STRATIGRAPHY OF TWO LATE PALEOZOIC BASINS:
IMPLICATIONS FOR THE TIMING OF FINAL EMPLACEMENT OF THE MEGUMA TERRANE

By

Scott J. Mooney ©

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ABSTRACT

Paleomagnetic studies indicate the Meguma terrane's final emplacement occurred between the Mid-Devonian and Early Permian. Lithostratigraphic units near the boundary of the terrane were investigated in order to provide constraints on the timing of this compressional event.

North of the Cobequid-Chedabucto Fault (Guysborough Basin), volcanic flows, pyroclastics and related sediments are overlain by gravelly to sandy braided fluvial and lacustrine lithofacies. East-southeast paleocurrents and variable (non-Meguma) clast lithologies are typical of these units. South of the Cobequid-Chedabucto Fault (St. Mary's Basin), coarse cobble - rich to sandy braided fluvial lithofacies are dominant. Paleocurrents indicate flow to the north and clast lithologies are representative of the Meguma terrane.

Post Acadian (Late Devonian) basement fragmentation and associated volcanism modified the area north of the Cobequid-Chedabucto Fault. Basement block rotation, east end down, initiated Latest Devonian through Mid-Carboniferous sedimentation in a transtensile tectonic environment. There

is no lithostratigraphic evidence to suggest the presence of the Meguma terrane immediately south of the Guysborough Basin during this time interval. However, the Meguma terrane was supplying sediment to the St. Mary's Basin by the Early Carboniferous. Collision and wrench faulting probably initiated formation of this basin in a transtensile tectonic environment. Subsequent dextral displacement along the Cobequid-Chedabucto Fault and transpressive tectonic conditions resulted in the removal of slices of both the St. Mary's and Guysborough Basins as these two distinct assemblages were juxtaposed.

CHAPTER 1

INTRODUCTION

Purpose Of The Study

The Meguma terrane of southern Nova Scotia has long been recognized as a displaced assemblage, foreign to North America (Schenk, 1980). It lies in fault contact with rocks of the Avalon terrane to the north, which is also foreign to the North American continent. No paleomagnetic data have been generated which directly indicate the time at which the Meguma terrane came to occupy its present position though several workers have investigated rocks of the Avalon terrane. Studies in the late 1970's postulated large-scale sinistral motion with suggested accretion times for the Avalonian microcontinent ranging from Late Devonian (Morris, 1976), to Mid-Carboniferous (Kent and Opdyke, 1978, 1979), to early Permian (Dihl and Shive, 1981).

More recent work has called this hypothesis into question on the basis of sampling technique and the lack of field evidence for large scale sinistral displacement (Roy and Morris, 1983, 1985; Irving and Strong, 1985). The hypothesis was subsequently retracted by Kent and Opdyke (1985).

The purpose of this thesis is to examine the relationship between tectonics and sedimentation near a major terrane boundary. The mode of basin formation will be established and lithostratigraphic constraints will be provided for the time of final emplacement of the Meguma terrane.

Methodology

The emplacement of the Meguma block involved compressive forces within a transcurrent fault zone, probably related to oblique collision and suturing between supercontinents (Dewey and Burke, 1973). Highlands formed as a result of the collision between the Meguma and Avalon terranes would be expected to shed coarse detritus into adjacent lowlands. The Meguma terrane is lithologically distinct from the Avalon in that it is composed predominantly of green sandstones and black shales, believed to represent deposition on a submarine fan complex (Schenk, 1980). The occurrence of Meguma-type clasts in coarse clastic sediments on Avalonian basement would provide a minimum age at which the Meguma terrane arrived at its present position.

This study uses integrated basin analysis to shed light on the regional tectonic problem. Identification of distinct lithostratigraphic units with their characteristic depositional environments, examination of clast lithologies in coarse clastic sediments, and determination of the paleocurrent directions within each major unit, are combined to provide a paleogeographic reconstruction through time for the study area.

Distinct depositional systems in the study area were delineated and identified by an informal lithostratigraphic formation name, following the method adopted by Smith (1980). This approach was deemed necessary due to the inherent difficulty in correlation of small basins with Horton Group type localities in the Appalachian Orogen.

Field work was conducted during the summer of 1986. Most of the outcrop in the study area was found in stream and coastal exposures. Various types of information was collected through the course of the field season, each of which contributed to the characterization of lithostratigraphic units and ultimately to basin evolution models. Lithologies and the relative amounts of fine versus coarse sediment along each section were recorded. Representative sections for each interpreted environment of deposition were measured and described as the basic unit of the larger depositional system.

In addition to the lithologic description, sand/shale ratios were calculated for preferred sections through each formation. The most complete section(s) available were utilized for this calculation to minimize the effects of recessive fine grained lithologies. The true thickness of conglomerate, sandstone and shale (+ siltstone) exposures were determined and totalled, respectively, for arbitrary portions of a generally incomplete section. The percentage of each lithology was subsequently calculated. Data is depicted in the form of percentage lithology versus the mid-point of the portion of stratigraphic column utilized to generate the raw data. Ratios of fine to coarse sediment, and coarse to fine sediment illustrate fining and coarsening trends through the formation. Clastic ratios were calculated and used to depict the variation of clastic and chemical sediments through a formation. Finally, entropy was calculated for each data point as a measure of the dominance of a particular lithology through the succession. Entropy is defined as the degree of mixing of three or more components which sum one hundred per cent (Potter and Pettijohn, 1963). Pelto (1954) defined relative entropy as

$$H_r = -100\left(\sum_{i=1}^{n} p_n \ \ln p_n\right)/H_m$$

where p = the proportion of the nth component expressed as a decimal,

n = the number of components, and

H_m = maximum entropy, defined as $-\ln\frac{1}{n} = \ln n$

According to these equations, if all components are present in equal amounts, relative entropy is a maximum value of 100%. If one component is dominant, relative entropy is low. Calculated values are presented in graph form for comparative purposes.

Pebble counts were collected at every available site in the section. A wire mesh was used to ensure a random sample of the unit counted. Fifty pebbles occurring at regular mesh intersections were identified and tabulated to determine the percentage of various clast types in the conglomerates. Information regarding provenance and unroofing trends in the source area were derived from this data. Histograms representing sequential points through a section are utilized to depict observed trends. Per cent clast lithology diagrams were constructed to show depositional patterns for the St. Mary's Basin.

Paleocurrents were measured in all formations except the basal unit, in which volcanics dominate. A total of 896 paleocurrent measurements were collected from such unidirectional indicators as ripple cross lamination, trough cross stratification, planar cross stratification, and bidirectional indicators such as oscillation ripple lamination, plant fragment elongation, scour marks, and tool marks. These data provided information regarding the dominant direction of flow for current systems which deposited sediment now exposed in the study area. The five largest clasts in conglomeratic units were measured, averaged and plotted to indicate down current fining trends in the St. Mary's Basin.

Location

The study area is located in northeastern mainland Nova Scotia, in the townships of Guysborough, Antigonish, and Pictou (Figure 1). It is bounded to the east by the Strait of Canso and Chedabucto Bay, to the south by the Salmon and St. Mary's Rivers, and to the west by Barren Brook. No major centres are located in the study area though numerous villages are present throughout. Highways 7, 16, 344 and 316 cross the study area. This area was chosen due to its proximity to the Cobequid-Chedabucto Fault, the major terrane boundary. Stream and coastal exposure was thought to be adequate for the type of work to be performed in the area.

Access

Most of the study area is accessible by paved and secondary gravel roads to variable extent. Numerous logging roads and cart tracks are locally useful. It is noteworthy that although general access is reasonable, access to several streams in the study area is limited.

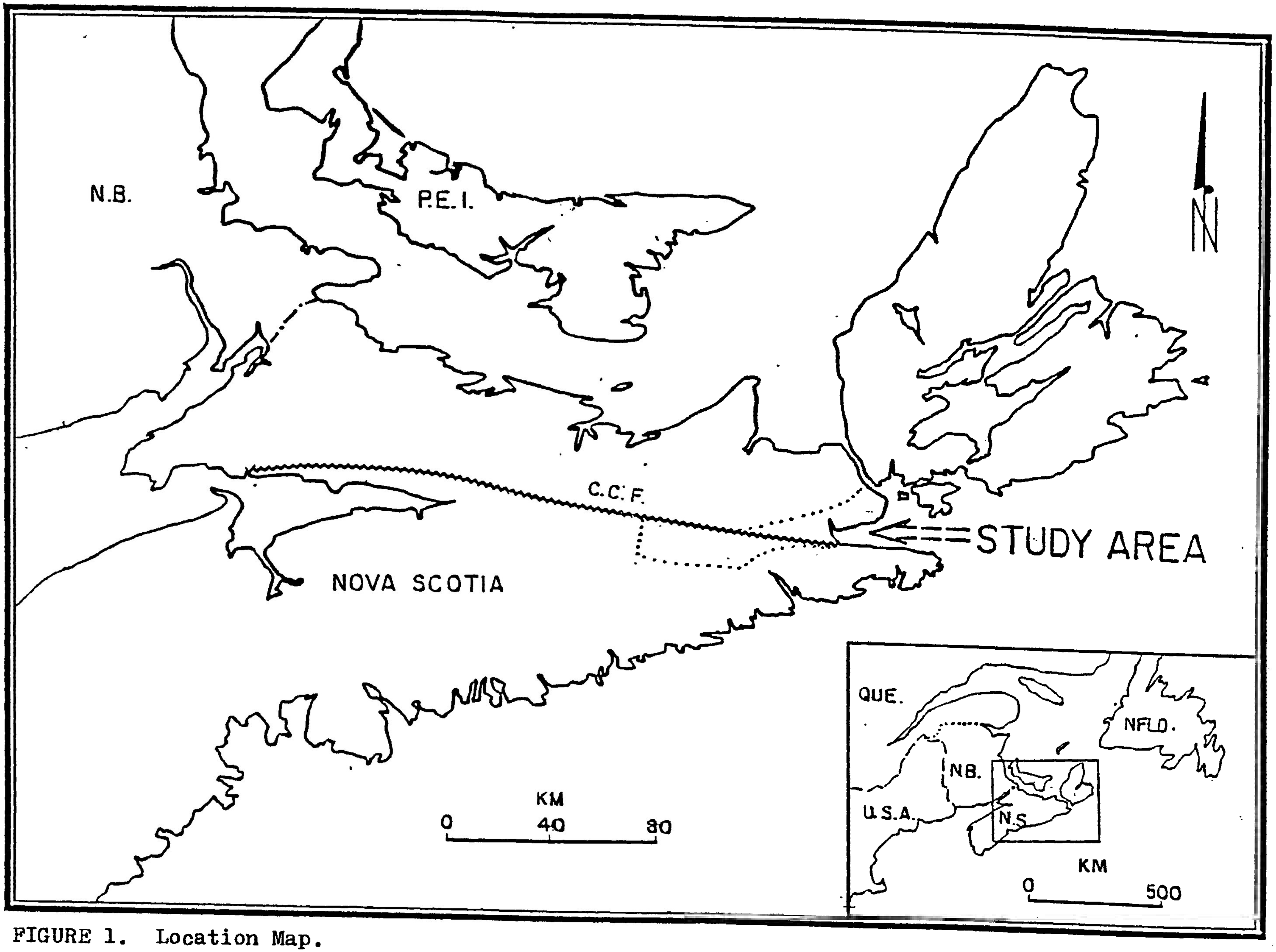


FIGURE 1. Location Map.

Physiography

North of the Cobequid-Chedabucto Fault, topography is generally rolling with highlands and lowlands exhibiting moderate relief. No obvious relationship is evident between topographic expression and underlying lithologies. Streams are gravel bottomed, are of variable width and depth, and have often formed stream valleys up to tens of metres deep along their course. Stream valleys are steep and densely vegetated. Consequently, walking the stream bed is often significantly less arduous than following the stream banks. South of the fault, relief is generally low, streams are sand to cobble bottomed and have only formed a significant stream valley close to the south boundary of the basin. Many stream outcrops are partially or wholly submerged, particularly after a rainfall.

Previous Work

The study area has not received a great deal of attention in the past. H. Fletcher of the Geological Survey of Canada first mapped the area between 1882 and 1886. The Devono-

Carboniferous strata recognized in the area are summarized below (Fletcher, 1886):

Carboniferous:	Millstone Grit
	Carboniferous Conglomerate
	Carboniferous Limestone
Devonian:	Upper Red Slate and Sandstone Group
	Middle Gray Slate
	Lower Conglomerate

Latest Devonian volcanic rocks were identified by Fletcher (1886) as the base of the exposed succession in the Guysborough area. The Lower Conglomerate is described as red with clasts of the underlying volcanics This author attributes most of the exposures north of the Cobequid-Chedabucto Fault to Devonian sedimentation.

The Guysborough area was the subject of a Ph.D. project by E. A. Schiller (1963). Volcanic rocks were recognized to constitute the base of the succession and overlying clastic rocks were interpreted to represent Horton Group equivalents. Correlation with the Horton Group type locality was not

Table 1 - Previous Work

		Fletcher, (1886)	Schiller (1963)	Smith (1980, 1981)	This Study Guysborough Basin	 St. Mary's Basin
	270					
CARBONIFEROUS	290					
	310					
		Millstone Grit		CANSO GROUP Hadley Cove Fm.	CANSO GROUP Eddy Point Fm.	
	330	Carboniferous Limestone	HORTON GROUP Ainslie Fm.	WINDSOR GROUP HORTON GROUP	HORTON GROUP Brandy Brook Fm. Minister Brook Fm.	HORTON GROUP Gunns Brook Fm.
				Tracadie Road Fm.		
	350	Carboniferous Conglomerate	Strathlorne Fm.	Clam Harbour River Fm.	St. Francis Harbour River Fm. Tower Fm.	
DEVONIAN	370	Upper Red Slate/ Sandstone Group	Craignish Fm.	St. Francis Harbour Fm.	Sunnyville Fm.	
		Middle Gray Slate				
	390	Lower Conglomerate		Glenkeen Fm.		
				Volcanics		
	410					

possible. However, Murray's (1960) subdivision of the Horton Group into lower Craignish, middle Strathlorne and upper Ainslie Formations was adopted for the study (refer to Table 1).

Amygdaloidal and porphyritic andesitic flows with subordinate tuff, agglomerate and intercalated fine grained red siltstones in the Guysborough area were referred to by Schiller (1963) as the Black Settlement Formation. The unit is predominantly red to maroon and conformably underlies Horton Group sediments. Although uncertain, Schiller (1963) suggested a Middle Devonian to Early Mississippian age based on contact relationships.

The Craignish Formation consists of red conglomerate with subordinate red hematitic wacke and siltstones. Conglomerate was described by Schiller (1963) as immature, poorly sorted and polymictic, with clasts of metaquartzite, orthoquartzites, impure siltites and quartzites, granite, vein quartz, chert, felsic to intermediate volcanics, laminated siltstones and argillites and mica. Metaquartzite clasts and mica were attributed to a Meguma source terrane. Wackes and siltstones were also described by Schiller (1963) as immature, poorly sorted and very hematitic. The Craignish Formation was observed to both conformably and disconformably underlie the Strathlorne Formation.

No fossil fauna or flora were identified from the Craignish Formation by Schiller (1963) but a Lower Mississippian age was proposed for the unit based on contact relationships in the study area. Schiller cautioned, however, that the Formation may be partially or entirely of Late Devonian age.

The Strathlorne Formation was described by Schiller (1963) as the predominant unit in the area. It consists of gray to green argillite, siltstone, sandstone with minor conglomerate, argillaceous limestone and bedded chert. Conglomerates were observed to be largely oligomictic, with rare clasts of chert, quartz, and volcanics. Fine to medium grained clastic sediments were observed to contain poorly preserved carbonized vegetable matter and spores, and the chemical sediments were termed laminated to thinly bedded calcisiltites (Schiller, 1963). The contact between the Strathlorne Formation and the overlying Ainslie Formation was described as both transitional and conformable.

The Strathlorne Formation yielded fossil fauna and flora which substantiated an Early Mississippian age.

Red siltstone, shale with minor sandstone were referred to as the Ainslie Formation by Schiller (1963). Conglomerates were notably absent (Schiller, 1963).

The total thickness of the Horton Group in Schiller's study area was determined to be 9,000 feet (2,743 metres).

P. Smith (1980, 1981) was the first to attempt to subdivide previously unsubdivided Horton Group strata in the Guysborough area. The relative ages for each formation were based on fossil evidence when possible combined with observed and inferred contact relationships. Smith's (1980, 1981) Horton Group stratigraphy in the Guysborough area is briefly discussed below and is summarized in Table 1.

The Devono-Carboniferous Glenkeen Formation is composed of predominant purple to gray polymictic conglomerate interpreted to represent a piedmont deposit (Smith, 1980, 1981). The formation is estimated to be 2,000 metres thick (Smith, 1980, 1981).

The Devono-Carboniferous St. Francis River Formation is characterized by gray sandstone with gray polymict conglomerate and blue-gray siltstone interpreted by Smith (1981) to represent deposition in a fluvial environment. Smith (1981) proposed a total thickness of 670 metres for the formation.

The Devono-Carboniferous Clam Harbour River Formation is characterized by interbedded thinly laminated dolomitic limestone and gray-green siltstone interpreted by Smith (1980, 1981) to represent a fluvio-lacustrine environment of deposition. The stratigraphic thickness of the unit is estimated by Smith (1980, 1981) to be 1,300 metres.

The Devono-Carboniferous Tracadie Road Formation is composed of shale, siltstone, sandstone and conglomerate interpreted by Smith (1980, 1981) to have been deposited in a fluvial environment. The formation is estimated to be 6,000 metres thick.

The ?Devono-Carboniferous Hadley Cove Formation consists thinly bedded dark gray shales and limy siltstones overlain by green, brown and mauve arenaceous siltstones interpreted by

Smith (1980) to represent deltaic sedimentation. Smith (1980) determined the maximum thickness to be 875 metres.

Smith (1980) estimated the Horton Group to be approximately 6,000 metres thick in the immediate Guysborough area.

CHAPTER 2

REGIONAL GEOLOGY AND TECTONIC FRAMEWORK

Regional Geology

General evolution of the Appalachian Orogen from Precambrian through Paleozoic time involved the formation and subsequent destruction of the Iapetus ocean. Recent studies have looked upon the orogen as a collection of suspect or displaced terranes outboard of cratonic North America which are internally homogeneous but distinct in terms of their stratigraphy, structure, metamorphic and plutonic history, fauna, mineral deposits, and paleomagnetic signature (Williams and Hatcher, 1982, 1983).

Several efforts have been made to distinguish tectonostratigraphic zones in the Appalachian Orogen (Poole, 1967, Belt, 1968, Williams, 1978, 1979, 1984). Five major terranes are identified, though several sub-terranes divisible on the basis of uncertain paleogeography are known. Various schemes are locally useful but correlation is difficult away from the type locality and there is some controversy as to the relative width of each major tectonostratigraphic zone (Schenk, 1978). Outward from the miogeocline, the five zones include the Piedmont, Dunnage, Gander, Avalon, and Meguma terranes (Williams, 1978, 1979). Figure 2 shows the distribution of these zones and the location of major faults in and proximal to the study area. Rocks of the latter two terranes are exposed in the Province of Nova Scotia and are treated in more detail below.

The Avalon Terrane

The Avalon terrane comprises calc alkalic and tholeiitic volcanics (Papezik, 1980) and sedimentary rocks typical of ophiolite melange (Rast and Skeehan, 1983) which are mainly of late Precambrian age. These rocks have generally suffered little deformation and are weakly metamorphosed (Williams and Hatcher, 1982). Further, they were not affected by the Ordovician Taconic Orogeny. Based on this and other evidence, it has been postulated that the Avalon terrane was accreted before Mid-Paleozoic time. Williams and Hatcher (1982) describe faulted terrane boundaries and steep mylonite zones which they interpret to suggest emplacement of the terrane along transcurrent faults.

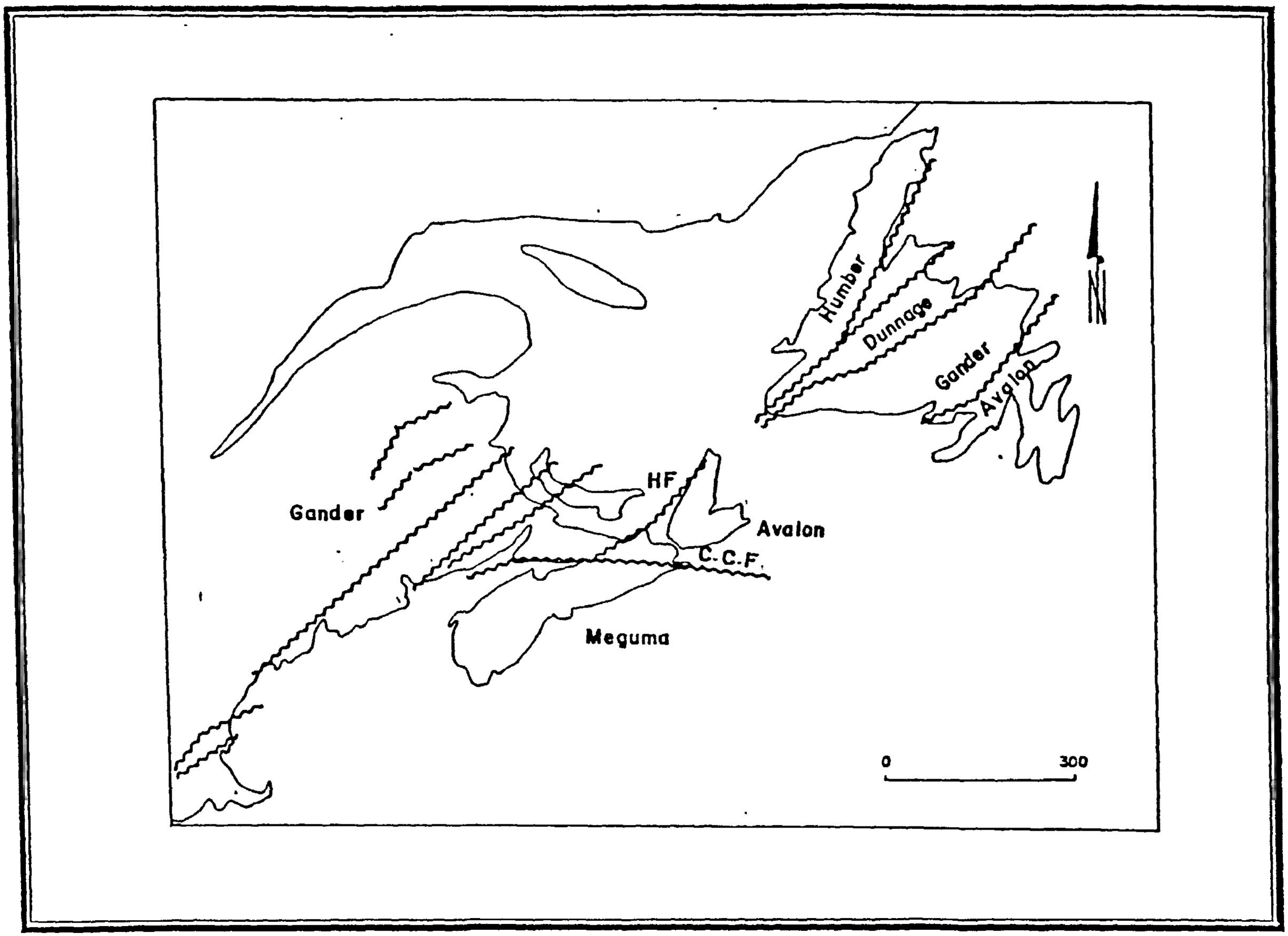


FIGURE 2. Terranes and major faults in the northern Appalachians. C.C.F. and H.F. represent the Cobequid-Chedabucto Fault and the Hollow Fault, respectively (modified after Williams and Hatcher, 1982).

The Meguma Terrane

The Meguma terrane is predominantly composed of two conformable and intercalated formations believed to be of Cambro-Ordovician age (Schenk, 1980). The lower Goldenville Formation is composed predominantly of quartz metawackes and the upper Halifax Formation is composed predominantly of black to dark green slates and thin metasiltstones (Schenk, 1980). The assemblage is interpreted by Schenk (1970, 1980) to represent a deep sea fan complex gradational to slope and outer shelf environments of deposition. Country rocks have been deformed by the Acadian Orogeny and are cut by Devonian intrusions (Clarke et al., 1980). Williams and Hatcher (1982) noted that Carboniferous deformation is only evident close to the boundary with the Avalon zone to the north. Steep fault contacts at the terrane boundaries are taken to imply emplacement by transcurrent faulting (Williams and Hatcher, 1982).

