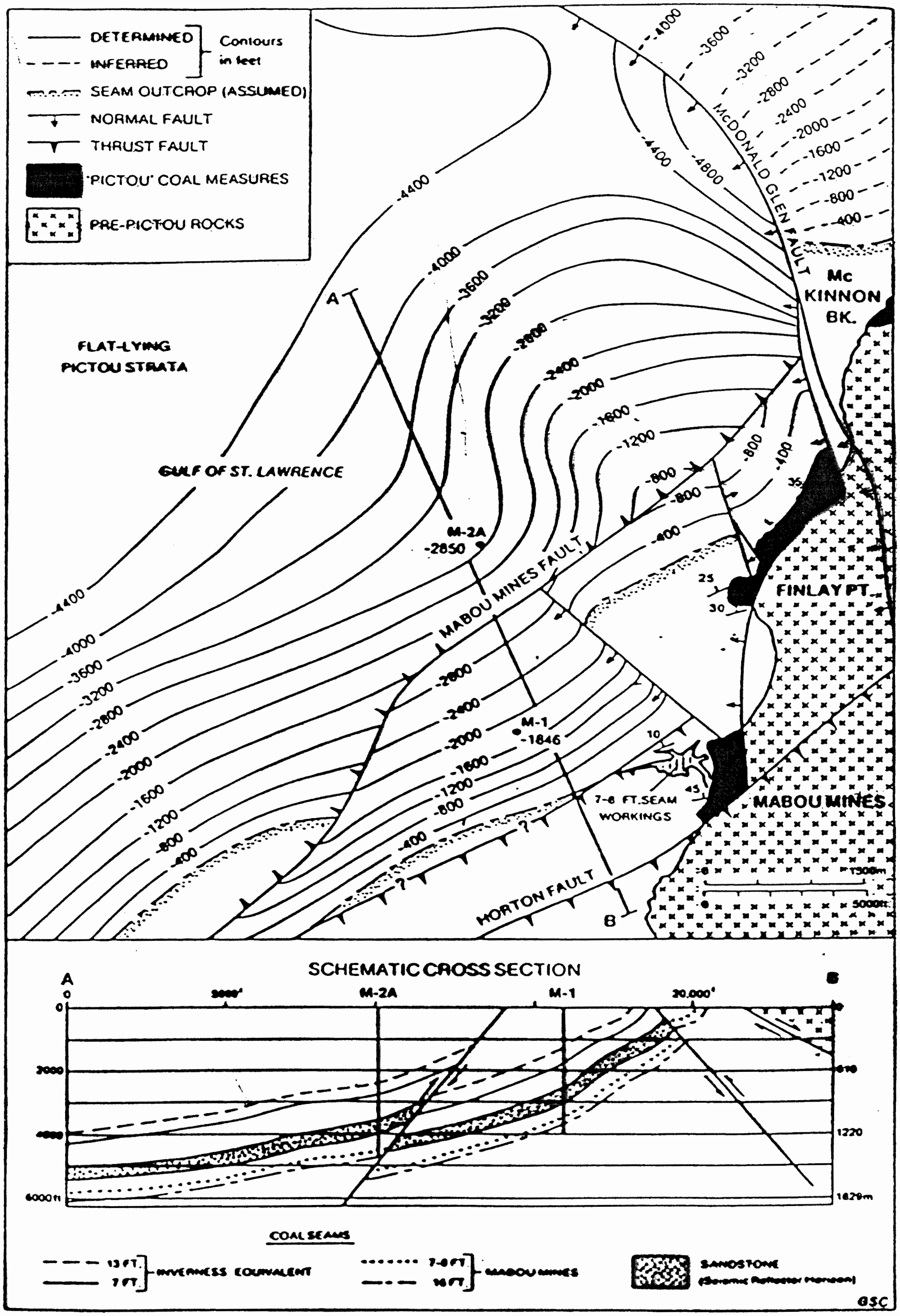


Figure 4 Structure of a Portion of St. Lawrence Basin (After Hacquebard, in press.)

The Pictou strata underlying the Gulf of St. Lawrence have also been explored for oil and gas. Potential hydrocarbon source rocks include the Pictou coal seams and dispersed organic matter as well as the underlying Windsor and Horton Groups. Gas shows and oil stains have led to testing for production but reservoir quality is poor, depending on good local porosity (Howie and Barss, 1974).

Chapter 2 Methods

2.1 Field Work

Field work at Finlay Point was carried out on three separate occasions in 1985. From April 24-27 a three-day reconnaissance of some of the shore exposure in Inverness County was completed. After a suitable study area was located, the cliff section was observed at close range, and sketches and photographs were taken. Samples were taken and a systematic survey of the exposure was initiated at this time. On August 10-11, another two days of field work included paleocurrent measurements, collection of rock samples, and a continuation of the description of the sedimentary sequence. A final day of field work was conducted on October 4, and the upper limit of safe, continuous exposure was reached.

Ten thin sections were cut from the hand samples and six samples were prepared for X-ray diffraction and were used in conjuction with the field notes for a petrographic description. Photographs and sketches were used to determine some lateral facies relationships to supplement the data provided by the stratigraphic column.

2.2 X-Ray Diffraction Technique

Samples prepared for X-ray diffraction were first crushed to silt-clay size with a mortar and pestle. This fine-grained material was then mounted on a smear slide using acetone. Using a Phillips X-ray Diffractometer located at the Dalhousie University Department of Geology, the sample was then irradiated with nickel filtered Cu-K alpha radiation generated by a source driven at 40kV and 20mA. A time constant of 4 seconds was used and traces of diffracted x-rays were recorded at 1 cm/min. The samples were run from 2^{o} to 50^{o}.

Diagnostic peaks of minerals were then compared to the traces produced to determine the minerals present in the sample. Relative intensity of the diagnostic peaks as produced by the irradiated sample was then used to estimate the relative abundance of the major mineral constituents.

2.3 Thin Section Examination

A total of ten thin sections from seven facies were prepared for examination from hand samples collected at Finlay Point. After the thin sections were cut and covered, they were examined under a Ziess binocular petrographic microscope. Using criteria such as the amount of matrix and the relative abundance of quartz, feldspar and lithic fragments the rocks were classified using the method described by Pettijohn et. al. (1970). Thin sections were also examined for composition and abundance of framework matrix and cement, texture, alteration and petrogenesis.

Thin section of siderite nodules were also examined from facies Fm, Gm and Sr by a similar method to describe the petrography of these nodules.

Chapter 3 Facies Description and Petrography

3.10 Facies Description

3.11 Introduction

The term "facies" has been used in several contexts but in general it links rocks of similar origin (Walker, 1984). For the study of fluvial deposits in the field it is necessary to define rock type based on lithological, structural and organic aspects detectable in the field particularly in complex fluvial sandstone units (Walker, 1984). The facies description combines the observation of internal features and spatial relationships. This description is then compared with facies developed in modern fluvial environments to interpret the environment of deposition. The relationships of these environments will then be interpreted and compared with a fluvial model including a modern analogue.

Miall (1978) defines 21 principal lithofacies for fluvial-dominated deposits as shown in Table 2. Eight facies types were described at Finlay Point based on Miall's classification. This systematic approach is necessary to provide for comparison between separate fluvial deposits. This approach must take into account that similar facies associations and sedimentary structures can be developed in different parts of the fluvial environment.

3.12 Massive Gravel (Gm)

This facies is a massive matrix-supported conglomerate of variable thickness and lateral extent. Clasts are composed of plant material, siderite nodules of various sizes and coal as angular blocks and gravel-sized pieces. Lithic fragments are composed of both metamorphic rocks and mudstone. Matrix

Table 2 Lithofacies and sedimentary structures of fluvial deposits (from Miall, 1978a).

Facies Code	Lithofacies	Sedimentary structures	Interpretation
Gms	massive, matrix supported gravel	none	debris flow deposits
Gm	massive or crudely bedded gravel	horizontal bedding, imbrication	longitudinal bars, lag deposits, sieve deposits
Gt	gravel, stratified	trough crossbeds	minor channel fills
Gp	gravel, stratified	planar crossbeds	linguoid bars or deltaic growths from older bar remnants
St	sand, medium to v. coarse, may be pebbly	solitary (theta) or grouped (pi) trough crossbeds	dunes (lower flow regime)
Sp	sand, medium to v. coarse, may be pebbly	solitary (alpha) or grouped (omikron) planar crossbeds	linguoid, transverse bars, sand waves (lower flow regime)
Sr	sand, very fine to coarse	ripple marks of all types	ripples (lower flow regime)
Sh	sand, very fine to very coarse, may be pebbly	horizontal lamination, parting or streaming lineation	planar bed flow (l. and u. flow regime)
Sl	sand, fine	low angle (<10°) crossbeds	scour fills, crevasse splays, antidunes
Se	erosional scours with intraclasts	crude crossbedding	scour fills
Ss	sand, fine to coarse, may be pebbly	broad, shallow scours including eta cross-stratification	scour fills
Sse, She, Spe	sand	analogous to *Ss, Sh, Sp*	eolian deposits
Fl	sand, silt, mud	fine lamination, very small ripples	overbank or waning flood deposits
Fsc	silt, mud	laminated to massive	backswamp deposits
Fcf	mud	massive, with freshwater molluscs	backswamp pond deposits
Fm	mud, silt	massive, desiccation cracks	overbank or drape deposits
Fr	silt, mud	rootlets	seatearth
C	coal, carbonaceous mud	plants, mud films	swamp deposits
P	carbonate	pedogenic features	soil

composition is variable but quartz predominates with other grains composed of chert, perthite, muscovite, siderite, plagioclase, microcline, and chlorite. Grains are subrounded to angular with the majority being subangular. Thickness was extremely variable among units, ranging from 0.1-1.5m, and any individual unit usually displayed a lateral variation in thickness. This facies always overlies an erosional contact of an irregular nature.

Interpretation Facies Gm is associated with lag deposits and longitudinal bars and is interpreted as deposited under conditions of very high flow rate. Transport of this coarse material is by rolling and saltation.

3.13 Massive Sandstone (Sm)

This facies has a variable thickness with units ranging from 0.5 to 5m, and some lateral thickness variation was observed. Coal clasts, plant debris and both gradational and erosional bases are present. Although no stratifcation was observed convoluted lamination and large scour-and-fill structures are common. Grain size is variable, from silt to very coarse sand. This was the most abundant facies observed at Finlay Point accounting for 47% of the Point and Finlay sandstones total thickness.

Interpretation The massive, structureless texture of this facies is interpreted to be the result of rapid sedimentation and dewatering of sediment's prior lithification. . Rapid deposition would account for the poor sorting observed and inhibit the development of well defined sedimentary structures. Subsequent dewatering of the poorly packed sediments could have destroyed any sedimentary structures and could have produced the convoluted laminations observed in this facies. Rapid sedimentation would increase the chance of preservation and account for the occurrence of coal clasts in this facies (Cant, 1978). (See Table 4.)

3.14 Planar Crossbedded Sandstone (Sp)

The thickness of the individual units of this facies type range from 0.5 to 2 metres. Planar crossbed sets up to 0.5 metres thick as well as plant material, coal clasts, sour and fill structures and some ripple masks were observed in this facies. Gradational contacts and lateral thickness variations were also noted in some units.

Interpretation: Setsof planar crossbeds are associated with the slip facies of sand bars and sand waves forming on the down current margin (Cant and Walker, 1976).

3.15 Trough Crossbedded Sandstone (St)

This facies occurs in units 1 to 2m thick and contains troughs of various sizes. Troughs are up to 0.5 m wide and 0.2 m thick with groups of troughs up to 1 m thick. Grain size varies from medium to very coarse sand. Plant debris is also present in this facies.

Interpretation: This facies is interpreted as being deposited by the aggradatoin of channel dunes migrating down current.

3.16 Horizontal Laminated Sandstone (Sh)

Laminations in this facies are parallel or at low angles to bedding surfaces. Thickness ranges from 0.2 to 4 m and varies considerably within individual units. Bipolar paleocurrent measurements were determined from primary current lineation exposed on bedding surfaces. Plant debris, convoluted lamination, and fining-upward of grain size were observed in addition to carbonate nodules.

Interpretation: Fast, shallow flow conditions are interpreted as the hydraulic regime which produce these laminae with primary current lineations as a result of planar bed flow. (Miall, 1981)

3.17 Rippled Sandstone (Sr)

Both small-scale planar and trough cross-beds are found in abundance in this facies derived from the preservation of two and three-dimensional ripples. This facies also contains erosional bases, siderite nodules, mudstone pebbles, convoluted bedding and dessication cracks. Unipolar paleocurrent measurements were obtained from the intersection of trough cross-beds and bipolar paleocurrent measurements were obtained from toolmarks preserved on bedding surfaces. Thickness of these units varied from 0.5 to 3 m and grain size ranged from silt to medium sand.

Interpretation: Rippled sandstone is interpreted as the result of deposition in lower flow regime by two and three dimensional ripples.

3.18 Grey Shale (Fm)

This facies is encountered throughout the exposure at Finlay Point. It is most significant in the Five-foot shale member and there constitutes almost 60% of the aggregate thickness. The predominant colour of this facies is light grey with occasional areas of orange (Fe) stains. The units vary in thickness from 0.2 to 6 metres and are soft and friable. Some rootlets are visible and concoidal weathering indicates that the massive texture is probably the result of bioturbation. Some rootlets are encased in tubes of siderite and nodules are abundant within most of the indivdual units of the facies. The petrography of these siderite nodules is dealt with in a later section of this chapter. Also present are plant debris and rippled sandstone interbeds. The grey shale units also have basal contacts on silty to very fine sandstone and all coal seams rest on grey shale. The units also show lateral thickness variation.

Interpretation: Fine grained sediments of this type have been interpreted as overbank deposits and seat-earths. Shales of this type are deposited in quiet waters and accrete vertically.

3.19 Coal and Black Shale (C)

Coal Seams

The thickness of the 3 seams exposed at Finlay Point varies from 0.5 to 2 metres as represented in the graphic log (at 9, 14 and 55 m). Keating (1950) reports that Macdonald Coal Mines Ltd. mined the Five-foot seam at Finlay Point in 1949. This accounts for the disturbed condition of the seam. The mine records from this operation report that the seam thins to zero thickness in the east and obtain a thickness of 1·95m (6'2") to the west over a distance of 0·5km indicating the erratic nature of the seam. This coal is of high volatile bituminous "C" rank and has vitrinite reflectance values in the range of 0.58-0.62 (±0.05) (Avery, 1985).

The coal seams at Finlay Point are underlain by grey shale and have gradational basal contacts. Black shale is interbedded in the coal seams with a thickness of 2 to 20 centimetres. Discrete bands of coal are up to 0.5 metres thick and contain abundant disseminated pyrite. The petrography of the coals at Mabou Mines is the subject of several reports (Avery, 1985; Douglas, 1944; Hacquebard, 1956, in press; Norman, 1935) and some of the data from these reports are summarized in Table 3. The coal seams are overlain by rippled sandstone and massive gravel with abrupt contacts.

