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GEOLOGY OF THE TATAMAGOUCHE SYNCLINE, CUMBERLAND BASIN, NOVA SCOTIA

by

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TABLE OF CONTENTS

		Page
Chapter 1:	Introduction	1
	Location and Access	2
	Introduction	2
	Previous Work	2
	General Geology	3
	Physiography and Glaciation.	4
	Acknowledgements	6
Chapter 2:	Stratigraphy	7
	Groups	8
	Formations	8
	Map Boundaries	10
	Age	11
Chapter 3:	Sediment Dispersal Patterns	12
	Paleocurrents	13
Chapter 4:	Lithofacies	15
	Millsville Formation	16
	Boss Point Formation	16
	Cumberland Group	16
	Pictou Group	17
Chapter 5:	Primary Sedimentary Structures	19
	Bedforms	20
	Linear-Erosional	23
	Deformational	25
Chapter 6:	Facies Models	28
	Straight Streams	29
	Meandering Streams	30
	Wet Alluvial Fans	30
	Lacustrine	31
Chapter 7:	Sedimentology	33
Chapter 8:	Paleontology	36
Chapter 9:	Structure	39
Chapter 10:	Economic Geology	41
	Copper, Lead, Silver	42
	Manganese	44
	Barite	45
	Uranium	45
Chapter 11:	Summary and Conclusions	47
References:		50

LIST OF FIGURES

Figure 1: Location Map, Tatamagouche Syncline Area, Cumberland Basin, Nova Scotia.....1 (a)

Figure 2: Groups in the Carboniferous of eastern Canada... 8 (a)

Figure 3: Generalized Carboniferous Stratigraphic column, Tatamagouche Syncline, Cumberland Basin, Nova Scotia..... 8 (b)

Figure 4: Drill hole cross section, Eastern Tatamagouche Syncline, Nova Scotia..... 9 (a)

Figure 5: Sea Sat image with linears, northern Nova Scotia 10(a)

Figure 6: Linear structures (unconformities ?) from sea sat image, northern Nova Scotia.....10(b)

Figure 7: Generalized geology map, Tatamagouche Syncline, Nova Scotia.....11(a)

Figure 8: Generalized tectostome map for the Pictou Group in the central part of Carboniferous Basin showing sediment dispersal (arrows).....13(a)

Figure 9: Sediment dispersal patterns (trough cross strata) in the Tatamagouche Syncline Area, Nova Scotia...13(b)

Figure 10a: Trough cross strata palaeocurrent trends, Tatamagouche Syncline, Nova Scotia.....14(a)

Figure 10b: Palaeocurrent trends for all the current structures, Tatamagouche Syncline, Nova Scotia.....14(b)

Figure 11: Clast lithology percentages, Millsville Formation, Tatamagouche Syncline, Nova Scotia.....16(a)

Figure 12: Large scale cross stratification, Pictou Upper Red Beds, Cape John, Nova Scotia.....20(a)

Figure 13: Small scale trough stratification, Pictou Middle Red Beds, Blockhouse Point, Colchester Co, Nova Scotia..... 20(b)

Figure 14: Convolute Laminations in a medium grained sandstone, Treen Point, Tatamagouche area, Nova Scotia..... 25(a)

Figure 15: Loading, pseudonodules, mud dykes and mud lens, Pictou Upper Red Beds, Cape John, Pictou Co., Nova Scotia 25(b)

Figure 16a: Pseudonodules and mud dykes, Treen Point, Colchester Co., Nova Scotia..... 25(c)

Figure 16b: Pseudonodules at Treen Point, Colchester Co., Nova Scotia..... 25(c)

Figure 17: Straight stream facies model..... 29(a)

Figure 18: Meandering stream facies model..... 30(a)

Figure 19: Wet alluvial fan facies model..... 31(a)

Figure 20: Braided stream facies model..... 31(b)

Figure 21: Idealized facies model for clastic lake deposition 32(a)

Figure 22: Idealized section of the Pictou Lower Red Beds, Tatamahouche Syncline, Nova Scotia..... 35(a)

Figure 23: Idealized section of the Pictou Middle Red Beds, Tatamagouche Syncline, Nova Scotia..... 35(b)

Figure 24: Idealized section of the Pictou Upper Red Beds, Tatamagouche Syncline, Nova Scotia..... 36(a)

Figure 25: Reconstruction of fossil myriapod, Arthropleura sp.38(a)

Figure 26a: Fossil myriapod trails, Dipliclinites sp., Cape John, Pictou Co., Nova Scotia..... 38(b)

Figure 26b: Fossil myriapod trails, Cape John, Pictou Co., Nova Scotia..... 38(b)

Figure 27 : Limestone bed, Pictou Grey Beds, Treen Bluff, Colchester Co., Nova Scotia..... 39(a)

Figure 28 : Negative photomicrograph, ostracod in biomicrite, Pictou Middle Red Beds, Murphy Point, Pictou Co., Nova Scotia..... 39(b)

Figure 29 : Negative photomicrograph, mullusc shell debris in biomicrite, Murphy Point, Pictou Co., Nova Scotia 39(b)

Figure 30 : Calamites stem, Pictou Middle Red Beds, Rushton's Beach, Colchester Co., Nova Scotia..... 39(c)

Figure 31 : Palaeoecological reconstruction of Carboniferous Mega-flora, after Scott (1979)..... 39(c)

Figure 32 : Metallic Mineral occurrences in the Tatamagouche Syncline area, Nova Scotia..... 43(a)

Figure 33 : Mineralized fossil wood fragment, inner cell structure replaced by digenite and chalcocite, oliver copper occurrence, Colchester Co., Nova Scotia.. 44(a)

Figure 34 : Chalcocite replacing bornite, Blockhouse Point Mineral occurence, Colchester Co., Nova Scotia.. 44(b)

Figure 35a: Copper values versus distance from Pre-Carboniferous Cobequid Highlands rocks..... 45(a)

Figure 35b: Lead values versus the distance from Pre-Carboniferous rocks..... 45(a)

Figure 35c: Silver values versus distance from the Pre-Carboniferous..... 45(b)

Figure 35d: Zinc versus distance from the Pre-Carboniferous rocks..... 45(b)

Figure 36 : Manganese mineralization associated with a strike slip fault, minor chalcocite mineralization in the channel sandstone on the left of the photo, Pictou Upper Red Beds, near Cape John, Pictou Co., Nova Scotia..... 45(c)

Figure 37 : Galena, photomicrograph, Skinner's Cove lead occurrence, cast of River John, Pictou Co., Nova Scotia..... 45(c)

Figure 38 : Reduction-oxidation front uranium mineralization Model (where the carbon is abundant the sandstone is re-reduced)..... 46(a)

Figure 39 : Groundwater flow within individual channel sandstone, (or Sedimentary Basin) after Galloway et. al, 1979..... 46(a)

Figure 40 : Secondary uranium roll fronts on lateral margins of channel sandstones, Tatamagouche syncline, Nova Scotia..... 46(b)

LIST OF TABLES

TABLE I: Map units of the Tatamagouche Syncline Area, Nova Scotia..... 8(c)

TABLE II: Generalized Stratigraphy of the Carboniferous strata in the Tatamagouche area, Cumberland Basin, Nova Scotia.....16(b)

TABLE III: Analyses for grab samples from the Tatamagouche Syncline area.....47(a)

ABSTRACT

The Carboniferous strata of the Tatamagouche Syncline area can be divided into nine lithostratigraphic units: 1) Windsor Group 2) Millsville Formation 3) Boss Point Formation 4) Cumberland Coarse Facies 5) Cumberland Fine Facies 6) Pictou Grey Beds 7) Pictou Lower Red Beds 8) Pictou Middle Red Beds 9) Pictou Upper Red Beds.

With the exception of the shallow marine rocks which characterize the Mississippian Windsor Group, the rest of the Carboniferous strata are predominantely fluvial continental in origin. The continental lithofacies range from boulder conglomerates deposited in the proximal alluvial fan environment to sandstones and mudstones deposited in low sinuosity streams.

Paleocurrent directions indicate a flow to the north-northwest within the study area. Some variation of this flow may result from evaporite diapirism in anticlinal areas to the north of the study area.

Copper, silver, lead, zinc and uranium occurrences are numerous within the study area. The mineralization is closely linked to the presence of coalified plant material within the channel lag sandstones and conglomerates. Exploration models must therefore incorporate paleocurrent studies to correctly predict potential mineralization trends.

CHAPTER 1

INTRODUCTION

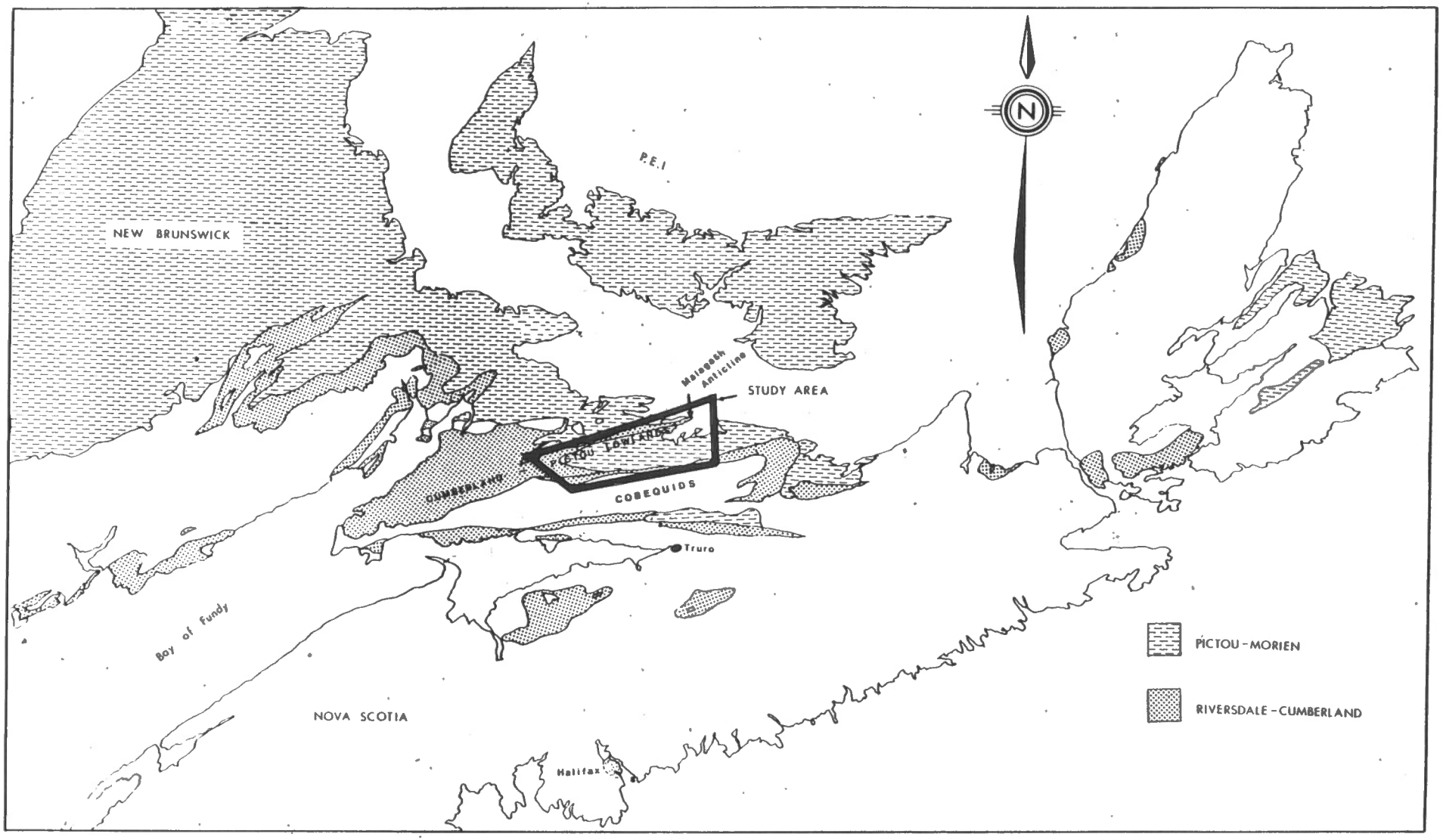

Figure 1: Location Map, Tatamagouche Syncline Area, Cumberland Basin, Nova Scotia

Location and Access

The area of study is located in Northern Nova Scotia, Canada, 40 Km north of Truro (Fig. 1). It is bounded by River John to the east and by Thompson Station to the west. The Cobequid Mountains define the southern limit of the study area and the northern boundary corresponds to the axis of the Malagash Anticline. The area lies between 63°50' and 63°00' longitude and 45°33' and 45°48' latitude. The study area is approximately 850 Km^2. (1:50,000 map; this report)

Access can be achieved by the Trans Canada Highway, Nova Scotia, 104 and numerous secondary roads. Major rivers can be navigated by canoe and provide excellent access to the inland areas. In addition, access to the shoreline can be accomplished by boat along the Northumberland Strait.

Introduction

A geological study of the Upper Carboniferous strata of the Tatamagouche Syncline, Cumberland Basin, Nova Scotia, was undertaken during the 1983-84 field seasons. Its purpose was to map the formations, investigate sedimentological features, to determine the stratigraphy, structure and diagenesis of the strata; to interpret paleocurrent patterns to log available drill core, and to evaluate the mineral potential of the area.

The Upper Carboniferous strata of the Tatamagouche Syncline area are folded into a gently plunging northeastly trending syncline and consist of red and grey conglomerates, sandstones and mudstones with minor limestones, totalling approximately 3400m in thickness. The rocks form a series of fining-upward fluvial cycles. The evaluation of the stratigraphy of the area was greatly aided by the availability of 50,000 feet of core from more than 100 diamond drill holes.

Previous Work

The first outline of the geology of Northern Nova Scotia was given by Dawson (1855). His work "Acadian Geology", gives a comprehensive account of the geology of the Maritimes Provinces of Canada.

Dawson reported that the Carboniferous section in the Tatamagouche area was about 16,000 ft. thick and he contrasted the broad open folds of this area to the irregular folds of the Pictou area.

Fletcher (1892) made the first detailed geologic observations in the area when he undertook a study of the Carboniferous rocks. However, the most significant contributions to the geology of the region have been made by Bell (1924, 1938, 1944, 1958) who established the stratigraphic framework for the Conboniferous of the Maritime Provinces. On the basis of his work, Howie & Barss (1974) divided Devono-Carboniferous into four divisions; the Horton, Windsor, Canso-Riversdale and the Cumberland-Pictou Groups.

Kelly (1967) redefined the Horton group as a distinctive litho-stratigraphic unit. Using his classification, the Horton group includes a

sequence of middle to Upper Devonian red beds and volcanics which overlie the Acadian Orogency unconformity.

The Windsor Group name was proposed by Bell (1929) for the marine limestones, evaporites and terrigenous clastics within the Windsor District of Nova Scotia.

The Canso-Riverdale Group overlap in age, as discussed by Kelly (1967), and were considered a separate division by Howie and Barss (1974). The Canso Group was defined by Bell (1944) as a sequence of Namurian A aged non-marine red and grey shales and sandstones that overlie the marine beds of the Windsor Group.

The Riversdale Group was also defined by Bell (1944) as a sequence of Westphalian A aged continental strata that lie stratigraphically between the Canso and the Cumberland Groups. Howie and Barss (1974) suggested that the Canso-Riversdale are regionally indivisible and range in age from late Visean to Westphalian A. Fossils and locally distinctive litho-stratigraphic units facilitate definition of some formations.

Bell (1944) defined the Cumberland Group as those rocks which overlie the Riversdale Group and underlie the Pictou Group. The Cumberland Group is restricted to the Cumberland Basin and to a few areas of southern New Brunswick. Bell (1926) defined the Pictou Group as Westphalian C to Stephanian aged sandstones, shales, and mudstones similar to those exposed to the West Branch of the River John, Nova Scotia. Howie and Barss (1974) combined the terms because they are in part contemporaneous and because of the limited geographic distribution of the Cumberland Group. Howie and Barss also suggested inclusion of the red beds of Prince Edward Island within the Pictou Group. Significant contributions to the understanding of the mineralization processes within the Upper Carboniferous of the Atlantic Region were made by Messervey (1929), Papenfus (1931), Shumway (1951), Brummer (1958), MacKay and Zentilli (1976), Dunsmore (1977) and van de Poll (1979), as well as numerous exploration companies.

General Geology

The Paleozoic of the Atlantic region forms a folded belt whic constitutes the northeastern part of the Appalachians. The earliest folding of the Paleozoic strata in the Atlantic region took place during the Ordovician Taconic Oroganey. Subsequent folding, faulting, intrusion, and metamorphism during the Acadian Orogeny (Early to late Devonian) stabilized the Appalachian geosyncline, which extends to the edge of the present day continental shelf (Poole, 1967).

Poll & Ryan (1985) state "The Carboniferous system of eastern Canada presently underlies a northeastern tract of land centered on the Bay of Fundy, Gulf of St. Lawrence. It extends from eastern Maine to Newfoundland from central New Brunswick to the Atlantic Ocean."

The present distribution of Carboniferous strata in Atlantic Canada (fig. 1) is only the erosional remnant of a much larger Basin that once covered most of New England and Atlantic Canada (Poll 1973).

Poll & Ryan (1985) suggested that the Carboniferous Basin should not be thought of as a single post orogenic basin, but rather a group of interrelated fault block basins and horsts with differing rates of subsidence and uplift.

The fragmentation of the Acadian Orogen into the New Brunswick Platform, Fundy Geosyncline, Nova Scotia Platform, Sydney Basin and Newfoundland Platform established a new set of tectonic elements which prevailed into the Permain Period (Howie & Barss, 1974). The fragmentation of the geosyncline into structural sub-basins is the result of major series of faults which have been interpreted as high angle normal and reverse faults (Gussow 1953), rotational faults (Poll 1970), and local thrusts or strike slip faults (Webb 1969), or transform (Bradley 1982).

Most of the warping and the down faulting was confined to the Fundy Geosyncline. The Cobequid, Caledonian, Westmorland, Antigonish and Cape Breton uplifts were tectonically active during the Acadian Orogen and divided the Fundy Geosyncline into the Moncton Basin, Cumberland Basin, Minas Basin and Magdalen Basin. Sediments that were deposited within the Fundy Geosyncline were derived from the platform areas as well as the positive relief features which were tectonically active during the period of sedimentation. The rock groups of the Upper Paleozoic (Fig. 2) exhibit regional similarities, although formations more closely reflect local tectonism (Howie & Barss 1974).

The rapid subsidence and sediment accumulation within the depositional basins correspond to periods of erosion on the uplifted or stable highland areas, resulting in paraconformities.

The maximum thickness of the Carboniferous Strata attained in the Maritime Provinces is approximately 40,000' (Howie & Cumming 1963).

Physiography and Glaciation

The dominant physiographic features of the study area are the Cumberland-Pictou lowlands which are associated with flat lying Upper Carboniferous sedimentary rocks of the Tatamagouche syncline. The lowlands are bordered to the south by the Cobequid Highlands and to the north by the low rolling hills associated with the Mississippian sedimentary rocks near the axis of the Malagash Anticline. The Cumberland-Pictou lowlands constitute a low relief coastal plain. (Fig. 1)

The lowlands extend in evalation from 0 to 130m, contrasting sharply with the Cobequid Highlands, which vary from 140 to 340m in elevation within the study area.

The whole area has been subjected to continental glaciation and is now covered with glacial deposits. It has undergone four phases of ice flow: 1) eastward which formed a compact red brown lodgement till, 2) south-southwestward, 3) north-northwestward 4) west-southwestward (Stea & Finck 1984).

Stea and Finck (1984) described the surface till sheet throughout most of the study area as a reddish-brown, jointed, sandy-silt till

composed primarily of Carboniferous sandstone clasts; igneous and metamorphic erratics are common in the top 2m of this till, and at surface. In the same paper, Stea and Finck (1984) described three till units exposed at Cape John. The three units are: (1) reddish brown silt till that rests on bedrock (11) greyish-brown till with a silty matrix and (111) greyish-red till with a sandy-silt matrix.

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CHAPTER 2

STRATIGRAPHY

"GROUPS" OF THE PERMO-CARBONIFEROUS STRATA OF THE CUMBERLAND BASIN

Nomenclature

Bell (1944) designated his basic divisions of the Carboniferous strata in Eastern Canada (Fig. 2) as "groups" instead of the previous designation of "series". Bell (1944) states his reason for doing so as: "The economic value of lithological classification of strata has already been mentioned and is generally understood. The value of classification based on age is not so generally appreciated". Kelly (1967) pointed out that the designation of these units as groups was not in accordance with the International Code of Stratigraphic Nomenclature.

Bell believed that all of his groups were separated one from another by unconformities or disconformities of regional time equivalence but Kelly (1967) stated that many of these contacts are conformable, at least at some localities. Because the periods of rapid subsidence and sediment accumulation within the depositional sub-basins are not time equivalent from basin to basin, the resultant unconformities, disconformities and paraconformities are also of differing age, basin to basin. Kelly (1967) revised the stratigraphic nomenclature in so far as he redefined the contact relationships between the groups.

Bell's (1944) terminology has been so widely accepted and used that it would be imprudent to change the nomenclature for the Carboniferous in the Maritime provinces on the basis of this study. Improvements of the stratigraphic nomenclature for the Carboniferous strata of Atlantic Canada may be possible on a formation level, using legitimate lithologic units to establish formations which can be mapped on a regional basis.

FORMATIONS WITHIN THE PERMO-CARBONIFEROUS STRATA OF THE TATAMAGOUCHE SYNCLINE AREA

Ryan (1984) established the basic stratigraphy for the Upper Carboniferous Strata for the east half of the Tatamagouche Syncline. Some refinements of the stratigraphy have taken place as a result of the 1984 field season, and the results are summarized in Table 1. The terms used are essentially field mapping terms and both formal and informal terms are used.

WINDSOR GROUP: This group is poorly represented in the study area and crops out only along the axis of the Malagash Anticline. The usually small exposures of the marine gypsum, siltstone and limestone of the Windsor Group make it impractical to map the individual units of the group and consequently all of the exposures are given the general group name.

