Sedimentology and Stratigraphy of Canso and Riversdale Fluvial Strata at Broad Cove, Cape Breton, Nova Scotia.

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ABSTRACT

The cliff section located on the northeast shore of Broad Cove, Cape Breton, contain fluvial strata of both the Canso and Riversdale Group. The Canso strata are composed of two facies assemblages. The Coarse Member facies assemblage consists of the sequence, massive conglomerate, planar laminated sandstone, massive sandstone, and rippled sandstone. This facies assemblage is restricted within the paleochannels of the Canso, and represents channel lag and fill units, deposited from waning flow. The Fine Member facies assemblage is composed of thickly bedded mudstone interbedded with the sheets of fining upward sandstone. These units represent overbank and splay deposits respectively. Width to depth ratios, and channel to overbank deposit ratios both suggest a moderate to high sinuoisity. Internal structure and the large vertical separation of the paleochannels indicates that the channels represent a single erosional event, followed by one or more infilling events. Petrographic data suggests a warm, arid climate. Thus the environment of deposition represents a periodically active, sinuous fluvial system traversing an arid alluvial plane. Other research indicates that the Canso strata at Broad Cove represent an arid fluvio-lacustrine system.

Two facies assemblages are present within the Riversdale strata of Broad Cove. The Gravel-Sand facies assemblage consists of a basal matrix-supported conglomerate, overlain

by trough cross-stratified sandstone, massive sandstone, rippled sandstone, with the sandstones often containing lenses of disturbed sandstone. This sequence represents a channel fill, consisting of a debris flow, overlain by a sequence of channel fill material deposited from waning flow and containing isolated pockets of bank collapse material. Lateral variations in structure suggest a complex and continually changing internal channel morphology. The second facies assemblage is composed of a massive mudstone which represents overbank flood material. The stacked, *en echelon* pattern of channel deposits is the result of channel aggradation followed by abrupt channels switching, and is typical of braided fluvial deposits. Longer term cyclic activation and abandonment of areas indicated at Broad Cove also suggests a braided system. Petrographic data indicates a warm, arid climate at the time of deposition. Thus, the environment of deposition represents a braided fluvial system, with cyclic depositional patterns over both the short and long term.

The lack of climatic change suggests the rejuvenation of the source area, which caused the change from a meandering to a braided system, was the result of tectonic activity during the time period represented by the unconformity between the Canso and Riversdale strata of Broad Cove.

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CHAPTER 1. INTRODUCTION

1.1 Purpose

The cliffs of Broad Cove, Inverness County, Cape Breton Island, provide a good cross-sectional exposure of the mid-Carboniferous strata of both the Canso and Riversdale Groups. The purpose of this thesis is to examine the sedimentology and stratigraphy of the strata exposed on the northeastern shore of Broad Cove, in order to propose interpretations of the depositional systems represented. These interpretations will then be used to draw some conclusions regarding the changes across this Canso-Riversdale boundary, and their courses.

1.2 Location and Description

Broad Cove is located on the northeast coast of Cape Breton Island, 5 km northeast of the community of Inverness, at 61°16"20" east longitude, 46°16"20" north latitude. The location of the section is shown in figure 1.

Broad Cove is a wide, asymmetric bay into which flows Smiths Brook (fig. 1). A narrow sand beach and a continuous cliff ranging in height from 4 to 8 metres is located south of Smiths Brook. This section is presently the subject of a 1985-86 Honours thesis by Y. Brown. North of the brook, the beach grades from a sand to a cobble and boulder beach as the coast curves to the northeast. The cliffs, which extend north from Smiths Brook to Kennedys shore and beyond, range

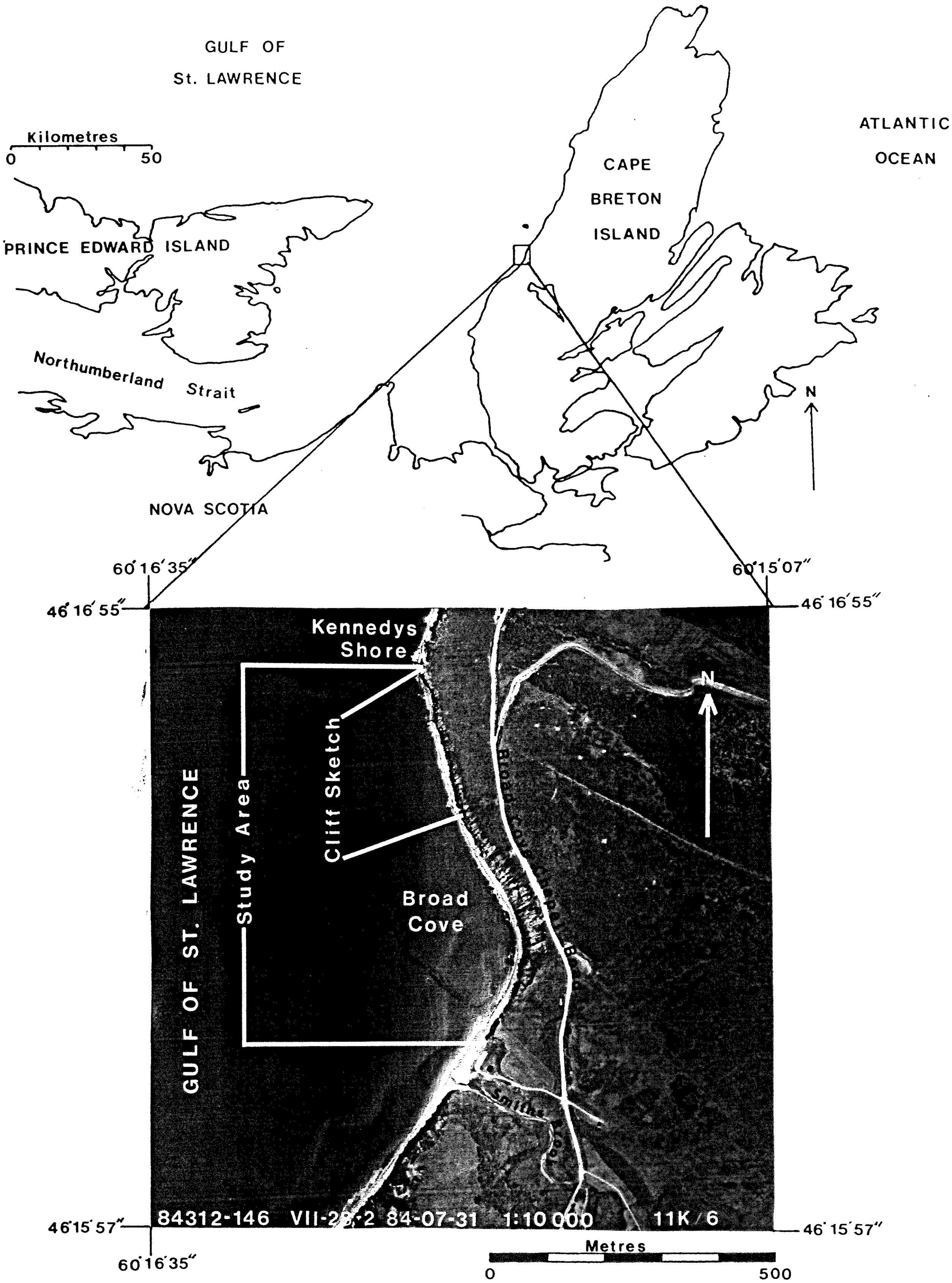


Figure 1. General location and aerial photograph of study area.

in height from 3 to 20m, and are the subject of this study. The area may be reached using the Broad Cove Chapel road from Route 19. Access to the beach is provided by a driveway to a cottage on the shore at Smiths Brook (fig. 1).

1.3 Previous Work

Broad Cove is part of an extensive exposure of Carboniferous strata located on the northern coast of Cape Breton. These strata have been studied since the 19th century, with most work concentrated in areas where coal measures are present. The strata exposed at Broad Cove have been examined as part of regional studies of the Carboniferous by Rostoker (1960) and Belt (1962). No detailed study has been carried out previously in this area.

1.4 Tectonic Framework

The Carboniferous strata of Nova Scotia are part of the Appalachian mountain system of eastern North America, which extends from the southern United States to Newfoundland (Hacquebard, 1972).

Following the Acadian Orogeny in the mid-Devonian a series of northeast trending faults developed in the northern Appalachians. Movement along these faults were largely right lateral strike slip (Belt, 1962). Crustal stretching produced by this movement resulted in a large subsiding region known as the Fundy Basin (fig. 2)(Bradley, 1982).

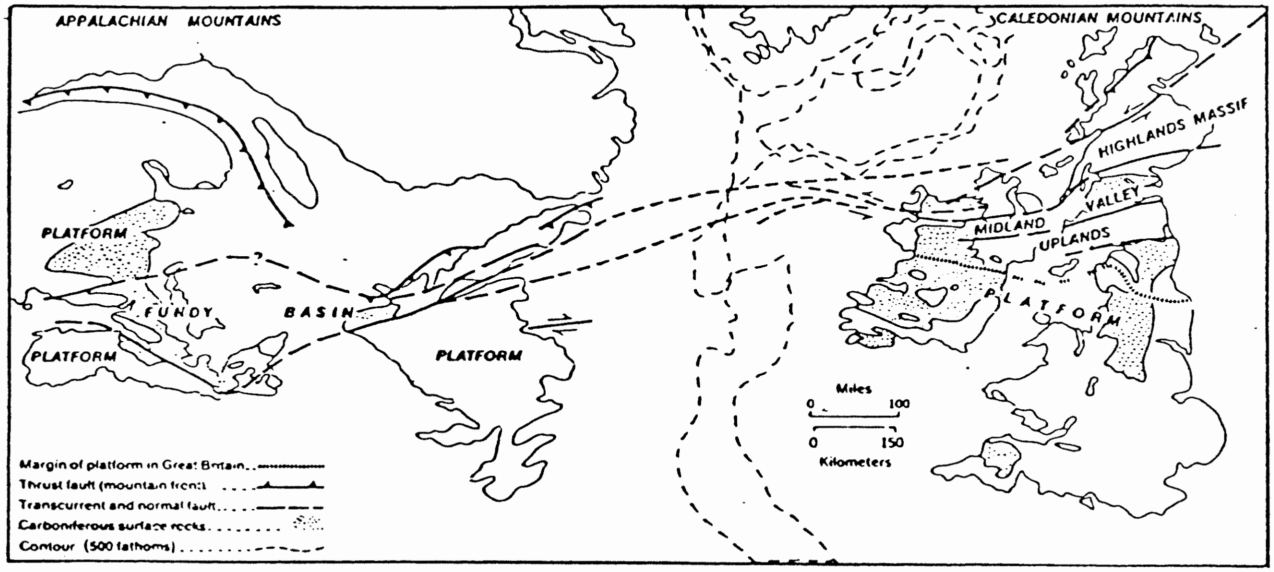


Figure 2a. Probable correlation of Fundy Basin to British Carboniferous basins.

(From Hacquebard, 1972.)

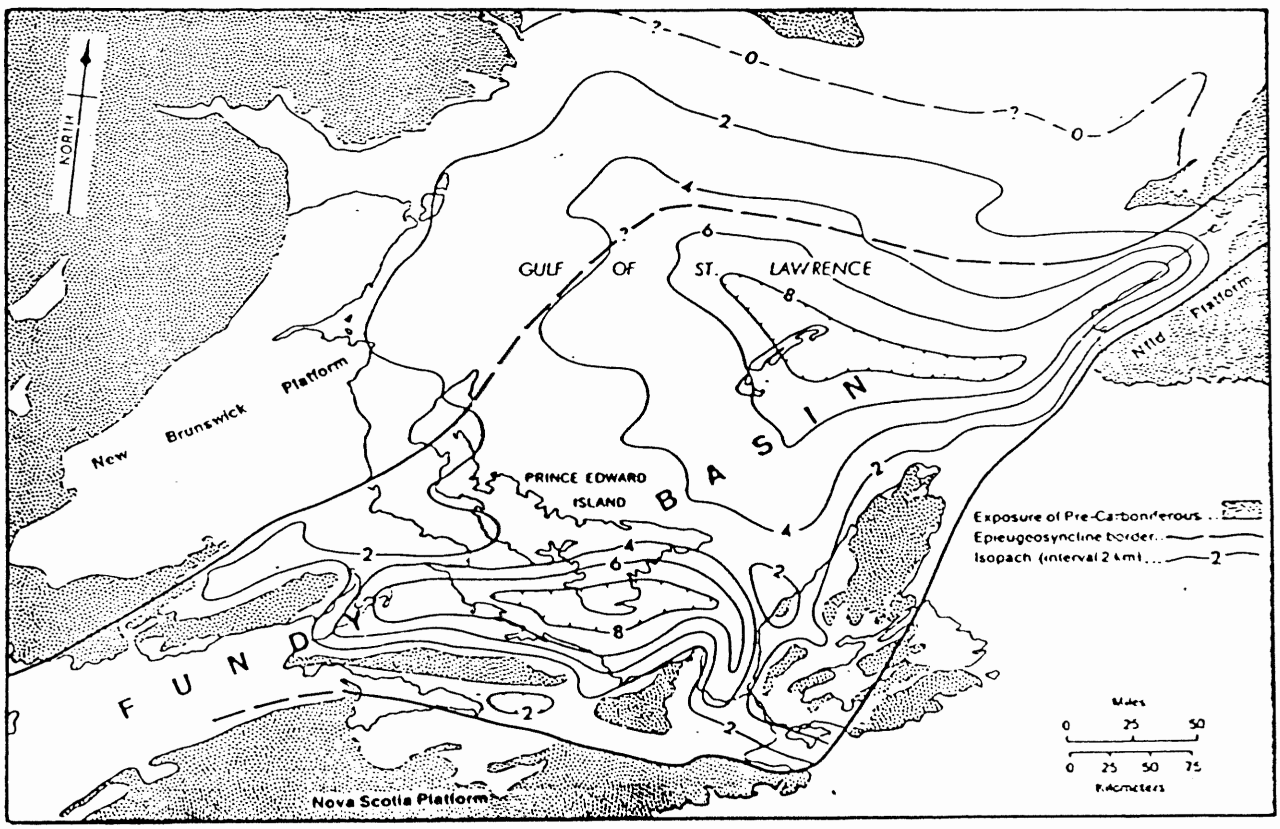


Figure 2b. Location, shape, and depth of the Fundy Basin.

(From Hacquebard, 1972.)

The initial stage of crustal stretching produced a series of fault-bounded sub-basins and intervening uplands (fig. 3)(ibid). Tectonism was both diachoronous and variable along strike, resulting in episodic movement of blocks of basement rock. These uplifted blocks, and the stable platform surrounding the Fundy Basin acted as sediment source areas for adjacent basins (Kelley, 1967). Thermal decay following the stretching event resulted in late-stage general subsidence of the entire basin (Bradley, 1982). Sedimentary deposition within the Fundy Basin was continuous throughout the Carboniferous (Hacquebard, 1972). The deposition of the Horton Group continental clastics represents the first indication of the early phase of block faulting. Late-stage themal subsidence is represented by the widespread deposition of the mid to upper Carboniferous sediments which blanket earlier sub-basins and uplands, and progressively onlap the surrounding basement (Bradley, 1982).

1.5 Stratagraphic Framework

The Carboniferous strata of eastern Canada were initially divided into 5 subdivisions by Sir William Dawson in 1891 (Kelley, 1967). The six groups of the Carboniferous used today were defined in 1927 by Bell. These groups, the Horton, Windsor, Canso, Riversdale, Cumberland, and Pictou, were defined largely on the basis of fossils. It was thought that these groups were time stratigraphic, separated by disconformities

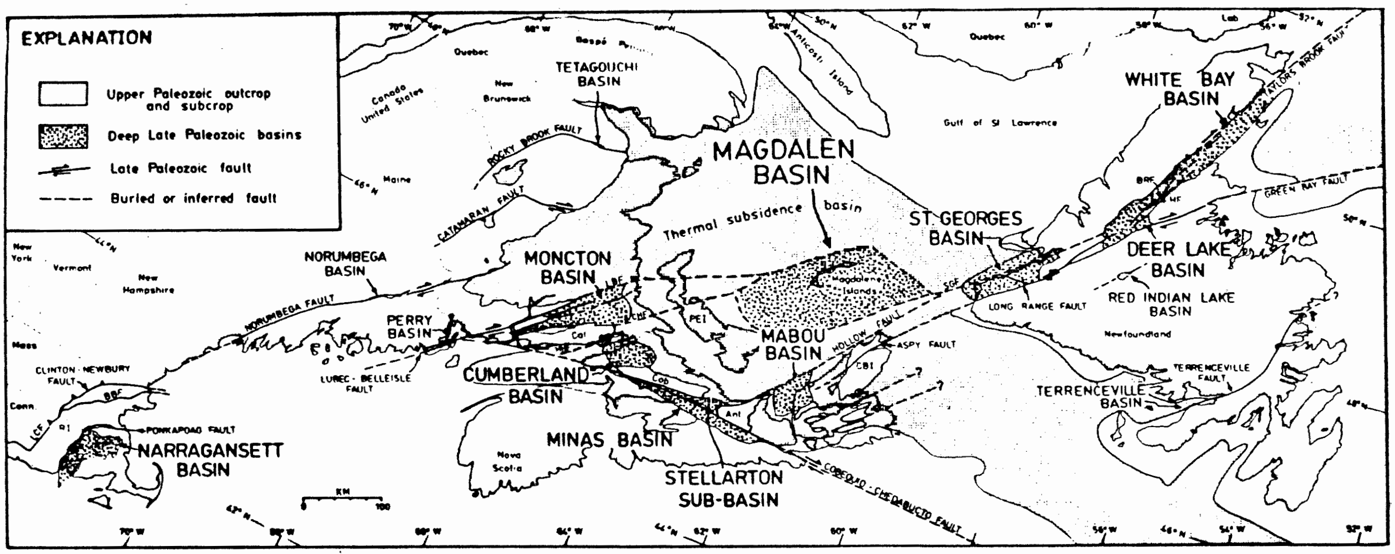


Figure 3. Lower to middle–Carboniferous sub-basins of the northern Appalachians. (from Bradley, 1982.)

and unconformities (Bell, 1927). Later research has revealed that deposition was regionally continuous throughout the Carboniferous (Bradley, 1982) and that the groups are diachronous (fig. 4), and thus cannot be considered time stratigraphic units (Hacquebard, 1972). For this reason these six groups are used as rock stratigraphic units.

Deposition of the oldest of these groups, the Horton, was initiated in the late Devonian (fig. 4)(ibid). These strata, which fine vertically and laterally from the basin boundaries, were deposited as alluvial fan, fluvial, and lacustrine deposits in fault-bounded basins (Bradley, 1982).

Repeated marine transgressions of the interconnected basins began at the close of Horton sedimentation (fig. 4) (Schenk, 1978). Within the shallow, hypersaline seas which developed, sediments of the Windsor Group were deposited. These consist of cyclic deposits of shallow marine to supratidal carbonates and evaporites, as well as red subaerial sediments (Hacquebard, 1972). Local fanglomerate deposits indicate continued tectonic activity. A gradual decrease in the extent of progressively younger Windsor strata indicates the gradual regression of the Windsor Sea (Kelley, 1967), and the initiation of Continental Canso Group sedimentation.

The Canso strata are composed of fluvial and lacustrine red and grey shales and sandstones, deposited in and around lake systems which developed following the regression of the Windsor Sea (Hacquebard, 1972).

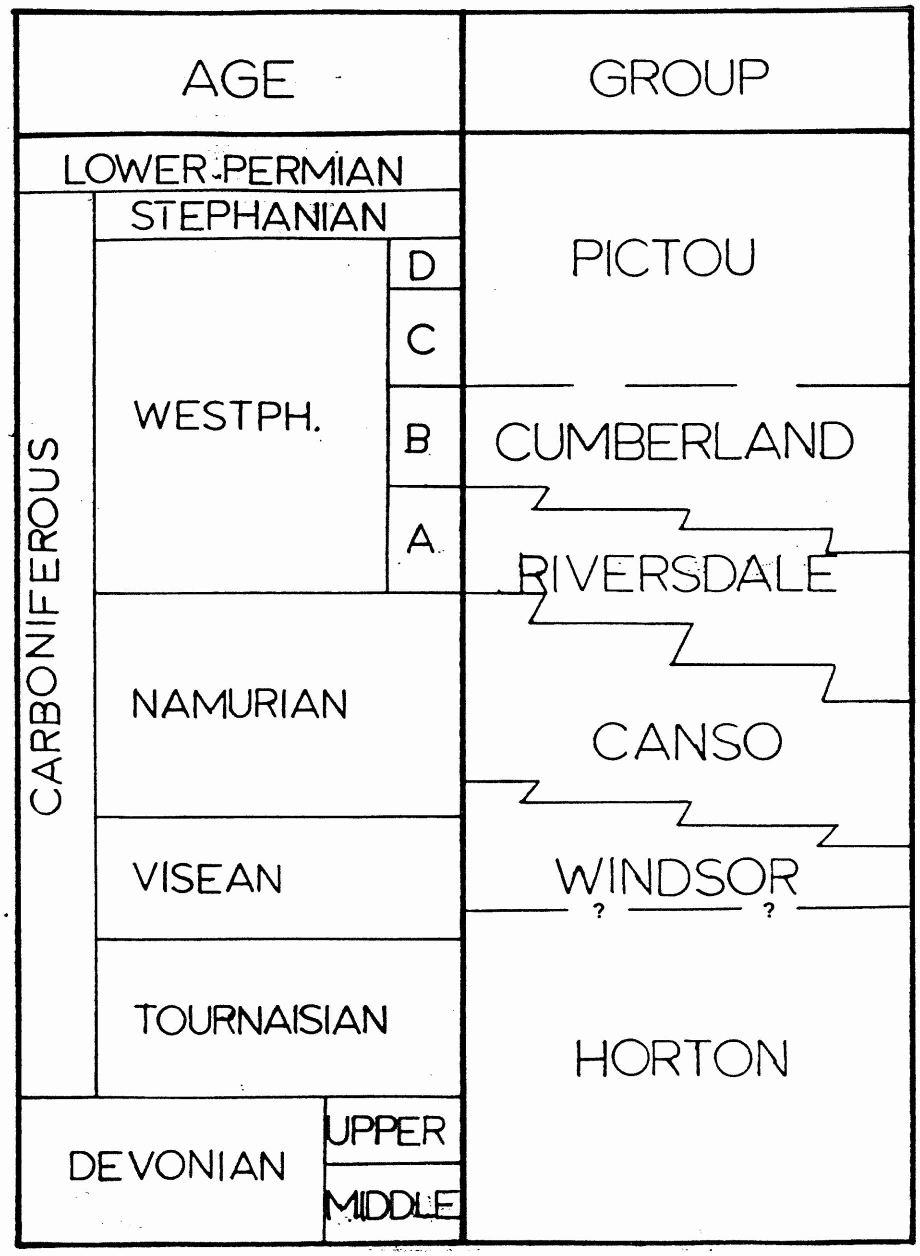


Figure 4. Stratigraphic subdivisions and age of Upper Paleozoic rocks in eastern Canada.