Hacquebard (1956) correlated the 17 metres of coal and shale containing the Five-foot seam with the Fifteen-foot shale member at Coal-mine Point with a thickness of 70 m. This suggests a great deal of lateral variability in these units.

Seam	Moisture %	Volatiles %	Fixed Carbon %	Ash %	Sulphur %	Calorific Btu Value per lb.
(1) Two-Foot	7.8	35.3	53.8	10.9	4.4	11,640
(2) Five-Foot	2.9	36.7	51.1	12.2	5.2	Not Given

Table 3 Coal Analysis (Douglas, 1944)

Coal Clasts

Lenses of normal banded coal were found associated with conglomerate, massive crossbedded and trough crossbedded sandstone as summarized in Table 4. The size of the blocks ranged from 0.3 and 1.5 metres to 0.05 and 0.2 metres as exposed in cliff section. Smaller clasts are randomly orientated but clasts larger than about 0.25 metres long are subparallel to bedding surfaces. Most coal clasts are associated with erosional surfaces and occur within one metre of these erosional surfaces. A few coal clasts were observed as much as five metres above an erosional surface.

Table 4 Coal Clast Occurrences

Facies	Total	%
Sm	4	44
Gm	2	22
St	1	11
Sp	1	11
Sr	1	11
Total	9	99%

Interpretation: Swampy low-lying areas permit the development and accumulation of peat deposits. Black shale possibly represents periods when the water table was lowered and peat did not accumulate.

3.20 Petrographic Data

3.21 Sandstone

Five thin sections from four of the sandstone facies and two thin sections of the massive gravel facies were subjected to petrographic examination (see Appendix II). Based on the classification system of Pettijohn et. al. (1972) the sandstones at Finlay Point may be described as lithic arenites or lithic wackes depending on the amount of matrix observed (Figure 5).

Grain composition is primarily quartz, ranging from 40 to 65 percent of the sample. Quartz grains were mainly monocrystalline with undulose extinction (up to 10^{o}). A few polycrystalline grains were observed and these exhibited sutured crystal boundaries. Elongate quartz grains are abundant in some of the thin sections.

Lithic fragments are also abundant composing 15-30 of the samples. These are about equally divided between metamorphic rock fragments (MRF) and sedimentary rock fragments (SRF). Some SRF were deformed by harder grains indenting their margins. These SRF are composed of pale brown mudstone and siderite and are associated with wood and coal fragments. MRF were very fine grained. Opaque grains, probably composed of organic matter, hematite and/or pyrite are common and plagiolase, microcline and orthoclase are typically abundant grains. These feldspars are partially altered to clay. Other detrital grains include chlorite, zircon, muscovite, chert and biotite.

The matrix of the sandstone ranges from 10 to 20%. This matrix is composed of clay minerals including chlorite and silt-sized quartz grains.

3.22 Grey Shale (Fm)

Three samples from this facies were subjected to x-ray diffraction to qualitatively determine the composition of the grey shale. Quartz is the predominant mineral, with kaolinite, illite and siderite present in lesser amounts. Feldspars (orthoclase and albite) are also present and in one sample chlorite was observed.

3.23 Nodules

Siderite nodules occur in several facies at Finlay Point, including Fm, Gm, Sr, and Sh. Siderite was also found in vertical tubes and the size of these siderite bodies varies from pebble to cobble size. Three thin sections were subjected to petrographic examination and three samples were subjected to x-ray diffraction.

X-ray diffraction traces indicate that siderite is the exclusive component of two of the samples with a minor amount of quartz present in the third sample. These nodules, however, revealed a more complex composition and petrography when observed in thin section.

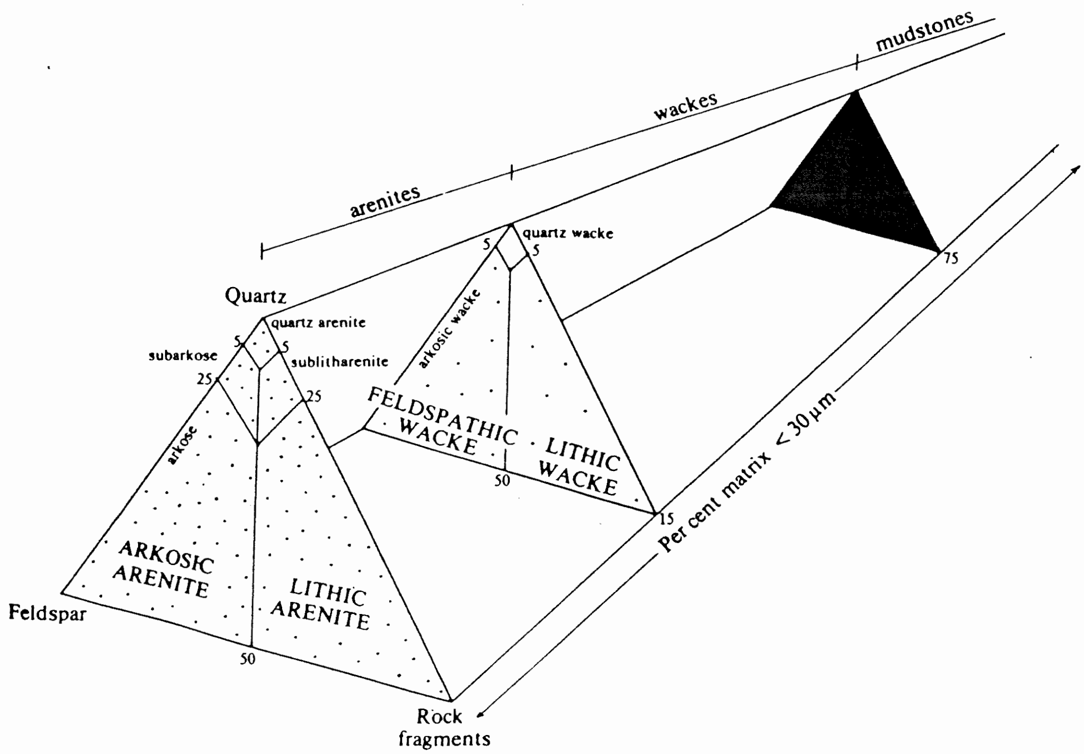


Figure 5. Sandstone Classification (after Pettijohn et. al.)

Siderite nodules were found to contain a fragment of a plant in the centre about which the nodule grew. Around this dark organic-rich centre a complex intergrowth of siderite was formed. Crystals are too small to allow careful scrutiny but towards the margin a rosette structure appears as a result of crystal intergrowth. The margin of one sample displayed a chert overgrowth. (Figure 6). Chert also infilled voids and replaced organic matter in the nodules and infilled veins, as did calcite. Opaque grains, possibly pyrite or hematite, are dispersed throughout the nodule and are associated with a dark brown stain. This structure was found best developed in the nodules associated with facies FM and may not be typical of all nodules, thus explaining the lack of secondary minerals, such as chert and calcite, observed in the x-ray diffraction traces.

In facies Sr siderite crystals displayed a rhombohedral cross-section and are concentrated around fragments of organic debris. The size of these sider -ite grains observed in cross section is about 0·1mm and no intergrowths of siderite appeared to develop. Siderite nodules were also found in facies Gm and these are believed to be intraclasts. In some cases indented margins were formed and other nodules appear to overgrow detrital grains and locally cement the conglomerate matrix. Thus a varied relationship of nodules and facies was observed by petrographic examination.

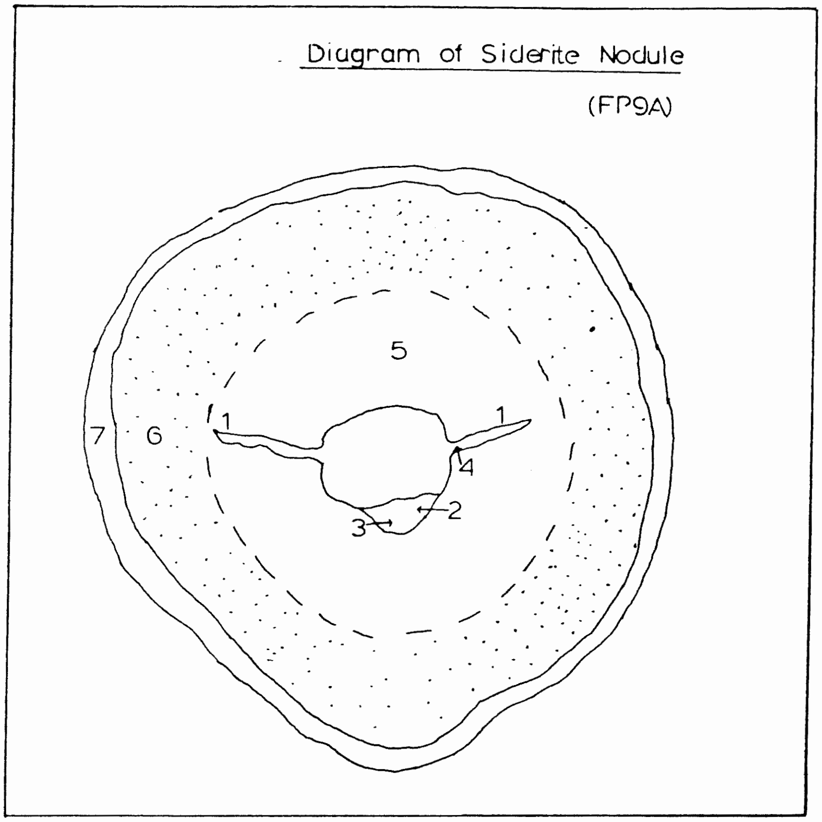


Figure 6

Key

(1) calcite lined vien

(2) **euhedral** calcite grains

(3) chert

(4) chert in vien

(5) siderite rosette intergrowth

(6) individual siderite rosettes

(7) chert fills veins and forms partial rim

opaque grains (concentrated away from nodule centre)

Chapter 4 Stratigraphic Data

4.1 Graphic Log

Introduction

A stratigraphic sequence 110 metres in thickness was recorded along the exposure at Finlay Point, beginning at the faulted base at the section. This base of the stratigraphic section is located on the south side of Finlay Point about 100 metres west of the wharf. Continuous outcrop, with only minor faulting and slumping, was logged along the south and west shores of Finlay Point (see Figure 2). A large fault and unstable coastal cliff sections prevented the continuation of the log around the north shore of Finlay Point.

The outcrop was logged from the base up in order to study the facies in the order they were deposited. Each unit, determined by observation of contacts and variation in sedimentary structure, was assigned a facies type as described in Chapter 3.

Table Summary of the Udden–Wentworth size classification for sediment grains (after Pettijohn *et al.* 1972). This grade scale is now in almost universal use amongst sedimentologists. Estimation of grain size in the field is aided by small samples of the main classes stuck on perspex.

	US Standard sieve mesh	*Millimeters*		*Phi (ϕ) units*	*Wentworth size class*
GRAVEL	*Use wire*	4096		-12	
	squares	1024		-10	boulder
		256	256	- 8	
		64	64	- 6	cobble
		16		- 4	pebble
	5	4	4	- 2	
	6	3.36		- 1.75	
	7	2.83		- 1.5	granule
	8	2.38		- 1.25	
	10	2.00	2	- 1.0	
SAND	12	1.68		- 0.75	
	14	1.41		- 0.5	very coarse sand
	16	1.19		- 0.25	
	18	1.00	1	0.0	
	20	0.84		0.25	
	25	0.71		0.5	coarse sand
	30	0.59		0.75	
	35	0.50	1/2	1.0	
	40	0.42		1.25	
	45	0.35		1.5	medium sand
	50	0.30		1.75	
	60	0.25	1/4	2.0	
	70	0.210		2.25	
	80	0.177		2.5	fine sand
	100	0.149		2.75	
	120	0.125	1/8	3.0	
	140	0.105		3.25	
	170	0.088		3.5	very fine sand
	200	0.074		3.75	
	230	0.0625	1/16	4.0	
SILT	270	0.053		4.25	
	325	0.044		4.5	coarse silt
		0.037		4.75	
		0.031	1/32	5.0	
		0.0156	1/64	6.0	medium silt
	Use	0.0078	1/128	7.0	fine silt
	pipette	0.0039	1/256	8.0	very fine silt
CLAY	*or*	0.0020		9.0	
	hydro-	0.00098		10.0	clay
	meter	0.00049		11.0	
		0.00024		12.0	
		0.00012		13.0	
		0.00006		14.0	