RIVERSDALE GROUP:
Millsville Formation: The term Millsville formation was introduced by Bell (1926) to refer to the exposures of reddish brown conglomerates located in the vicinity of Millsville, Pictou County, Nova Scotia. Numerous conglomerates of similar age were mapped by Bell (1944) within the study area. For the purpose of this study, all of these units are considered as

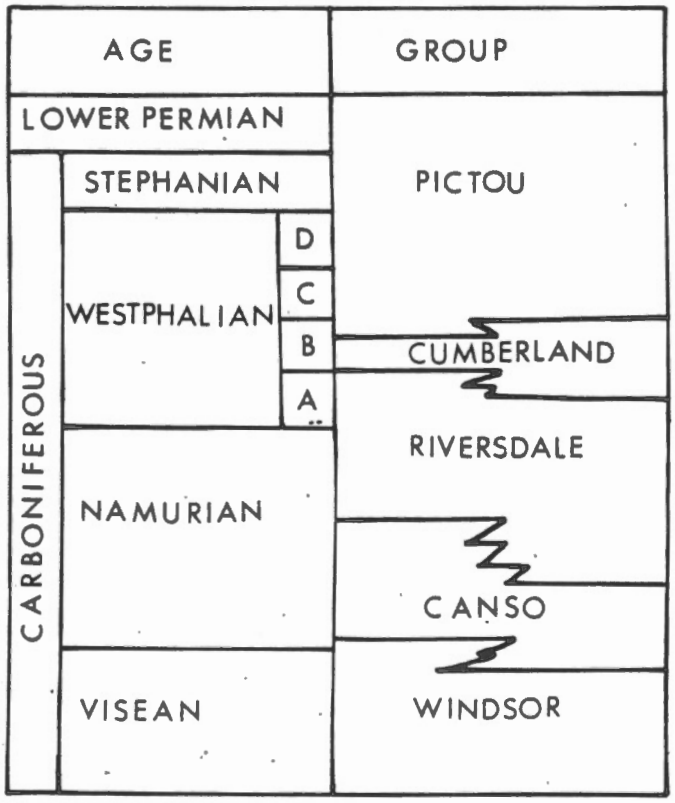


Figure 2: Groups in the Carboniferous of Eastern Canada

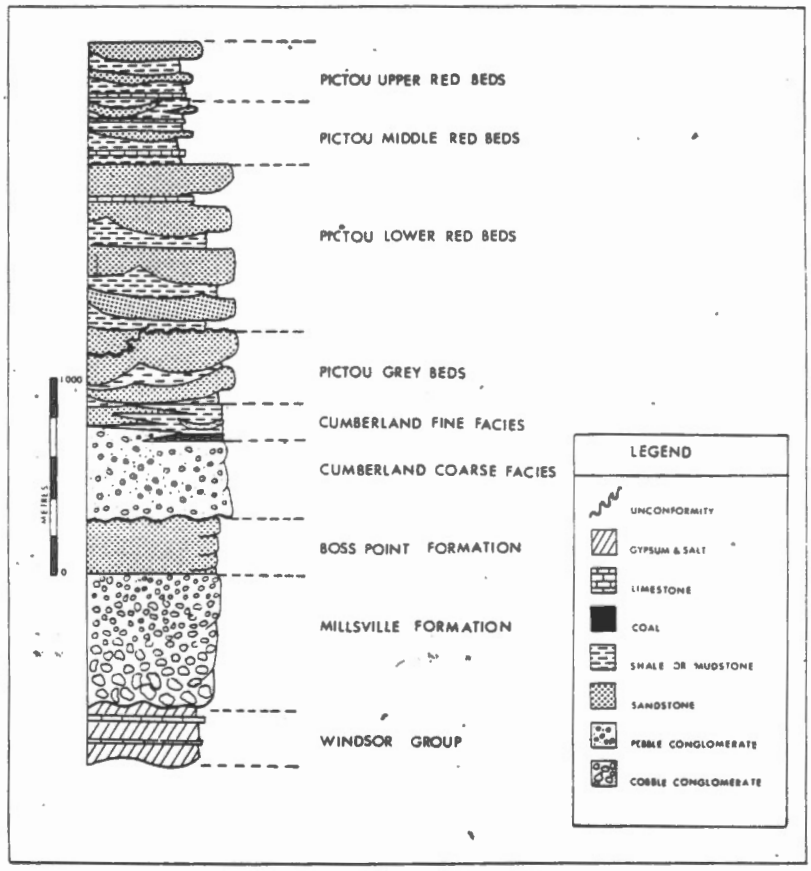


Figure3: Generalized Carboniferous Stratigraphic column, Tatamagouche Syncline, Cumberland Basin, Nova Scotia

AGE	THICKNESS	SAND:SILT RATIOS	BEDFORMS	LITHOLOGIES	MAP UNIT
STEPHIAN TO EARLY PERMIAN	300m+	1:5	Trough cross stratified conglomerates and sandstones, fining upward cycles, ripple drift and lunate rippled siltstone, planar mudstone and limestone.	Red to reddish grey shale mudstone, siltstone, medium grained sub arkose, pebbly aricose, and mud chip conglomerate, thin laterally continuous grey micritic limestones.	Pictou Upper Red Beds
WESTPHALIAN D TO STEPHANIAN	310m	1:3	Trough cross bedded sandstones and conglomerates, most fine upward in cycles, planar siltstone, mudstone and limestone.	Red, coarse grained arkose, medium grained sub arkose, calcareous mud chip conglomerate, siltstone and mudstone, minor thin grey limestone	Pictou Middle Red Beds
WESTPHALIAN C-D	800 TO 900m	1:1	Trough cross bedded sandstone and conglomerate, fining upward cycles, ripple drift and lunate ripple siltstone, planar mudstone.	Red calcareous mud chip conglomerate, arkose, subarkose siltstone, mudstone and shale, sandstones are usually coarse grained.	Pictou Lower Red Beds
WESTPHALIAN C	100 TO 400m	2:1	Trough cross stratified conglomerate and sandstone, ripple drift siltstone, planar mudstone and shale fining upward cycles.	Calcareous mud chip conglomerate, coarse grained arkose, fine grained subarkose, siltstone, mudstone and shale, reddish brown to grey, rare coal.	Pictou Grey Beds
WESTPHALIAN B?	0.0 (EAST) TO 700m(WEST)	(SOUTH) 15:1 to 8:1 (NORTH)	Large trough cross stratification, cross bed imbrication, high flow planar beds .	Red polymictic cobble to pebble orthoconglomerate red coarse grained pebbly arkose	Cumberland Coarse Facies
WESTPHALIAN A	200 TO 600m	10:1	Trough cross bedded, sandstones, rare planar beds, ripple drift siltstones, low flow planar mudstones.	Greyish brown coarse to fine grained subarkose, minor arkose, siltstone, thin interbedded red and green shale and mudstone.	Boss Point Formation
NAMURIAN	0.0 TO 700 m	25:1	Upper flow planar beds, some pebble imbrication, massive to thickly bedded.	Red, rarely grey, boulder to pebble conglomerate, polymictic, orthoconglomerates with rare paraconglomerates present. Rare coarse grained sandstone interbeds	Millsville Formation
VISEAN	1000m±	N/A	Planar accretion salt tectonism obscures bedding.	Marine fossilferous limestone, salt, gypsum and minor siltstone.	Windsor Group

Table I : Map Units of the Tatamagouche Syncline Area, N.S.

Millsville Formation They are for the most part indistinguishable one from another, all of Namurian age and, therefore, considered to be equivalent. The best reference section of the Millsville Formation within the study area is on River John near West Branch, Nova Scotia.

The conglomerates of the Millsville Formation rest uncomformably on either the Middle Devonian Fountain Lake Group in the southeastern portion of the study area, or the Windsor Group along the axis of the Malagash anticline.

Boss Point Formation Bell (1914) defined the Boss Point Formation as being units VI and VII of Logans section at Joggins, Nova Scotia. It is composed of a lower red sandstone and siltstone and an upper greyish yellow sandstone with some interbedded brick red shale. In the Tatamagoughe area, the formation consists of greyish brown coarse to fine grained subarkose with minor conglomerate, pebbly arkose, siltstone, and interbedded red and green shale. The best reference section for the Boss Point Formation in the Tatamagouche Syncline is located along River John upstream from West Branch, Nova Scotia. The Boss Point Formation lies unconformably on the red conglomerates of the Millsville Formation and is disconformably or unconformably overlain by either the Cumberland Coarse Facies in the west or by the Pictou Grey Beds in the east.

CUMBERLAND GROUP

Cumberland Coarse Facies: The term Cumberland Coarse Facies was first introduced to define the lower coarse polymictic conglomerates of the Cumberland Group within the type area. (Bell 1944). This map unit is absent in the extreme eastern portion of the Tatamagouche syncline area, indicating that, during deposition, the tectonic events controlling the rate of sedimentation within the Tatamagouche area were not the same as those controlling the rest of the Cumberland Basin. In the Tatamagouche syncline area, the Cumberland Coarse facies lies unconformably or disconformably on the Boss Point Formation. The unit is overlain conformably by either the Pictou Grey Beds or the Cumberland Fine Facies (which may be equivalent).

Cumberland Fine Facies The term Cumberland Fine Facies was reintroduced by Copeland (1957) to define the upper fine-grained sediments within the Cumberland Group in the southwestern Cumberland Basin. This unit as mapped by Bell (1944) is not well exposed within the Tatamagouche syncline area. A problem arises, moreover, in attempting to distinguish this unit from the lithologically similar Pictou grey beds which Bell assumed to be unconformably overlying these beds. On the basis of the palynological studies completed to date, there does not appear to be any discernable difference in age between the Cumberland Fine Facies and the Pictou Grey Beds, thus suggesting that the two may indeed constitute only one lithostratigraphic unit. Until further study of the age relationship can be undertaken, however, they are separated in accordance with the work of Bell (1944).

PICTOU GROUP The name Pictou Group was first intoduced by Bell (1926) to describe the reddish-brown sandstones, mudstones and conglomerates and their equivalents exposed along River John, Pictou County, N.S.

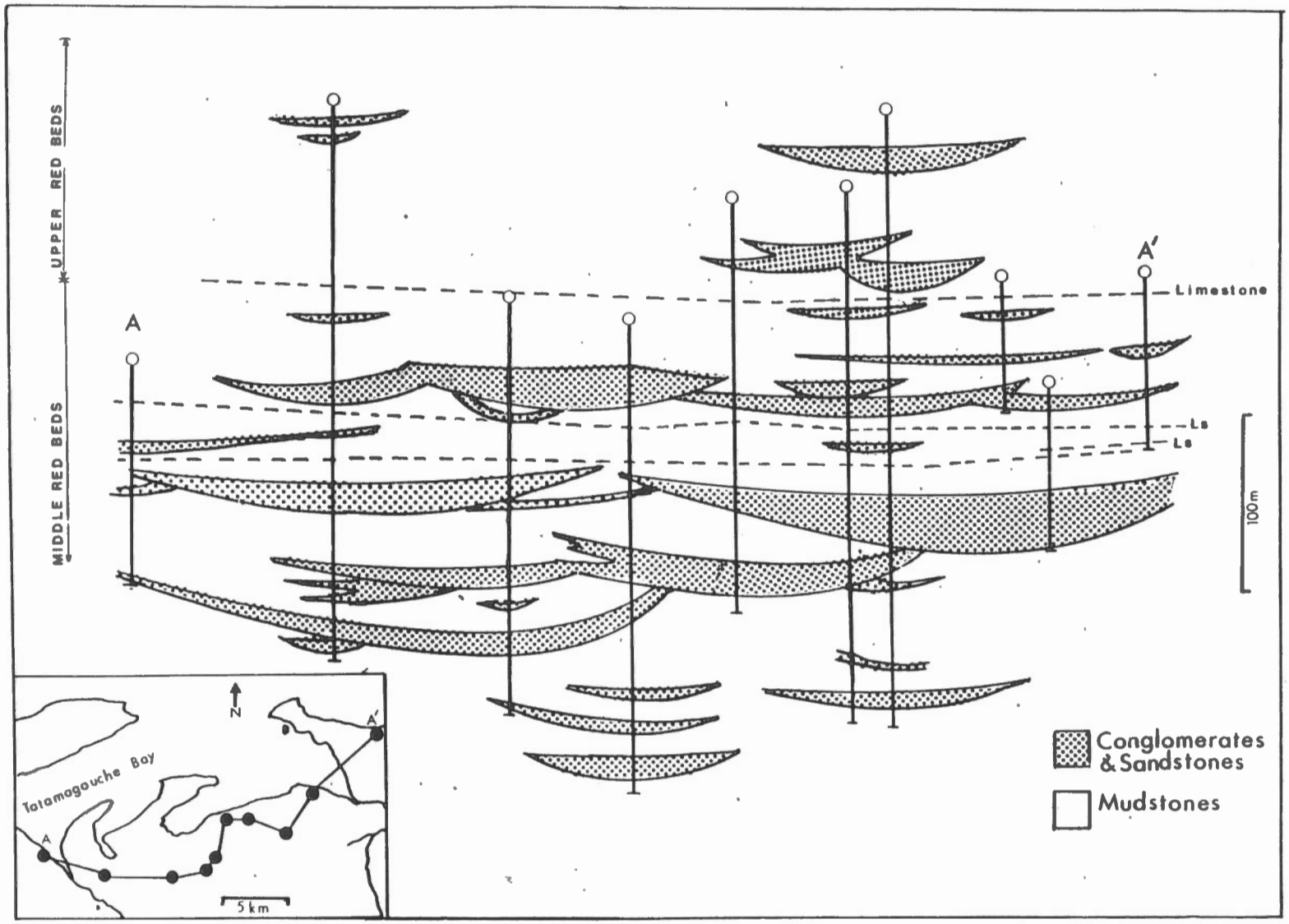


Figure 4: Drill hole cross section,Eastern Tatamagouche Syncline, Nova Scotia

Pictou Grey Beds The term Pictou grey beds was introduced to define the grey to greyish-brown sandstones, conglomerates and mudstones at the base of the Pictou Group in the eastern half of the Tatamagouche Syncline. As mentioned in the discussion of the Cumberland fine facies, the two units may constitute a single lithostratigraphic unit. In the eastern part of the study area, the unit disconformably overlies the Boss Point Formation, whereas in the west, it overlies either the Cumberland fine facies or the Cumberland coarse facies. It is probable that workers working familiar with the type area of the Cumberland Group would include these strata in the Cumberland Group, whereas those workers starting at the type section of the Pictou Grouop would include them in the Pictou Group.

Pictou Lower Red Beds The Pictou Lower Red Beds are red to reddish brown conglomerates, sandstones and mudstones exposed throughout most of the Tatamagouche syncline. The unit has a coarse to fine ratio of approximately 1:1. The unit lies with low angle unconformity upon each of the older map units including the Pre-Carboniferous Basement.

Pictou Middle Red Beds This unit consists of red arkosic and quartz sandstones, calcareous mud chip conglomerates, and mudstones. The coarse to fine ratio is approximately 1:3. This unit lies with apparent para conformity upon the Pictou lower red beds. The presence of thin but laterally continuous limestone beds, probably representative of shallow lacustrine deposition, facilitates correlation within the unit. (Fig. 4)

Pictou Upper Red Beds These red, and more rarely grey conglomerates, sandstones and mudstones are most likely equivalent to the lower red beds of Prince Edward Island and are the youngest beds exposed within the Tatamagouche Syncline study area. The unit conformably overlies Pictou middle red beds. The main distinguishing features of these beds is a sand silt ratio of 1:5 with the dominant lithology being mudstone.

MAP UNIT BOUNDARIES IN THE CARBONIFEROUS OF THE TATAMAGOUCHE SYNCLINE

Kelly (1967) suggested that there may be problems with the contact relationships between the lithostratigraphic units within the Carboniferous sediments of Northern Nova Scotia. He suggested that Bell's (1944) assumption that all of the groups are separated by disconformities or unconformities was incorrect, and that at least some of the units are conformable. During the field mapping, the contact relationships were examined, and on a single outcrop basis, the contacts appear to be conformable within the Upper Carboniferous Strata. However, it must be noted that determination of the relationships at the contacts is difficult due to the paucity of outcrop and to the internal cross stratified nature of the beds. Clearly, it is very difficult to discern low-angle angular unconformities when the beds immediately above and below the contact consist of low-angle foreset bedding.

In the Tatamagouche syncline area the contacts between the Windsor Group and the groups below and above it are not exposed, but elsewhere in the Cumberland Basin they are both angular unconformities or nonconformities.

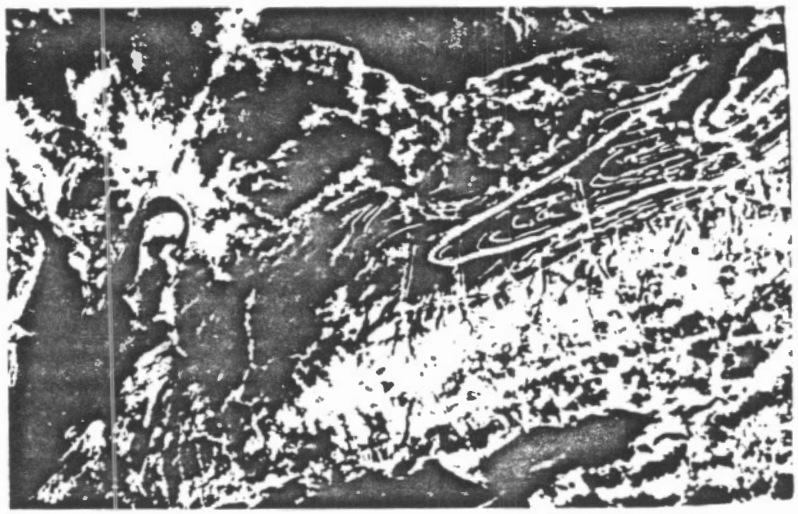


Figure 5; Seasat image with linears, Northern Nova Scotia

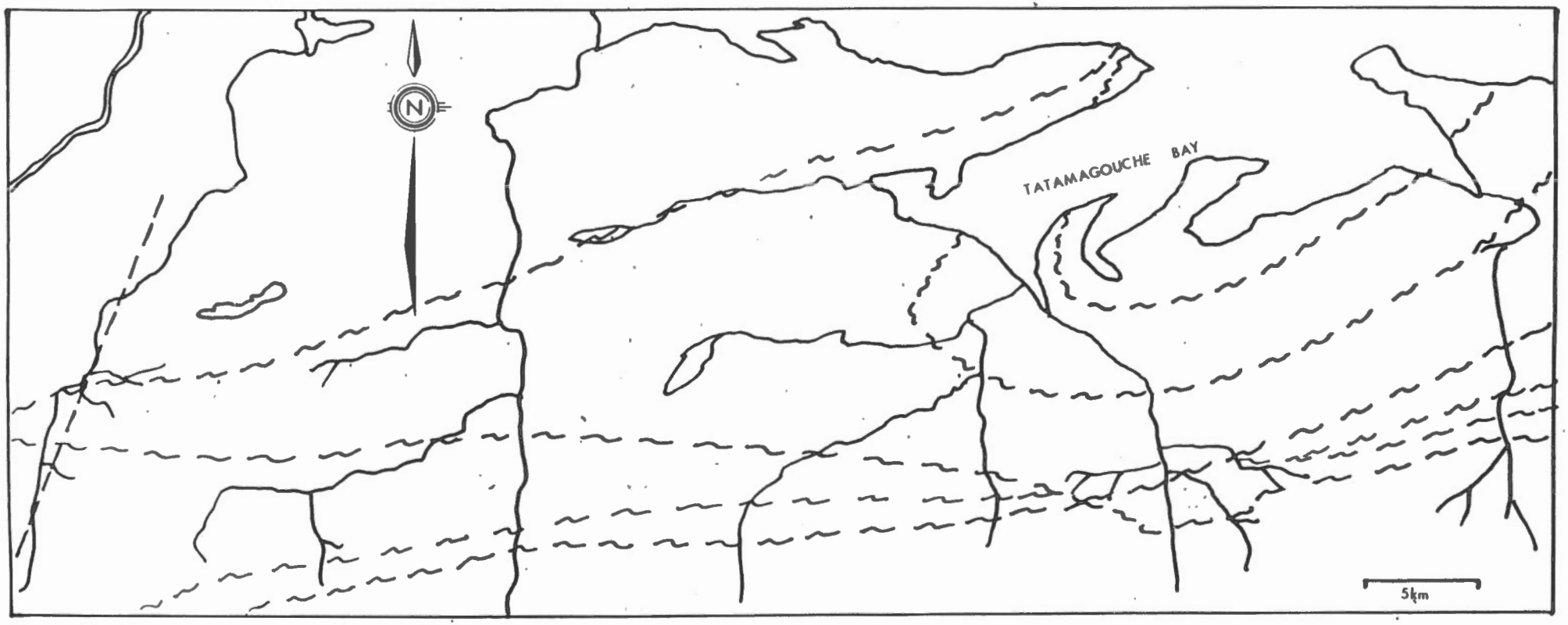


Figure 6: Linear structures (unconformities ?) from the seasat image,Northern Nova Scotia

The contact between the Millsville Formation and the Pre-Carboniferous basement is an angular unconformity, or a nonconformity.

The contacts between the various other Carboniferous units are not clear, either in the field, or from the low level air photos. The basic configurations of the units on the map at a 1:50000 scale do, however, suggest that some of the contact must be angular unconformities. Satellite photos (Seasat) for the area exhibit lineaments at the contacts between several of the units, which further support the existence of unconformities (Fig. 5 & 6).

AGE OF THE CARBONIFEROUS LITHOSTRATIGRAPHIC UNITS IN THE TATAMAGOUCH SYNCLINE, CUMBERLAND BASIN, NOVA SCOTIA

The ages of the units are summarized in Table 1 of this chapter.The ages for the older units are based on the work of Hacquebard (1967). The ages of the younger units are based on correlation with the red beds of Prince Edward Island and on the preliminary palynological investigations of Ryan (1984).

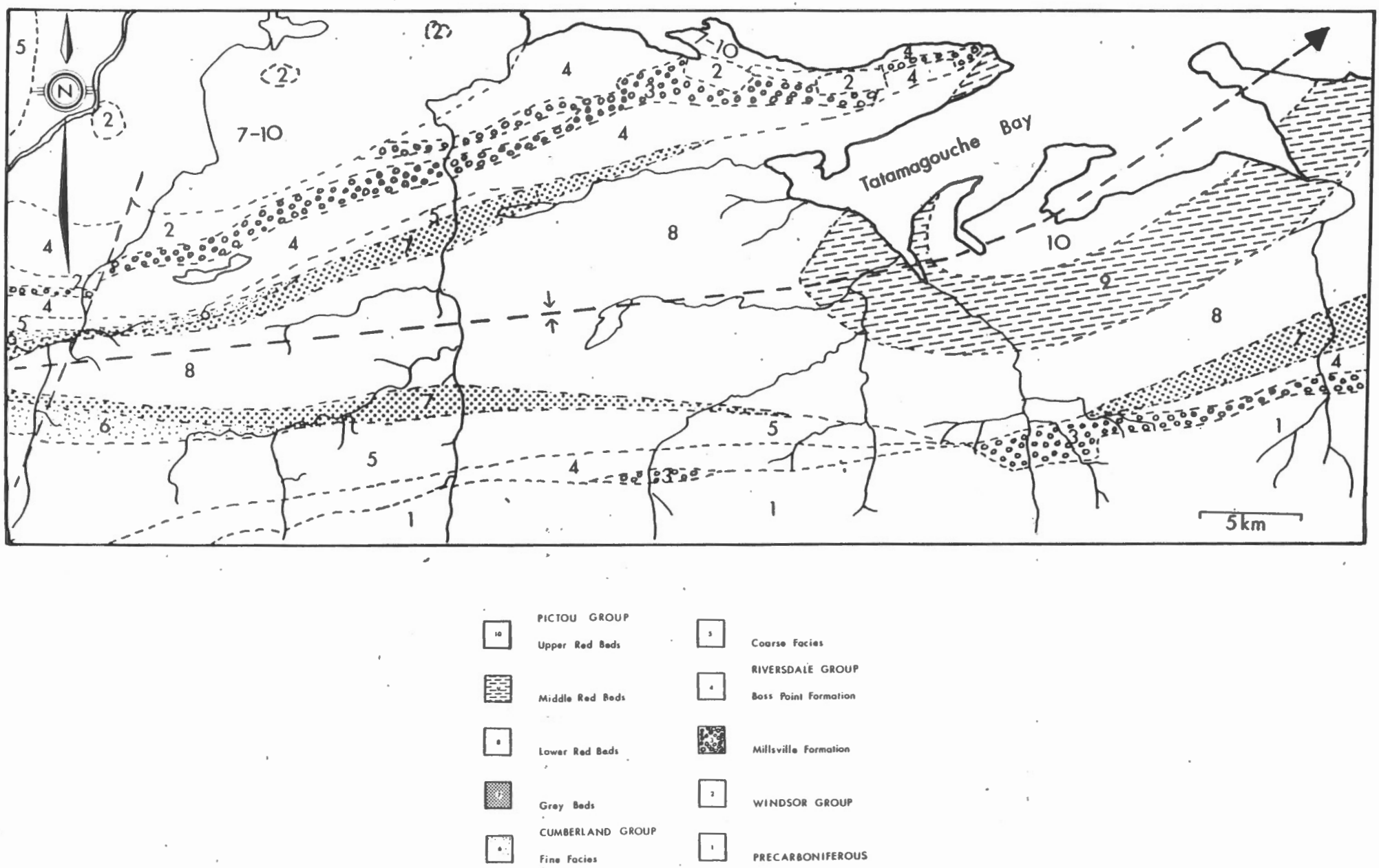


Figure 7: Generalized geology map, Tatamagouche Syncline, Nova Scotia

CHAPTER 3

SEDIMENT DISPERSAL PATTERNS

PALEOCURRENT STUDIES:

Over 600 paleocurrent measurements were recorded, including ripple marks, parting lineations, cross bed truncation ridges, preferred plant fragment orientations, flute marks, tool marks, pebble imbrications and cross bedding.