General Geology

The study area lies within the Maritimes Carboniferous Basin System (Figure 3), which formed as a result of basement

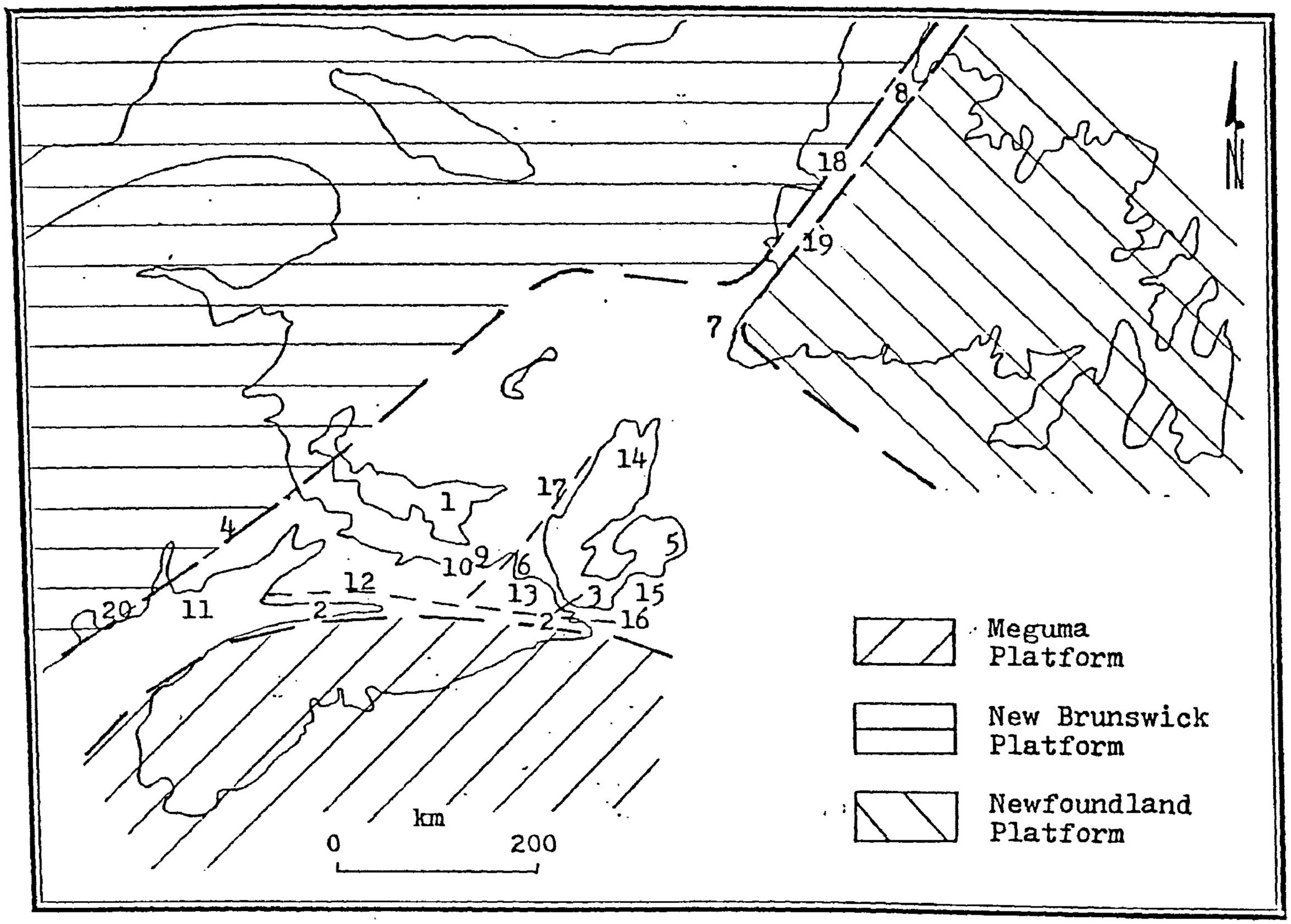


FIGURE 3. The Maritimes Carboniferous Basin System. Basins: 1) Cumberland; 2) Minas-St. Mary's; 3) Guysborough; 4) Moncton; 5) Sydney; 6) Antigonish; 7) Southwestern; 8) North-Central; 9) Merigomish; 10) Stellarton. Massifs: 11) Caledonia; 12) Cobequid; 13) Browns Mountain; 14) Cape Breton Highlands; 15) Louisburg. Faults: 16) Cobequid-Chedabucto; 17) Hollow; 18) Taylors Brook; 19) Long Range; 20) Bellisle. (Modified after Howie and Barss, 1975; Belt, 1968; and Fralick, 1980).

fragmentation subsequent to the Mid-Devonian Acadian Orogeny (Belt, 1968; Schenk, 1969; Fralick and Schenk, 1981; Bradley, 1982). This basin system is bounded by the New Brunswick Platform to the north, by the Newfoundland Platform to the northeast, and by the Meguma Platform to the south. Basin formation and subsequent evolution was controlled by periodic adjustment along wrench faults (Webb, 1969). Early volcanism and subsequent sedimentation is therefore largely controlled by and directly related to tectonism in this structural environment (Bradley, 1982). Local source areas supplied voluminous amounts of detritus which produced thick accumulations of terrestrial to shallow-marine sediment, within which rapid facies changes and unconformable contacts are common.

The general Devono-Carboniferous geology of northeastern Nova Scotia is presented as a stratigraphic column in Figure 4. Volcanic rocks occur at the base of the succession considered here. Coarse and fine clastic alluvial sediments of the Horton Group were deposited near basin margins as volcanic activity waned (Murray, 1960). The incursion of the Windsor sea marked the end of Horton Group sedimentation. It resulted in the deposition of intercalated chemical and red clastic

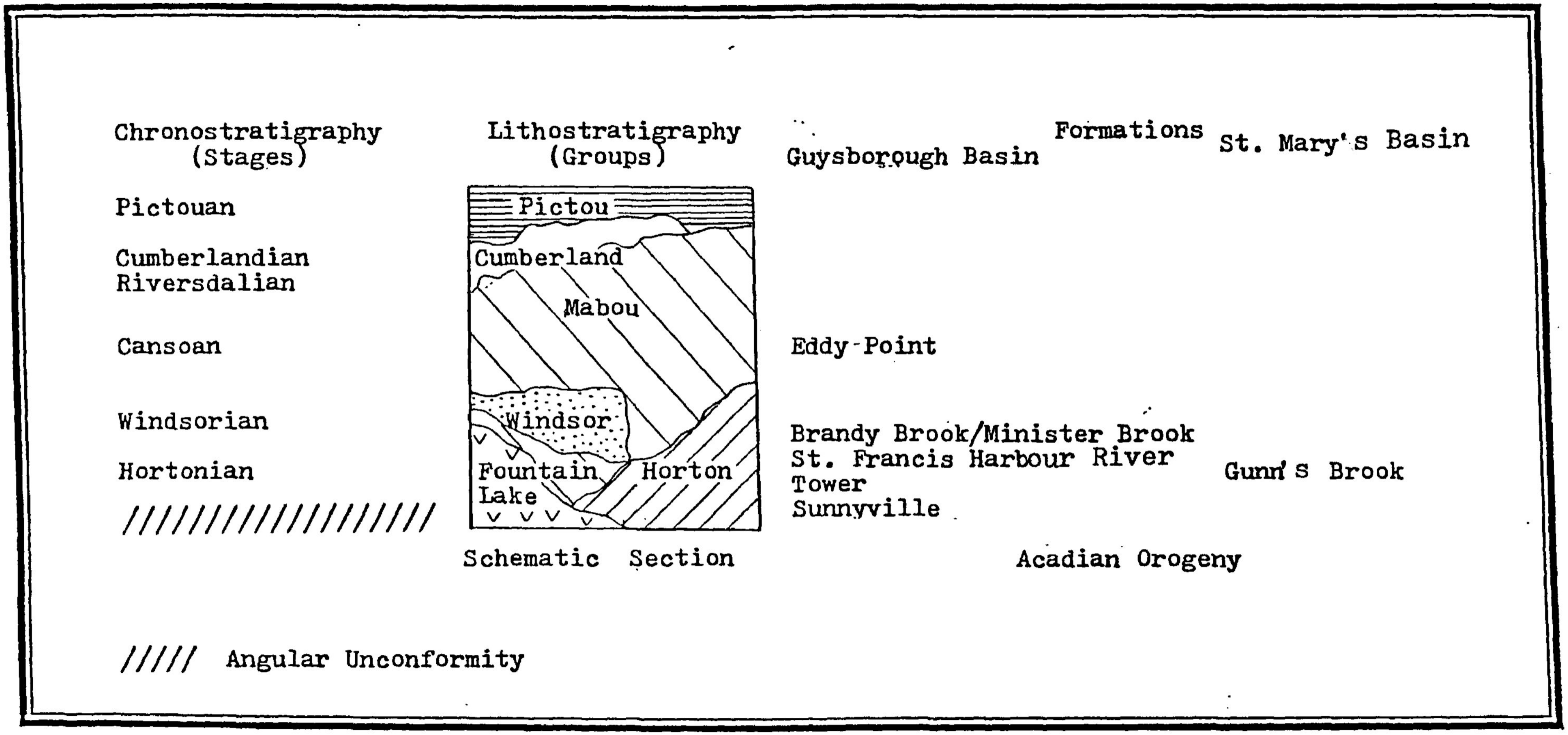


FIGURE 4. General Devono - Carboniferous stratigraphy of northeastern mainland Nova Scotia. No Windsorian strata were described from the study area (modified after Fralick, 1980).

sediments over a time period which may have lasted as little as four million years (Mamet, 1970). Fluvial-deltaic or lacustrine sediments characterize the Middle to Late Carboniferous Mabou Group (Belt, 1965). A regional unconformity separates the upper Mabou Group from overlying coarse fluvial sediments of the Pictou Group. By this time, basin subsidence was insufficient for the Maritimes Carboniferous Basin to accommodate sediment supply and onlap onto the surrounding platforms occurred (Belt, 1968). The youngest rocks of the Maritimes Carboniferous Basin are Pictou Group sediments exposed on Prince Edward Island (Prest, 1972).

Paleomagnetic Evidence

Paleomagnetic studies have generated considerable controversy about the latter stages of formation of the Appalachian Orogen. The interpretations which attracted most widespread criticism advocated large scale (2,000 kilometres) sinistral displacement of Avalonia relative to cratonic North America which culminated in final accretion times ranging from the Mid-Devonian (Morris, 1976), to Mid-Carboniferous (Kent and Opdyke, 1978, 1979) to the Early Permian (Dihl and Shive, 1981). In addition to the lack of suitable faults for any large scale transcurrent motion and the scarcity of field evidence for such displacement, the data upon which the interpretation was based has been questioned by several authors (Roy et al., 1983; Seguin and Fyffe, 1983, 1986; Irving and Strong, 1985). Roy et al. (1983) charged that pole ages had been equated with rock ages without clear proof of this relationship. Seguin and Fyffe (1983, 1986) conducted studies which indicated no appreciable discrepancy between poles from cratonic North America and the Avalon terrane. Finally, Irving and Strong (1985) criticized Kent and Opdyke's choice of sample sites and consider their data and interpretations invalid.

Paleomagnetic studies are fraught with difficulty in regions which have suffered extensive deformation, such as the Appalachian Orogen. Though large scale fault motions are not supported by other data, dextral transcurrent fault displacements on a smaller scale may be indicated and are known to have occurred on some faults in the area, including the Cobequid-Chedabucto Fault (Webb, 1969; Eisbacher, 1967, 1969; Donohoe and Wallace, 1978; Keppie, 1982; White, 1983; Mawer and White, 1987). Furthermore, terranes north and south of the Cobequid-Chedabucto Fault possess markedly different plutonic histories according to Clarke et al. (1980). They suggest relative displacement of hundreds of kilometres to account for the weak intrusive correlation across this fault.

Tectonic Framework - Summary

The study area straddles the contact between two of the five main tectonostratigraphic zones described by Williams and Hatcher (1982). Further, faulted terrane boundaries and steep mylonite zones have been interpreted to suggest emplacement along transcurrent faults (Williams and Hatcher, 1982). In the study area, the Avalon Microcontinent to the north and the Meguma terrane to the south are separated by the Cobequid-Chedabucto Fault. Though large scale displacements along transcurrent terrane boundary faults has been effectively refuted (Irving and Strong, 1985), smaller scale displacements may be indicated. No paleomagnetic studies have been conducted along the Cobequid-Chedabucto Fault but structural evidence indicates a minimum dextral displacement of 40 kilometres (Mawer and White, 1987) to hundreds of kilometres (Webb, 1968, 1969; Donohoe and Wallace, 1978; Keppie, 1982). Furthermore, Clarke et al. (1980) have demonstrated that a weak plutonic correlation exists across the Cobequid-

Chedabucto Fault and suggest Post-Acadian displacement of hundreds of kilometres to account for this observation.

Basement fragmentation associated with the Mid-Devonian Acadian Orogeny (Belt, 1968; Schenk, 1978; Fralick and Schenk, 1981; Bradley , 1982) resulted in the formation of the Maritimes Carboniferous Basin. Periodic adjustment along terrane boundary wrench faults (Webb, 1969; Eisbacher, 1969) controlled basin formation and evolution through time (Bradley, 1982).

CHAPTER 3

LITHOSTRATIGRAPHY

INTRODUCTION

Distinct formations are identified by characteristic combinations of lithology, clast composition in coarse clastic units, paleocurrents, and facies typical of a particular depositional environment. Each has been assigned an informal formation name based on the location of a representative section. Seven formations are recognized in the study area. These include the basal Late Devonian Sunnyville Formation, the Tower Formation, the St. Francis Harbour River Formation, the Minister Brook Formation, the Brandy Brook Formation, the Eddy Point Formation and the Gunns Brook Formation. Figure 5 is a general geology map showing the relative surface distribution of each formation in the study area. It represents an amalgamation of previous work as well as results of the field work conducted for this thesis.

The Cobequid-Chedabucto Fault effectively defines the southern limit of the formations exposed in the Guysborough Basin. The

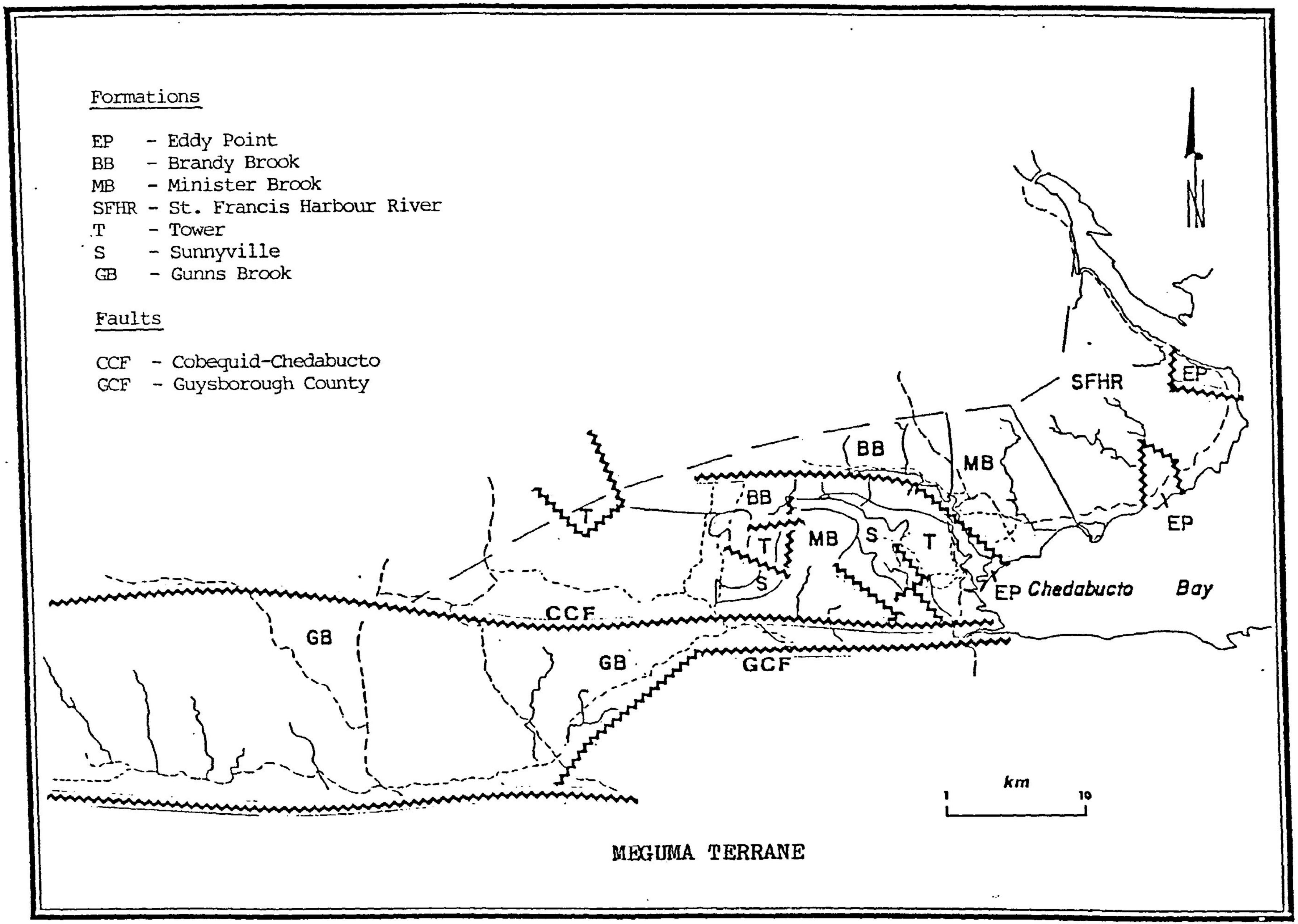


FIGURE 5. General geology of the study area.

Gunns Brook Formation is the only formation identified south of this structure. A general stratigraphic column for the formations listed is provided as Figure 6. Formations exposed in the Guysborough Basin will be discussed from the base of the section to the top, followed by a discussion of the Gunns Brook Formation, which constitutes the only formation exposed in the St. Mary's Basin.

A total of 27 samples from seven formations were submitted for palynological analysis courtesy of Dr. J. Utting of the Institute of Sedimentary and Petroleum Geology, Calgary, Alberta. Spores were studied in an attempt to identify the species present, and therefore the age associated with the assemblage. Analysis proved disappointing due to the lack of organic matter and the high level of oxidation in many samples, and the high thermal maturity of the area in which the samples were collected. Three samples contained identifiable spores which were all derived from land plants. None of the samples collected from Guysborough Basin yielded useful results, though comparisons with the fauna and flora collected and identified by Fletcher (1986) and Schiller (1963) will be discussed.

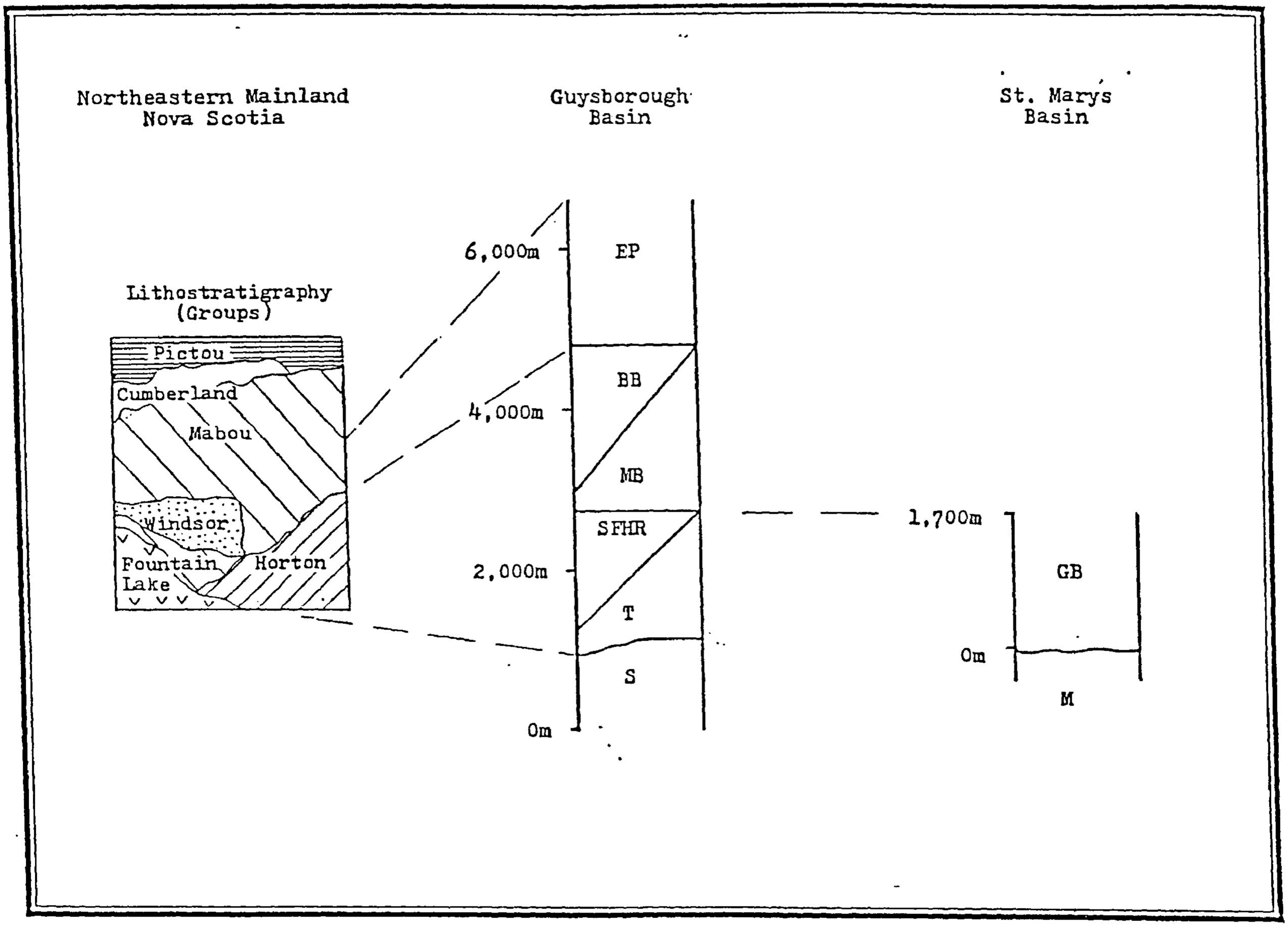


FIGURE 6. General stratigraphic sections through the study area. Devono-Carboniferous stratigraphy of northeastern mainland Nova Scotia is shown for comparison. Most of the formations recognized in the study area are Horton Group equivalents. Symbols: S - Sunnyville Formation; T - Tower Formation; SFHR - St. Francis Harbour River Formation; MB - Minister Brook Formation; BB - Brandy Brook Formation; EP - Eddy Point Formation; GB - Gunns Brook Formation; M - Meguma Terrane (refer to Table 1).

GUYSBOROUGH BASIN

Sunnyville Formation

Lithology

The Sunnyville Formation is predominantly composed of strongly hematitic volcanic flows and pyroclastics with subordinate amounts of fine to coarse grained interflow sediment. Flows are typically massive or amygdaloidal with amygdules of calcite, chlorite and zeolites. Pipe vesicles are locally evident. These rocks are gray to maroon and are often porphyritic with plagioclase phenocrysts locally up to 4 millimetres long. Tuffs are typically fine grained, maroon rocks which contain abundant plagioclase crystals. Lapilli tuff is characterized by the presence of plagioclase phyric fragments generally up to 5 centimetres diameter with occasional bombs up to 8 centimetres diameter in a fine grained tuffaceous matrix. Siltstones and sandstones are maroon and massive to well laminated, and locally contain clasts and bombs of plagioclase phyric andesite. Matrix supported conglomerate is composed of pebbles and occasional cobbles exclusively of volcanic composition. Clasts are massive to amygdaloidal, locally porphyritic, and are angular to rounded. The beds are poorly sorted and lack internal structures.

Figure 7 shows the areal extent of this unit and the location of three sections across the formation. The vertical sections are presented as Figure 8 for comparative purposes. It is important to note that these sections are partial due to the incomplete exposure of the unit. Further, sections presented here and for the remainder of the formations are composites of the best available exposures.

The Campbell Lake section is composed entirely of volcanic flows. Noteworthy is the lack of interflow sediment near the top of the section. This may be a result of poor exposure, although conglomerates in the overlying Tower Formation do not contain any clasts of red siltstone or sandstone. Interflow sediment may not have accumulated in this portion of the Sunnyville Formation. The Nickerson Lake section has a significant pyroclastic component, with minor siltstone and conglomerate near the top of the section. Finally, the Sunnyville section is composed predominantly of flows in the lower and middle portions of the section though an appreciable

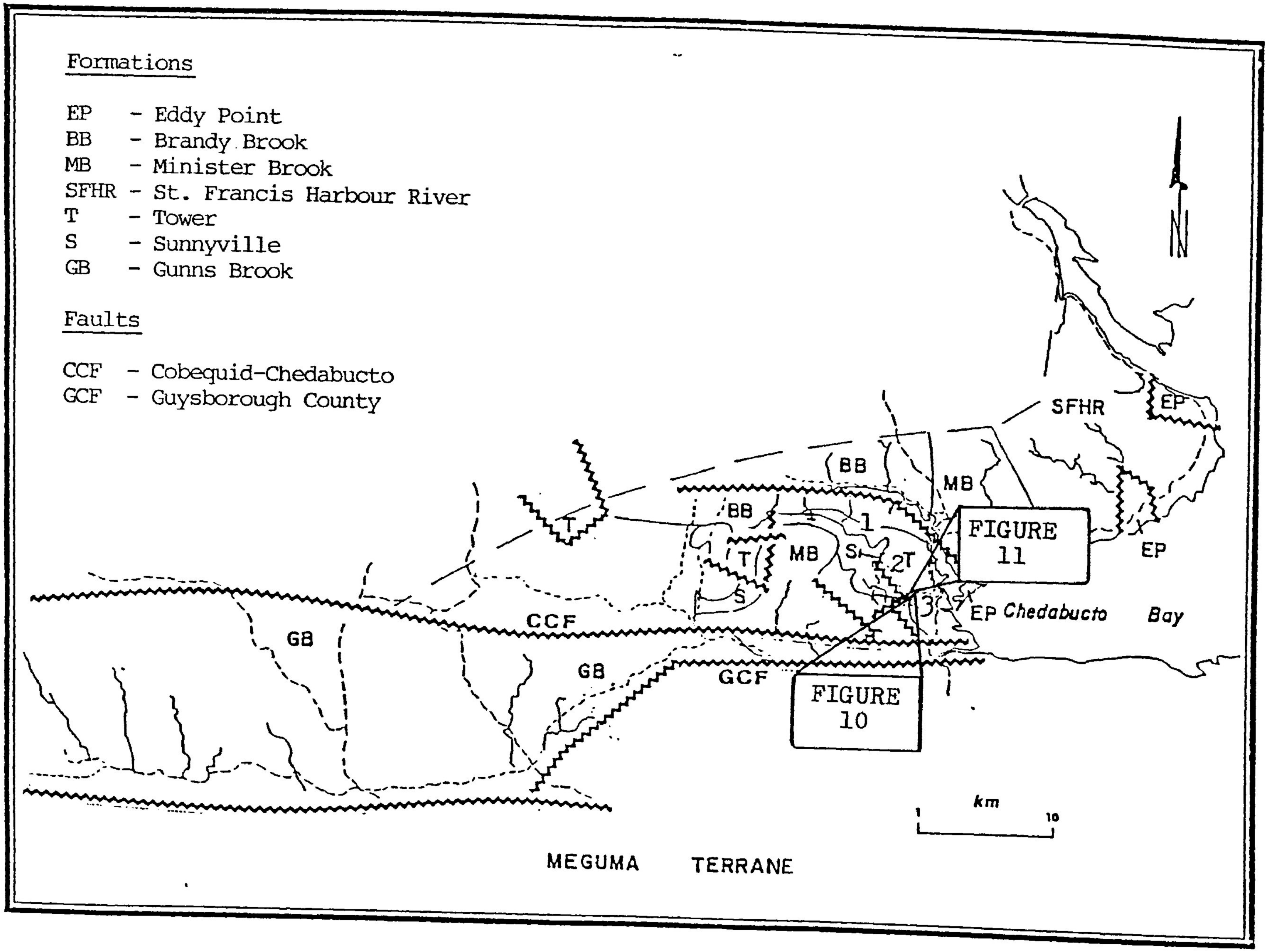


FIGURE 7. Sunnyville Formation: areal distribution and location of partial sections: 1 - Campbell Lake; 2 - Nickerson Lake; 3 - Sunnyville.