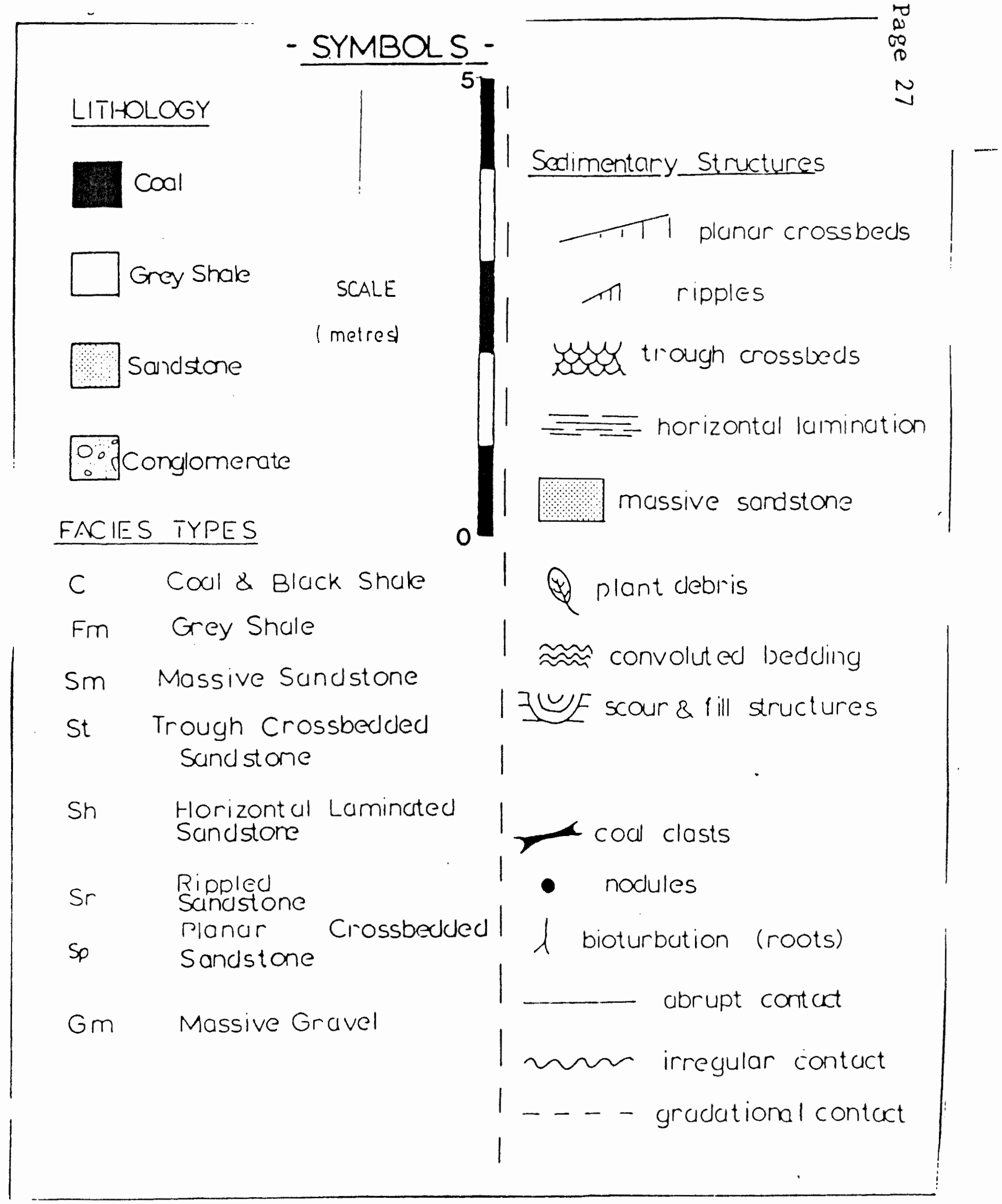
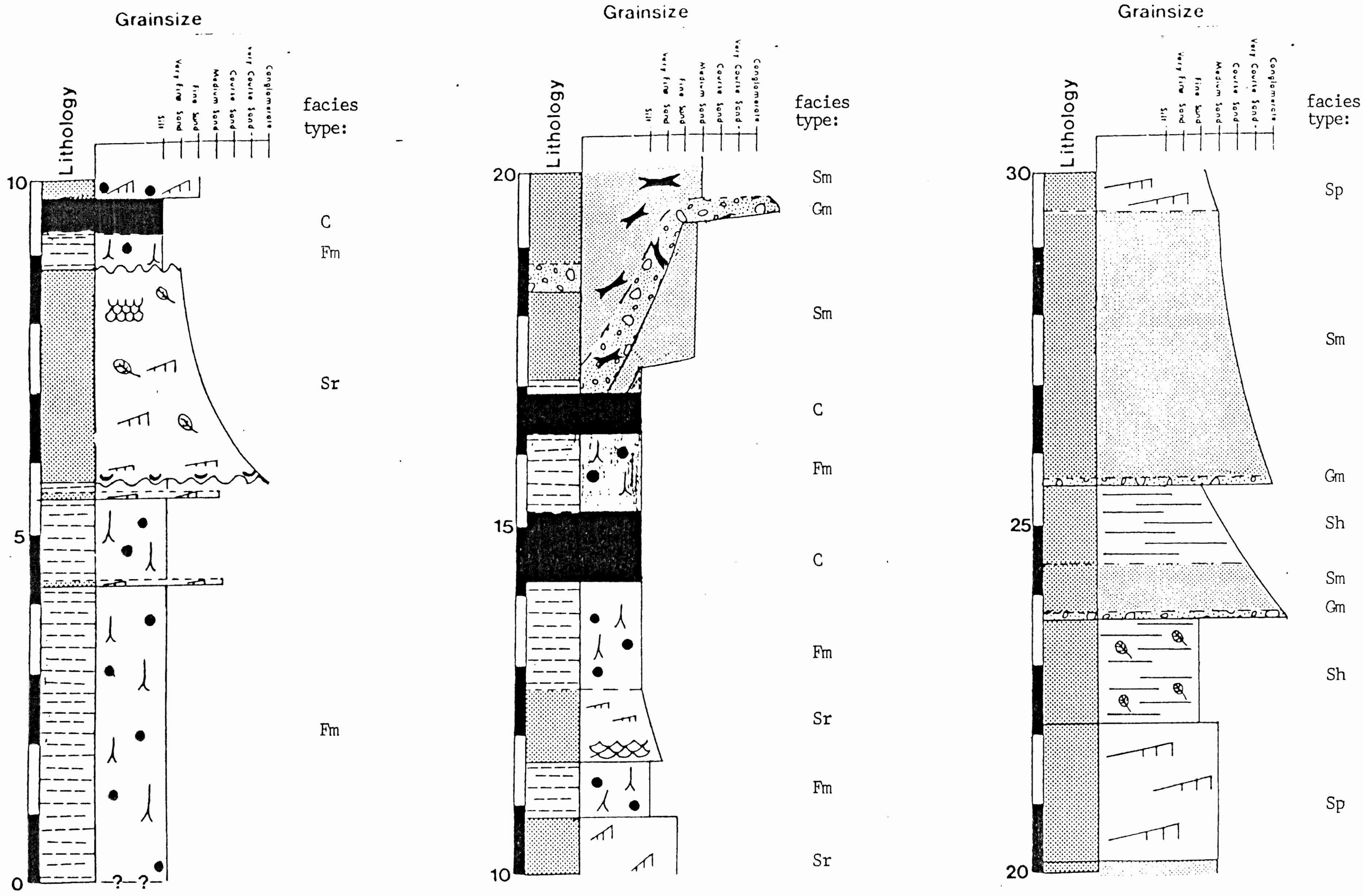
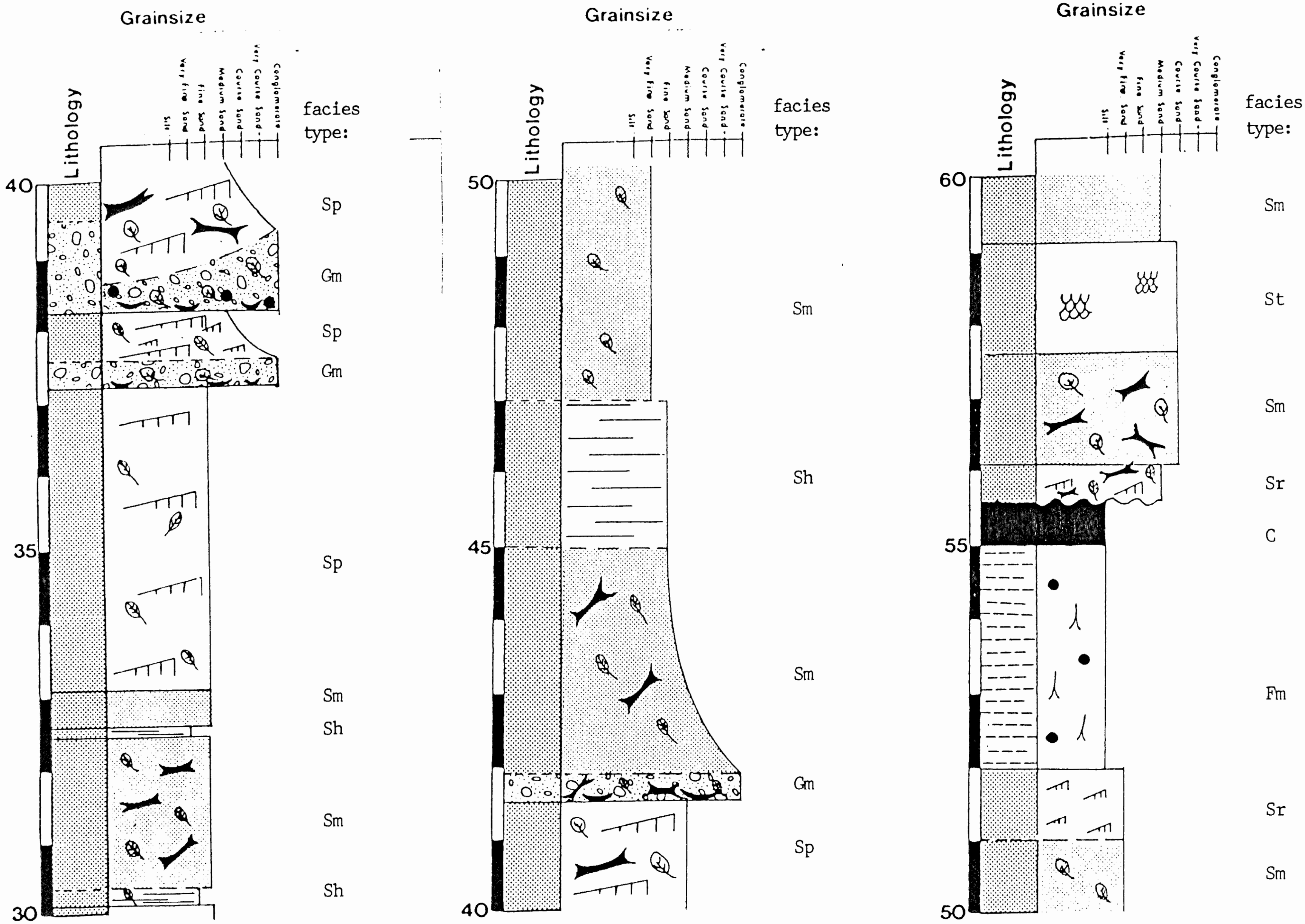
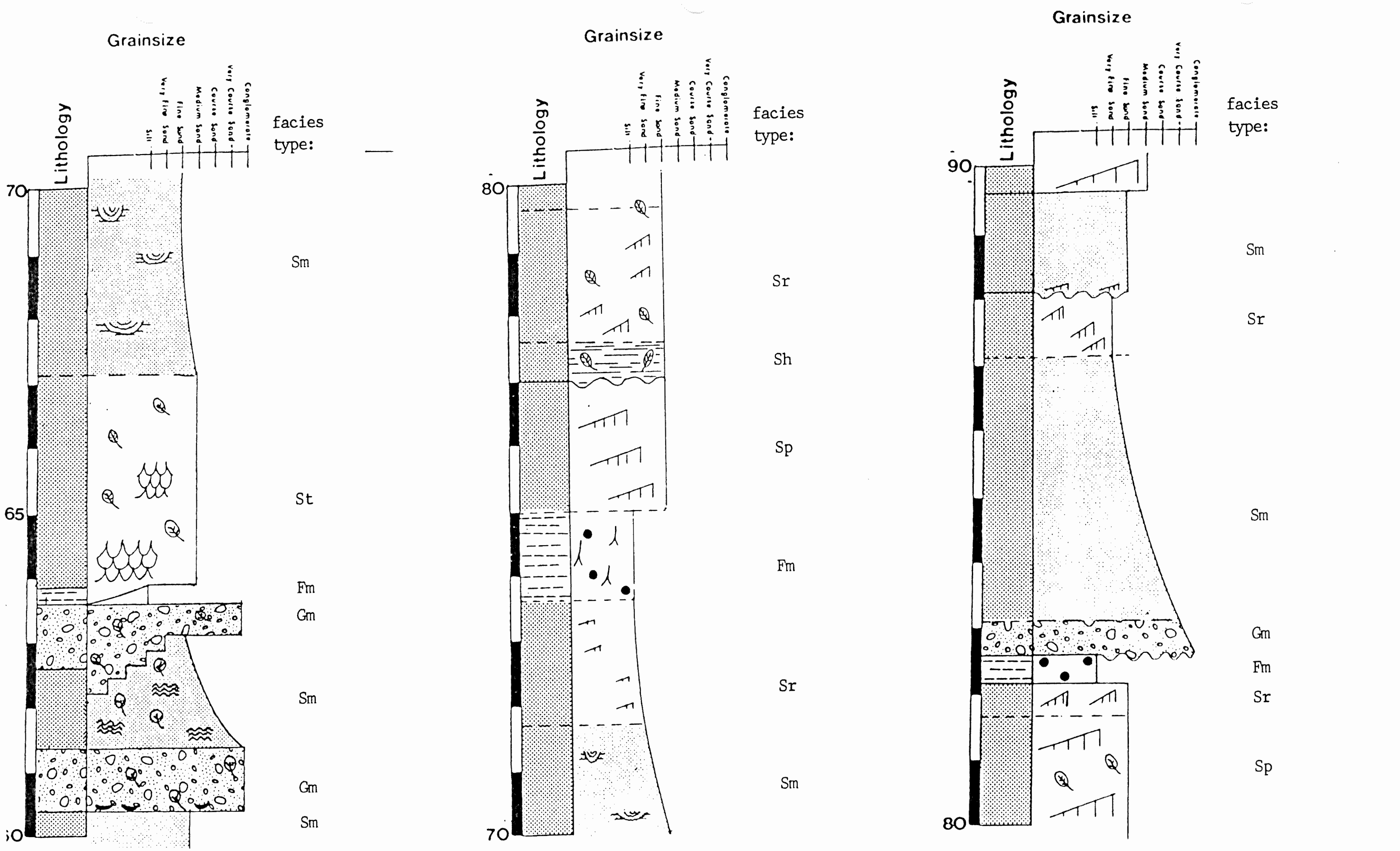


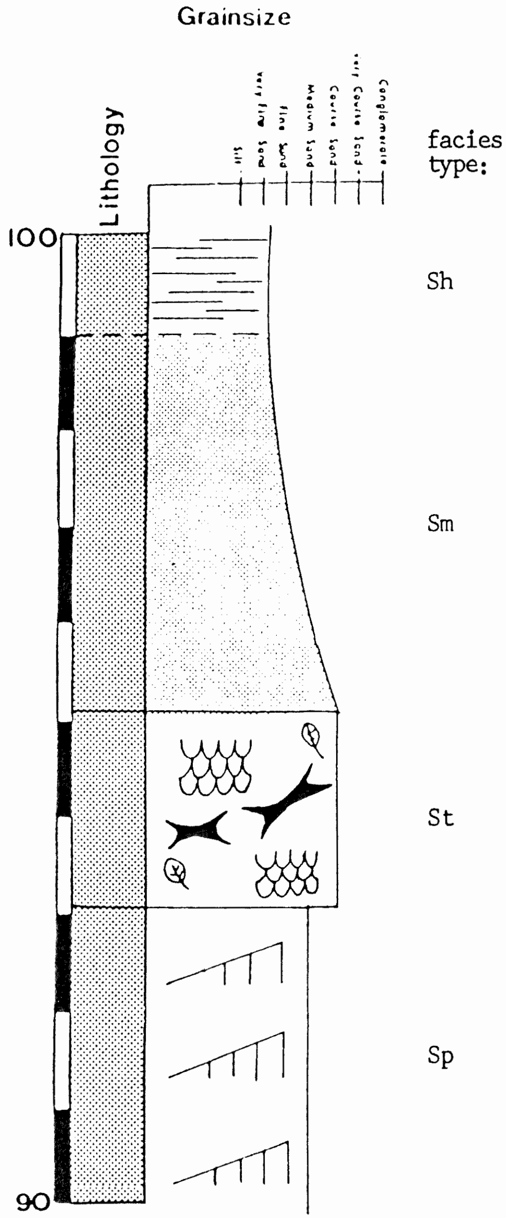
Figure 7. Key to Graphic Log and Grain Size Scale