Many of the more common paleocurrent measurements are not always the most reliable. Parting lineations, for example, often diverge by as much as 180 degrees within a single outcrop in which the trough cross strata are unidirectional (Poll 1984). In light of recent studies by Poll and Patel (1982) and Poll and Plint (1984) on the creation of flute like structures during liquifaction by flow moulding along sand silt interfaces, it was considered advisable to use discretion in the utilization of flute mark orientations in the paleocurrent reconstruction. Many thousands of measurements of cross strata are possible within the study area; however, only cross strata where three dimensions were exposed or where vector analysis was possible, were measured.(fig 8)

Pebble imbrication measurements also can be misleading as there are two varieties, planar bed pebble imbrication and the cross strata pebble imbrication. The two varieties of pebble imbrication give the opposite sense of paleocurrent direction, and therefore, it is essential to ascertain the nature of the bedform from which the imbrication measurements are taken. This is not always possible within large scale cross stratified units of only limited exposure, as these large scale foresets may easily be confused with planar beds.

Ripple mark orientations also pose problems for paleocurrent studies, as they are often more representative of the waning flow conditions and, therefore, do not necessarily conform to the overall gradient of the stream. Many examples of ripple marks exhibiting paleocurrent directions at 90 degrees to the cross strata are found within the study area.

Overall, the trough cross beds gave the most consistent paleocurrent determinations (Fig. 9) and are regarded as the most reliable.

The paleocurrent data for the eastern part of the Tatamagouche Syncline area exhibit strongly unimodal distributions with a modal trend of north northwest, 340° (Fig. 10). The low variance in the paleocurrent data indicates that deposition, for the most part, occurred as a result of low sinuosity flow, due in part to steeper gradients than those found elsewhere within the Upper Carboniferous rocks of the Atlantic region. The Pictou Upper Red Beds and the Boss Point Formation exhibit significant variability in the paleocurrent directions.

The north northwest direction of flow was therefore dominant from Namurian to the Early Permian times in the eastern half of the Tatamagoughe Syncline.

The data for the western part of the Tatamagouche syncline indicate a division of flow at approximately the synclinal axis. On the southern limb, the flow continues to be to the north northwest. On the northern

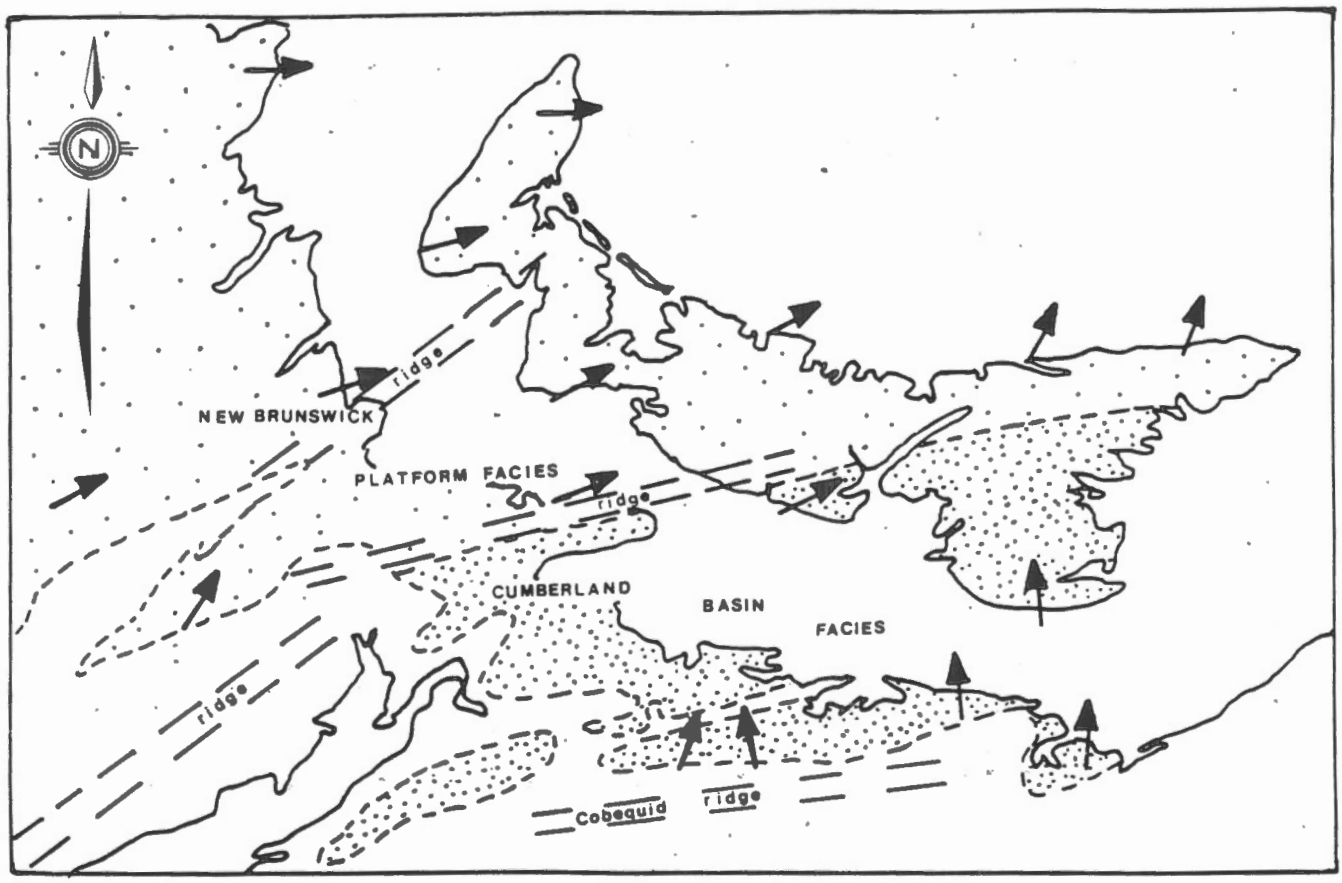


Figure 8: Generalized tectostome map for the Pictou Group in the Central Part of the Carboniferous Basin showing sediment dispersal(arrows)

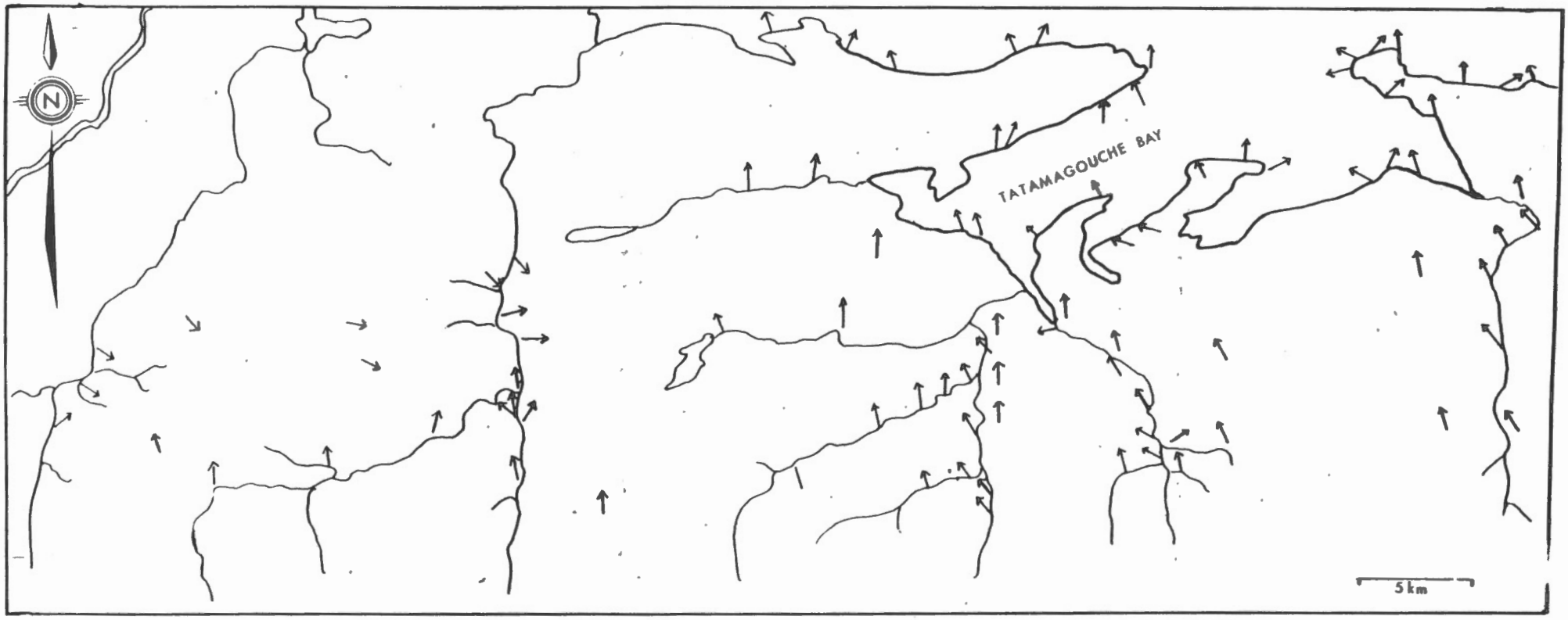


Figure 9: Sediment dispersal patterns(trough cross strata) in the Tatamagouche Syncline Area,N.S.

limb, flow is to the south southeast, indicating a possible topographic high to the northwest.

The southerly flow directions observed on the northern limb are found in progressively older beds towards the west, suggesting that diapirism of the Windsor Group evaporites was initiated in the west during the Westphalian B. The first indication of topographic relief (divergent paleocurrents) in the northeastern part of the Malagash Anticline is found within the Pictou upper red beds of Stephanian age, suggesting that Windsor Group evaporite diapirism migrated through time from west to east. Further paleocurrent studies north of the Malagash Anticline may confirm this suggestion.

TROUGH CROSS BED PALEOCURRENTS

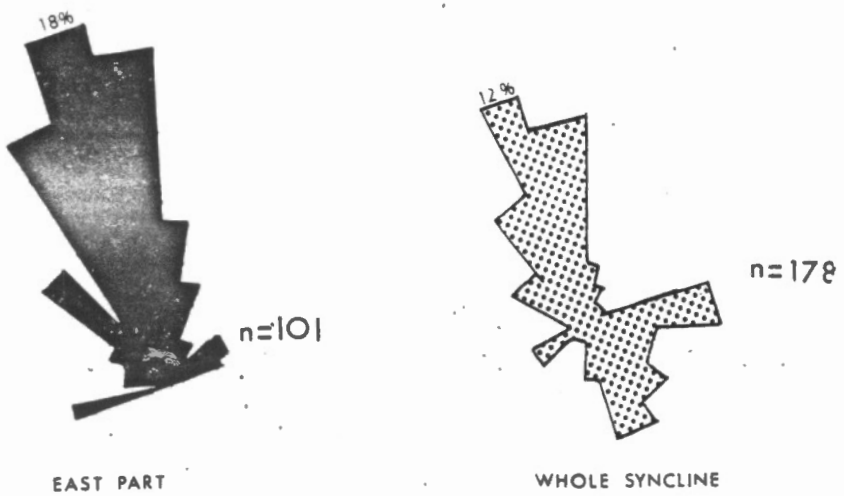
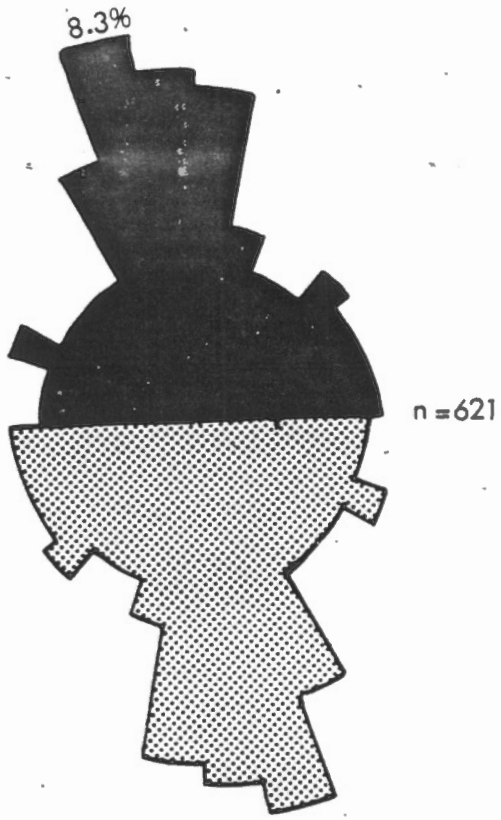


Figure 10a: Trough cross strata paleocurrent trends, Tatamagouche Syncline ,N.S.

Figuer 10b: Paleocurrent trends for all the current structures,Tatamagouche Syncline,N.S.



CHAPTER 4

LITHOFACIES OF THE CARBONIFEROUS STRATA OF THE TATAMAGOUGHE SYNCLINE AREA

Lithofacies of the Millsville Formation in the Tatamagouche Area

M-BGp Boulder to cobble conglomerates: These conglomerates are polymictic and contain subangular to subrounded clasts of rhyolite, basalt, granite and metasediments. The conglomerates are clast supported orthoconglomerates which exhibit planar bedding. The relative proportions of the different clast lithologies varies upward (Fig. 11). The size of the clasts also decreases upwards, with a corresponding increase in the proportion of matrix.

M-PGp Pebble Conglomerates: The pebble conglomerates are either clast or, more rarely, matrix supported. Planar bedding and graded bedding are the most common bedforms. The matrix is a red litharenite containing abundant mica. The clasts are made up of basalt, granite, rhyolite and metasediment. The relative proportions of the various clast lithologies show no spacially consistent trend.

Lithofacies of the Boss Point Formation in the Tatamagouche Area

BP-PGt Calcareous Mud Chip Conglomerate: These matrix supported paraconglomerates have pebble size clasts of calcareous mudstone or limestone. The clasts are usually elongate and supported within the fine to medium grained arkosic sandstone matrix. Plant debris is common. The lithofacies is generally micro-micaeous. The calcareous material is most likely reworked calcrete material eroded from the floodplain deposits.

BP-PSt Pebbly Subarkose: This lithofacies is polymictic and contains clasts of orthoclase, quartz and lithic fragments, which vary in size from large to small pebbles. The matrix is a coarse to medium grained subarkosic sandstone. The composition of this lithofacies is 60-65% quartz, 10-20% feldspar (orthoclase) 3-5% lithic fragments, 2-4% mica, and 1-2% kaolinite.

BP-St Subarkose: Fine to medium grained, cross laminated sandstones exhibit subangular to subrounded grains. This lithofacies exhibits moderate sorting. The composition is approximately 65-75% quartz, 10-20% feldspar (albite and orthoclase) 5-7% lithic fragments, 1-3% mica (muscovite and biotite), and 1-2% kaolinite. The cementation of the units varies from calcite cement to iron oxides and clay. Plant debris is locally very abundant.

BP-Fm Mudstones and shales: The mudstones and shales are usually red to green in color, but there are several black shale horizons. These beds are usually planar laminated, although there are some cross laminations present. Plant debris is abundant in the green and black shales and mudstones.

Lithofacies of the Cumberland Group in the Cumberland Area

C-PGp Pebble - Boulder Conglomerates: These are polymictic orthoconglomerates. The clasts are granite, rhyolite, basalt, metasediment, and some reworked Carboniferous sedimentary fragments. The clasts

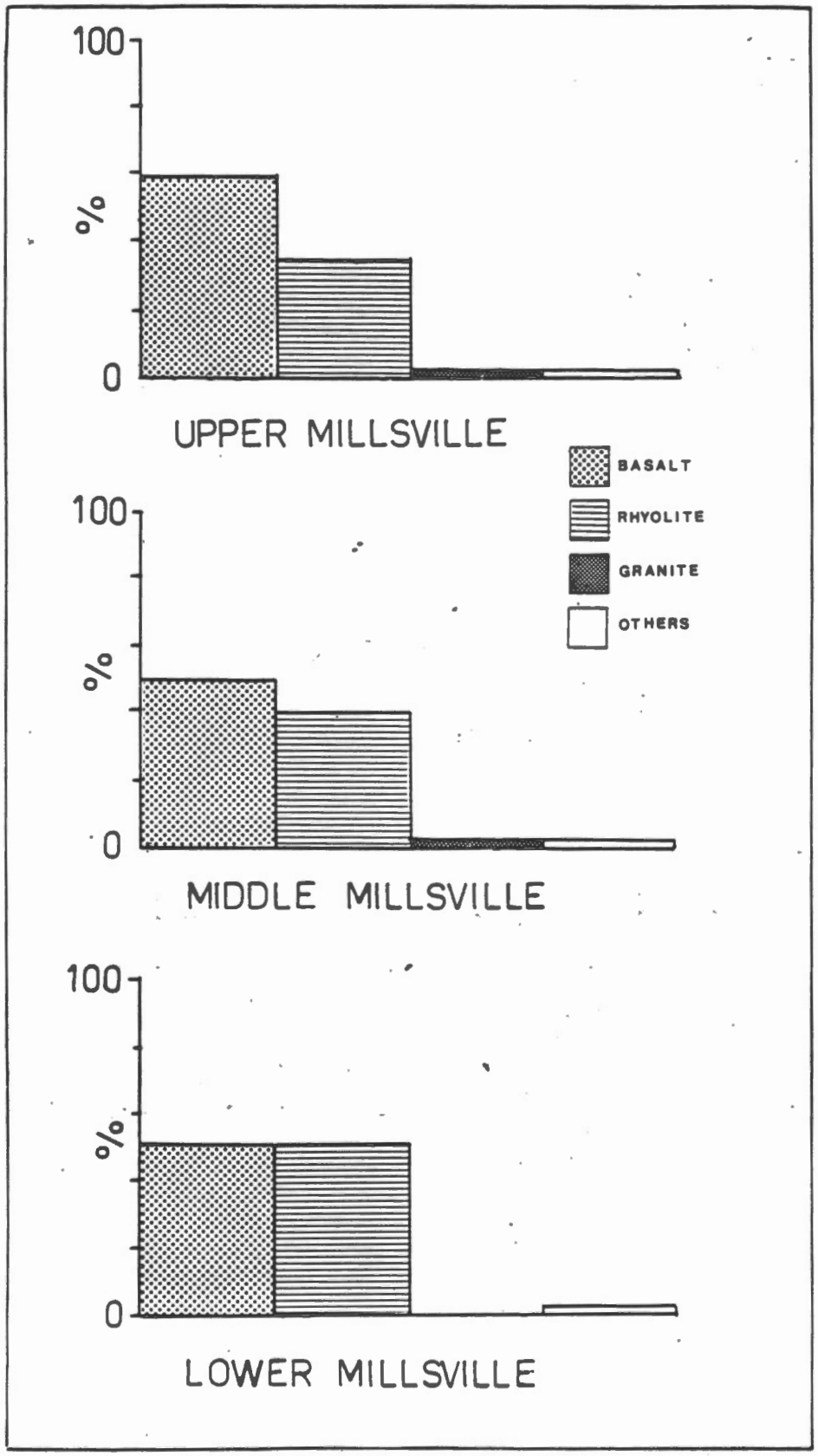


Figure 11: Clast lithology percentages,Millsville Formation,Tatamagouche Syncline,N.S.

MAP UNIT	%	LITHOLOGY	COLOR	GRAIN SIZE	SORTING	ROUNDNESS	COMPOSITION				BEDFORM
							QTZ	FLD	MIC	PLDER	
Cumberland Fine Facies	10	mud-chip conglomerate	h.grey	pebble 26%	poor	sub rd	40	20	5	2	large troughs
	10	pebbly arkose	h.grey	v. coarse	poor	sub ang	65	25	6	4	large troughs
	30	arkoses	h.grey	medium to coarse	mod.	sub ang	60	30	7	3	large troughs
	10	sub arkoses	h.grey	fine to medium	well	sub rd	75	15	8	2	large troughs
	40	siltstones and shales	black to red brown	silt to clay	well	sub rd	qtz and clay micromicaceous				ripple drift and planar
Cumberland Coarse Facies	90	conglomerate	red brown	cobble to pebble	poor	sub rd	p o l y m i c t i c				large trough
	10	arkose	red brown	coarse sand	poor	sub ang	70	25	5	-	trough cross
Boss Point Formation	10	mud-chip conglomerate	brown grey	pebble 25%	poor	sub rd	40	20	5	2	large trough
	70	subarkose	grey brown	fine-medium sand	mod.	sub ang	80	15	1-5	2	large trough
	10	siltstone	light grey	silt	well	sub rd	90	5	3	2	planar
	10	shale	grey to black	clay	-	-	clay			5	planar
Millsville Formation	100	ortho & para-conglomerate	red	boulder to pebble	v poor	sub rd	p o l y m i c t i c				planar high flow regime

TABLE IIa

MAP UNIT	%	LITHOLOGY	COLOR	GRAIN SIZE	SORTING	ROUNDNESS	COMPOSITION				BEDFORM
							QTZ	FLD	MIC	PLDEB	
PICTOU LOWER RED BEDS	2	Calcareous mud-chip conglomerate	red-grey to red-brown	pebble	poor	moderate	50	5	1	2	large trough
							40%-clasts				
	2	Pebbly Arkose	red-brown	pebble in coarse sand	poor	sub ang	66	27	3	4	large trough
	6	Arkose	red-brown	v. coarse sand	poor	ang	63	30	5	2	large trough
	15	Subarkose	red-brown to red-grey	coarse to fine sand	moderate	sub ang	80	12	6	2	coarse large and small troughs, fine-planar
	76	Siltstone, Mudstone, Shale & Limestone (thin)	red to red-brown	silt to clay	moderate	----	Qtz + clay + calcite				Planar, ripples and ripple drift worm burrows
PICTOU GREY BEDS	3	Calcareous mud-chip conglomerate	grey with red and grey clasts	pebble	poor	moderate	50	5	2	2	large trough
							40%-clasts				
	3	Pebbly arkoses	grey to grown	pebbles in v. coarse ss	poor	sub ang	65	25	6	4	large trough
	50	Arkose	lt. pink grey	coarse sand	poor	sub ang	70	25	2	2	large and small troughs
	5	Subarkose	lt. grey	medium to fine sand	moderate	sub rd	75	15	7	2	planar coarse upwards
	40	Siltstone and mudstone	red-brown	silt to clay	moderate	--	quartz and clay				planar beds

TABLE III b

MAP UNIT	%	LITHOLOGY	COLOR	GRAIN SIZE	SORTING	ROUNDNESS	COMPOSITION				BEDFORM
							QTZ	FLD	MIC	PLDEP	
PICTOU UPPER RED BEDS	2	Calcareous mud-chip conglomerate	grey to red brown	pebble	poor	sub-rd	50	15	2	1	large troughs
							30%-clasts				
	3	Pebbly Arkose	red brown to red grey	pebble in coarse sand	poor	sub-ang	65	30	4	1	large troughs
	5	Arkose	red-brown	coarse sand	poor	sub-ang	70	25	4	1	large and small troughs
	3	Subarkose	red-brown to red-grey	medium to fine sand	moderate	sub-rd,	80	15	4	1	planar, small troughs, tabular cross strata
	86	Siltstone, mudstone and shale	red	silt-clay	---	---	quartz + clay				planar, ripple ripple drift
	1	Limestone	grey	micrite	---	---	c a l c i t e				fossiliferous
PICTOU MIDDLE RED BEDS	1	Calcareous mud-chip Conglomerate	red-brown	pebble	poor	sub-rd	50	15	2	1	large troughs
							32%-clasts				
	1	Pebbly Arkose	red-brown	pebbles in coarse sand	poor	angular	65	28	5	2	large troughs
	4	Arkose	red-brown	coarse sand	poor	sub-ang	70	25	4	1	large and small troughs
	10	Subarkose	red-brown	coarse to find sand	moderate	sub-rd	80	15	4	1	small troughs and tabular cross strata
	83	Siltstone, Mudstone and Shale	red-brown	silt to clay	---	---	quartz to clay				planar, ripple & ripple drif worm burrows abundant
	1	Limestone	grey	micrite	---	---	c a l c i t e				fossiliferous

TABLE IIc

are usually well rounded and hematite-stained. The conglomerate clasts shokw a moderately well developed cross strata imbrication. The matrix is a coarse grained feldspathic litharenite.