(After Hacquebard, 1972.)

Rejuvenation of source areas by tectonic activity produced a reduction and eventual disappearance of the Canso lake system, as well as initiating deposition of the coarser fluvial Riversdale Group sediments (fig. 4)(Hacquebard, 1972). Continued tectonic activity resulted in the deposition of the conglomerate, sandstone, shale, and coal of the Cumberland Group in some basins (fig. 4)(Kelley, 1967).

Cessation of tectonic activity combined with general subsidence of the Fundy Basin in the late Carboniferous resulted in the widespread deposition of the Pictou Group fluvial red sandstones and coal sequences (fig. 4)(Bradley, 1982). This group blankets all the older groups, and onlaps surrounding basement rock (Kelley, 1967). Deposition of this final lithological group ended during the early Permian (ibid).

1.6 Section Morphology

The cliff section studied consists of poorly to well exposed, unfaulted strata with an average strike and dip of 322°/22°NE. This provides approximately 185m of vertical section. The cliff face of the southern portion of the studied section (fig. 1) runs almost parallel to the dip direction of the strata. This, combined with an average cliff height of 10m, results in a long vertical section, but little lateral exposure. In the northern portion of the studied section (fig. 1) the cliff face runs almost parallel to the strike of the strata, resulting in very shallow apparent dips. This, and an average cliff height of 17m, results in a much smaller vertical sequence, but a very wide lateral exposure. It is this portion of the section which is illustrated in figure 20(see also fig. 1).

The strata exposed at Broad Cove can be divided into two major units, based on lithology and geometry of the strata (fig. 12). These units have been identified as strata representing two of the lithostratigraphic groups of the Carboniferous: the Canso and Riversdale (fig. 4)(Rostoker, 1960). A maximum of 115 metres of Canso strata are exposed in the southern half of the section. This is stratigraphically overlain by 90m of Riversdale strata exposed in the northern portion of the section (fig. 12). The contact between these two groups is an erosional unconformity, with the Riverdale strata cutting in excess of 15m into the underlying Canso strata.

CHAPTER 2. METHODS

Initial field work was carried out at Broad Cove on April 26-May 3, 1985. A further 3 days of field work were carried out on June 1, and August 24 and 25. After analysis of the data collected in these trips, a final two day period of field work was carried out on September 28 and 29.

During the initial trip, a detailed description of the sedimentary sequence was completed. On the second and third trips, a photo mosaic of the entire cliff was taken, and a series of corresponding sketches were made. Problems with photographic equipment required the photo mosaic be taken again, necessitating the fourth period of field work. Rock types were sampled, paleocurrent measurements were taken, and detailed measurements of rock units were recorded on all trips.

An overlay of part of the photo mosaic was used to map features of significance, such as rock boundaries and partings. Additional information, including rock types, cliff face orientation, and cliff length were obtained from sketches and aerial photos of the section. Using this method an accurate diagram of the northern portion of the section (fig. 1) was made. This was photographically reduced and is given as figure 20. From the data collected a general and detailed stratigraphic column were also drafted (figure 12 and 11, respectively).

Representative samples of the major rock types were chosen for further examination. Those with sufficiently large grainsize were examined using a petrographic microscope. (See Appendix A). A total of 15 thin sections were prepared, and corresponding rock slabs cut and strained in order to confirm the presence and location of calcite.

The composition of the remaining fine-grained samples was determined using x-ray diffraction techniques. Samples were crushed to silt-clay grain size, and mounted on smear slides with acetone. Each slide was analyzed on the Phillips X-ray diffractometer of the Dalhousie University Geology Department using nickel-filtered Cu K-alpha radiation generated by a x-ray tube driven at 40kv and 20mA. A time constant of 4 seconds was used, and all traces were recorded at 1cm per minute. All slide mounts were scanned between 2 and 50° at 1° 2θ/minute. Samples were then re-scanned from 24° to 26° at 1/4° 2θ/min to resolve overlapping peaks of kaolinite and chlorite. The relative abundances of component minerals was determined from the area of diagnostic peaks using the method of Cook and others (1975), with the area of the kaolinite and chlorite peaks determined following the techniques developed by Biscaye (1965) and described by Umpleby and others (1978). A total of 20 samples were studied in this manner.

CHAPTER 3. FACIES DESCRIPTION

3.1 Introduction

The term facies was initially defined as the entire aspect of a part of the earth's surface during a certain interval of time, by Nicholaus Steno in 1669 (Walker, 1984). The term was reintroduced by Amanz Gressly (1838), who used it to define rock units of similar lithologic and paleontologic character (Davis, 1983).

The term "facies' has been used in many ways, with its application often having inherent genetic or environmental implications. Since the facies are the descriptive units upon which interpretations are based, they should be objective, based only on the observations of the rocks themselves (Walker, 1984). For this reason it is best to restrict the term facies to rock units ranging from centimetres to metres, defined by geometry, sedimentary structures, lithology, and fossil content, representative of a distinct process of sedimentation (Gibling & Rust, 1984).

Miall (1977) has developed a system of twenty standard lithofacies which can be used to describe most fluvial deposits (Table 1). This system cannot however, be easily applied to the rocks of Broad Cove, as several facies present do not correspond to any of the lithofacies described by Miall. For this reason, an independent series of facies were developed for the section. Some mention of Miall's classification system will be made, as much of the recent work in fluvial

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

Table 1. Standard lithofacies developed by Miall (1977) for the description of fluvial deposits. (From Miall, 1978.)

sedimentology is based on this system. A total of 10 facies have been identified at Broad Cove.

3.2 Massive Conglomerate Facies

This facies is composed of a pebble gravel having no recognizable sedimentary structures. The gravel is clast-supported, and the clasts range in size from 2 to 15mm. These clasts are composed mainly of carbonate, and will be discussed in the following chapter. The clasts are well rounded, and moderately sorted. Vertical or lateral grain size variation was not observed. The facies occurs as irregular discontinuous units, having an undulatory base, and a sharp non-erosional contact with the overlaying sandstone facies (fig. 5). Units of the Massive Conglomerate facies are very thin and discontinuous, having a mean thickness of 8cm, and no lateral continuity beyond 1m. This facies corresponds to Miall's 6m lithofacies (Table 1), and is restricted to the Canso strata at Broad Cove (fig. 5).

This facies is interpreted to represent sedimentation in high flow conditions in which only the coarsest grain sizes are deposited. This is based on the relatively large grain size, the lack of matrix, and the massive texture of these units. This is further supported by the fact that this facies has an erosional basal contact, which indicates fluid flow sufficient to erode the sediments of the underlying unit.

FACIES	PERCENT OF CANSO STRATA	PERCENT OF RIVERSDALE STRATA	PERCENT OF TOTAL SECTION
Massive Conglomerate	<1	–	<1
Matrix-supported Conglomerate	–	9	3
Rippled Sandstone	12	19	13
Massive Sandstone	2	48	19
Horizontally Laminated Sandstone	<1	–	<1
Trough Cross-stratified Sandstone	–	9	3
Disturbed Sandstone	–	2	1
Sheet Sandstone	10	–	6
Massive Mudstone	–	13	5
Bedded Mudstone	76	–	49

(—: Facies not present.)

Figure 5a. Relative proportions of facies in measured section.

Underlying Facies \ Overlying Facies	Bedded Mudstone	Sheet Sandstone	Rippled Sandstone	Hz. Laminated Sandstone	Massive Sandstone	Massive Conglomerate
Bedded Mudstone		S	G	–	E	E
Sheet Sandstone	G		E	–	E	E
Rippled Sandstone	G	G		–	E	–
Hz. Laminated Sandstone	–	–	G		E	–
Massive Sandstone	–	–	G	G		–
Massive Conglomerate	–	–	–	–	S	

E: Erosional

G: Gradational

S: Sharp, Non-erosional

Figure 5b. Contact type between facies of the Canso strata.

Underlying Facies \ Overlying Facies	Massive Mudstone	Disturbed Sandstone	Rippled Sandstone	Massive Sandstone	Trough X-Strat. Sandstone	Scour Sandstone	Matrix Supp. Conglomerate
Massive Mudstone		–	E	E	E	–	E
Disturbed Sandstone	–		S	S	–	–	E
Rippled Sandstone	G	S		E	E	E	E
Massive Sandstone	S	S	G		E	E	E
Trough X-Strat. Sandstone	–	–	G	G		–	E
Scour Sandstone	–	–	G	G	–		E
Matrix Supp. Conglomerate	S	–	S or G	S or G	S	–	

E: Erosional

G: Gradational

S: Sharp, Non-erosional

Figure 5c. Contact type between facies of the Riversdale strata.

3.3 Matrix-supported Conglomerate Facies

This facies consists of pebble gravels which may or may not show horizontal stratification (fig. 10). These clasts are supported in a martrix of fine sand, and are highly variable, ranging in size from 0.2cm to 15cm with an average of 1cm. Clasts in excess of 2cm tend to be elongated or flattened, commonly showing imbrication (fig. 6). The gravels are well rounded, variable in sorting, and often show lateral and vertical grain size variations. The composition of the gravels (mainly carbonate) will be discussed in Chapter 4.

This facies occurs as planar, lensoid, or discontinuous bodies, with an undulatory erosional base, and a sharp, non-erosional to gradational contact with overlying sandstone facies (fig. 5). The gradation to sandstone is characterized by the appearance of sandstone lenses, which increase in size and number until the conglomerate disappears. Units of this facies are up to 4m in thickness, with an average of 1m. The Matrix-supported Gravel facies is only found in the rocks of the Riversdale group at Broad Cove (fig. 5) and corresponds to Miall's facies 6ms (Table 1).

This facies is interpreted to be a deposit produced by a gravity flow. The presence of a high proportion of matrix material supporting the clasts of this gravel suggests that these units were not deposited by normal stream flow, as sediments of such contrasting grain sizes do not normally

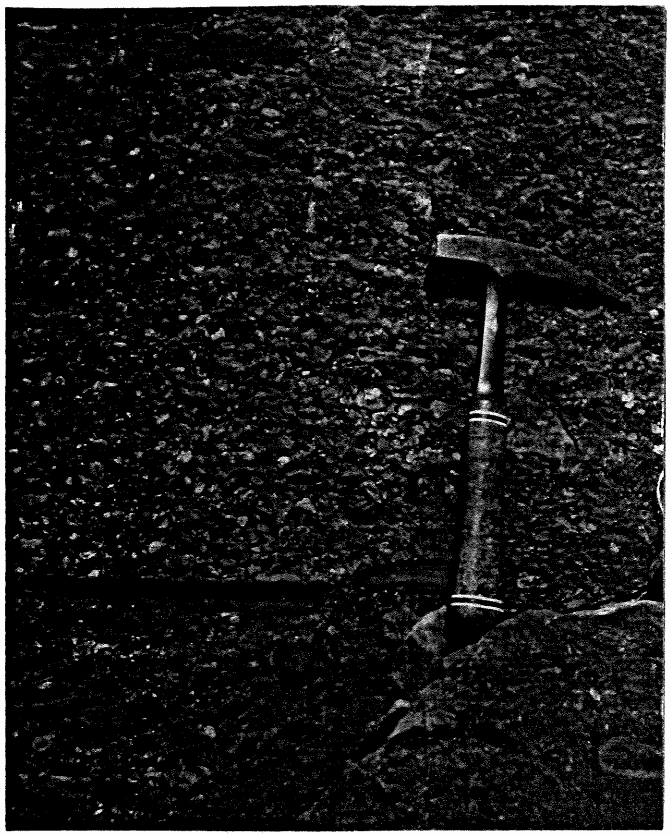


Figure 6. Matrix supported conglomerate.

deposit from flowing water at the same time. A gravity flow origin is further suggested by the poor sorting of the clasts. The consistent imbrication of the elongate clasts shows that the deposition must be the result of flowage, and not rock falls.

3.4 Rippled Sandstone Facies

This facies is composed of a fine sandstone containing a variety of asymmetric ripple types. Ripple amplitude is less than 5 centimetres. Ripple type is largely dependent on sediment supply and flow velocity (Miall, 1977), with small-scale ripple-drift cross-stratification, ripple trains, climbing ripples, and planar cross bedding all present within the section. This facies occurs as continuous beds ranging from a few centimetres to 2m in thickness, and extending laterally from 1m to several ten's of metres. This facies shows several contact types, the form of which is dependent on the surrounding facies. These contact relationships are shown in figure 5. This facies corresponds to lithofacies 5r of Miall's classification system (Table 1). The Rippled Sandstone facies is found in both the Canso and Riversdale strata at Broad Cove (fig. 5).

The sedimentary structures present in this facies indicate that the sediments were deposited under lower flow regime conditions. It has been recognized that flow rate and water depth are major factors in determining the size and type of sedimentary structures developed in a sandstone (Selley, 1979). Laboratory experiments have shown that small-scale ripples are developed in shallow water with low flow velocities (fig. 7).

3.5 Massive Sandstone Facies

The Massive Sandstone facies is composed of fine-grained sandstone in which no sedimentary structures can be recognized. This facies occurs as thick beds or lensoid units, and more rarely occurs within single broad concave-up erosional surface. The boundaries of this facies may be erosional, gradatronal, or sharp and non-erosional, depending on their relationship to other facies. These contact relationships are detailed in figure 5. Beds of this facies range in thickness from 10cm to 2m, and are laterally continuous from 1m to several tens of metres. The rare concave up erosional surface in which this facies occurs are between 5 and 10m in width, with a maximum thickness of 0.5m. This facies is present in both the Canso and Riversdale strata at Broad Cove, with units found within the broad erosional surfaces being restricted to the Riversdale rocks (fig. 5).

The interpretation of the hydraulic conditions of this facies is difficult due to the lack of sedimentary structures. It has been noted by Selley (1981) that true massive sand deposits are rare, and that many seemingly massive sandstones have sedimentary structures which cannot be seen due to a

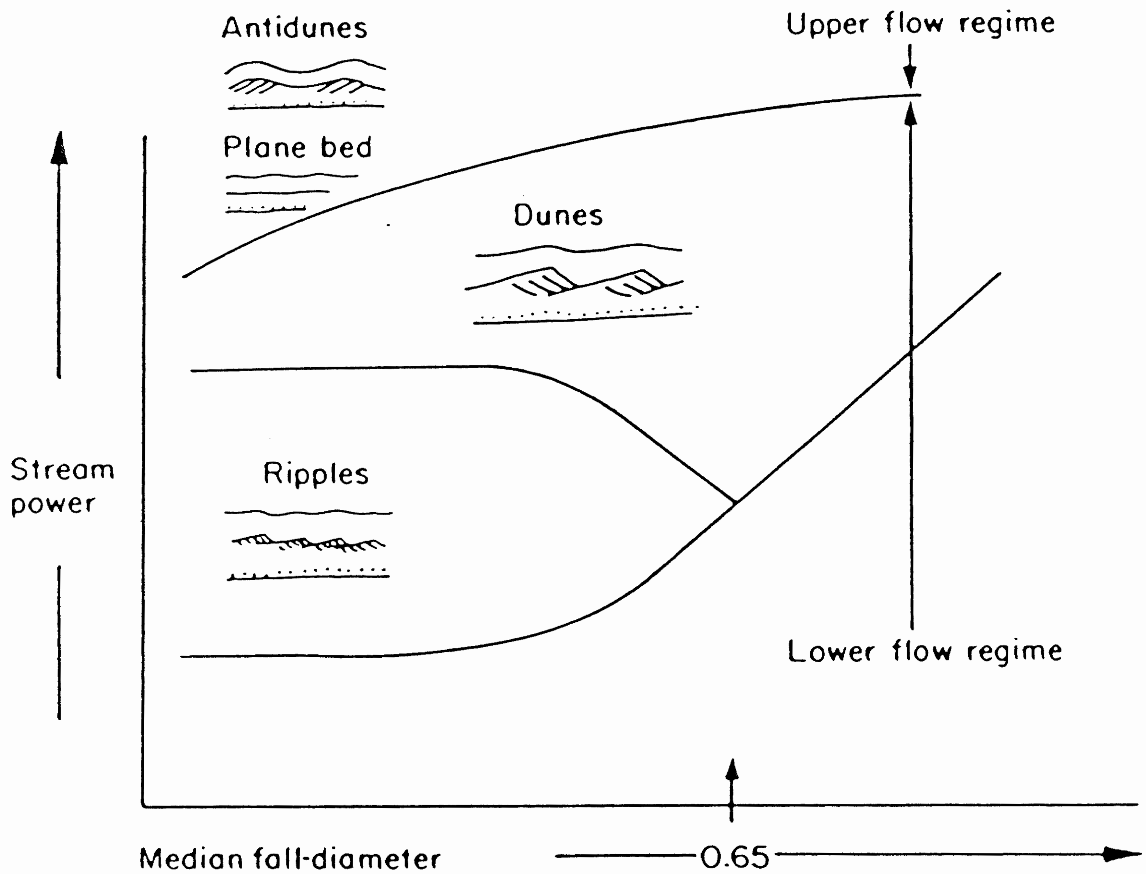


Figure 7. Relationship between stream power, fall diameter, and bedform and sedimentary structures. (From Selley, 1981)

lack of textural or color visibility. Alternatively, sedimentary structures may have been destroyed after sedimentation by processes such as de-watering, compaction, or bioturbation. Because sedimentary structures are visible in the other sandstone facies it is unlikely that lack of color or textural visibility is the cause of the massive form. This also rules out burial compaction as a cause, as all of the sandstone facies would be affected by such a process. It is unlikely that bioturbation would occur in a fluvial environment, and there is no evidence to support this cause. Thus the probable cause of the massive form of this facies is the de-watering of the sediments. This would be the result of very rapid deposition, supported by the presence of de-watering structures in some units of the Sheet Sandstone facies (discussed below). Because sedimentary structures are not seen, the hydraulic conditions which produced this facies may be suggested through the interpretation of flow conditions of overlying and underlying facies into which the massive sandstone grades. For this reason, the hydraulic conditions which produced this facies must be deduced from facies assemblages.

3.6 Trough Cross-stratified Sandstone Facies

This facies consists of fine-grained grey sandstone showing large-scale trough cross-stratification. These trough cross-strata occur in groups, with widths of troughs ranging from 50cm to 3m, and individual trough sets being 2 to 10 cm thick. Trough cross-stratification is visible on both the wave-cut platform and on the cliff face. The Trough Cross-stratified sandstone facies occurs as thick beds, with a sharp, non-erosional basal contact on the Matrix-Supported Gravel facies, or erosionally on all other facies. This facies always grades up into other sandstone facies, or is cut by an overlying unit of Matrix-Supported Gravel (fig. 5). Units of this facies range in thickness from 1 to 4m, with an average of 2m. This facies corresponds to Miall's St facies (Table 1), and is found only within strata of the Riversdale at Broad Cove (fig. 5).

This facies is interpreted to represent deposition of sediment under moderate flow and depth conditions. The large size of the trough cross-strata indicates that they were formed by the migration of dune-size bedforms. Laboratory experiments have shown that dune bedforms will form in a sandstone under lower flow regime conditions (fig. 7)(Selley, 1981).

3.7 Sheet Sandstone Facies

The sediments which compose this facies consist of thin beds of red sandstone, or less commonly siltstone (fig. 9). Sedimentary structures found within this facies include small-scale trough cross-stratification, planar cross-beds, and ripple-drift cross-lamination. The sheet sandstone facies occurs as broad thin sheets within thick mudstone units, having a gradational base on sandstone facies, or a sharp non erosional base on mudstone (fig. 5). The units of this facies generally fine upwards into the overlying mudstones, although erosional contacts do occur where the facies is cut by other sandstone facies. Individual units range in thickness from 2 to 70cm, with an average of 40cm, and often occur in stacked groups. The facies is restricted to the Canso strata of Broad Cove (fig. 5), and is similar to Miall's Fl lithofacies (Table 1).

This facies is interpreted to represent periods of active flow, with flow conditions declining with time. The small-scale sedimentary structures indicate low flow regime conditions (fig. 7), with the gradation upward through silt to mudstone representing a decline in carrying power of the water. The mudstone represents the final settling of clay-sized particles from still water.