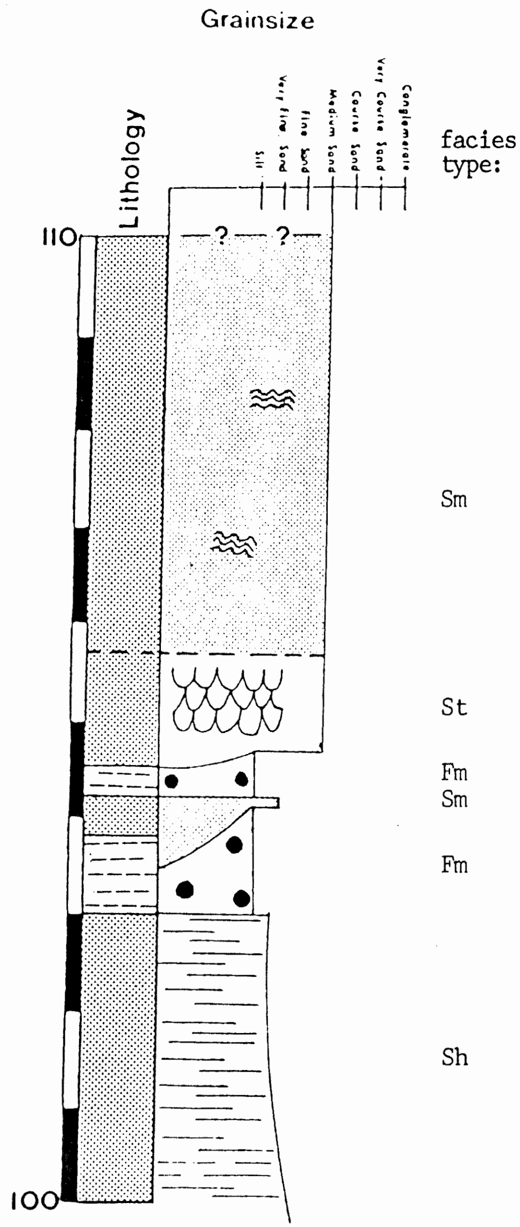

Grainsize
Lithology
Silt
Very fine sand
fine sand
Medium sand
Coarse sand
Very Coarse sand
Conglomerate
facies type:
10
5
0
C
Fm
Sr
Fm
Grainsize
Lithology
facies type:
20
15
10
Sm
Gm
Sm
C
Fm
C
Fm
Sr
Fm
Sr
Grainsize
Lithology
facies type:
30
25
20
Sp
Sm
Gm
Sh
Sm
Gm
Sh
Sp


Grainsize
Lithology
Silt
Very fine Sand
Fine Sand
Medium Sand
Coarse Sand
Very Coarse Sand
Conglomerate
facies type:
40
35
30
Sp
Gm
Sp
Gm
Sp
Sm
Sh
Sm
Sh
Grainsize
Lithology
facies type:
50
45
40
Sm
Sh
Sm
Gm
Sp
Grainsize
Lithology
facies type:
60
55
50
Sm
St
Sm
Sr
C
Fm
Sr
Sm



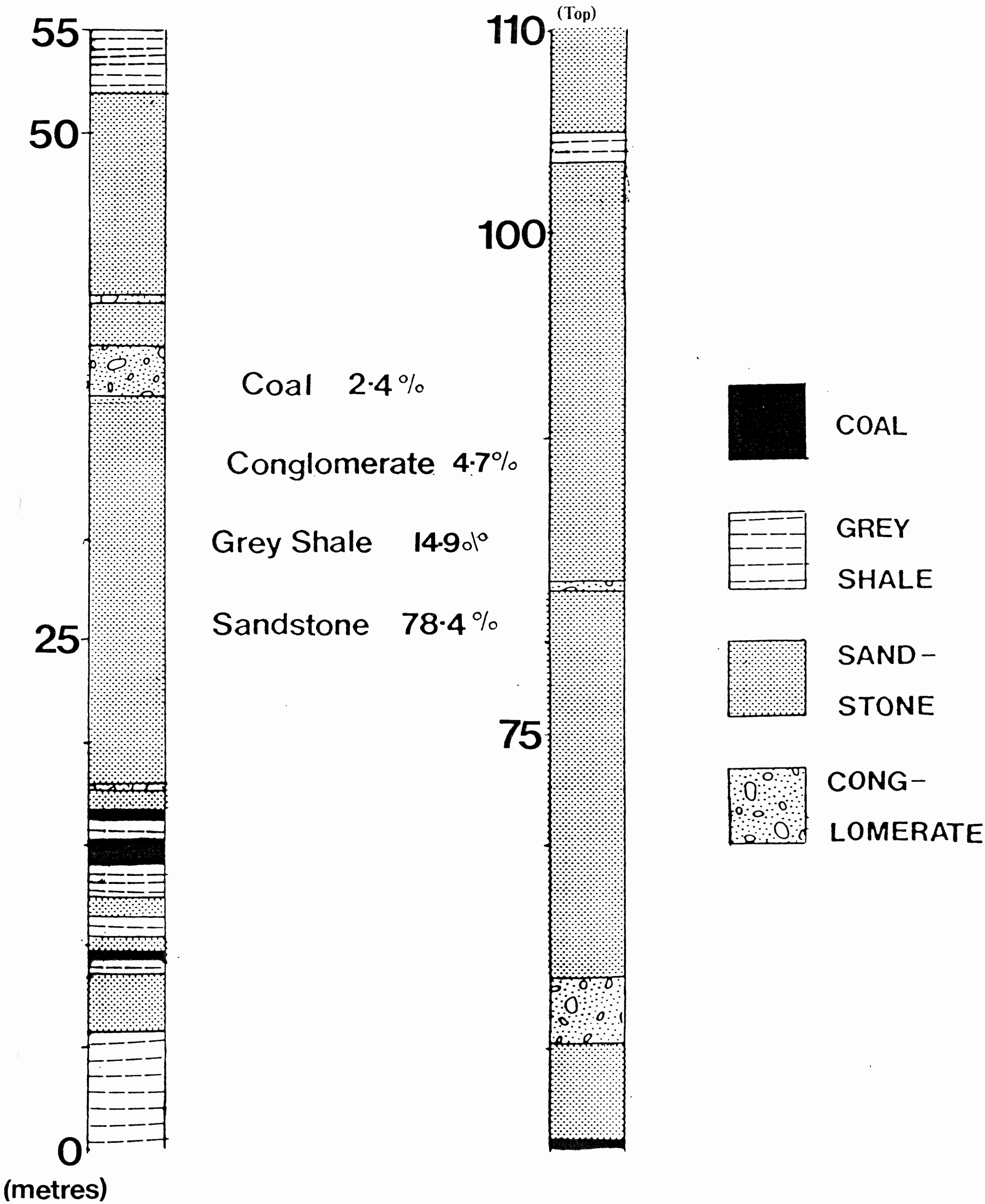
Grainsize
Lithology
facies type:
70
65
Sm
St
Fm
Gm
Sm
Gm
Sm
Grainsize
Lithology
facies type:
80
70
Sr
Sh
Sp
Fm
Sr
Sm
Grainsize
Lithology
facies type:
90
80
Sm
Sr
Sm
Gm
Fm
Sr
Sp


Grainsize
Lithology
Silt
Very fine Sand
fine Sand
Medium Sand
Coarse Sand
Very Coarse Sand
Conglomerate
facies type:
100
90
Sh
Sm
St
Sp


Grainsize
Lithology
Silt
Very fine Sand
fine Sand
Medium Sand
Coarse Sand
Very Coarse Sand
Conglomerate
facies type:
110
100
?
?
Sm
St
Fm
Sm
Fm
Sh

4.2 Lithic Log

Figure 8. LITHIC LOG



4.3 Coarse to Fine Ratio

The ratio of coarse-grained strata to fine-grained strata is a basic tool in interpretation of sedimentary environments. In the lithic log (Figure 8) it can be seen that sandstone and conglomerate account for 83% of the total thickness, whereas 17% is composed of grey shale and coal. Within the Point and Finlay sandstones 93% of the bodies are coarse-grained and only 7% are fine-grained strata. This ratio is plotted on Figure 9 and used in the interpretation of channel morphology.

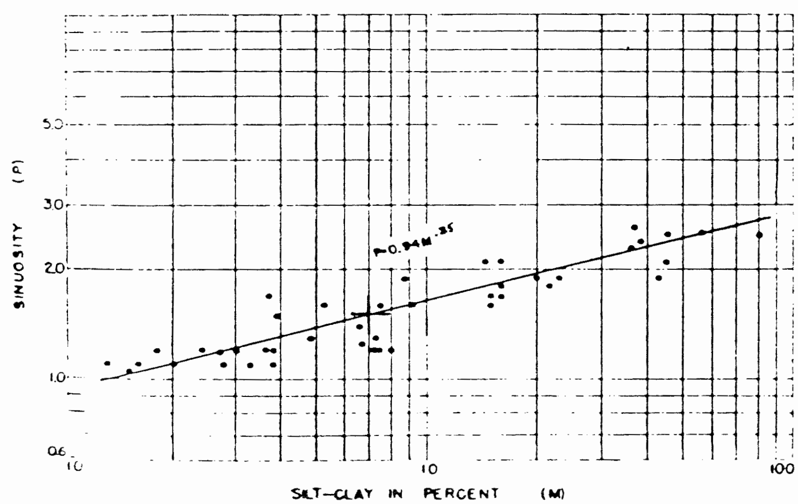


Figure 9 Coarse to Fine Ratio (Schumm, 1963)

4.4 Facies Abundance

Table 5

POINT AND FINLAY SANDSTONE BODIES FACIES	TOTAL THICKNESS (m)	NO. OF UNITS	AVERAGE THICKNESS (m)	% OF TOTAL THICKNESS
Conglomerate	5.1	9	0.5	5.5%
Massive Sandstone	43.2	17	2.5	46.8%
Trough Crossbedded Sandstone	8.2	3	2.7	8.9%
Planar Crossbedded Sandstone	12.8	8	1.6	13.9%
Rippled Sandstone	6.9	6	0.9	7.5%
Horizontal Laminated Sandstone	9.6	7	1.4	10.4%
Grey Shale	6.2	6	1.0	6.7%
Coal	0.6	1	0.6	0.6%
Total	92.4m	58	1.6m	100.3%

FIVE-FOOT SHALE MEMBER	TOTAL THICKNESS (m)	NO. OF UNITS	AVERAGE THICKNESS (m)	% OF TOTAL THICKNESS
Grey Shale	10.1	6	1.7	59.0%
Rippled Sandstone	5.0	3	1.7	29.2%
Coal	2.1	3	0.7	11.7%
Total	17.2m	12	1.4m	99.9%

4.5 Markov Chain Analysis

4.51 Introduction

A Markov process is defined as one in which the probability of the process being at a given state at a particular time may be deduced from the knowledge of the immediately preceding state (Miall, 1973). Many sedimentary environments develop a definite vertical relationship between facies. These cyclic sequences may be preserved and recorded in the outcrop. Other cyclic events such as seasonal climatic changes are superimposed on the sedimentary cycles, creating a complex vertical sequence. Markov chain analysis provides a statistical technique for testing the vertical transitions recorded in the outcrop on a statistical basis.

The facies described previously were used to compile a facies transition count from the stratigraphic base to the top of the outcrop (see Appendix I). This transition count was then converted to a matrix, the Transition Count Matrix (Table 6). Each element in the matrix (fij) is the actual transition from state i to j. Transitions from a particular facies to the same facies are not counted and a run of zeros is recorded where i=j.

From the total number of transitions and the proportion of states a theoretical value for the transitions from state i to j was compiled. This is displayed in the Independent Trials Probability Matrix (Table 8). The Transition Probability Matrix (Table 8) is derived from the actual transitions observed and the frequency of each state. This matrix indicates the observed transition from one facies to another based on the total number of transitions from the first facies.

The Difference Matrix (Table 9) is obtained by subtracting the observed value from the predicted value. Differences greater than +0.1 were interpreted as significantly more frequent transitions than totally random processes would produce. Using these data a Markov Chain Diagram was constructed. This represents a summary of the significant transitions (D.J. Cant, 1978). The facies were arranged in a general fining upward sequence and a fair degree of correlation was found.

This indicates that there is a fining-upward trend expressed in the outcrop , but that it is complex and probably a result of both cyclic and random processes interacting. In general it can be observed that there is a crude vertical cyclicity in the sequence, particularly in the finer grained facies such as Fm, C, and Sr.

Some sedimentologists have criticized the Markov Analysis Method because it represents a single vertical sequence and ignores spatial relationship. Use of this technique in the study of Finlay Point is justified by the nature of the exposure. While some variation along strike was noted only limited lateral exposure was available for close and safe examination. Lateral variations were noted wherever possible, but exposure within reach of the geologist limited data to the generation of a single column ,

4.52 Formula and Sample Equation

1) Independent Trials Probability Matrix (r_{ij})

Each element in the matrix

$$r_{ij} = \frac{s_j}{t - s_i)}$$

s_j = column sum

s_i = row sum

t = total transitions

Example For the transition from the large-scale crossbedded sandstone (3) to the planar-laminated sandstone facies (5).