C-PSt Pebbly lithic arkose: Quartz, lithic fragments and feldspar pebbles are contained within a lithic arkose matrix. The composition of the unit is approximately 60-70% quartz, 10-15% lithic rock fragments (usually sediment or metasediment) 15-25% feldspar (orthoclase) with minor kaolinite. This lithofacies is sub-angular and poorly sorted. The cement appears to be iron oxides and clay.

C-PGt Calcareous Mud Chip Conglomerates (see lilthofacies P-PGt Pictou Group)

C-ASt Arkoses: (See Lithofacies P-ASt Pictou Group)

C-St Fine Subarkoses (see Lithofacies P-St Pictou Group)

C-Fm Siltstones and Mudstones: (see Lithofacies P-Fm Pictou Group)

Lithofacies of the Pictou Group in the Tatamagouche Area

P-PGt Calcareous Mud Chip Conglomerates. These conglomerates contain clasts of calcareouos lutite and red to grey clasts of limestone. The clasts are generally elongate and are usually supported in a fine-medium grained arkosic sandstone matrix. The clasts vary from 0.5 to 3 cm in length and have a diameter of approximately 0.5 cm. The calcareous mud chip conglomerates occur either near the base of the channel sandstones or at the base of the component trough cross beds. Plant debris is abundant at some localities but absent to near absent in others. The calcareous clasts are reworked calcrete material that had formed proximal to plant roots in the red silts and muds within the floodplain areas.

DP-PSt Arkosic Conglomerates or Pebbly Sandstones: These conglomerates are polymictic and contain pebble sized clasts of quartz, orthoclase, and metasediment in a coarse to medium grained arkosic sandstone matrix. The composition of these units is 60-70% quartz, 15-25% feldspar (mostly orthoclase), and 0-5% mica. The conglomerates contain abundant plant debris which occasionally shows preferred orientation in the flow direction. These grains are poorly sorted and sub-rounded. The arkosic conglomerates are found at the base of large trough cross beds.

P-ASt Arkoses: The arkosic sandstones are medium to coarse grained, sub-angular, poorly sorted and usually fine upwards. The arkoses contain: 60-70% quartz, 15-25% feldspar (mostly orthoclase), 0.5% kaolinite, and up to 5% mica (muscovite and biotite). The arkoses are trough cross stratified, and may contain thin interbeds of fine-grained sandstones. Plant debris is scarce but ubiquitous.

P-St Coarse Subarkoses

The subarkoses are reddish-brown to reddish-grey in color. They are usually coarse grained, poorly sorted, and sub-angular. These units consist of 75% quartz, 10-15% feldspar (mostly orthoclase), 5% kaolinite, and up to 5% biotite and muscovite. These sandstones fine upwards, and have partings every 10-20 cm. The coarse subarkoses are found within trough cross beds and are up to 4 m in width and 2 m in depth. The subarkoses also contain minor plant debris.

P-Sp Fine Subarkoses

The fine subarkoses are reddish-brown in colour. These beds usually exhibit coarsening upward cycles, and planar or ripple marked bedding. The composition of the fine subarkoses is: 70-80% quartz, 10-20% K-feldspar, 5% biotite + muscovite, 2-4% kaolinite, 1-3% lithic fragments and up to 5% plant debris.

P-Fm Siltsones and Mudstones: The finer grained sedimentary rocks are reddish-brown in color, locally mottled greyish-green. The siltstones and mudstones are micromicaeous, cross laminated and ripple drifted. There are a few thin interbeds of fine grained arkosic sandstones. The siltstones and mudstones are locally modified by calcite cementation around plant roots.

P-Lf Limestones: A few thin, but laterally continuous limestones are present. The limestones are ostracodal micrites, grey to light buff in color. Several of the limestone beds have algal stromatolites and low spired gastropods near their base. Fresh water calcareous algae may also be present. The upper limestones are often intramicrites containing intraclasts of micritic ostracodal limestone.

CHAPTER 5

PRIMARY SEDIMENTARY STRUCTURES

PRIMARY SEDIMENTARY STRUCTURES

Primary sedimentary structures can be classified into three basic units; bedforms, erosional and linear structures, and deformational structures. Potter and Pettijohn (1962) published the first truly comprehensive volume on the morphology, origin and the practical application of sedimentary structures. Since that time, much work has been published on the origin and significance of sedimentary structures. (Allen 1965, 1968, 1969, Dzulynski and Walton, 1965, and others).

Bedforms of the Carboniferous Sediments of the Tatamagouche Area

Cross Stratification

There are several forms of cross stratification found within the beds of the study area. The classification of the various forms are in accordance with Allen (1963). The cross strata are: (a) Large scale trough shaped Pi-cross strata, (b) small scale trough shaped Pi-Cross strata, (c) large scale irregular Alpha cross strata (tabular). For simplification, the bedforms will be referred to as large scale trough cross strata, small scale trough cross strata and tabular cross strata respectively.

(a) Large scale trough cross stratification: This is by far the most abundant bedform within the sandstone and conglomerate beds of the Carboniferous strata. The troughs are almost always grouped, varying from 20 cm to 5 m in height and from 1 to 25 m in width. The lower bounding surface is erosional and irregularly trough shaped (Fig. 12). The angular relationship with the underlying stratum can either by concordant or discordant. Lithologically, the sets of cross strata are heterogeneous within the arkosic sandstones. Harms et al. (1975) suggest that this type of cross strata is formed as a result of progradation of linguoid dunes.

(b) Small scale trough cross stratification: Towards the top of most of the channel sand units in the Carboniferous strata of the study area, small scale trough cross strata become the dominant bedform. The troughs are grouped, and are approximately 5-30 cm in height and 50 cm to 1.5 m in width. The lower bounding surface is erosional and trough shaped. The angular relationship to the underlying strata is usually concordant. Lithologically, the sets are homogeneous and generally are composed of medium to fine grained arkose or subarkose. On the basis of the work of Harms et al (1975), it is reasonable to assume that these beds are resultant from progradational of small amplitude lunate dunes or megaripples.(Fig.13)

(c) Tabular cross stratification: In the upper beds of the Pictou Group, this bedform is common. The tabular cross strata are usually solitary and are approximately 20-40 cm in height. The lower bounding surface is typically planar, non-erosional and concordant. Lithologically, the tabular cross strata are homogeneous fine to medium grained arkose. Harms et al (1975 attribute this bedform to the progradation of sandwaves. Planar Beds: There are two forms of planar beds within the Carboniferous strata, upper flow regime; planar beds and lower flow regime planar beds. The different planar-beds correspond to differing grain sizes in the sediment being moved. The upper flow regime planar beds are found within

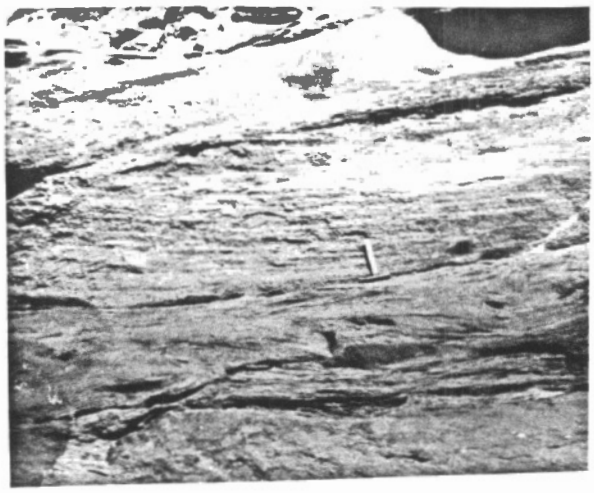


Figure 12: Large scale cross stratification, Pictou Upper Red Beds, Cape John, N.S. (hammer for scale)

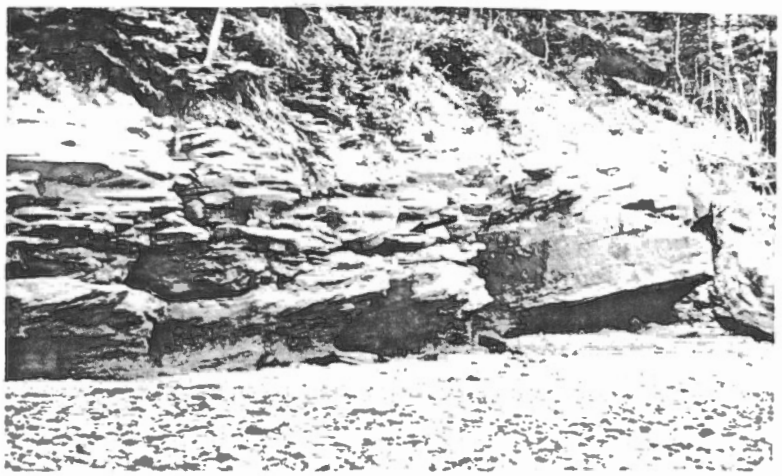


Figure 13: Small scale trough cross stratification, Pictou Middle Red Beds, Blockhouse Point, Colchester County, N.S.

the conglomerates and sandstones whereas the lower flow regime planar beds are found almost exclusively in the siltstones and mudstones.

Upper Flow Regime Planar Beds: The conglomerates of the Millsville Formation, and to a lesser extent, the conglomerates of the Cumberland Coarse Facies exhibit this bedform. The planar beds are interpreted as being the result of high flow velocities at flood stages, producing sheet flow. Such conditions might be expected in proximal alluvial fans and within crevasse splay deposits where the breaching of the levee by flood waters creates high flow velocities.

Lower Flow Regime Planar Beds: These beds may be considered in two divisions, (a) vertical accretion beds deposited as a result of settling of suspended material by waning flow conditions or (b) streams of low velocity flowing over sediments that have a modal diameter in excess of 0.7 mm. The vertical accretion is the most common phenomena, and this accounts for the floodplain mudstones and shales. At the top of some of the channel sand units, planar beds within coarse sands may be attributed to the second type of lower flow regime planar beds.

Graded Bedding: The graded beds within the Carboniferous strata of the Tatamagouche Area are of two varieties; (a) graded beds with fine grained material only at the top of the unit and (b) reverse graded bedding (those which coarsen upward). The first type of graded bedding can be distinguished from graded bedding caused by turbidity currents by the absence of an admixture of fine grained material throughout the unit (Jackson 1970). The graded beds which occur within the strata of the study area appear to represent waning current velocity over time.

The reverse graded bedding appears to be the result of subsequent progradation of microdeltas or fans of sediments. The reverse graded beds range from tens of meters thick to one meter thick, whereas, the graded beds are scale independent.

Laminated Beds: There are several varieties of laminated sediments. The three most abundant types of lamination are: planar lamination, cross lamination, and ripple drift lamination. The laminated beds are usually fine sandstones, siltstones and silty mudstones.

Planar Laminations: These laminations are equivalent to the planar parallel or the planar discontinuous parallel of Collinson and Thompson (1982). This type of lamination is most abundant in the silty mudstones of the Upper Carboniferous beds. The laminations are generally 3-10 mm in thickness. They appear to be the result of vertical accretion with the laminae are of varying grain size but rarely of differing compositions.
Cross Laminations: Cross laminations are very abundant within the siltstones and fine sandstones of the study area. The cross laminations could also be subdivided into two categories; curved non-parallel and curved discontinuous non-parallel (Collinson and Thompson 1982). The laminations are usually 3-10 mm in thickness, equivalent to medium laminations (Reineck and Singh 1973). The cross laminations are attributed to progradation of ripples (Allen 1968).

Ripple Drift Laminations: This type of lamination is very common in the siltstones and fine sandstones at the top of the channel sandstones. Instead of having an erosional subhorizontal lower bounding surface, these cross laminations have inclined and non-erosive lower boundaries. At the top surfaces of these cross laminated beds, there are often linguiod ripples preserved.

Ripples: The strata of the study area contain various forms of ripple mark beds. The ripple mark beds include: linguoid ripples, interference ripples, catenary out of phase, lunate and straight ripples. All of the ripples are asymmetrical current ripple varieties.

Linguoid Ripples: Climbing linguoid ripples are the most abundant type of ripples in the Tatamagouche area. The length of the linguoid ripple are approximately 4-9 cm. The ripples occur within the silty mudstones and siltstones and less commonly in the fine grained sandstones.

Interference Ripples: Interference ripple marks do occur but are not common in the study area. The ripples formed within sinuous out of phase ripple beds which coalesced to form polygonal interference patterns.

Catenary out of phase: Within the upper beds of the Pictou group, a few examples of this form of ripple marks can be observed, however, they seem to change to a form of lunate ripples over short distances. The wavelength is variable depending upon the grain size of the ripple bed. The average wavelength is approximately 4-7 cm with a height or amplitude of 1-1.5 cm. These ripples are most abundant in siltstones and fine sandstones.

Lunate Ripples: These ripples appear to be related to the catenary out of phase form, although a few lunate beds have been observed in isolation.

Straight Ripples: These ripples are rare within the Carboniferous Strata of the Tatamagoughe area and are confined to the fine sandstones. The wavelength is approximately 3-8 cm and the amplitude ranges from 1-3 cm.

Erosional and Linear Sedimentary Structures in the Carboniferous Strata of the Tatamagouche Syncline Area

Four varieties of erosional or linear structures are found within the strata of the study area; flute marks, drag marks, rill or gutter marks and parting lineations. In recent years, these structures have been widely used for paleocurrent studies and as guides to the depositional environments. New theories about the origin of some of these sedimentary structures have been proposed by Poll et al. (1981) and cast some doubt on the reliability of flutes and grooves as paleocurrent indicators. Following is a description of the various structures found in the Carboniferous Strata of the Tatamagouche area.

Flutes: Flutes are scour erosional features which can occur individually or in clusters. Flutes are usually concentric "horseshoe" shaped features with flattened curved 'noses' at one end. The maximum relief is attained near or at the 'nose' region of the flute. (Collinson and Thompson 1982) Allen (1971) devised a classification scheme for flutes based on their morphology and the numbers present in the bed. Allen (1968) suggested that flutes developed as a result of original irregularities on the underlying beds that were scoured by currents. He suggested that the shape and size of the flutes were dependent on the nature and structure of the nose eddies, and the grain size of the sediment being eroded.

Flute marks are one of the most common of the linear sole markings, and have been utilized extensively in paleocurrent investigations. Poll and Patel (1981) suggested that erosion scour may not be the only mode of flute formation. They conclude that flute-like structures may also result from flow moulding at the sand silt interface during displacement of the underlying silt and clay on loading. Examples of highly variable flute orientations within small areas, and the presence of flutes that are discordant to bedding may be indications of flow moulding (Poll & Patel 1981). Large fluted mudlumps at the base of channel sandstones are interpreted as mud diapirs or pods with flow moulded surfaces. The alternative explanation is that these are the result of mud overbank material which has fallen into the stream and been rolled and fluted. This explanation is not reasonable, as the stream velocities necessary to move mud balls up to several meters in diameter would be so great that the mud balls would disaggregate. Whether or not the formation of flutes can occur as a result of flow moulding, warrants more detailed investigation; however, it is clearly feasible and, therefore, casts doubt upon the reliability of flute marks orientation as paleocurrent indicators.

Flute marks within the strata of the study area can be divided into two varieties: (a) narrow parabolic and (b) spindle like (Allen 1971).

The parabolic shaped flutes found in the study area are the narrow parabolic type. There are parabolic flutes found at Cape John which have a nose width of 2-5 cm., a length of 9-13 cm., a relief of 1.0-1.5 cm and a width of 5-10 cm. at the tail.

The spindle-like flutes found at Oliver have a nose width of 1-2 cm., a length of 5-7 cm., a relief of 0.7-1.2 cm., and a width at the tail of 2-3 cm.

Flute-like marks are also found at Treen Point within the study area. These flutes are not at sand silt interfaces however, but are instead within interbedded fine grained sandstones. On the surface, these structures look very much like parabolic clustered flute marks. When the flute-like structures were cut, internal convolute laminations were revealed, suggesting the structures were in fact resultant from sedimentary deformational formation probably related to loading and dewatering. These structures will be discussed in the sections on deformational sedimentary structures.

Drag or Tool Marks: The only drag or tool marks observed in the study area were groove marks. Groove marks are elongate ridges on the base of sandstone or conglomerate beds. Groove marks can be useful for paleocurrent trend determinations. Groove marks are rare within the strata of the study area. Where groove marks do occur, they are generally 10-15 cm in length, 2-4 mm in width and have a maximum relief of approximately 2mm. Groove marks are interpreted as being the casts of grooves created in the underlying silt or clay by objects being dragged along the surface by the current.

Rill Marks: Rill marks are small scale dendritic erosional patterns on the sole surface of sandstone beds. They are interpreted as being the result of erosion of the underlying sediment by small riverlets of water (Collinson and Thompson 1982). Rill marks are, however, almost always destroyed by any rise in the water level and therefore have an extremely low preservation potential. (Collinson and Thompson 1982). Similar structures can be created as a result of loading in reverse density experiments. In the discussion of deformational structures, the processes of formation for these rill mark-like structures will be discussed. Where rill mark structures are found to exist on loaded surfaces, it would seem likely that their mode of origin may be deformational rather than erosional.

Parting or Current Lineations: Parting lineations are a series of closely spaced ridges and hollows on the bedding surfaces of fine to medium grained flaggy bedded sandstones. The origin of these structures is not well understood but they have been used extensively as paleocurrent trend indicators. Their value as paleocurrent indicators are limited however, as deviations of up to 180° within the same bed have been observed (Poll 1983). Variations of 80-90 degrees within the same bed have been observed within the study area. The parting lineations are usually spaced 2-6 cm apart on the bedding surfaces of the low angle flaggy bedded foresets within the trough cross strata.

Deformational Sedimentary Structures in the Tatamagouche Syncline Area

Nova Scotia

Deformational sedimentary structures are useful indicators of sedimentation conditions and paleoclimate. The primary utilization of these structures has been as tops indicators and as paleoenvironmental indicators. Many of the structures help in determination of the paleoslope and in some cases are useful in determination of the intensity and periodicity of seismic activity. Deformational sedimentary structures are common throughout the Upper Carboniferous strata of the area studies. No distinct patterns or distributions have been noted within the study area to date. There is, of course, a natural paucity of these structures within the conglomeratic strata.

Potter and Pettijohn (1977) defined deformational sedimentary structures as disturbed, distorted and sometimes deformed bedding or deformed primary sedimentary structures. Such deformational structures range from mild forms of low relief load casts to more severe forms such as sedimentary sills and dykes. The deformational structures are penecontemporaneous and do not reflect post consolidation tectonic movement.

Deformational sedimentary structures can be divided into two major groups: (1) slide or slump deformations, which are related to slides due to gravity down slopes at the time or shortly after sediment accumulation, and (2) differential vertical movements (loading) usually occuring in reverse density situations.

The second group of structures would include those structures resultant from fluidization of beds due to over-pressured pore fluids (liquefaction) and the related water escape structures.

The penecontemporaneous nature of these structures was recognized as early as 1882 by Geike when he used these soft sediment deformations to explain deformation in unconsolidated sands and gravels caused by loading of stranded ice blocks. Nevin (1942) in his review of the criteria for the penecontemporaneous nature of these structures cites the chaotic nature of the folding, the fact that the structures are sometimes truncated by erosional features, the lack of cleavage and the ill defined nature of the fault-like feature boundaries, as well as the presence of these structures between two undeformed beds, as evidence for their digenetic nature. Table II summarizes and categorizes the sedimentary deformational structures.

There are many deformational (secondary) sedimentary structures present in the strata of the study area. Most of these structures can be attributed to "physical diagenesis" (Poll et al., 1982; Poll and Plint, 1983).

"Physical diagenesis is the process of post-depositional, premetamorphic dewatering, compaction and subsurface remobilization of sediments" as defined by Poll et al. (1982).

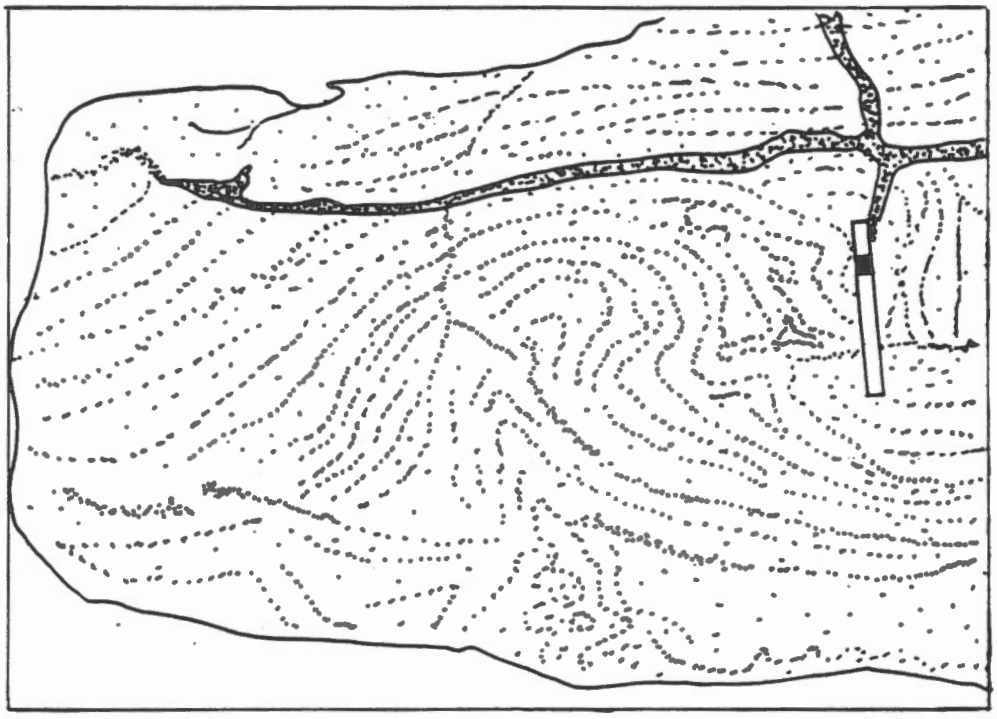


Figure 14: Convolute laminationin a medium grained sandstone,Treen Point, Tatamagouche area, N.S. (9 cm pen for scale)

Figure 15: Loading,pseudonodules (P) mud dykes (D) and mud lens (L) Pictou Upper Red Beds,Cape John, Pictou County, N.S.

Figure 16a: Pseudonodules (P) and mud dikes (D), Treen Point, Colchester County,N.S.

Figure 16b: Pseudonodules (P) at Treen Point, Colchester County,N.S.

Unstable density gradients, rapid sedimentation and high porosities, result in overpressured pore fluids which in turn may result in physical diagenesis (Poll and Plint 1983). The following are the common structures found within the study area:

a) Mud Diapirs:

Many low amplitude mud diapirs occur coincident with sandstone loading. The average upward displacement of the low amplitude diapirs is from 0.25 m to 1.0 m with a width of approximately 0.2 m to 1.0 m. Wherever loading takes place an equal and opposite upward rising of mud occurs. Many of the low amplitude mud diapirs have sole marked surfaces. Rill-like structures are common as are loaded flutes.

b) Larger Mud Diapirs and Pods:

Two examples of larger mud diapirs or pods occur within strata studied along the French River, 600 m downstream from Balfron, an example of large amplitude mud diapirism is found. The displacement of this mud/silt relative to the present position of the sandstone bed sole, is approximately 1.5 m - 2.0 m. The width of this diapiric structure varies from 2-5m. Along the interface with the sandstone there are many load structures, loaded flutes, rill-like structures. The mud itself is discordant with the existing bedding. One explanation for this feature is that it is a remnant of overbank mudstone preserved between two channel sandstone units. In such an event, it is impossible to explain loaded flutes and load casts discordant to bedding, unless the overbank material is overturned into the channel. However, such an event is not supported by the configuration of the beds within the outcrop.