3.8 Horizontally Laminated Sandstone Facies

This facies consists of fine-grained horizontally laminated red sandstone. Due to the lack of exposure of upper or lower lamination surfaces, primary current lineations were observed only in one location. Units of this facies occur as thin beds, with the boundary type related to the facies which overlie and underly the unit. These contact relationships are described in figure 5. This facies has an average unit thickness of 25cm, with little lateral variation. The Horizontally Laminated Sandstone facies is present only in the Canso strata (fig. 5), and corresponds to Miall's Sh lithofacies (Table 1).

The Horizontally Laminated Sandstone facies is interpreted to represent deposition in upper flow regime conditions. It has been shown that under high flow velocities, in relatively deep water, sediment is transported and deposited in horizontal beds (fig. 7)(Selley, 1981).

3.9 Disturbed Sandstone Facies

The Disturbed Sandstone Facies consists of a massive, poorly consolidated, muddy fine sandstone which contains a high proportion of coalified plant fragments (fig. 8). The material which composes the facies is generally more highly weathered than the surrounding sandstone, and is stained yellow due to the weathering of pyrite which is present in association with the coal fragments. This facies occurs as small, isolated, irregular lensoid bodies within other sandstone facies. Contacts of this facies are sharp and non-erosional (fig. 5). The mean thickness of units of this facies is 50cm, with a width of between 2 and 10m. This is a minor facies, and is restricted to the Riversdale strata (fig. 5).

The poor sorting of the material which composes this facies, the random orientation and deformed nature of the

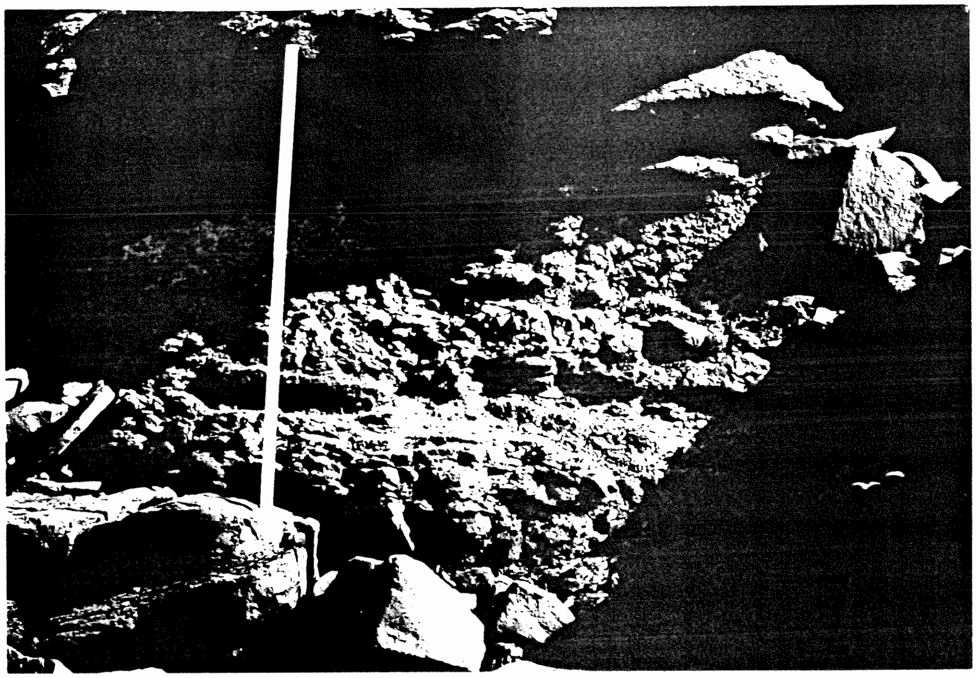


Figure 8a. Disturbed sandstone body. Note the sharp contrast in composition when compared to the surrounding material. (Metre stick for scale.)

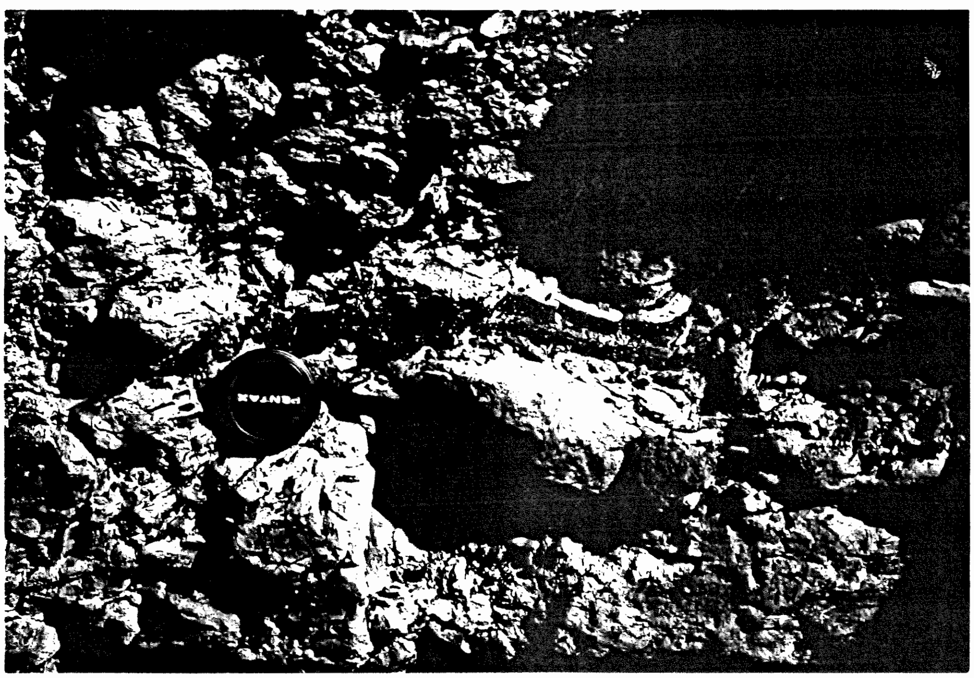


Figure 8b. Close up of Disturbed Sandstone facies showing coalified plant fragments.

plant fragments, and the lack of bedforms, which may be present in the surrounding facies, all suggests that this facies not represent deposition from water, or by gravity flow, but is the result of deposition by gravity in the form of a fall. However, compaction of the woody fragments during burial may have disrupted the original sedimentary features.

3.10 Bedded Mudstone Facies

This mudstone facies is composed of bedded red mudstone, which may contain bands of nodules which extend across the exposure (fig. 9). These nodules range in size from 2 to 20 cm, with the smaller sizes being generally spherical, and the larger sizes becoming increasingly elongate and flattened. The composition of both the mudstone and nodules will be discussed in the following chapter. The mudstone commonly shows green mottling, which tends to increase upward, often becoming predominantly just below erosional surfaces. This facies also contains some laminae, with a similar green color, which extend completely across the exposure. Slight changes in color, as well as the laminae define the beds of the mudstone. The weathered surface of the mudstones shows a conchoidal fracture pattern. Very rare mudcracks are the only sedimentary structure found within the mudstones. Units of this facies are broad and thick, containing one or more individual beds. The basal contact of units is gradational, and the upper contact sharp or erosional (fig. 5). Both individual beds

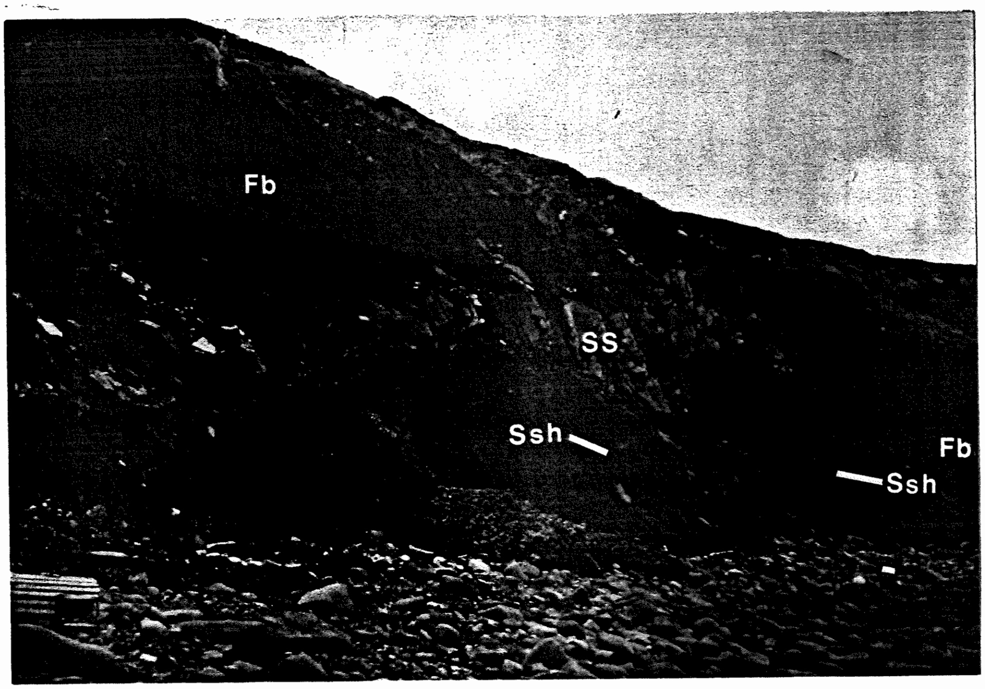


Figure 9. A portion of the Canso section showing the Bedded Mudstone facies (Fb), the Sheet Sandstone facies (Ssh), and a large erosional surface filled by several other sandstone facies (SS).

and units are of variable thickness, but tend to be uniform across section. The average unit thickness is 3m. This facies is found only within the Canso Strata (fig. 5), with all other Canso facies being intercalated with it. The Bedded Mudstone facies is similar to both the Fsc and Fm facies of Miall's system (Table 1).

Since the deposition of mud will only occur under quiet conditions, this facies represents the deposition of clay-sized sediments by settling from non-flowing water.

3.11 Massive Mudstone Facies

This facies is composed of a massive red mudstone which may contain nodules (fig. 10). The Massive Mudstone facies is similar to the Bedded Mudstone facies in appearance, but does not show any internal bedding. Nodules also are not found in distinct bands, but are scattered throughout the units, generally being more numerous in their upper parts. The nodules are irregular in shape, and range in size from 2 to 15cm. The composition of both the nodules and the mudstone will be discussed in the following chapter. The mudstones also show a pattern of green mottling increasing upward, becoming predominant below the upper erosional contact (fig. 10). The Massive Mudstone facies occurs as broad thick beds, or thin discontinuous lenses. Basal contacts of units of this facies are generally sharp, and non-erosional, with upper contacts being undulatory and erosional (fig. 5). Units

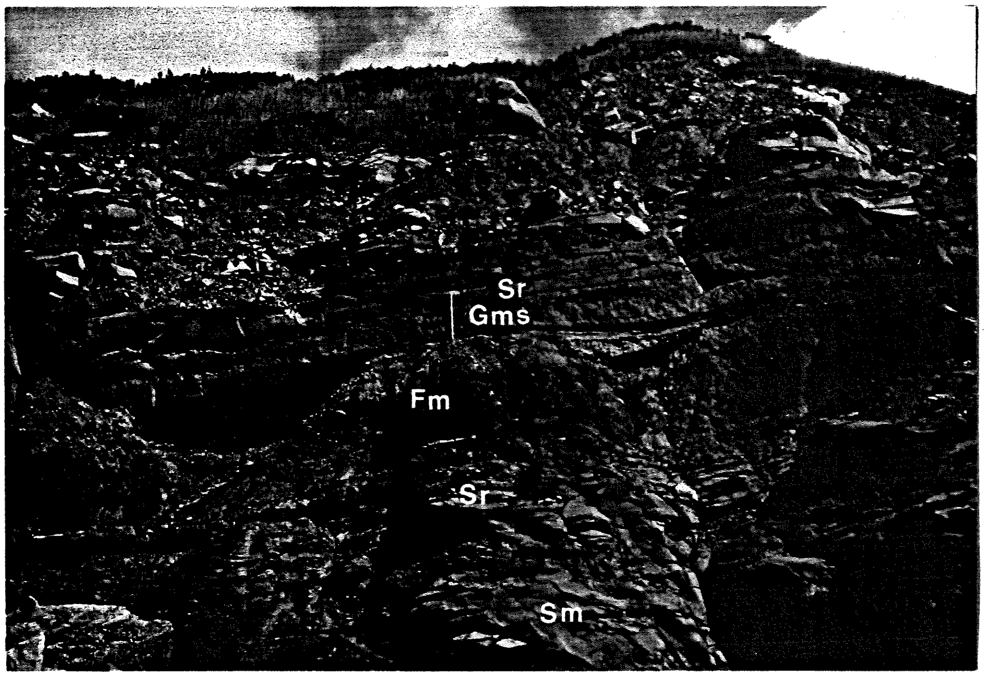


Figure 10. A portion of the Riversdale strata showing Massive Sandstone facies (Sm), Rippled Sandstone Facies (Sr), Massive Mudstone facies (Fm), and Matrix-supported Conglomerate facies. (Meter stick for scale.)

of this facies may reach 5m in thickness, and extend laterally in excess of 50m, but the average thickness is 3m, with units often pinching out laterally. This facies is restricted to the Riversdale strata at Broad Cove (fig. 5) and is similar to Miall's Fm lithofacies (Table 1).

This facies is also composed of material which will only settle from essentially still water, and thus is interpreted to represent deposition from water in non flow conditions.

CHAPTER 4. PETROGRAPHY

4.1 Introduction

A total of 31 samples of representative rock types of both the Canso and Riversdale strata were examined in detail petrographically. From these, fourteen samples of sandstone and conglomerate were thin sectioned and studied. The remaining 17 mudstone, nodule, and conglomerates were analyzed using the x-ray diffraction techniques described in Chapter 1. Detailed petrographic descriptions and x-ray diffraction analysis results are presented in Appendix A, and are summarized in Table 2.

4.2 Canso Mudstone

Illite is the predominant mineral of the mudstones of the Canso strata at Brood Cove. Secondary constituents include quartz and albite, with lesser amounts of hematite, kaolinite, and chlorite. Trace amounts of montmorillonite and calcite are also present. The variations in the red colouration of the mudstones may also be the result of changes in hematite abundance.

4.3 Canso Nodules

The nodules found within the bedded mudstone facies of the Canso are generally finely crystalline. Some contain a core of large calcite crystals which is visible in hand sample. Calcite is the most common constituent, being found in all nodules examined. Dolamite also occurs in some nodules, and where present is also abundant. Quartz and illite are less common, but are present in all nodules examined. Other secondary minerals include kaolinite and hematite. Trace amounts of chlorite and montmorillonite were also detected. Hematite is the probable cause of the red colouration of the nodules.

4.4 Canso Sandstone

In the Canso sandstone, quartz is the predominant grain type, making up 60 to 70% of the thin section. From 5 to 15% of the thin section is composed of grains of chlorite and muscovite in a ratio from 2:1 to 3:1. The samples also contain 5% opaque, and 1% plagioclaise grains. No lithic fragments are found within the Canso sandstones. The grains are well sorted, angular, and of low sphericity, with an average grainsize of 0.08mm.

The matrix is composed of fine clays, though little is present. The cement of these sandstones is composed of hematite, making up from 10 to 15% of the sample. The hematite is deep red brown to opague in transmitted light, and tends to fill most intergranular space, as well as rim quartz grains. Porosity in the sandstones is very low, and no calcite cement is present.

4.5 Canso Conglomerate

The clasts which form the Canso conglomerate are composed almost entirely of limestone. These clasts are of two types: those of calcite alone, and those which have a large number of quartz grains within the calcite clasts. The clasts compose 55% of the thin sections, with 90% of these being composed of calcite alone. The calcite which forms the clasts is generally finely crystalline, though some clasts have a core of large calcite crystals. These clasts are poorly sorted, subrounded, have a moderate sphericity, and range in size from 1 to 15 mm, with an average of 3mm. The similarity in composition and structure of the conglomerate clasts and the nodules found in the Bedded Mudstone facies suggests that the clasts of the conglomerate were derived from the erosion of the nodule-bearing mudstones.

The matrix of the conglomerate consists of quartz grains similar to those found in the sandstones. These grains make up less than 5% of the thin section. The lack of matrix results in the conglomerate being clast-supported.

The cement of the conglomerate is composed of calcite and hematite, each forming 10% of the total thin section. The calcite forms as coarse crystalline overgrowths on the clasts. Hematite rims the clasts, with accumulations located both at the base and top of the calcite overgrowths, indicating multiple stages of cementation. The conglomerates of the Canso are highly porous, with up to 20% of the thin section being void space. The presence of well-developed crystal faces of calcite overgrowths indicate that the porosity existed prior to calcite cementation, but it cannot be determined if the porosity is primary, or the result of dissolution of a previous cement.

4.6 Riversdale Mudstone

The composition of the mudstones of the Riversdale is quite variable. In all samples illite is abundant. Some samples are also abundant in quartz and albite, with the proportion of illite being correspondingly reduced. Those mudstones in which illite is the only common mineral, contain less abundant quartz, and only trace ammounts of albite. Other secondary minerals include kaolinite, chlorite, and hematite, with calcite and montmorillonite also present in trace amounts. The hematite is the probable source of the red colour of these rocks.

4.7 Riversdale Nodules

Some nodules of the Riversdale massive mudstone facies have a visible core of coarsely crystalline calcite, but in general the nodules are microcrystaline. Calcite is the only abundant mineral present in the samples analyzed. Secondary constituents include quartz and illite, with lesser ammounts of kaolinite, chlorite, albite, and hematite. The red coloration of the nodules may be due to the presence of the hematite.

4.8 Riversdale Sandstone

Quartz is the dominant grain type in the Riversdale sandstones, composing 70-80% of the thin section. Chlorite and mica grains make up between 15 and 25% of the thin section. Of these, chlorite is predominant with lesser amounts of biotite, and minor muscovite present. Both plagioclaise and opaque mineral grains are also present, but these compose less than 5% of the thin section.

The grains are well-sorted, angular, with low sphericity, and an average grain size of 0.11mm. Little matrix, and no cement or pore space is visible in thin section. The predominantly quartzose composition and the lack of staining minerals result in this sandstone being grey in color. Staining of hand samples indicates a lack of calcite.

4.9 Riversdale Conglomerate

The clasts which compose the Riversdale conglomerates are of two types, those composed largely of calcite, and those consisting of clays cemented by calcite. The calcite clasts are most common, comprising between 25 and 30% of the thin sections. These clasts are highly variable, being coarsely to finely crystalline, with crystal size varying within the clasts. The clasts may contain from 0 to 30% quartz, and are commonly stained red brown, due to the presence of hematite. The micaceous clasts are less numerous, being less than 20% of the total clasts present. They are composed of up to 80% mica flakes, with lesser amounts of quartz, and calcite cement. The clasts are poorly sorted, well rounded, and have a moderate to high sphericity.

The clasts are supported within a matrix which forms from 30 to 40% of the thin section. This matrix is composed almost entirely of quartz, with minor amounts of mica, feldspar, and opaque grains. This matrix is similar to Riversdale sandstone, being angular, well sorted, having low sphericity, and an average grain size of 0.1mm. The matrix is poorly compacted, being largely supported by the calcite cement. This indicates that cementation occurred shortly after deposition, before lithostatic loading could cause further compaction. The calcite cement composes 30 to 40% of the thin section, and is generally very finely crystalline. Porosity of the conglomerates is very low due to the infilling of open spaces by cement. Again, the similarity in composition and structure between the conglomerate clasts and nodules found in both mudstone facies indicates that these nodules are the source of the clasts. It cannot be determined however, whether these nodule are derived from the erosion of Riversdale mudstones, Canso mudstones, or both.

4.10 Petrographic Comparison of Canso and Riversdale

A comparison of the major rock types of both the Canso and Riversdale strata exposed at Broad Cove is given in Table 2. The most obvious feature shown by this table is the

PETROGRAPHIC SUMMARY

CANSO		RIVERSDALE	
Mudstone:			
Abundant	- Illite	Abundant	- Illite ± Quartz & Albite
Less Common	- Quartz & Albite	Less Common	- ± Quartz
Trace	- Kaolinite, Chlorite Hematite, Calcite, & Montmorillonite	Trace	- Kaolinite, Chlorite, Hematite, Montmorillonite, ± Albite
Nodules:			
Abundant	- Calcite ± Dolomite	Abundant	- Calcite
Less Common	- Quartz & Illite	Less Common	- Quartz & Illite
Trace	- Kaolinite, Chlorite Albite, Hematite, Montmorillonite	Trace	- Kaolinite, Chlorite, Albite, Hematite
Sandstone:			
Grains	- 60-70% Quartz	Grains	- 70-80% Quartz
	- 5-15% Chlorite & Muscovite		- 15-25% Chlorite, Biotite, & Muscovite
	- Angular		- Angular
	- Low Sphericity		- Low Sphericity
	- 0.08mm average		- 0.11mm average
Matrix	- Little present	Matrix	- Little present
Cement	- Hematite	Cement	- Silica
	- 15% of total		- Little present
Conglomerate:			
Clasts	- 55% of total	Clasts	- 35% of total
	- Calcite & Calcite-Quartz types		- Calcite & Mica-Calcite Types
	- 1-15mm in size		- 2-150mm in size
	- Well rounded		- Well rounded
	- Moderate sorting		- Poor sorting
Matrix	- Little present	Matrix	- 30-40% of total
	- Largely quartz		- Largely quartz
Cement	- 20% of total	Cement	- 30-40% of total
	- Calcite & Hematite		- Calcite
Pore Space	- 20% of total	Pore Space	- Little present

Table 2. Petrographic summary of the rocks of the Canso and Riversdale groups examined at Broad Cove.

similarities of the rocks of the two groups. Both the Canso and Riversdale mudstone are essentially identical, being composed largely of illite, with lesser amounts of a variety of other minerals. Nodules from both groups are also very similar in composition, although dolomite appears to be restricted to the nodules of the Canso strata. The sandstones and conglomerates of both groups are also similar, although several distinctive features are present. Biotite, which is common in the Riversdale sandstone, is not present in sandstones of the Canso, whereas the reverse is true for hematite, which is abundant in the Canso sandstone, and absent in the Riversdale. The Riversdale sandstones also have a larger average grain size than those of the Canso. The clasts of the Riversdale conglomerates are generally larger, and more poorly sorted than those of the Canso. Matrix material, which is not abundant in the Canso, makes up a large proportion of the Riversdale conglomerates. Hematite cement is restricted to the conglomerates of the Canso.