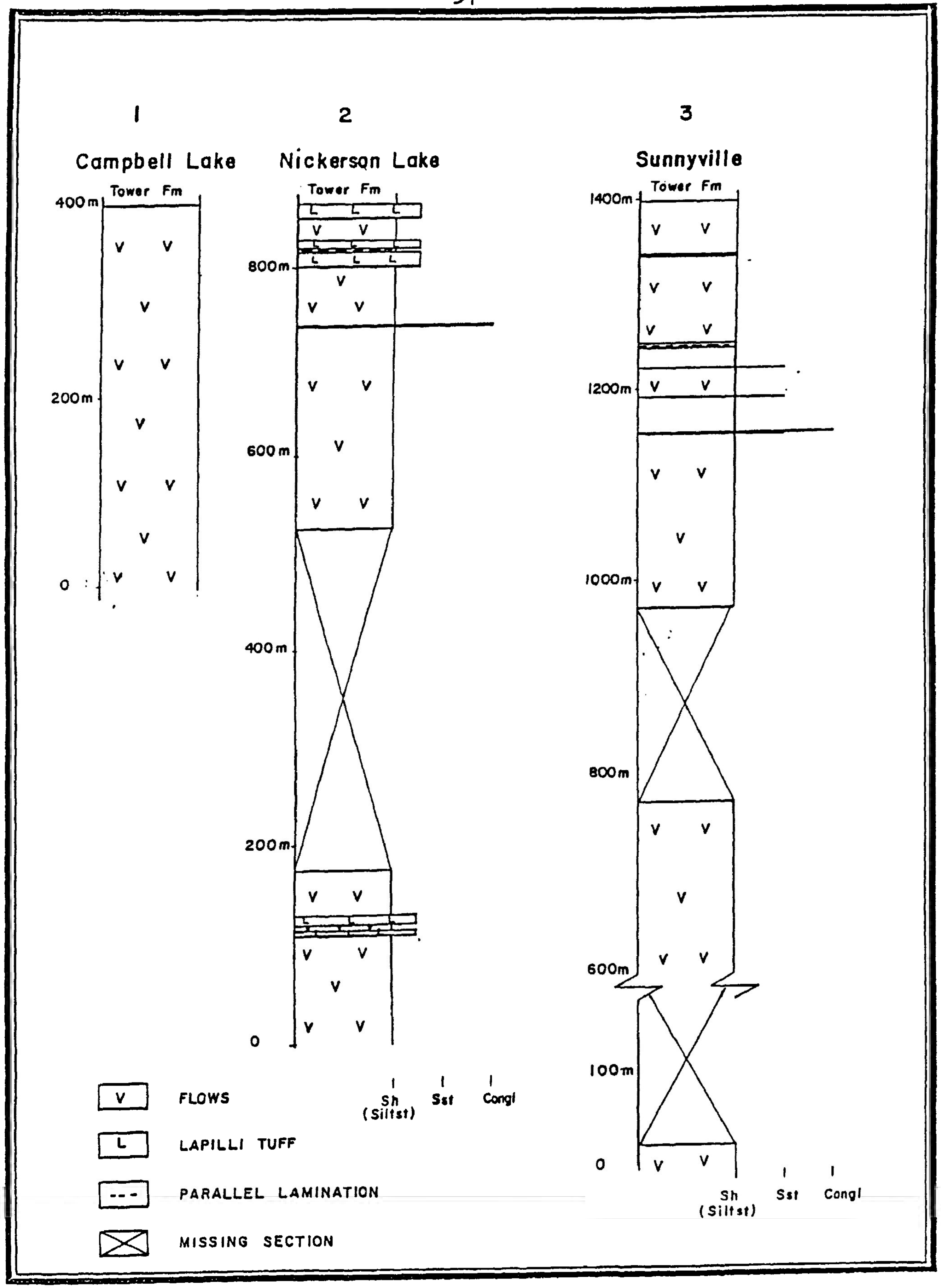


FIGURE 8. Sunnyville Formation: partial sections (refer to FIGURE 7).

part remains unexposed. The upper 250 metres of the section contains several beds of interflow siltstone, sandstone and conglomerate. In this respect, the latter two sections are remarkably similar with the exception of the lack of observed pyroclastic units in the Sunnyville section.

Thickness and Contact Relationships

The Sunnyville Formation forms the lowermost unit of the exposed section in the Guysborough Basin, north of the Cobequid-Chedabucto Fault. The base of the formation is unexposed in the study area. The minimum thickness for the Sunnyville Formation varies from 400 to 1,400 metres in the Campbell Lake and Sunnyville sections, respectively.

No bedding indicators are available for flows in the Campbell Lake section. However, pyroclastic and interflow sedimentary units in the Sunnyville section do provide suitable determinations of local strike and suggest that a conformable contact exists between the Sunnyville Formation and the overlying sediments of the Tower Formation here. Schiller (1963) described the contact as locally conformable and unconformable. Smith (1980) considered the contact questionably unconformable. The contact was not observed in the field and though it is inferred to be locally conformable, a low angle discontinuity may, in fact, exist.

Age

Though poorly constrained in the study area, the Sunnyville Formation is assigned an age of Middle to Late Devonian. It is interpreted to represent volcanic activity which followed the Mid-Devonian Acadian Orogeny. Volcanic sequences in the Appalachians are described by several authors including: Mackasey (1963) - pre-Horton; Cormier and Kelly (1964) - Early Carboniferous; Blanchard (1982) - Devono-Carboniferous; Dostal et al. (1983) - Devono-Carboniferous; Blanchard et al. (1984) - Devono-Carboniferous) which occupy similar positions in the stratigraphic column (Figure 9). One sample collected from interflow sediment for palynological analysis contained no in situ organic matter and was intensely oxidized.

Sedimentary Lithofacies

Mudstones, siltstones and fine grained sandstones are typically massive to weakly laminated and are invariably

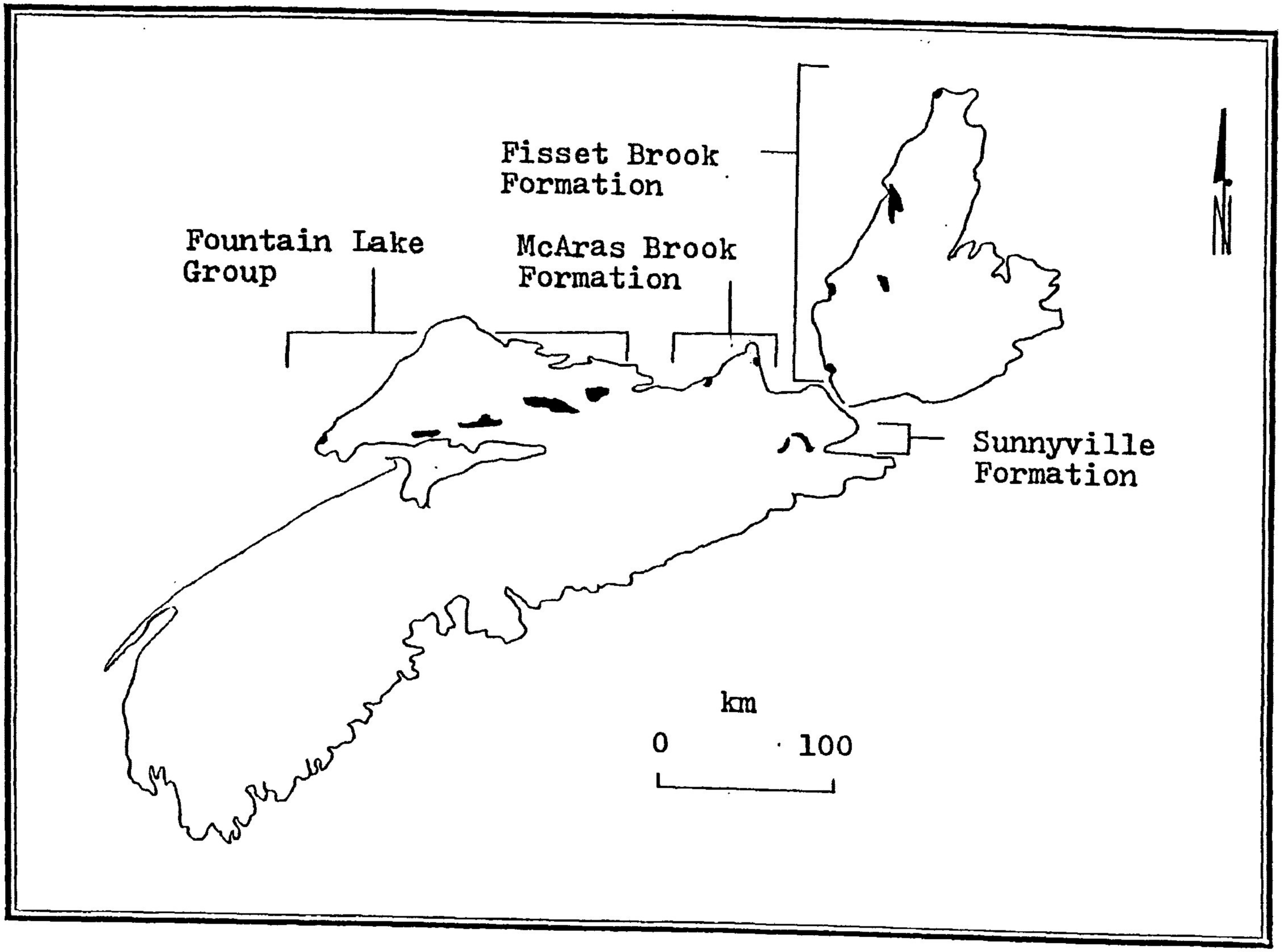


FIGURE 9. Areal distribution of Devono - Carboniferous volcanic rocks in Nova Scotia (modified after Dostal et al., 1983).

maroon to red. Beds are locally up to one metre thick. Figure 10 depicts one such siltstone between flows. Pipe vesicles are present in the flow to the right side of the photograph and significant mud infiltration is evident in the lower portions of the overlying flow to the left side of the picture. Also noteworthy is the presence of volcanic bombs and lapilli within the sediment.

Conglomerate is characteristically chaotic, very poorly sorted, and clasts exhibit variable roundness and sphericity. Angular to rounded clasts are up to 5 centimetres in diameter and are all of volcanic derivation. The matrix is a mixture of fine volcanic clasts and maroon sandstone or mudstone.

Figure 11 exhibits characteristics typical of the fine to coarse interflow sedimentary units of the Sunnyville Formation. The lower contact is vague due to the abundance of hematite in both the flow and the sediment. A massive medium grained maroon sandstone contains occasional volcanic pebbles and a single cobble. Weakly developed cross stratification is exhibited by the sandstone on either side of the cobble which protrudes above the upper contact of the lower unit. The overlying matrix-supported conglomerate is comprised of a

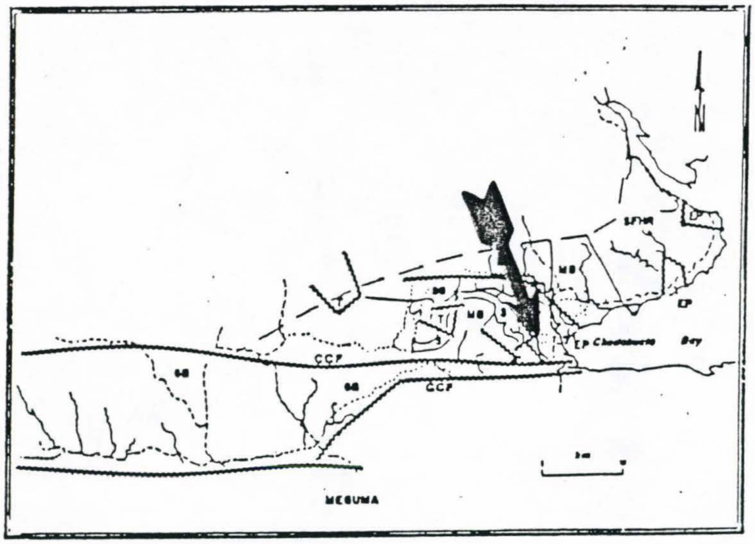


FIGURE 10. Sunnyville Formation: siltstone lithofacies. Massive to parallel laminated siltstone occurs between amygdaloidal (right) and massive (left) volcanic flows and locally contains bomb and lapilli sized fragments. Prominent mud infiltration is evident in the upper flow to the left side of the photograph. This section is also located on FIGURE 7.

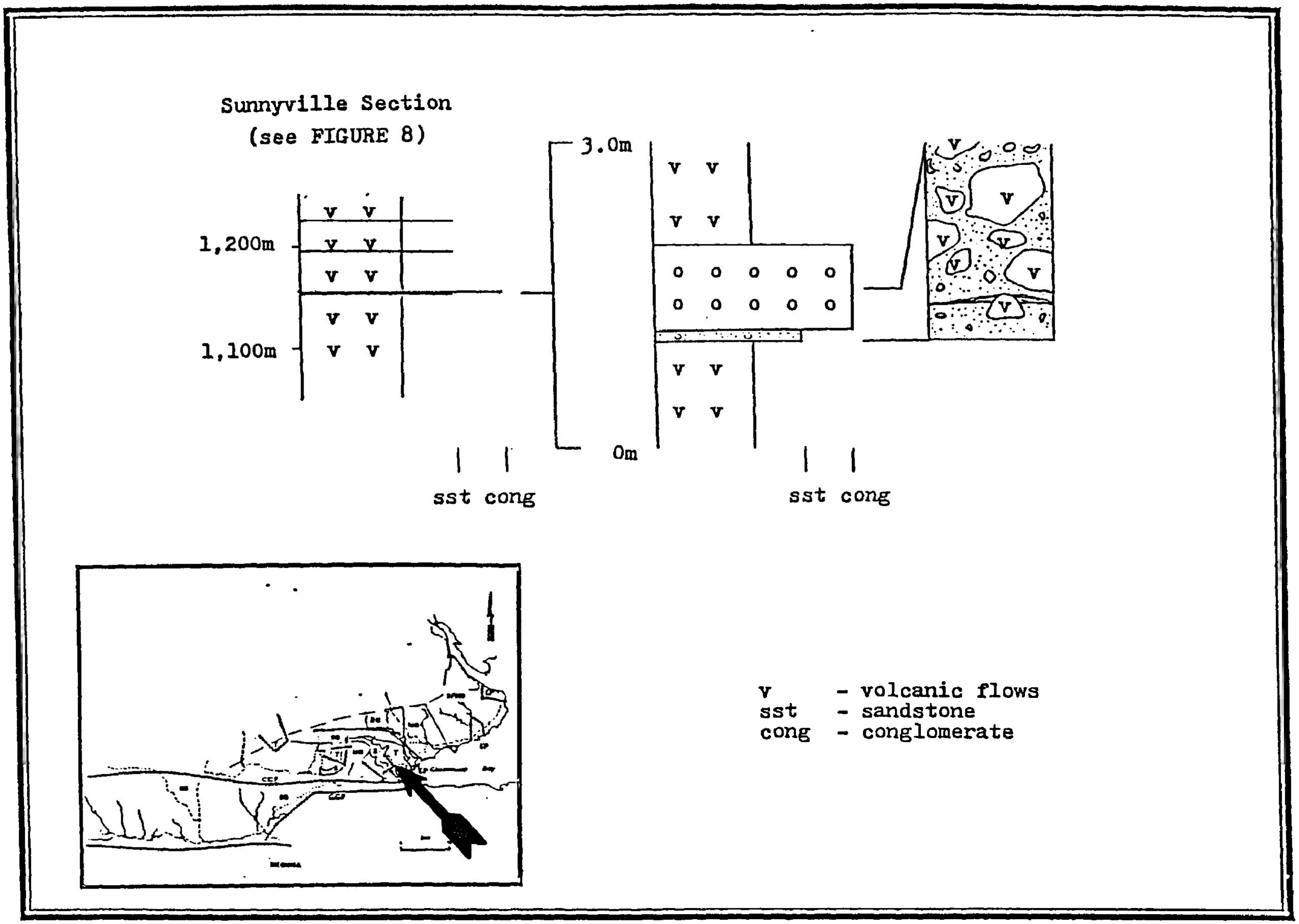


FIGURE 11. Sunnyville Formation: conglomerate-sandstone lithofacies. Conglomerate is matrix supported and poorly sorted. Clasts are angular to rounded and are exclusively of volcanic derivation. Sandstone locally exhibits cross stratification adjacent to boulder sized clasts. This section is also located on FIGURE 7.

chaotic mixture of volcanically derived clasts from less than 1 to 26 centimetres diameter in a matrix of fine to coarse grained maroon sandstone. The contacts between these three units are slightly irregular, but the upper contact between the conglomerate and the overlying volcanic flow is sharp.

Depositional Environment

Although volcanic flows and pyroclastic rocks dominate the section, intercalated interflow sediments provide clues regarding the environment of deposition. Several units, including those depicted in Figure 11, resemble the products of mass flow processes as reviewed by Middleton and Hampton (1976). Four types are recognized (see Figure 12) including turbidity currents, fluidized-liquified flows, grain-flows, and debris flows. Debris flows are commonly composed of clasts and a muddy matrix in variable percentages, are typically structureless, chaotic, and form a matrix supported unit up to several metres thick (Middleton and Hampton, 1976). Basal scouring is not characteristic though clast transport may result in the development of occasional tool marks. These sediment mass flows are described by Middleton and Hampton (1976) as highly concentrated, viscous, non-Newtonian sediment

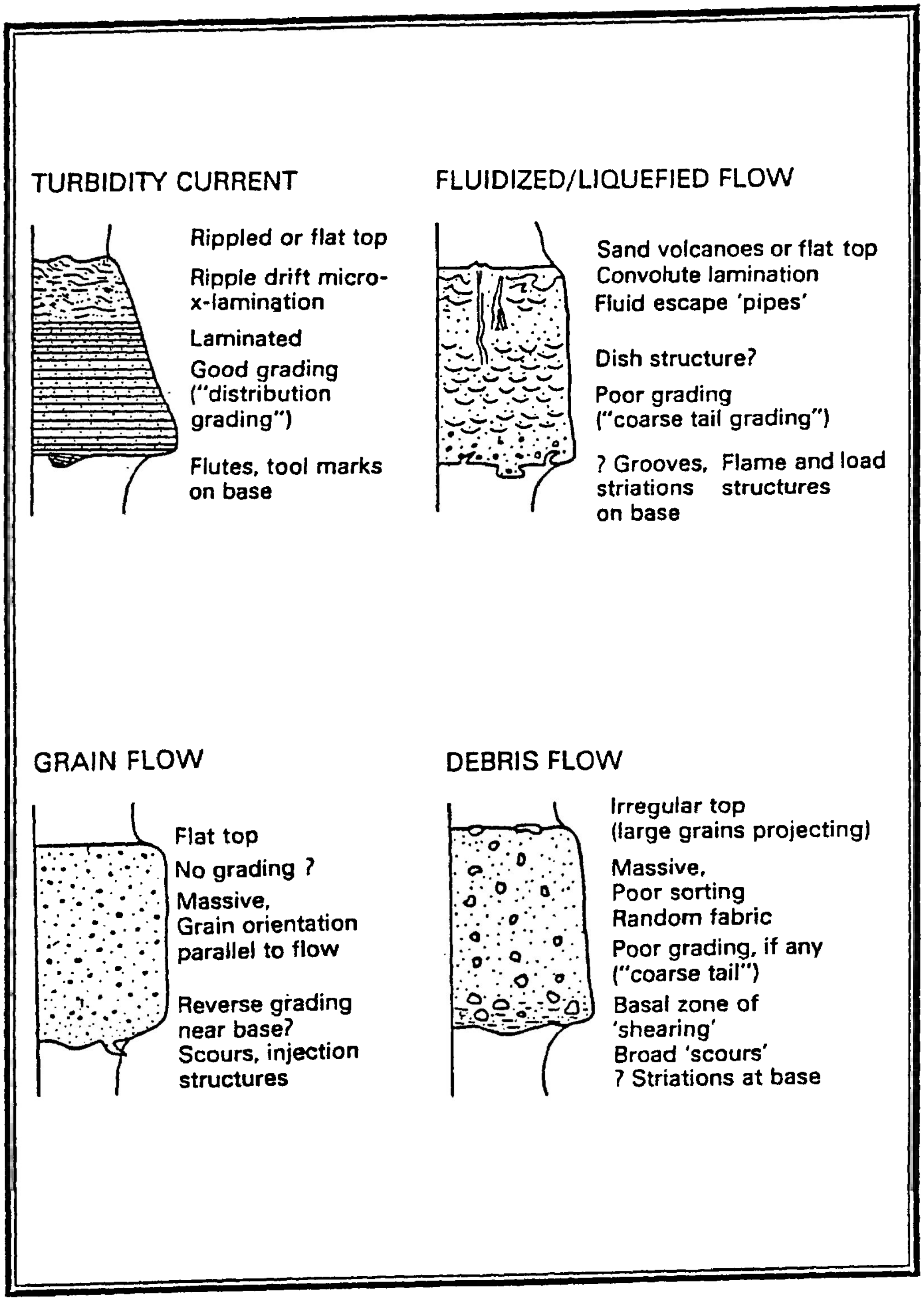


FIGURE 12. Schematic deposits of mass flow processes (from Middleton and Hampton, 1976).

dispersions which possess a yield strength. Further, laminar flow is characteristic and depositional slope may be as low as two degrees (Middleton and Hampton, 1976). Interflow units such as conglomerate and pebbly sandstone are interpreted as the product of debris flows, whereas massive sandy beds are probably the result of grain flow processes. Local cross stratification proximal to coarse clasts (Figure 11) is interpreted to represent a cross section through a sand shadow transverse to the dominant flow direction.

Parallel laminated siltstone and mudstone within parts of the Sunnyville Formation suggest deposition in a quiet subaqueous environment. Periodic instability on a relatively steep depositional slope, such as the flank of a volcanic centre, probably resulted in sporadic sediment accumulation by mass flow processes including debris flows and grain flows.

At times when volcanic activity waned, fine sediments accumulated from suspension and occasionally incorporated minor pyroclastic debris (as in Figure 10), in a quiet subaqueous setting such as a lacustrine environment. No clasts suggestive of an extrabasinal source area are present in the conglomeratic units. Clast lithologies are exclusively of volcanic derivation and interflow sediments are iron rich. Local volcanic source areas supplied the detritus for the sedimentary component of the Sunnyville Formation.