At Cape John 100 m along the shore east of the Cape, an isolated mud pod crops out. The Cape John Mud pod is not a mud diapir, as it has no visible lower bounding surface connections to a mudstone bed. The closest mudstone bed lies stratigraphically 3 m below the pod. The pod of mud is roughly tear drop shaped with dimensions of 1.7 x 2.5 m. At the base of the pod there are nearly vertical sand-on-sand surfaces which resemble intrastratal surfaces (Poll 1981). At the top of the pod, two distinct mud dykes approximately 1-2 cm wide cut through the overlying sandstone unit. The mud pod has loads, that is, loaded flutes which occur on the walls and roof. The orientations of the flute-like structures are extremely variable. Rill mark-like structures are preserved. However, the co-existance of flutes and loads with rill marks is unlikely, given the poor preservation potential of primary rill marks. Collinson & Thompson 1982). The rill mark-like structures are therefore more likely the result of thin bifurcating sandstone loading. There are two alternative explanations for the isolated pod of mudstone/siltstone at Cape John. The first alternative is that the mudstone is a preserved in situ overbank deposit. Within the Cape John area the paleocurrents often diverge by as much as 180° within a few meters. Under such conditions it would seem reasonable that overbank material may be preserved between two divergent streams. The preservation of such a structure would be unusual, given that the flow velocities, and wetting by the stream currents, would create slumping and destruction of the overbank mud. It is difficult to explain the highly variable paleocurrent indicators on the surface of the remnant.

Traditional vertical loading and fluting of such a block of mudstone cannot possible create the variable paleocurrents observed, if the block remained as an upright remnant of overbank material. The second alternative explanation is that the mudstone pod represents a block of overbank material which has fallen into the stream channel due to undercutting of the bank (McKee et al. 1967). Foley (1984) points out that although McKee et al. (1967) describe large rounded clay blocks in the flood sediments of Bijou Creek, Colorado, associated fluted surfaces are not described. Allen (1969) indicates that flutes result from intense scour of cohesive sediments by localized vortices. To account for the multidirectional sedimentary structures, it would be necessary to roll the block, scour the surface, and then roll it again (Gibling and Rust 1984). To have flow velocities roll large blocks of mudstone and not destroy the block seems improbable (cf. Turnbull et al. 1966). A block of this size would almost certainly result in an obstacle mark of large proportions if it had been in the stream flow. Such a structure has not been observed.

It would seem, in this instance, that the most plausible explanation for the block of mud would be that it is an instrusive pod.

c) Mud Dykes and Mud Boils:

Where mud dykes occur with distinct sub-circular conduits as opposed to sheets, mud dykes and mud boils are terms used for the cross cutting and surficial sections of the same sedimentary structure. These sedimentary structures are common within the Upper Carboniferous strata of the Tatamagouche Syncline Area. The mud conduits are from 15 mm to 2.5 cm in diameter, and generally can be traced for 15-25 cm to the rooted mud source. The upward flow of the mud-water mix often contorts the laminations within the sandstone beds through which the mud is escaping, resulting in concentric ring laminations. Most of the mud dykes are nearly perpendicular to bedding, but variation in orientation of up to 45° is common.

d) Convolute Laminations and Pseudonodules:

Foley (1984) defines convolute laminations as discrete intervals of irregularly folded strata within well-bedded sedimentary sequences.

The convolute laminations in the Tatamagouche area vary from oversteepened ripple laminations to pseudonodules. Small scale convolute laminations are common within the overbank siltstones and mudstones of the area. Convolute laminations within the sandstones are rare and are usually associated with loading (Fig. 14).

In some instances, when sand progressively loads into the underlying mud layer, sand lumps separate and sink into the mud bed, forming isolated convolute laminated pseudonodules (Fig. 15).

At Treen Point with the study area, convolute laminations and pseudonodules are common (Fig. 16). Within the sandstone beds, sand-on-sand bed soles have flute-like features which result from convolute laminations. The convulute laminations within these sandstones are caused by sediment dewatering, liquefaction (cf. Visher and Cunningham, 1981) and/or fluid drag during during consolidation (Lowe, 1975).

CHAPTER 6

FACIES MODELS

FACIES MODELS

Since Gressly (1838) first intoduced the term "facies", it has been used to delinate lithologic and biologic characteristics of stratigraphic units.

In recent years, facies models based on modern sedimentary environments have established reasonable standards to which rock units may be compared.

In fluvial sedimentary environments, the introduction and use of facies models has been one of the most active research areas in the fields of stratigraphy and sedimentation (Walker 1979).

Straight Streams (Low Sinuosity Streams)

Traditionally, straight streams were thought to represent stream flow in areas of higher stream gradients (Potter and Pettijohn, 1976). Higher stream gradients, however, tend to result in straight braided patterns, which are dominantly composed of coarse alluvium. Some experimental evidence (Schumm et al. 1972) indicates that straight stream sedimentation may also occur in the lower reaches of the stream system in areas of low gradients. Leeder (1982) suggests that the major contributing factor to the development of low sinuosity streams is the cohesiveness of the overbank muds. When drawing modern analogies to ancient sedimentary environments, the absence of binding grass may contribute to variations in stream morphology.

The strongly unimodal cross strata paleocurrent directions within the Upper Carboniferous strata of the Tatamagouche syncline area, suggest that sedimentation was taking place within straight sections of the river systems (Fig. 17). How extensive these straight sections were, is difficult to determine. However, the lack of lateral accretion bedforms suggests that most of the sediment accumulation took place as a result of progradation of lunate dunes. Point bars are rare to absent. The channel sandstones and conglomerates of the study area commonly are multichannelled, multistoried and multilateral. Lateral bars were developed and bar surface sand waves resulted in the formation of tabular cross strata. Levee deposits are rarely preserved except at the very top of the multichannelled sequence.

Sinuosity indices extrapolated from paleocurrent measurements for the streams within the Pictou Grey Beds, Pictou Lower Red Beds, and Pictou Middle Red Beds approximate 1.30.

Branching in these mixed load, low sinuosity streams would most likely have formed an anastomising configuration (true amastomising, not braided anastomising) given the unimodal nature of paleocurrent determinations (cf. Galloway 1979).

Cutoffs or branching, due to preferential down-cutting in alternate channels, resulting from inhomogenities in the overbank material or debris blockage of a channel, are common.

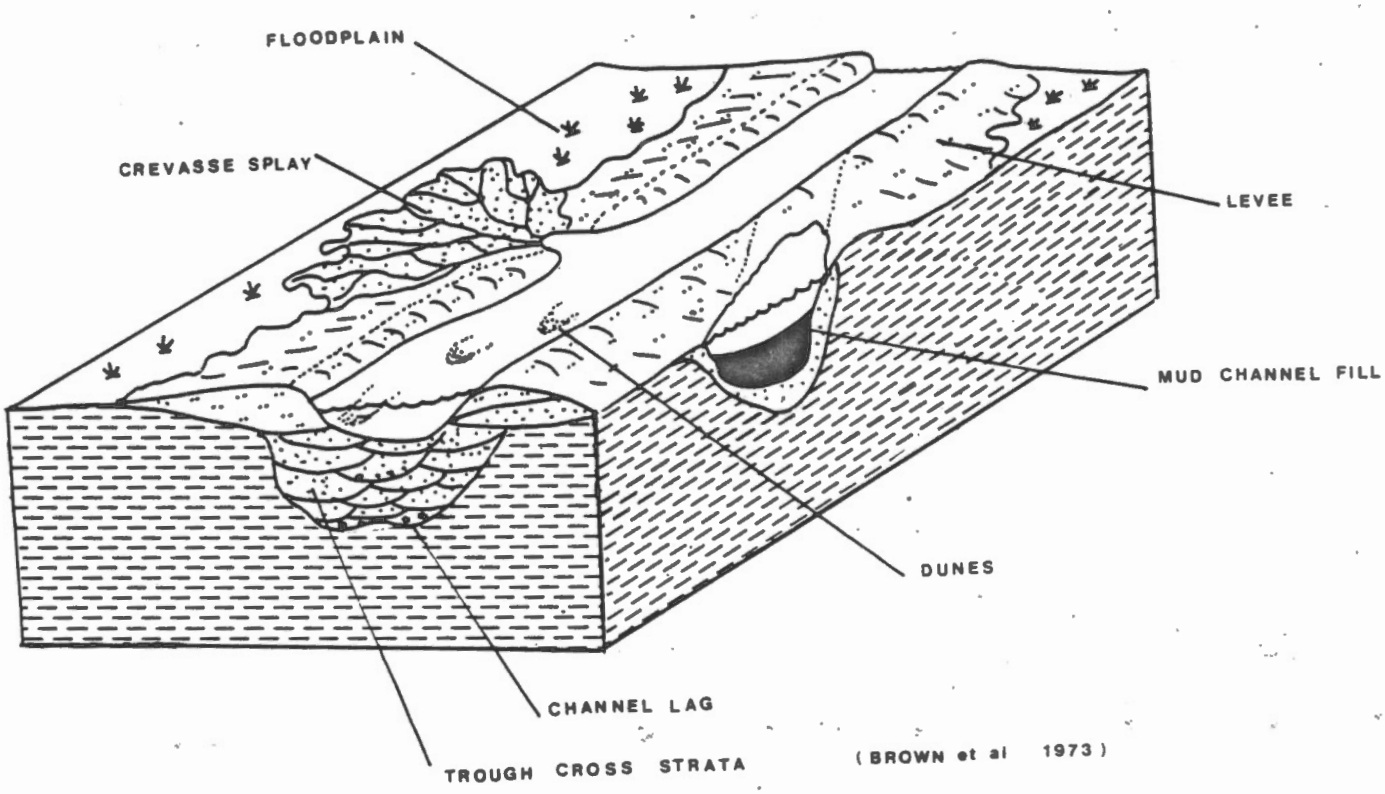


Figure 17: Straight stream facies model, after Brown et al (]973)

The crevasse splays in low sinuosity streams may exhibit atypical geometry due to the elongate nature of flooding spills in straight sections of rivers. Within any stream channel, flow conditions vary laterally, and consequently dunes, sandwaves, ripples and flat beds may coexist in cross section within a single channel, yeilding a fluvial fining upward sequence similar to that of a meandering stream.

Meandering Streams (Moderate to high sinuosity)

Galloway (1979) suggests that moderate to high sinuosity streams formed by similar depositional mechanisms to straight straight streams and differ from them by the abundance of point bars, chutes, and chute bars.

Point bars represent an environment of greatest accumulation of sediments in the meandering system. (Davies 1983). These deposits accumulate on the convex side of meanders within moderate to high-sinuosity stream systems. Allen (1965) described the flow dynamics in meanders, and summarized the resultant sedimentation, presenting a model for point bars (Fig. 18).

McGowen and Garner (1970) refined the point bar model to include flood stage channels and resultant bars. These channels and bars, which modify the point bar, are called chutes and chute bars.

In the Upper Carboniferous strata of the Tatamagouche area, moderate to high-sinuosity stream systems are found within the Boss Point Formation and possibly within the Pictou Upper Red Beds.

Although no evidence of lateral accretion has been documented for the Pictou Upper Red Beds the sand-silt ratios, paleocurrent variations and the presence of multilateral channel sandstones (Fig. 5) suggest deposition in moderate to high-sinuosity streams.

The Boss Point Formation exhibits a more typical meandering stream lithological succession, and closely parallels the idealized point bar succession of Reineck & Singh (1980).

Preservation of diagnostic epsilon cross stratification or ridge and swale bars is not apparent in the map area.

The absence of such sedimentary features and the similarity of sedimentary successions of low and high sinuosity streams makes differentiation of such environments difficult. The paleocurrent determinations, geology of the channel sands and sand to silt ratios are therefore the most reliable indicators of sinuosity (cf. Galloway 1979).

Wet Alluvial Fans

Wet Alluvial fans are constructed by episodic, high-intensity, short-duration processes which are sedimentologically controlled by rainfall (McGowen 1979). McGowen and Groat (1971) subdivide fans into three facies, which grade laterally into one another (Fig. 19). The proximal fan facies is dominated by coarse boulder to pebble conglomerates, which may be imbricated. The mid-fan facies is characterized by graded pebble

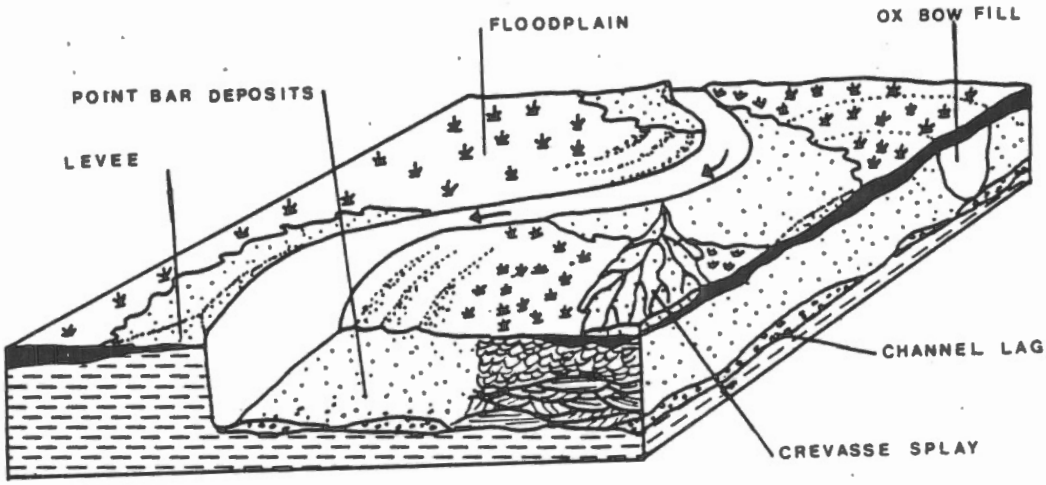


Figure 18: Meandering stream facies model,after Allen (1969)

conglomerates and cross stratified pebbly sandstones. The distal fan facies is more varied, and is predominantly composed of tabular to trough cross stratified sandstones (McGowen & Groat 1971). The channel patterns change from that of a confined mountain stream to unconfined flow at the apex of the alluvial fan (McGowen 1979). The proximal facies is predominantly a straight channel. The presence of the straight confined channel may only represent the low flow conditions, whereas unconfined sheet flow may dominate the periods of higher recharge (McGowen 1979). Wide braided patterns become abundant a short distance downcurrent from the apex of the fan. The distal fan facies exhibits stream patterns of narrow braided and distributary channels (McGowen & Groat 1971).

In the study area, the boulder and pebble conglomerates of the Millsville Formation which are planar bedded, exhibit poor imbrication and crude graded beds are interpreted as proximal alluvial fan deposits. Within the Cumberland corase facies, the pebble conglomerates and pebbly sandstones are trough cross stratified and were deposited in the mid to distal alluvial fan environment.

Straight Braided Streams (Low Sinuosity Streams)

Sand-rich braided streams are abundant in mid to distal alluvial fans.

Miall (1977) classified the bars which divide the stream flow in braided channels into longitudinal, linguoid, modified linguoid, point and side bars (Fig. 20).

The resultant geological sequences form tabular, multilateral sand belts with high width-thickness ratio (Galloway 1979). The sequences are dominantly sandstone, pebbly sandstone and pebble conglomerates, with volumetrically minor silt and clay. No well defined vertical trends can be discerned. The internal structures include planar, low angle avalanche, tabular cross-stratification and trough cross-stratification. Local scour surfaces are common, and result in lags consisting of pebble sheets within the sandstones (Galloway 1979).

In the study area, the Cumberland Coarse facies and possibly part of the Boss Point Formation exhibit the characteristics of braided stream sedimentation.

The presence within these units of broad, multilateral sheets of pebbly sandstones and conglomerates of consistent composition, with only minor silt and clay, suggests braided stream deposition.

Lacustrine

Lake sedimentation was common in the low lying areas of the floodplain between the rivers in the Upper Pennsylvannian-Lower Permian rocks of the Tatamagouche Syncline area.

The most important parameter of lake sedimentation is climate (Reineck & Singh 1980). For practical purposes, Reineck & Singh (1980) divided lakes into two major divisions: (1) clastic lakes (2) chemical lakes.

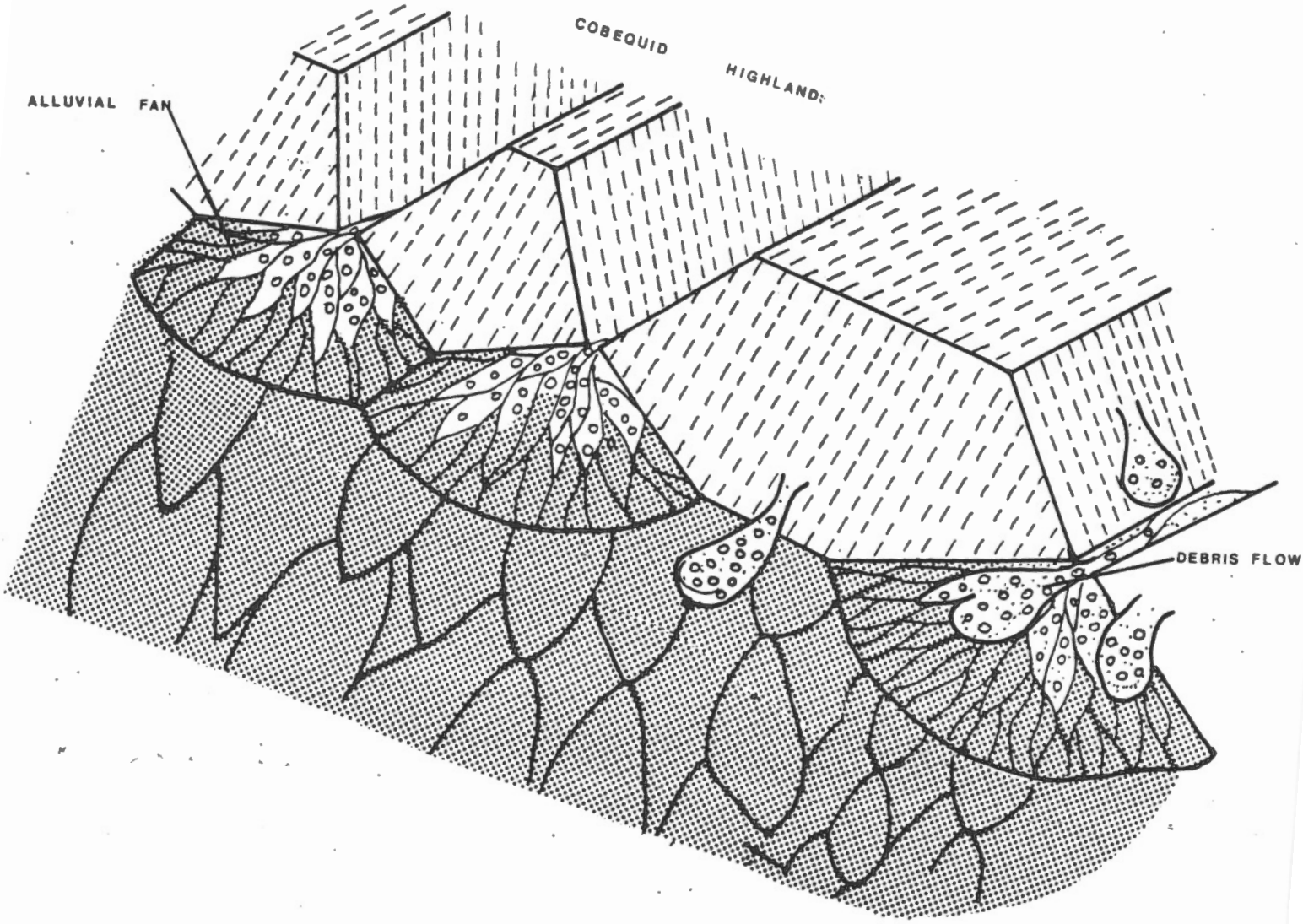


Figure 19: Wet alluvial fan facies model, after Miall (1979)

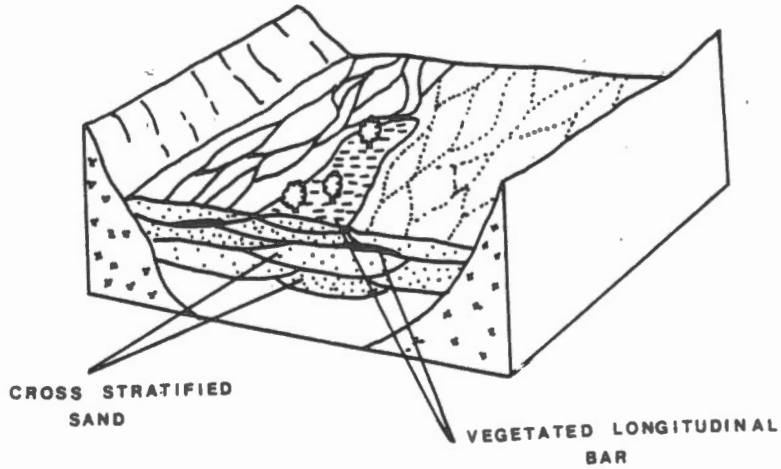


Figure 20: Braided stream facies model, after Allen (1965)

Twenhofel (1932) proposed an idealized model for lake sediment distribution (Fig. 21). Recognition of fine grained clastic lake deposits within the overbank sediments is difficult. However, where limestone beds are encountered containing fresh water fauna, recognition of the environment is possible. The extend of lake sediment accumulation above and below this horizon is none the less difficult to determine.

The major contributors to biologically derived carbonates within the lakes of the study area are ostracods, algae, and gastropods. The micritic lime mud with little recognizable biological constituents is probably derived from disintergration of the skeletal remains of calcium carbonate supported algae.

Lake sedimentation within the study area resulted in the development of thin but extensive carbonate units. Single limestone beds, 0.5-1 m thick, can be traced for 35 km along strike without significant lithological or biological variation (Fig. 5).

These laterally extensive lacustrine limestones are excellent marker beds and facilitate correlation within the Pictou Upper and Middle Red Beds (Fig. 5).

Reineck & Singh (1980) suggested that sedimentation rates within lacustrine environments are slow, that even thin lacustrine beds may represent considerable time periods.

If the dimensions of the lake are symmetrical, the minimum areal extent of such lakes would be in excess of 1225 km^2.

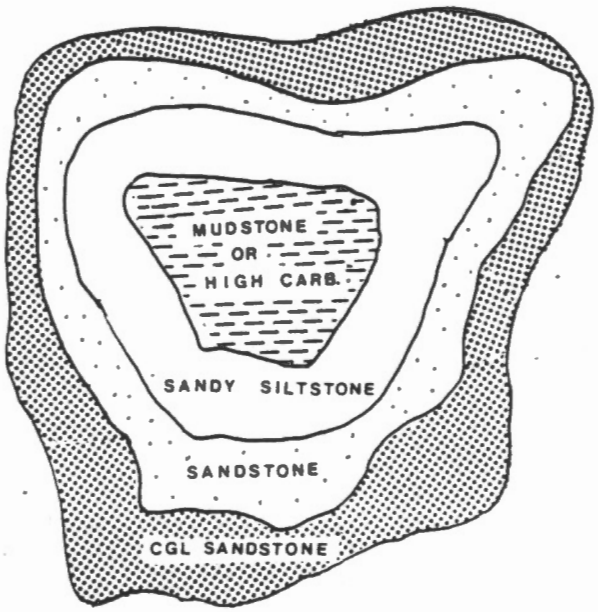


Figure 21: Idealized facies model for clastic lake deposition, after Twenhofel (1932)

CHAPTER 7

SEDIMENTOLOGY

SEDIMENTOLOGY

Riversdale Group

Millsville Formation

This formation is characterized by pebble imbrication, coarse, poorly-sorted boulder to pebble conglomerates and only rare evidence of cross stratification. The presence of planar beds support the existence of episodic sheet flow. Some of the conglomerates appear to be matrix-supported, and were probably the result of debris flows. The sedimentological factors, together with geographical distribution of the Formation, indicate that the environment of deposition was a proximal alluvial fan. Lithofacies: $M\text{-}BG_p$, $M\text{-}PG_p$

Boss Point Formation

The formation is sand-dominated with only thin interbeds of siltstone and shale. The sandstone and conglomerate beds are generally tabular and trough cross stratified. Deposition of the Boss Point Formation of the Tatamagouche area probably took place in moderate to low sinuousity, meandering, (possibly braided), sand dominated streams (Fig. 18). Lithofacies: $BP\text{-}PS_t$, $BP\text{-}S_t$, $BP\text{-}PG_t$, $BP\text{-}F_m$

Cumberland Group

Cumberland Group Coarse Facies

This formation, which is made up of polymictic conglomerates, exhibits both obscure cross stratification and planar graded beds. The presence of some trough cross stratification and the finer grain size of the conglomerates, suggests deposition in braided streams in a mid to distal alluvial fan environment. The existence of planar bedded coarse sands and conglomerates indicates that during flood stage, sheet flow could have dominated (Fig. 19). Lithofacies: $C\text{-}PG_p$, $C\text{-}PS_t$, $C\text{-}AS_t$

Cumberland Fine Facies

The conglomerates are interpreted as being channel lag, traction load, deposits. The sandstones appear to be trough cross stratified and are probably resultant from channel dune progradation. The red and grey shales and minor thin coals represent the flood plain and back swamp environments marginal to the fluvial channel deposits. Lithofacies: $C\text{-}AS_t$, $C\text{-}S_t$, $C\text{-}PS_t$, $C\text{-}F_m$

Pictou Group

Pictou Grey Beds

This unit exhibits unimodal paleocurrent data of low variance and fining upward sequence of conglomerates to sandstones. These have similar characteristics to sedimentary rocks which Campbell (1976) attributed to deposition in low sinuousity streams. The conglomerates representing the channel lags, the sandstones (arkoses) the channel fill due to the

migration of dunes, which resulted in trough cross stratification, the subarkoses were deposited as coarsening upward cycles of levee and crevasse splay deposits, and the finer grained sedimentary rocks were deposited on the flood plains. Lithofacies: $P\text{-}PS_t$, PAS_t, $P\text{-}S_t$, $P\text{-}S_p$, $P\text{-}F_m$, $P\text{-}PG_t$

Pictou Lower Red Beds

The environment of deposition is very similar to the Pictou Grey Beds. Low sinuosity, possibly anastomosing streams, yeilded channel lag conglomerates. The arkoses and coarse subarkoses were deposited in the channels by migrating dunes. The fine subarkoses represent levee and possibly crevasse splay deposition. The fine-grained sediments were deposited on the flood plains, and the limestones resulted from lake deposition within back swamp areas (Fig. 22). Lithofacies: $P\text{-}AS_t$, $P\text{-}F_m$, PS_t, $P\text{-}PG_t$, $P\text{-}S_p$

Pictou Middle Red Beds

The arkoses and coarse-grained subarkoses of this unit exhibit tabular cross bedding in addition to the more common trough cross bedding.