From Transition Count Matrix: $s_j = 8$, $s_i = 9$, $t = 69$

$$r_{3,5} = \frac{8}{(69-9)} = .13$$

2) Transition Probability Matrix (p_{ij})

$$p_{ij} = \frac{f_{ij}}{s_i}$$

for transitions from facies 3 to 5

$$p_{3,5} = \frac{3}{9} = 0.33$$

3) Difference Matrix (d_{ij})

$d_{ij} = p_{ij} - r_{ij}$ for transitions from facies 30 to 5

$$d_{3,5} = 0.33 - 0.14 = 0.19$$

4.53 Markov Matrices

Table 6 TRANSITION COUNT MATRIX (f_{ij})

Facies	Gm	Sr	Sp	St	Sh	Fm	Sr	C	Row Sum
Gm	0	6	1	0	0	1	0	0	8
Sm	2	0	5	0	4	1	3	0	15
Sp	3	1	0	1	3	1	1	0	9
St	0	5	0	0	0	1	0	0	6
Sh	3	3	1	0	0	1	1	0	9
Fm	1	1	0	2	1	0	2	4	11
Sr	0	0	1	0	0	5	0	0	6
C	0	0	0	0	0	1	3	0	4
Column Sum	9	16	8	3	8	10	10	4	Total 69

Table 7 INDEPENDENT TRAILS PROBABILITY MATRIX (r_{ij})

Facies	Gm	Sm	Sp	St	Sh	Fm	Sr	C
Gm	0	.27	.13	.10	.13	.17	.12	.07
Sm	.17	0	.15	.06	.15	.19	.19	.08
Sp	.15	.27	0	.05	.14	.17	.17	.07
St	.15	.26	.13	0	.13	.16	.11	.06
Sh	.15	.27	.14	.10	0	.17	.12	.07
Fm	.16	.28	.14	.11	.14	0	.12	.07
Sr	.15	.26	.13	.10	.13	.16	0	.06
C	.14	.25	.12	.05	.12	.17	.15	.0

Table 8 TRANSITION PROBABILITY MATRIX (p_{ij})

Facies	Gm	Sm	Sp	St	Sh	Fm	Sr	C
Gm	0	.75	.12	0	0	.12	0.20	0
Sm	.13	0	.33	0	.27	.06	0	0
Sp	.33	.13	0	.11	.33	0	.11	0
St	0	.83	0	0	0	.17	0	0
Sh	.33	.33	.11	0	0	.11	.11	0
Fm	.09	.09	0	.18	.09	0	.18	.44
Sr	0	0	.17	0	0	.83	.0	0
C	0	0	0	0	0	.25	.75	0

Table 9 DIFFERENCE MATRIX (d_{ij})

Facies	Gm	Sm	Sp	St	Sh	Fm	Sr	C
Gm	0	.48	-.01	-.10	-.13	-.05	-.12	-.07
Sm	-.04	0	.18	-.06	.12	.13	.01	-.08
Sp	.18	-.16	0	.06	.19	-.17	-.06	-.07
St	-.15	.57	-.13	0	-.13	.01	-.11	-.06
Sh	.18	.06	-.03	-.10	0	-.06	-.01	-.07
Fm	.07	-.17	-.14	.07	-.08	0	.06	.37
Sr	-.15	-.26	.04	-.10	-.13	.67	0	-.06
C	-.14	-.25	-.12	-.05	-.12	.08	.60	0

4.54 Markov Chain Diagram

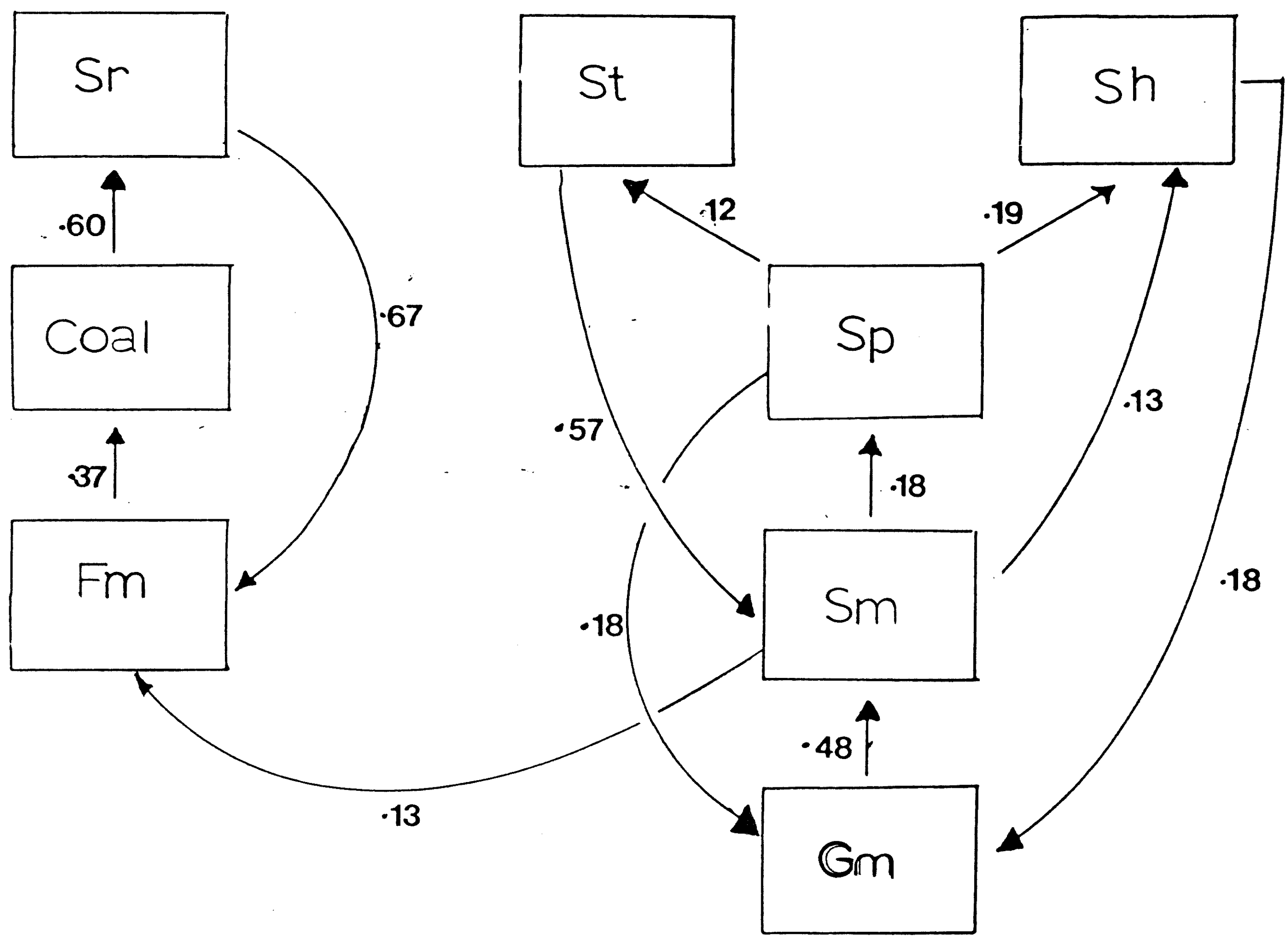


Figure 10 MARKOV CHAIN DIAGRAM

4.6 Paleocurrent Data

4.61 Introduction

Paleocurrent analysis is a valuable tool in the reconstruction of ancient sedimentary environments. Such analysis may yield information about paleoslope and the direction of sediment supply. Ancient paleoflow structures may yield information about their formation by comparison with modern analogies. Generally, poor outcrop exposure limits paleocurrent analysis rather than a lack of modern analogy.

Available paleocurrent data were recorded during field work at Finlay Point. Data came from two populations, the sandstone bodies and the shale member. From the Point and Finlay sandstones sedimentary structures include 3-D ripples intersections, 2-D rippled crests and primary current lineation. Data from the shale member included 3-D ripple intersection, tool marks and undulatory bases of sandstone units.

These randomly selected measurements were then separated on the basis of different sedimentary structure and plotted on rose diagrams. These diagrams were then compared for paleocurrent direction.

Data from the five-foot shale (Figure 11) indicate an overall paleocurrent direction of about 135° based on trends from tool marks and undulatory bases of sandstone units and azimiths from three-dimensional ripples. Dispersion is moderate at about 45°.

An overall paleocurrent trend of about 170°, based on primary current linitation and to a lesser extent data obtained from ripples, was obtained from the channel (Figure 11). Data from the three dimensional ripples indicate a trend of about 125°, but these structures are associated with low flow-rates and may be oblique to the paleoslope and may not be indicative of the major flow direction. Dispersion of this population was high, about 105°.

4.62 Paleocurrent Data

Table 10 Population 1 - Five-Foot Shale Member

Trend	Azimuth	Sedimentary Structure	Strike and Dip of Strata
130	--	Tool Mark	--
152	--	Tool Mark	--
--	136	3-D Ripple	072/38N
--	138	3-D Ripple	"
--	125	3-D Ripple	069/32N
136	--	undulatory base	046/38N
126	--	"	"
106	--	"	"

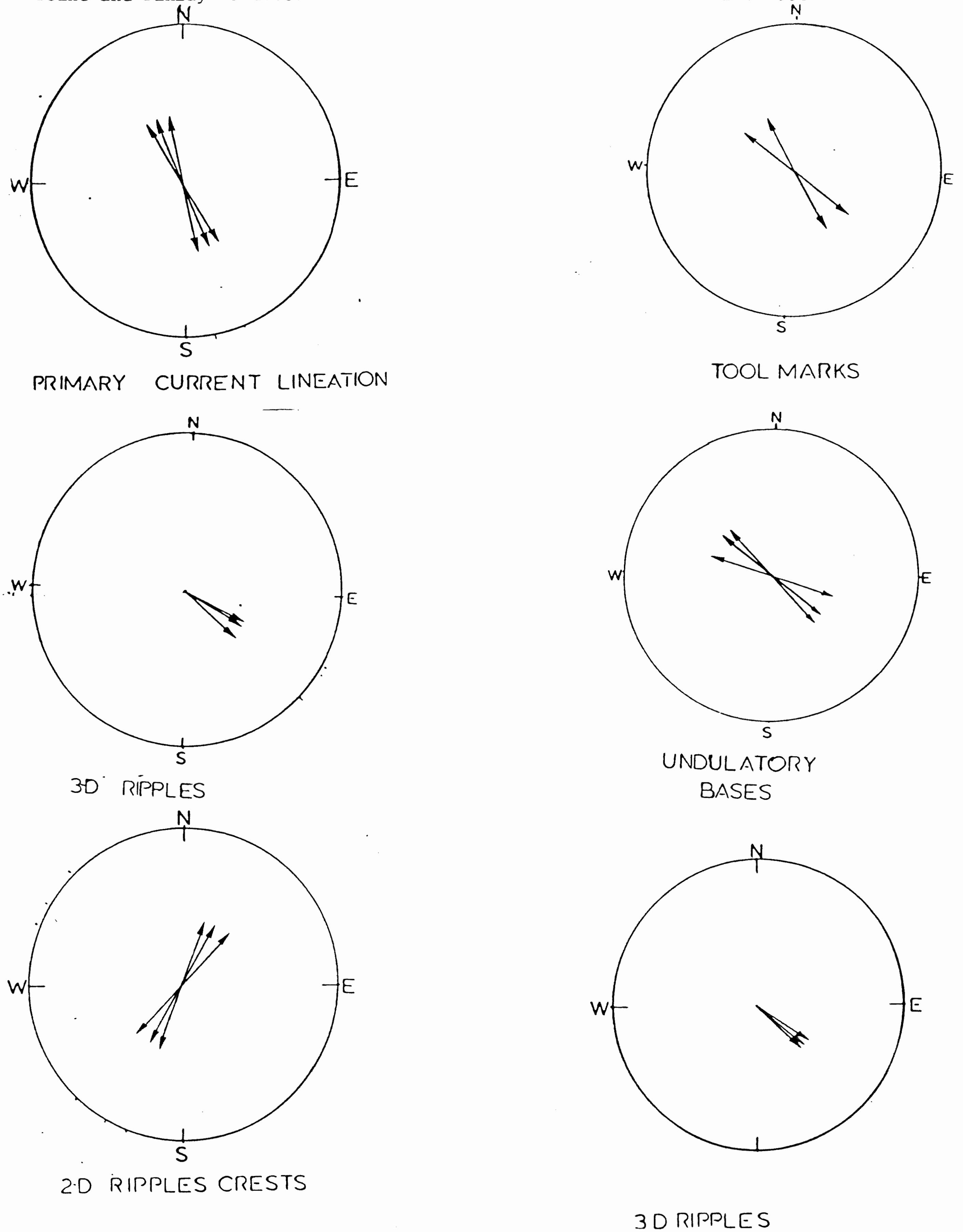
Table 11 Population 2 - Point and Finlay Sandstones

Trend	Azimuth	Sedimentary Structure	Strike and Dip of Strata
	120^{o}	3-D Ripples	046/24N
	131	"	"
200		2-D Ripple Crest	064/24N
224		"	060/21N
	117	3-D Ripple	046/21N
158		Primary Current Lineation	051/26N
202		2-D Ripple Crest	"
150		Primary Current Lineation	067/28N
170		"	063/22N

Figure 11 Paleocurrent Data

Point and Finlay Sandstones

Five-Foot Shale



4.7 Facies Interpretation

The Facies Interpretation Diagram represents a summary of the trends observed in the facies exposed at Finlay Point. From this diagram the multi-storied nature of the sandstone bodies can be observed.

The Five-foot shale member as well as the Finlay and Point sandstones can be easily recognized in the diagram. From 0 to 17 metres is the Five-foot shale member; from the erosional base of the first major sandstone body at about 17 metres to the Two-foot coal seam at 55 metres in the Finlay sandstone; and the remainder of the sequence of the Point sandstone.

Represented by the numbered arrows in the Facies Interpretation Diagram are fining-upward sequences observed in the graphic log. Three of the nine fining-upward sequences are complete, based on erosional contacts and topped with fine-grained shale and coal. The majority of the fining-upward sequences are truncated by erosional surfaces. Thickness of the fining-upward sequences varied from 2 to 20 metres. The majority of the vertical sequence is composed of sand bodies overlying a thin erosional base with a minor amount of grey shale and coal, caused by truncation of the complete sequence.

4.8 Lateral Variations

When describing an ancient fluvial system it is important to consider the lateral extent and relationship of the facies preserved. This is a particularly important criterion for identifying ancient deposits with abundant channel bar migration as predicted in the sandy braided system (Miall, 1982). A unique channel type can rarely be determined from a vertical sequence and local sedimentary pattern may be quite variable.

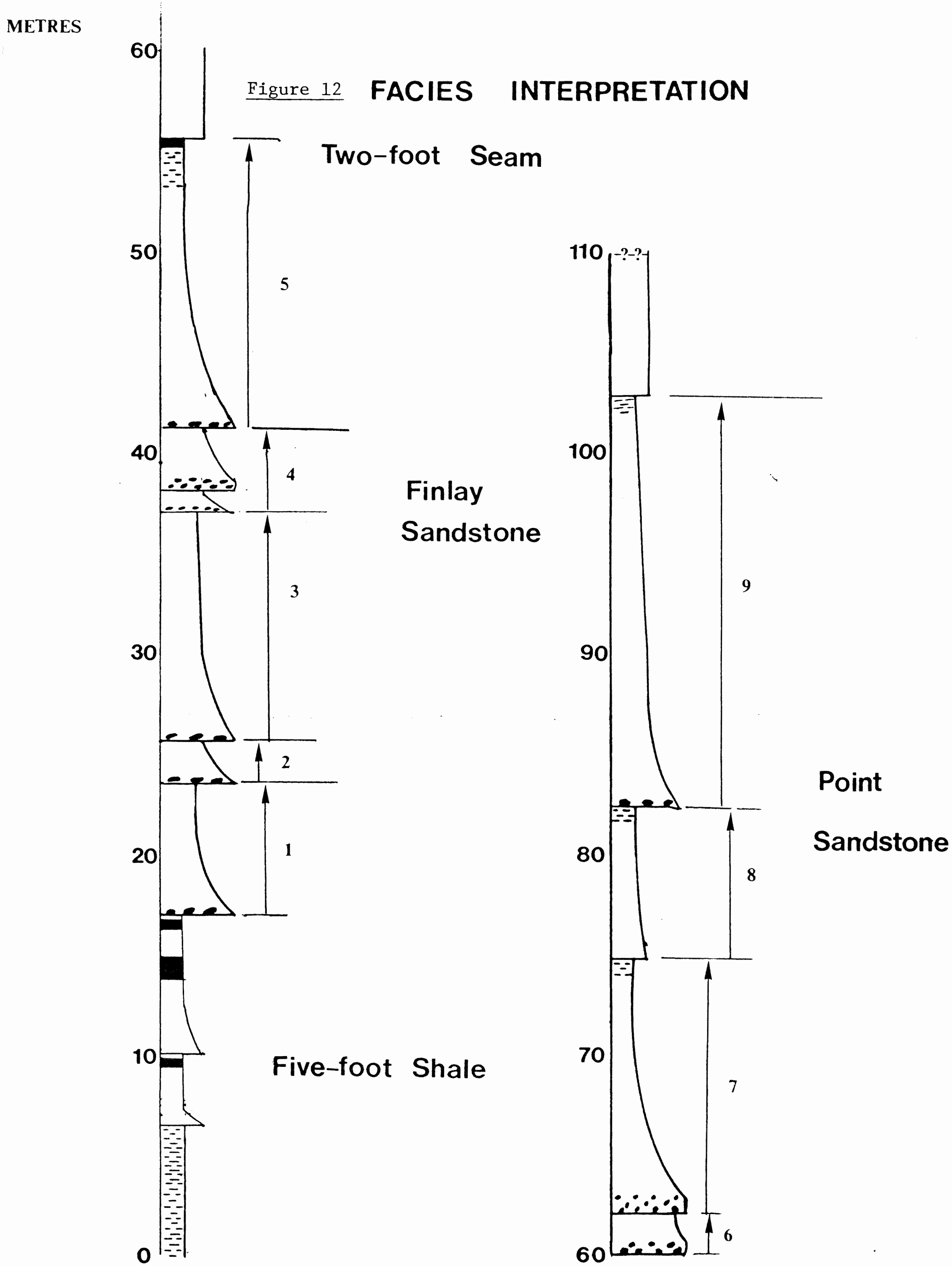


Figure 12 FACIES INTERPRETATION

One method of determining the relationship between channel bars is to study their contacts and spacial relationships. Allen (1983) developed criteria for identification and description of channel bars based on a hierarchy of bedding contacts. This approach divides sandstone bodies, such as the Point sandstones, into genetically related packages.