Geochemistry

Major and trace element geochemical data derived for samples collected from the Sunnyville Formation are presented in TABLES 2 and 3, respectively. The Lakehead University facilities were utilized to generate an initial data set. The procedures followed for sample preparation and analysis are outlined by Mitchell et al. (1980). Totals were significantly less than 100% and suggested that the abundance of one or more elements had been inaccurately determined. Pulps from the original sample material were sent to X-Ray Assay Laboratories, Don Mills, Ontario, for analysis. Potassium is the only element markedly different in the check analyses and accounts for the poor totals obtained in the initial data set. A poor correlation coefficient existed for the standard data when the potassium determination was completed using Lakehead University instrumentation. The data is plotted on an AFM diagram, presented as Figure 13. Most of the points cluster in the upper central part of the diagram reflecting MgO and

TABLE 2

Major Elements of the Sunnyville Formation

(%)

SAMPLE	S102	AL203	CA0	MG0	NA20	K20	FE203	MND	T102	P205	L01	SUM
1	48.8	16.5	4.20	4.32	5.85	1.59	11.5	0.22	3.18	1.35	3.08	100.9
2	46.0	15.3	5.67	5.61	5.41	0.62	11.9	0.27	2.84	1.21	5.38	100.4
3	45.7	15.8	2.74	8.45	5.50	0.28	13.2	0.14	3.07	0.97	4.77	100.8
4	51.0	15.4	5.05	3.40	4.34	2.04	10.6	0.09	2.63	1.18	4.46	100.3
5	49.4	16.6	2.55	4.37	5.10	1.39	14.3	0.16	2.18	0.92	3.08	100.3
6	46.0	15.7	1.98	7.09	4.15	0.83	16.5	0.15	3.00	1.21	3.85	100.6
7	46.3	16.9	2.08	6.13	5.79	0.67	15.2	0.18	2.82	0.68	4.00	100.9
8	46.6	17.8	2.51	6.23	5.89	0.67	12.9	0.22	3.23	0.78	3.85	100.8
9	45.6	17.4	3.91	9.27	5.07	0.46	9.17	0.24	3.75	0.92	4.77	100.8
10	48.2	16.2	0.72	6.52	4.90	0.44	17.2	0.22	2.20	0.37	3.80	100.9
11	47.6	15.5	3.50	6.79	5.77	0.39	13.9	0.53	2.33	0.61	3.69	100.8
12	47.5	16.6	2.49	5.52	5.37	1.32	14.5	0.59	2.31	0.52	3.85	100.8
13	47.3	17.1	2.15	6.70	5.91	0.60	14.4	0.17	2.26	0.30	3.69	100.7
14	45.1	15.7	5.27	7.96	4.43	0.27	11.6	0.18	2.49	0.79	6.92	100.8
15	41.2	15.7	6.66	7.58	3.54	0.66	14.1	0.21	2.68	0.82	7.54	100.8

TABLE 3

Minor Elements of the Sunnyville Formation

(ppm)

SAMPLE	CR	RB	SR	Y	ZR	NB	BA
1	180	30	230	30	380	50	1250
2	150	30	240	30	330	40	440
3	410	20	190	30	240	50	340
4	100	70	250	40	330	40	660
5	110	40	580	30	360	40	760
6	300	40	160	40	270	40	460
7	260	30	200	30	210	20	490
8	300	20	190	20	220	40	500
9	300	30	570	40	240	30	470
10	360	20	180	10	110	10	320
11	310	10	400	20	140	30	420
12	250	40	490	10	160	20	1340
13	390	20	290	20	80	20	300
14	280	20	130	30	200	30	260
15	260	40	120	40	210	30	370

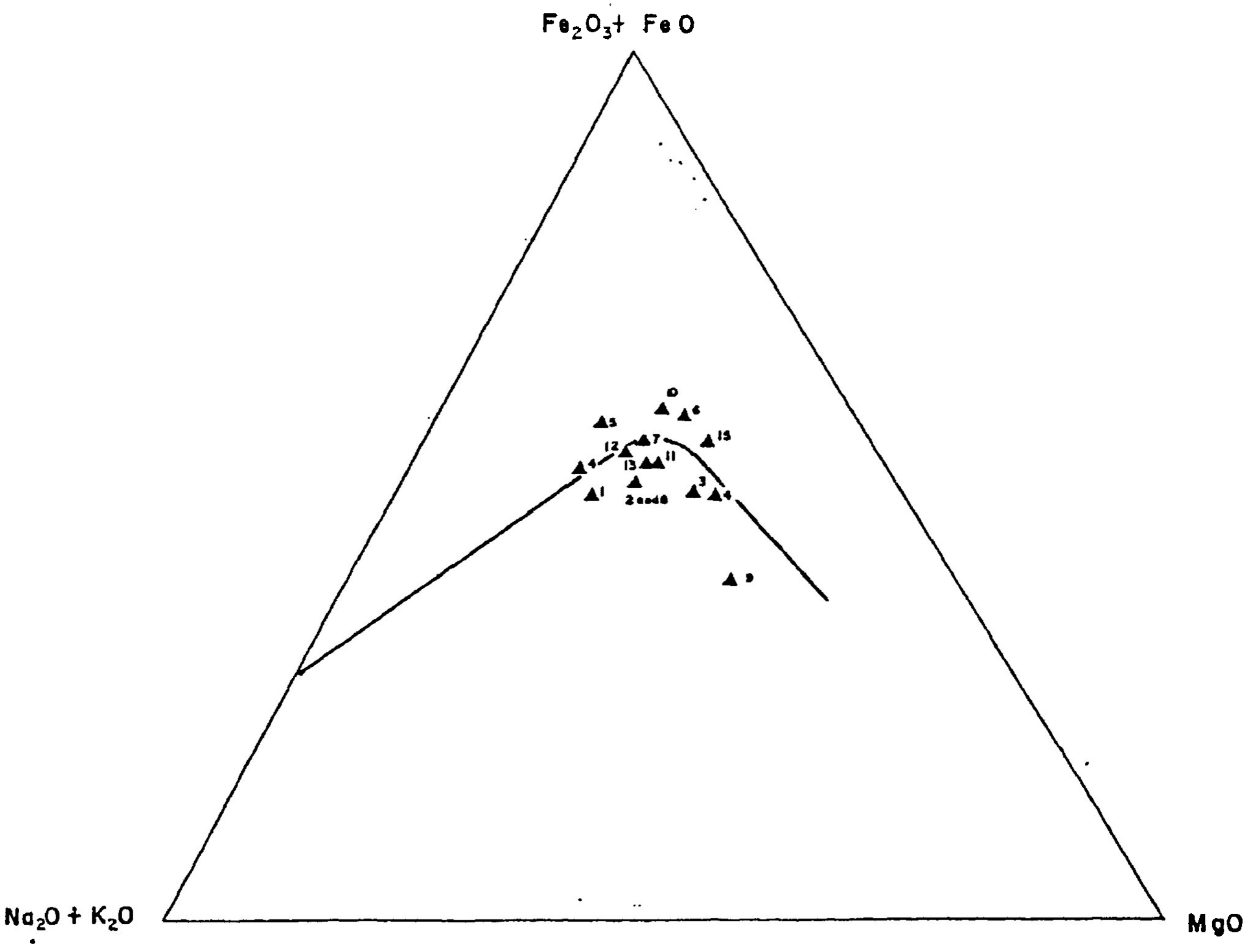


FIGURE 13. Sunnyville Formation: AFM diagram. Samples straddle the tholeiitic-calc-alkalic boundary as delineated by Irvine and B arager (1971).

alkalis in approximately equal proportions and 45 to 69 per cent total iron. One sample contains only 39% total iron, and significantly more MgO than total alkalis. The majority of samples plot near the boundary separating calc-alkalic and tholeiitic compositions.

Tower Formation

Lithology

The Tower Formation is exposed in the central portion of the study area (see Figure 14) and the general sections through the formation are shown on Figure 15. It is composed of dominant maroon sandstone and polymict conglomerate with subordinate amounts of maroon siltstone and mudstone. Occasional gray beds occur.

A series of per cent lithology diagrams and sand/shale ratios were generated for the Nickerson Lake section and are provided as Figure 16. Diagrams schematically illustrate the distribution of exposed lithologies up section. Where the section is incomplete, relationships are inconclusive due to the recessive tendency of fine grained clastic sediments. The

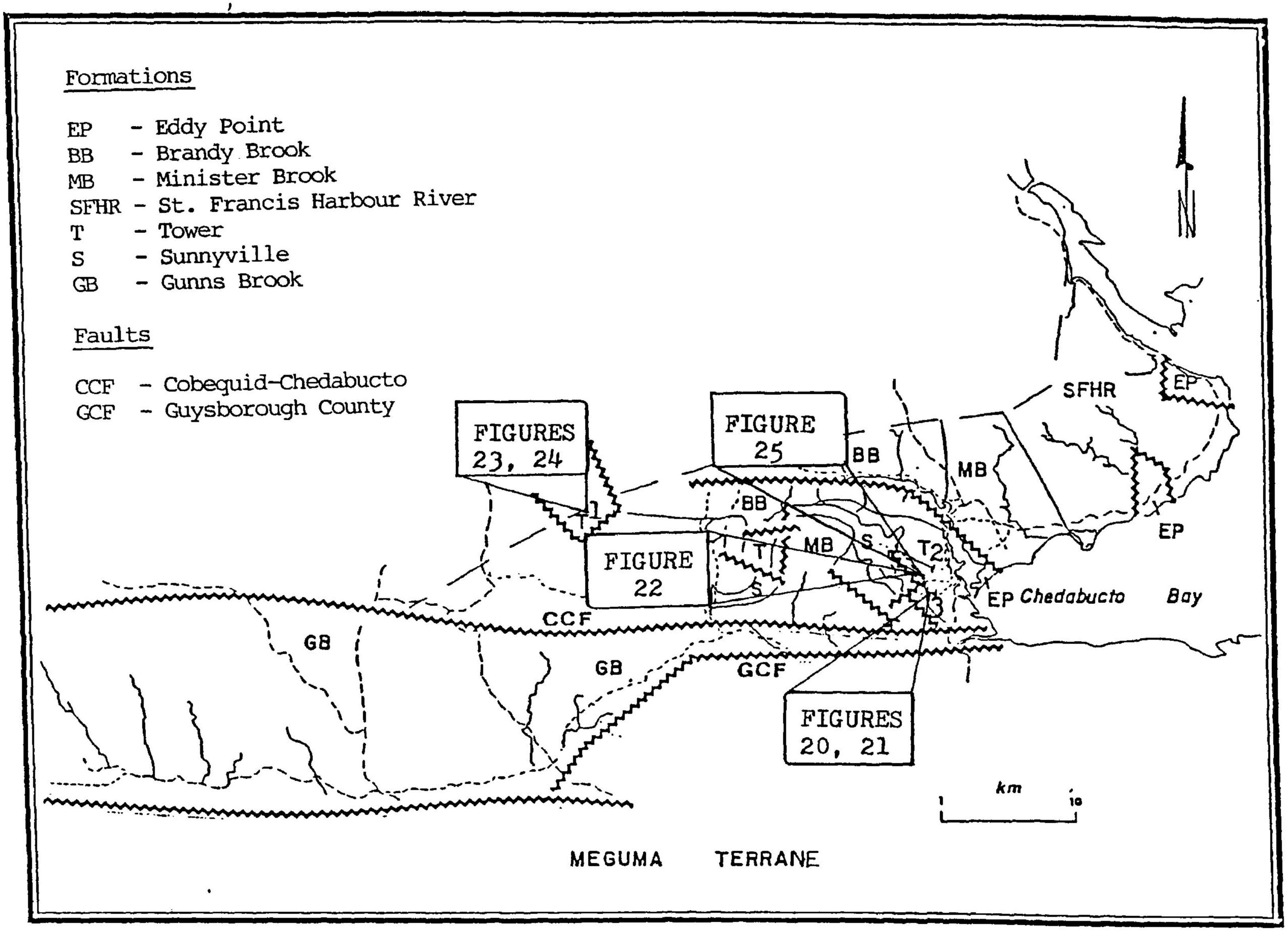


FIGURE 14. Tower Formation: areal distribution and location of partial sections: 1 - Tower; 2 - Nickerson Lake; 3 - Sunnyville.

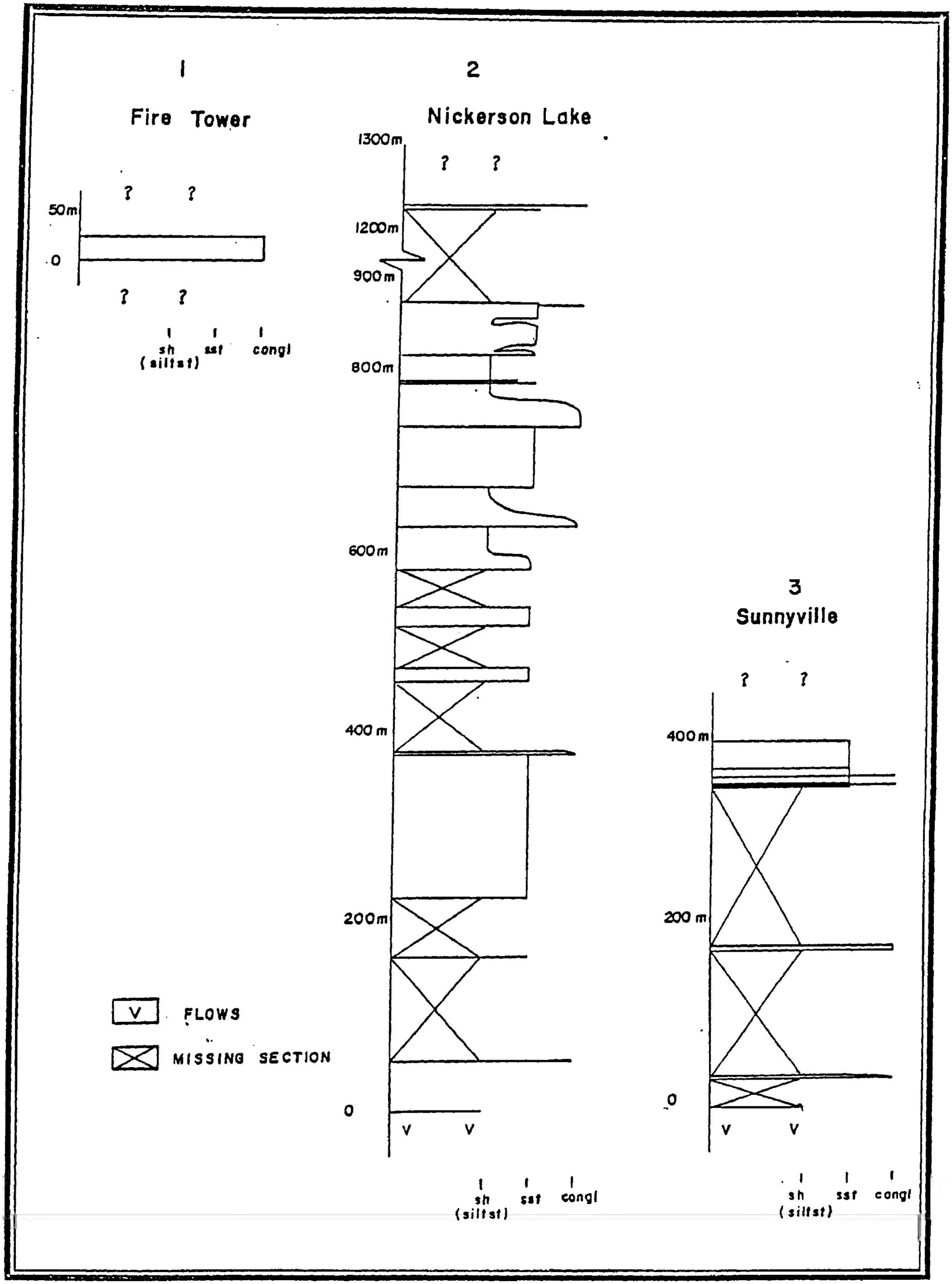


FIGURE 15. Tower Formation: partial sections (refer to FIGURE 14).

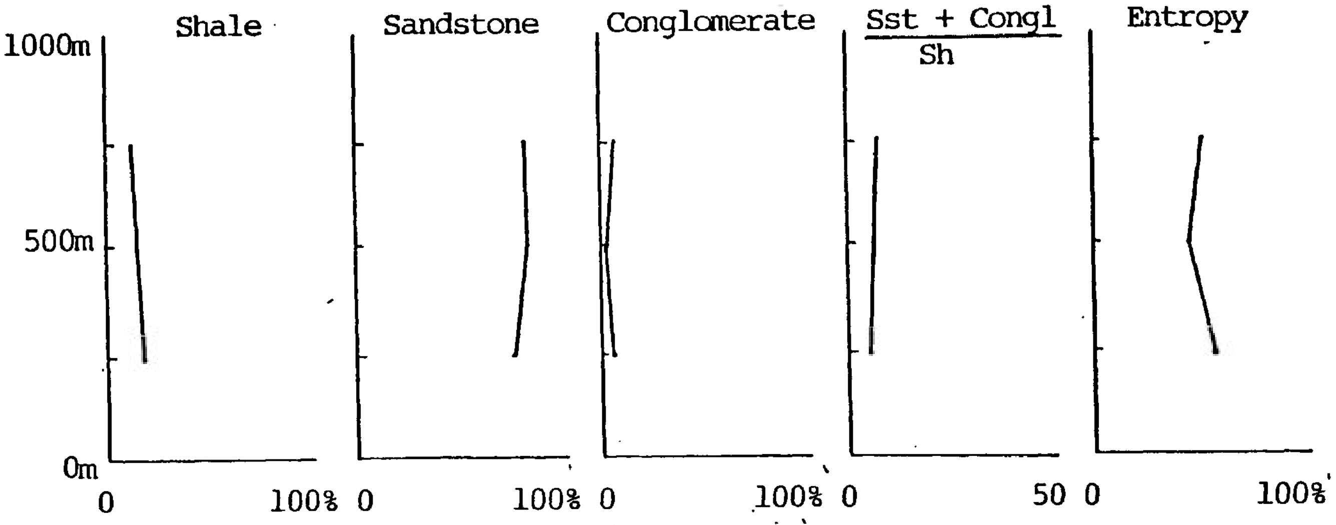


FIGURE 16. Tower Formation: per cent lithology diagrams and sand/shale ratios.

amount of exposed shale decreases in abundance up section. Sandstone is dominant and is only slightly more important up section. The proportion of conglomerate decreases to the mid-point of the section and becomes more important again toward the top of the unit. A slight increase in the coarse to fine clastic sediment ratio is evident. Finally, the entropy decreases to the mid-point of the section and again increases to the top of the formation. This represents the most complete section through the unit and as such it is noteworthy that the more isolated exposures to the north and west are dominated by coarse sediment and corresponding low to moderate entropy values.

Up section variations in the composition of clasts in conglomeratic units are presented as a series of histograms reflecting pebble count data. Again, the most suitable section is the exposure near Nickerson Lake though comparisons are made with other partial sections and isolated outcrops. Near the lower contact with the underlying Sunnyville Formation, the conglomerates of the Nickerson Lake, (Figure 17) and Sunnyville (Figure 18) sections contain a high proportion of volcanic and red sedimentary clasts. Clasts are macroscopically identical to lithologies characteristic of the

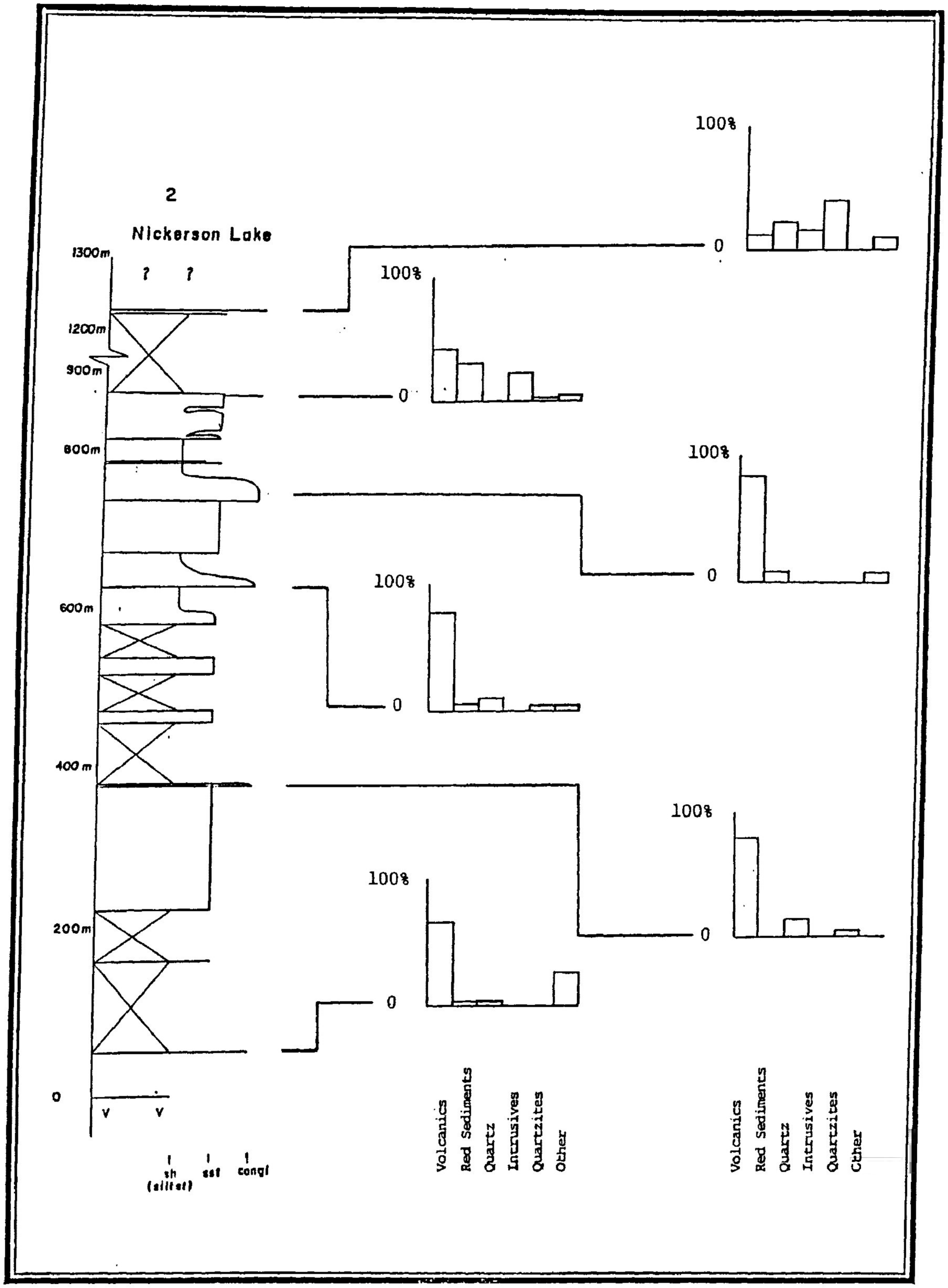


FIGURE 17. Tower Formation: clast lithologies of the Nickerson Lake section.

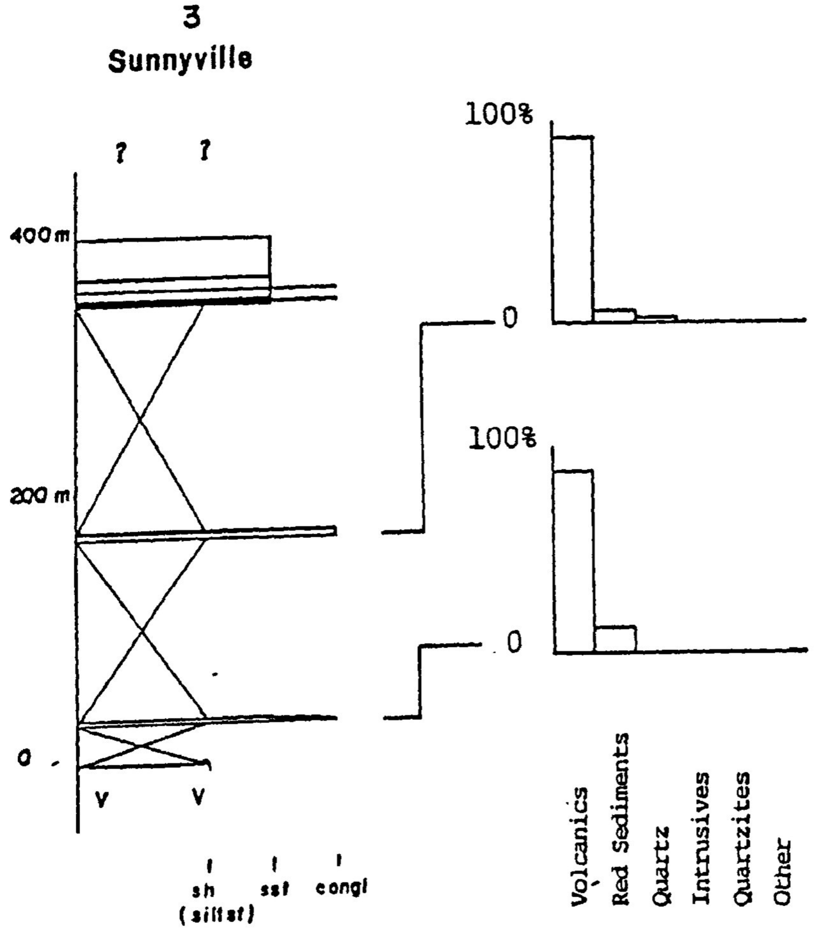


FIGURE 18. Tower Formation: clast lithologies of the Sunnyville section.

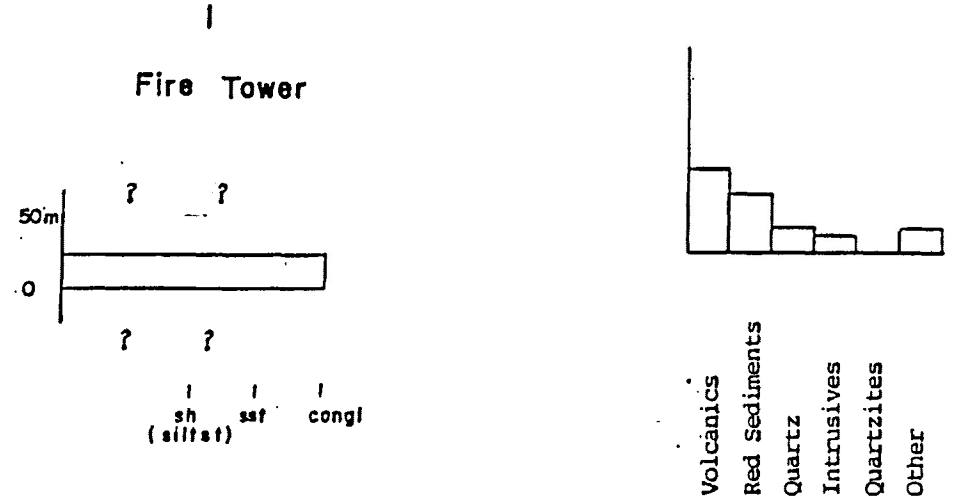


FIGURE 19. Tower Formation: clast lithologies of the Tower section.

underlying unit. Volcanic clasts become less prevalent in the upper part of the section (Figure 17) due in part to a greater abundance of red sedimentary clasts as well as the significant proportion and first appearance of intrusive clasts in the conglomerates. Intrusive clasts are dominant in the uppermost conglomerate sampled in the Nickerson Lake section though volcanic and red sedimentary pebbles still account for 34 per cent of the total (Figure 17). Several outcrops interpreted to represent higher portions of this formation contain fewer intrusive clasts than conglomerates occupying similar positions in the stratigraphic column (compare Figures 17 and 19).

Thickness and Contact Relationships

The formation is described in terms of three partial sections located on Figure 14. Schematic representations of the three sections showing their relative position in the stratigraphic column are provided as Figure 15. The Nickerson Lake section is the closest approximation to a complete section through the Tower Formation in the study area. The lower contact with the Sunnyville formation is unexposed, but tightly constrained. The Sunnyville section provides additional information regarding the lower portion of the formation and the Tower section, although of limited thickness, is an excellent exposure of the upper part of the unit.

The maximum thickness of the Tower Formation is estimated to be 1,300 metres. This is in contrast to Schiller's (1963) estimation of 2,000 feet (610 metres) for Craignish Formation strata (equivalent to the Tower Formation). It is important to note that several localities exist which severely limit the thickness of this unit relative to older and younger formations. For example, exposure of the Tower Formation near Campbell Lake is restricted to conglomerate and sandstone, and the maximum thickness is only on the order of 100 metres. This is also the case near Fraser lake and along the road from Sunnyville to Roachvale.

