A DETAILED STUDY OF PICTOU GROUP

ROCKS AT CAPE JOHN NOVA SCOTIA

BSc. Thesis, by
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ABSTRACT

The Pictou Group of northern Nova Scotia has to date received relatively little study. Several authors have studied these rocks in context with other groups in the area and as part of regional basinal studies.

This study looks at a small (310 m) section of Pictou Group rocks which are well exposed and easily accessible at Cape John, Nova Scotia. Detailed attention is paid to lithology, relative position in the sequence, fossils, relative thickness and paleocurrents.

Results of the study favour a meandering fluvial model of deposition for these rocks. Paleocurrent and mineralogical data suggest a source area to the north, south or east and provide finer resolution of the geomorphology of the depositional basin.

Variations from the classical meandering fluvial model are seen in the section and are discussed as to their implications regarding the environment and basin of deposition.

I AIMS OF STUDY

The project undertaken involved a detailed study of Pictou Group sediments at Cape John, Pictou County, Nova Scotia. Rock units cropping out along approximately 1 km of coastline (Fig. 1 for outcrop locations) presented 310 m of section.

Relatively little study has been done in the Pictou Basin to date. The Carboniferous rocks of the Canadian Atlantic Provinces were described by Lyell (1843) as being 90% "fluviolacustrine" in origin, and subsequent studies by Dawson(1855, 1894), Fletcher (1877, 1903) and Bell (1912, 1927, 1944) concurred with the initial assessment. Fossil evidence presented by Copeland (1957), Bell (1960), Donald Baird (1963) and Rodgers (1965) confirmed the non-marine origin of these rocks.

In this study the rock units are analysed in terms of bed thickness, lithology, sedimentary structures, fossil content, paleocurrents and facies association. The data collected provides information on the paleogeography, paleoenvironment, mode of deposition, paleoclimate and the regional Pennsylvanian-Permian basin geometry and tectonic setting. The proximity and location of possible Pictou Group source areas are inferred from examination of the mineralogy and paleocurrent data.

The 310 m studied in detail represent 13% of the total (2,250 m; Bell, 1944) thickness of exposed Pictou Group rocks in central Nova Scotia. The type section for the Pictou Group is located along the west branch of the River John. The rocks in the study area are generally well exposed and yield a great deal of data concerning Pictou Group despositional events (Fig. 2). The detail of study, along with the extensive exposure, provides

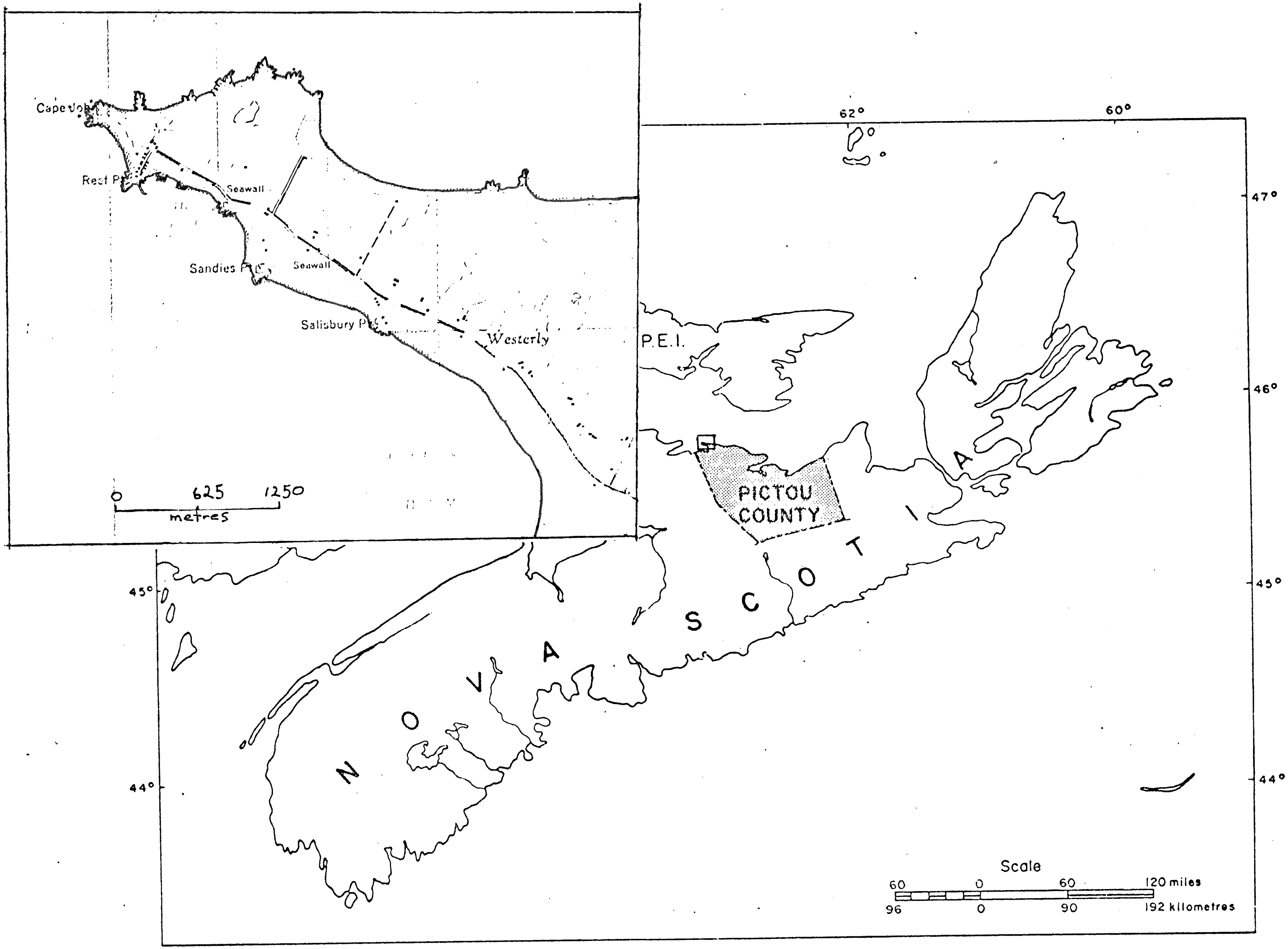


Figure 1.1 Key Map

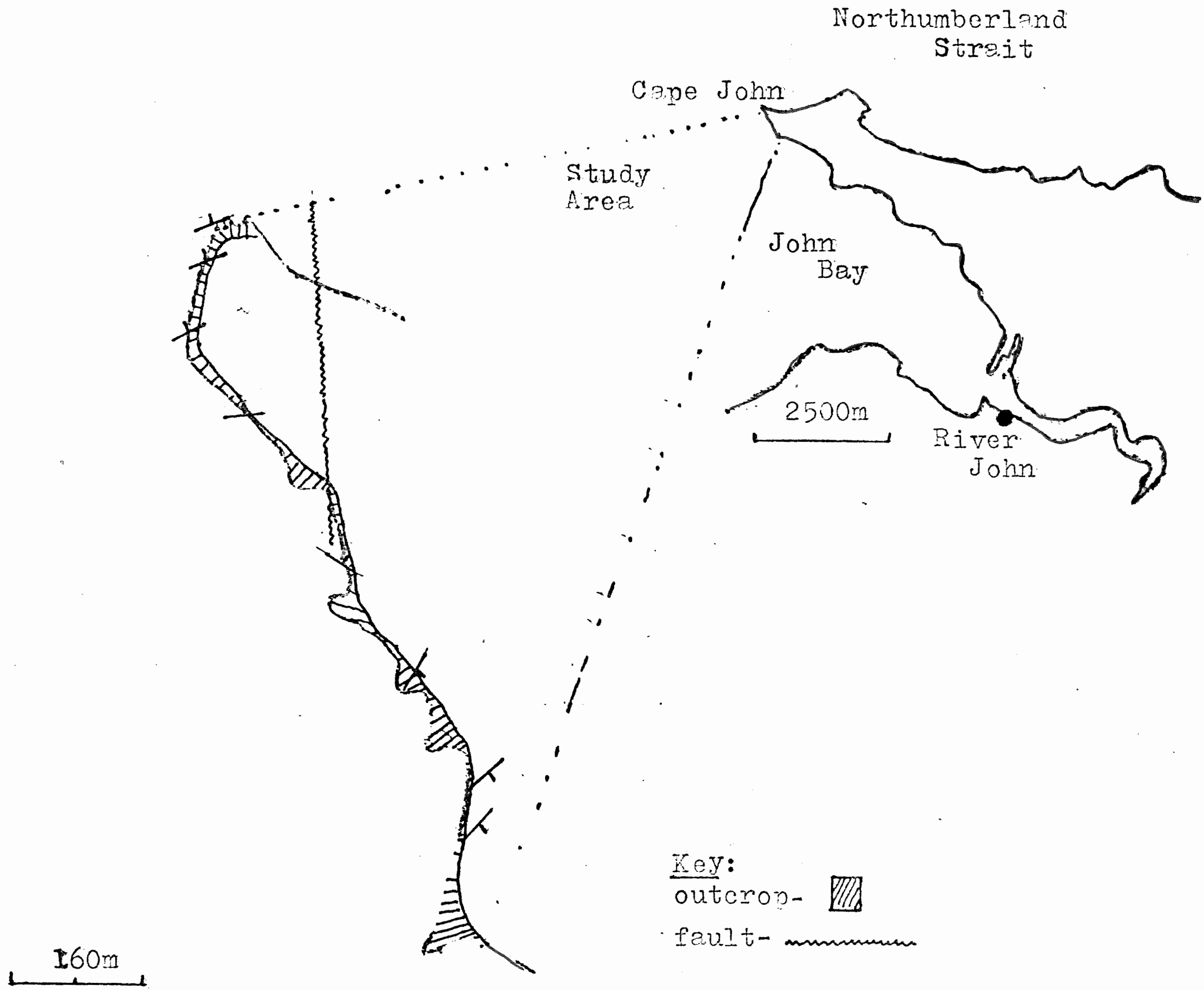


Figure 1.2-Map of study area showing
outcrop locations.

finer resolution on this portion of the basin than any previous work.

II PHYSIOGRAPHY OF STUDY AREA

Cape John is presently located in an area of gently rolling topography at the mouth of River John which empties into John Bay on the Northumberland Strait. The exposures in the study area between Cape John and Reef Point, (latitude 45^{o}, 42' north; longitude 63^{o} 15' east; Grid 11-E-14-C-42), consist of eroding sea cliffs with heights ranging from 4 to 10 m. The coastline consists of small projections of more resistant rocks separated by small embayments created by more rapid erosion of less resistant rocks. (Fig. 2).

The lowland plain on which the study area is located is called the Cumberland-Pictou Lowland (Fig. 3). The elevation of the lowland ranges from sea level to 150 m. The main topographic features are low undulating hills which more or less reflect the underlying geologic structure. There is a system of minor folds with east-west axes following the coastline. Differential erosion of harder and softer strata form ridges and valleys which are parallel to the fold axes and determine the outline of the coast along the Northumberland Strait. The ridges run out into points at Pugwash, Wallace, Smith Point, Malagash Point, Cape Tormentine, N. B., and Cape John.

Immediately south of the lowland plain are Cobequid Mountains, an older bedrock massif. To the east is located the Pictou-Antigonish Highland composed of metamorphosed slates and quartzites. The average elevation of the highlands is 275 m. Drainage in the county runs predominately north-south. The study area presently receives its sediment from the Cobequid

Figure 2. - Basal part of the section near Reef Point showing good exposure. Note the resistant sandstone and conglomerate forms small promontories while the mudstones form shallow embayments.