The paleocurrent data for this unit exhibit slightly more variance than the Pictou Lower Red Beds and the Pictou Grey Beds. Therefore, although still within a low sinuosity stream system, some meandering occurred in the streams at the time of the Pictou Middle Red Bed deposition. The increased proportion of finer grained sedimentary rocks, together with the variance in paleocurrent data, would indicate a lessening in the stream gradient. Limestones were deposited in large lakes which periodically extended over most of the flood plain area. The presence of these extensive lakes would further suggest a lower stream gradient within the Pictou Middle Red Bed unit. The extensive channel sands are concave upward at their bases, further suggesting that they represent low sinuosity streams. The great width of the streams is due in part to the lack of soil binding grasses during the Carboniferous Period (Poll 1984). Lithofacies: $P\text{-}F_m$, $P\text{-}AS_t$, $P\text{-}S_t$, $P\text{-}PG_t$, $P\text{-}S_p$, $P\text{-}L_f$ (Fig. 23)

Pictou Upper Red Beds

The Upper Red Beds have numerous mud-filled abandoned channels. Tabular cross stratification is present but trough cross strata is the common sandstone bedform. Plant debris is abundant within most of the channel sand units. Reduction spheres are locally abundant within the siltstones and fine grained sandstones. The diameters of the reduction spheres can be up to 8 cm. The fine sandstones and siltstones almost always contain lunate ripples. Reverse graded bedding is ubiquitous within the planar bedded fine grained subarkoses.

Limestone beds are common. The limestones are light to medium grey biomicrites containing abundant ostracodal, gastrapodal and algal constituents. The upper limestones often are intraclastic and contain micritic clasts of ostracodal limestones. (Fig. 24)

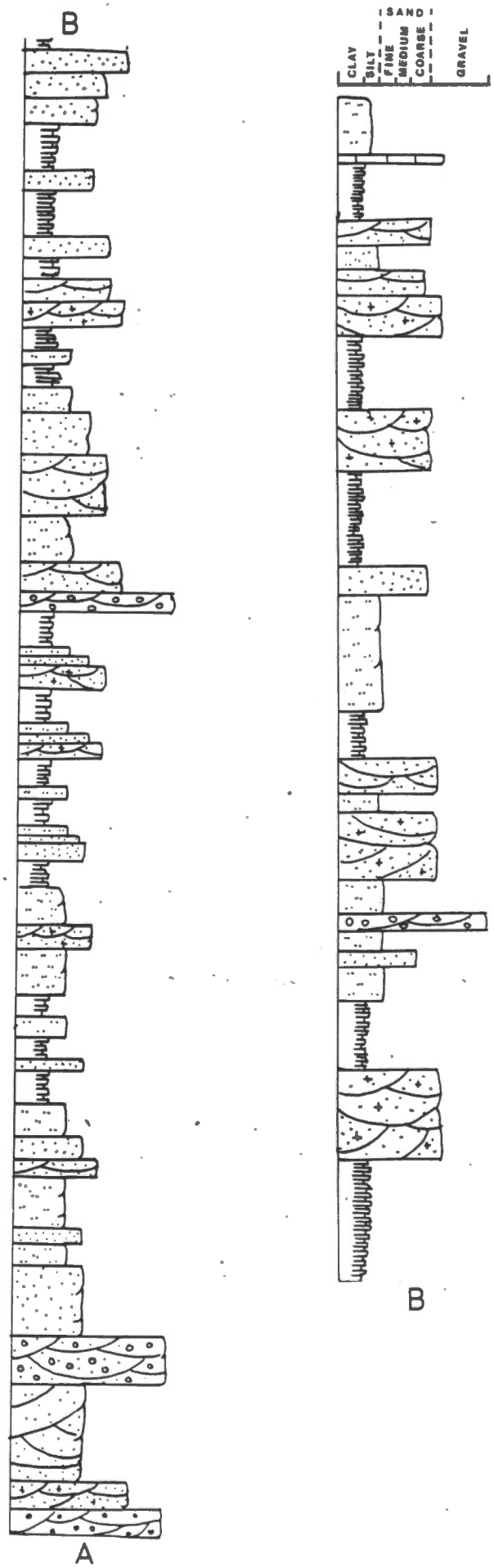


Figure 22: Idealized section of the Pictou Lower Red Beds, Tatamagouche Syncline

scale?

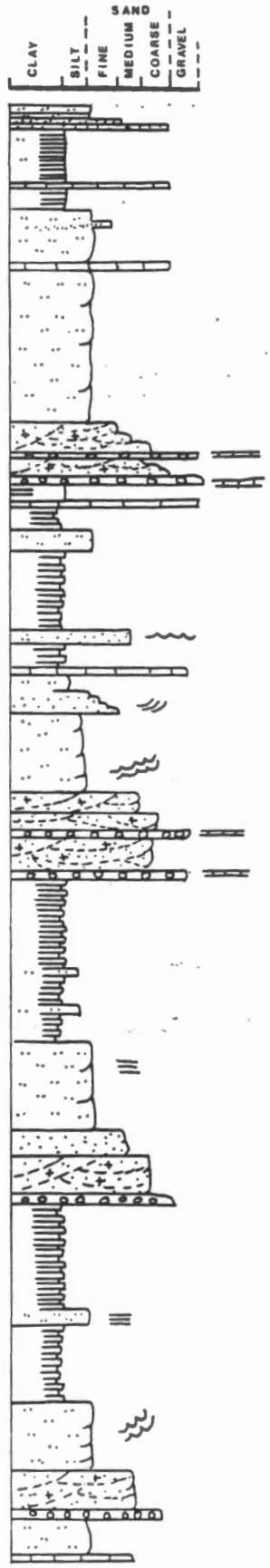


Figure 23: Idealized section of the Pictou Middle Red Beds, Tatamagouche Syncline area, N.S.

The paleocurrent directions of the Upper Red Beds are much more varied than those of the underlying strata (Fig. 9). Direction reversals within a few tens of meters can be observed in the Cape John area. Although the paleocurrent data is polymodal, the north-northwest, 340°, direction is still dominant. The paleocurrent data suggest a meandering stream environment. However, Ox bow configurations are not present near the mud filled abandoned channels as would be expected in a meander cut off situation. It is concluded that the configuration for these streams is perhaps an anastomosing one. Divergent branches could explain the paleocurrent reversals and channel abandonment. Lithofacies: $P\text{-}F_m$, $P\text{-}AS_t$, PS_t, $P\text{-}PG_t$, $P\text{-}S_p$, $P\text{-}L_f$

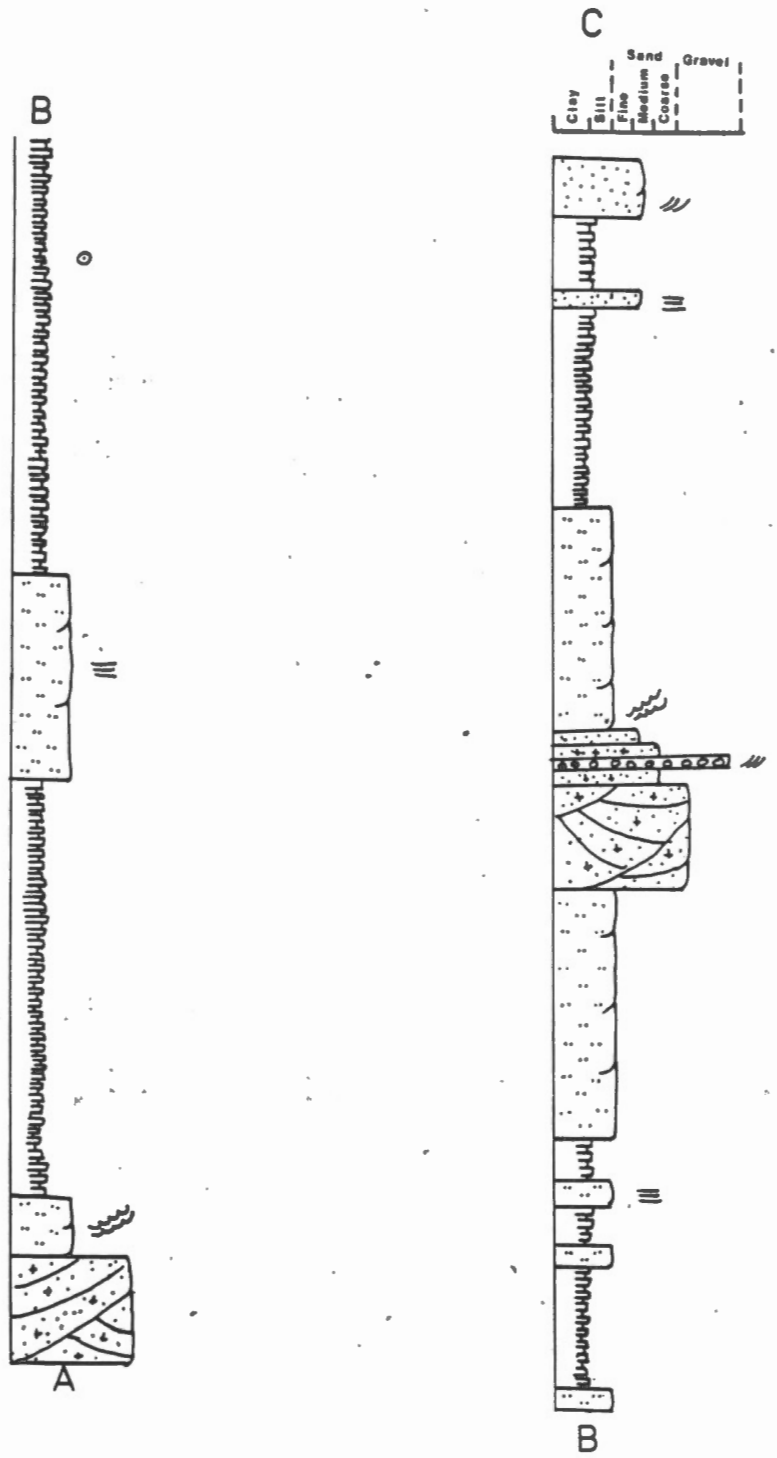


Figure 24: Idealized section of the Pictou Upper Red Beds,Tatamagouche syncline,N.S.

CHAPTER 8

PALEONTOLOGY

PALEONTOLOGY

Trace Fossils

Ichnogenus Diplichnites - Dawson, 1873 (Amended).

Amended diagnosis (Briggs et al. 1985): Morphologically simple trail, up to 37 cm wide, consisting of two parallel rows of tracks (each up to 11 cm wide); width of opposed rows increasing on curves corresponding to greater lateral separation of individual tracks, each row may divide into two on acute curves; individual tracks elongate roughly normal to trail axis, spaced closely and regularly at as few as one per cm in large examples.

Cape John locality

Briggs et al, 1985 have described in detail the morphology of a Diplichnites cuithesis from the Tymouth Creek Formation of Southern New Brunswick and compared it to the previously described specimen from Joggins, Nova Scotia (Ferguson 1966). In addition, they attributed these trails to the myriapod, Arthropleura (Fig. 25).

The Cape John locality is 500 m north of Reef Point near Cape John, Pictou County, Nova Scotia. The trace fossil is preserved within medium to coarse grained, trough cross stratified, arkosic sandstone. Three trails are found at this locality, two crossing each other and the third trail a few meters away. All three of the trails exhibit the same average width and are therefore interpreted as being made by a single Arthropleura. The width of the trails varies from 50.25 cm to 46.3 cm with the straight sections of the trails being 47 cm in width (Fig. 26).

The trails are simple, parallel rows of tracks (up to 13 cm wide), and are elongate and perpendicular or nearly so to the trail axis. There are approximately 25 track depressions per meter on each side of the trail.

Remarks

Except for the width, the Cape John trails are similar to D. aenigma described by Dawson (1873) and should therefore be considered as the same species.

Worm Burrows

Many of the fine grained red beds of the Pictou Group were highly bioturbated and contain well preserved worm? burrows. The burrows are both bifurcate and singular and vary in diameter from 0.25 cm to 1 cm. The burrows occur both along bedding planes and also at right angles to bedding. Detailed investigation of these smaller ichno-fossils is in progress.

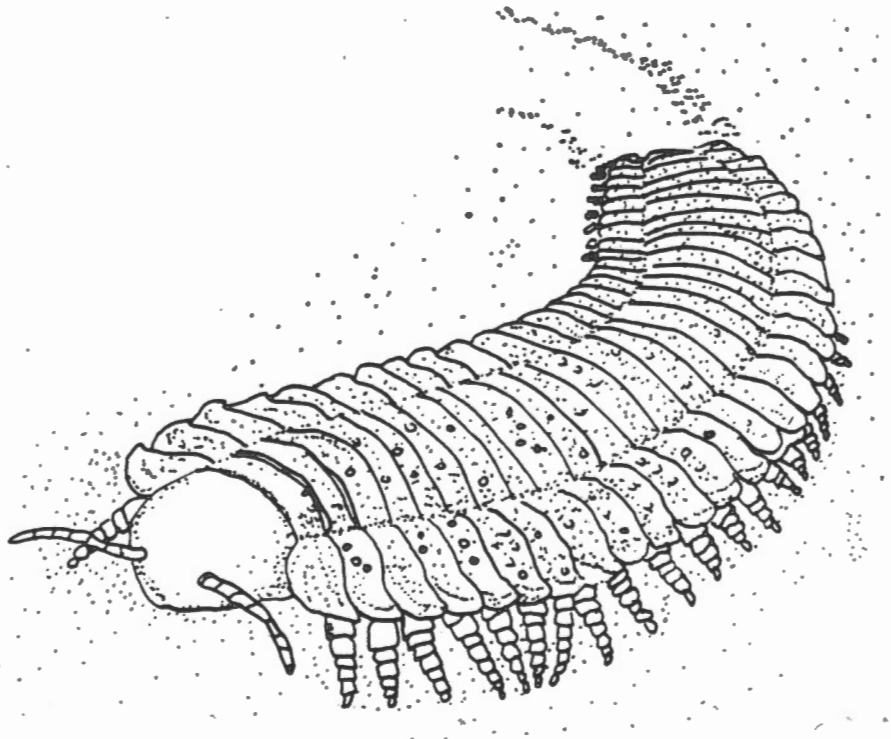


Figure 25: Reconstruction of fossil myriapod, Arthopleura sp.,after Briggs et al (1984)

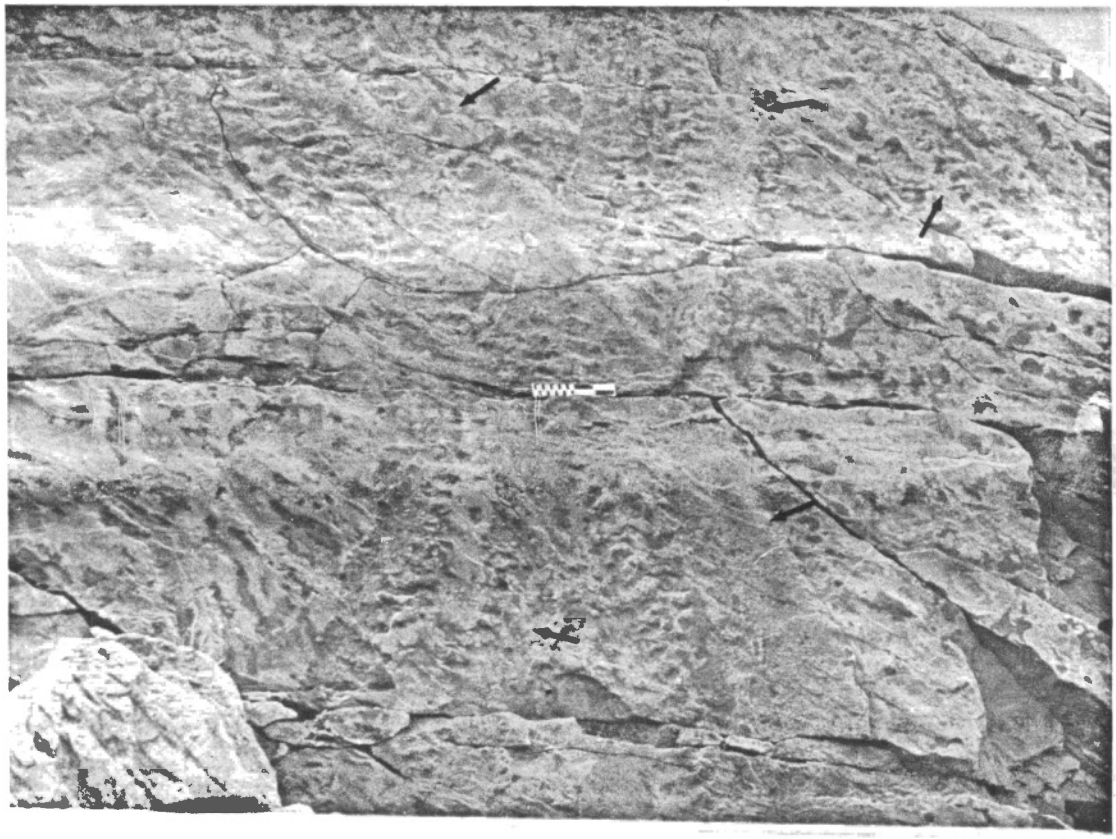


Figure 26a: Fossil myriapod trails, Diplichnites, Cape John,Pictou County,N.S.
scale = 25 cm

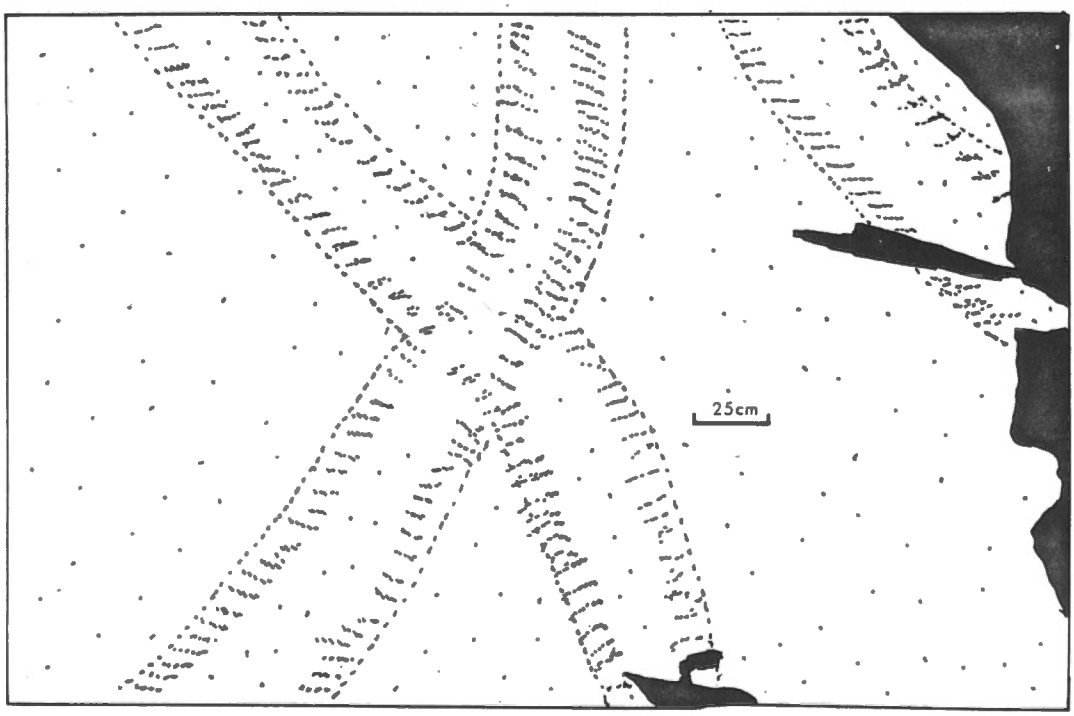


Figure 26b: Fossil myriapod trails,Cape John, Pictou County,N.S.

Invertebrates

Windsor Group

Hansford, Cumberland Co., N.S.

Aviculopecten lyelli	Leptodesma acadica
Composita windsorensis	Batostomella sp.
crinoid stems	Ovatia lyelli
Horizon: SUBZONE "B"	

Pictou Group

Numerous grey shales and limestones of the Pictou Group in the study area contain fossil anthropod fauna. Among those identified in the Upper Carboniferous of the study area are (Fig. 27-29):

Carbonita fabulina	Leaia silurica
Carbonita inflata	

PALEOBOTANY

Algae: Many of the limestones of the Pictou Red Beds contain fresh water calcareous algae, charophycophyta. Plant fossils identified during the geological investigation of the Pictou Group include; e.g. Fig. 30;

Neuropteris rarinervis	Calamites ramosus
Calamites sp.	Annularia pseudostellata
Asterophyllites grandis	
Cordaites principalis	Lepidodendron pictoense
Pecopteris acadica	Sphenopteris whittii
Stigmaria sp.	Sigillaria tessellata

Scott (1979) was the first to attempt a comprehensive reconstruction of the paleoecology of the Carboniferous flora. The distribution of macro-floral remains, in conjunction with the facies models for the sedimentation, were examined by Scott (1979) and a paleoecological reconstruction presented (Fig. 31).