Bedding indicators in the formation are similar to those measured in the underlying Sunnyville Formation. However, the contact is unexposed in the study area. This relationship is true also for the upper contact with rocks of the Brandy Brook Formation. Both the upper and lower contacts are locally observed in fault contact with adjacent formations. Schiller (1963) noted the existence of both conformable and unconformable upper and lower contacts for the Craignish Formation in the Guysborough area, but no definite contacts were observed by the present author.

Age

Seven samples were submitted for palynological analysis but it was found in all cases that little or no organic matter was present and that the samples had suffered moderate to extreme oxidation (pers. comm., 1989, J. Utting, Institute of Sedimentary and Petroleum Geology). This unit probably lies conformably and unconformably on volcanic rocks of the Sunnyville Formation and is therefore interpreted to be of Latest Devonian to Earliest Carboniferous age.

Sedimentary Lithofacies

Lithofacies will be discussed with respect to the position in which they occur in the composite section, from the base to the top. Coarse sediments exposed near the base of the formation are very poorly sorted, a feature characteristic of diamictite (Frakes, 1978). Eyles et al. (1983) proposed a lithofacies code for diamictite in the context of glacigenic sequences, but pointed out that their classification is applicable to poorly sorted sediments deposited in any environment and may include both clast and matrix supported units. Their classification scheme is adopted for the discussion of coarse sediments. Sandstone and shale lithofacies are also described.

Sandstone and conglomerate are abundant close to the lower contact, and mudstone occurs only in subordinate amounts. A section through some of the units near the base of the succession is provided as Figure 20. Conglomerate beds are all poorly sorted and matrix supported, and therefore satisfy the requirements of diamictite as discussed above. Conglomerate facies observed include massive, structureless and imbricate units (Dmr), poorly horizontally stratified units (Dmsr) and normally and reverse (see Figure 21) graded units (Dmgr). Sandstone beds are fine grained to pebbly and are massive (Sm), horizontally laminated (Sh) and normally or reverse graded. Siltstone and shale are parallel laminated (Fl) or massive (Fm).

Lower contacts of massive, pebbly sandstones and conglomerates are flat to slightly irregular. The upper contacts are sharp

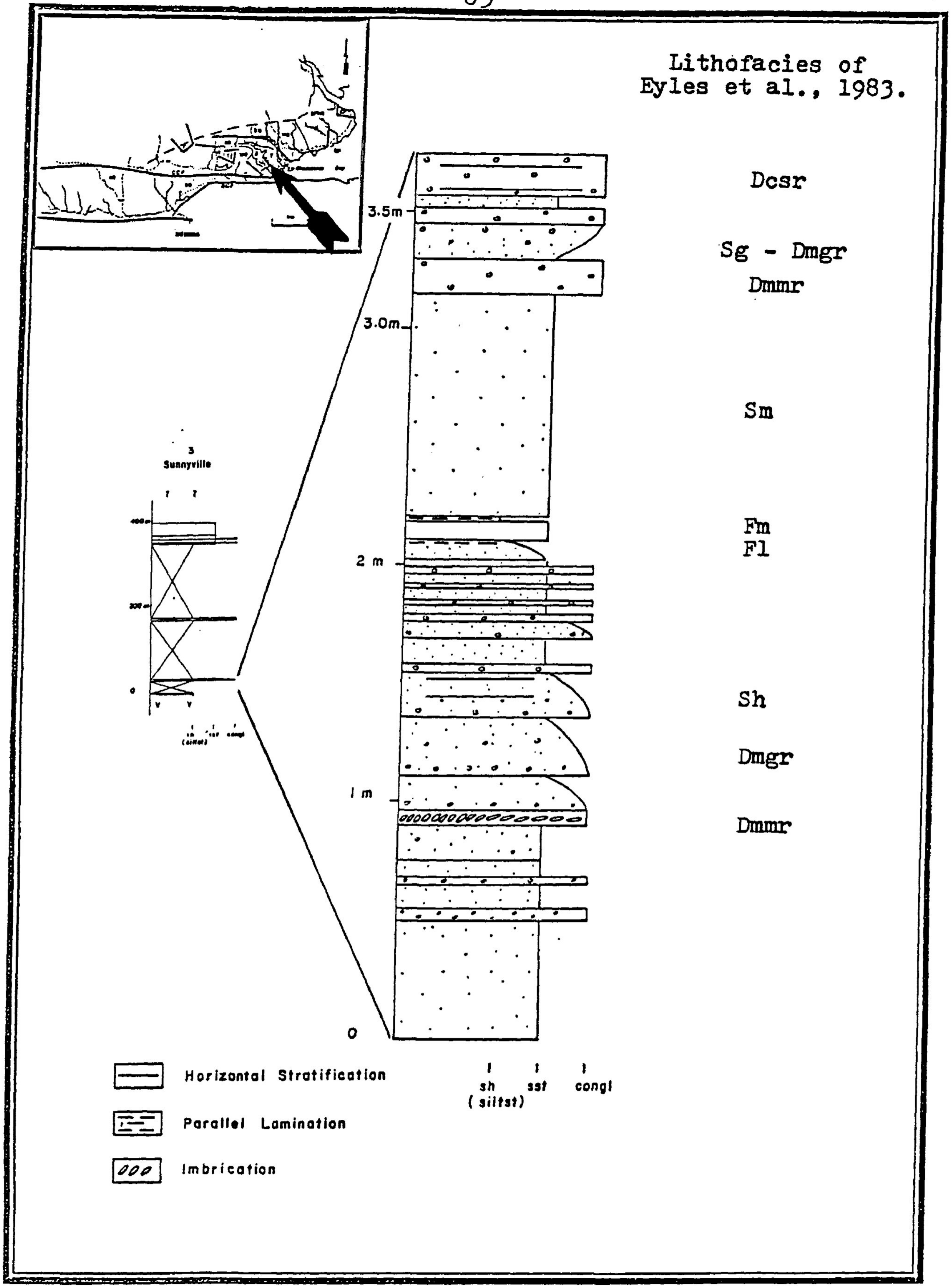


FIGURE 20. Tower Formation: lower conglomerate-sandstone lithofacies. This section is also located on FIGURE 14.

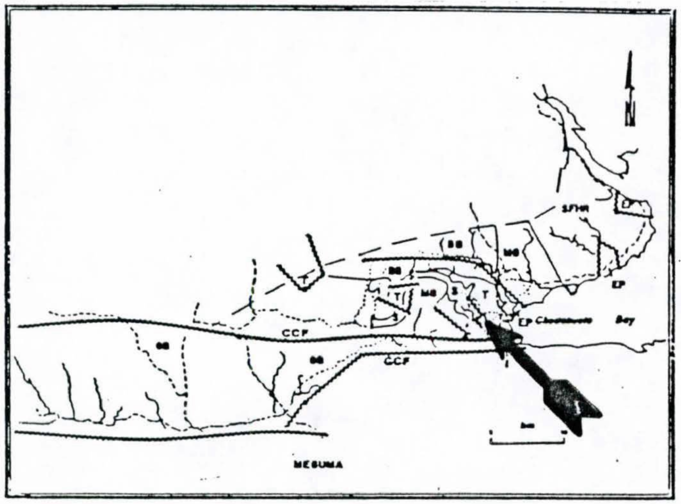


FIGURE 21. Tower Formation: lower sandstone-conglomerate lithofacies (lithofacies Sg to Dmgr of Eyles et al., 1983; see FIGURE 20). Pebble conglomerate is poorly sorted, matrix supported and exhibits inverse grading. Clasts are almost exclusively of volcanic derivation. This section is also located on FIGURE 14.

and flat. Injection structures and fluid escape features are not present in the measured section though similar outcrops nearby exhibit most of the features noted above as well as clastic dikes.

Normally graded, matrix-supported pebble conglomerates (Dmg), pebbly and coarse to fine sandstone beds (Sg) up to several centimetres thick with parallel laminated maroon mudstone drapes (Fl) occur through much of the lower central portion of the Tower Formation (Figure 22). Sandstones are locally massive (Sm) to ripple laminated (Sr) whereas mudstones are parallel laminated to massive.

Lithofacies observed at higher levels of the formation are markedly different than those described above. Units of the upper Tower Formation are similar to facies of alluvial association outlined by Miall (1977, see Table 3, 1978) and his classification is adopted for this discussion. Figure 23 is a partial section interpreted to represent the upper portion of the unit. Conglomerates are clast supported, poorly to moderately well sorted units in which clasts range up to cobble size. Beds are massive (facies Gm) to lensoid on a lateral scale of several metres and commonly exhibit trough

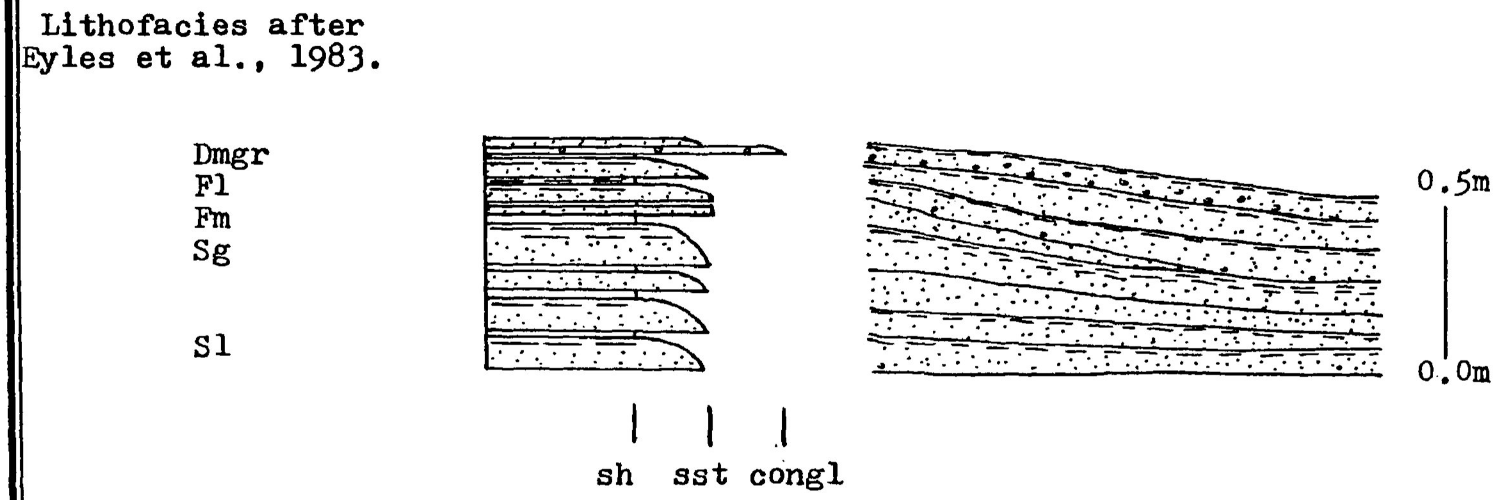


FIGURE 22. Tower Formation: lower conglomerate-sandstone-siltstone-mudstone lithofacies. Normally graded sandstone (medium to fine grained) to mudstone is prevalent with occasional beds of poorly sorted, matrix supported pebble conglomerate. This section is located on FIGURE 14.

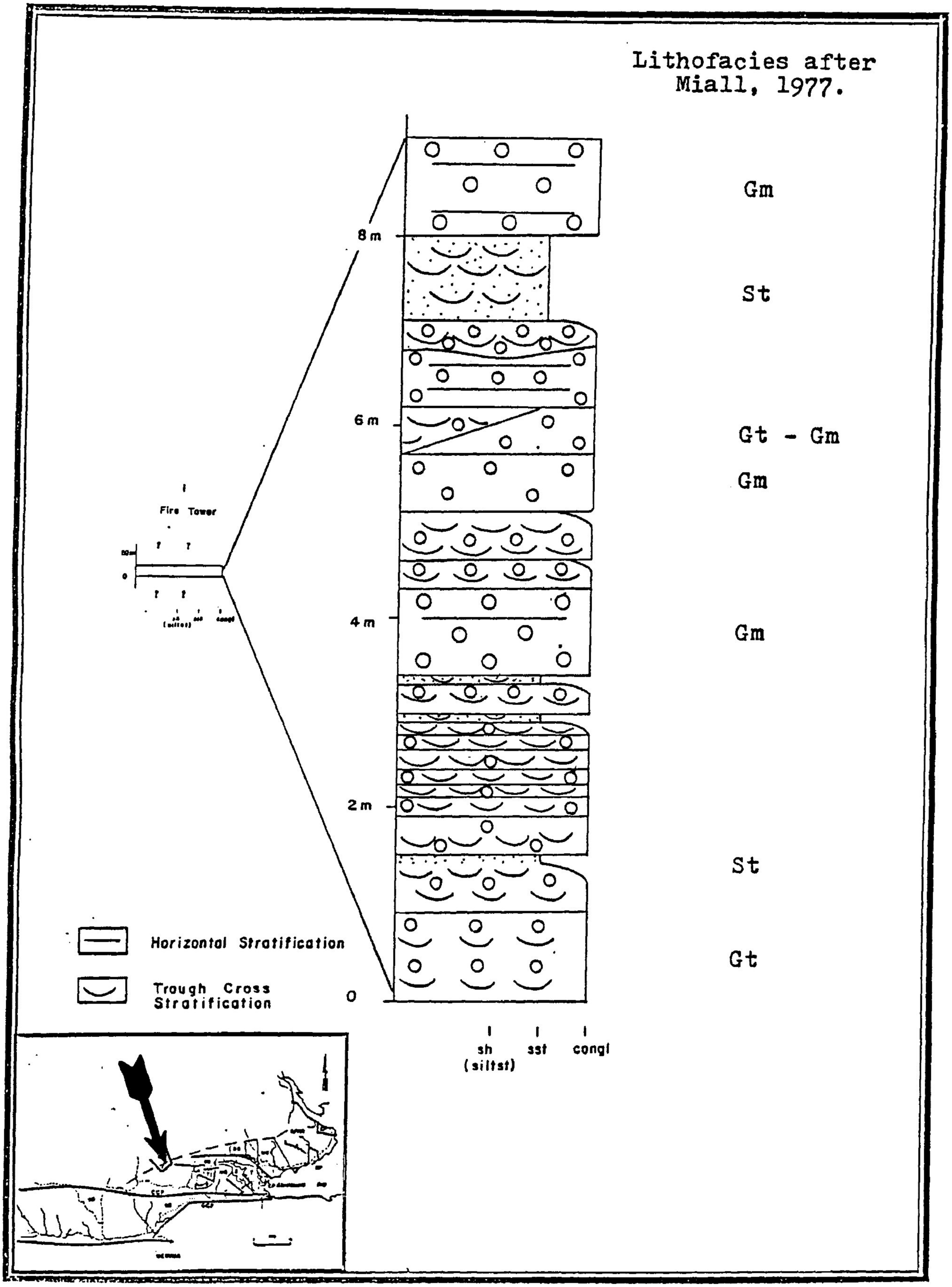


FIGURE 23. Tower Formation: upper conglomerate-sandstone lithofacies. This section is also located on FIGURE 14.

cross stratification (facies Gt) and normal grading. Erosive truncations and scoured basal contacts are common. Bed thickness is variable up to one metre.

Sandstones are fine to very coarse grained and commonly exhibit normal grading. They are horizontally bedded or trough cross stratified (facies Sh and St, respectively). Fine grained sandstone beds are occasionally ripple cross laminated (facies Sr). Figure 24 illustrates the character of several of these facies. Massive, poorly sorted, clast supported conglomerate (Gm) is occasionally interbedded with horizontally stratified sandstone (Sh) and conglomerate. Sandy units are occasionally graded normally and are typically of limited lateral extent.

The section shown in Figure 25 is located near the top of the Nickerson Lake exposure. Conglomerate and sandstone are typically trough cross stratified (facies Gt and St, respectively) and normally graded. Minor horizontally laminated sandstone (facies Sh), ripple and parallel laminated mud (facies Fl and Fm, respectively) occur above sandy units. Dessication cracks are locally evident. Overlying coarse beds commonly lie on a scoured, erosional surface.

FIGURE 24. Tower Formation: upper conglomerate-sandstone lithofacies. Structureless, poorly sorted, clast supported conglomerate (Gm of Miall, 1977) is interbedded with coarse to fine grained, horizontally stratified sandstone (Sh of Miall, 1977) and horizontally stratified conglomerate (Gm of Miall, 1977). Stratified units are normally graded. Beds young toward the upper part of the photograph. This section is also located on FIGURE 14.

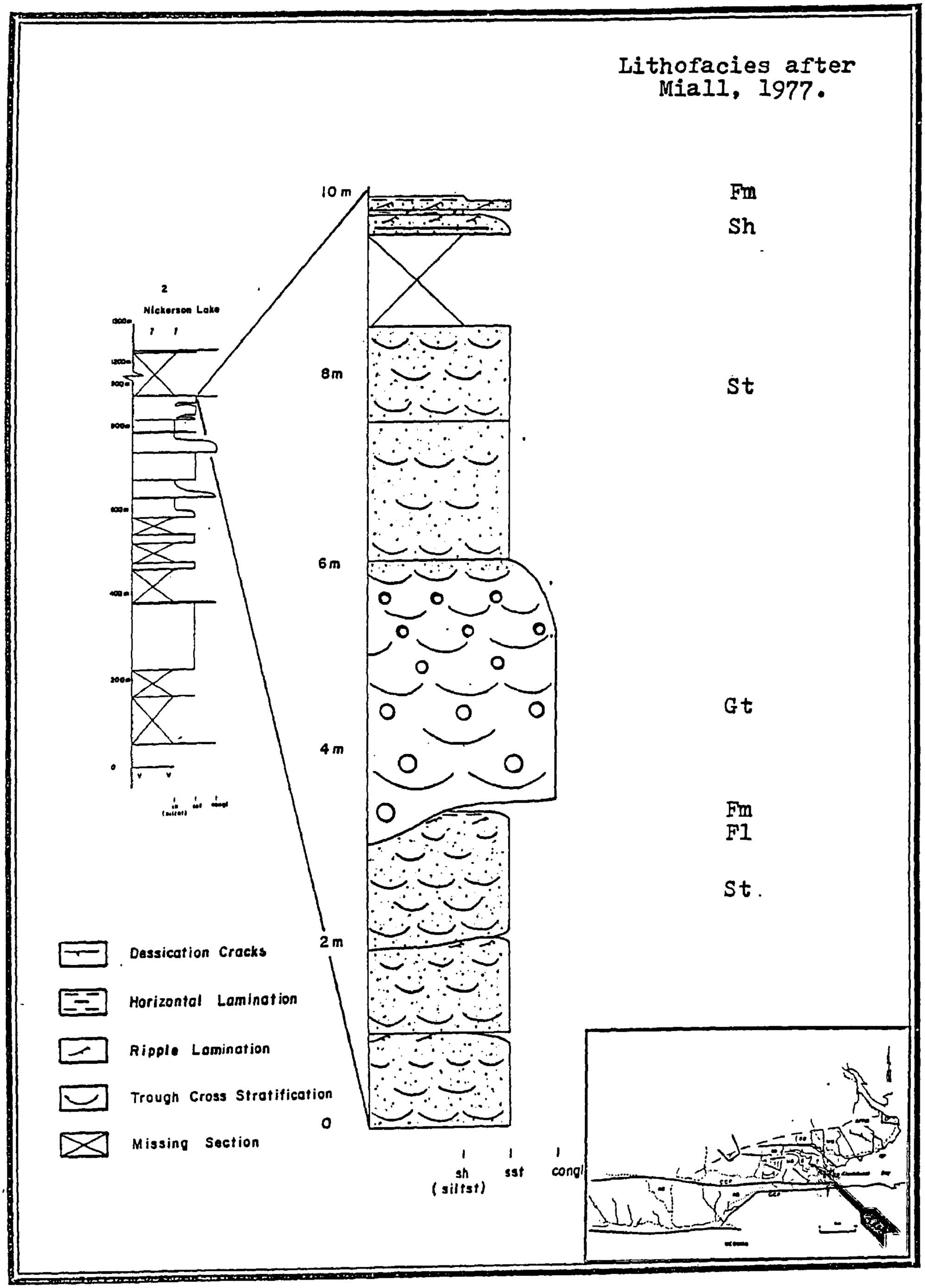


FIGURE 25. Tower Formation: upper sandstone-conglomerate-mudstone lithofacies. This section is also located on FIGURE 14.

Depositional Environment

Interpretation of depositional environment will be presented in two parts due to the marked difference between lithofacies present at the bottom and the top of the formation. Units exposed near the bottom of the formation exhibit features typical of resedimentation, such as poor sorting, matrix support, local normal or reverse grading and imbrication. They do not display any features supportive of traction type deposition.

Sediments in the lower portions of the formation exhibit features which are similar to those formed as a result of mass flow processes. A detailed classification of these deposits was proposed by Middleton and Hampton (1976) who recognized four types, depicted in Figure 12. Though they are described as distinct flows, mass gravity events may involve some combination of these four processes and reflect this in the nature of the deposits (Lowe, 1976). Debris flows have been described in a previous section and the treatment will not be repeated here. Outcrops of Tower Formation strata in the vicinity of Sunnyville and nearer the lower contact of the unit exhibit features consistent with deposition by this process and contain clasts considerably coarser than those present in the thin units in Figure 20.

Massive, locally reverse-graded, medium grained to pebbly sandstone (Sm and Sg), and conglomerate (Dmmr and Dmgr) with flat tops are very similar to grain flow deposits described by Middleton and Hampton (1976). Middleton (1970) noted that the depositional slope required for a sustained grain flow is on the order of 18 degrees, slopes which may be found on the flanks of a volcanic centre.

Massive, graded and horizontally stratified pebble conglomerate (Dmgr and Dmsr), and fine grained to pebbly sandstone (Sm and Sh), such as those shown in Figure 20 and 22, exhibit features characteristic of turbidity current deposition (Figure 12). Fine grained, parallel laminated sediments (Fl) marking the tops of these normally graded units are interpreted to represent deposition from suspension in a quiet, subaqueous environment, such as a lacustrine setting.

Imbricate conglomerate (Dmmr) (Figure 20) is rare in the Tower Formation. The long axes of imbricate pebbles dip up paleoflow and define the structure. This fabric indicates that there was no bedload rolling of clasts and precludes deposition in a fluvial environment (Walker, 1981). Walker (1981) suggests that clasts are supported above the bed in a turbulent flow with fluid turbulence and clast collision contributing to the overall support mechanism. He considers debris flows as an alternative but these deposits do not allow for the production of internal structures such as horizontal stratification, evident in Figure 20. Grading was not observed in this bed. Walker (1975) has proposed four models for resedimented conglomerate facies in a deep water environment (Figure 26). According to this hypothesis, graded, stratified conglomerate represents deposition at the downslope limits of conglomerate sedimentation, and at a reduced flow strength. Since the conglomerate in Figure 20 is well stratified but does not exhibit grading, the unit may represent deposition at some point up current and near the point at which graded, stratified conglomerates are deposited.

In the upper portions of the formation, coarse clastic units exhibit features suggestive of fluvial deposition. A comprehensive review of braided fluvial styles of sedimentation is provided by Miall (1977). According to Miall (1977, Table 3), facies Gm represents deposition on

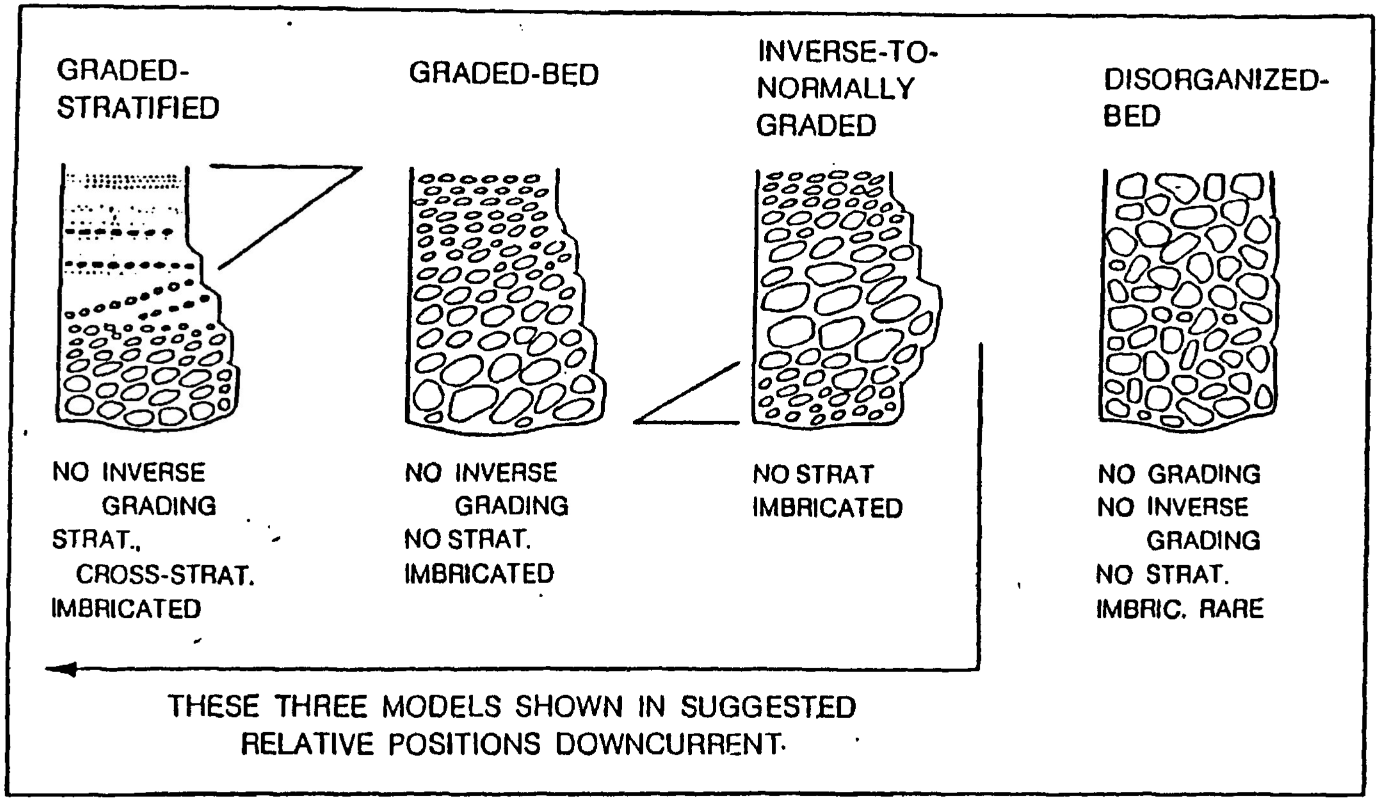


FIGURE 26. Models for deposition of resedimented conglomerates (Walker, 1975).

longitudinal bars, facies Gt is interpreted to reflect channel fill, and facies St represents the migration of dunes in a channel environment. Normal grading in these units is indicative of waning stream flow. Horizontally laminated (Sh) and ripple cross laminated (Sr) sandstones are interpreted to reflect lower flow regime planar bed flow and ripple migration, respectively. Ripple cross laminated fine sandstone, siltstone and parallel laminated mudstone (Fl and Fm, respectively) occur at the tops of coarser beds. Due to their position in the section, they are interpreted to be the products of reduced stream flow, with mud accumulation from suspension at times when portions of the stream became inactive, leaving sporadically replenished pools of quiet water. Mudstones exposed here exhibit weak parallel lamination and poorly developed dessication cracks. These sediments may represent the products of overbank deposition after channel abandonment switched the area of active sedimentation away from this section. Miall (1977) appropriately states that facies associations and vertical sections must be considered to accurately attribute sedimentary deposits to a braided fluvial mode of sedimentation. The association of lithofacies illustrated and discussed above is believed to reflect deposition in this environment, and specifically of the Donjek type (Williams and Rust, 1969; Rust, 1972; reviews by Miall, 1977, 1978). Due to the incomplete nature of the composite section, cyclicity cannot be confirmed, though features which are observed discount the applicability of five of the six models proposed by Miall (1978).