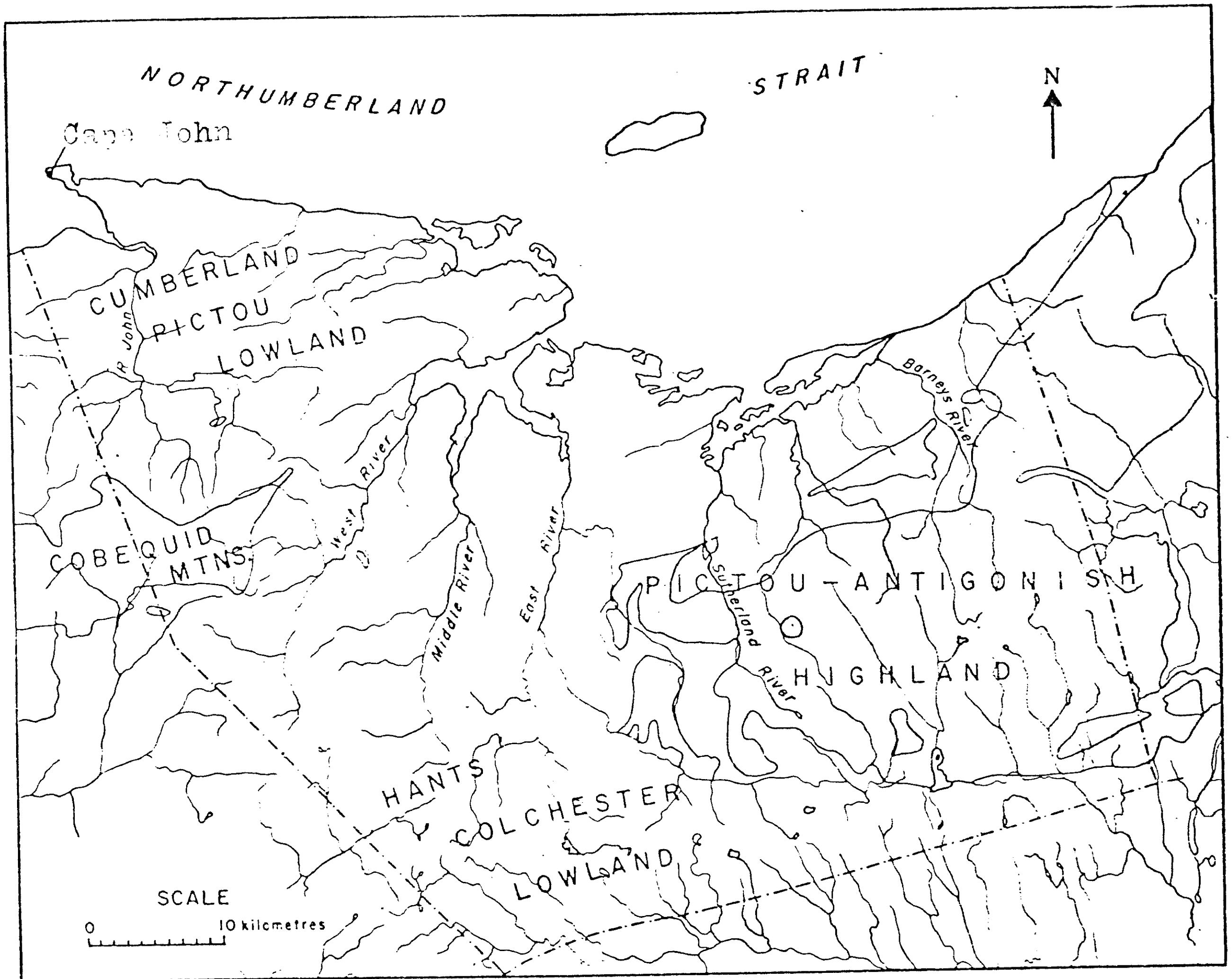


Figure 3 Physiographic Regions of Pictou County
From Gibb and McMullin (1980).

Massif which is well drained.

III GEOLOGIC SETTING

Pictou Group rocks range in age from mid-Pennsylvanian (westphalian C) to lower Permian (Barss and Haquebard, 1967) and are largely contemporaneous with the Stellarton Group rocks in the Pictou coalfield to the east (Fig. 4).

The Pictou Group, as previously stated, is a non-marine sequence of predominantly red rocks that include alternating bands of red and grey sandstones, siltstones, shales and pebble conglomerates. Bell (1944) estimated a thickness of 2,250 metres for the Pictou Group at the type section along the west branch of River John.

The basin in which the sediments were deposited developed as a faulted basin during or following the Acadian Orogeny (Rodgers, 1970). Belt (1968) determined the basin to have developed in an active rift zone (Fundy Rift Zone) forming a complex rift valley region (Fundy Basin), the pattern for which is believed to have been established in Late Devonian and Early Mississippian time. During this time interval the Fundy Basin and surrounding platforms (Fig. 5) experienced predominantly continental sedimentation with "rivers depositing sediments in the lower regions of a very uneven terrain" (Rodgers, 1970).

The Fundy Basin rift zone and surrounding platforms were the primary control for the distribution and thickness of the various Lower and Middle Carboniferous (pre Hortonian through Riversdalian; see stratigraphic section Fig. 6) facies (Belt, 1968). The basin and platform system included what is

* From Gibb and McMullin (1980).

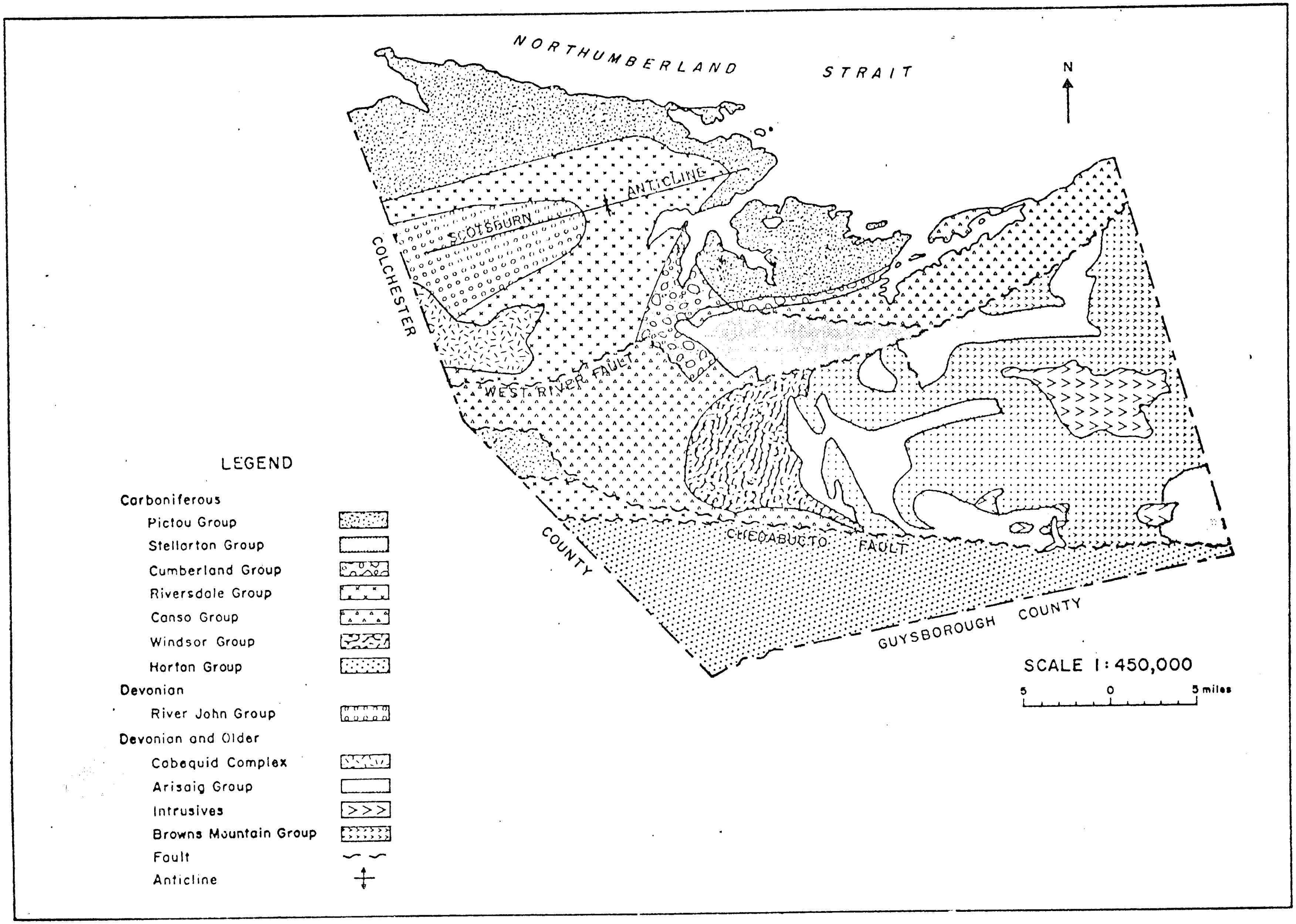


Figure 4 Regional Geology of Pictou County

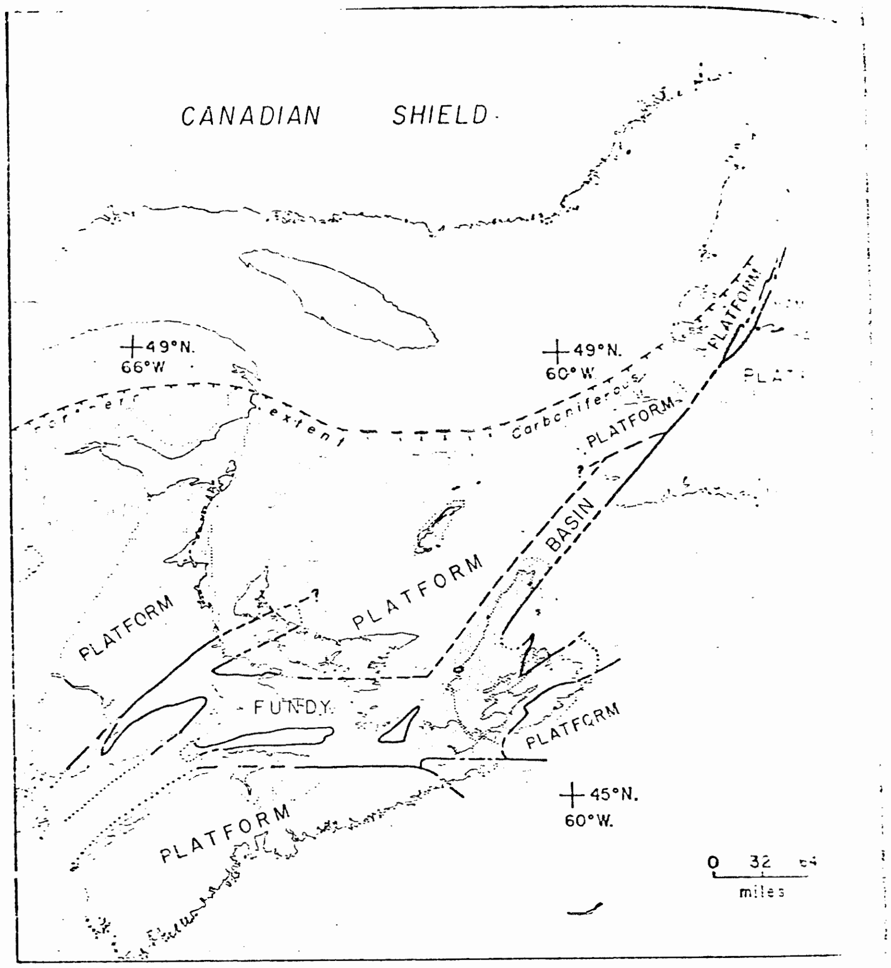


Figure 5.-Fundy Rift Zone showing basin boundaries (From Belt 1968).

presently central and eastern New Brunswick, northern Nova Scotia, Prince Edward Island, The Gulf of St. Lawrence and eastern Newfoundland.

After the Riversdalian, the rift zone was disrupted by movements that folded most of the Lower and Middle Carboniferous strata within the Fundy Basin. These movements were followed by the desposition of fluvial facies on the platforms and basins which had their greatest development during Late Pennsylvanian time when the Pictou Group was deposited. Rodgers (1970) proposed a broad basin hundreds of kilometres across with oxidizing conditions, initially on the basin margins, spreading to the centre of the basin before the end of sedimentation. Van de Poll (1973) however postulated a fluctuating climate to account for the changes from red (oxidized) to grey (non-oxidized) facies in Pictou Group strata in New Brunswick. He further concluded that a somewhat more humid climate would account for the greater stream competence in evidence during the depositional interval of the grey-facies sequences.

Subsequent tetonic activity in the area has left the beds relatively undeformed except for some minor faulting and folding.

The stratigraphic relationships between the Pictou Group and surrounding rock units are summarized in Fig. 6. The oldest Pictou Group rocks overlie the Lismore Formation with angular uncomformity (Bell, 1944), but conformably overlie the New Glasgow Conglomerate to the west in the Stellarton Structural sub-basin.

IV METHODS OF STUDY

The field study of these Pictou Group rocks was conducted between

Figure 6.- **Table of Formations**

a) From Gibb and McMullin (1980).