CHAPTER 5. CANSO GROUP SEDIMENTATION

5.1 Canso Group Facies Assemblages

5.1.1 Introduction

In general, facies defined in the field will give ambiguous interpretations if analyzed separately. The key to interpretations is to analyze groups of facies which tend to occur together in consistent proportions in a vertical sedimentary sequence. By examining the relationship between these facies, an environment of deposition may be interpreted for a sedimentary sequence. From the stratigraphic data collected at Broad Cove (fig. 11), facies associations were identified in both the Canso and Riversdale strata (fig. 12). Within the Canso strata studied at Broad Cove, two facies assemblages have been identified, the Coarse Member facies assemblage, and the Fine member facies assemblage.

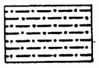
5.1.2 Coarse Member Facies Assemblage

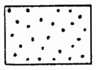
The Coarse Member facies assemblage makes up only 20% of the total Canso strata (fig. 11), and is composed of the following facies: the Massive Conglomerate facies, the Planar Laminated Sandstone facies, the Massive Sandstone facies, and the Rippled Sandstone facies. Although all of the facies are not present in one location, they each occur with several others at various locations (fig. 12). By examining the relationships between the facies, it can be shown that in a continuous sequence containing all of the

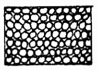
SYMBOLS

LITHOLOGY

 MUDSTONE

 SILTSTONE

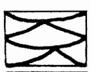
 SANDSTONE

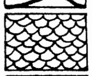
 CONGLOMERATE

COLOR

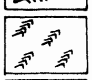
R	RED
Gn	GREEN
Gy	GREY
R+GM	RED With GREEN MOTTLING

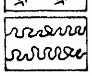
SEDIMENTARY STRUCTURES

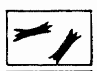
 LARGE SCALE TROUGH X-STRATA

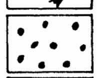
 SMALL SCALE TROUGH X-STRATA

 RIPPLES

 CLIMBING RIPPLES

 CONTORTED BEDDING

 FOSSIL PLANT FRAGMENTS

 NODULES

 MUDSTONE LENS

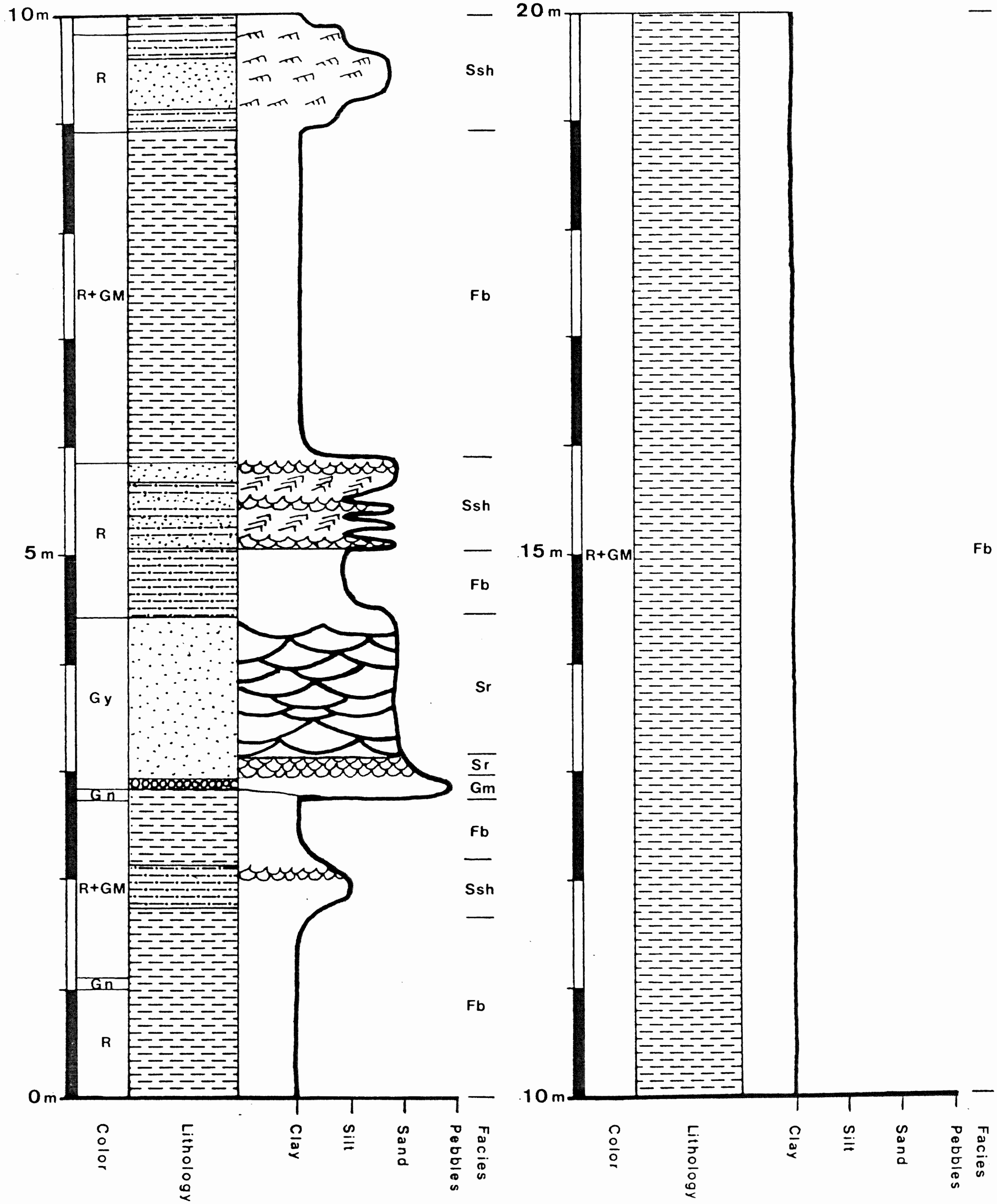
 SILTSTONE LENS

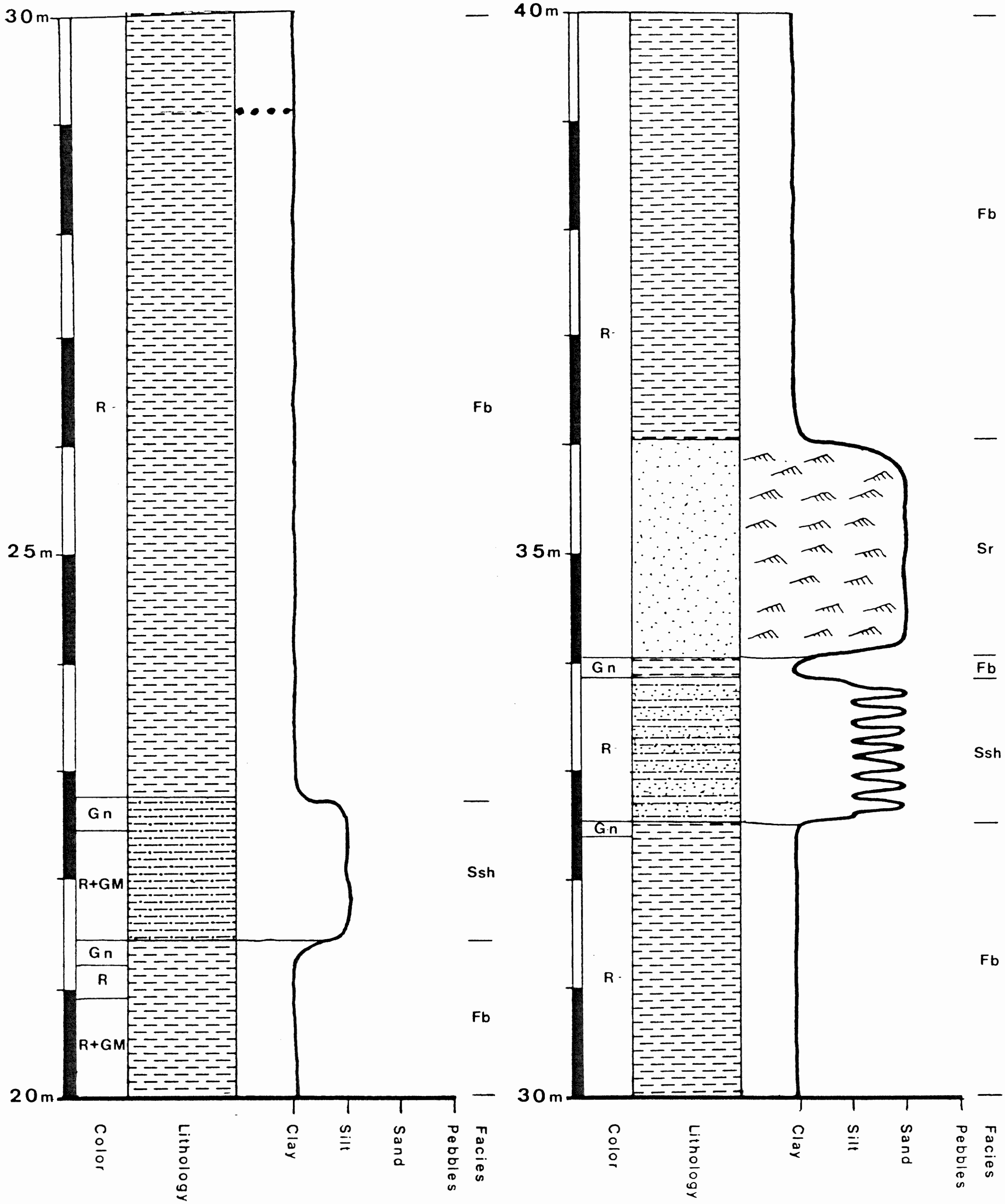
 SANDSTONE LENS

 CONGLOMERATE LENS

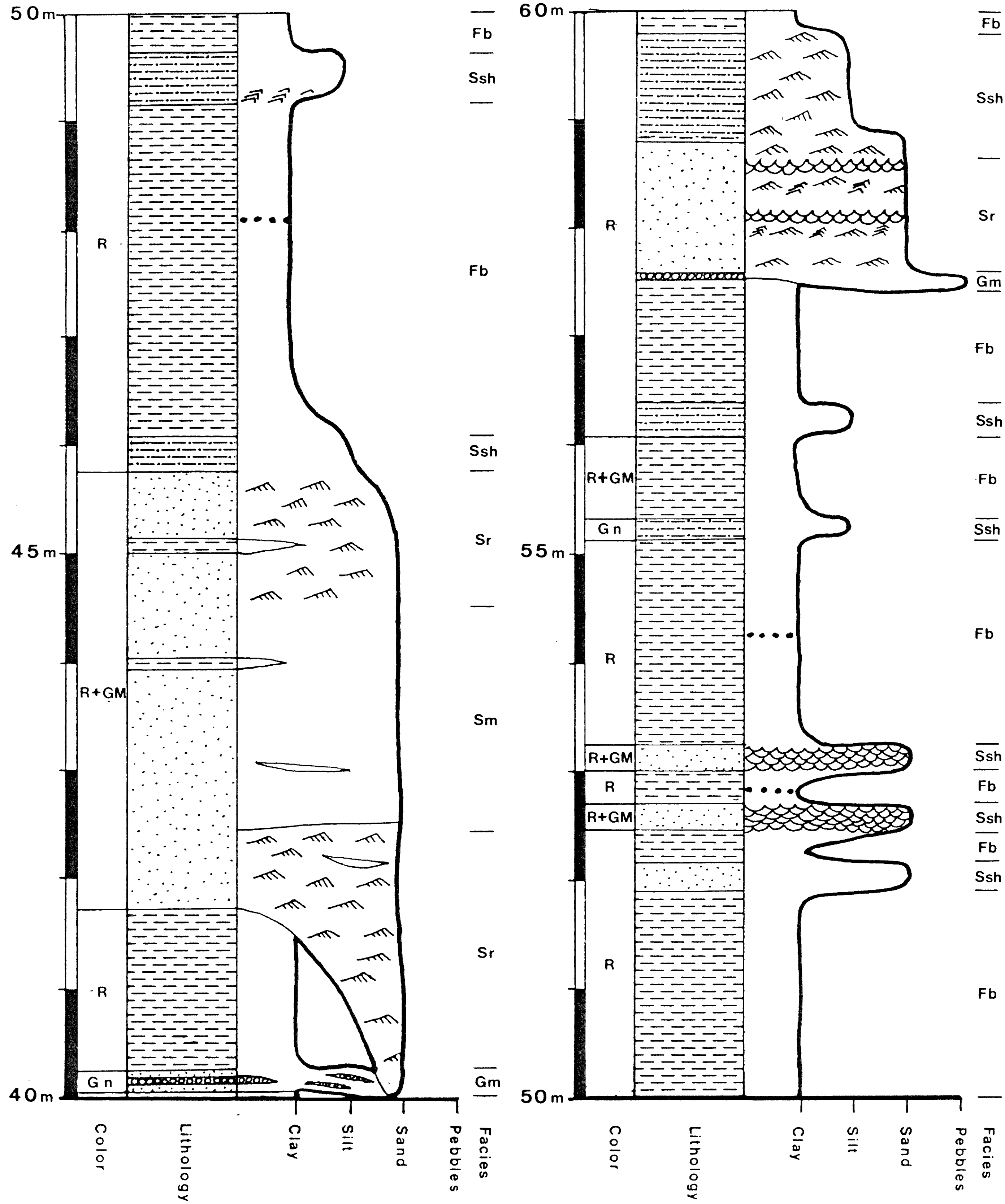
FACIES

Fb	BEDDED MUDSTONE	Fm	MASSIVE MUDSTONE
St	TROUGH X-STATIFIED SANDSTONE	Sh	HORIZONTALLY LAM. SANDSTONE
Sm	MASSIVE SANDSTONE	Ssh	SHEET SANDSTONE
Sr	RIPPLED SANDSTONE	Sd	DISTURBED SANDSTONE
Gms	MATRIX-SUPP. CONGLOMERATE	Gm	MASSIVE CONGLOMERATE


10m
R
R+GM
R
5 m
Gy
Gn
R+GM
Gn
R
0m
Ssh
Fb
Ssh
Fb
Sr
Sr
Gm
Fb
Ssh
Fb
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
20 m
15 m
R+GM
10 m
Fb
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies



30m
R
Fb
25m
Gn
R+GM
Ssh
Gn
R
R+GM
Fb
20m
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
40m
Fb
R
Sr
35m
Gn
Fb
R
Ssh
Gn
R
Fb
30m
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies


50m
45m
40m
Fb
Ssh
R
Fb
Ssh
Sr
R+GM
Sm
Sr
R
Gn
Gm
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
60m
55m
50m
Fb
Ssh
R
Sr
Gm
Fb
Ssh
R+GM
Fb
Gn
Ssh
R
Fb
R+GM
Ssh
R
Fb
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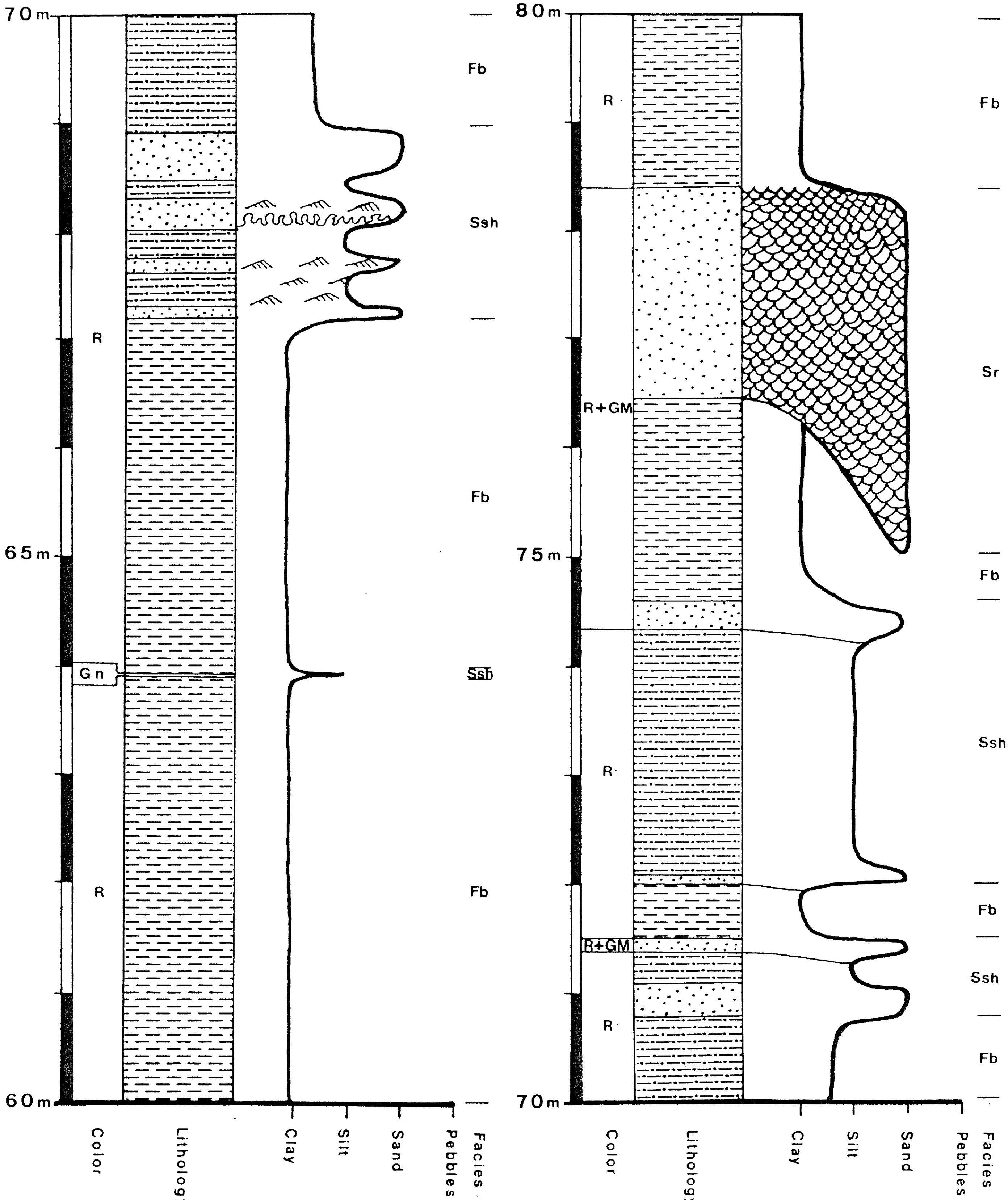
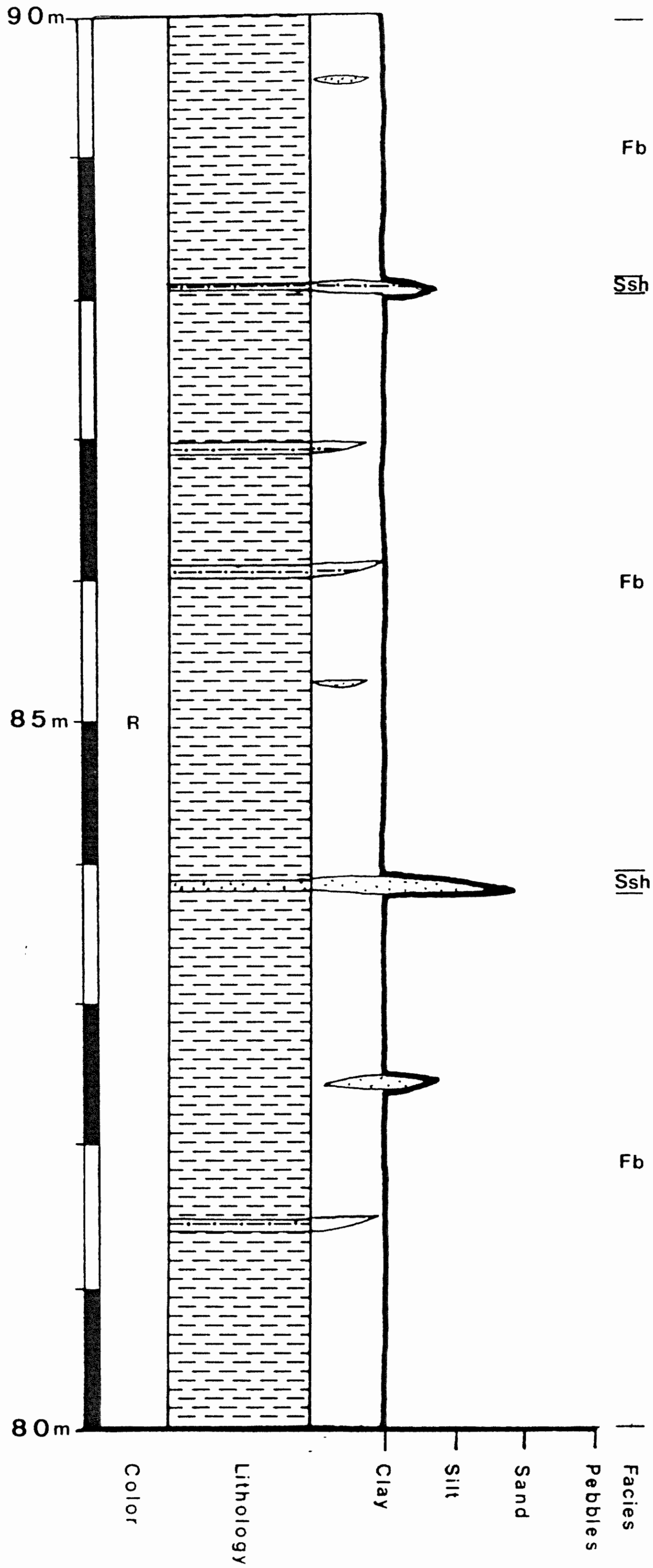
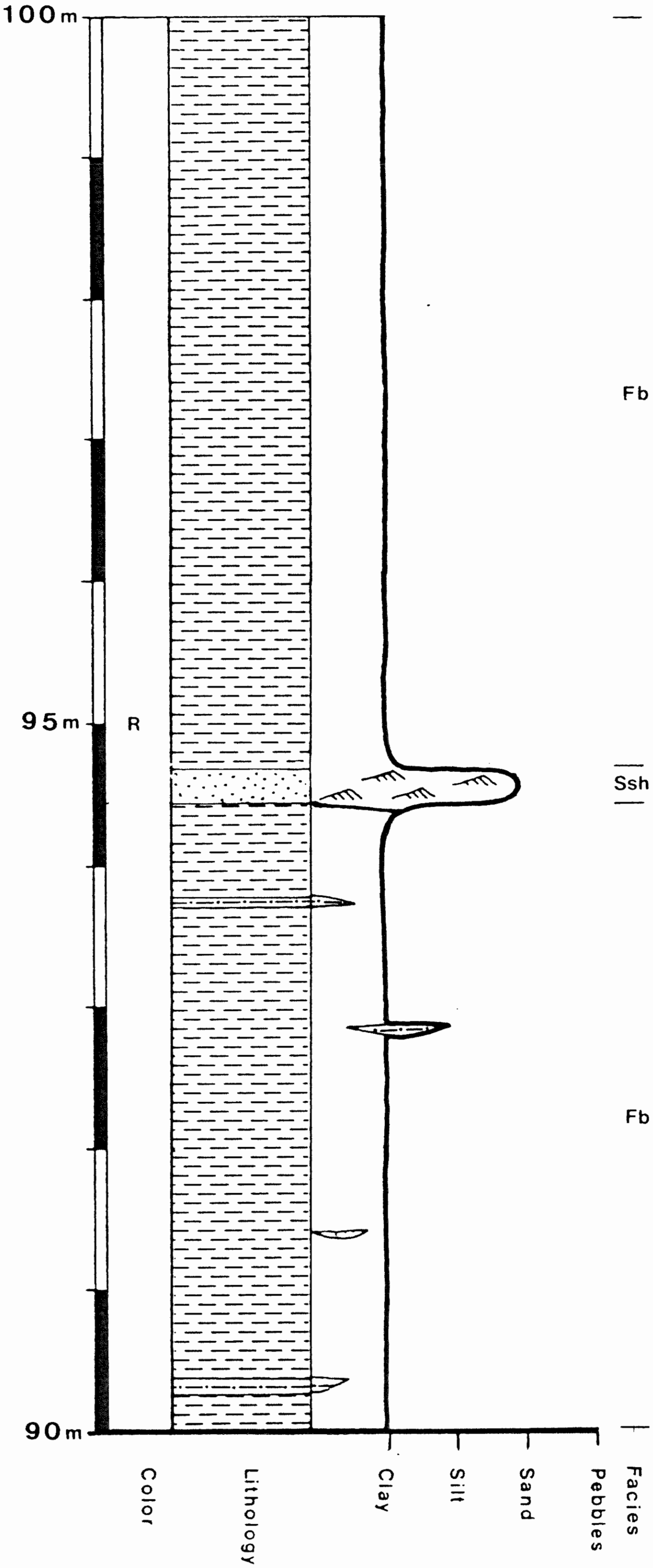
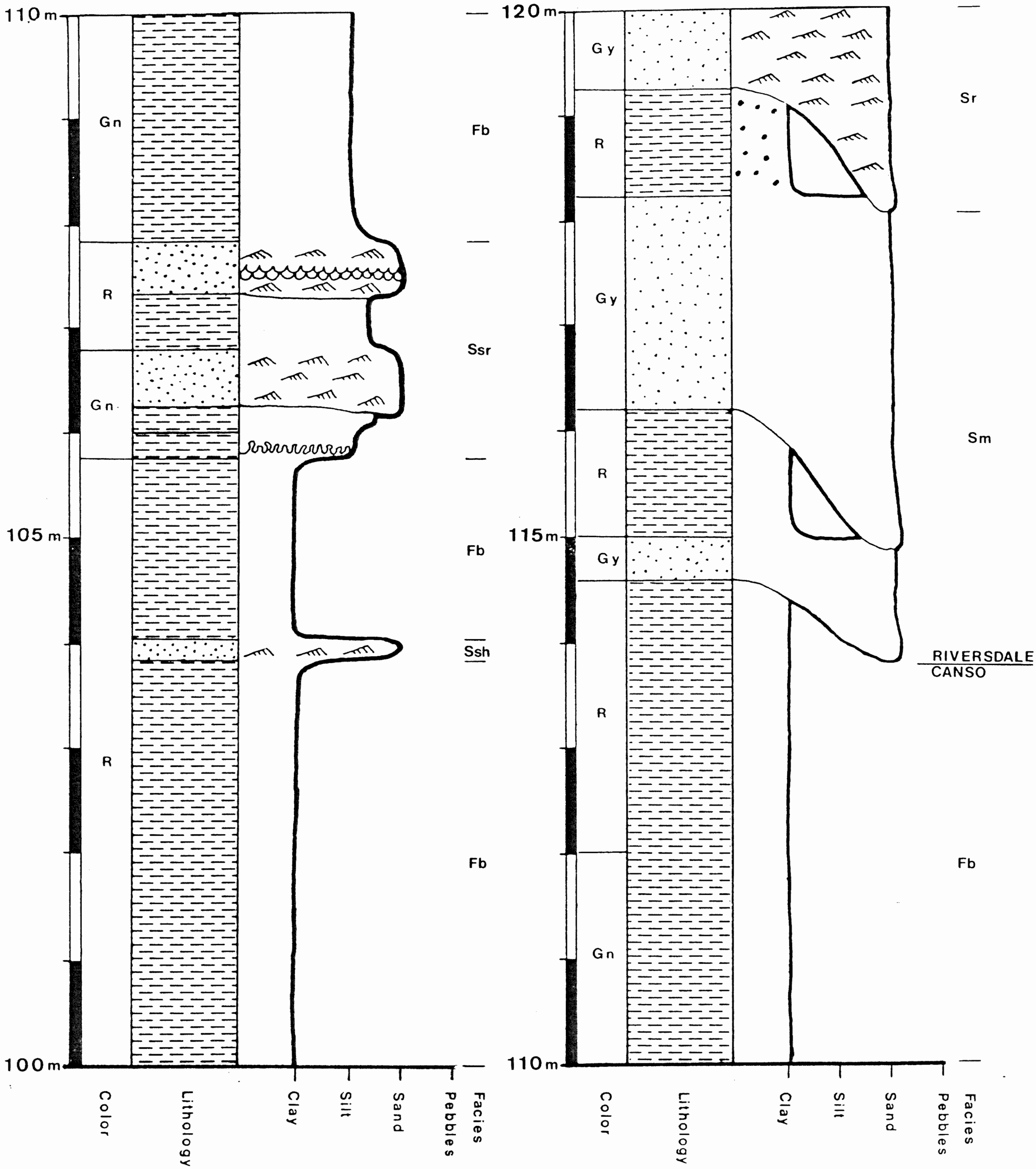
Ssh
Fb
Ssh
R
Fb
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies

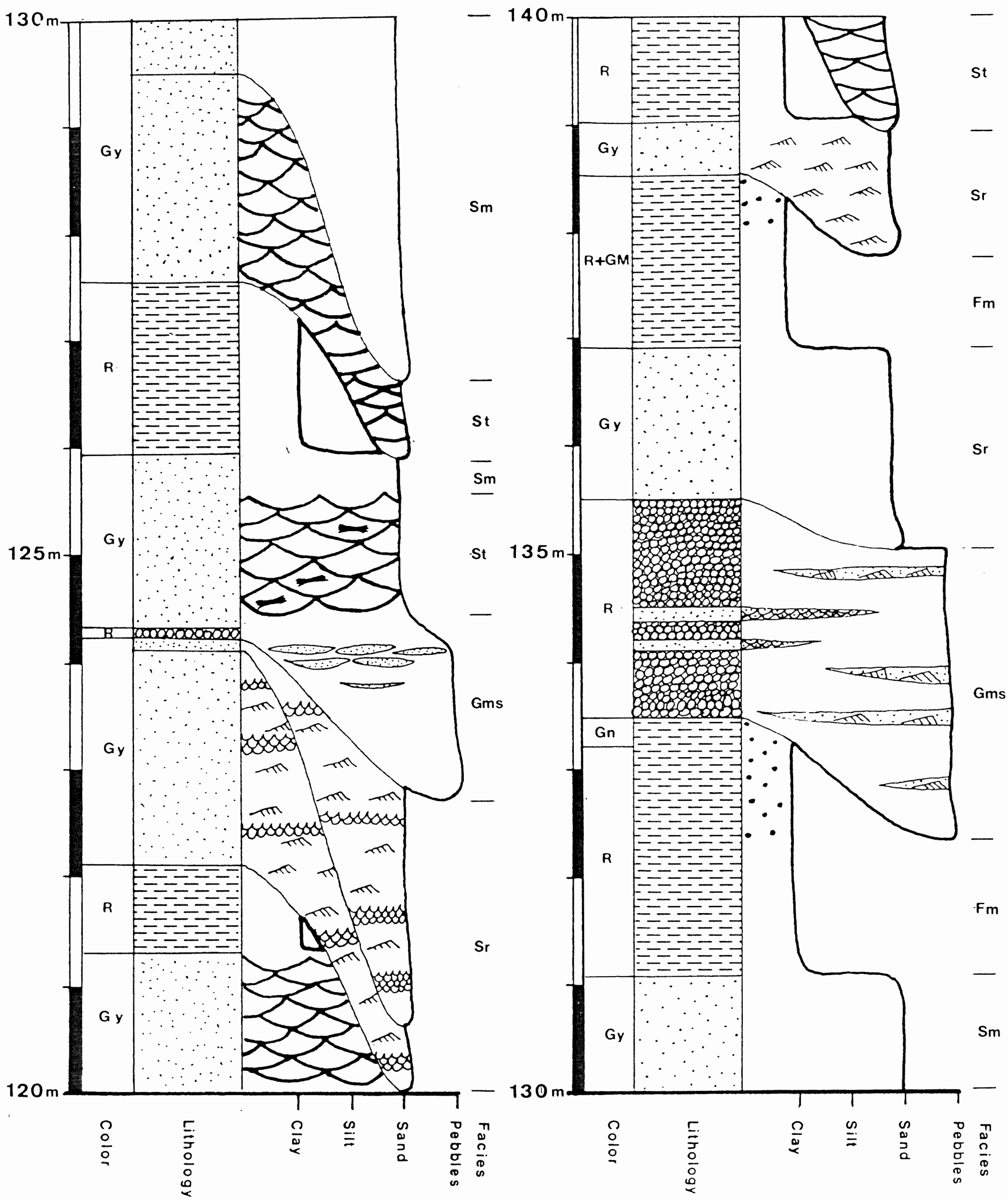

70 m
Fb
Ssh
R
Fb
65 m
Gn
Ssh
R
Fb
60 m
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
80 m
R
Fb
Sr
R+GM
75 m
Fb
Ssh
R
Fb
R+GM
Ssh
R
Fb
70 m
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies

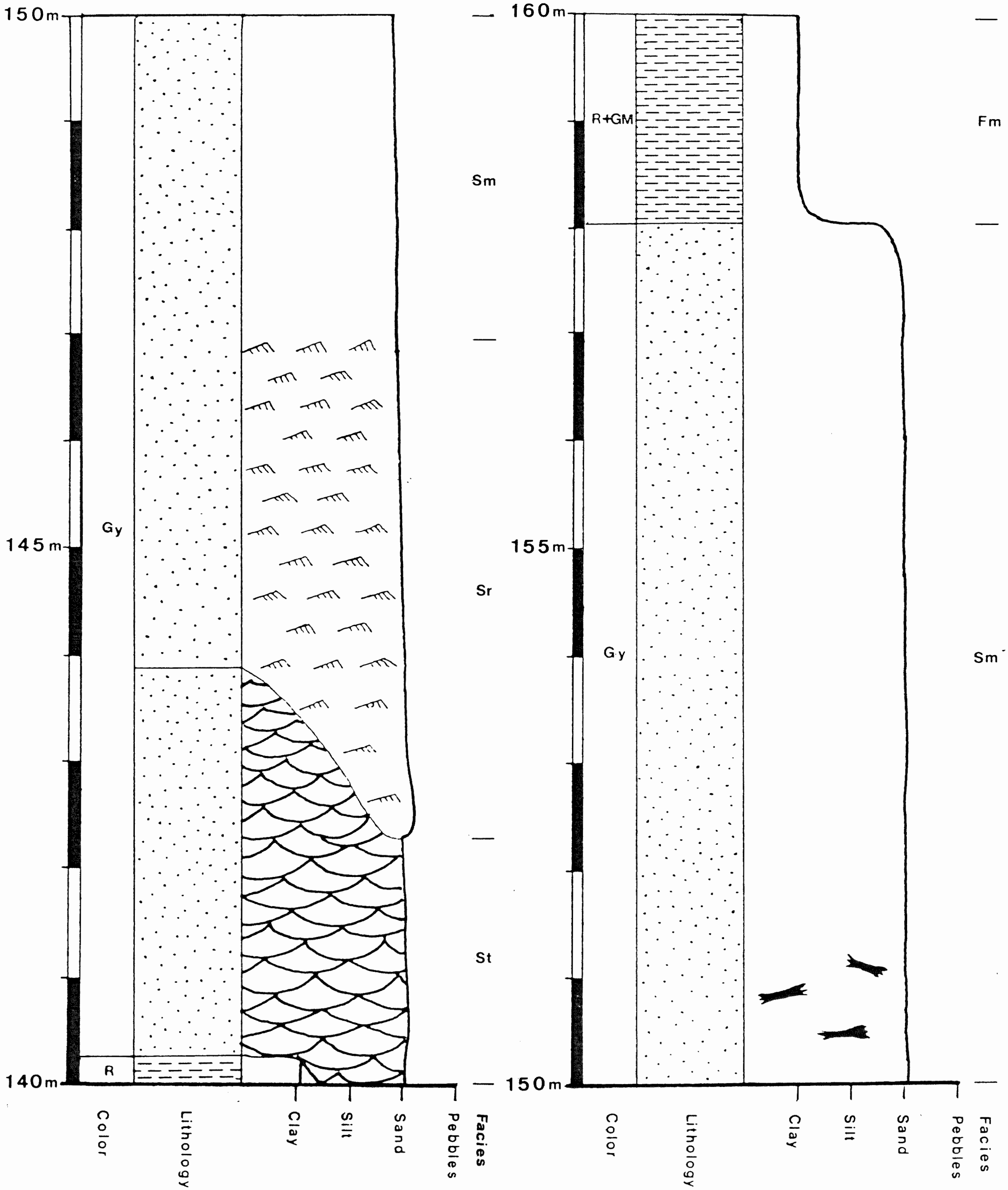

90m
85m
80m
R
Fb
Ssh
Fb
Ssh
Fb
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies

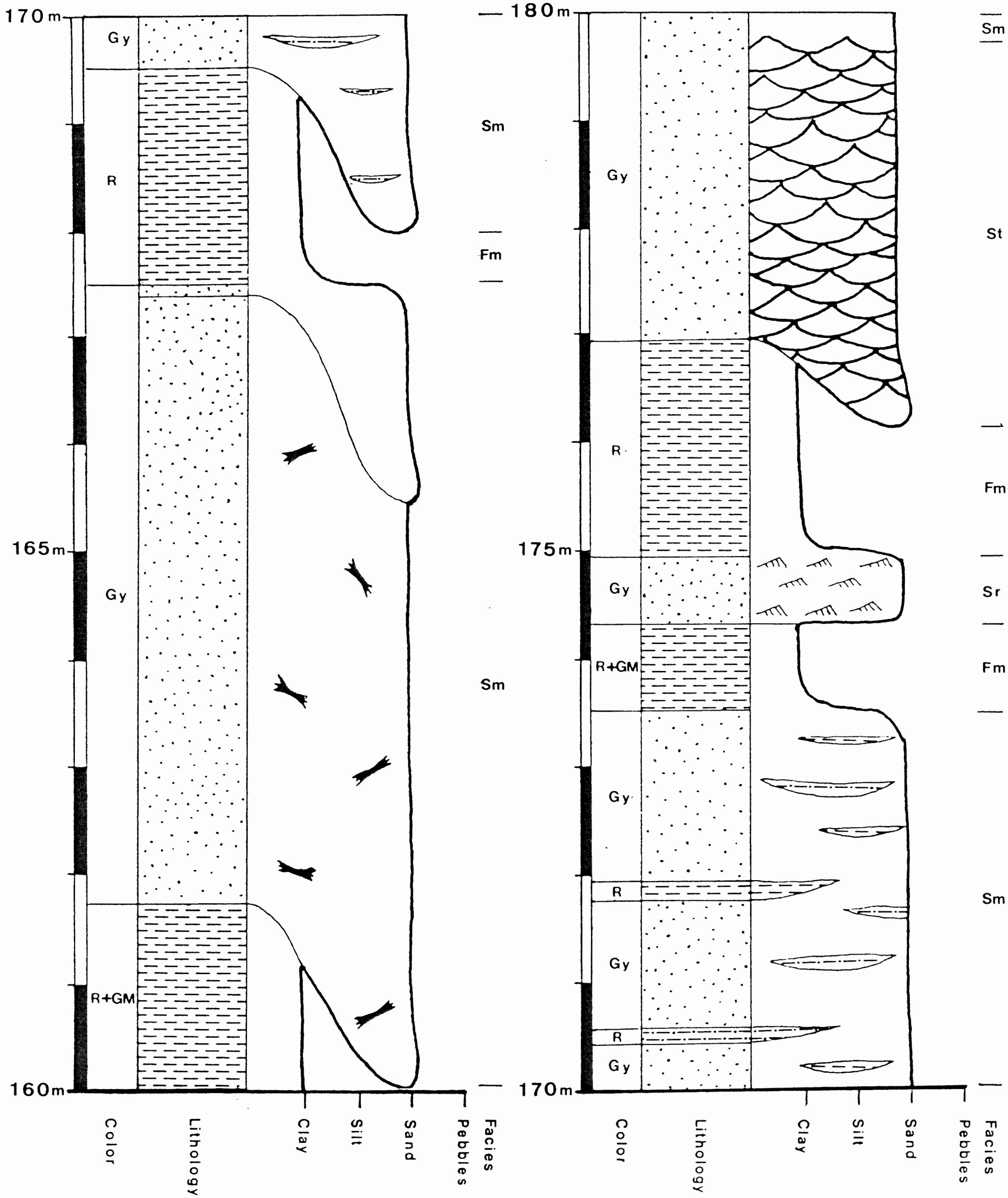

100m
95m
90m
R
Fb
Ssh
Fb
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies



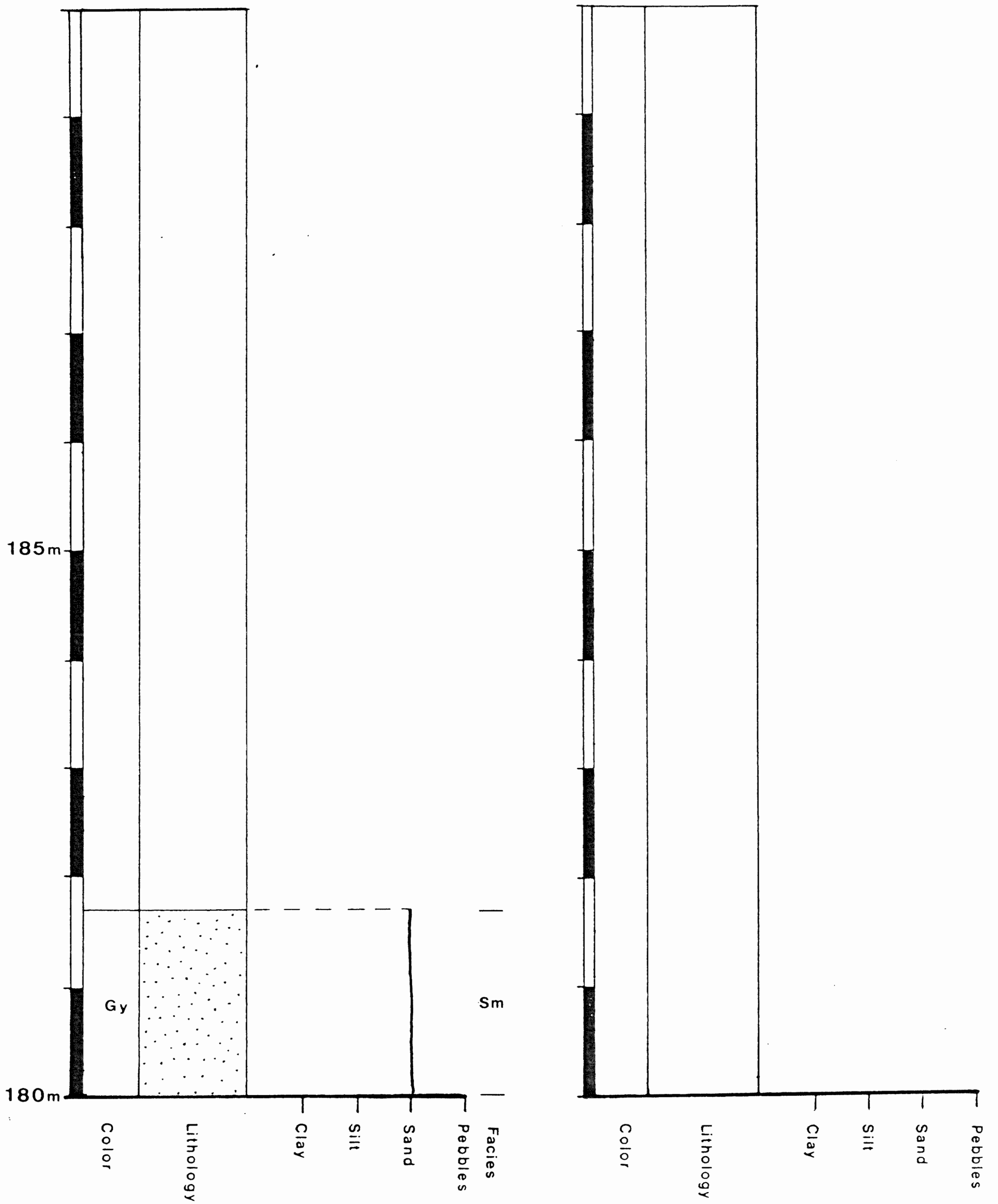
110 m
105 m
100 m
120 m
115 m
110 m
Gn
R
Gn
R
Gy
R
Gy
R
Gy
R
Gn
Fb
Ssr
Fb
Ssh
Fb
Sr
Sm
Fb
RIVERSDALE
CANSO
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies


130m
125m
120m
Gy
R
Gy
R
Gy
R
Gy
Sm
St
Sm
St
Gms
Sr
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
140m
135m
130m
R
Gy
R+GM
Gy
R
Gn
R
Gy
St
Sr
Fm
Sr
Gms
Fm
Sm
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies


150m
145m
140m
Gy
R
Sm
Sr
St
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
160m
155m
150m
R+GM
Gy
Fm
Sm
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies



170m
Gy
R
Gy
R+GM
165m
160m
Sm
Fm
Sm
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
180m
Gy
R
Gy
R+GM
Gy
R
Gy
R
Gy
175m
170m
Sm
St
Fm
Sr
Fm
Sm
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies


185m
180m
Gy
Sm
Color
Lithology
Clay
Silt
Sand
Pebbles
Facies
Color
Lithology
Clay
Silt
Sand
Pebbles

SYMBOLS

LITHOLOGY

- MUDSTONE
- SILTSTONE
- SANDSTONE
- CONGLOMERATE

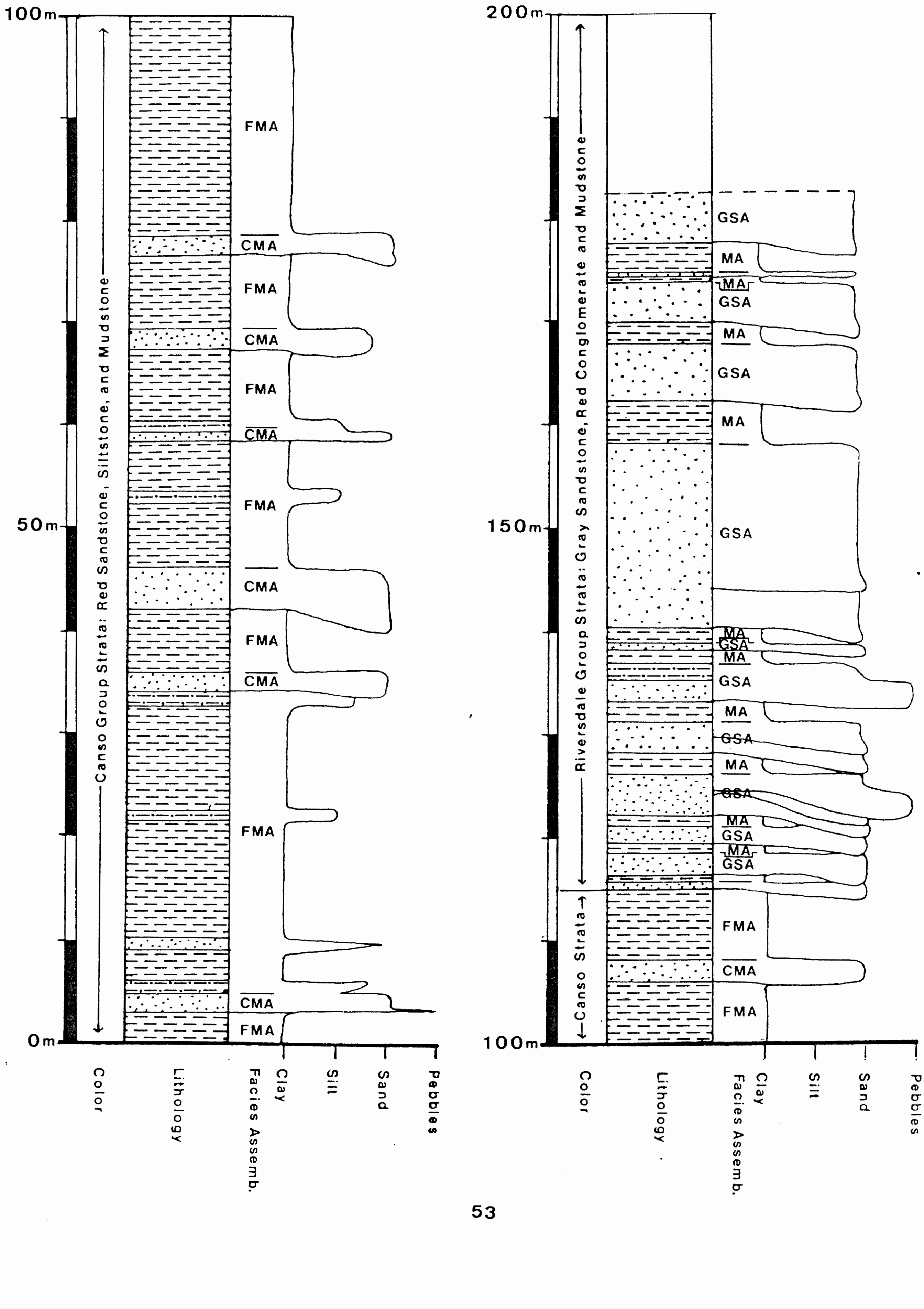
COLOR

R	RED
Gn	GREEN
Gy	GREY
R+GM	RED with GREEN MOTTLING

FACIES ASSEMBLAGE

CMA	COARSE MEMBER (Canso)
FMA	FINE MEMBER (Canso)
GSA	GRAVEL-SAND (Riversdale)
MA	MUDSTONE (Riversdale)

Figure 12. General summary of measured section stratigraphy.



100m
50m
0m
Canso Group Strata: Red Sandstone, Siltstone, and Mudstone
FMA
CMA
Color
Lithology
Facies Assemb.
Clay
Silt
Sand
Pebbles
200m
150m
100m
Canso Strata
Riversdale Group Strata: Gray Sandstone, Red Conglomerate and Mudstone
GSA
MA

facies the following sequence will occur: 1) erosional base overlain by a thin unit of massive gravel, 2) a thin unit of horizontally laminated sandstone, with the contact between these units being sharp and non erosional, 3) a thin unit of massive sandstone having a gradational base, 4) a thick rippled sandstone unit with a gradational basal contact, 5) the Fine Member facies association having a gradational basal contact. This pattern, and the approximate thickness and proportions is shown in figure 13.

5.1.3 Fine Member Facies Assemblage

This assemblage makes up 80% of the total Canso strata at Broad Cove (fig. 12). It consists of only two facies, the Bedded Mudstone facies, and the Sheet Sandstone Facies. The Bedded Mudstone is by far the predominant facies (fig. 11), making up almost 90% of the assemblage (fig. 13). Typical sequences of this assemblage would consist of thick units of bedded mudstone interbedded with thin sheets of sandstone having a sharp non-erosional base, and a gradational top. These sandstone sheets often occur in stacked sequences. This pattern, along with average thicknesses and proportions is shown in figure 13. The Fine Member facies assemblage overlies, underlies, and surrounds the Coarse Member facies assemblage as discussed in the following section.

5.2 Fluvial Architecture

The Canso strata studied at Broad Cove are composed

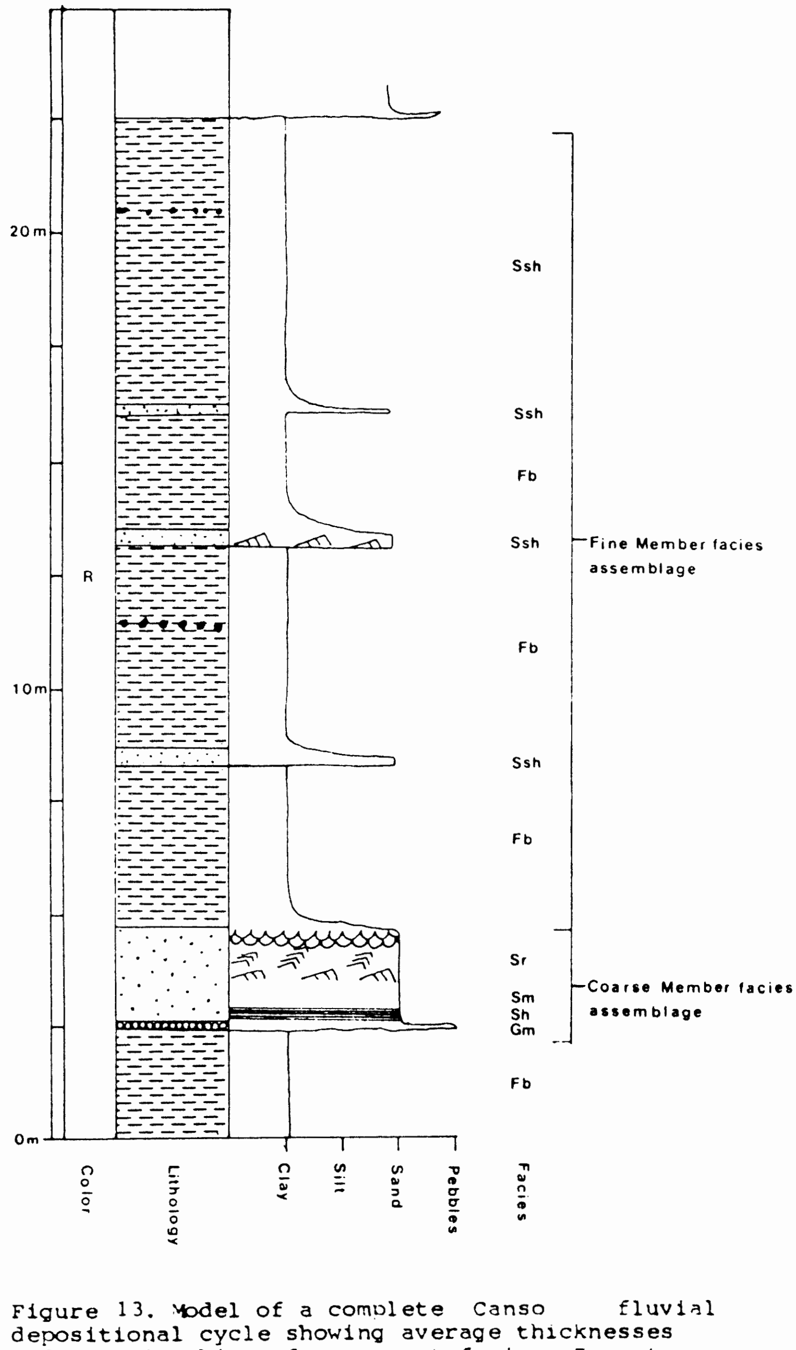


Figure 13. Model of a complete Canso fluvial depositional cycle showing average thicknesses and relationships of component facies. In outcrop 1 or more of the facies is commonly missing.

largely of the Fine Member facies assemblage which is continuous throughout the section. Within this facies assemblage isolated large-scale, broad, concave-up erosional features occur (fig. 9 and 14). These features cut the underlying regularly bedded strata, and are filled by the facies of the Coarse Member facies assemblage. A total of seven of these filled erosional features are present in the Canso section studied. The size is variable, ranging in thickness from 0.8m to 6.8m, and in width from 7 to 60m (see Table 3). In all cases the erosional contact is sharply defined (fig. 9 and 14), with the Fine Member facies assemblage both underlying and surrounding the erosional feature.

In the four largest features the infilling material is composed of a complex stacked sequence of two or more units of the Coarse Member facies assemblage, which are confined within the erosional surface. In those features less than 3m in thickness, only one sequence of the Coarse Member facies assemblage occurs, generally with one or more of the component facies missing.

The infilled erosional surfaces are well separated vertically, with an average of 18m of Fine Member facies assemblage between each (fig. 11 and 12). There is only one example of two features found at the same stratigraphic level, although the lateral extent of the exposure is limited.

One such infilled erosional surface located at the top of the Canso cliff, 4.4m from the base of the stratigraphic

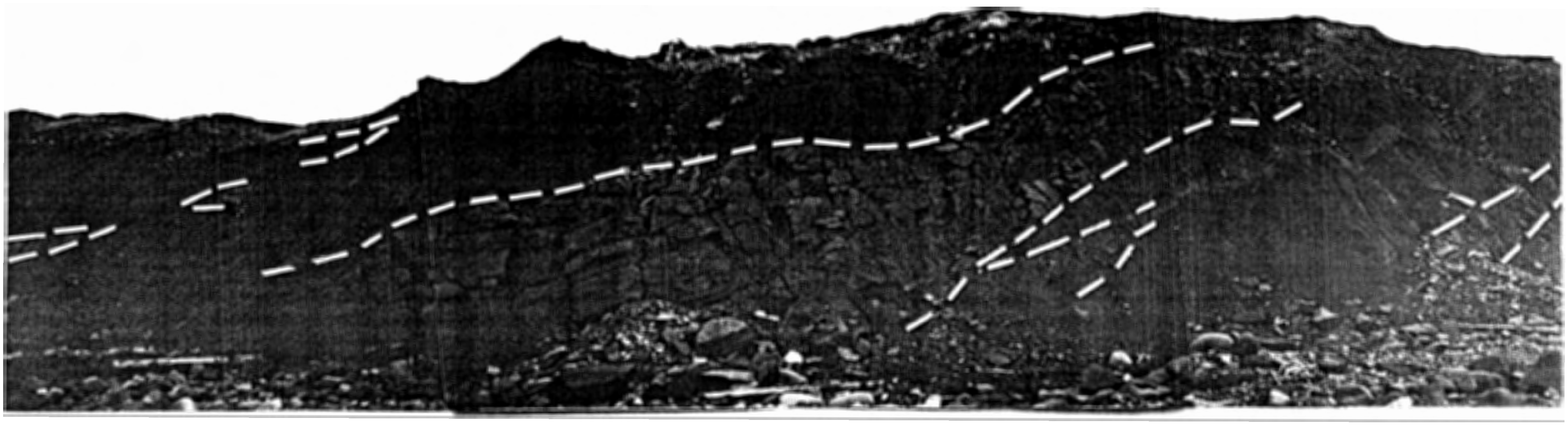


Figure 14. A portion of the Canso section showing several infilled erosional structures (outlined in white). Note that upper contacts of infilled structures are planar, but are distorted by the cliff-face geometry.

column (fig. 11 and 12) rests uncomfortably on the dipping beds of the Bedded Mudstone facies (fig. 15). This feature is 1.5m thick, and is grey in color, in contrast with the red of all other Canso units. It contains plant fragments, and large-scale trough cross-strata, both of which are not found in any Canso unit. Petrographically, the sandstone and conglomerate of this feature is similar in grain size, composition, and cement type, to the rocks of the Riversdale. These properties indicate that this may not be of Canso origin, but it is difficult to explain the presence of this single small feature, 110m stratigraphically below the nearest Riversdale unit.

5.3 Interpretations.

5.3.1 Introduction

The interpretation of a sedimentary sequence should be based on a critical evaluation of all available lines of evidence. The interpretation of the Canso strata of the studied section is based on the geometry, lithology, and sedimentary structures of the component facies.

5.3.2 Canso Paleochannels

A channel is a modern geomorphological feature which can be developed in many modern sedimentary environments. A paleochannel is a feature in ancient rocks which has a channel

Figure 15. Unusual infilled erosional structure of the Canso. Note the dipping mudstone beds below this structure.

form, and whose environment of formation is consistent with modern channel-forming processes.

All of the filled erosional surfaces of the Canso show a regular concave-up erosional base which cuts down into the underlying regularly bedded strata (fig. 9 and 14). These features are filled by the facies of the Coarse Member facies assemblage, all of which have been deposited from flowing water. The surrounding Fine Member facies assemblage was deposited largely during non-flow conditions. This pattern of deposition from flowing water confined within a concave-up erosional surface, which cuts surrounding material, is consistent with channel processes. Thus these filled erosional features are interpreted to be paleochannels, with the erosional base delineating the maximum extent of erosion by the channels, and the sedimentary sequence contained within it representing the later infilling of the channel.

5.3.3 Internal Structure of Canso Channel Bodies

A detailed examination of the internal structure of the paleochannels reveals several trends. The most noticable feature of the paleochannels is the nature of the infill. In the small paleochannels, those less than 3m thick, the channel fill is a continuous sequence with no internal erosional surfaces. This pattern indicates a single infilling event of the channel. Larger channels show an infill consisting of a complex sequence of stacked deposits which are confined within the banks of the channel. This pattern represents a multievent infilling of the channel, with each event represented by an individual sandstone body. The shape of the erosional channel base is not modified by the erosional contacts between sandstone body, suggesting that the channel was formed by a single erosional event, and that subsequent sequences of erosion and infilling, which produced the stacked sand bodies, were confined within the banks of the original channel.

A significant feature of both the single and multi-event channel fills is the lack of lateral accretion sets. This pattern, along with a low width to depth ratio, which will be discussed in a later section indicates that the paleochannels represent simple cut and fill structures, with vertical aggradation, but very little lateral migration through time. Thus each channel represents an event, rather than continuous deposition from a fluvial system, indicating that water flow was periodic rather than continuous through time.

5.3.4 Coarse Member Facies Assemblage

Within the erosional surface which defines the base of the paleochannels, the facies of the Coarse Member facies assemblage are found. An examination of the sequence of these facies (fig. 13) in relation to the hydraulic conditions they represent indicates deposition from waning flow. The erosional base represents maximum flow conditions, when active erosion takes place. The Massive Conglomerate facies, which occurs in only one third of the paleochannels (fig. 10), is interpreted to be a channel-lag deposit, based on its large grain size, its lack of bedding, its lack of matrix, and its association with the central portion of the channel base. Overlying this lag are the sequence of sandstone deposits of the Planar-laminated facies, the Massive facies and the Rippled Sandstone facies, which represents deposition from water of decreasing flow rate and depth (fig. 7).

Each unit of the Coarse Member facies assemblage is interpreted to represent one sequence of erosion followed by infilling by sediments deposited under decreasing flow conditions.

5.3.5 Fine Member Facies Assemblage

Units of this facies assemblage are the host material through which the paleochannels cut, and thus represent the material of the plane on which the channel flowed. Because the paleochannels are not restricted to one horizon, both the paleochannels and surrounding material are of essentially the same age, with both aggrading vertically with time. The Bedded Mudstone facies is interpreted as overbank flood material, deposited by settling from water carried beyond the channel banks during flooding. The sedimentary structures and larger grain size of the sediments of the Sheet Sandstone facies suggest initial higher flow conditions, which wane vertically to the very low flow conditions of the overlying mudstone. This facies is interpreted to represent splay deposits on the floodplain, produced by a breach in the channel bank. The rapid waning of flow is the result of the water spreading over the flood plain after leaving the confining channel. The fact that the Fine Member facies assemblage makes up 80% of the total Canso strata (fig. 13), indicates that the flood plain was a stable aggrading area, through which the periodic channels cut.

5.3.6 Canso Stratigraphy

One of the most obvious traits of a fluvial sedimentary sequence is the ratio of coarse to fine material. Since these materials are deposited by the fluvial system, it is likely that some relationship exists between this ratio, and the nature of the system which produced it.