The lower portion of the formation is comprised of lacustrine facies which suggest a similar environment of deposition to that which existed during deposition of the Sunnyville Formation. Debris flows and grain flows are interbedded with normally graded and locally parallel laminated turbidites. Minor parallel laminated siltstone accumulated from suspension when sediment influx waned. Sedimentation rates were relatively rapid as indicated by the presence of clastic dikes and the rarity of fine sediment in this portion of the section. Sedimentary detritus which accumulated near the base of the section was largely of local derivation.

The upper, Donjek type braided fluvial portion of the section is exposed predominantly to the north and west of the lacustrine sediments described above. Sand/shale ratios show a slight coarsening upward trend which reflects locally abundant conglomerate. Clast lithologies begin to suggest the increasing influence of a non-local sediment source, as indicated, in particular, by the greater percentage of intrusive clasts at the expense of volcanically derived and associated red sedimentary clasts up section. Though the fluvial system identified here is believed to have fed the lacustrine system discussed above, no transitional environment of deposition is recognized in the study area.

St. Francis Harbour River Formation

Lithology

Maroon to gray sandstone and polymict conglomerate are intercalated with minor siltstone and shale. The areal distribution of this formation is shown in Figure 27 along with the locations of partial sections, which are presented in Figure 28.

Per cent lithology diagrams and sand/shale ratios for the composite section are presented in Figure 29. Little of the lower portion of the section is exposed in the St. Francis Harbour River, though scattered outcrops of sandstone are

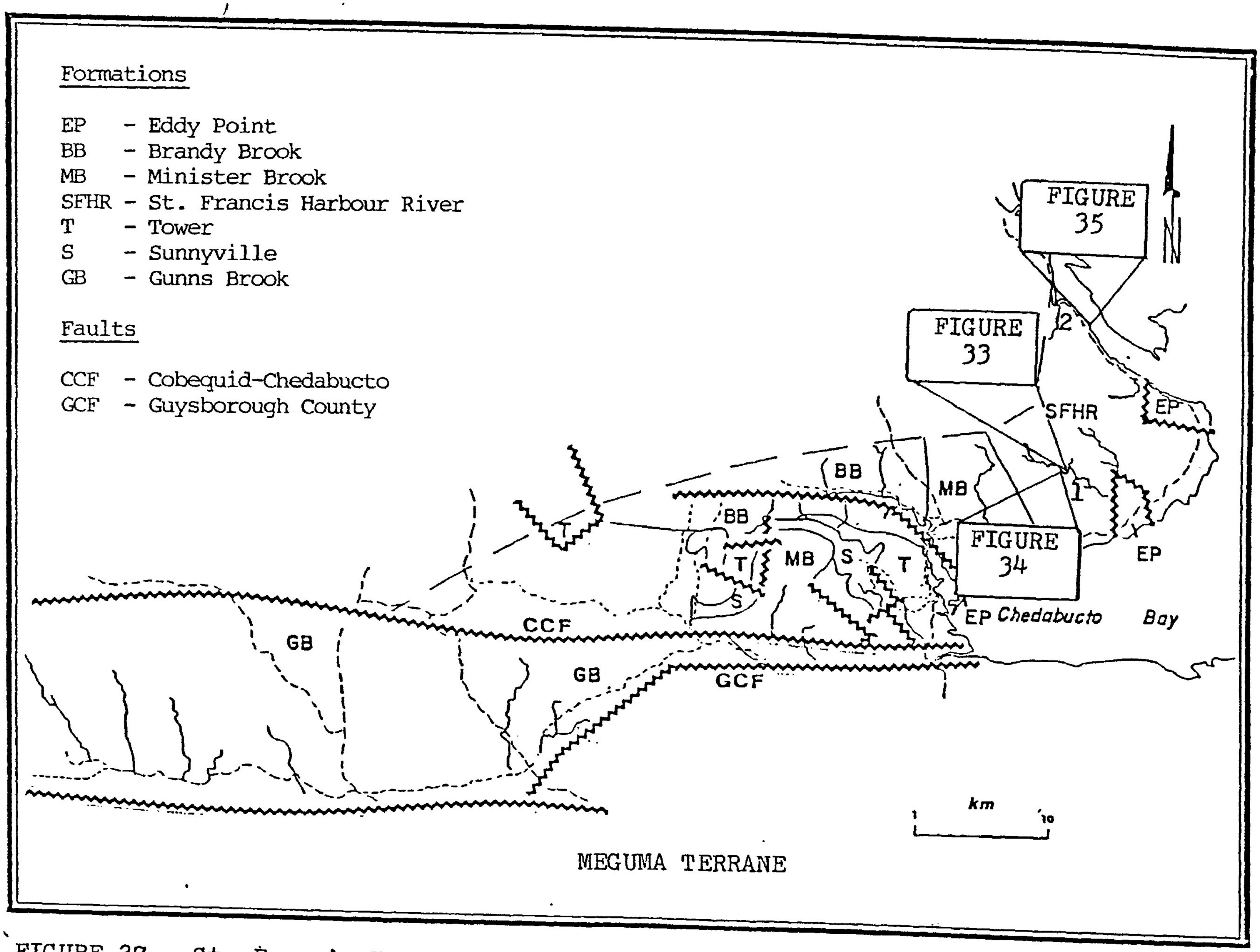


FIGURE 27. St. Francis Harbour River Formation: areal distribution and location of partial sections: 1 - St. Francis Harbour River; 2 - East Brook.

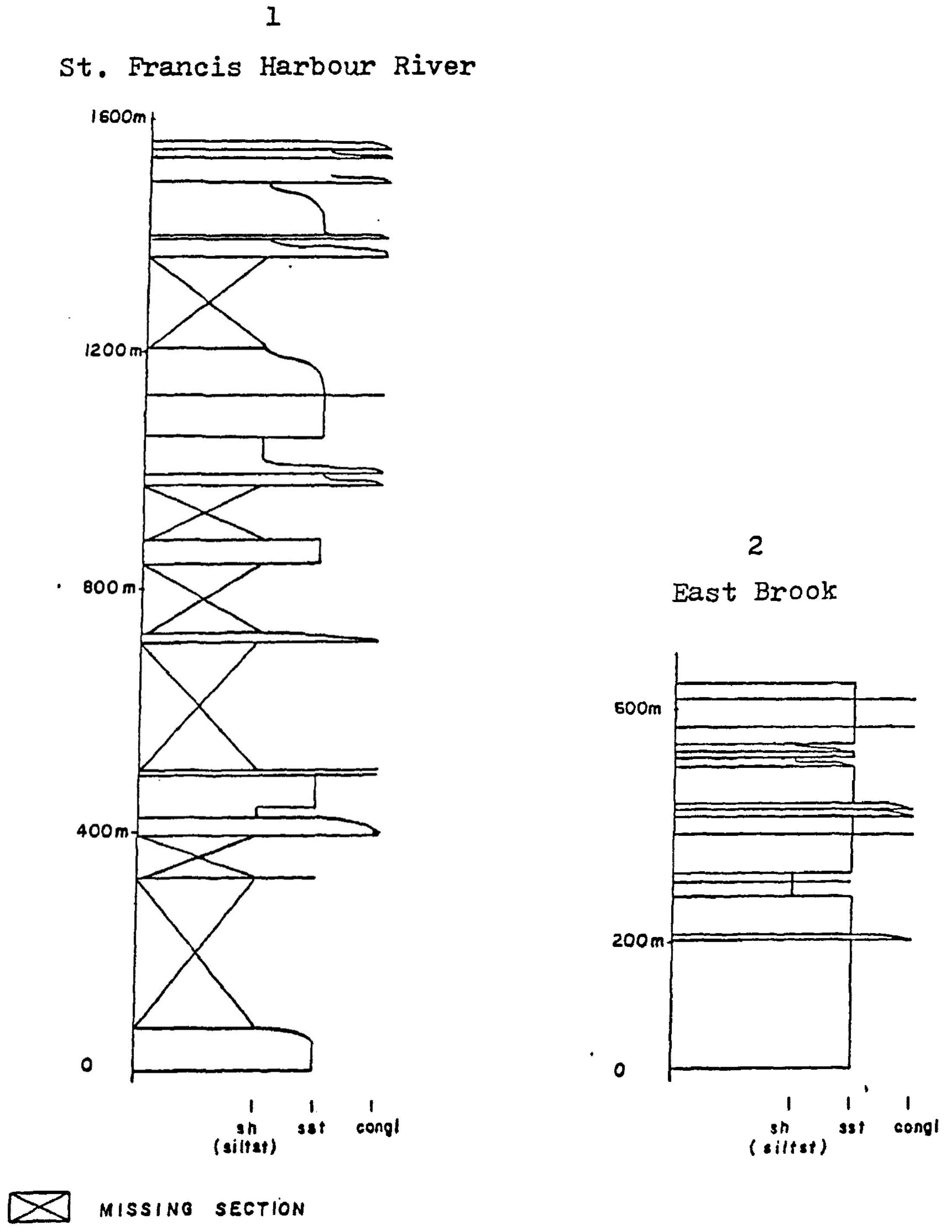


FIGURE 28. St. Francis Harbour River Formation: partial sections (refer to FIGURE 27).

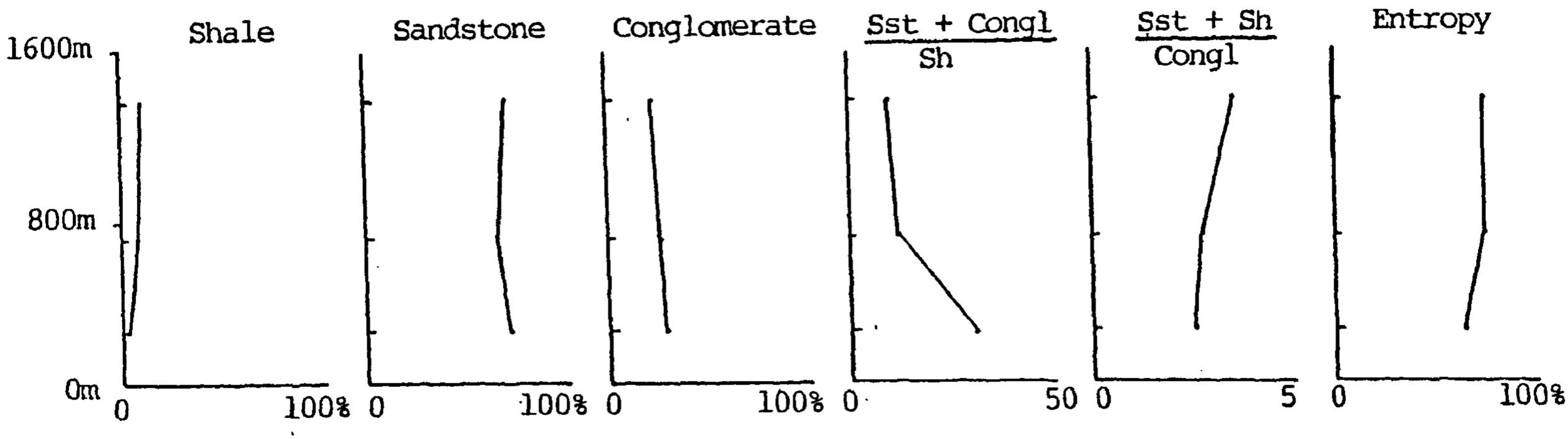


FIGURE 29. St. Francis Harbour River Formation: per cent lithology diagrams and sand/shale ratios for the St. Francis Harbour River section.

present. Shale and sandstone + conglomerate to shale decreases towards the top of the unit. Entropy increases through the lower part of the formation and remains constant to the top of the section.

The lower part of the section is better exposed in East Brook (refer to Figure 28). Sand/shale ratios for the basal section exposed here (Figure 30) show an increase in the relative proportion of shale and particularly of conglomerate. The amount of sandstone decreases markedly. Note that the actual amount of shale in this section is minimal, and thereby helps to explain the unusual increase evident in the figure. Entropy decreases significantly up section. These trends are similar to those derived for the lower part of the succession in the St. Francis Harbour River section (compare Figures 29 and 30).

Clast lithologies in conglomerates of the St. Francis Harbour River Formation also exhibit similar trends in the St. Francis Harbour River and East Brook sections (compare Figures 31 and 32). In the St. Francis Harbour River, the conglomerate exposed nearest the base of the succession contains abundant clasts of volcanic composition but no red sedimentary clasts.

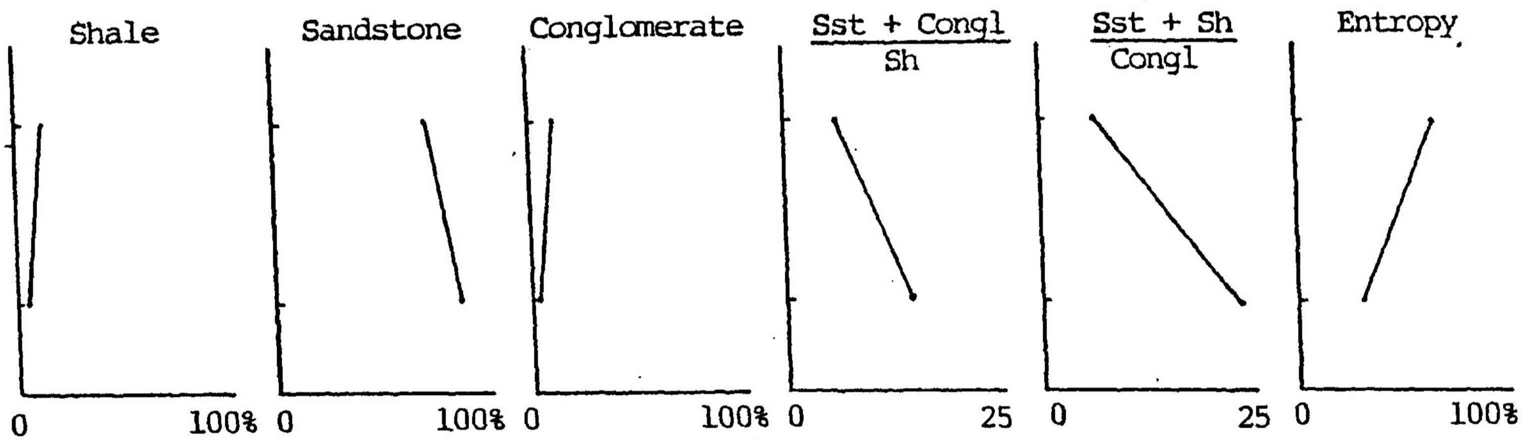


FIGURE 30. St. Francis Harbour River Formation: per cent lithology diagrams and sand/shale ratios for the East Brook section.

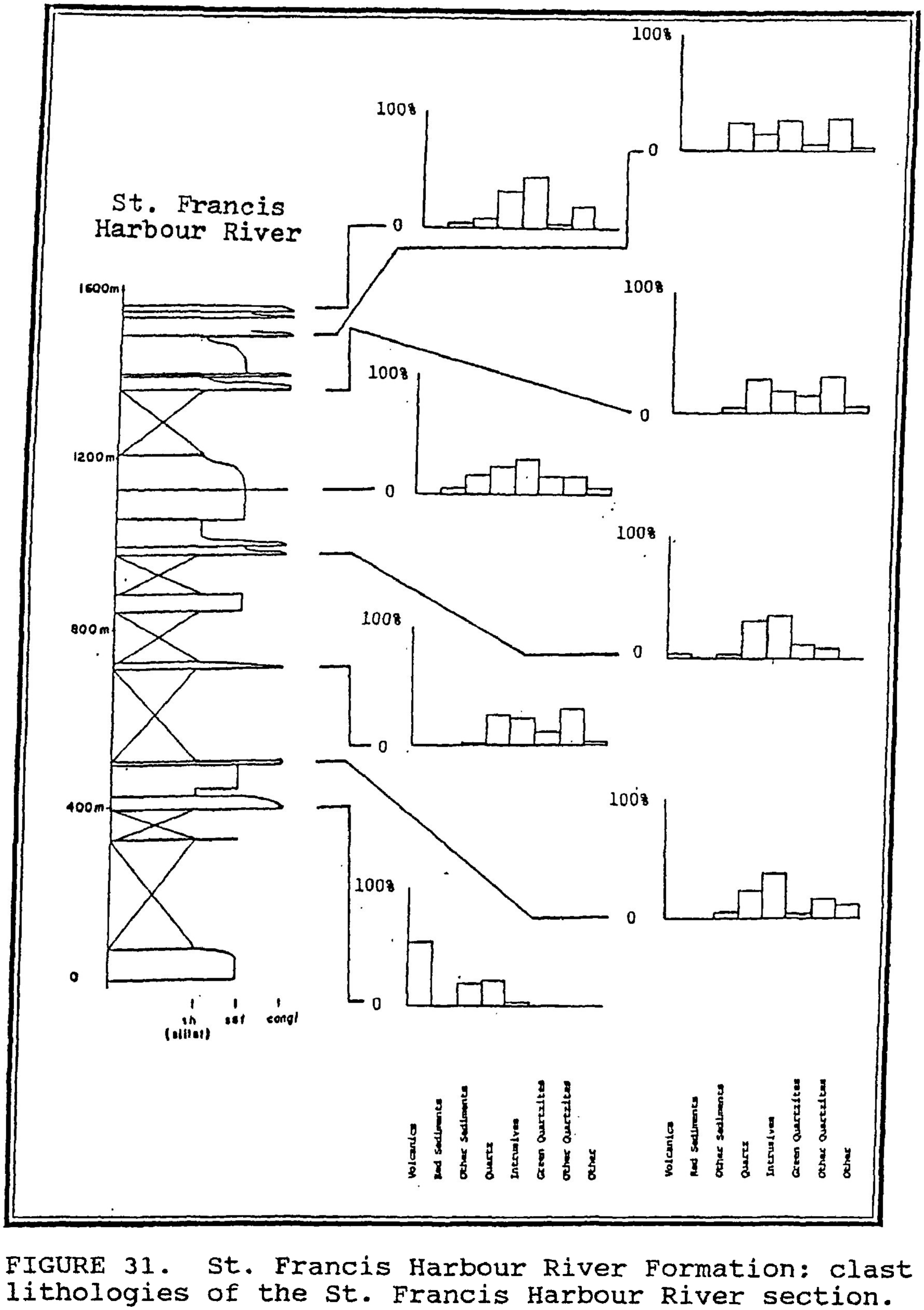


FIGURE 31. St. Francis Harbour River Formation: clast lithologies of the St. Francis Harbour River section.

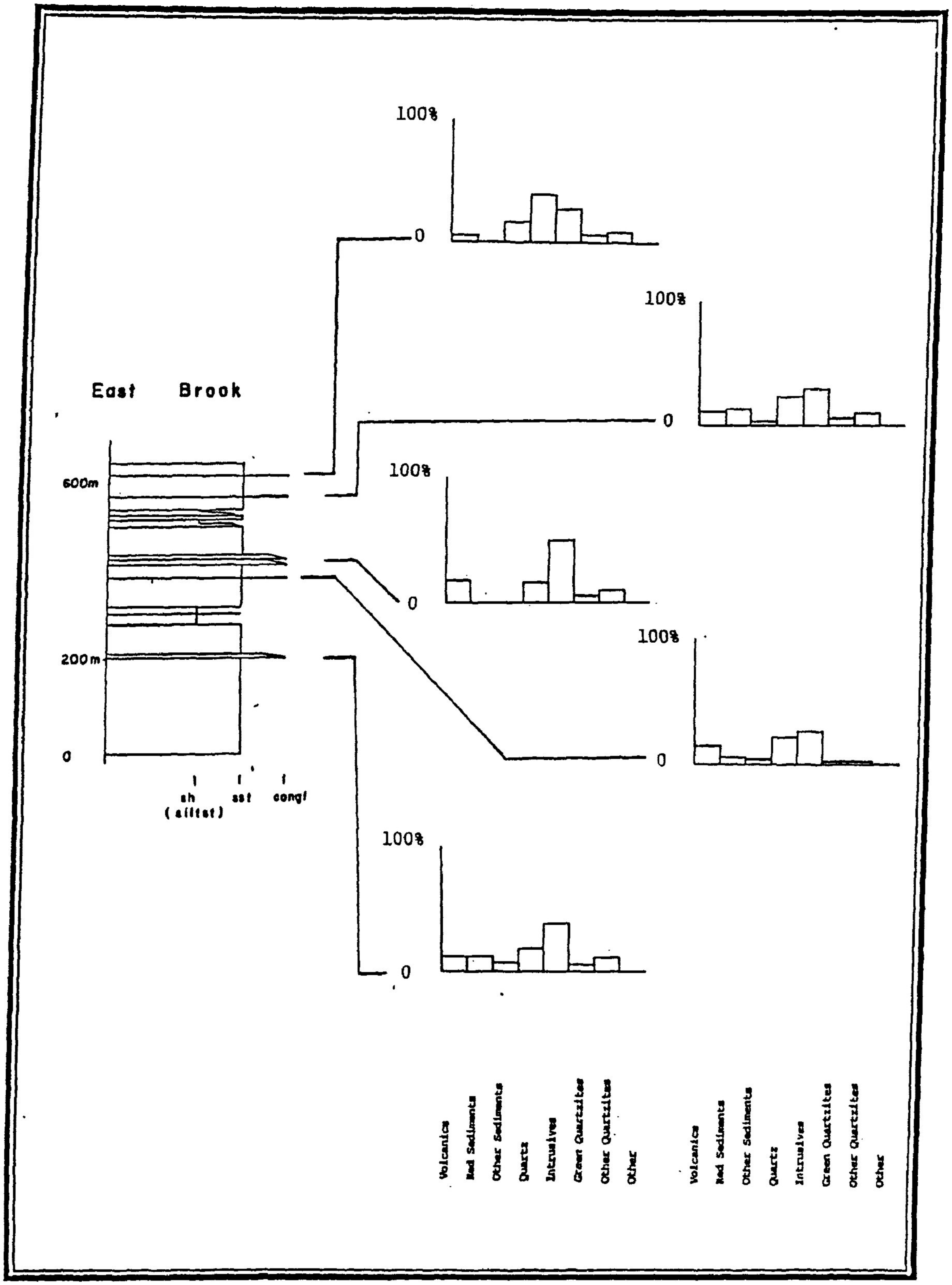


FIGURE 32. St. Francis Harbour River Formation: clast lithologies of the East Brook section.

Up section, conglomerates rarely contain a subordinate percentage of sedimentary clasts and no volcanic clasts are evident in conglomerates more than 1,000 metres through the unit. The percentages of mudstone and sandstone clasts increase toward the top of the formation. With the exception of the lowermost pebble count, clasts of quartz, felsic intrusives and various quartzites account for the majority of the detritus. Conglomerates in the East Brook section (Figure 32) all contain volcanic clasts, and the percentage decreases up section from 24% at the base to 6% at the top. Mudstone and sandstone clasts are minor constituents of conglomerates near the base of the section but account for 16% of the pebbles in the uppermost units. Quartz increases up section whereas intrusive clasts increase to approximately the mid-point of the exposed section and begin to decrease slightly. Quartz and intrusive clasts account for 54% to 68% of pebbles in these conglomerates. The percentage of quartzite remains fairly constant through the East Brook section.

Thickness and Contact Relationships

A complete section through this formation is not available in the study area and this is reflected in the partial sections presented above (refer to Figures 27 and 28). Several northeast - southwest trending fold axes plunge at low angles (10° to 15°) where this unit is exposed. In addition, bedding measurements suggest the presence of a larger scale, relatively open anticlinal structure. Repeated strata were removed from the section. The thickness of the formation is estimated to be 1,600 metres.

Neither the upper nor the lower contacts of the St. Francis Harbour River Formation are exposed in the study area. These rocks are observed in fault contact with the Eddy Point Formation (discussed below).

Age

Four samples from this formation were submitted for palynological analysis. Though minor organic matter was present, oxidation and the high thermal maturity of samples precluded accurate spore identification. Spores were found in two of the samples but they were described as black and unidentifiable (pers. comm., 1989, J. Utting, Institute of Sedimentary and Petroleum Geology).