Period	Group	Formation	Lithology
Recent	-----	-----	Stream gravels, residual soils, modified glacial gravels
Pleistocene	-----	-----	Till; stratified and unstratified sand and gravel
Pennsylvanian	Pictou (2,250m)		Red and grey sandstone, siltstone; red pebble conglomerate, minor shale
	Stellarton (series) (2,860m)		Grey and black coal shale, red and grey sandstone; conglomerate
	Disconformity		
	Cumberland (580m)	New Glasgow Conglomerate	Greyish red pebble to cobble conglomerate; sandstone and siltstone
	Disconformity		
	Riversdale (2715 m.)	Boss Point	Grey and red sandstone, pebble conglomerate, minor limestone pebble conglomerate
		Millsville Conglomerbte	Reddish to brown pebble to boulder conglomerate, minor sandstone, siltstone
Mississippian	Canso (850m)		Grey and red-brown siltstone, argillite and minor sandstone, claystone; limestone, and limestone pebble conglomerate
	Disconformity ?		
	Windsor (580m)		Shale; calcareous shale, grey limestone; gypsum, anhydrite; conglomerate
	Disconformity		
	Horton (2040m)		Grey arenite, grey siltstone, shale; and conglomerate
	River John (1830m)		Pebble to boulder conglomerate; siltstone, and sandstone
Devonian			Siltstone; sandstone, minor shale, pebble conglomerate, limestone conglomerate; oil shale, felsite, breccia

Period	Group	Formation	Lithology
	Unconformity (?)		
Devonian (cont.)	-----	-----	Dark green, fine to medium grained diabase
	-----	-----	Grey biotite and muscovite granite; minor syenite, pink and green granite
	Cobequid Complex		Granodiorite, minor syenite, granite, meta sedimentary rocks, andesite, minor felsite and tuff
		Knoydart (305m)	Red sandy slate; grey sandstone
	Arisaig (1070m)	Stonehouse	Blue-grey calcareous and argillaceous sandstones and siltstones
Silurian		Moydart	Grey mudstone; sandstone, siltstone, minor limestone, red calcareous mudstone
		McAdam	Grey shale, bluegrey siltstone, sandstone and calcareous siltstone
		French River	Blue-grey sandstone; blue-grey and green-grey muddy sandstone
		Ross Brook	Grey mudstone and shale, blue-green quartz sandstone and siltstone
		Beechhill Cove	Green and blue-grey sandstone and siltstone
Ordovician	-----	-----	Hornblende granite and quartz feldspar granodiorite
Cambro-Ordovician	-----	-----	Gabbro, medium grained hornblende diorite
	Brown's Mountain (760m+)	Brierly Brook	Dark green andesite, tuff, breccia, sandstone, argillite and dacite
		Baxter Brook	Red and grey sandstone and slate, schist
		Keppoch	Leuco-dacite rhyolite, breccia and tuff; minor grey quartzite and phyllite

b) From Fralick and Schenk (1980).

GEOCHRONOLOGY			CHRONOSTRATIGRAPHY	LITHOSTRATIGRAPHY		
	Period		Stage	Group	Lithology	Formation
	Permian					
Carboniferous	Stephanian		Pictoan	Pictou	*course sandstones* conglomerates shales	
	Westphalian	D C B A	Cumberlandian Riversdalian	Cumberland	coarse clastics predominate, rapid facies change due to *limited extent* of depositional basins	Stellarton, Middle River, New Glasgow
	Namurian		Cansoan			
				Mabou*	*fine sandstones*, shales, siltstones	Lismore
	Visean		Windsorian	Windsor*	*marine:* limestones, evaporites, siliclastics	Ardness
	Tournasian		Hortonian	Horton*	*conglomerates*, sandstones, shales	Hollow
Devonian				Fountain Lake	*volcanics*, siliclastics	McAras Brook

*This relationship between chronostratigraphy and lithostratigraphy is valid only in the study area.

June 1982 and October 1982. During that time interval eight days were spent at the study area. The data collected was interpreted between September 1982 and January 1983.

The study area presented approximately 1 km of generally well-exposed beds along an eroding coastline. The beds are readily observable with the exception of some beds of a laminated, fissile mudstone facies which are poorly exposed and inferred to be present from screes.

Orientation of beds, paleocurrents and faults were measured with a Brunton compass. Bed thickness was measured directly with a tapemeasure perpendicular to the dip direction. Bed thickness ranges from 20 m to approximately 10 cm. Each bed was described in detail with regard to

(1) contacts

(2) lithology

(3) sedimentary structures

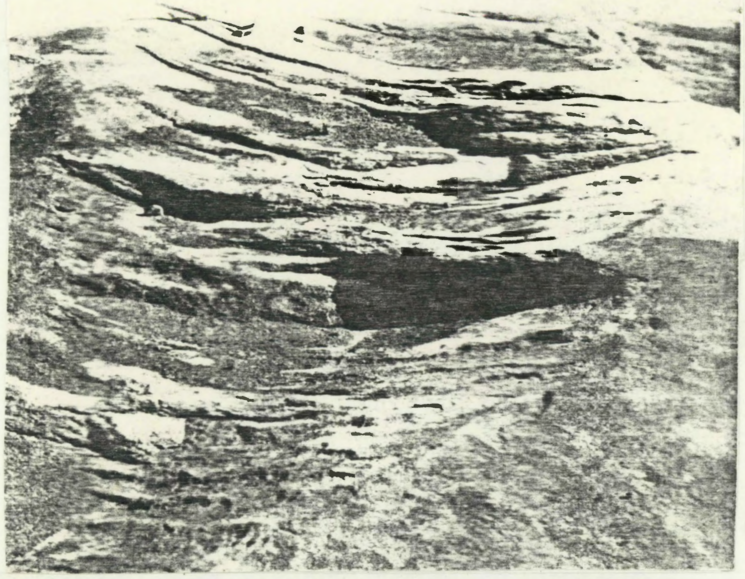
(4) approximate grain size

(5) fossil content

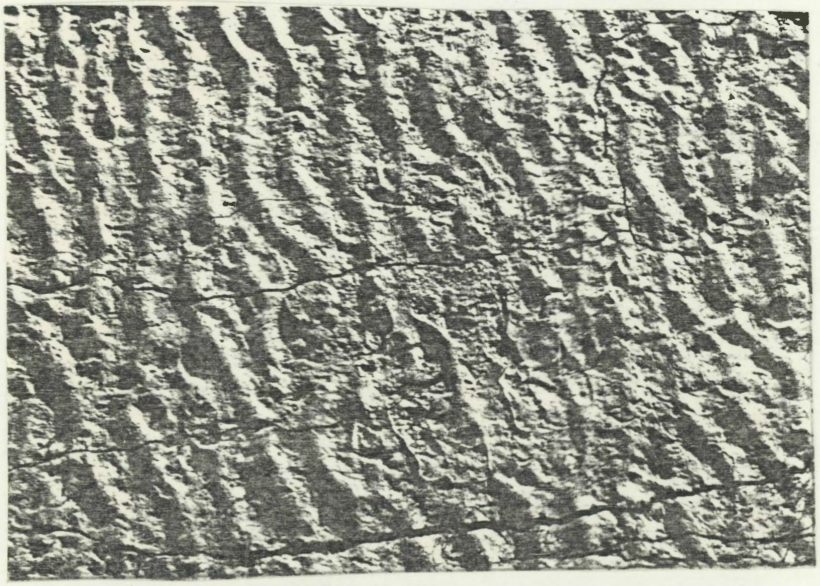
Paleocurrent data was taken from several types of sedimentary structure (Fig. 7). The methods of Potter and Pettijohn (1963) were used in the measurement and interpretation of paleocurrents (Fig. 8 for summary of methods).

The data were plotted on a detailed section to show their relative stratigraphic positions (Fig. 9). The section is a visual representation of the field data and hypotheses regarding the rock units are based on interpretation of the constructed section. Relative grain size is shown by change in column width. Sedimentary structures and paleocurrents are symbolized approximately adjacent to their actual position of occurrence. Facies types

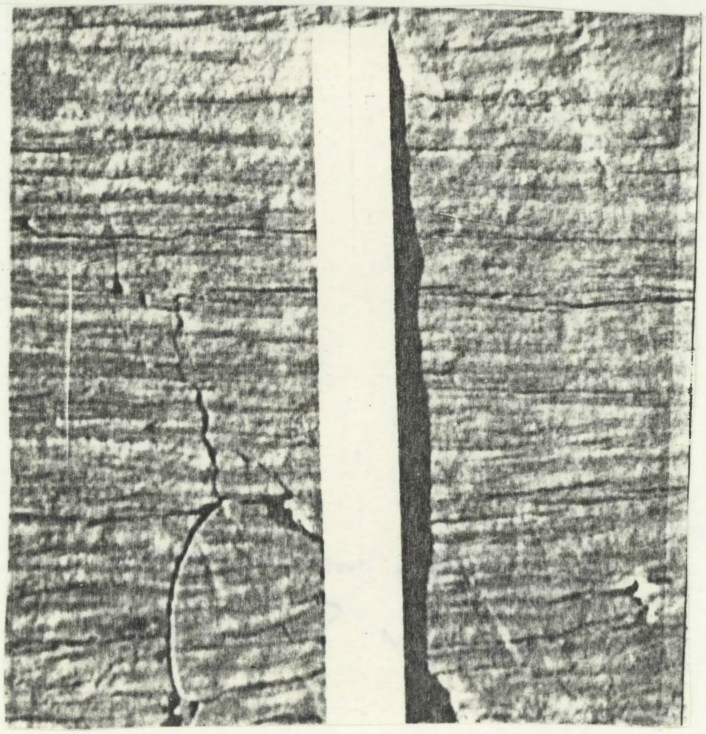
Figure 7.-Sedimentary structures and inferred paleocurrent directions.



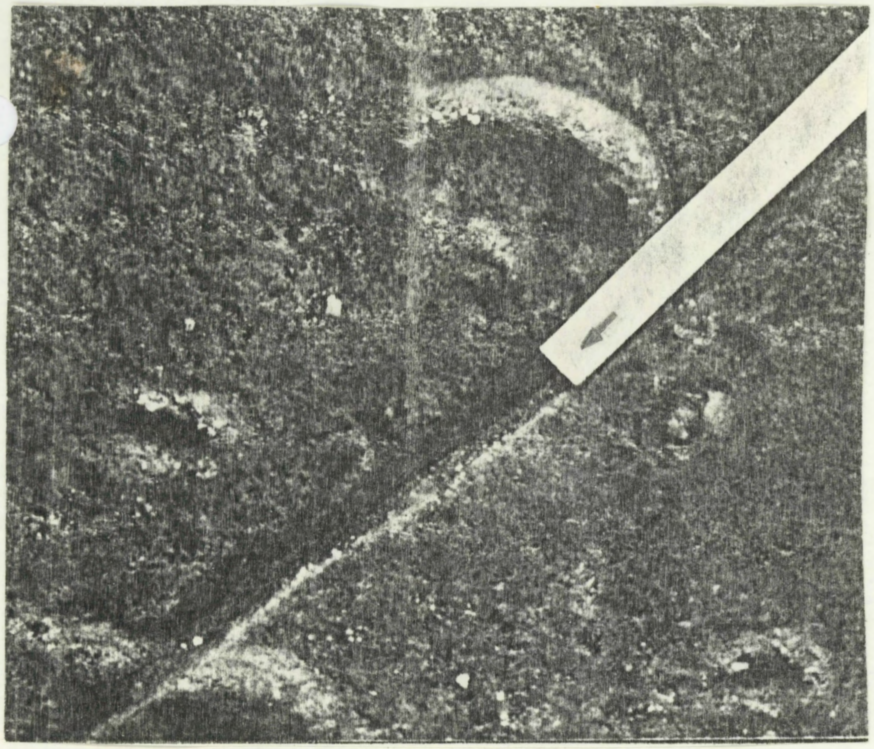
7.1-Trough cross-beds in sandstone.-Flow is from left to right. (photo from Potter and Pettijohn)



7.2-Transverse ripples. -Flow is from right to left. (Potter and Pettijohn)