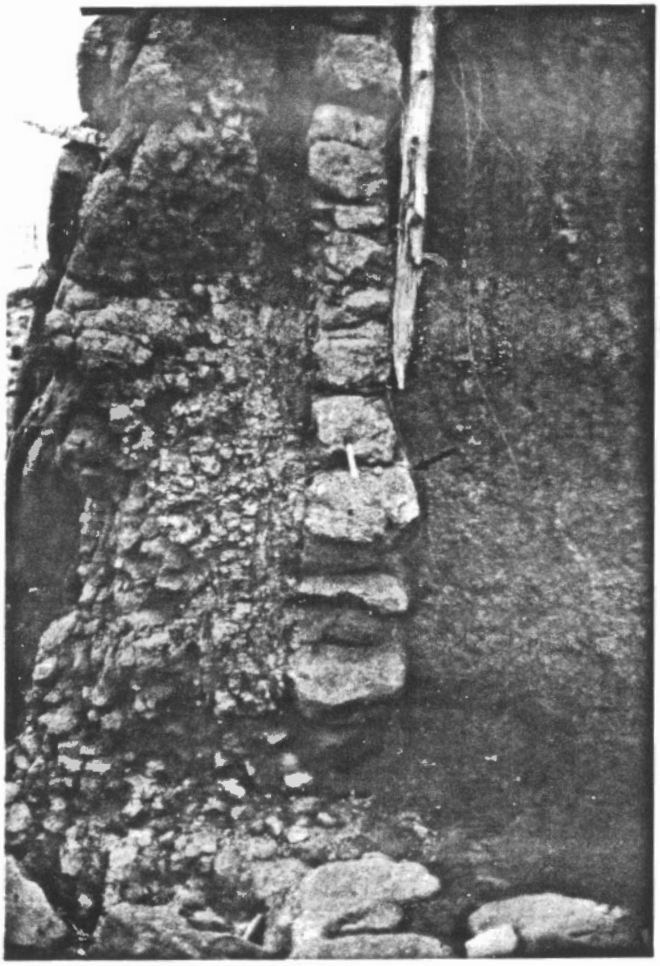


Figure 27: Limestone bed, Pictou grey beds, Treen Bluff, Colchester County, Nova Scotia, 10 cm felt pen for scale

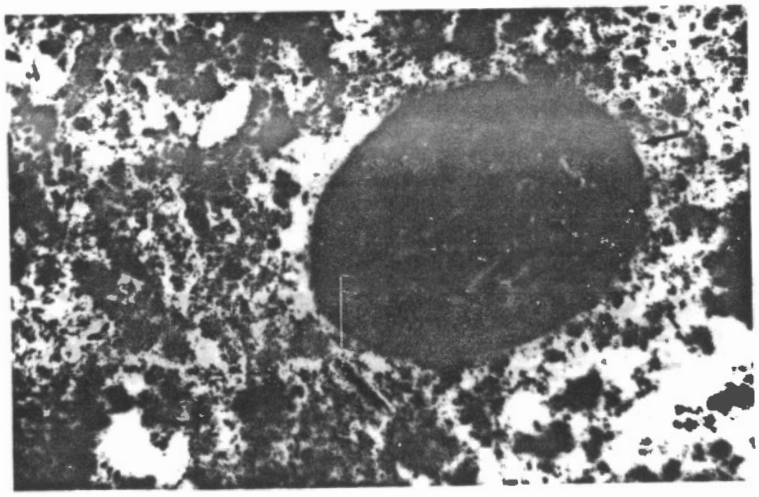


Figure 28: Negative photomicrograph,ostracod in biomicrite,Pictou Middle Red Beds, Murphy Point ,Pictou County,N.S.

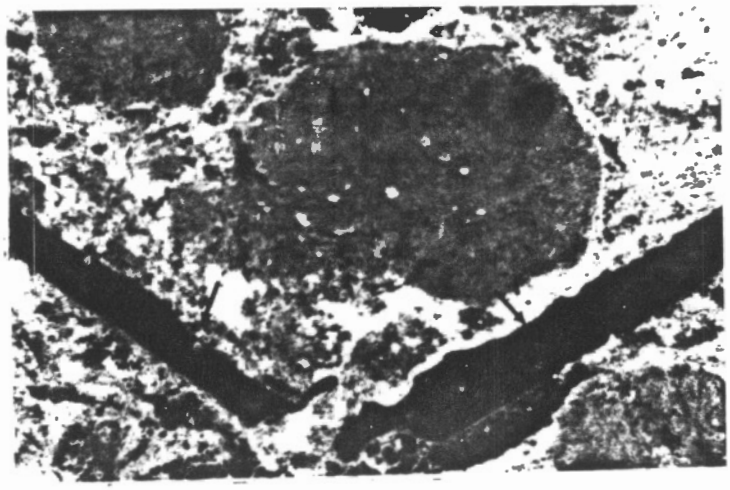


Figure 29: Negative photomicrograph,mullusc shell debris in biomicrite,Murphy Point Pictou County, N.S.

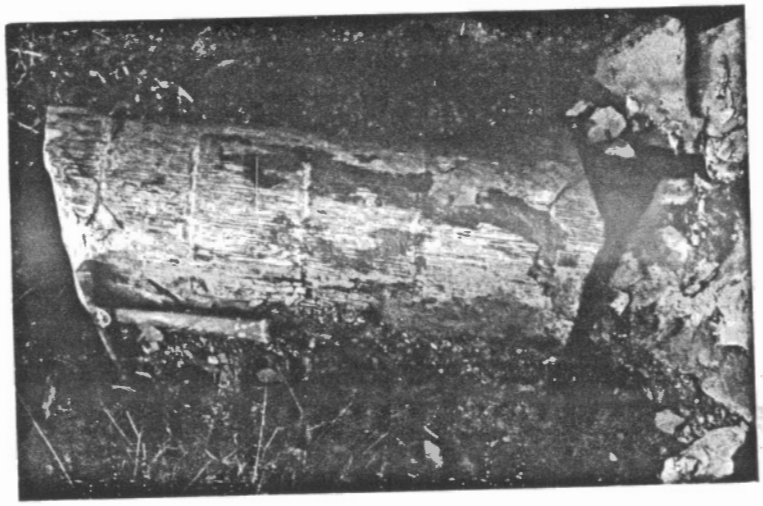


Figure 30: Calamites stem,Pictou Middle Red Beds, Rushton's Beach ,Colchester County,N.S.

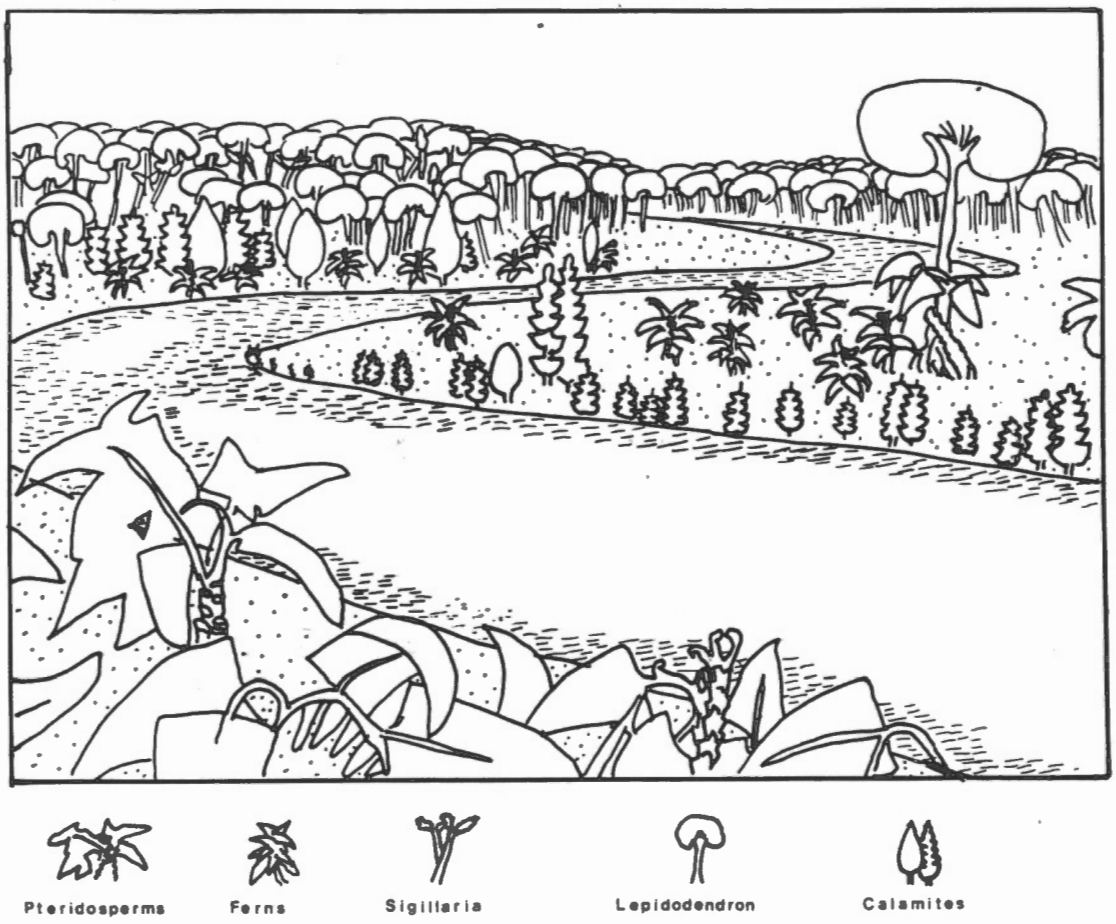


Figure 31: Paleoecological reconstruction of the Carboniferous Mega-flora,after Scott (1979)

CHAPTER 9

STRUCTURE

The study area is structurally simple. The major structural features are the Tatamagouche syncline, the Malagash anticline and the North Cobequid fault.

The Tatamagouche syncline and the Malagash anticline are genetically related structures. The shallow northeasterly plunging Tatamagouche syncline is probably the result of flowage removal of salt, gypsum and anhydrite from the underlying Windsor Group. The evaporite removal is caused by differential basinal loading in areas of rapid sedimentation. The evaporites, which are removed from the basin depocenters, migrated to form a series of diapirs that developed into an antiform parallel to the Tatamagouche syncline fold axis.

An eroded fault scarp known as the North Cobequid fault forms a geological boundary between the Carboniferous strata and the Pre-Carboniferous rocks of the present day Cobequid Highlands. There is no evidence of faulting near the Carboniferous strata along this boundary. The geological unit boundaries suggest that the North Cobequid fault has remained inactive throughout the Upper Carboniferous and has been overstepped by the sedimentary units.

Adjacent to areas of diapirism, there is broad folding, normal faulting, strike slip faulting, and more rarely, reverse faulting. Displacement along these faults is minor and rarely exceeds 200 m.

Dips in the central syncline are approximately 10-15 degrees. Adjacent to the Carboniferous boundary with the Cobequid Pre-Carboniferous rocks, the dips increase to 25-35 degrees. In areas of diapirism, the strata can have steep dips (80-90 degrees) and can occasionally be slightly overturned.

CHAPTER 10

ECONOMIC GEOLOGY

Economic Geology:

In North America, the terms strataform and stratabound are both used and are not necessarily synonymous. In Europe more emphasis is placed on the morphology or the ore body. Pelissonier (1972) classified copper deposits with the use of the terms; discordant (vein and multifissured), sub-concordant and concordant in relationship to the sedimenatary strata.

In addition to these morphological classifications, there are classifications based on genesis of the ore deposit. Lindgreed (1933), Scheinderhohn (1962), and Gustafson and Williams (1981) have all proposed genetic classification schemes.

For the purpose of simplification, the mineral occurrences of this study are classified on the basis of a) morphology, b) genetic character.

In addition, the author adopts the definition of diagnetic ore deposits proposed by Gustafson and Williams (1981) that is; diagentic ore mineralization results from the early concentration of substances contained within the rock or sedimentary basin.

Copper was mined from the time of first settlement of the Tatamagouche area until 1908. In 1905, Fletcher defined a copper belt during his mapping in the Tatamagouche area. In 1920, Merservey examined the old copper mines. Papenfus (1931) was the first to describe the copper mineralization in detail. Bancroft (1943) evaluated the copper occurrences, and established the possibility of renewed economic exploitation. Shumway (1951) described the mineralogy of the copper mineralization in the Tatamagouche area. Brummer (1958) determined that the origin of copper mineralization was a result of supergene enrichment. Duncan Range Iron Mines (1962) and Esso Minerals (1982) carried out a copper exploitation in the Tatagamouche area. Lacana (1977-1980) and Noranda (1977-1979) ran exploration programs for uranium in the study area. Bluestack (1984) carried out an exploration program for lead an silver along the southern margin of the study area.

In all, there are at least 40 potentially significant copper, silver, uranium mineral occurrences within the Tatamagouche syncline area (Fig. 32). (McNabb 1977; MacDonald 1978; Chatterjee 1979). One lead occurrence was recently discovered in channel lag sandstone boulders near Skinner's Cover (Ryan 1984) (Fig. 32).

Copper - Silver - Lead

The copper minerals comprise both malachite stains and thin encrusted layers of malachite around either chalcocite nodules or more rarely bornite. Papenfus (1931) demonstrated that the copper ore occured in three forms, 1) nodules and concretions of chalcocite and pyrite, 2) chalcocite as replacement of pre-existing cementing material in the sandstone and 3) chalcocite and pyrite associated with coalified plant material. Papenfus (1931) showed that the chalcocite nodules pseudomorphs after pyrite nodules and that many of the chalcocite nodules have a pyrite core (Shumway 1951).

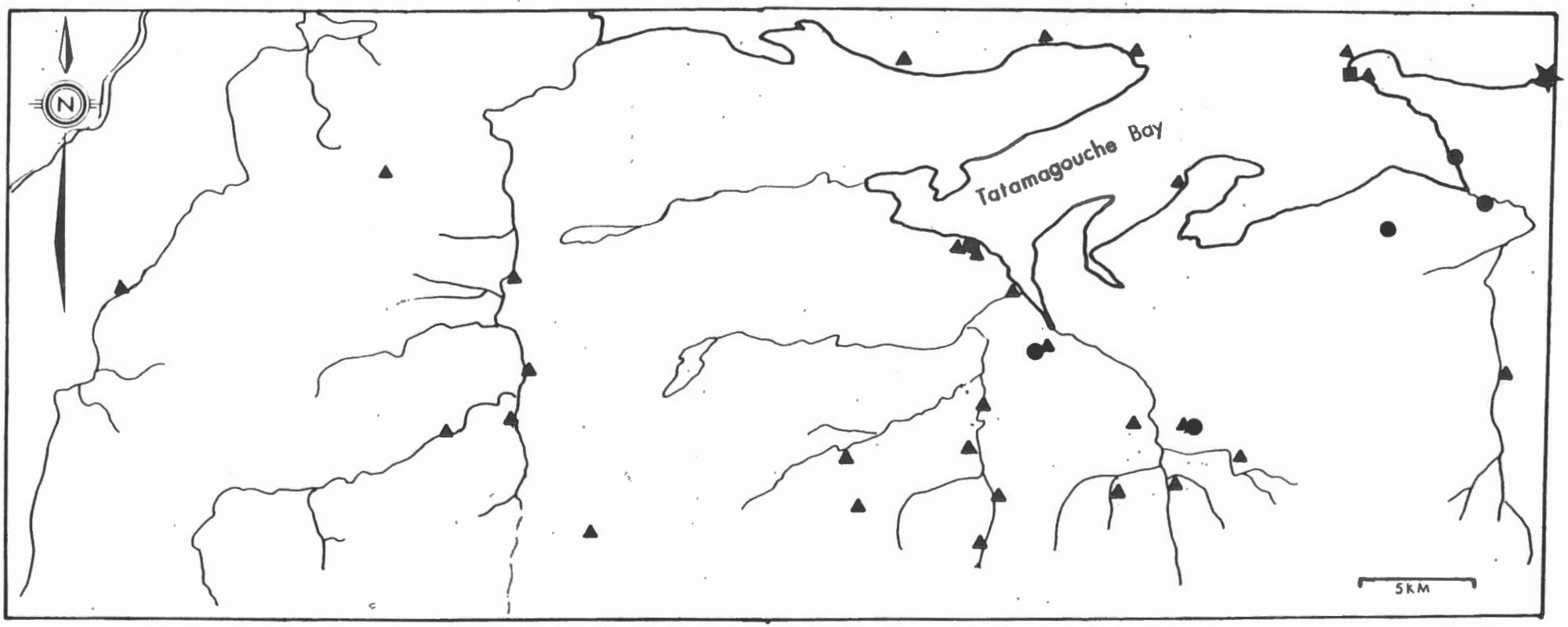


Figure 32: Metallic mineral occurrences in the Tatamagouche Syncline Area,Nova Scotia,(triangle = copper, star = lead, circles = uranium,square = manganese)

Where chalcocite and pyrite occur in association with carbonaceous matter, the pyrite originally occurred either as a coating in the coalified plant material, or botryoidal nodules, or as partial replacement of woody material. When copper is present, the pyrite is replaced to varying degress by chalcocite and bornite. Shumway (1951, Plate 3 and 4) shows outstanding examples of mineralized fossil-wood fragments still exhibiting the original cell structure in which the inner parts of the cells are filled with pyrite while the cell walls are replaced by chalcocite. Similar textures have been encountered during the present study, in which inner parts of the cells have been infilled by pyrite, covellite and digenite or, more rarely chalcocite (Fig. 33). Bornite (which is locally abundant) is replaced by chalcocite (Fig. 34) which in turn replaces pyrite, suggesting that the bornite mineralization predated the chalcocite mineralization.

Dunsmore (1977) suggested that the uranium and/or copper mineralization of the Carboniferous strata usually occurs at the base of finin gupward fluvial sequences, where most of the coalified plant material is concentrated.

This is an important consideration, because it means that the best mineral concentrations are most likely to be found by following the mineralized beds in the direction of the channel, which is not necessarily down dip. Most of the exploration carried out in the area has concentrated on down dip delineation of the mineral occurrence, and therefore have had limited success. Almost all of the mineral occurrences are associated with these carbon-rich channel lag sandstones which usually, although not everywhere, occur at the base of the fining upward fluvial sequences. Because the conglomerates and sandstones are part of a multilateral, multistoried channel sequence, the mineralized channel lags may also occur at various levels within the larger channel unit.

Brummer (1958) suggested that the chalcocite had formed as a result of supergene enrichment, and that its vertical extent had been restricted by the local ground water table. If this is true - it would seriously limit the potential for the formation of sizeable deposits. On the basis of more recent work, however, it became apparent that chalcocite (difficult to spot in the absence of malachite) occured in drill core to a depth of 100 metres, challenging the accuracy of the supergene enrichment interpretation.

Silver (native silver) appears to be co-genetic with the chalcocite mineralization, and occurs as thin encrustations on remnant pyrite crystals that are partially replaced by chalcocite.

Silver assays of up to 470 ppm have been obtained from the massive chalcocite. Silver is also associated with lead occurrences in the Boss Point Formation outside the study area. Limestone-chip conglomerates, which form the basal channel lags of the Boss Point Formation and are rich in coalified plant material, contain galena, and are probably the same age as the copper-silver occurrences of the Tatamagouche Area. The lead occurrences at Skinner's Cove, which occurs in the Pictou Middle Red Beds has only minor amounts of associated silver.

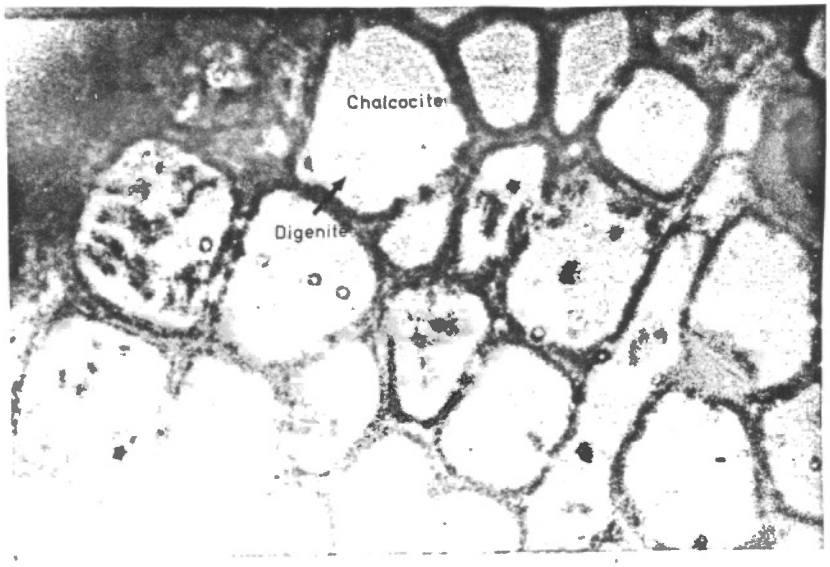


Figure 33: Mineralized fossil wood fragment,inner cell structure replaced by digenite and chalcocite, X 60, Oliver Copper Occurrence,Colchester County, Nova Scotia

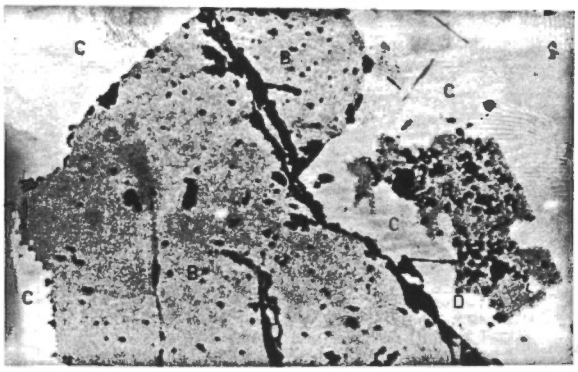


Figure 34: Chalcocite (light grey) replacing bornite (medium grey), Blockhouse Point Mineral occurrence, Colchester County, Nova Scotia.X 60

The origin of the economic minerals is not clearly understood. Their close association with coalified plant material clearly implies some genetic link between the presence of carbon and the metallic mineral occurrence. The plant material may provide a place for bacterial reduction, forming free sulfur within the channel lag sandstones. The underlying evaporites of the Windsor Group may also provide sulfur by bacterial sulfate reduction.

Stea (1984) noted a strong Pb within the tills anomaly trend east-west at a distance of 14-16 km north of the Cobequid Highlands.

This trend is also evident from whole rock geochemistry (Fig. 35) Table III. Stea (1984) suggests that the anomalies are related to elevated Pb-Cu values in the Carboniferous strata. Fletcher (1905) also postulated a copper-rich zone which runs parallel to the Cobequid Highlands. The whole rock geochemistry, which reflects these trends, further indicates that the mineralization within the Carboniferous strata of the Tatamagouche area may be zoned. The parameters controlling such a zonation are unclear, but perhaps they are related to the maximum upward mobility of basinal mineral-enriched solutions, during low temperatures diagenetic stratabound ore formation.

In addition to the chalcocite copper mineralization, there are abundant reduction spheres, with concentrations of copper and silver in the dark cores. The reduction spheres are most common in the Pictou red beds. They range in size from 1 to 10 cm in diameter. Poll and Sutherland (1976) found cuprite, native copper, silver, mercury (schachnerite) and vanadium in reduction sphere cores in the Mississippian Hopewell Group at Dorchester Cape, New Brunswick. In their study, no organic material was detected either in the cores, or in surrounding spheres. The reduction spheres may represent migration of minerals to local sites of chemical reduction during a diagenetic enrichment. Malachite copper occurrences also occur within the conglomerates of the Millsville Formation near Annandale. A 5 m mineralized section of ploymictic cobble to pebble orthoconglomerate was encountered in DDH-AN-4 drilled by Wyoming Minerals. There is no evidence of organic debris present in the conglomerates, and the origin of this mineralization is not clear. An assay of the mineralized sample yielded 0.46% Copper, 501 ppm Zn and 16 ppm Pb.

One copper occurrence is found within a Windsor Group limestone near Hansford. The copper occurs both as malachite encrustations on brachipod fossils, and as smears along bedding plane surfaces. The assay is 0.27% copper.

In the Donaldson,s Mill Brook mineral occurrence, chalcocite occurs as nodules up to 1 cm in diameter within medium grey silty shale. Chalcocite also occurs as replacement of coalified calamites stems. The assay of the coalified material at this locality was 42% copper, 470 ppm Ag, 165 ppm Zn and 858 ppm Pb.

Manganese

A Manganese occurrence is found near Cape John within a fault zone. The manganese occurs as massive, finely crystalline pyrolusite (Fig. 36.