Allen divided his contacts into four types based on concordance and the presence of erosional surfaces. A concordant, non-erosional contact is described as the description of strata parallel to strata directly below it or laterally adjacent to it, with no intervening erosional contact. This is termed a 0th order contact. A first order contact is characterized by strata that onlap but do not erode older strata and is termed a discordant, non-erosional contact. A concordant erosional contact is a second order contact and is locally irregular but separate strata are parallel overall. Third order contacts are discordant and erosional and transect groups of strata separating them from younger beds of different dip.

These third order contacts define the limit of the sandstone body. They are generally concave up and overlain by a basal lag conglomerate facies. A third order contact is exposed at the base of the Finlay sandstone (see Graphic Log 17m). This contact extends across the entire outcrop exposure and displays a concave up nature as indicated by the pinching out down dip of the underlying facies.

In Figures 13 and 14 examples of lateral variation drawn from sketches and photographs at Finlay Point are shown. In Figure 13 a third order contact is overlain by a massive gravel unit. This unit is overlain by both planar cross-bedded and massive sandstone units. These units are bounded by discordant non-erosional surfaces or first order contacts. Above the massive sandstone is a unit of horizontal laminated sandstone is observed with a first order basal and lateral contact. This facies "pocket" is truncated by a second order (concordant erosional) contact.

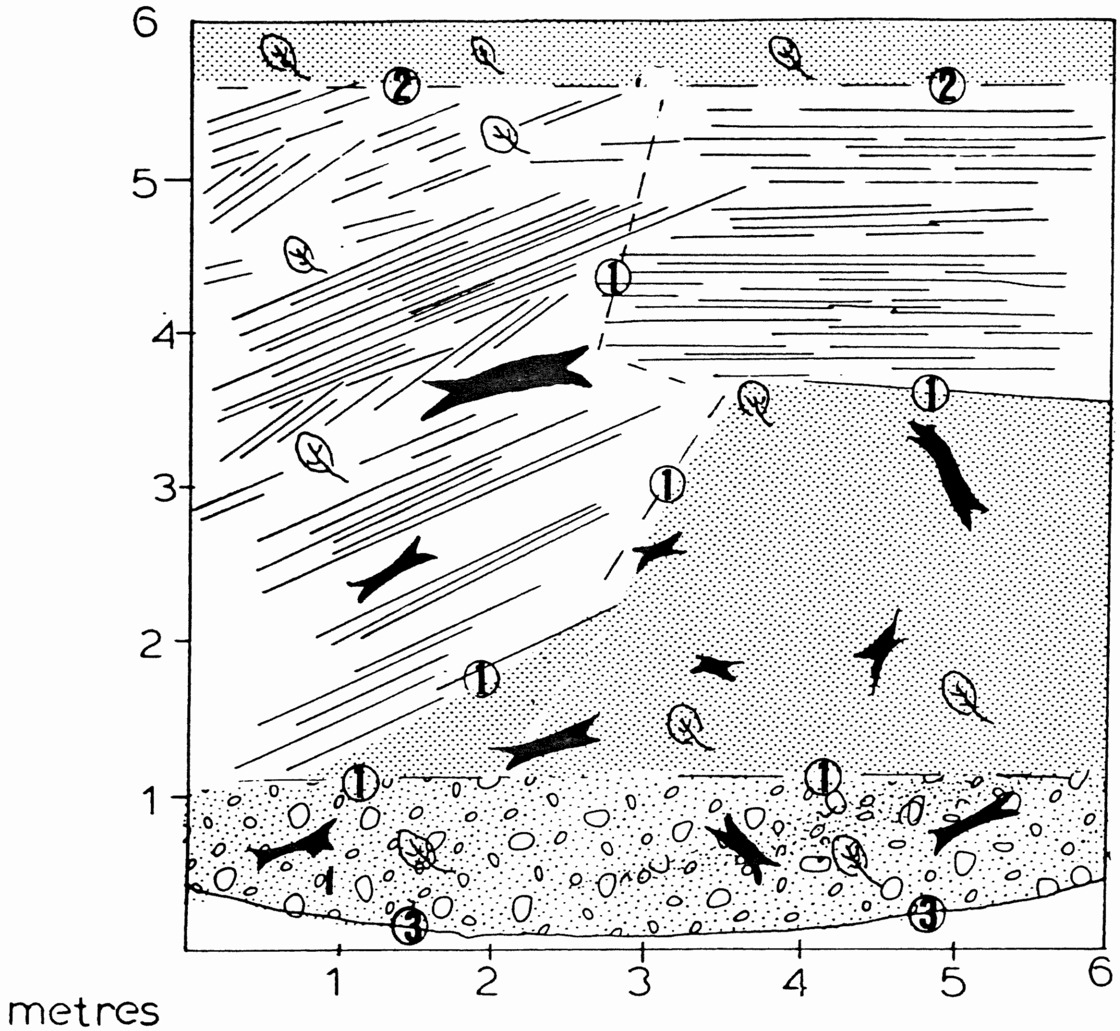


Figure 13 Lateral Facies Variations

Figure 14 represents a massive gravel unit concordantly overlain by a massive sandstone unit. This massive unit is laterally concordant with a unit of rippled sandstone. This partial facies pocket is truncated by a third order contact. This erosional surface is overlain by a massive gravel unit which grades laterally into a pebble-rich sandstone. Above both units is a unit composed of trough crossbedded sandstone with a first order basal contact is exposed. The pockets above and below the third order contact represent facies assemblages.

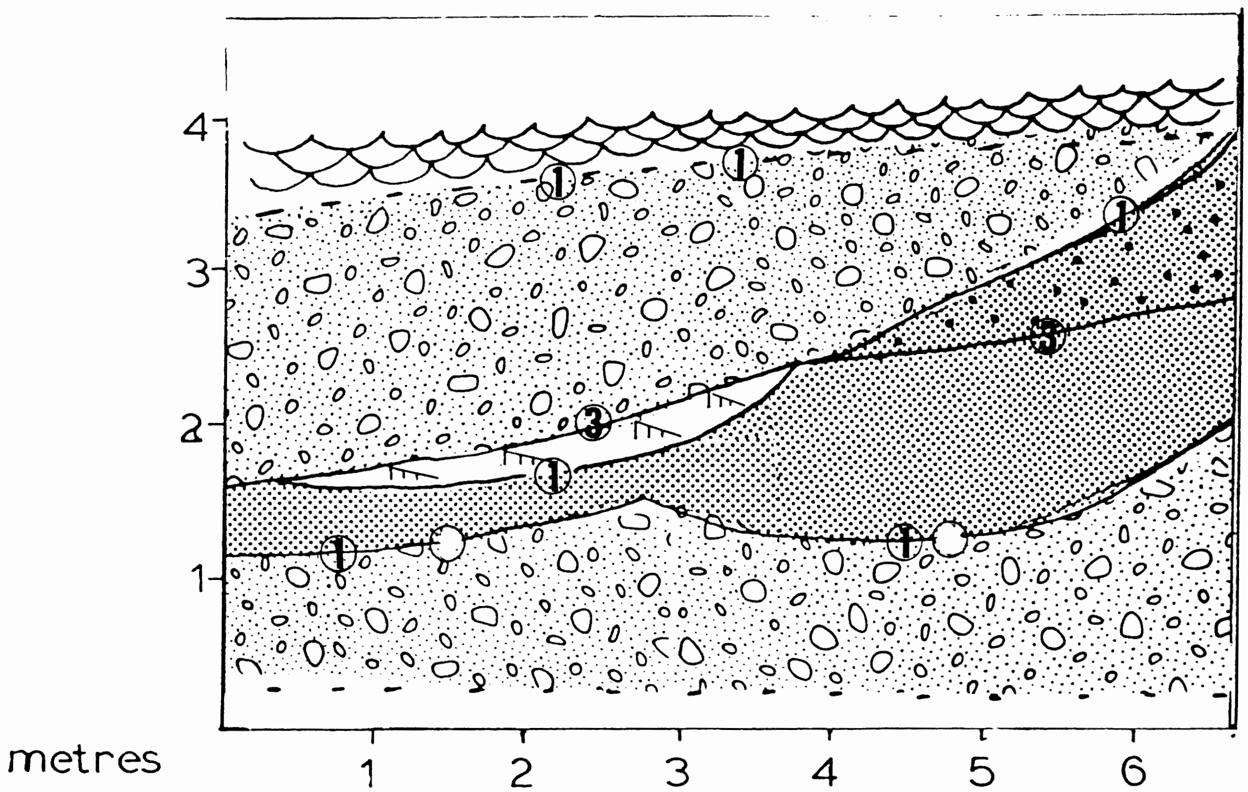


Figure 14 Lateral Facies Relationships

Chapter 5 Discussion

5.1 Fluvial Properties

The interpretation of the strata exposed at Finlay Point as fluvial depends not on a single diagnostic characteristics but on the consideration of several properties in combination. One of the most fundamental properties of terrestrial sediments is the abundance of iron oxides. These oxides impart the red colour to the strata exposed at Finlay Point. The terrestrial origin of these sediments is further supported by the abundance of terrestrial plant debris (stems and leaves) and by abundant distribution of the grey shale facies by plant roots. These roots are also associated with siderite nodules, a characteristic of soil-forming processes.

Coal seams at Finlay Point result from the accumulation of peat in terrestrial swamps. Contacts between units associated with coal exhibit dessication cracks, indenting sub-aerial exposure. Features such as concave-up erosional surfaces and intraclasts in massive gravel suggest that channels cut these subaerial deposits. These properties, as well as the lack of any marine fossils, provide evidence of the fluvial nature of the strata at Finlay Point.

5.2 Fluvial Facies Interpretation

5.21 Introduction

Facies described at Finlay Point were previously interpreted in terms of possible flow regimes based on preserved sedimentary structures (Sections 2.11 - 2.19). At this point it is necessary to reinterpret the eight facies with reference to fluvial aspects of deposition and preservation. It should be noted, however, that different fluvial environments may produce similar facies. This will be followed by an interpretation of the observed facies associations in order to interpret subenvironments of the fluvial system. This interpretation will incorporate the results of the Graphic Log, the Markov Chain Analysis and Lateral Variation. From this interpretation characteristics of the ancient fluvial system, such as channel morphology, paleohydraulics and cyclicity will be discussed.

5.22 Individual Facies

Massive Gravel (Gm): This facies is associated with an underlying erosional scour and is interpreted as the basal lag deposited in the deepest channels at highest flow stage. This facies is associated with the establishment or deepening of channels (Cant, 1978). The base of the Finlay sandstone (at 17m, Graphic Log) is composed of massive gravel probably associated with establishment of a major channel. Clasts in this gravel are composed of coal, plant debris, siderite nodules and grey shale derived from collapse of island and flood plain material and deposition of this material in the deepest part of the channels.

Massive Sandstone (Sm): The structureless nature of this facies and its coarse to medium grain size indicates it was deposited in conditions of rapid sedimentation and possibly high flow state. These conditions could exist in channels and in areas subject to channel bar migration, particularly if during waning flow. Several processes which could produce this massive structure are suggested in the facies description in section 2.12.

Trough Crossbedded Sandstone (Sm): This facies is interpreted as the result of aggradation of three-dimensional dunes. This facies is associated with low flow regime (Miall, 1981) and is interpreted as the result of deposition of sand in channels containing dunes. The size of these dunes, and the resultant troughs, is related to channel size and discharge, large troughs being associated with main channels at low flow stage. Smaller troughs are associated with emphemeral streams topographically higher in the channel (Cant and Walker, 1984). These topographically higher streams are active in areas between bars and sand flats and modify these channel sandbodies .

Planar Crossbedded Sandstone (Sp): Planar crossbeds are associated with channel bars and sandwaves (Miall, 1981). In the fluvial environment this facies may be deposited in channels by straight-crested sandwaves migrating downstream. Another source of this facies is the avalanche faces of channel bars migrating across the channel. Migration of these bars is a major process in the formation and accretion of sand flats and vegetated islands in modern channels (Cant, 1978). This would lend to the preservation of cosets of planar crossbeds.

Horizontal Laminated Sandstone (Sh): Planar bed flow is one cause of the generation of horizontally laminated sands. Planar bed flow can exist in deep channels at high flow stage or on shallow bar tops at low flow stage. On bar tops deposition occurs at flow rates typically the same as that which deposited Sp but on a flat-lying surface so that no avalanching occurs (Allen, 1983).

Rippled Sandstone (Sr): This facies is interpreted as being deposited at the lowest stage because of the generally finer grain size and smaller scale of sedimentary structure observed. Deposition at low stage typically occurs on sandy tops of bars as a result of reworking of material deposited at higher flood stages.

This facies also occurs intercalated with mudstone units and these particular units are interpreted as sand swept onto the floodplain during highest flood stage. These units also contain dessication cracks on their bases and climbing ripples suggesting rapid sedimentation in subaerial environments.

Grey Shale (Fm): This facies is associated with vertical accretion of predominantly quartz silts by flood waters in areas of the floodplain normally subaerially exposed. Nodules and bioturbution by roots suggest thin facies developed into a soil, enabling abundant growth of vegetation on floodplains and the tops of channel bars (Cant and Walker, 1984).