It has been recognized that in general, meandering channel systems are favored by cohesive channel banks. Schumm (1963) showed a general relationship between the amount of silt and clay in a fluvial deposit, and the sinuosity of the channel (fig. 16). Schumm's study was carried out on 43 streams of the southwestern United States, all flowing in channels formed of alluvium containing less than 10% gravel or larger sediments. These parameters are similar to those of the Canso fluvial deposits. The data (fig. 16) indicate that

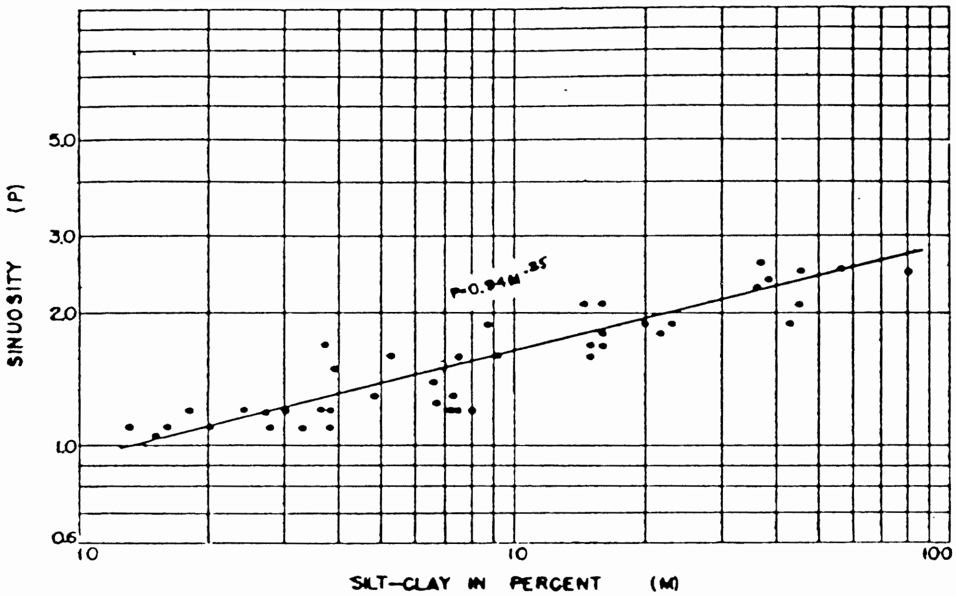


Figure 16. Relationship between sinuosity and percent of overbank deposits (silt-clay). Standard error is 0.059 log units. Correlation coefficient is 0.91. (From Schumm, 1963.)

sinuous channels have a moderate to high silt-clay percentage, and those streams where bank material contains in excess of 30% silt and clay, the channel tends to have a sinuosity in excess of 2.

This relationship allows an interpretation of channel patterns from a vertical section. Because all the clay-silt material of the Canso strata are found in the Fine Member facies assemblage; with only a small proportion being composed of sand, a comparison of the Coarse and Fine Member facies assemblages may be used to determine a probable sinuosity. The Fine Member facies assemblage composes 86% of the total Canso strata at Broad Cove (fig. 13). This very high percentage of fine material gives a probable sinuosity of greater than 2 (fig. 15). A sinuosity in excess of 1.5 is considered to be highly sinuous, typical of meandering or anastomosing fluvial systems (Rust, 1977).

5.3.7 Canso Sandstone Body Morphology

The morphology of a stable fluvial channel is determined in part by the water and sediment which pass through it (Schumm, 1968). In the previously described study of streams, Schumm (1963) determined that a direct relationship exists with increasing sinuosity, and decreasing width to depth ratios (fig. 17). In Schumm's study the width to depth ratios were calculated from measurements taken perpendicular to the channel path, approximately at right angles to flow.

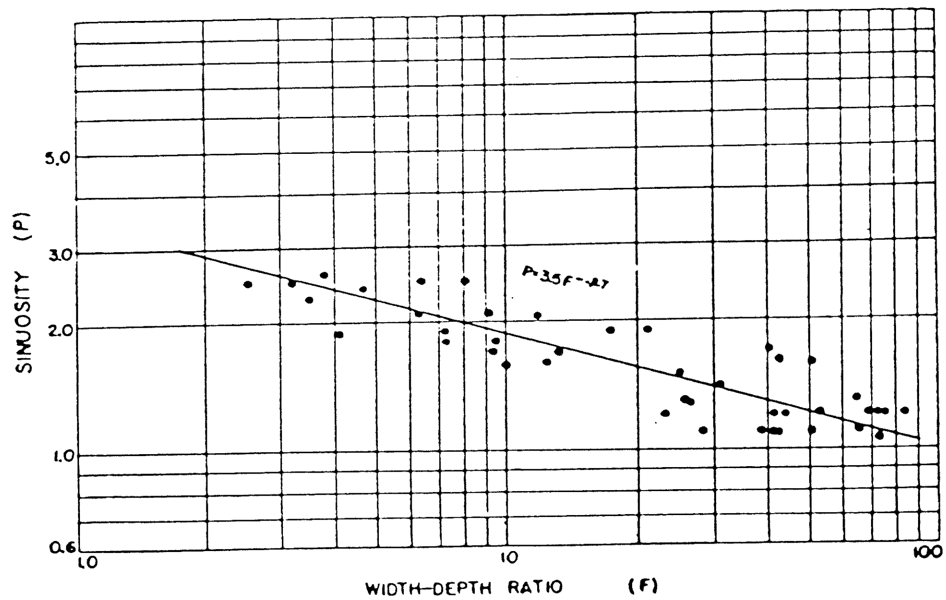


Figure 17. Relationship between sinuosity and width-depth ratio. Standard error is 0.064 log units. Correlation coefficient is —.89.

(From Schumm, 1963.)

	WIDTH	DEPTH	W. to D. RATIO
	40 est.	4.8	8.3
	25	2	12.5
	60 est.	6.3	9.5
	7	1.5	4.6
	16	2	8
	36 est.	4.5	8.3
	5.9	.85	6.9
AVERAGE	27.1	3.1	8.3

Table 3. Dimensions and width to depth ratios of Canso paleochannels of Broad Cove.

The exposure of the paleochannels in the cliff face of Broad Cove is two-dimensional. The lack of paleocurrent data from these channels does not allow apparent widths of channels to be corrected to true widths. Thus the calculated width to depth ratios represent a maximum, with the true value being somewhat less. In three cases, the width of the paleochannel was estimated, as both terminations were not exposed. For these channels the width was estimated using twice the distance from the thalweg the channel termination. These can be considered relatively accurate as all of the other paleochannels are symmetrical about the thalweg.

At Broad Cove, width to depth ratios of paleochannels range from 4.6:1 to 12.5:1, with a mean of 8.3:1 (Table 3). By applying this maximum width to depth ratio to the relationship derived by Schumm (fig. 17), a sinuosity in excess of 1.5 is indicated. A more precise value could be determined, but the scatter of Schumm's data, combined with the use of apparent widths, would produce such a large error that no additional information would be obtained. The value in excess of 1.5 is sufficient to conclude that the paleochannels of the Canso are relatively sinuous in nature.

5.3.8 Canso Petrographic Data

The most prominent petrographic feature of the Canso rocks is the large proportion of hematite cement. Research has shown that little or no hematite is transported from source areas along with other sediments (Van Houten, 1973). Thus hematite cement must be developed in situ, essentially syndepositionally, by the alteration of Fe-bearing minerals. This process requires pervasive oxygenating conditions, and has been shown to be largely restricted to humid and arid parts of the tropics (Pye, 1983).

The presence of hematite coatings between tightly packed grains at Broad Cove, demonstrates the early diagenetic origin of the hematite. This requires the environment which induces the formation of hematite to be present soon after deposition. This indicates a probable arid or humid tropical environment at the time of deposition.

The fresh appearance of unstable grains such as muscovite and feldspar, which tend to after early diagenisis under normal conditions (Millot, 1970), implies a chemically inactive environment. Such conditions would be rare in a humid climate, but common in an arid environment. The presence of carbonate nodules in the mudstones of the Canso also support a hot, arid environment, as they are most characteristic of warm areas with limited precipitation (Goudie, 1983).

5.4 Canso Environment of Deposition

The paleoenvironment is interpreted to be a periodic, sinuous fluvial system developed in hot, semi arid to arid conditions. Periodic downpours produced channel formation, splay deposits, and overbank flooding. Small channels are infilled by sediments deposited during the waning of flow. Waning flow deposition within large channels is insufficient to fill the channel. Subsequent erosional and depositional events eventually filled the channel with a stacked, vertically aggraded sequence of sandstone bodies. Succeeding flood periods produce new channels, and general aggradation of the entire system.

Interpretation is consistent with the conclusions of Howie (1979) for the entire Canso Group, and with the findings of Brown (Personal communications, 1986) for the Canso strata exposed immediately south of Smiths Brook (fig. 1). The findings of Brown (ibid), and this study suggest that the Canso strata at Broad Cove represent a periodic fluvial system prograding into a saline lake in a tectonically stable area (fig. 18). This system is represented by lacustrine deposits in the southern portion of Broad Cove, which gradually pass upward into the fluvial sediments north of Smiths Brook (fig. 1).

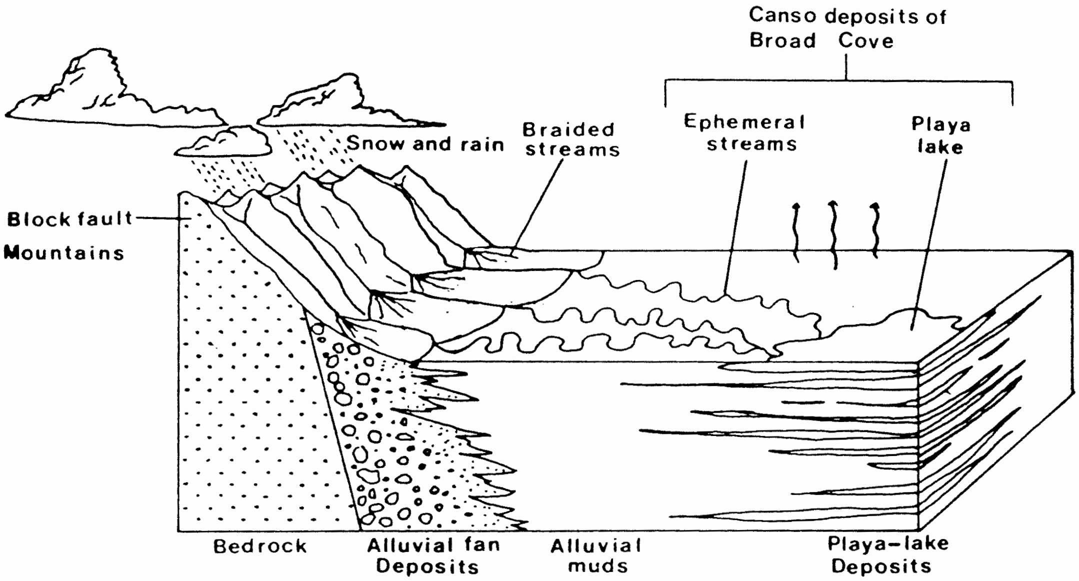


Figure 18. Environment of deposition of Canso strata. (After Egster and Kelts, 1982.)

CHAPTER 6. RIVERSDALE GROUP SEDIMENTATION

6.1 Riversdale Group Facies Assemblages

6.1.1 Introduction

Two facies assemblages have been identified in the Riversdale strata examined at Broad Cove, the Gravel-Sand facies assemblage, and the Mud facies assemblage.

6.1.2 Gravel-Sand Facies Assemblage

The Sand and Gravel facies assemblage makes up 72% of the total Riversdale strata exposed in Broad Cove (fig. 11). This assemblage is composed of the following facies: the Matrix-Supported Conglomerate facies, the Trough Cross-stratified Sandstone facies, the Massive Sandstone facies, the Rippled Sandstone facies, and the Disturbed Sandstone facies. An examination of the associations of these facies throughout the Riversdale strata (fig. 12) indicates a general ordering. In a single unit of the Gravel-Sand facies assemblage containing all of the facies listed, they will occur in the following sequence: 1) the erosional base overlain by a unit of matrix-supported conglomerate, 2) a thick unit of cross stratified sandstone, 3) a thick massive sandstone unit, 4) a thin unit of rippled sandstone, 5) the disturbed sandstone lens is found within one or more of the other sandstone facies.

Also present in many of the sandstone facies are a large number of Calamites plant fragments. The vertical facies pattern, and average thicknesses and proportions are shown in figure 19.

6.1.3 Mudstone Facies Assemblage

This facies assemblage makes up 27% of the total Riversdale rocks (fig. 11), and consists solely of the Massive Mudstone facies (fig. 12). This facies assemblage is barren of fossils or sedimentary structures. Its average thickness, and its relationship to the Gravel-Sand facies assemblage is given in figure 19.

6.2 Fluvial Architecture

Because of the relationship between the strike of the strata and the orientation of the cliff face, the northern portion of the studied section (fig. 1) provides an excellent opportunity to study the large-scale vertical and lateral structure of the Riversdale fluvial deposits. Figure 20 is an accurate diagram of the cliff face, produced from field notes, and a photomosaic. This diagram allows a detailed study of the section as a whole, which would be difficult to carry out from field notes alone. The diagram reveals relationships between sedimentary units on several scales, with the following observations being noted:

1.) The section contains many bodies of the Gravel-Sand facies assemblage (fig. 20). In most cases one or more of the component facies is missing, and the facies

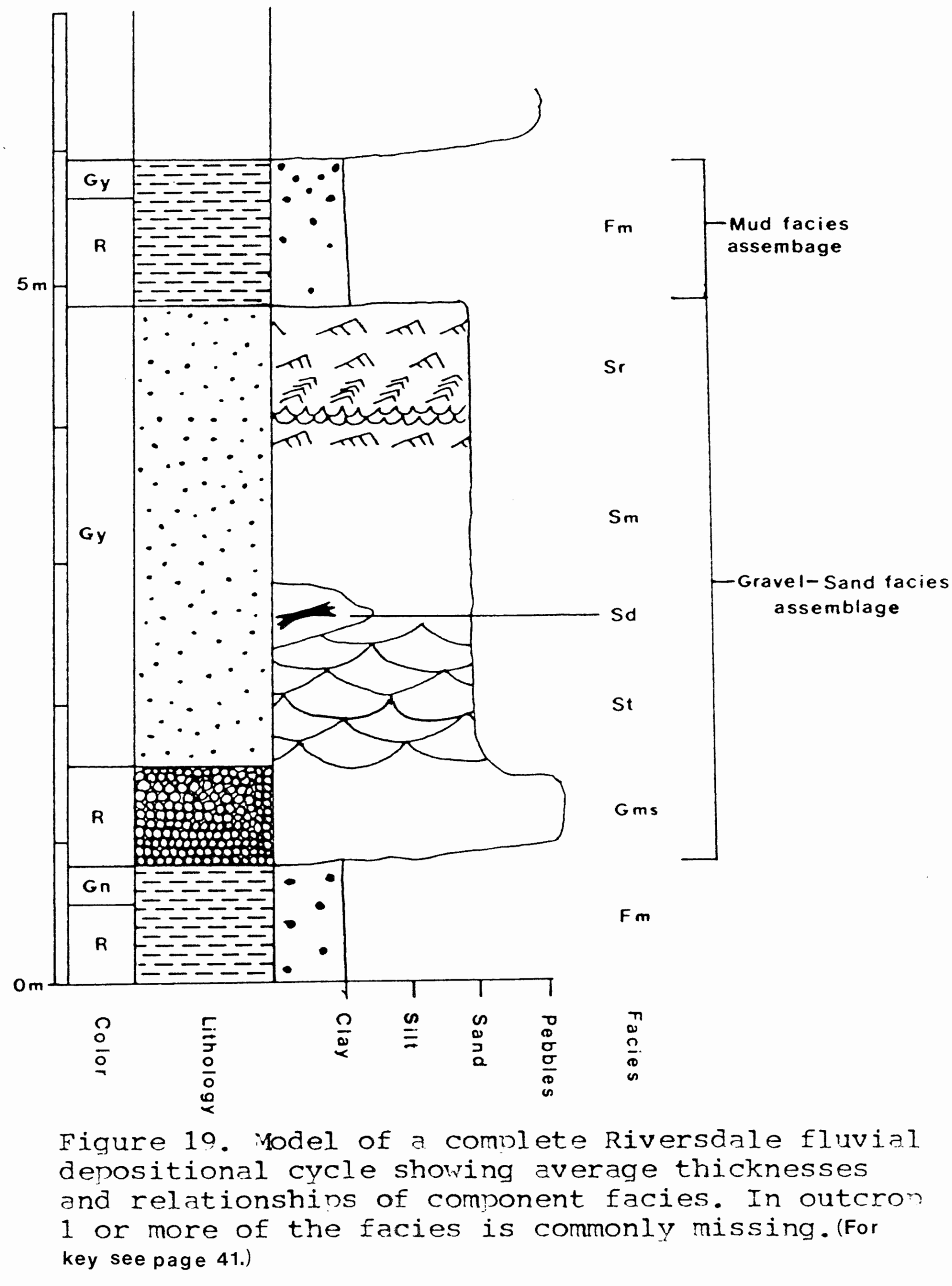


Figure 19. Model of a complete Riversdale fluvial depositional cycle showing average thicknesses and relationships of component facies. In outcrop 1 or more of the facies is commonly missing. (For key see page 41.)

present change laterally. These facies always conform to the vertical sequences of the assemblage. The Gravel-Sand bodies are very broad, and relatively thick, with an average thickness of 2.3m (Table 4). They are irregular in shape, having an undulatory erosional base, and either a sharp, planar, non-erosional contact with overlying mudstones, or an undulatory erosional contact with overlying Gravel and Sand bodies. A total of 20 of these units can be identified, though more may exist as parts of the cliff face are poorly exposed.

2.) The Gravel-Sand facies bodies occur vertically in a stacked, en-echelon pattern. This pattern can most clearly be observed 20m along the section, between 5 and 15m above the beach (fig. 20). In this location, three Gravel-Sand bodies can clearly be distinguished. The basal unit is between 3 and 5m thick, and is relatively uniform across the section. Immediately overlying this unit is a second unit, whose center is located to the south of the underlying unit. The second unit is in turn overlain by a third unit, whose center is located near that of the basal unit, north of the second unit. These Gravel-Sand bodies have no lateral acretion sets, and the contacts between them are erosional.

Maximum Thickness (m)	Minimum Thickness (m)	Average Thickness (m)	Lateral Exposure (m)
4	0	2.5	63-
4.2	0	2.6	51-
5.7	0.4	2.7	68-
5.4	1.7	2.7	60-
3.4	0	2.3	50-
2.7	0	2.3	51-
3.5	0	2.3	36-
4.2	1.5	3.4	63-
3.2	0	2.7	67-
1.9	0	1.5	40-
1.9	0	0.7	37-
4.6	0	3.4	43-
1.9	0	1.1	17-
13.4	?	?	78-
7.3	2.5	4.2	50-
3.8	1.1	1.9	26-
4.2	0	2.7	55-
1.9	0	1.1	37-
6.5-	?	?	53-
2.7	0.7	1.9	86-
Total Average Thickness		2.3	

Table 4a. Dimensions of Riversdale channel deposits (?= unknown due to talus cover, -= entire unit not exposed, value given is of exposed portion).

Maximum Thickness (m)	Minimum Thickness(m)	Average Thickness (m)	Lateral Exposure (m)
11.5-	6.5	8	95-
7.6 -	6.5	7	76-
5.7 -	2.6	5.3	76-
3.8 -	1.5	2.7	90 -
6.1 -	0.9	3.4	66-
15 -	?	1	77-
12.7-	10.7	11.7	60 -
6.1 -	?	?	53 -
Total Average Thickness		6.8	

Table 4b. Dimensions of Riversdale sandstone packets (symbols as in 4a).

Maximum Thickness	Minimum Thickness	Average Thickness	Lateral Exposure
2.1	0	0.7	78-
1.9	0	1.1	38-
2.3	1	1.9	56-
4	0.6	2.3	72-
2.7	0	?	28-
3.5-	1.1	2.3	28-
5.7-	0.4	3.5	56-
Total Average Thickness		2	

Table 4c. Dimensions of mudstone units which separate sandstone packets (symbols as in 4a).

3.) The contact between an underlying Gravel-Sand body and an overlying mudstone unit is generally sharp and non-erosional.

4.) The Gravel-Sand bodies occur in distinct packets. Each packet consists of one or more Gravel-Sand bodies and some discontinuous mudstone units (fig. 20). These packets extend completely across the cliff face, and are laterally relatively uniform in thickness, having an average of 6.8m (Table 4). Each packet is separated from those above and below by a thick, relatively continuously mudstone unit having an average thickness of 2.0m (Table 4). This pattern is most clearly visible from 0-150m of the section (fig. 20), where five such packets can be identified. Three additional packets are present in the upper portion of the section.

6.3 Interpretation

6.3.1 Facies Assemblages

The individual units of the Gravel-Sand facies assemblage represent an interval of deposition from a fluvial system. This interpretation is based on the presence of an irregular erosional base, the lack of continuous internal erosional surfaces, and presence of facies which are continuous from base to top and which conform to the vertical pattern of the Gravel-Sand facies assemblage. It is obvious from the irregular shape, the lateral variation in facies, and the presence of local internal erosional surfaces that each unit does not represent the deposit of a single simple channel. Thus each Gravel-Sand body is interpreted to represent deposition within a broad channel, which has a complex, and rapidly changing internal morphology.

The Matrix Supported Conglomerate facies is interpreted to be a debris flow deposited locally on the channel base. The debris flow is composed of a matrix of sand transported within the channel, and nodules derived from the erosion of nodular overbank mud material of either the Canso or Riversdale. The remaining sequence of overlying sandstone facies represent deposition from waning flow. The Massive Sandstone facies, which is found between the Trough Cross-stratified Sandstone and the Rippled Sandstone facies is interpreted to be a unit deposited very rapidly probably in the form of climbing ripples, which was subsequently dewatered, destroying the sedimentary structures.