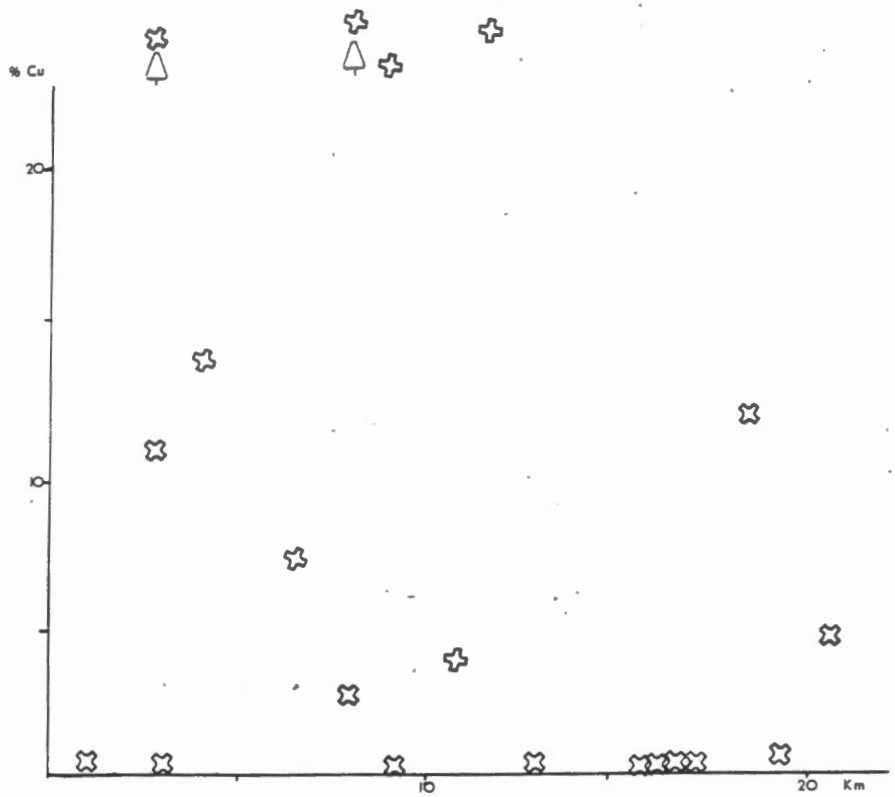


Figure 35a: Copper values versus distance from the Pre-Carboniferous Cobequid Highlands rocks.

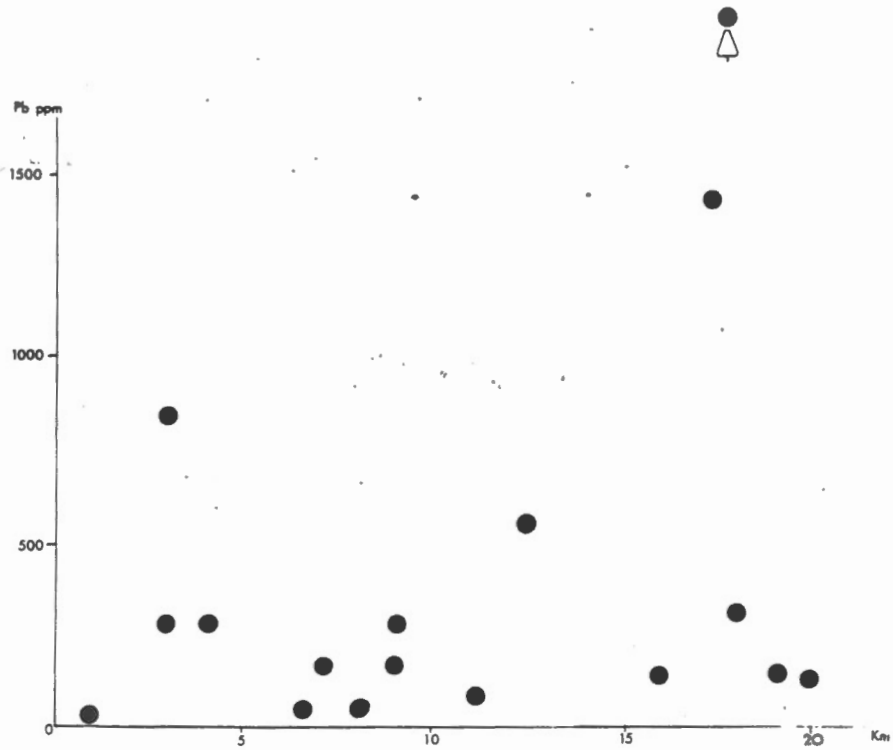


Figure 35b: Lead values versus the distance from Pre-Carboniferous rocks (grab samples of mineral occurrences)

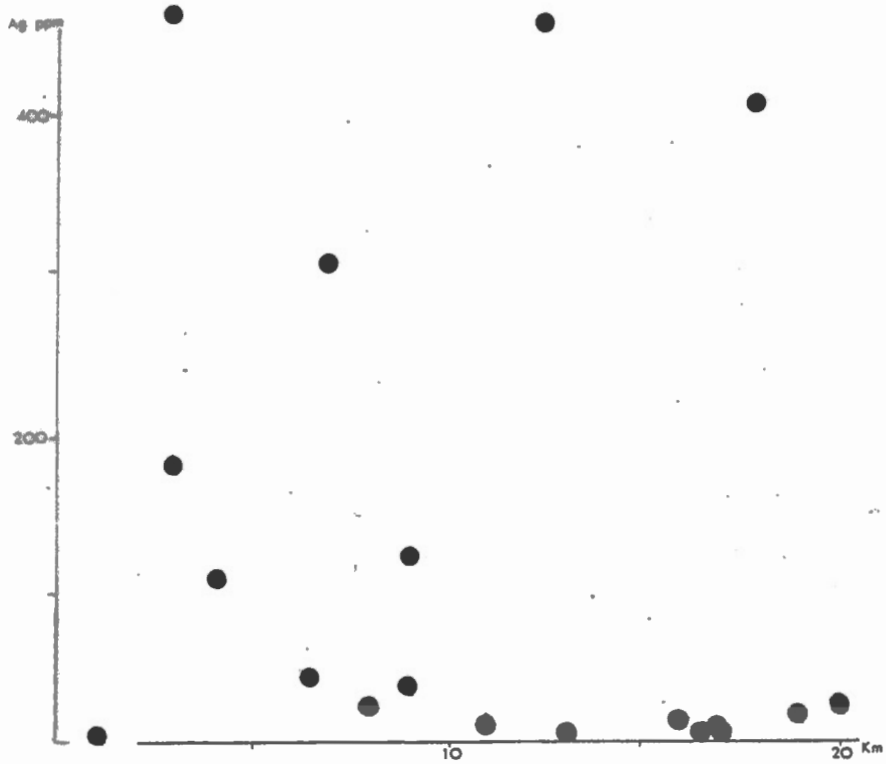


Figure 35c: Silver Values versus distance from the Pre-Carboniferous

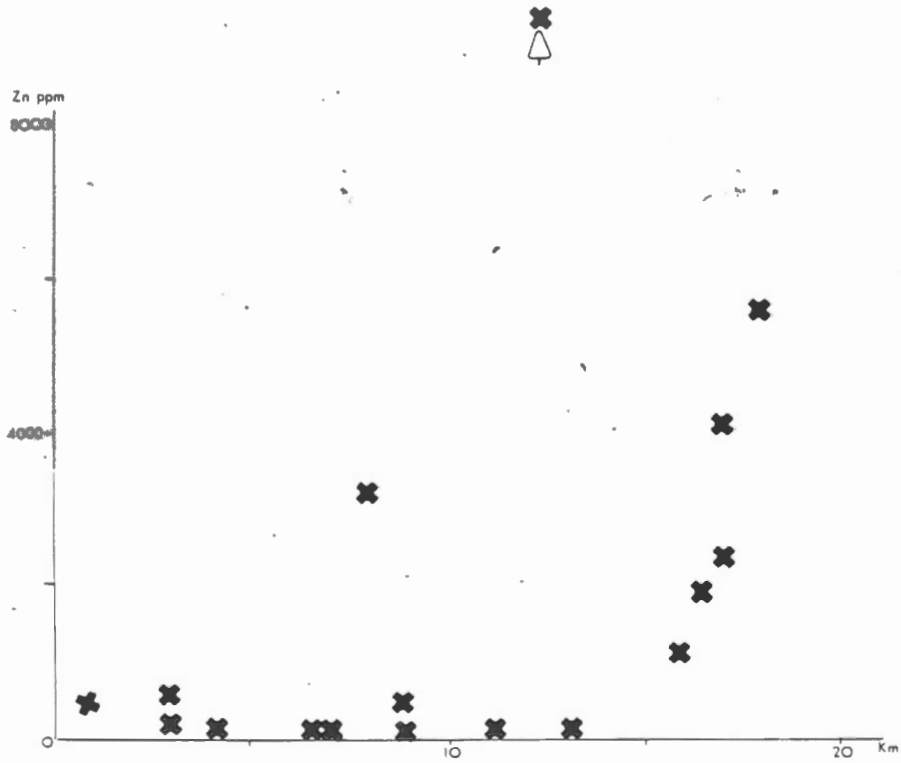


Figure 35d: Zinc versus distance from the Pre-Carboniferous rocks

Figure 36: Manganese mineralization associated with a strike slip fault, minor chalcocite mineralization in the channel sandstone on the left of the photo,Pictou Upper Red Beds, near Cape John, Pictou County, Nova Scotia.

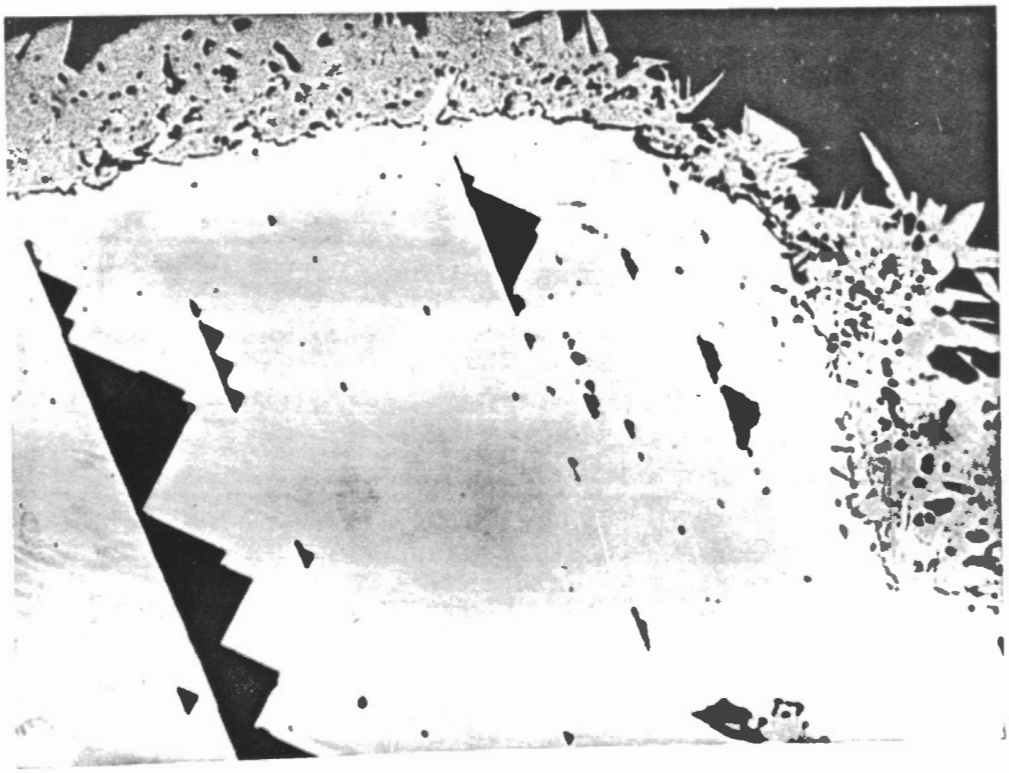


Figure 37: Galena,photomicrograph X60, Skinners Cove lead occurrence, east of River John, Pictou County, Nova Scotia

Barite

Barite occurs in minor amounts at several localities within the study zone. The barite usually occurs as thin smears on slicken side surfaces or replacing coalified plant material.

Uranium

The distribution of the uranium occurrences indicates that the uranium was deposited post-folding in two phases (McNabb 1979). The original uranium mineralization is the result of strataform low temperature subsurface epigenetic mineralization (trend type deposition). This uranium is found proximal to original plant debris within channel sandstones. Evidence of secondary migration of this uranium by small roll fronts has been preserved on the lateral margins of several channel sands (Fig. 39).

Dunsmore (1977) suggested that the uranium mineralizing fluids were derived from the underlying Windsor Group evaporites. During dewatering, (compaction) uranium-enriched conate brines would, in most cases, be expelled into the overlying Upper Carboniferous sandstones, shales and conglomerates. The uranium-enriched solutions would then migrate within the permeable sediments until they reached areas of chemical reduction. Dunsmore (1977b) also suggested that the uranium and copper may have been mobilized by the same aqueous solution. He noted no similarity to roll front deposits.

The randon and uranium trends in groundwater and in soil geochemisty, indicate that the movement of uranium-enriched fluids was from south to north. This direction of migration is not consistent with a Windsor Group source. If the uranium-enriched solutions were derived from the underlying Windsor Group, the grey carbon-rich sandstones of the Boss Point Formation or the Pictou Grey Beds would be the most proximal sites for chemical reduction. These units are rarely enriched in uranium.

If the source were to the south, the most likely contributor of uranium would be the uraniferous granites and felsic volcanics of the Harts Lake Pluton (Cobequid Highlands). This suggests that at the time of mineralization, the Boss Point Formation and Pictou Grey Beds were not accessable to the uranium-bearing solutions and the Pictou Red beds were the only permeable beds into which the solutions could migrate. The solutions migrated down "present day" dip, and precipitated uranium in the vicinity of coalified plant material within the channel lag sandstones. This uranium was then remoilized in some instances by hydraulic pressures into clean sandstones on the channel lateral margins (Fig. 40).

The textural relationships of the ore minerals indicate that the following order of mineralization is most probable for the Tatamagouche Syncline Area.

1) pyrite (oldest)
2) Bronite - trace chalcopyrite
3) Chalcocite, digenite, silver and galena?
4) Uranium (youngest)

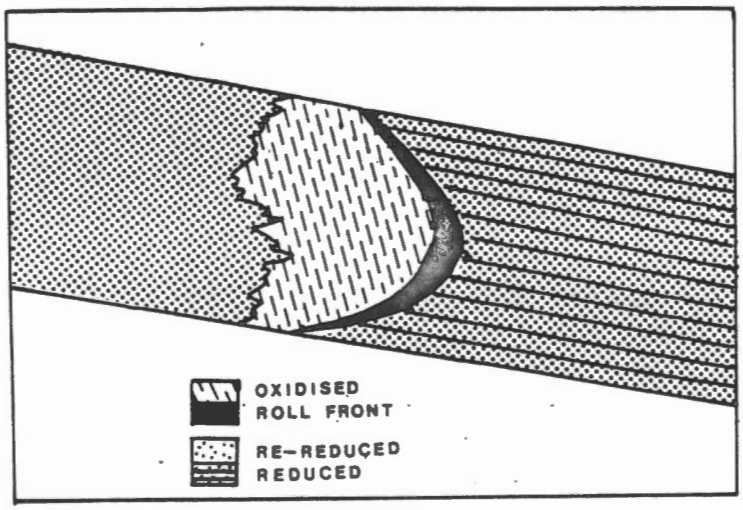


Figure 38: Reduction-oxidation front uranium mineralization model
(where the carbon is abundant tne sandstone is re-reduced)

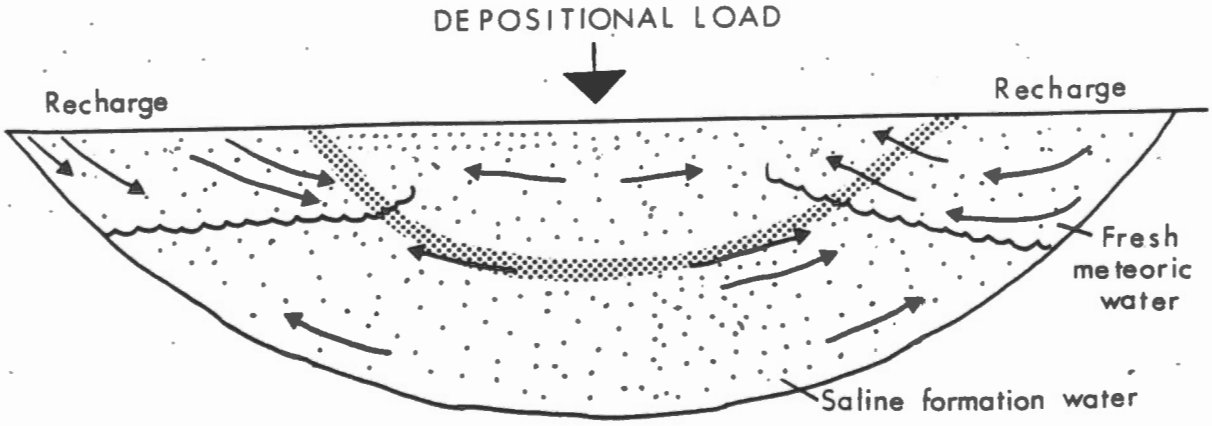
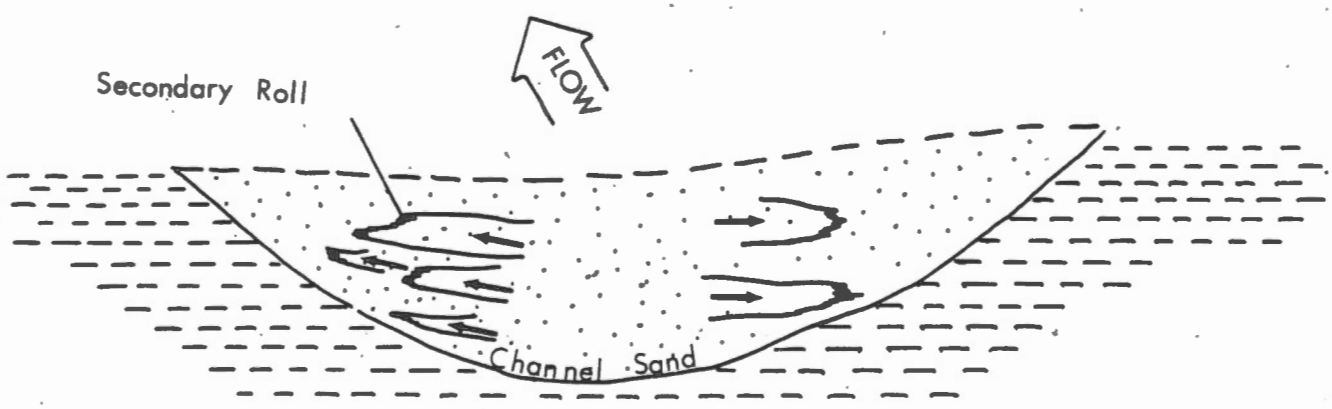


Figure 39: Groundwater flow within individual channel sandstone,
(or sedimentary basin) after Galloway et al,1979



Figuer 40: Secondary uranium roll fronts on lateral margins of channel sandstones, Tatamagouche syncline; Nova Scotia

The nature of the mineralizing processes within these continenatl red beds is clearly dependent upon the composition, texture and morphology of the sedimentary units. It is, therefore, essential that investigations for mineralization within similar geological settings require concurrent detailed studies of stratigraphy, structure and sedimentology, in order to formulate a comprehensive exploration model.

Table III

LOCALITY	NORTHING	EASTING	ppm Ag	ppm Pb	ppm Zn	% Cu
Gravois Pt	5071600	472500	26	144	5500	6.53
McLean Beach	5071500	471400	20	158	7500	1.16
Hansford	5063000	440700	<1	16	27	0.27
Wallace River	5057000	453000	107	288	40	13.1
Centre Wentworth	5058000	457000	15	72	45	4.8
Seafoam	5070000	502000	7	144	1700	0.61
Skinners Cove	5071000	497000	5	7460	2200	0.05
Chisholm-Wallace R.	5063000	457000	111	282	128	23.5
Blockhouse Pt.	5064900	457000	460	552	15000	26.0
Hole Brook	5060050	495005	39	46	43	7.5
Malagash Pt.	5072000	482000	401	316	5500	12.7
Oliver	5056500	475000	303	176	41	31.0
Miller Bk	5055100	475500	170	290	662	11.5
Woodlock Bk	5060500	478000	22	88	3200	2.5
Donaldson's Mill Bk	5054100	464100	470	858	165	42.4
Bailey Brook	5055000	481080	37	160	439	0.81
Brule-Pennensula Pt.	5074094	483080	<1	2	61	0.70
Cape John	5072000	490000	<1	2	4500	0.62
DDH-AN-4	5053000	467000	<1	16	501	0.46

Table III Analyses for grab samples from the Tatamagouche Syncline Area

CHAPTER 11

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

1. The Carboniferous strata can be divided into nine lithostratigraphic map units within the study area: (a) Windsor Grop - Visean, (b) Millsville Formation - Namurian, (c) Boss Point Formation - Westphalian A, (d) Cumberland Coarse Facies - Westphalian B, (e) Cumberland Fine Facies - Westphalian C, (f) Pictou Grey Beds - Westphalian C, (g) Pictou Lower Red Beds - Westphalian C-D, (h) Pictou Middle Red Beds - Westphalian D to Stephanian, (i) Pictou Upper Red Beds - Stephanian to Early Permian.

2. The "groups" within the Carboniferous strata were defined on the basis of time or biotic assemblage rather than lithology. The assumption of unconformities between each of the units is not consistent with field data. Within the study area lithologic definition of the Cumberland Fine Facies and the Pictou Grey Beds is difficult. These two units may represent only one distinct lithostratigraphic unit.

3. Uncomformities exist between the Pre-Carboniferous and the Millsville Formation, the Millsville and the Boss Point Formation, the Boss Point Formation and the Cumberland Group and/or the Pictou Grey Beds, the Cumberland Group or Pictou Grey Beds and the Pictou Lower Red Beds, and the Pictou Lower Red Beds and the Pictou Middle Red Beds.

4. The sediment dispersal trends within the study area are towards the north-northwest which compares to a northeasterly trend for the rest of the Carboniferous Basins in the Maritime Provinces.

5. Paleocurrent patterns are unimodal except where measurements are taken proximal to areas of Windsor Group evaporite diapirism. The dispersal away from areas of diapirism appears to occur at different times within the study area. The paleocurrent data suggest that the synclines and aniclines of the area result from syndepositional evaporite mobility. The dispersal away from areas of diapirism suggests that diapirism migrated through time from west to east.

6. With the exception of the shallow marine evaporites and carbonates of the Windsor Group, the remainder of the Carboniferous strata of the area are predominantly fluvial-continental in origin.

7. Laterally continuous thin (0.5-3.0 m) lacustrine limestones facilitate correlation of the Pictou Red Beds.

8. The Millsville Formation boulder to pebble conglomerates represent deposition in proximal alluvial fan environment.

9. The Boss Point Formation sandstones, siltstones and mudstones were deposited in a meandering stream environment.

10. The Cumberland Coarse Facies conglomerates and sandstones appear to have been depostied in braided streams within the mid to distal alluvial fan environment.

11. The Cumberland Fine Facies and the Pictou Grey Beds sandstones, siltstones and mudstones were deposited by low sinousity meandering streams.

12. The Pictou Red Beds sandstones and mudstones appear to have been deposited in low sinuosity anastomising streams.

13. The paleontology suggests that there was no significant paleoclimatic change associated with the younger beds. The red colouration of the younger beds may be the result of carbon depletion and aeration due to extensive bioturbation.

14. There are numerous occurrences of copper, silver, lead, zinc and uranium within the Tatamagouche area.

15. The metallic mineral occurrences are closely linked to the presence of coalified plant material within the conglomerates and sandstones in the channel lags. Exploration must therefore be carried out down channel and not down dip from the mineral occurrences. Paleocurrent analysis is therefore essential to any exploration model in the Tatamagouche Syncline area.

16. Silver values up to 470 ppm are associated with copper (chalcocite) mineralization.

17. The copper occurrences are the most abundant metallic mineral occurrence in the area. The chalcocite does not appear to have been significantly supergene enriched. Chalcocite has been reported as the primary copper ore at depth in core. The copper mineralization is low temperature, diagenetic and stratbound.

18. Uranium occurrences may occur away from coalified plant material on the lateral flanks of channel sandstone units. This suggests that the uranium may have undergone secondary mobilization due to hydraulic groundwater movement within the channel sandstones. The uranium mineralization appears to be low temperature (below 200°C), epigenetic and stratbound.

19. The timing of the mineralization within the study area has the following relationship: pyrite → bornite → chalcocite → uranium.

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