At one location at Finlay Point (64m, Graphic Log) a laterally discontinuous shale unit is associated with massive growth and trough crossbedded sandstone. This is interpreted as the collapse of a large block of bank material into the base of the channel.

Coal and Black Shale: Coal deposits and interbedded black shale are interpreted as swamp deposits on flood plain areas where peat accumulated. These deposits are associated with vertical accretion of fine-grained sediments in areas with elevated water tables.

5.30 Facies Assemblages

5.31 Introduction

A facies assemblage is a group of facies that tend to occur together in consistent proportion in vertical sequence. The large-scale bodies exposed at Finlay Point, the Five-foot shale, the Point and Finlay sandstones, are composed of two facies assemblages. The sandstone facies assemblage comprises the Point and Finlay sandstone while the alternating facies assemblage comprises the Five-foot shale member. These assemblages are discussed below with reference to facies type, cyclicity, vertical and lateral variations.

5.32 Alternating Facies Assemblage

This facies assemblage was deposited in areas adjacent to the channel and is composed of fine-grained silts and clays. This assemblage consists of facies Sr, Fm and C. The Five-foot shale member is the best developed example of this style of deposition exposed at Finlay Point.

Cyclicity of the facies composing this assemblage is well preserved as seen in the Markov Chain Diagram (Figure 10). Facies Sr is overlain by grey shale (fm). Coal overlies grey shale which is in turn truncated by Sr, completing the cycle.

As observed in the facies description this assemblage varies in thickness along strike. Hacquebard's (1956) correlation reveals the rapid thinning of shale members from Coal-mine Point to Finlay Point.

5.33 The Sandstone Assemblage

This facies association was deposited in a sand-dominated channel. Facies comprising these fluvial strata are Gm, Sm, Sp, St, Sh, Sr and Fm. The Point and Finlay sandstones are composed of these facies.

Facies Gm overlies an erosional surface and represents the channel thalweg eroded during high flow regime. As seen in the Markov Chain Diagram (Figure 10), there is a strong tendency for Sm to overlie Gm. Transitions become more random above this point in the Markov Chain Diagram suggesting that intercalation of these facies is very complex, and cyclicity is the result of migration of bars and sand waves. Facies associated with channel bars and sand waves are Sp, and those associated with channels include Sp, Sm and Gm.

As seen in the Facies Interpretation (Figure 12), these assemblages are arranged in fining up sequences. Some of these are capped by Fm or coal indicating that channel activity has primarily ceased. Abundant internal erosional surfaces also truncate these sequences and are overlain by plant debris, reworked siderite nodules, coal clasts, and intraclasts of grey shale. This indicates that the channel aggraded laterally across the flood plain by a collapse of material into the channel floor.

The lateral relationship of these facies also may be interpreted in terms of the migration of channels and bars. Figure 13 is interpreted as a channel being infilled by a cross-channel bar. The erosional surface at the base of the facies assemblage was cut during high flow power and a basal lag was deposited. Planar crossbeds overlie this channel base and grade laterally into massive sandstone overlain by horizontally laminated sandstone. No erosion occurred between these units and therefore this represents a packet of genetically related facies.

The planar cross beds represent the slipface of the bar and the horizontal lamination represents the deposition of sediments on the bar top. These facies developed around a massive sand body which represents the poorly developed early bar. This bar infilled the channel at an angle as indicated by the orientation of the slipface to the channel cross section indicated by the erosional base.

Figure 14 shows lateral variation in individual facies thickness. The base of the lower Gm unit is obscured but presumably is underlain by an erosional base. Facies Sm overlies this and in a minor unit of Sr. This assemblage is truncated by a third order contact overlain by Gm. Facies Gm grades laterally into a pebbly sandstone and is in turn overlain by facies St. This sequence is presumably the result of the lateral migration and aggradation of a channel.

From the diagrams and the nature of the cyclicity observed in the sandstone assemblages, it is clear that channel migration and bar migration are important aspects of the ancient fluvial system which deposited the strata at Finlay Point.

5.4 Coarse to Fine Ratio

One of the first things considered in fluvial sedimentary interpretation is the ratio of sand and conglomerate to shale. It has been argued (Schumm, 1963) that sinuosity increases with the proportion of fine-grained material in the channels. This property is useful when used in combination with other information. Within the sandstone facies assemblages (channel) coarse material accounts for 93% of the observed section while fine-grained material accounts for 7%. This is illustrated best in the Lithic Log (Figure 8). This high proportion of sandstone and conglomerate may not be the true coarse to fine ratio because of incomplete exposure, but it suggests a sinuosity (ratio of thalweg length to valley length) of about 1.5 (Figure 9).

This sinuosity value is transitional between high and low sinuosity streams. This suggests that the fluvial system that deposited the strata at Finlay Point was transitional between meandering and straight, or anastomosing and braided, if it was a multiple channel river system (Miall, 1981).

5.5 Paleocurrent Interpretation

Some sedimentologists have argued that dispersion of paleocurrent direction is related to sinuosity of ancient fluvial systems. Cant (1978) demonstrated that this criterion is invalid for determining channel morphology because even relatively straight channels can produce paleocurrent indicators with a high degree of dispersion.

From the map of the structure of Finlay Point (Figure 4) it can be seen that structural contours are roughly parallel across faults in the area and structural rotation was minor. The data from the Point and Finlay sandstone suggest channel trends were roughly northwest-southeast. The azimuth indicated by the 3-D ripples (Figure 11) is probably not indicative of the paleoslope because they were formed in lower flow regime and may be oblique to the main channel trend. The 2-D ripples and primary current lineation are found in facies associated with channel bars (Sr and Sh) and may be formed by currents oblique to the main channel trend.

5.7 Channel Morphology

Several criteria for determining the nature of the channel pattern at Finlay Point will be discussed. This will include cyclicity within the sandstone body, overall thickness of fine material preserved in the channel, thickness of preserved flood plain material, the interconnectiveness of the fining upward cycles and the presence of vegetated banks.

Wihtin the sandstone assemblage at Finlay Point, cyclicity is not well developed. A general fining upwards sequence is displayed in the Markov Chain Diagram but it is clear that bar migration has complicated the cyclicity developed within the channels. This type of cyclicity is observed in braided streams (Cant, 1978). Trough crossbeds overlie basal lags which are in turn overlain by channel bars and sand flats consisting of facies Sh, Sp, St, Sr and Fm. Several of the fining upward sequences in the Graphic Log may be interpreted to be the result of channel migration and infilling by channel bars.

These fining upward cycles are rarely preserved intact and are usually truncated by another overlying fining upward sequence. When they are preserved intact as observed in cycle 5 in the Facies Interpretation, they are 10-15m thick. A minor amount of this is fine-grained material (2-3m). This is comparable to the amount of fine-grained sediment predicted to be preserved in a braided sequence (Cant, 1978). In meandering systems, individual fining upwards sequences are usually capped by thick fine-grained members (Walker, 1984), but this is not the case at Finlay Point.

Thick fine-grained sequences are developed in the five-foot shale member at Finlay Point suggesting abundant deposition of fine-grained flood plain facies. It is not clear how these deposits would develop in a braided system where over-bank deposits are assumed to be of little importance (Miall, 1978).

It has been argued (McLean and Jerzykiewicz, 1978) that the thickness of fine-grained flood plain deposits is unrelated to channel morphology, and this appears to be the case at Finlay Point. Thick fine-grained flood plain sequences would lead to a cohesive bank structure and inhibit the development of braided channel sequences. Although there are no banks or levees observed at Finlay Point, the abundance of coal and mudstone intraclasts as well as plant debris suggest that cohesive banks did exist and were undercut by channels.

This apparent contrast in morphological criteria can be attributed to the development of sandy fluvial facies models . At present, fluvial facies models are based on two well developed vertical sequences, the meandering model and the braided model (Walker, 1984). While similarities between ancient deposits and these models are understood, differences are not as clearly understood.

The abundance of erosional surfaces within the Point and Finlay sandstones reveals the multi-storied nature of these bodies (Figure 12). The majority of finding upward cycles are truncated by the erosional base of the overlying cycle. A combination of prevailing rate of subsidence and the width of the flood plain determine the thickness of flood plain deposits preserved. It is apparent that areas on the flood plain were not subjected to channel activity, for long periods, because of the thick accumulations of coal seams. This, as well as the abundance of bank collapse material in channels, indicates that vegetated banks restricted channel migration across the floodplain. This restricted channel mechanism could produce the multi-storied sandstone bodies.

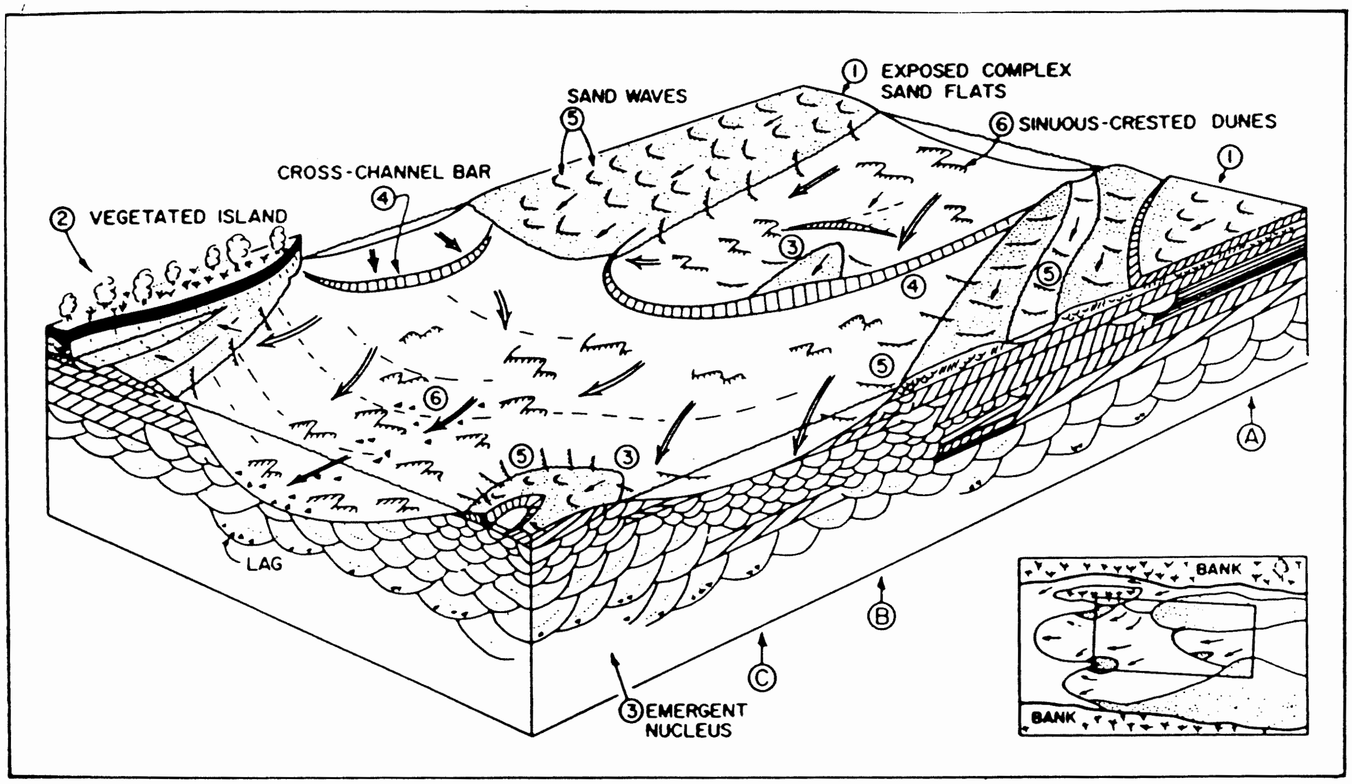
When this restricted channel activity is considered in conjunction with the similarity of the cycles within the fining upward sequences to the braided model, the transitional nature of the fluvial strata at Finlay Point becomes more apparent. It is possible that a sandy braided fluvial body restricted by resistant banks could generate the facies assemblages within the sandstone bodies and allow the large thickness of flood plain deposits preserved at Finlay Point. This development of a transitional channel morphology is not well understood and parameters such as variability of discharge, subsidence rates and frequency and nature of channel which affect channel morphology are not accounted for in the present fluvial models.

5.8 A Modern Analogue: The South Saskatchewan River

This fluvial system is a major drainage system in the southern prairies of western Canada. This river was the subject of a report by Cant (1978) and Cant and Walker (1984). A model for sandy braided river systems is based on this work and although incomplete, it is still useful for comparison.

The South Saskatchewan River has several geomorphic elements including channels, compound channel bars, sand flats, vegetated islands and floodplains. Sand flats are emergent all but a few days of the year, and islands and floodplains are submerged once very 2.2 years during peak discharge periods. Rapid discharge fluctuations, abundant coarse bedloads and easily erodable banks all tend to favour braiding (Cant and Walker, 1984).

Channels are typically parallel to local river direction and are floored by large and small dunes and ripples depending on their discharge. Major channels curve and deposit cross-channel bars. Sand flats may develop, coalesce and are modified by erosion and accretion, creating a complex morphology. Sand flats consist of planar crossbeds and are modified by superimposed small crossbeds and laminations created at lower flow regime. Topographically higher areas of these fluvial deposits are covered by vertical accretion muds. A range of facies sequences is displayed in Figure 15. These arise from the complex interaction of channels, sand flats, cross-channel bars, and floodplain deposits.



Block diagram showing elements (numbered) of a braided sandy river, based on the South Saskatchewan. Stippled areas exposed, all other areas underwater. Bar in left corner is being driven laterally against a vegetated island, but is separated form the island by a slough in which mud is being deposited. Large sandflats (e.g., right-hand corner) may develop by growth from an emergent nucleus on a major cross-channel bar (see Figs. 15 and 16). Vertical fining-upward sequences A, B and C are shown in Figure 17 and include in-channel and bar top" deposits. See text for details.

Figure 15. Facies Relationships - South Saskatchewan River (after Cant and Walker, 1984)

Allen (1984) described hydraulics of braided systems and related these to various bed forms. A high flow stage is usually developed very quickly transporting a bedload of coarse sand and a minor amount of gravel. Channels at this stage are usually straight with a few large vegetated bars remaining exposed.

Usually a prolonged period of falling flow stage follows flooding. Channels will develop sinuosity or braiding before the lowest flow stage is reached and is present in this lowest flow stage.

As the river migrates laterally across the valley floor with its muddy floodplain and peat swamps the erosional scour at the base of the channel makes the erosional base of the channel unit. A broad, braided channel is developed, composed of complex bars, sand flats and channels. These are preserved within the channel by lateral aggradation and migration into deeper parts of the channel.