The disturbed sandstone facies is interpreted to be blocks of bank material which have collapsed into the channel. This is based on the limited size of these units, their irregular shape, their deformed internal structure, their contrast in composition from the surrounding sandstone material, and their association with the channel bodies.

The Mud Facies Assemblage is interpreted to be overbank flood deposits, based on its fine grain size, and its occurence conformably on top of the channel sequence. The *en echelon* stacking of channels has caused the erosion of much of this material, but more continuous units do occur between the channel pockets.

6.3.2 Architecture

The stacked, *en echelon* pattern of the Gravel-Sand depositional units, each having en erosional base, suggests a periodic change in the location of the fluvial channel. The sharp, non-erosional contact of Gravel-Sand unit with overlying mudstones indicates that the transition of an area from channel to non-channel deposition is abrupt. This pattern is interpreted to be the result of fluvial path switching resulting from channel aggradation followed by the breaching of the channel bank. The breach causes the channel path to suddenly change to the topographically lower surrounding area.

The pattern of channel packets separated by thick mudstone units suggest active fluvial deposition for a period, followed by a change in the *locus* of deposition, with the old channel system becoming progressively covered by overbank flood material. This area then becomes reactivated, producing the cyclic pattern of paleochannel packets, and thick overbank material. It cannot be determined from this section if the change from active to inactive fluvial deposition is the result of a rapid fluvial system path change, or a gradual migration caused by channel switching in a consistent direction.

The erosive and depositional behavior of a fluvial system will determine what will be preserved in the rock record. For this reason the depostional pattern recorded in a fluvial sequence may be used to identify the type of system which produced it.

The depositional pattern of vertical aggradation followed by an abrupt channel path change is considered to be typical of a braided river system (Miall, 1977). The large-scale abandonment and reactivation of areas of the fluvial system has also been recognized in many modern braided rivers (ibid).

6.3.3 Petrographic Data

The most notable petrographic feature of the Riversdale strata is the variation in color and hematite content of the rocks of the Riversdale. The mudstones of the Riversdale contain hematite and are red in color, suggesting oxygenated conditions (Van Houten, 1973). The sandstone contains no hematite, are grey in color, and contain grains of muscovite and plagioclase which show partial alteration to clay, this suggests more active chemical conditions in a reducing environment. The conglomerate contains hematite within the clasts, but none in the pore spaces. This again suggests reducing conditions at, or shortly after deposition. The presence of carbonate nodules, which are characteristic of warm dry regions (Goudie, 1983), suggests dry, and thus chemically inactive conditions.

This apparent contradiction is interpreted to be the result of the reduction, or removal of Fe from some sediments due to ground water movement. All of the units of the Riversdale were deposited in warm dry conditions favorable to hematite formation. Percolation of ground water, or flood water, through the stacked, relatively permeable Gravel-Sand units produced reducing conditions, resulting in the reduction of the Fe. This process was enhanced by the presence of plant fragments within the Gravel-Sand bodies. The relatively impermeable muds retained their hematite coloration, with the green mottling along the upper erosional contacts (fig. 10) marking the effect of the reducing conditions in the over-lying Gravel-Sand unit.

Because the mud units are less susceptible to this bleaching process, environmental interpretations should be based on their composition. The presence of hematite, and calcite nodules both suggest an arid, and probably warm climate at deposition.

6.3.4 Riversdale Fossils

The presence of plant fossils within the channel deposits indicates conditions favorable for plant growth within the drainage basin of the fluvial system. Plant fragments also occur in the bank collapse material found within the channels (fig. 8). The climate suggested by petrographic data, combined with the lack of plant material or rooted horizons in the overbank mudstones indicate that these plant fragments were probably not locally derived. The plant fragments found within the channel sand deposits are interpreted to be plant fragments transported from the source area of the fluvial system. The plant fragments of the bank collapse material may be transported fragments incorporated into the bank, and subsequently slumped into the channel. Alternatively these plant fragments may be plants which grew along the channel banks, where water was readily available.

6.4 Riversdale Environment of Deposition

The paleoenvironment of deposition of the Riversdale strata is interpreted to be a sand-dominated braided fluvial system developed in an arid climate (fig. 21). Channels are produced by high-energy erosional flooding events, with local debris flows deposited at the channel base. Channel aggradation occurs as sediments are deposited by waning flow. Breaches in the channel bank, or subsequent flood events cause channel switching. Local collapsing of banks into the channels occurs. Longer term changes in the path of the fluvial system produce cyclic activation and abandonment of areas through time.

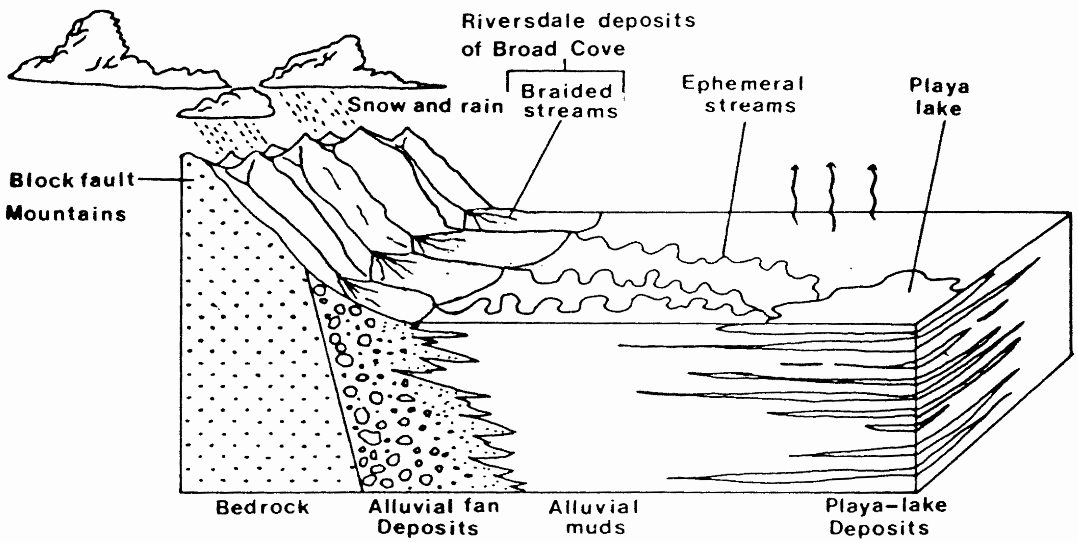


Figure 21. Environment of deposition of the Riversdale strata of Broad Cove.

(After Egster and Kelts, 1982.)

Six facies models for braided fluvial systems have been recognized (Davis, 1983). Of these models, the Riversdale strata of Broad Cove most closely resemble the South Saskatchewan River type (fig. 22). The presence of large debris flows, and the lack of large scale planar cross-bedding suggest however, that there are distinct differences between these systems.

6.5 Relationship of Canso and Riversdale

Carboniferous sedimentation in the Maritime Provinces is considered to be continuous on a basin-wide scale. Canso and Riversdale sedimentation occurred from the upper Visean to the end of the Westphalian A, a period of approximately 30 million years (fig. 4). At Broad Cove, a local unconformity between the Canso and Riversdale strata represents a gap in the stratigraphic record, the length of which cannot be determined from the study. A comparison of the paleoenvironments determined on both sides of the unconformity allows for some interpretation of the changes which occurred during the time gap. In the case of Broad Cove, only one major change can be inferred.

The change from lacustrine-periodic meandering fluvial to a braided fluvial system involved an increase in average grain size, an increase in flow rate, and an increase in slope. These features essentially reflect a rejuvenation of the source area. This can occur as a result of climatic change,

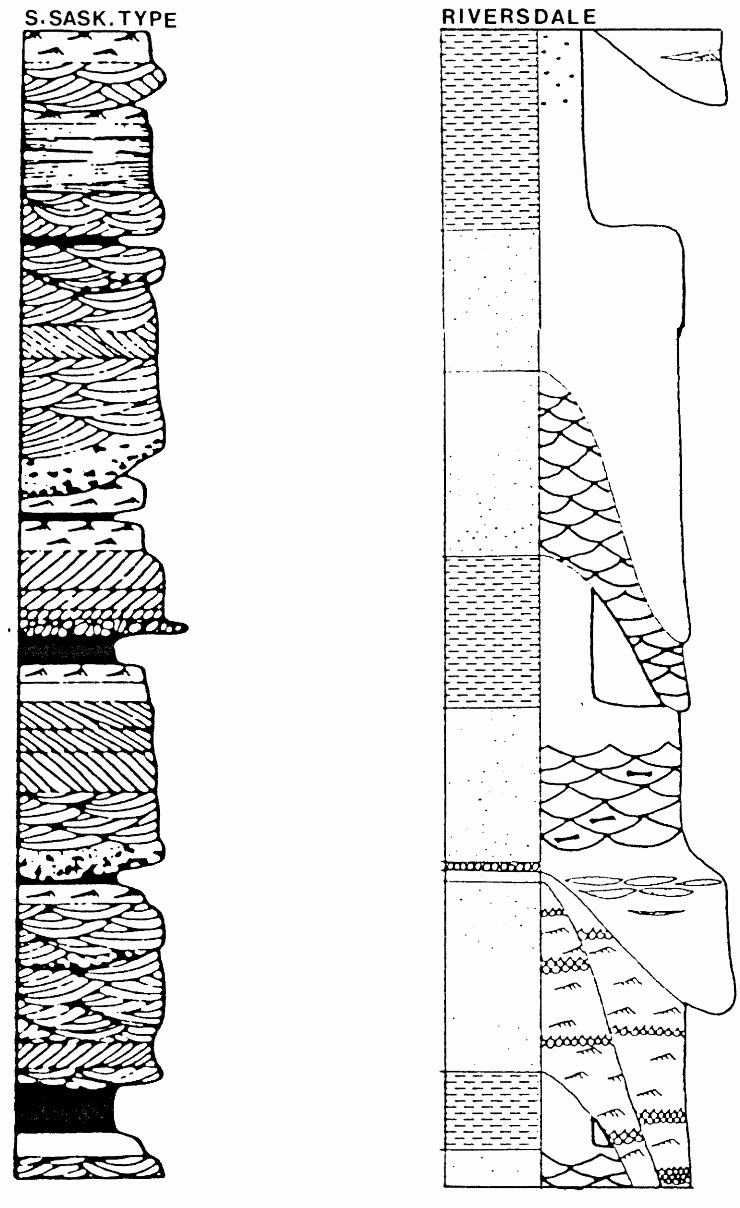


Figure 22. A comparison of the South Saskatchewan River model to a typical Riversdale section at Broad Cove.

tectonic uplift, or both. The evidence at Broad Cove indicates that the paleoclimate changed little during the period represented by the unconformity. Thus, at Broad Cove, the unconformity between the Canso and Riversdale group represents a gap in time during which tectonic movements occurred.

CHAPTER 7. CONCLUSIONS

1.) The paleoenvironment for the Canso strata studied at Broad Cove was a hot, arid alluvial plain traversed by a periodically active sinuous fluvial system. Further research by Brown (Personal communications, 1986) also indicates that the Canso strata at Broad Cove represent deposits of a fluviolacustrine system in a hot, arid environment.

2.) The fluvial deposits of the Riversdale group at Broad Cove were produced by a sandy braided stream under hot, arid conditions.

3.) The morphology of the Riversdale fluvial strata suggests cyclicity both on the scale of individual channel switching, and on the scale of area abandonment and reactivation by the fluvial system as a whole.

4.) The changes in paleoenvironment from the Canso to the Riversdale during the time gap represented by the unconformity of Broad Cove indicate source rejuvenation due to tectonic activity, but little change in climate.

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	QUARTZ %	ILLITE %	KAOLINITE %	CHLORITE %	ALBITE %	MONTMORILLONITE %	HEMATITE %	CALCITE %	DOLOMITE %	SIDERITE %
CANSO MUDSTONE										
2604 01	18	43	6	9	16	2	6	2	–	–
2604 07	23	50	8	5	10	2	1	1	–	–
2408 04	17	41	5	7	10	3	11	5	–	–
2408 14	18	41	9	6	16	2	6	2	–	–
CANSO NODULE										–
2408 03	15	7	2	3	3	2	2	66	–	–
2604 13	21	13	4	3	19	2	5	33	–	–
2604 14	11	13	4	1	6	–	10	32	23	–
RIVERSDALE MUDSTONE										
0305 02	21	65	2	2	3	4	2	1	–	–
3004 10	29	34	8	5	20	3	–	1	–	–
0305 11	30	20	4	7	25	2	6	6	–	–
0305 27	14	51	8	8	9	4	6	–	–	–
RIVERSDALE NODULE										
0305 13	15	15	3	4	5	–	5	53	–	–
2704 20	11	13	2	5	11	9	9	40	–	–
RIVERSDALE CNGLM.										
3004 12	22	10	2	3	13	–	1	49	–	–
3004 11	23	19	4	7	10	–	4	33	–	–
3004 14	21	12	3	7	9	5	–	42	–	1
RIV. DISTURBED SS										
2508 03	28	14	10	6	16	6	2	12	10	–
0305 28	44	18	4	6	20	2	4	2	–	–

Appendix A1. X-ray diffraction analysis results.

Appendix A2. Thin-section descriptions.

SAMPLE: Canso Sandstone 2408-05

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	65			Hematite	16
		Muscovite	5				
		Chlorite	8				
		Opaques	5				
		Plagioclaise	1				
Size Max			0.125 mm				
Min			0.025 mm				
Ave			0.1 mm				
Angular.			Angular				
Spheric.			Low				
Sorting			Good				
Contacts			Points				

Comments: Quartz crystals monocrystalline - shows undulatory extinction. Hematite rims all grains. Plagioclaise and muscovite fresh. No porosity

SAMPLE: Canso Sandstone 2408-10

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	59			Hematite	15
		Chlorite	12				
		Opaques	5				
		Muscovite	4				
		Biotite	3				
		Plagioclaise	2				
Size Max			0.17 mm				
Min			0.025 mm				
Ave			0.095 mm				
Angular.			Angular				
Spheric.			Low				
Sorting			Good				
Contacts			points				

Comments: Quartz monocrystaline. Shows undulatory extinction. Shows layering but no preferred orientation. Uneven distribution of hematite cement. Plag. and Musc as above

SAMPLE: Canso Sandstone 2408-11

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	80			Hematite	9
		Chlorite	4				
		Opaques	4				
		Muscovite	2				
		Plagioclaise	1				

	Clasts	Grains	Matrix	Cement
Size Max		0.1mm		
Min		0.03mm		
Ave		0.07mm		
Angular.		Angular		
Spheric.		Low		
Sorting		Good		
Contacts		Point		

Comments: Quartz monocrystalline. Shows undulatory extinction Shows layering but no preferred orientation. Hematite rims all grains

SAMPLE: Canso Sandstone 0106-02

Clasts	%	Grains	%	Matrix	%	Cement	%
Carbonate	4	Quartz	65			Hematite	10
		Chlorite	14				
		Opaques	5				
		Muscovite	3				

	Clasts	Grains	Matrix	Cement
Size Max	1.4mm	0.1mm		
Min	0.3mm	0.025mm		
Ave	1mm	0.1mm		
Angular.	rounded	Angular		
Spheric.	moderate	low		
Sorting		good		
Contacts		Point		

Comments: Similar to above but contains carbonate clasts. No porosity. Plagioclaise and Muscovite fresh.

SAMPLE: Riversdale Sandstone 0305-19

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	73			Silica ?	1
		Chlorite	15				
		Muscovite	4				
		Biotite	4				
		Opaques	4				
		Plagioclase	2				
Size Max			0.2mm				
Min			0.025mm				
Ave			0.12mm				
Angular.			Angular				
Spheric.			moderate				
Sorting			good				
Contacts			long				

Comments: Quartz monocrystalline - Shows undulatory extinction little matrix or cement. Muscovite and Plagioclase show some alteration. Hand sample does not fizz with acid

SAMPLE: Riversdale Sandstone 2508-08

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	75			Silica ?	1
		chlorite	17				
		Muscovite	4				
		Opaques	3				
		Plagioclase	1				
Size Max			0.25mm				
Min			0.02mm				
Ave			0.1mm				
Angular.			Angular				
Spheric.			Low				
Sorting			Moderate				
Contacts			long				

Comments: Not as densely packed as above. No layering or preferred orientation. Hand sample does not fizz with acid. Quartz similar to above.

SAMPLE: Riversdale Sandstone 24L

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	71	Clays	1	Silica?	1
		Biotite	7				
		Chlorite	13				
		Opaques	4				
		Muscovite	3				
		Plagioclase	1				

	Clasts	Grains	Matrix	Cement
Size Max		0.21mm		
Min		0.03mm		
Ave		0.05mm		
Angular.		Angular		
Spheric.		Moderate		
Sorting		Good		
Contacts		long		

Comments: Muscovite and Plagioclase show alteration. Some interlocking grain contacts (sutured) no layering Hand sample does not react with acid.

SAMPLE: Riversdale Sandstone 25U

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	80	Clay	1	Silica?	1
		Biotite	9				
		Chlorite	7				
		Muscovite	2				

	Clasts	Grains	Matrix	Cement
Size Max		0.23mm		
Min		0.02mm		
Ave		0.085mm		
Angular.		Subangular		
Spheric.		Moderate		
Sorting		Good		
Contacts		long		

Comments: Quartz monocrystalline. Little porosity, no layering or preferred orientation. Quartz more abundant than other Riversdale Sandstones. Alteration as above.

SAMPLE: Canso Conglomerate 2604-15

Clasts	%	Grains	%	Matrix	%	Cement	%
Calcite	58			Quartz	2	Calcite	10
+ quartz ± Hematite						Hematite	10

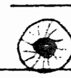
	Clasts	Grains	Matrix	Cement
Size Max	15mm		0.21	
Min	0.025mm		0.025	
Ave	3mm		0.11	
Angular.	subrounded		Angular	
Spheric.	High		Low	
Sorting	Poor		Good	
Contacts	long		Points	

Comments: Overall poor sorting. Clasts may (95%) or may not (5%) contain quartz. Quartz is similar to the Sandstones. Calcite overgrowths on clasts, Hematite on inside and outside of overgrowths. 20% Pore space

SAMPLE: Canso Conglomerate 2604-05

Clasts	%	Grains	%	Matrix	%	Cement	%
Calcite + Quartz	32			Quartz	25	Calcite	25
Calcite + Clay	6			muscovite	2	Hematite	5

	Clasts	Grains	Matrix	Cement
Size Max	5mm			
Min	0.025mm			
Ave	2.0mm		0.07mm	
Angular.	rounded		angular	
Spheric.	moderate		low	
Sorting	poor		Good	
Contacts	long		points	

Comments: Some clasts show rounded off overgrowths  Clasts show preferred orientation if elongate. Clast support, similar to above. 5% pore space

SAMPLE: Riversdale Conglomerates

Clasts	%	Grains	%	Matrix	%	Cement	%
Calcite + Clay	15			Quartz	35	Calcite	33
Calcite + Quartz	17			plagioclase	Tr		
				Muscovite	Tr		
				Opaques	Tr		

	Clasts	Grains	Matrix	Cement
Size Max	12mm		0.17mm	
Min	1mm		0.05mm	
Ave	4mm		0.1mm	
Angular.	Rounded		Angular	
Spheric.	Moderate		Low	
Sorting	Poor		Good	
Contacts	Matrix Support		points	

Comments: Some clasts are composed of several smaller ones cemented togeather. Some overgrowths of clasts are hematite rich. Center of some clasts coarsly crystaline.

SAMPLE: Riversdale Conglomerate 0305-25

Clasts	%	Grains	%	Matrix	%	Cement	%
Calcite + Quartz	25			Quartz	45	Calcite	8
Calcite + Clay	7			Clay	12		
				Other	5		

	Clasts	Grains	Matrix	Cement
Size Max	15mm		0.35mm	
Min	3mm		0.13mm	
Ave	3mm		0.17mm	
Angular.	Rounded		Angular	
Spheric.	High		low	
Sorting	Poor		Moderate	
Contacts	Matrix Supported		Points	

Comments: Clasts containing quartz - the quartz grain size is 1/2 of the matrix size. Some have core of coarsly crystalline calcite. Colored red by hematite?

SAMPLE: Riversdale Conglomerate 3004-03

Clasts	%	Grains	%	Matrix	%	Cement	%
Calcite + Quartz	15			Quartz	37	Calcite	40
Clay + Calcite	5			Opaques	1		
				Other	2		
Size Max	5 mm				0.11 mm		
Min	1 mm				0.01 mm		
Ave	1.5 mm				0.075 mm		
Angular.	Rounded				Angular		
Spheric.	Low-Moderate				Low		
Sorting	poor				good		
Contacts	Matrix Support				edge		

Comments: Fining up of Clasts visible in thin Section. Matrix shows preferred orientation ⊥ to grading. Cement is more coarsly crystalline than clasts.

SAMPLE: Riversdale Disturbed Sandstone 0305-01

Clasts	%	Grains	%	Matrix	%	Cement	%
		Quartz	70	Quartz	24	Silica ?	1
		Muscovite	2	± Musc			
		Kaolinite	2	± Kao			
		Plagioclaise	1	± Plag			
Size Max			0.25 mm		0.05 mm		
Min			0.04 mm		0.01 mm		
Ave			0.08		0.04 mm		
Angular.			Angular				
Spheric.			Moderate				
Sorting			Good				
Contacts			long				

Comments: Quartz undulatory extinction. No porosity. Bands of mica. 1 clast of clays present. More matrix than Riversdale Sandstone. No Coal.