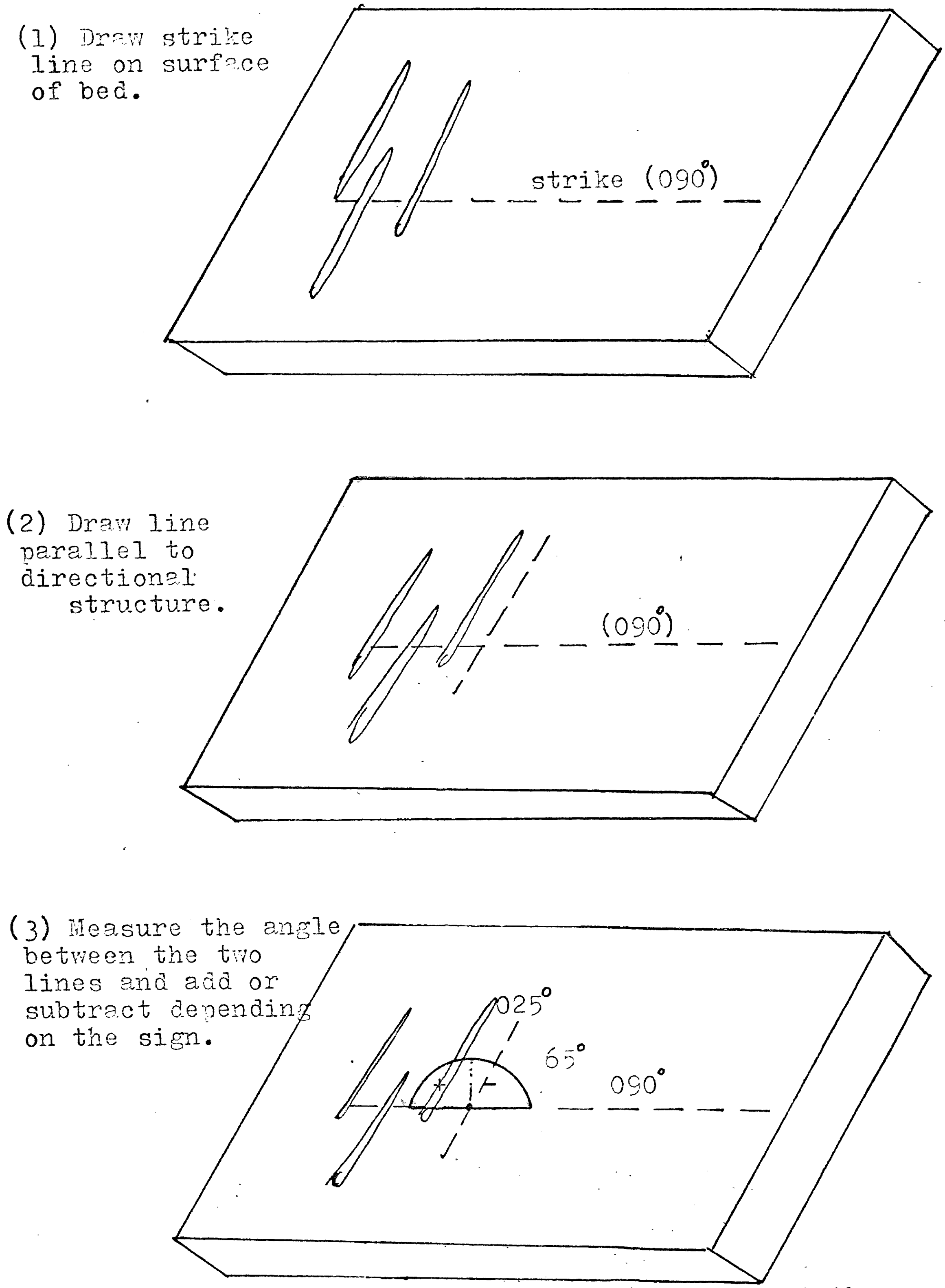


7.3-Climbing ripples. -Flow is from right to left. (photo from study area)



7.4-Current crescent.
-Flow is shown by the arrow.
(photo is from study area)

Figure 8.-Method of correcting orientation of directional structures for tectonic tilt.



NB- For directional structures parallel to the strike or dip, no correction is required. For dips less than 25° no correction is required. (Potter and Pettijohn, 1977)

KEY TO STRATIGRAPHIC COLUMN (Fig.9)

Scale: 1cm = 2m

Sedimentary Structures

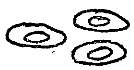
 large-scale cross-beds

 small-scale cross-beds

 parallel laminations

 ripple current marks

 climbing ripples

 nodules

Contacts

sharp

gradational

Paleocurrents

 unidirectional indicator

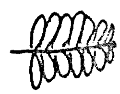
 bidirectional indicator

Fossils

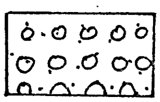
 burrows

 rootlets

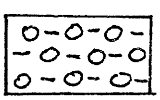
 woody fragments

 leaves

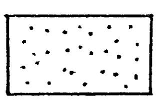
Facies



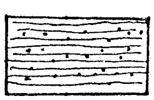
facies (1)
- grey,poorly sorted pebbly sandstone and pebble extra-basinal conglomerate



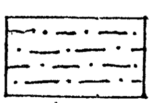
facies (2)
-red intraformational conglomerate with nodule and mudstone clasts



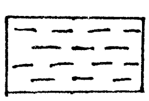
facies (3)
-brown or grey medium-grained sandstone with large and small-scale cross-bedding B= brown ; G= grey



facies (4)
-brown,laminated,fine sandstone

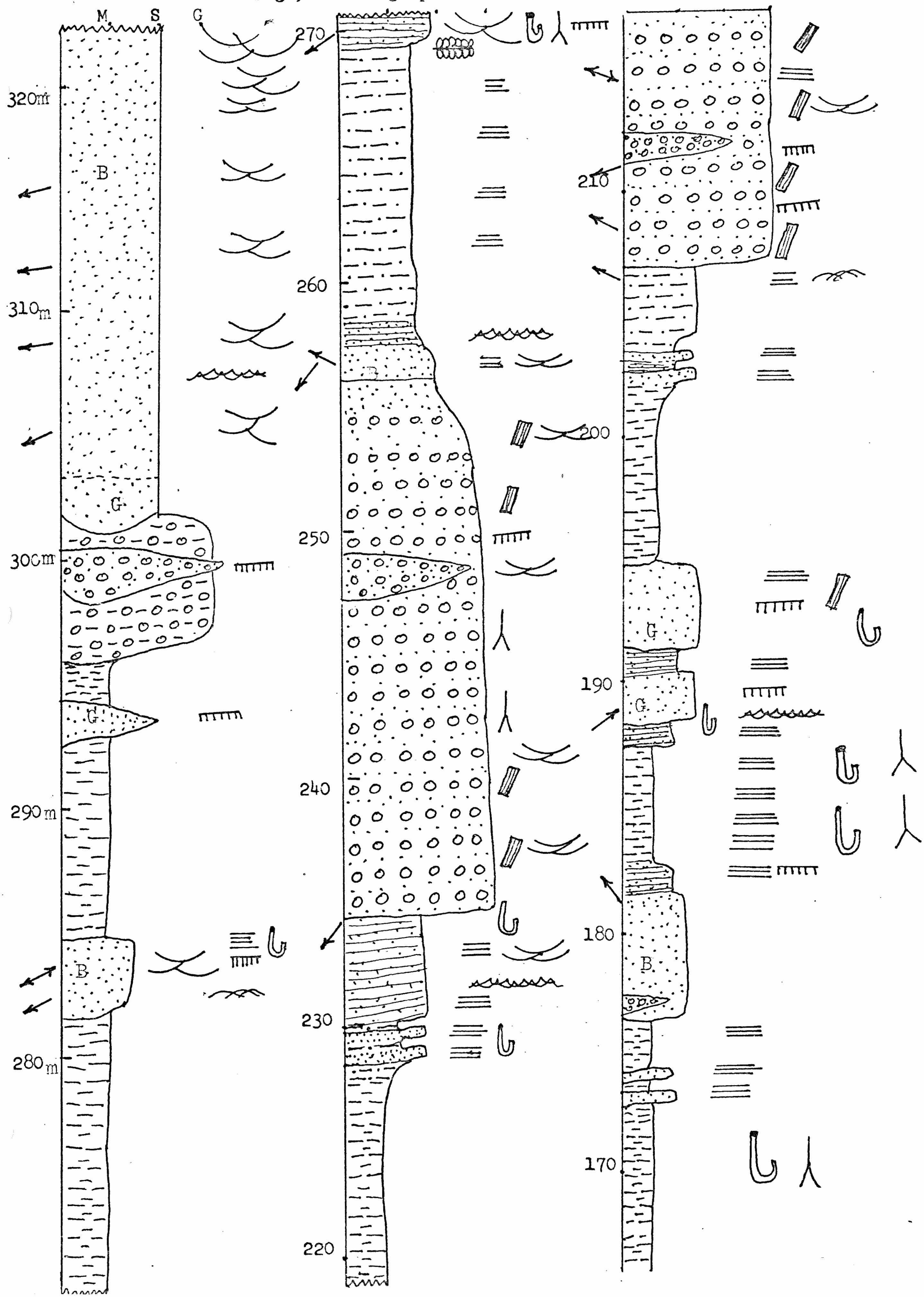


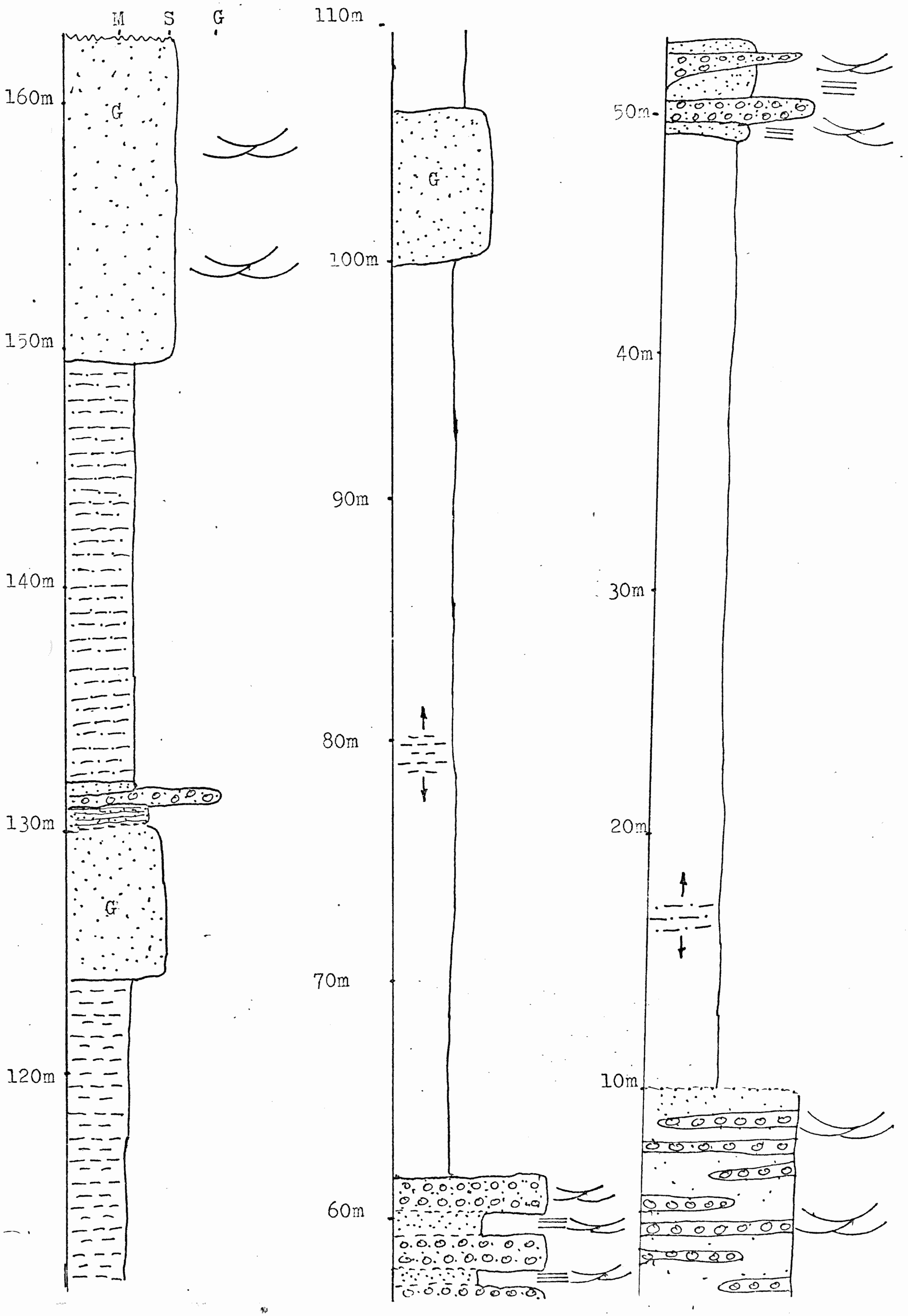
facies (5)
-red-brown,very fine sandstone-very coarse siltstone
-massive as well as laminated.



facies (6)
-red mudstone ; fissile,massive,bioturbated and laminated

Fig.9 -Stratigraphic Column





M S G
160m
G
150m
140m
130m
G
120m
110m
G
100m
90m
80m
70m
60m
50m
40m
30m
20m
10m

are drawn directly on the column.

The constructed section represents 310 m of actual section. A strike-slip fault repeats the strata in part of the section. Paleocurrents are also presented as rose diagrams (Fig. 10) which abstract paleocurrent data from the column to allow for more detailed analysis.