Floodplain At Finlay Point thick sequences of floodplain deposits are preserved, as seen in the Five-foot shale member. The floodplains adjacent to the South Saskatchewan River are assumed not to be preserved but accounts of modern braided streams systems, such as the Brahmaputra (Coleman, 1969), report peat accumulation several metres thick. These vertical accretions deposits are deposited on alluvial plains. Swamp areas will accumulate peat deposits and flood water periodically deposit sands upon the floodplains .

5.9 Source Areas

The petrology of the sandstones at Finlay Point also provides some insight into the nature of the source area. Grains of sand are varied in composition, size and sphericity. Angular to subangular grains are common and sorting is often poor. This immaturity of the sandstones can be related to close source areas and limited transport, preventing the development of quartz-rich, well sorted sandstones.

Metamorphic rock fragments are also present as well as quartz grains with undulose extinction indicating source areas included metamorphic terrains. Such a source area could be represented by the highlands to the east of Finlay Point (Figure 3). There is no independent verification of an east-west channel trend by paleocurrent data, but the data collected is not broad enough a survey to dispute this interpretation. Source areas also include the flood-plains as indicated by sedimentary rock fragments, siderite nodules and coal clasts.

Hacquebard (in press) correlates the strata at Finlay Point with those at the base of a 1700m thick section of the Inverness Formation. Strata near the top of the section outcrop at Inverness. It is therefore possible that Finlay Point could represent the early phase of the filling of an extensive alluvial basin.

Chapter 6 Conclusions

6.1 Fluvial Morphology

The strata at Finlay Point were deposited in a sand-dominated river system. From the ratio of coarse to fine-grained strata, the cyclicity of the sandstone assemblages, the multi-storied nature of the channels, and the inferred cohesive banks, a transitional system between meandering and braided rivers is interpreted to have deposited the strata at Finlay Point. Controls on sedimentation such as climate and tectonism are difficult to investigate and may account for the transitional nature of these strata (Cant, 1978).

6.2 Flood Plain Morphology

Abundant vegetation flourished on a fine grained flood plain where peat accumulated in swampy areas for long periods of time. These areas were adjacent to channels and served as both a source of sediment, derived by bank collapse, and an area of deposition following periodic flooding. Cohesive banks developed and restricted channel migration as seen by the multi-storied sandstone bodies and thick flood plain deposits. Controls on flood plain sedimentation such as rates of channel migration, avulsion and vertical floodplain accretion (Leeder, 1978) are difficult to determine on the outcrop scale and could explain the thick floodplain sequences preserved near a sandy, braided fluvial system contrary to the model of Cant and Walker (1984).

6.3 Source Areas

Sources of sediment supply included metamorphic highlands, presumably to the east, and the flood plain adjacent to the channel. The immaturity of grains composing the sandstones and the rapid lateral thinning of the coal seams and shale members on both the outcrop and basin scale could be interpreted as a result of deposition near the source area of the basin.

6.4 Economic Considerations

The coal seams exposed at Finlay Point and the seams correlated with them offshore are at present uneconomic (Hacquebard, in press). The poor quality (high sulphur content), rapid thinning to the north and limited onshore area make the coal seams at Finlay Point uneconomic and the depth (about 1200-1400m below sea level) and length of an entrance tunnel make the coal reserves offshore Mabour Mines presently uneconomic.

Because of the stratigraphic relationship of the strata at Finlay Point to the rest of the Inverness Formation, which places these strata near the base of the Inverness Formation, fluvial controls on coal seam geometry must be interpreted with care. It can be concluded that thick coal seams accumulate in areas that are remote from the channel influences for long periods. The nature and relative timing of channel avulsion cannot be reasonably predicted from this study because of the transitional nature of the interpreted fluvial morphology and the limited number of coal seams exposed. It should also be noted that the strata at Finlay Point are stratigraphically about 1500m below the coal seams exposed near the top of the Inverness Formation and it is likely that fluvial morphology evolves and changes throughout the Inverness Formation.

APPENDIX I

Facies Abbreviations

Fm	Grey Shale
Sh	Horizontal Laminated Sandstone
Sp	Planar Crossbedded Sandstone
Sr	Rippled Sandstone
Sm	Massive Sandstone
St	Trough Crossbedded Sandstone
Gm	Massive Gravel
C	Coal and Black Shale

Unit #	Facies Type	Markov Facies Code	Thickness (m)	Comments
1	Fm	6	5.75 m	nodules; concoidal weathering; thin sandstone interbeds (.2 - .4 m); basal contact faulted
2	Sr	7	3.0 m	intraclasts; mudcracks on base; large scale troughs; paleocurrent 136, 138, 125; fining up grain size; fault within this unit
3	Fm	6	0.5 m	organic debris; iron and sulphur staining; nodules; concoidal weathering
4	C	8	0.5 m	interbedded carbonaceous shale
5	Sr	7	1.0 m	erosional base; nodules near base; possible crevasse splay; some small ripples
6	Fm	6	0.8 m	flattened nodules; some layered; concoidal weathering
7	Sr	7	1.0 m	ripples; orange stain; paleocurrent from small troughs 125, 138, 136

Unit #	Facies Type	Markov Facies Code	Thickness (m)	Comments
8	Fm	6	1.5 m	nodules in vertical tubes; concoidal weathering
9	C	8	1.0 m	coal with carbonaceous shale interbeds
10	Fm	6	1.1 m	nodules, concoidal weathering
11	C	8	0.5 m	abundant carbonaceous shale
12	Fm	6	0.3 - 0.0 m	lateral thickness variation; no nodules; concoidal weathering
13	Sm	2	(ave.) 1.2 m	lateral thickness variation
14	Gm	1	0.4 m	basal lag; coal clasts
15	Sm	2	1.3 m	coal clasts
16	Sp	3	2.0 m	large scale cross beds; some troughs
17	Sh	5	(ave.) 1.5 m	carbonaceous material (plant debris) in laminations slightly contorted; lateral thickness variation; paleo-current 170
18	Gm	1	0.1 m	gradational upper contact
19	Sm	2	0.7 m	gradational upper contact
20	Sr	5	1.1 m	paleocurrent from primary current lineation, 150
21	Gm	1	(ave.) 0.1 m	undulatory basal contact; lateral thickness variation
22	Sm	2	2.8 m	gradational upper contact
23	Sp	3	0.6 m	crossbed sets ave. 0.3 m thick
24	Sh	5	0.25m	abundant plant debris at base
25	Sm	2	2.1 m	coal clasts up to 0.25 m thick; plant debris
26	Sh	5	0.15m	

Unit #	Facies Type	Markov Facies Code	Thickness (m)	Comments
27	Sm	2	0.5 m	gradational contacts above and below
28	Sp	3	4.6 m	fossil imprints of plant debris
29	Gm	1	0.3 m	lithic clasts; plant debris
30	Sp	3	0.7 m	paleocurrent from ripple crests 202°
31	Gm	1	(ave.) 1.5 m	abundant plant debris; lithic clasts erosional base; variable thickness
32	Sp	3	2.0 m	abundant plant debris; coal clasts; crossbed sets up to 0.5 m thick
33	Gm	1	0.4 m	coal clasts, lithic clasts
34	Sm	2	3.1 m	poor exposure; coal clasts; plant debris
35	Sh	5	±2.0 m	bottom contact not exposed; paleocurrent 158° primary current lination
36	Sm	2	4.0 m	plant debris
37	Sr	7	1.0 m	organic material present
38	Fm	6	3.0 m	a few small (0.01 m) nodules; concoidal weathering
39	C	8	0.6 m	some interbedded carbonaceous shale
40	Sr		0.5 m	paleocurrent 120; plant debris; coal clasts
41	Sm	2	1.5 m	plant debris; coal clasts
42	St	4	1.5 m	
43	Sm	2	1.2 m	

Unit #	Facies Type	Markov Facies Code	Thickness (m)	Comments
44	Gm	1	1.0 m	plant debris; lithic clasts
45	Sm	2	1.0 m	plant debris; convoluted laminations
46	Gm	1	(ave.) 1.0 m	plant debris; lithic clasts; lateral thickness variation
47	Fm	6	(ave.) 0.2 m	laterally discontinuous
48	St	4	3.25m	abundant plant debris; some organic-rich layers
49	Sm	2	4.9 m	some scour and fill surfaces
50	Sr	7	2.0 m	gradational upper contact; paleocurrent 200
51	Fm	6	1.4 m	nodules
52	Sp	3	(ave.) 2.0 m	variable thickness (some 2-D ripples); paleocurrent 224
53	Sh	5	0.6 m	some convoluted laminations; plant debris
54	Sr	7	2.0 m	gradational basal contact; plant debris; 3-D ripples; paleocurrent 117^{o}
55	Sp	3	2.0 m	plant debris; cross bed sets 0.15 - 0.5 m in thickness
56	St	4	0.5 m	
57	Fm	6	0.4 m	
58	Gm	1	0.5 m	lithic clasts
59	Sm	2	4.0 m	poor exposure
60	Sr	7	1.0 m	very weathered
61	Sm	2	1.5 m	some faint cross beds; erosional base

Unit #	Facies Type	Markov Facies Code	Thickness (m)	Comments
62	Sp	3	3.5 m	cross beds at low angle (less than 10 degrees); sets up to 1.0 m thick; large concretions
63	Sr	7	2.0 m	troughs are 0.6 x 0.08 m in cross section; coal clasts; plant debris; paleocurrent 131
64	Sm	2	4.0 m	
65	Sh	5	4.0 m	laminations 0.2 - 2.0 cm thick; fines up with unit
66	Fm	6	(ave.) 0.8 m	no concoidal weathering; nodules present
67	Sm	2	(ave.) 0.4 m	lateral thickness variation
68	Fm	6	(ave.) 0.3 m	shale is hard with a few nodules present
69	St	4	1.2 m	
70	Sm	2	(min.) 4.0 m	top of unit obscured by over-burden; some convoluted laminations

APPENDIX II

Sandstone Petrography

Thin Section No. FPA29
Facies Conglomerate
Unit No. 44

Composition:

Framework	80%	Matrix	20% - Clay and Siderite
quartz	40%		
MRFs	5%		
microcline	3%	Cement	local hematite cement
muscovite	7%		
siderite	10%		
plagioclase	5%		
opaques	10%		
chlorite	5%		

Texture:

Grainsize average 0.75mm; range 0.25 - 2.0mm
Sorting poor
Grain Shape very angular to rounded, low sphericity

Alteration plagioclase relatively fresh

Petrogenesis plant material with some fibrous structure intact; siderite nodules with indented grain boundaries, a few detrital coal grains, some polycrystalline quartz grains present.

CLASSIFICATION: Lithic wacke

Thin Section No. FPA2
Facies Rippled Sandstone
Unit No. 2

Composition:

Framework	80%	Matrix	20% - Clays
quartz	50%		
plagioclase	5%		
microcline	5%	Cement	
siderite	0-10%		
chlorite	10%		
opaques	10%		
lith. frags.	10%		
others			

Texture:

Grainsize	average 0.125mm, range 0.062 - 0.125mm
Sorting	good
Grain Shape	subrounded - angular

Alteration Some fresh microcline; plag. is highly altered to clays.

Petrogenesis Chlorite rims on some grains; most qtz. is monocrystaline; abundant clay overgrowths.

CLASSIFICATION: Lithic wacke

Thin Section No. FPA6
Facies Rippled Sandstone
Unit No. 6

Composition:

Framework	80%	Matrix	20% - Clays, including chlorite
quartz	65%		
plag.	10%		
ortho.	5%	Cement	
chlorite	5%		
SRFs	5%		
opaques	10%		

others: muscovite, MRFs, siderite, zircon, microcline

Texture:

Grainsize	average 0.1mm, range 0.125 - 0.05mm
Sorting	fair
Grain Shape	subrounded - angular, high sphericity

Alteration Plagioclase altered by vacuoles, few other distinguishable feldspars because of clay alteration.

Petrogenesis Quartz very undulose extinction

CLASSIFICATION: Lithic wacke

Thin Section No. FPA18
Facies Horizontal Laminated Sandstone
Unit No. 20

Composition:

Framework	90%		Matrix	10% - Clays
quartz	60%			
plag.	5%			
chlorite	5%		Cement	
muscovite	5%			
opaques	10%			
lithic frags:				
MRFs	10%			
SRFs	5%			
others: zircon, chert				

Texture:
Grainsize average 0.25 - 0.125mm; range 0.62 -0.5mm
Sorting poor
Grain Shape subangular - rounded, low sphericity

Alteration Feldspars are very altered, mainly by inclusions

Petrogenesis monocrystaline, elongate quartz grains with undulose extinction, foliation imparted by organic matter and coal grains.

CLASSIFICATION: Lithic wacke

Thin Section No. FPA23
Facies Conglomerate
Unit No. 34

Composition:

Framework	90%		Matrix	10% - Clays, Hematite
quartz	60%			
plag.	5%			
chert	10%		Cement	
opaques	5%			
microcline	5%			
lithic frags:				
MRFs	5%			
SRFs	10%			
others: chlorite, muscovite, zircon, siderite				

Texture:
Grainsize average 0.125 - 0.25mm; max. 1.0mm
Sorting poor
Grain Shape angular, low sphericity, many elongate quartz grains

Alteration Microcline very altered, plag. altered along lamella but most are clean and free of alteration .

Petrogenesis Quartz mainly monocrystaline with very undulose extinction, a few polygonal grains with sutured boundaries, Fe stain near siderite nodules, nodules with overgrowths and crude structures.

CLASSIFICATION: Lithic arenite

Thin Section No. FPA28B
Facies Trough Cross-Bedded Sandstone
Unit No. 42

Composition:

Framework	90%
quartz	35%
plag.	5%
musc.	5%
opaques	5%
chlorite	5%
chert	5%
ortho.	10%
lithic frags:	
MRFs	10%
SRFs	20%

Matrix 10% - Clays, rims and intergranular spaces

Cement

Others: zircon,microcline,hematite

Texture:
- **Grainsize** average 0.125mm; range 0.062 - 0.25mm
- **Sorting** poor
- **Grain Shape** subangular

Alteration Some feldspars (plag. and ortho.) are completely altered to fine grained clays, some with alteration around rims.

Petrogenesis Abundant SRFs with indented boundaries.

CLASSIFICATION: Lithic arenite

Thin Section No. FPA28C
Facies Massive Sandstone
Unit No. 41

Composition:

Framework	90%
quartz	50%
lithic frags:	
MRFs	10%
SRFs	10%
opaques	10%
plag.	5%
others	5% (muscovite, wood siderite, chert, biotite,microcline)

Matrix 10% - Clays

Cement

Texture:
- **Grainsize** average 0.5mm; range 1.5 - 0.05mm
- **Sorting** fair
- **Grain Shape** angular, low sphericity

Alteration all feldspars are cloudy as a result of vacuoles and clay replacement; some plagioclase and all microcline are extremely altered and barely recognizable.

Petrogenesis quartz and biotite grains exhibit very undulose extinction, some quartz grains are polycrystaline with sutured intragranular boundaries, abundant elongate quartz grains, SRFs are extremely indented (max. 50%) and some organic fragments display fibrous structure.

CLASSIFICATION: Lithic Arenite

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