Although this formation is isolated in terms of its true contact relationships, two observations contribute to a determination of its relative position in the stratigraphic column for the Guysborough Basin. Volcanic clasts of intermediate to felsic composition occur in conglomerates of this formation as do a significant percentage of intrusive clasts. Clast lithologies are similar to those observed within coarse members of the Tower Formation and suggest a similar source terrane for these two units. Furthermore, the depositional environment (see the discussion below) is similar to that of the upper Tower Formation. Sediments of the St. Francis Harbour River Formation are considered to have been deposited immediately after and in part, at the same time as those of the upper Tower Formation. The unit is therefore assigned an age of Earliest Carboniferous.

Sedimentary Lithofacies

The lithofacies which characterize the St. Francis Harbour River Formation are similar to those described for the upper Tower Formation, and to those attributed by Miall (1977, 1978) to an alluvial style of sedimentation. The terminology proposed by Miall (1977, 1978) is applied to these sediments.

Conglomerates are maroon to gray, clast supported, poorly to moderately sorted units. Clasts range up to cobble size, though the average clast size in most beds is pebble size. Coaly fragments and organic debris are locally evident. The matrix is typically coarse to very coarse grained sandstone and the lower contacts are generally scoured surfaces. Internally, very coarse grained units tend not to exhibit any form of stratification (facies Gm). However, pebble conglomerates are trough cross stratified (facies Gt) and normally graded. These units are often stacked (Figure 33), with individual beds up to 0.7 metres thick. Furthermore, beds are commonly lens shaped and are observed to pinch out laterally. Figure 34 is a section illustrating coarse to medium grained units typically found in this formation.

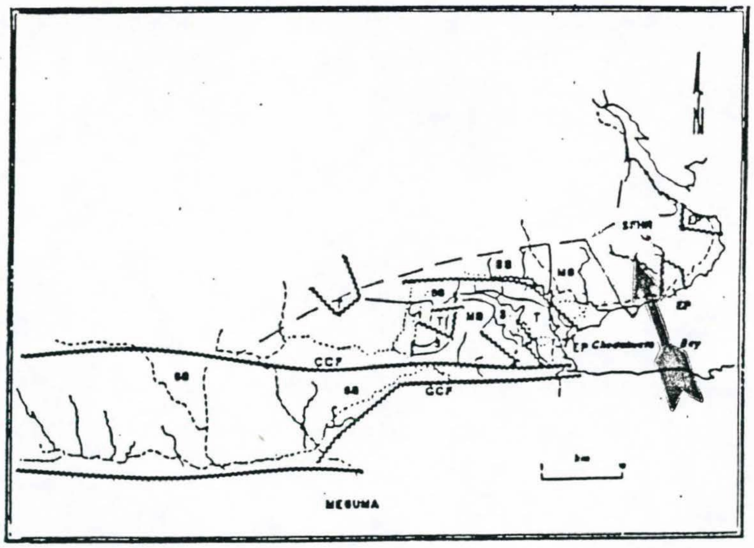


FIGURE 33. St. Francis Harbour River Formation: conglomerate lithofacies. Poorly sorted, clast supported pebble conglomerate beds up to 70 centimetres thick are stacked and pinch out laterally. Internally, beds are trough cross stratified and normally graded. This section is also located on FIGURE 27.

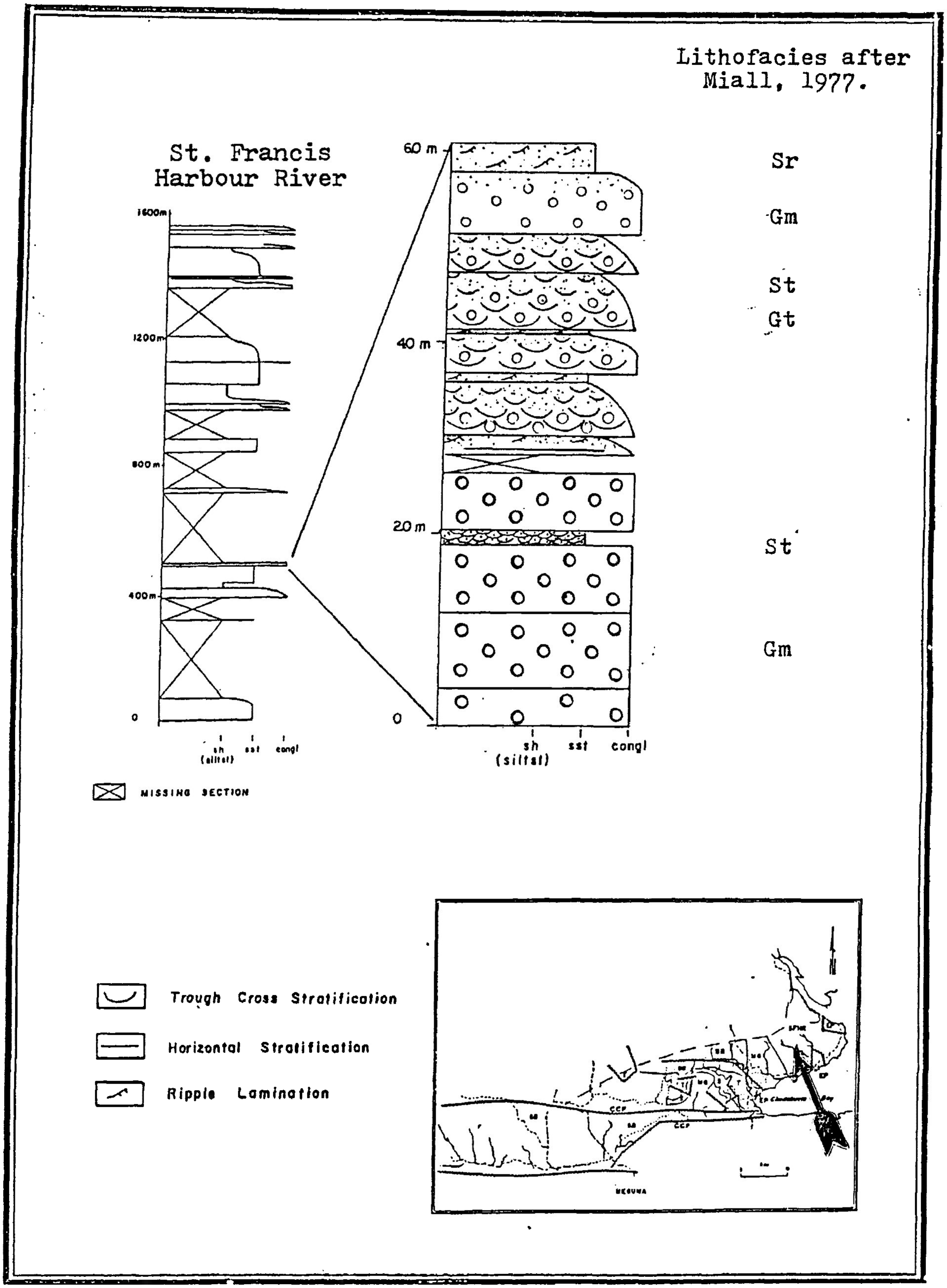


FIGURE 34. St. Francis Harbour River Formation: conglomerate-sandstone lithofacies. This section is also located on FIGURE 27.

Sandstones are very coarse to fine grained units which are commonly trough cross stratified (facies St) and normally graded. Bed thickness is generally less than a metre. Planar cross stratified beds (facies Sp) are locally observed and in one instance, are stacked over a vertical thickness of 1 metre. Additional structures observed include parallel lamination (facies Sh) and ripple cross lamination (facies Sr). Lenticular bed contacts are often present and units are commonly several metres thick. Figure 35 illustrates the nature of stacked trough cross stratified units within the formation. Beds are normally graded and broad scours are common.

Siltstones and shales occur as thin beds above medium to fine grained sandstones as described above. They are massive to parallel laminated (facies Fm) and locally exhibit ripple cross lamination (facies Fl). Moderately to poorly developed mud cracks are locally evident.

Depositional Environment

Lithofacies described above are similar to those present in the upper part of the Tower Formation. Interpretation is, therefore, based on Miall's (1977, 1978) summary of lithofacies and their mode of deposition in the braided fluvial environment. Most of the facies described above have been interpreted for the Tower Formation. Massive pebble conglomerate (Gm) with minor interbedded pebbly sandstone (Ss) is interpreted to represent the product of longitudinal bar formation and minor channel scouring on the bar top. Trough cross stratified pebble conglomerate (Gt) grading normally to trough cross stratified sandstone (St) reflects dune migration within a channel (Figure 34). Horizontally laminated sandstone (Sh) grading normally to ripple laminated sandstone (Sr) is interpreted as upper flow regime planar bed flow and low flow regime sedimentation, respectively. To summarize, Figure 34 illustrates a longitudinal bar which is overlain by a channel system in which the deposits suggest periodic flood events and subsequent waning flow.

Channel deposition is indicated by the trough cross stratified coarse to medium grained sediments in Figure 35 and no fine grained facies are present. Bed thickness is significantly greater in this section than in Figure 34, which reflects deposition by higher energy flood events.

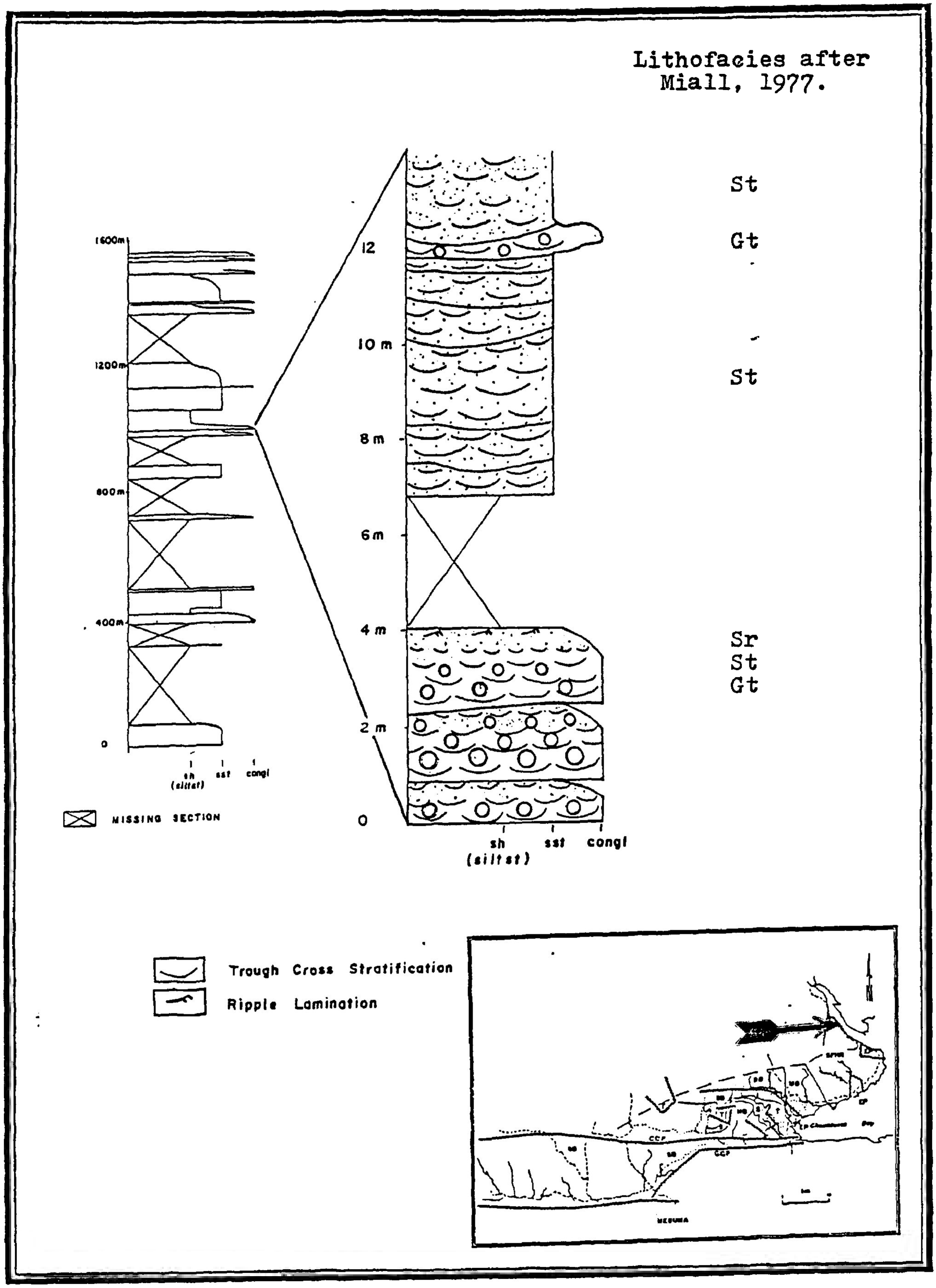


FIGURE 35. St. Francis Harbour River Formation: conglomerate-sandstone lithofacies. This section is also located on FIGURE 27.

Features not depicted in these sections but present in isolated exposures include individual and stacked planar cross stratified sandstones (Sp) up to 0.15 metres thick, interpreted by Miall (1977, 1978) to represent deposition on transverse bars. Minor ripple laminated to parallel laminated siltstone and mudstone (Fl and Fm, respectively) often contain organic remains and exhibit locally well developed mud cracks. They are interpreted to represent overbank deposits.

The presence of facies typical of deposition on longitudinal bars and in channels, with rare transverse bar deposits, are suggestive of sedimentation in a braided fluvial system. The proportion of conglomerate is slightly higher than in the upper Tower Formation discussed above. Similar arguments to those made in the previous section are invoked to suggest that the Donjek type braided stream model (Williams and Rust, 1969; Rust, 1972; Miall, 1977, 1978) is most applicable for the sediments of the St. Francis Harbour River Formation.

Though the lower portion of the succession exposed in East Brook exhibits a coarsening upward trend (refer to Figure 30), a fining upward trend is evident through the formation (Figure 29). Vegetation was present as indicated by the occurrence of coaly fragments incorporated in bar and channel conglomerates high in the section. Clast lithologies indicate a general reduction in the importance of the local volcanic rocks and associated interflow sediments up section. External source areas become prevalent with the proportion of intrusive clasts and associated quartzites denoting the change initially observed in the underlying Tower Formation sediments. The presence of sedimentary clasts of local origin becomes more important up section. The St. Francis Harbour River Formation is interpreted to represent Donjek type braided fluvial deposition at least partially contemporaneous with accumulation of the upper Tower Formation.

Minister Brook Formation

Lithology

The Minister Brook Formation consists of interbedded siltstone, shale, sandstone and dolomitic limestone with subordinate conglomerate. Figure 36 shows the areal distribution of this unit in the study area and the location of partial sections shown in Figure 37.

Per cent lithology diagrams and clastic ratios for the Minister Brook Formation are provided as Figure 38. The

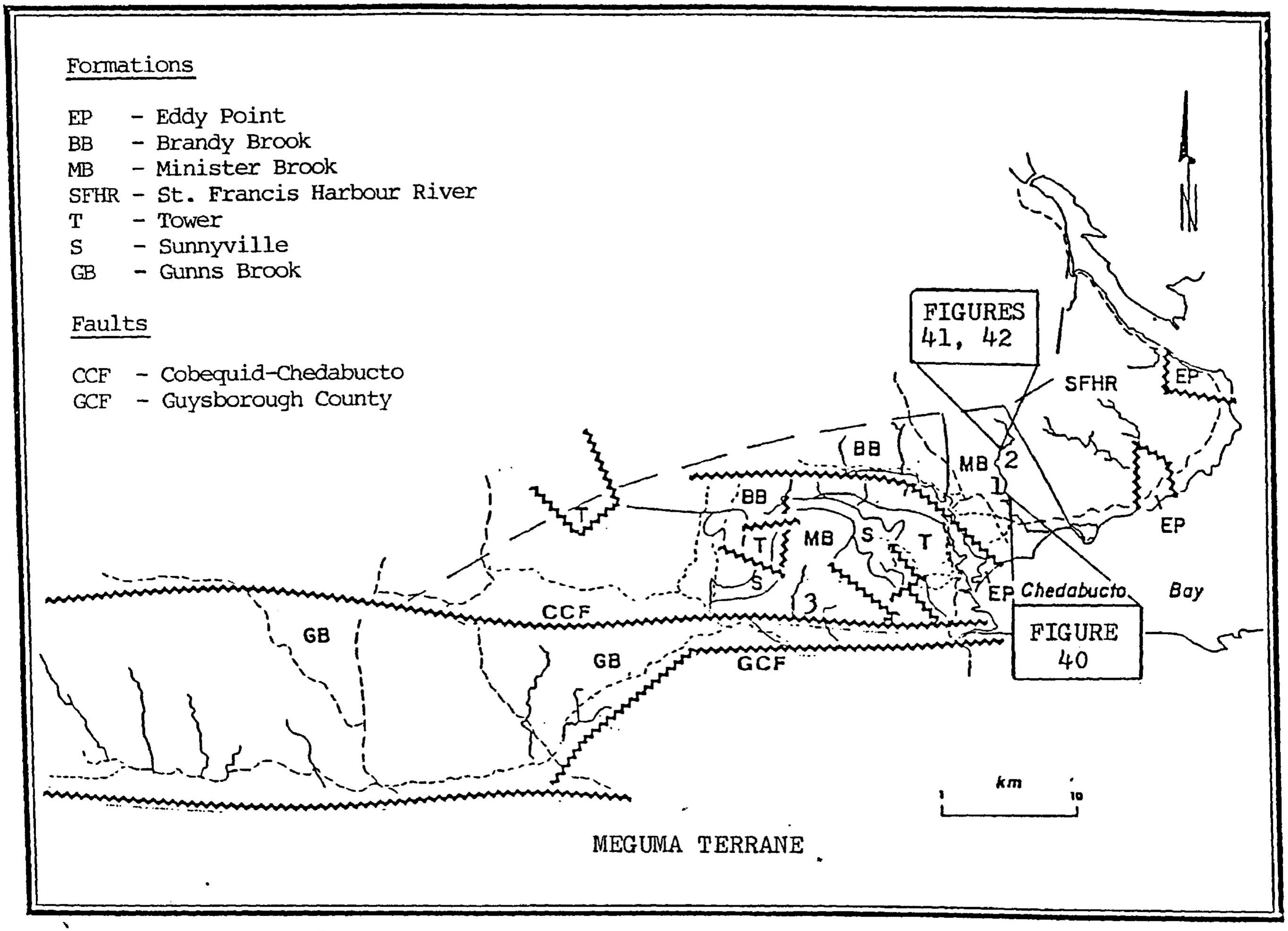


FIGURE 36. Minister Brook Formation: areal distribution and location of partial sections: 1 - Clam Harbour River West; 2 - Clam Harbour River East; 3 - Minister Brook.

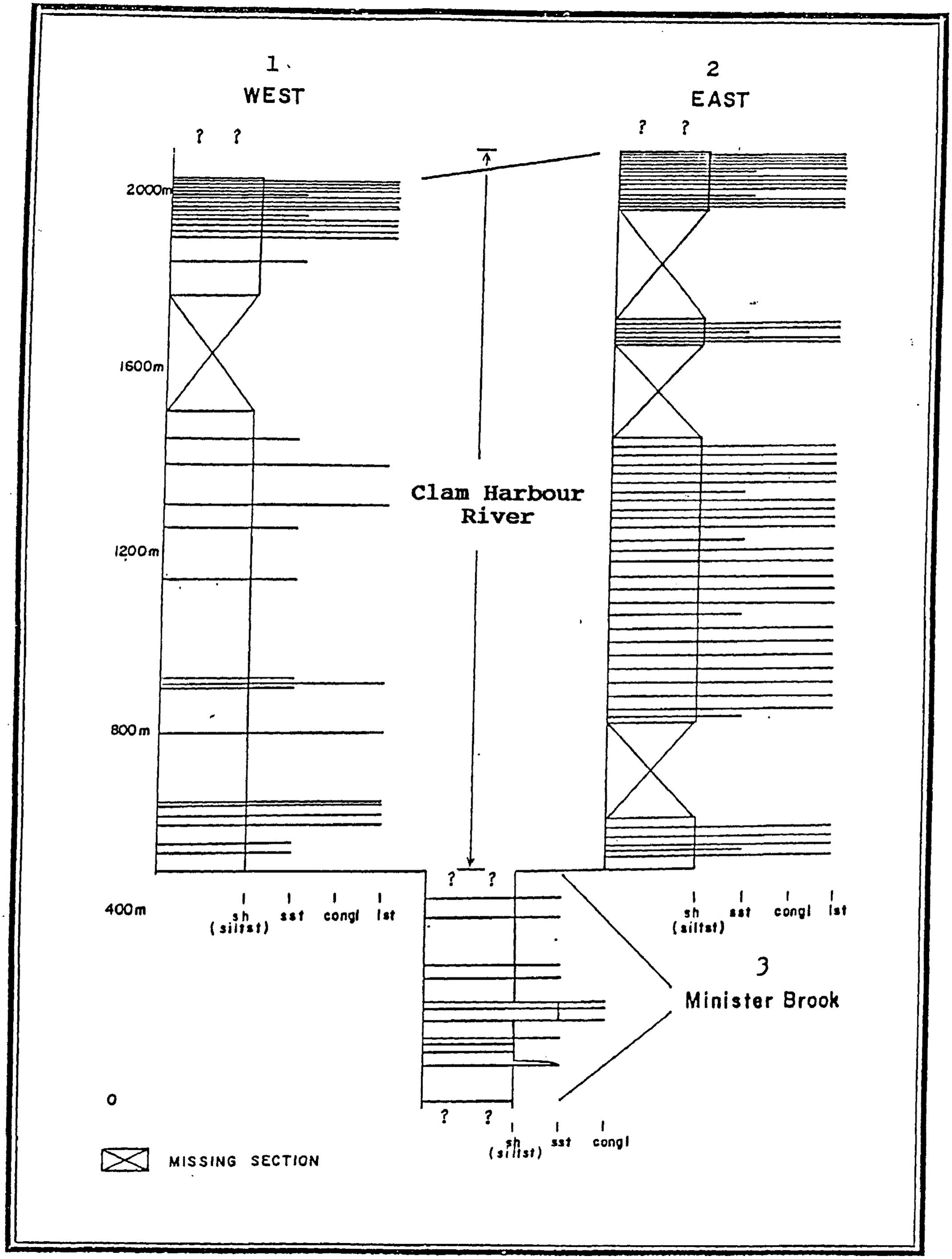


FIGURE 37. Minister Brook Formation: partial sections (refer to FIGURE 36).

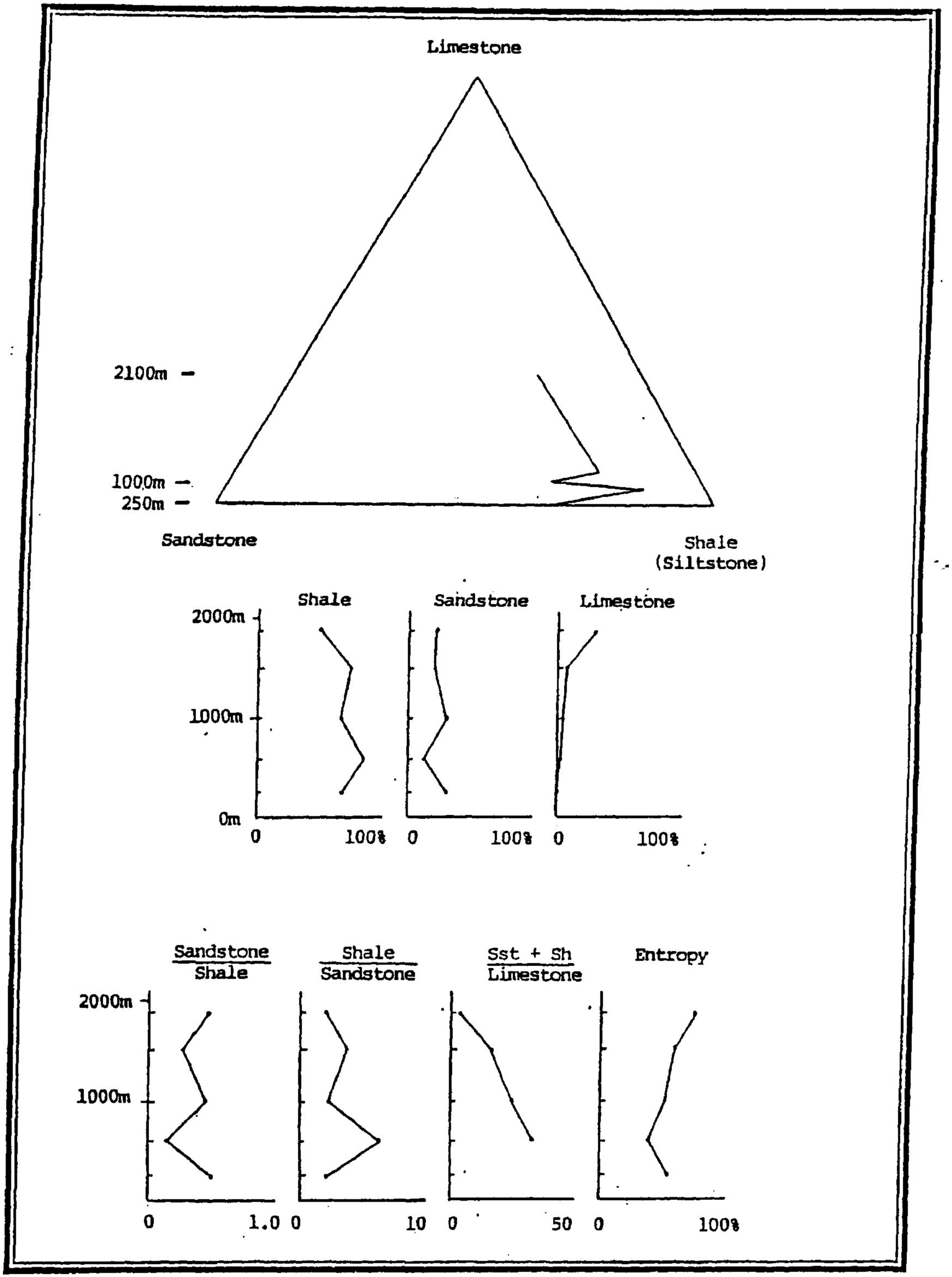


FIGURE 38. Minister Brook Formation: per cent lithology diagrams, sand/shale ratios and clastic ratios for the Minister Brook and Clam Harbour River sections.

proportion of sandstone to shale fluctuates up section though a general fining upward trend is evident. The amount of limestone increases up section and the resultant ratio of clastic to chemical sediments steadily decreases. Entropy generally increases up section. The ternary diagram depicts all components of the unit. The fluctuating proportion of clastic sediments and the gradual increase in limestone up section are evident in this figure.