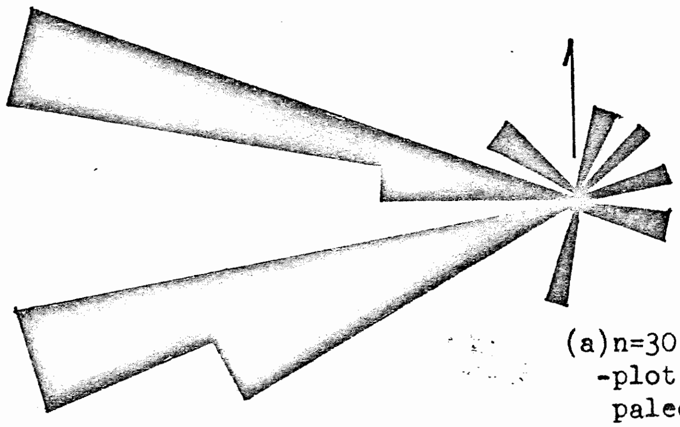
V ROCK TYPES

The strata consist of six distinctive rock types, referred to as facies. The coarsest facies is a grey, pebbly massive to trough crossbedded orthoconglomerate occasionally interbedded with medium sandstone. The grains vary from medium sand to pebbles approximately 3 cm in diameter. The pebbles are extrabasinal well rounded, poorly sorted, and consist of quartz, quartzite, plagioclase, orthoclase, calcite, siderite, and mica fragments. Also present are plant stems and woody fragments which are also visible in thin sections (Fig. 12:1). (See also Fig. 11:1). This facies occurs as thick beds (10 m) and as gravel lags in other facies and represents approximately 12% of the measured section.

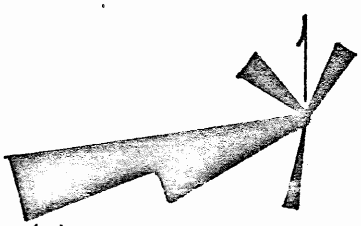
A second conglomerate facies is distinguished from Facies 1 by the different nature of the clasts. This facies is red-brown in color and the clasts are intraformational. The clasts are nodules of siderite and fragments of mudstone derived from other facies within the basin of deposition. (See Fig. 11:2). There is only one good exposure of this facies and it is calculated to represent 2% of the studied section. No thin sections were made of this facies due to the incompetent nature of the rock.

The third facies type is a trough cross-bedded medium grained sand-

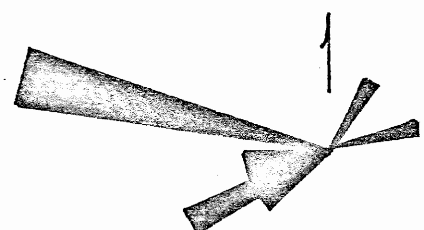
Figure 10. Paleocurrent Roses.



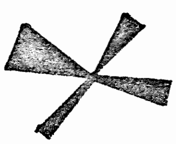
(a) n=30
-plot of all forms of paleocurrent data.



(b) n=11
– plot of large-scale cross-beds (troughs).



(c) n=11
-plot of small-scale cross-beds. (ripples)



(d) n=8
-primary current lineations, current crescents.

stone, grey or brown in color (Figs. 11:3, 12:2). This facies has several good exposures in the study area and forms small promontories due to its resistant nature. This facies occurs as thin beds (0.5 m) and as thick bed associations (17 m). Burrows and plant fossils are found on contacts with mudstones. This facies represents approximately 19% of the section.

Laminated fine sandstone (Figs. 11:4, 12:3) occurs frequently in beds of 0.5-2 m thickness. This facies is brown in color and shows parting lineation on laminae surfaces. Ripples are found on some surfaces. This facies constitutes 4% of the measured section.

Massive, very fine-grained sand-very coarse siltstone (grain size .05-0.1 mm) is common in the section (11%) and is designated as Facies 5 (Figs. 11:5, 12:4).

The most abundant facies in the section is a mudstone which is variable in grain size as can be seen in Figs. 11:6, 12:5, 12:6, 12:7 and 12:8. This facies is brown, contains large amounts of hematite, is extensively bioturbated, massive to laminated and contains rootlets and calcareous nodules. This fine-grained facies forms small embayments along the coastline in the study area (Fig. 2). This facies is present in 52% of the section.

VI FOSSILS

Fossils are found in the section in relative abundance. Burrows are very common in the mudstone facies and can be seen on sandstone contacts with mudstones (Fig. 13). Plant rootlets penetrate several mudstone units

Figure 12.- Thin section sketches of the facies types.
NB- All sketches are drawn from crossed-nicols.

Fig.12.1 - Thin section of <u>conglomerate</u> (Facies 1).

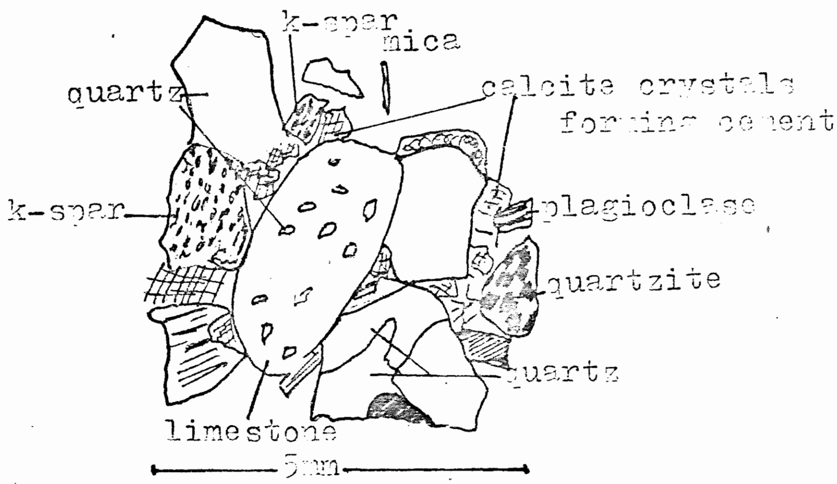


Fig.12.1 -Thin section of <u>conglomerate</u> (facies 1).

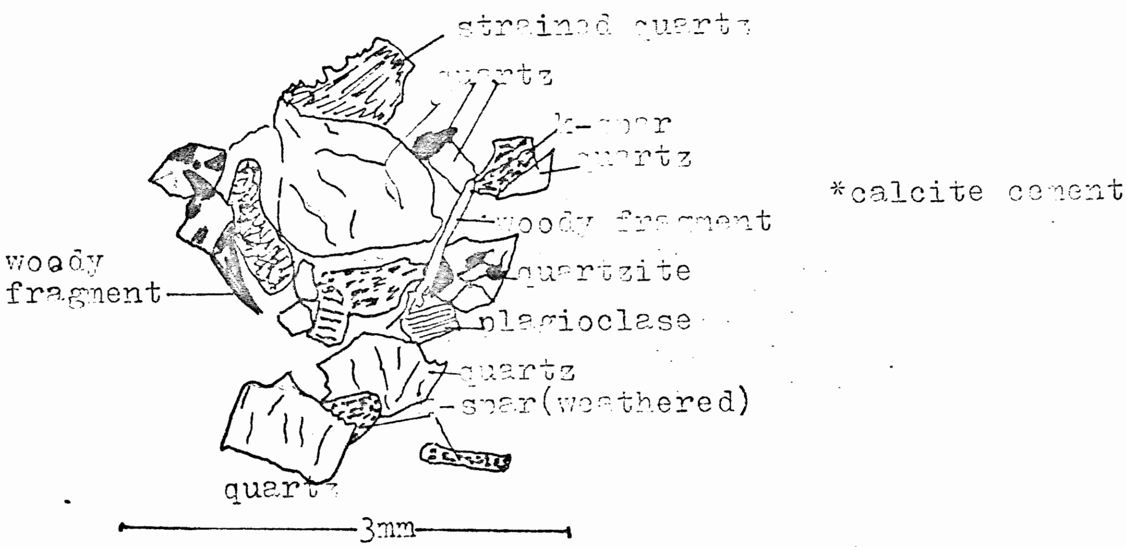
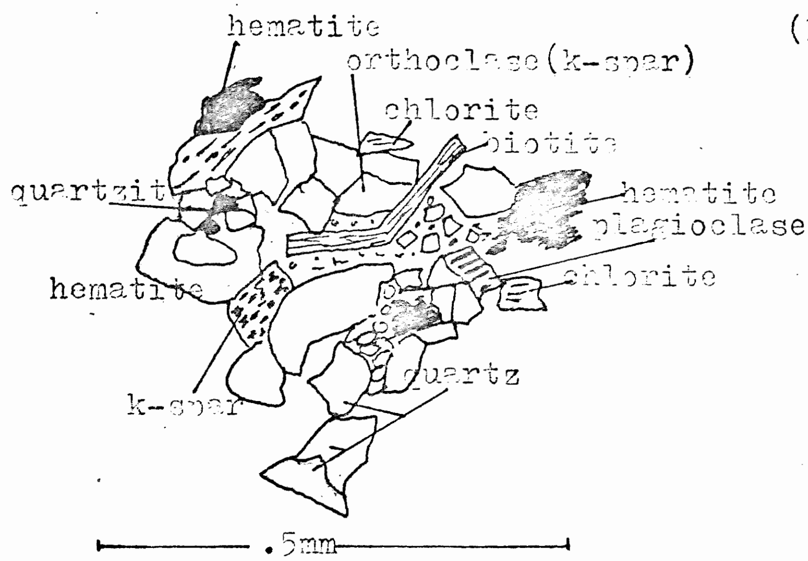


Fig.12.2 -Thin section of medium sandstone.

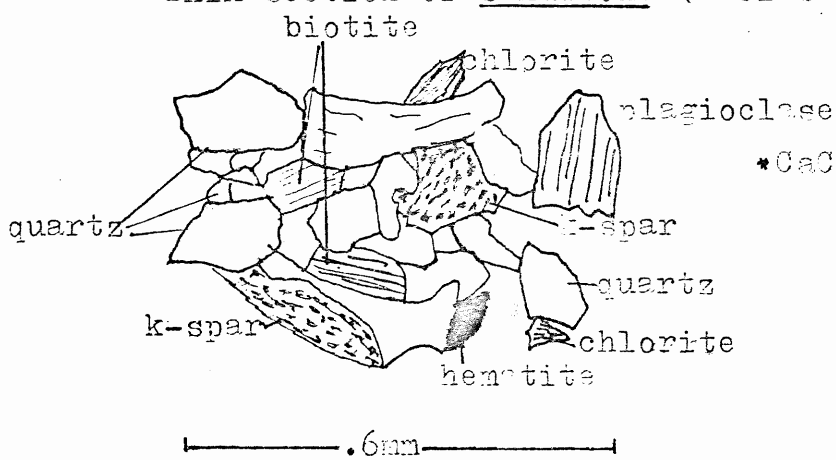
(Facies 3)



*clast supported
- cement is $CaCO_3$.
-80% quartz
-10% feldspar
-10% others

Fig.12.2-

Thin section of sandstone-(Facies 3).



*$CaCO_3$ cement

Fig.12.2 -medium sandstone.

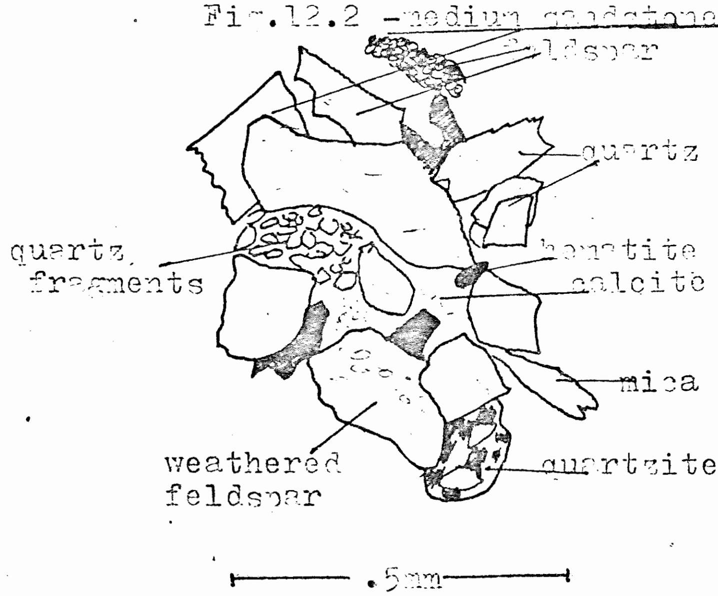


Fig.12.3 -Thin section of laminated fine sandstone (Facies 4).

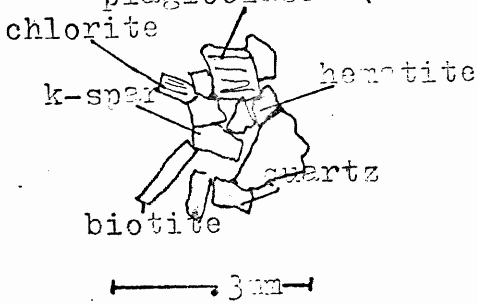


Fig.12.4 -Very fine-grained sandstone-very coarse siltstone. (Facies 5)

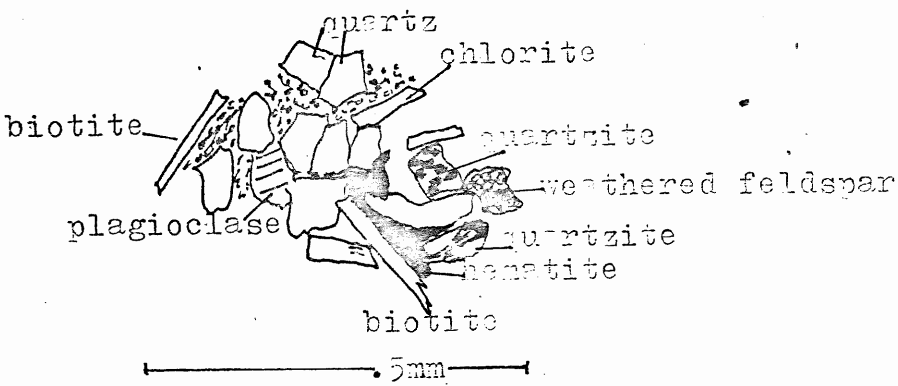


Fig.12.5 - Thin section of mudstone (Facies 6)

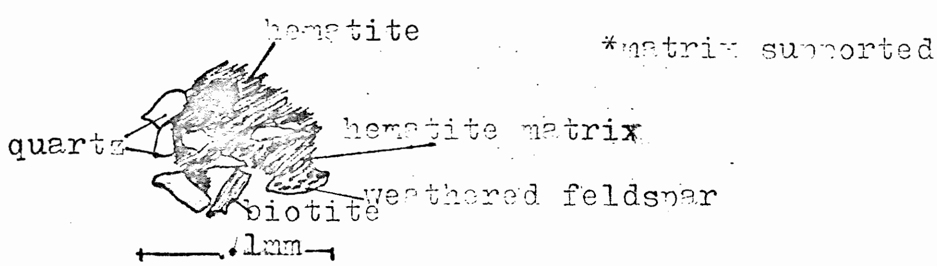
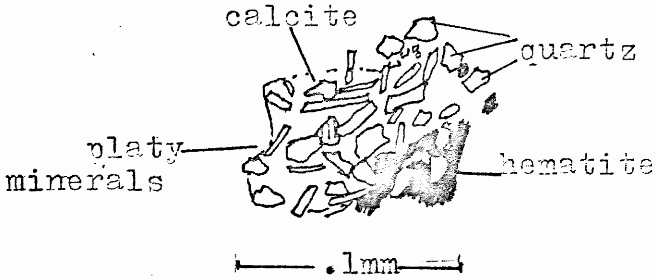


Fig.12.6 -Thin section-mudstone (Facies 6).



- cement is calcite and hematite.

Fig.12.7 -mudstone

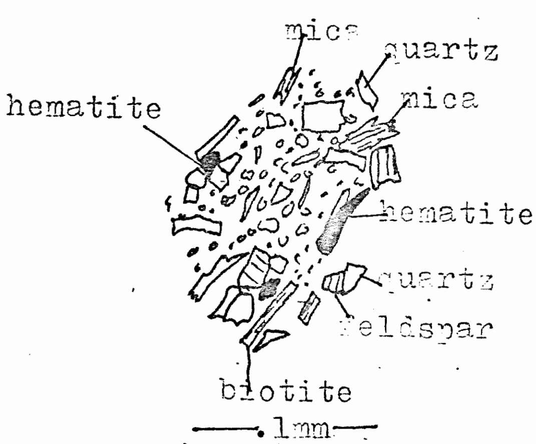


Fig.12.8 -Mudstone.

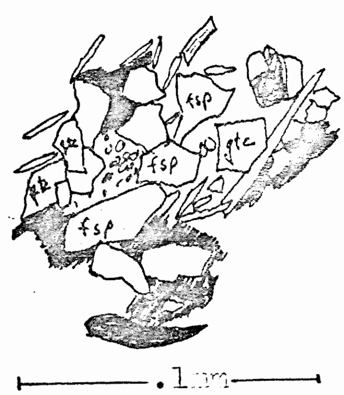


Figure 13a.

Burrows on sandstone-mudstone contact.

Figure 13b.

Burrows on mudstone bedding surface.

Figure 14.

Stem fragment, order Lepidodendrales (right) and unidentified root cast.

with one good exposure in sandstone-conglomerate. (Fig. 15). Rootlets and burrows are partially responsible for the massive and incompetent nature of mudstone.

Fossil plants of the division Lycophyta, order Lepidodendrales, are common as stem fragments in sandstone and conglomerates (Fig. 14). A well preserved leaf of the division Pteridospermophyta was also found in the section on a mudstone/fine sandstone contact (Fig. 16). These plant groups are all Carboniferous in age and are terrestrial.

VII PALEOCURRENTS

Paleocurrent data has been summarized in Fig. 10. The rose diagram for the entire section indicates a unimodal westerly flow direction. The average calculated from the data indicates an azimuth of 240^{o} for paleocurrent direction with a standard deviation of $\pm 55^{o}$. When divided according to sedimentary structure, the large-scale crossbeds and the small-scale crossbeds are 40^{o} apart.

Paleocurrent information is important to this study as it can give: the direction of initial dip or paleoslope; the relations between facies and current direction, and the direction of sediment source. This analysis can then be extended to establish the relationship between the internal directional structures and the geometry of a lithostratigraphic unit.

On a larger scale of study, paleocurrents could allow prediction of local and regional sedimentary trends along with information about sedimentary tectonics. In short, field observation of directional structures, the shapes

Figure 14 (con't).

Stem in conglomerate.

Stem cast in sandstone.

Herbaceous Lycopod on mudstone bedding surface.

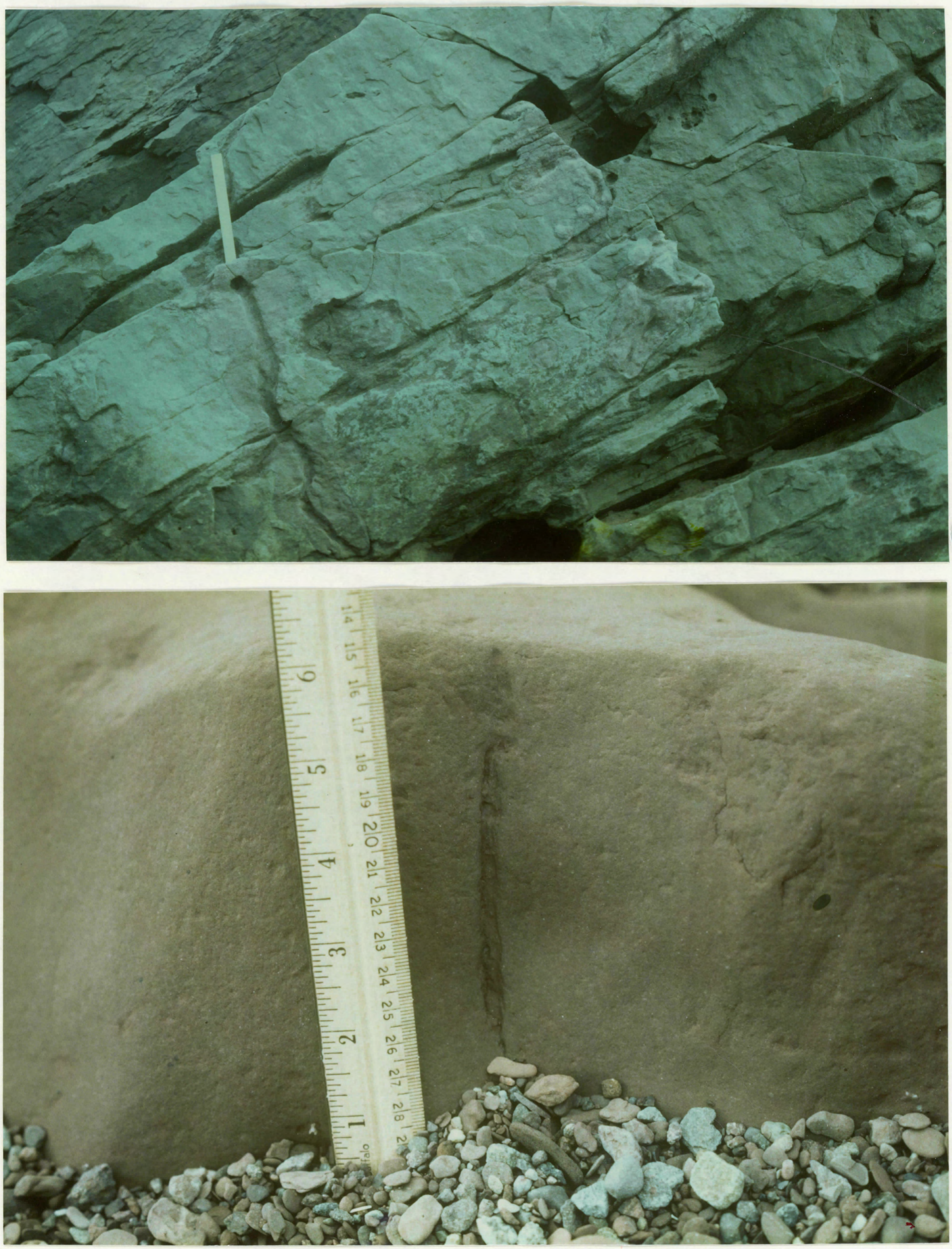


Figure 15.-Root fossils in sandstone-conglomerate(top)
and in medium sandstone (bottom).
Ruler is 30cm long.

Figure 16.- Well preserved leaves of Phylum Pteridospermatophyta. The one on the left is in mudstone and the one on the left in sandstone. The paper-clip is 3cm long.

Figure 17.-Channel-fill displaying erosive base on contact with mudstone.

Figure 20.-Fossil Lycopod

of sedimentary bodies and their stratigraphic relationships assist recognition of depositional facies and sedimentary basin models.

At Cape John a variety of sedimentary structures yield paleocurrent data including trough crossbeds, ripples, ripple crests, climbing ripples primary current lineations and current crescents. Large scale trough crossbeds give more reliable paleocurrents than do small-scale crossbeds. The similarity of ripples and troughs in the paleocurrent diagrams (Fig. 10) suggests they were formed in a coherent flow system.

The paleocurrent data presented has important implications for facies models and tectonic setting (See below). Great care was taken in data collection. Measurements were corrected for structural dip and were also checked for variation due to position in the section and to type of structure. The data is considered reliable.

VIII MARKOV CHAIN ANALYSIS

Strata can be tested for patterns of vertical sequence (e.g. cyclicity) by Markov chain analysis (see Miall, 1973, for details). The section gave 51 transitions between strata of the six facies types, and the data was analysed by the embedded chain method (Krumbein and Dacey, 1969). The results are presented as a facies flow chart with probabilities of transition shown (Fig. 18a) and a hypothetical vertical sequence constructed from the flow chart (Fig. 18b).

Markov analysis of the section shows a rough fining-upward cycle. The cycle begins with conglomerate (facies 1) at the base, fining upward to medium sandstone (facies 3) with fine sandstone (facies 5) interbeds. The association fines up to a very fine sandstone-fine sandstone association (facies 4 and 5).

Mudstone (facies 6) is topmost in the cycle either through abrupt change to mudstone or by fining from the other facies types.

IX DEPOSITIONAL ENVIRONMENT

(1) GENERAL ENVIRONMENT

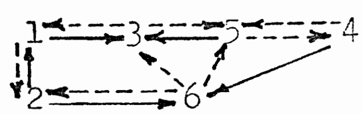
The data collected and analysed at Cape John favors a terrestrial environment of deposition. This can be inferred from the presence of non-marine fossils such as the vascular plants mentioned earlier and from the absence of marine fossils. In addition the predominantly red color in the section indicates oxidizing conditions due most likely to subaerial exposure.

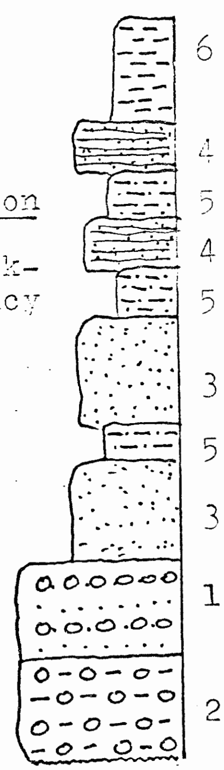
Figure 18. MARKOV ANALYSIS

a) Transitions

Key:

Symbol	Facies no. (this study)	Rock type	
1	Facies 1	extrabasinal conglomerate	
2	Facies 2	intraformational conglomerate	
3	Facies 3	medium-grained sandstone	
4	Facies 4	laminated fine-grained sandstone	
5	Facies 5	very finesand-very coarse siltstone	
6	Facies 6	mudstone	
——→	frequent transition		
- - - -→	infrequent transition		





b) Composite section showing most common transitions. Bed thickness denotes frequency of transition.

The data does not favor a transitional (deltaic) environment as there is no evidence for a marine base in the section. There is a possibility that this sequence is a delta plain (non-marine). Channels filled with sandstones and conglomerates contain flow structures such as trough cross-beds, ripples and current crescents. In addition, paleocurrent data suggests a unimodal flow pattern (Fig. 10). A fluvial setting appears to best fit these data.

(2) FLUVIAL MODELS

In the continuum of modern fluvial settings, Collison(1978) recognized two main types of alluvial sequence: one dominated by sandstones and conglomerates with little fine-grained sediment, which includes semi-arid fan, pebbly braided river and humid fan deposits; the other is dominated by sandstones and siltstones with only rare conglomerates, including low and high sinuosity stream deposits. He emphasized that these are broad distinctions of fluvial facies types and that they are intergradational. The section at Cape John is predominantly of the fine-grained type (50% mudstone, 20% fine sandstone, 30% medium sandstone and conglomerate).

The section fits Collison's low sinuosity to high sinuosity group. These equate roughly to braided and meandering stream types respectively. Moody-Stuart (1966) listed a number of useful criteria for distinguishing low sinuosity (braided) and high sinuosity (meandering) stream deposits. Low sinuosity stream deposits have the following characteristics:

(1) Channel deposits show an approximately horizontal top, and the lower surface is erosional and trough shaped. Deposits are rather thin.

(2) Since channels are abandoned by avulsion, the fine-grained sediment is spread across the whole upper surface of the coarse grained channel deposits.

(3) Large-scale cross-bedding is well developed.

(4) Natural levee deposits are rare and are preserved only on the sides of channel deposits.

(5) Paleocurrent data show only minor deviations in the flow pattern.

High sinuosity streams deposits have the following characteristics:

(1) In cross-section, the coarser material (sand) forms a tabular body which is surrounded by floodplain deposits.

(2) Sand bodies are often associated with fine-grained channel fill deposits. The original channel form is present.

(3) Thin natural levee deposits may be present on the top of the point bar deposits.

(4) Paleocurrent data show wide variation.

Further diagnostic features of braided streams were noted by Selley (1970) who described them as typically composed of sand and gravel channel deposits to the exclusion of fine-grained overbank silts and clays. There is generally an absence of laterally extensive cyclic sequences of the kind produced by meandering channels. Williams and Rust (1969) described thin fining-up sequences of gravel, sand and silt created by waning flow in the Donjek river. Coarsening-up sequences have been recorded in glacial outwash braided streams (Costello and Walker, 1972). Silt deposits in abandoned channels resemble channel-fill sequences in meandering streams.

The classical model for meandering rivers describes a fining-upward cycle (Allen, (1970) created by lateral deposition of a point bar on the inner bank in the direction of meander migration (Fig. 19). Shanaster (1951) subdivided meandering river deposits into 3 main subfacies. The floodplain subfacies is composed of sheets of very fine sand, silt and clay deposited on the overbank areas of the river flood plain. These are laminated, ripple-marked, contain carbonate caliches, ferriginous laterites and rootlet horizons. Detrital plant debris may be preserved on bedding surfaces.

The channel sub-facies consists of an erosive base overlain by extra-formational pebbles, intraformational mud clasts and debris. These are overlain by sand which fines upward. Massive, flat bedded and trough cross-bedded sands grade up into tabular planar cross-bedded sands of diminishing set height. These in turn pass up into micro-cross laminated and flat bedded fine sands which grade into muds of the floodplain subfacies. The channel subfacies has been well documented by Vishen (1965), Allen (1964, 1970), and Miall (1977).

The third subfacies described by Shanaster is the abandoned channel fills described by Moody-Stuart (1966) (See above).

INTERPRETATION OF FACIES

The section at Cape John conforms more closely to the meandering model than to the braided model. Most notable is the high percentage of fine-grained sediment. The floodplain subfacies of Shanaster (1951) and Miall (1977) is remarkably similar to the mudstone facies in the study area,

Figure 19.-"Classical" fining-up model.
(after Allen, 1964)

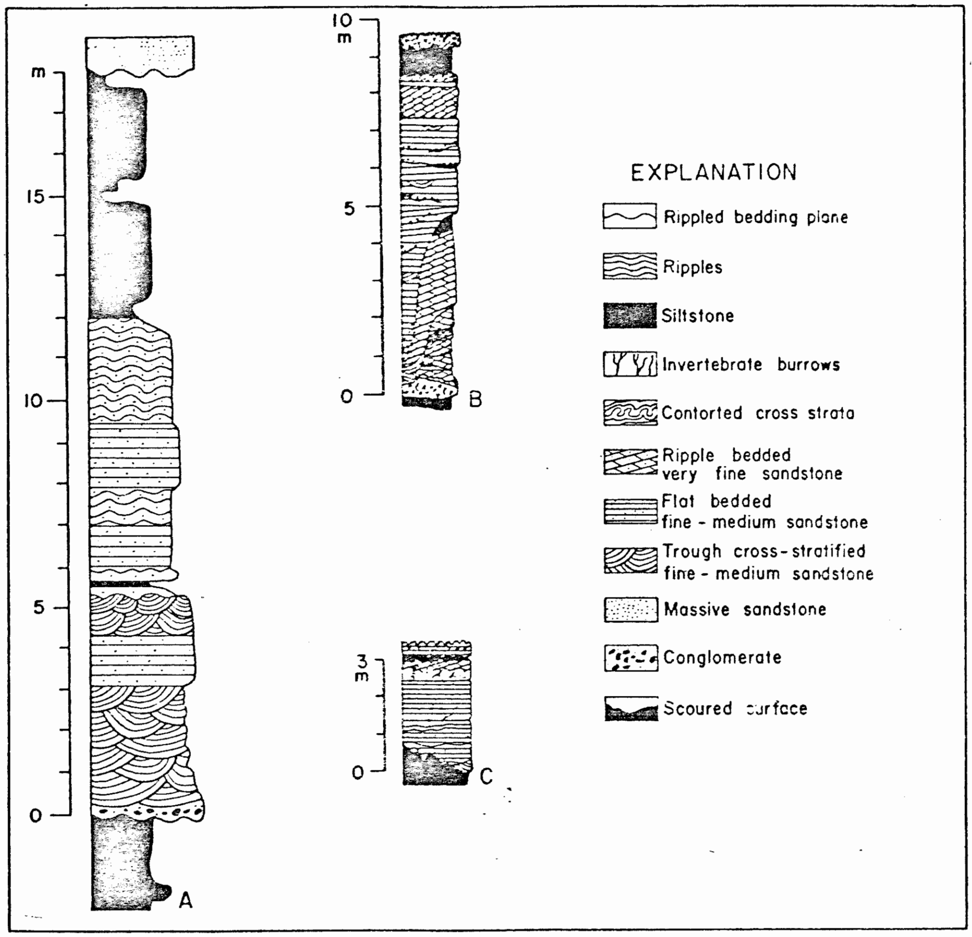


Figure 8-55 *Columnar sections through various examples of inferred deposits of ancient flood-plain rivers of Devonian age.*

A. Cyclothem AI, north side of N.Y. route 23A, about 1.5 miles east of Haines Falls, New York (After J. R. L. Allen and P. F. Friend, 1965, Fig. 9, p. 51.)

B. Cyclothem of early Devonian age (Dittonian) exposed in stream at Tugford, Shropshire (SO566873). (After J. R. L. Allen, 1964, Fig. 10, p. 181.)

C. Lowermost cyclothem of early Devonian age (Breconian), exposed in wilderness quarry (SO672185), ⅔ mile east of Mitcheldean, Gloucestershire. (After J. R. L. Allen, 1964, Fig. 12, p. 188.)

containing rootlet horizons, lamination and calcareous nodules. Figs. 11:6, 12:5, 12:6, 12:7, 12:8 and Table 1 support the contention that this is indeed a floodplain facies. In addition, the great thickness of mudstone units implies a wide horizontal extent for this facies which is indicative of a meandering system.

In the stratigraphic column between 285 and 320 m (Fig. 9) a multistorey sand body is situated above a fine-grained channel fill. Fine-grained fills are one of the criteria for high sinuosity streams, as noted above. The original channel form is visible (Fig. 17).

Of ten facies described by Miall (1977), four resemble facies found in the section at Cape John:

(1) Massive crudely bedded gravel facies (pebble to cobble size) resembles facies 1 of the study area. This facies is common in braided rivers but is also found as lay gravel deposits in meandering rivers. Thin gravel layers can be seen throughout the section (51 m, 132 m, 176 m, 212 m, 300 m), but thick units of conglomerate present (e.g. 235-257 m) are more typical of a braided model.

(2) Trough cross-bedded sand which contains solitary or grouped trough cross-bed sets resembles facies 3 from Cape John. Miall's sets range from 5-60 cm in thickness and grainsize is medium to very coarse. This correlates well with 30-40 cm sets of medium sand in the study area. The base of this facies is commonly an erosion surface (Fig. 17). The facies is equally common in braided and meandering rivers. In the latter, it forms the bulk of lower point bar deposits.

(3) Ripple cross-laminated sand characterized by Miall as a variety of asymetric ripple types, including climbing ripples, is found at Cape John

(Facies 4, Fig. 12:4). This facies is equally common in braided and meandering environments. In the latter it commonly forms upper point bar deposits.

(4) Mudstone-siltstone facies; this facies corresponds to facies 6 in the study area and has been discussed above in relation to Shanaster and Miall. It is common in a meandering setting as a flood plain deposit.

Two other facies types found in the study area do not fit directly into Miall's scheme. Facies 2 (intraformational conglomerate) is included in the massive, crudely bedded gravel facies described above. This facies was distinguished by this author due to the different nature of clasts (intra-basinal as opposed to extra-basinal). Facies 5 in the study area (very fine sandstone-very coarse siltstone) is probably included by Miall in the mudstone facies. In the study area it forms thick units as does the mudstone but was separated due to its more resistant nature and higher average grain size. It also occurs as thinner units associated with sandstones and conglomerates.

Allen (1965) distinguished two general facies associations in fine-grained meander belts: coarse and fine (Fib. 19). The coarse members are laterally accreted channel deposits, and the fine members are vertically accreted inter-channel deposits.

The fine members of Cape John are the products of interchannel deposits. They are abundant and show evidence of bioturbation, plant life and are laminated horizontally. Calcareous nodules present in the mudstone facies indicate an arid or semi-arid environment with low soil solution rates due to low water input. Periodically, siltstone-mudstone deposition was interrupted by thin sandbodies. The interbedding can be seen at 175 m, 190 m and 202 m (Fig. 9).

The coarse members (conglomerates and sandstones) at Cape John represent in-channel deposits. The conglomerate mainly occurs as beds only a few clasts thick and is interpreted as channel lags. The clasts are extrabasinal, or intrabasinal derived from reworking of the inter-channel deposits. Clasts in the latter may be reworked carbonate or siderite concretions. Grey to brown cross-bedded sandstones are common in the section (e.g. 302-322 m, 150-65 m, Fig. 9). Through cross-bedding is the most abundant sedimentary structure and occurs in sets of approximately 40 cm. Small-scale cross-beds or cross-laminae, interpreted by Allen (1965) to be the product of migrating current ripples, are also found throughout the sequence where large sandbodies are encountered.

DEVIATIONS FROM MEANDERING MODEL

Conglomerates constitute 12% of the section and form thick units (12 m) which interrupt the classical meandering sequence. Although significant they do not make up a substantial proportion of the overall thickness which tends to preclude an alluvial fan model for this facies (Collison 1978). Bluck (1964) interpreted a similar facies type to be the product of multiple reworking in stream channels on fans. McGowan and Grant (1972) interpreted this type of conglomerate as a distal fan deposit. McGowan and Garner (1970) noted a non-fining up tendency in larger coarse-grained point bars of the Amite river. Although the conglomerates at Cape John resemble facies type from alluvial fan sequences they require intrepretation in the context of their relationship with other facies types. It is possible that these conglomerates represent a change in climate and a period of higher discharge in the basin. This conglomerate is grey, indicating non-oxidizing conditions, and contains abundant plant fragments in the form of stems (Fig. 20) and roots (Fig. 15). In thin section (Fig. 12:1) woody fragments are visible as well. This idea of a climate fluctuation concurs with that of Van de Poll (1973), mentioned earlier in this report.

The facies relationships do not conform to the classical fining-upward model in every respect. At 300 m (Fig. 9) a large sandstone body is seen to have accreted above a former channel fill (Fig. 17) which itself has an erosive contact with mudstone. This would indicate meander migration across an abandoned channel or cut-off creating a non-classical sequence. This multistorey situation could in part represent a balance between lateral migration and vertical sedimentation rate.

Fining-up can be seen in several places where sandstone grades to fine sandstone to thick mudstone. Markov analysis (Fig. 18) indicates a generally fining-upward sequence for the Cape John section. However, there are numerous variations. A fining-upward sequence (Allen 1964, 1970) is considered by most workers to be the most characteristic feature of meandering stream deposits. Absence of fining-upward sequences in fluvial deposits is sometimes taken as a criteria for braided stream deposits. Several researchers in modern fluvial systems do not feel that this is necessarily so (Bridge, 1978; Jackson, 1976). McGowan and Garner (1970) found no fining-upward tendency in coarse-grained point bars. Rust (1978) found fining-up sequences in distal gravelly braided streams. Fining-upward sequences are most often but not always produced by migrating point bars. The corollary is that migrating point bars do not always produce fine-upward sequences.

Although data taken from the study area indicate a meandering system more strongly than a braided system, it should be noted that many authors feel that differentiation between meandering and braided stream deposits is a complex problem (Reineck and Singh, 1980: Jackson, 1978; Shelton and Noble, 1974). No river pattern produces a single characteristic sequence but rather a number of sequences of highly variable character. Similar looking sequences may be produced by rivers of different patterns. Further, not all parts of a sequence are preserved and the probability of preservation of a certain type of sequence is strongly controlled by the pattern of migration of the channel (Reineck and Singh, 1980). A meandering model best fits the data but it is important to recognize the problems inherent in this area of study. Hence, complete point bar sequences are not found and the fining-up sequence at best, approximates Allen's model. It is possible that the meander belt had a somewhat flashy discharge or possibly a higher than average gradient than suggested by the classical model.

The Cape John section fits the classical model of Allen (1970) in a general sense. That is, the presence of fine interchannel sediments with evidence of paleosoil (concretions, root horizons) along with the general fining-up trend of coarse members could almost be termed diagnostic. The major deviation from Allen is the interruption of the section by thick (20 m) extrabasinal conglomerates in the middle of the section.

X PALEOHYDROLOGIC ANALYSIS

Paleohydrologic analysis is the study of the ancient river type and magnitude. Miall (1977) proposed that in meandering river fining upward cycles, the thickness of the sand unit corresponds to the height of the point bar and this in turn is approximately equal to the channel depth during the annual flood. The best preserved sand unit at Cape John is the thick (19 m) sand unit at the top of the section. If Miall's relationship is applied then this would also be the minimum depth of this river as the outcrop passes under the ocean. The channel width can sometimes be judged in outcrop by means of sand body dimensions but this was not possible at Cape John as there were no suitable exposures.

XI TECTONIC SETTING

Fluvial sequences accumulate sediment by both vertical and lateral accretion. The style of sedimentation reflects geomorphic variables. Included are sinuosity, sediment load, discharge quantity and variability, and the presence or absence of vegetation. These can yield information valuable in interpreting tectonic variables such as paleoslope, rate of subsidence and geometry of the receiving basin.

The study area, as mentioned earlier, was formerly located in an intracratonic basin (Fundy Rift Zone). Belt (1965) proposed that the Fundy Basin is a complex rift valley (graben system) bounded by high angle faults and surrounded by relatively stable platforms (Fig. 5).

The tectonic style and facies of the Fundy Basin have many similarities to features found in the East African rift system (McConnell, 1967 quoted by Belt, 1968), as well as rift troughs of Late Triassic age in eastern North America. Lacustrine, fluvial and fanglomerate facies characterize the African rift basins which may show paired faults, determine a graben in one region and a down flexed rift margin elsewhere. Horst-like structures within the rift basin are not uncommon in the East African rifts. This description fits well with Belt's (1968) paper on Carboniferous sedimentation in Eastern North America.

Paleocurrent studies by Van de Poll (1973) in New Brunswick and by Fralick and Schenk (1981) in the Cumberland Basin, indicate an easterly slope for the basin. Van de Poll proposed a source area for New Brunswick Pictou Group rocks to be north of the Catskills. Fralick and Schenk studied Pictou Group paleocurrents (Fig. 21) and obtained what are essentially polymodal rose diagrams with a mean easterly flow direction. They also proposed a source area to the west.

Paleocurrent data from this study show a definite trend to the west. Since the study area is small, it is possible that the fluvial system studied was part of a more complex flow distribution across the basin, with overall flow as indicated in the large-scale interpretations of previous authors. Indeed, drainage directions in Nova Scotia today can vary within a few miles (Musquodoboit and Shubenacadie rivers). A complicated drainage pattern may have existed in this area during Pennsylvanian time.

Source areas for this sequence would have to be eastward or possibly,

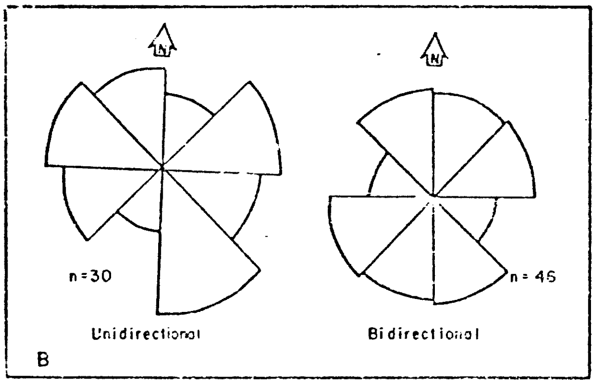


Figure 21 (From Fralick and Schenk,1980).
Two distinctive conglomerate Paleocurrents inferred from unidirectional and bidirectional indicators in the Pictou Group.

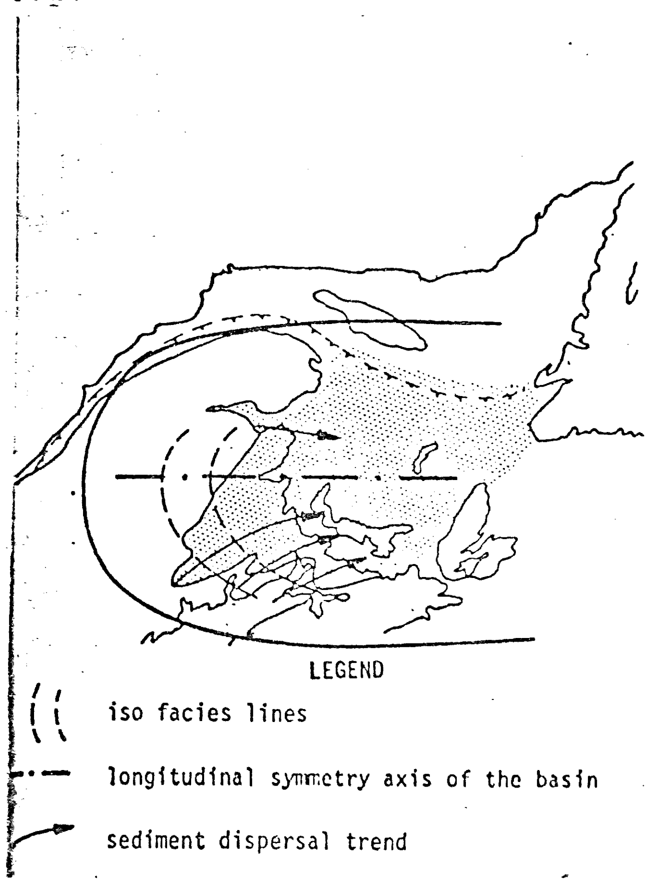


Figure 22(From Van de Poll,1973).

Paleocurrents and paleogeographic limits of the Pictou Group depositional basin.

with more complex flow systems, north and south of the study area. The sandstone grains include quartz, quartzite, plagioclase, orthoclase, mica, chlorite and their weathering products (Fig. 12). Hematite and clay minerals are present but are derived from decay of original source rocks. These grains indicate a granitic and/or possibly a metamorphic source for these sediments.

A possible source area is the Cobequid Complex or a northern extension of this massif system. It is a metavolcanic-metasedimentary assemblage intruded by plutonic rocks varying from coarse-grained granite to diorite. The metamorphic rocks consist of fine grained purplish argillites; red and grey shales; green, grey and brown sandstones; and felsites and tuffs. They are highly sheared and fractured and cut by numerous quartz and calcite veins.

Another possibility is the Brown's Mountain Group presently to the east of the study area. The rocks here comprise a resistant metamorphic complex of volcanic and sedimentary rocks ranging in age from Early Cambrian to Late Ordovician. The Brown's Mountain rocks underlie the greater part of the Pictou-Antigonish Highlands. They are unfossiliferous and are composed primarily of interbedded basic volcanic and pyroclastic rocks, argillite and siltstones.

The mineralogy of these two Highlands is compatible with the mineralogy of the study area. Quartz, felspar and mica are abundant in the thin sections indicating acid and intermediate plutonic rocks as possible source rocks. Pebbles in the conglomerates include plagioclase, orthoclase, greywacke and quartz.

Paleocurrent data for the section also supports these massifs as source areas for this portion of the Pictou Group. Paleocurrent direction is dominantly to the west and if these areas were not the original source areas it is possible the original sources were later eroded away or down faulted.

Bell (1944) and Gillis (1964) concluded that these were indeed the source areas for the Pictou Group. This has been disputed by others such as Van de Poll (1966, 1973) who proposed a source area north of the Catskills, with transport of sediment to the east (Fig. 22). Fralick and Schenk (1980) stated that stratigraphic sections (outside the study area) disprove a decrease in grainsize to the north. They also noted that paleocurrents within the group do not display a significant trend (Fig. 21) possibly because a number of source areas were active.

Belt (1968) proposed that pre-Hortonian through Riversdalian facies of fanglomerate, fluvial, lacustrine and mixed origin were derived locally from pre-Carboniferous basement blocks. During Pictou time, widespread blanket deposits were laid down on what had essentially become a large platform. He further contended that the platform sagged in some areas more than others to accommodate local thickening.

It seems likely that a number of source areas were active and flow, which on a large scale may have trended eastwards was somewhat more complex on a local scale. The Pictou Group rocks in New Brunswick, Prince Edward Island, and Nova Scotia represent penecontemporaneous deposition in a large rift basin which does not necessarily imply a common source area for all sediments. Similar weathering and oxidation processes acting on the entire basin would produce the similarities in facies between the widely separated locations.

The basin during this time was probably generally low gradient with low uplands. Oxidizing conditions existed over a large area although the climate may have fluctuated (Van de Poll, 1973).

XII CONCLUSIONS

The Pictou Group rocks cropping out of Cape John consist of alternating mudstones, sandstones and conglomerates. A meandering fluvial model most adequately explains the deposition of this rock sequence. The abundance of mudstones and the rough fining-up pattern of the facies along with unidirectional paleocurrent data are best interpreted by the meandering model.

Variations from the classical model in the form of thick conglomerate units are explained by a flashy discharge or by fluctuations in climate during the period of deposition.

Paleocurrent directions combined with the depositional model have important implications regarding analysis of the depositional basin. This study provides evidence for a westerly flow trend for this portion of the Pictou Group depositional basin. It is evident from research conducted during this study that more investigation of the Pictou Group is required to determine source areas and the geometry of the basin. There is discord among several authors with regard to lateral facies distributions and sediment dispersal patterns. A section by section study would more accurately describe the overall sequence than would regional studies as have been conducted to date.

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APPENDIX

A) Markov Analysis constructions.

i) Transition count matrix

UPPER BED

LOWER BED	1	2	3	4	5	6	Si
1		/	卌	/	/	/	8
2	/					/	2
3	卌			///	///	卌	17
4	/		//		/	////	8
5	/		///	/			5
6	//	/	卌	///			11
Sj	10	2	15	8	5	11	

total transitions (t) = 51

ii) Independant trials matrix

$r_{ij}=S_j/(t-S_i)$

i \ j						
		.043	.34	.18	.11	.25
	.2		.30	.16	.10	.22
	.29	.06		.23	.14	.32
	.23	.043	.34		.11	.25
	.22	.043	.32	.17		.23
	.25	.05	.375	.2	.125	

iii) Transition probability matrix.

$P_{ij}=f_{ij}/S_i$

	.125	.625	.125	.125	.125
.5		0	0	0	.5
.35	0		.18	.18	.29
.125	0	.25		.125	.50
.2	0	.6	.2		0
.18	.09	.45	.27	0	

iv) Difference matrix

$d_{ij}=P_{ij}-r_{ij}$

	.082	.285	-.055	.015	-.125
.3		-.3	-.16	-.10	.28
.06	-.06		-.05	.04	-.03
-.10	-.04	-.09		.015	.25
-.02	-.04	.28	.03		-.23
-.07	.04	.07	.07	-.125	

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