Clast lithology information is limited as coarse units are present only in the lower portions of the formation (Figure 39). A significant proportion of intrabasinal red mudstone clasts occur in the lower conglomerate and none are evident in the upper bed. Various other intrabasinal sedimentary clasts comprise a large portion of the pebbles in these units and their abundance increases up section to 56%. Finally, quartzite pebbles are important in both conglomerate beds.

Thickness and Contact Relationships

As with previous formations, a complete section through the unit is not available in the study area (refer to Figures 36 and 37). Contacts are unexposed, though the unit locally

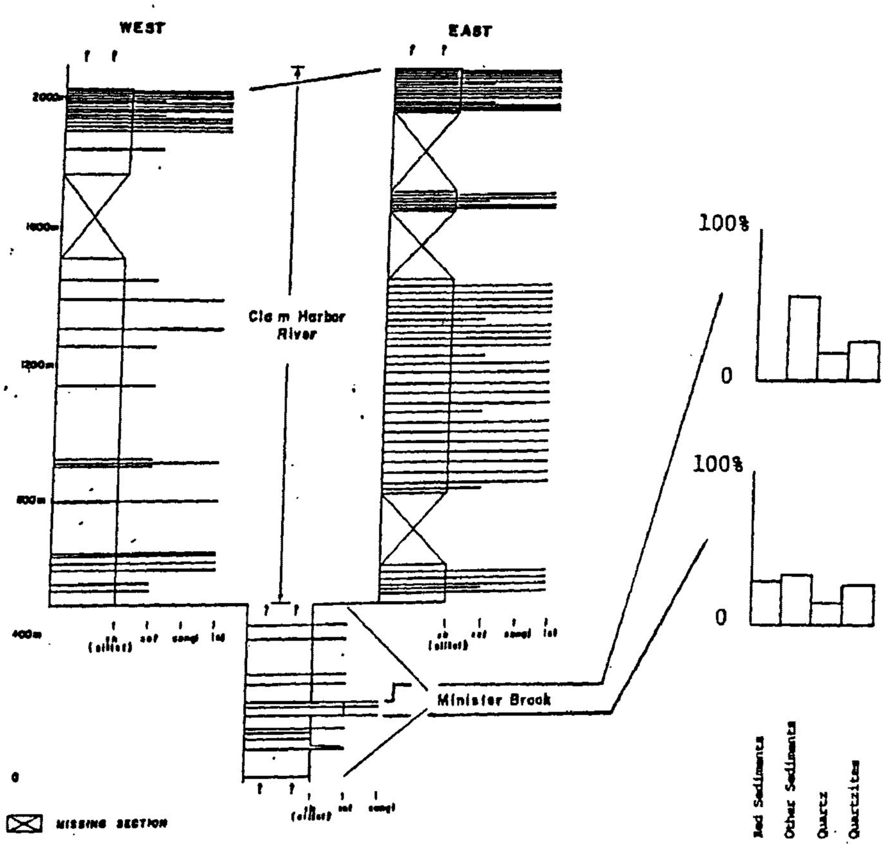


FIGURE 39. Minister Brook Formation: clast lithologies of the Minister Brook section.

occurs in close proximity to outcrops of Tower Formation strata and bedding attitudes are similar in both formations (South Brook, for example). Furthermore, rare red beds similar to those of the Tower Formation are intercalated with gray to green Minister Brook sediments. The contact between these two units is therefore inferred to be locally conformable.

Isolated parts of the section are placed to reflect the rare, thin limestone beds found in Minister Brook and the lower proportion of limestone beds at the bottom of the Clam Harbour River section than at the top. Furthermore, exposures of conglomerate are restricted to the Minister Brook section. Northeast-southwest trending axial traces were identified in this unit and repeated strata were removed from the section. The combination of structure and the course of the Clam Harbour River offered an opportunity to examine lateral variation through the formation. Two partial sections are presented for the upper part of the general section (Figure 36). The most obvious difference is the greater percentage of chemical sediment evident in the eastern exposure along the river. The minimum estimated thickness for the Minister Brook Formation is 2,100 metres.

Age

A single sample from this formation was submitted for palynological analysis. Rare woody and coaly fragments were present but identifiable spores were lacking (pers. comm., 1989, J. Utting, Institute of Sedimentary and Petroleum Geology).

The Minister Brook Formation is interpreted to lie conformably above the Tower Formation and is assigned an age of Early to Mid-Carboniferous.

Sedimentary Lithofacies

Minor conglomerate is exposed in the lower portion of the Minister Brook section. Clasts are generally less than one centimetre in diameter though course pebbles are locally evident. Units are clast supported, poorly to moderately poorly sorted, and often exhibit an irregular lower contact. They are massive to stratified and grade normally to parallel laminated sandstone and mudstone.

Sandstone occurs throughout the formation but in subordinate amounts to fine grained sediments. Figure 40 illustrates the character of the formation where chemical sediments are lacking. Bed thickness ranges up to 20 centimetres though thin bedded units are typical. Internally, beds are normally graded, ripple laminated to parallel laminated and are commonly draped by mudstone.

Siltstones and mudstones account for the majority of the section. Beds are typically green to gray with occasional maroon units near the bottom of the succession. They are generally on the order of one centimetre thick, are massive to parallel laminated and exhibit normal grading. These units commonly overlie normally graded fine grained sandstones (Figure 41).

Dolomitic limestone beds commonly occur above fine grained horizontally laminated mudstone. Bed contacts between clastic units and overlying limestone are gradational, whereas contacts between limestone and overlying clastic sediment are sharp. Though limestones are exposed throughout the section, they become more significant towards the top of the formation, particularly in the eastern part of the Clam Harbour River

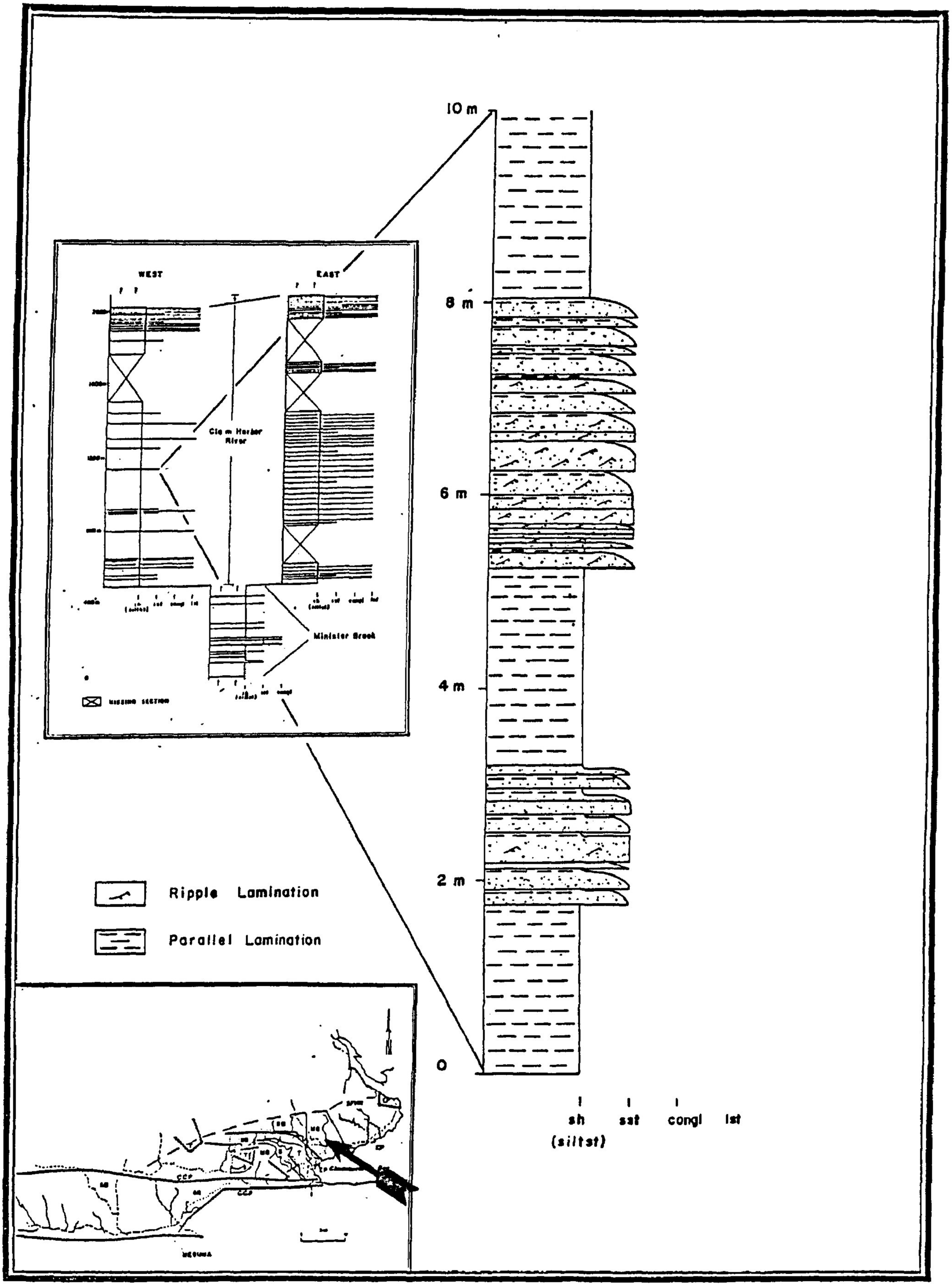


FIGURE 40. Minister Brook Formation: sandstone-shale lithofacies. This section is also located on FIGURE 36.

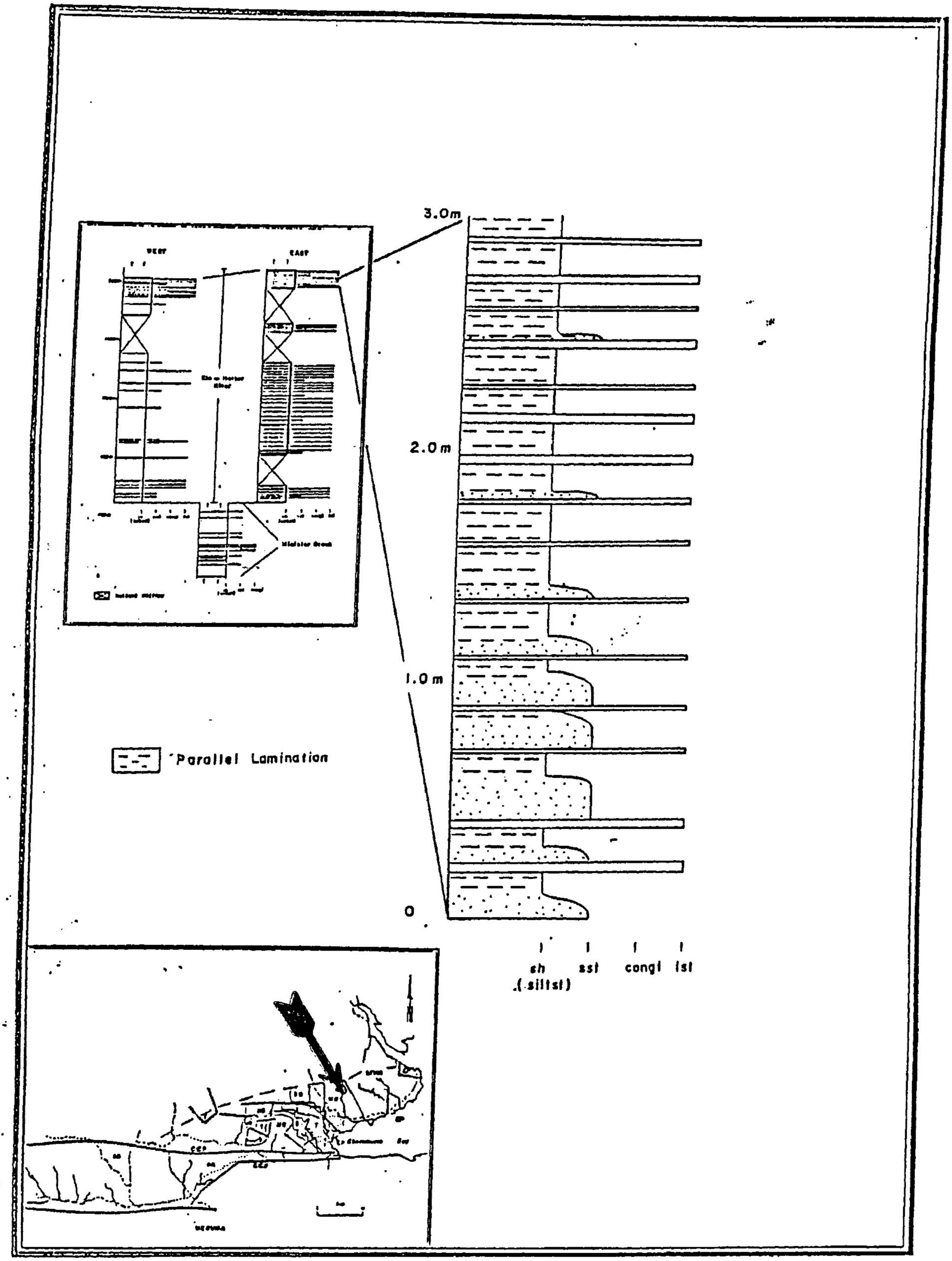


FIGURE 41. Minister Brook Formation: sandstone-shale-limestone lithofacies. This section is also located on FIGURE 36.

(Figure 37). Limestone is creamy white to gray to locally pink, and differentially weathers a distinct pale yellow. In the lower part of the formation, chemical sediments occur as isolated beds and in thin groups of beds (3 beds totalling 15 centimetres over 1 metre of clastic sediment, for example). Related clastic sediments ordinarily range up to fine sand size, though coarser sandstone is occasionally observed. Figure 42 illustrates the character of finely interbedded clastic and chemical sediments near the top of the exposed section. Here, dolomitic limestone beds typically overlie normally graded clastic sequences which vary from 30 centimetres to less than a centimetre in thickness. Not only are chemical sedimentary beds more numerous at the top of the section, they are also considerably thicker. In some areas, beds up to 20 centimetres thick are present.

Depositional Environment

The association of normally graded parallel laminated shale, siltstone and fine sandstone with interbedded limestone throughout the section strongly suggest a subaqueous environment of deposition such as a lacustrine setting. Four main components of lacustrine sediments in temperate lakes

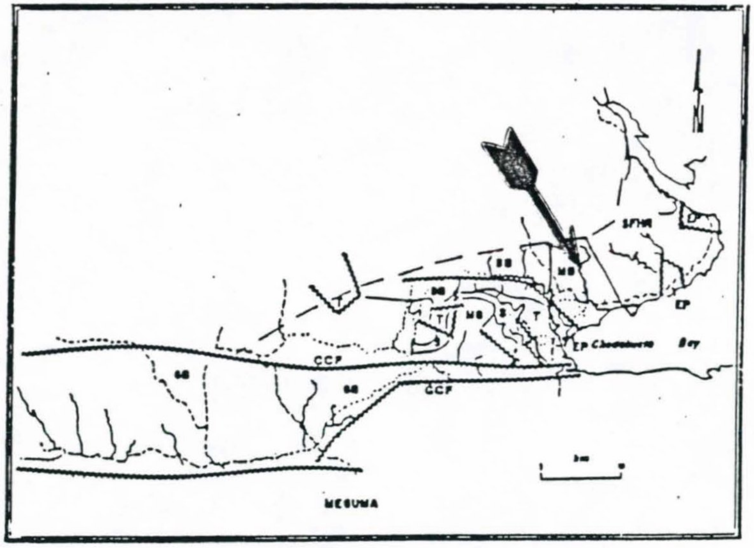


FIGURE 42. Minister Brook Formation: sandstone-shale-limestone lithofacies. Yellow weathering dolomitic limestone beds up to several centimetres thick overlie parallel laminated, normally graded clastic beds (fine grained sandstone, siltstone and shale). Refer to FIGURE 41. This section is also located on FIGURE 36.

were recognized by Dean (1981) and include clastic material derived within the confines of the basin, biogenic silica, carbonates and organic material. Each of these components is discussed in more detail below. Clastic lithofacies typically exhibit distinct trends within a given basin. Sediment dispersal patterns within modern and ancient lakes generally portray coarse to finer grained sediments towards the basin centre (Amiel and Friedman, 1971; Arnal, 1961; Hough, 1935; Thomas et al., 1972, for example) where fine grained sediment accumulation is almost entirely from suspension (Collinson, 1978).

Clastic lithofacies and depositional processes were studied by Sturm and Matter (1978) in Lake Brienz, Switzerland. Four lithofacies were recognized, including: 1) interbedded sand and mud; 2) laminated mud; 3) homogeneous mud; and 4) laminated mud with interbedded, normally graded sand and silt (Sturm and Matter, 1978). Sediment is supplied to the lake by low to high density turbidity currents (overflows, interflows and underflows). The style of sedimentation is directly related to thermal stratification of the lake and the density difference between river and lake water (Sturm and Matter, 1978). Facies 1 is interpreted to represent deltaic sedimentation, facies 2 is interpreted as the product of non glacial varves, facies 3 represents mud accumulation on the upper slope and facies 4 reflects deposition by turbidity currents (Sturm and Matter, 1978). Clastic facies in the Minister Brook Formation are similar to those described above. Most prevalent are normally graded ripple laminated sandstones to siltstones and shales, interpreted as turbidity current deposition and sediment accumulation from suspension, respectively (Figures 40 and 41).

Coarse sediments are described in the context of an offshore decrease in grain size and are interpreted as near shore gravels, deposited above wave base (Picard and High, 1981). Conglomerates near the base of the Minister Brook Formation contain an increasing amount of extrabasinal clasts. Clast lithologies are similar to those identified in fluvial conglomerates near the base of the Brandy Brook Formation and suggest that the two formations may be lateral equivalents.

Chemical sediments appear near the base of the section and become more important towards the top of the formation. They reflect an increasing amount of dissolved calcium carbonate leached from rock in the catchment basin and supplied to the depocentre (Dean, 1981). Two models for carbonate deposition are proposed by Picard and High (1981). Greater carbonate accumulation toward the centre of a lake results from dilution by clastic sediments near the shore. Conversely, carbonate productivity is higher in shallow water and may lead to significant accumulation near the lake margins (Picard and High, 1981). Dolomitic limestones are prevalant in the Minister Brook Formation and reflect a higher magnesium to calcium activity ratio in the lake water, than what is considered typical of lacustrine sediments (Folk and Land, 1975).

Organic matter becomes a more important constituent of lacustrine sediments with time, as vegetation is established in the drainage basin and as productivity increases in the littoral zone (Dean, 1981). Facies proposed by Picard and High (1981) include nearshore accumulations of plant debris and offshore deposition of organic matter below wave base, thereby facilitating preservation. The bulk of the sediments in the Minister Brook Formation are green to light gray and imply that a minimal amount of organic matter was incorporated into these sediments.

Most of the sediments in the Minister Brook Formation are interpreted to have been deposited from turbidity currents originating near the lake margin and from suspension. The association of normally graded turbiditic clastic sediments overlain by carbonate is suggestive of seasonal cyclicity. Carbonate precipitation is influenced by temperature and abundant clastic sediment would be supplied to the basin during spring floods (Picard and High, 1981). Autocyclic and allocyclic processes are evident in the measured sections. Individual fining upward, clastic sequences reflect single, autocyclic depositional events (Figure 40). Normally graded sandstone units thin upward as carbonate beds thicken and become more frequent (Figure 41), and reflect decreasing terrigenous sediment influx to this portion of the basin. Fluctuation of lake level is proposed as a mechanism for the development of a swampy flood plain during deposition of the Brandy Brook Formation in the following section. Higher base level would cause aggradation up paleoslope, hence sediment starvation of the lake with respect to medium grained detritus. Consequently, carbonate deposition would be interrupted less often and for shorter periods of time. This relationship is indicated by an increasing frequency and thickness of chemical sedimentary beds toward the top of the Minister Brook Formation.

At this point it is interesting to refer back to the general section depicted in Figure 37. The course of the Clam Harbour River provides an opportunity to examine lateral variation in the formation. The frequency of chemical sedimentary beds increases upwards in both sections though limestone is considerably more abundant in the eastern section. Terrigenous sediment occurs throughout the unit and little organic matter is observed. Carbonate deposition in the Minister Brook Formation was directly dependant on the rate of clastic sediment influx to the lake, hence the facies model which proposes greater carbonate accumulation offshore is applied. The eastern section is interpreted to represent deposition further into the basin at greater water depths, and therefore farther from the influence of clastic sediment.

Brandy Brook Formation

Lithology

Gray sandstones and gray to dark gray and black siltstones and shales dominate in the Brandy Brook Formation. Rare red sandstone and gray polymict conglomerate occur in the lower portion of the unit. The outcrop distribution in the study area and section locations are shown on Figure 43. Partial sections through the unit are depicted on Figure 44. Per cent lithology diagrams and sand/shale ratios for the general section are provided as Figure 45. The lower part of the section is exposed in South Brook where the assemblage is sand-dominated with minor conglomerate and shale. Up section, shale first increases markedly, then gradually becomes less important, and finally becomes more abundant. An inverse trend is exhibited by the proportion of sandstone in the section. Orthoconglomerate is only exposed in the lower South Brook portion of the section. Above this, thin paraconglomerates are locally evident. The sandstone + conglomerate to shale ratio shows a sharp increase near the base, a gradual decrease to approximately the mid-section, followed by a gradual decrease to the top of the unit exposed

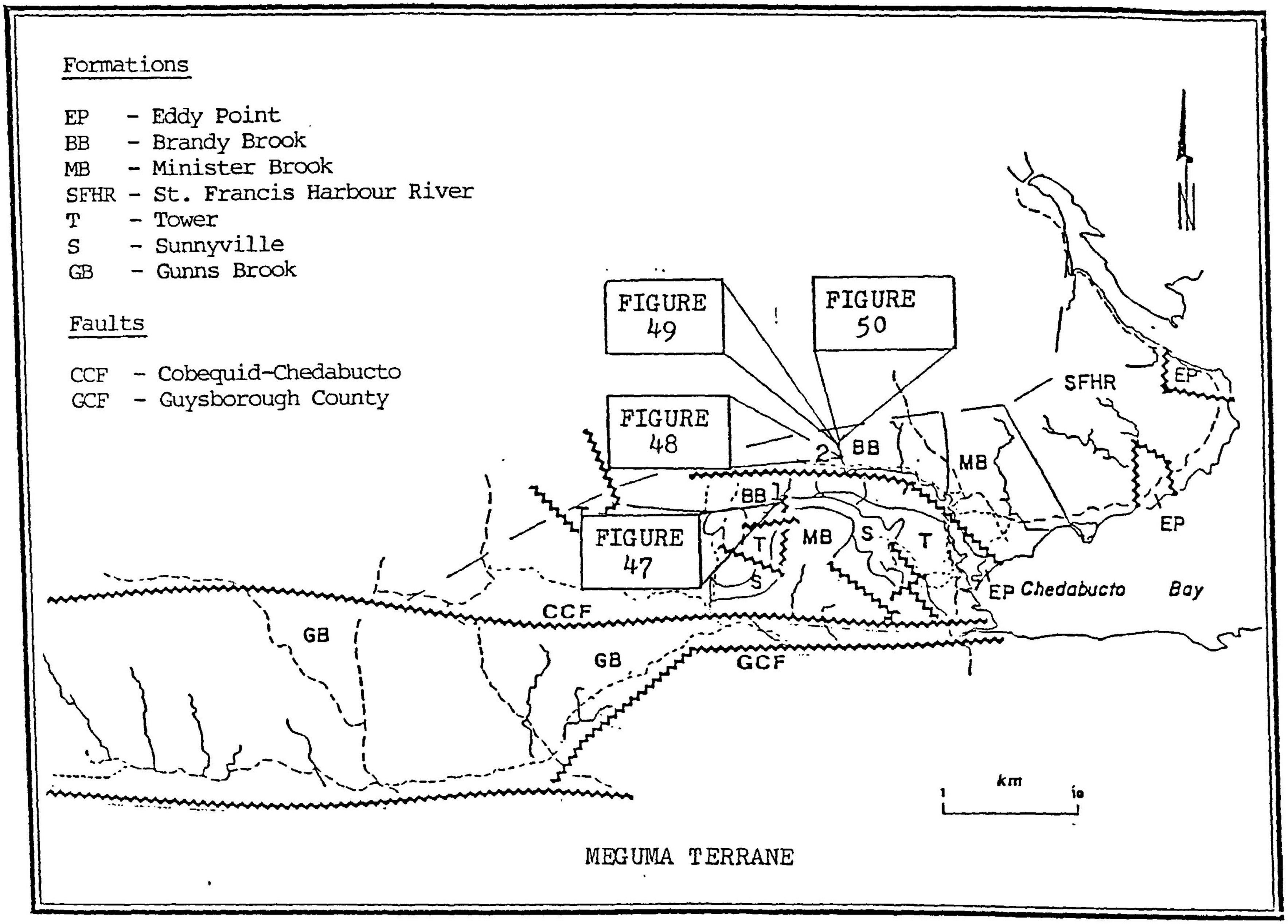


FIGURE 43. Brandy Brook Formation: areal distribution and location of partial sections: 1 - South Brook; 2 - Brandy Brook.

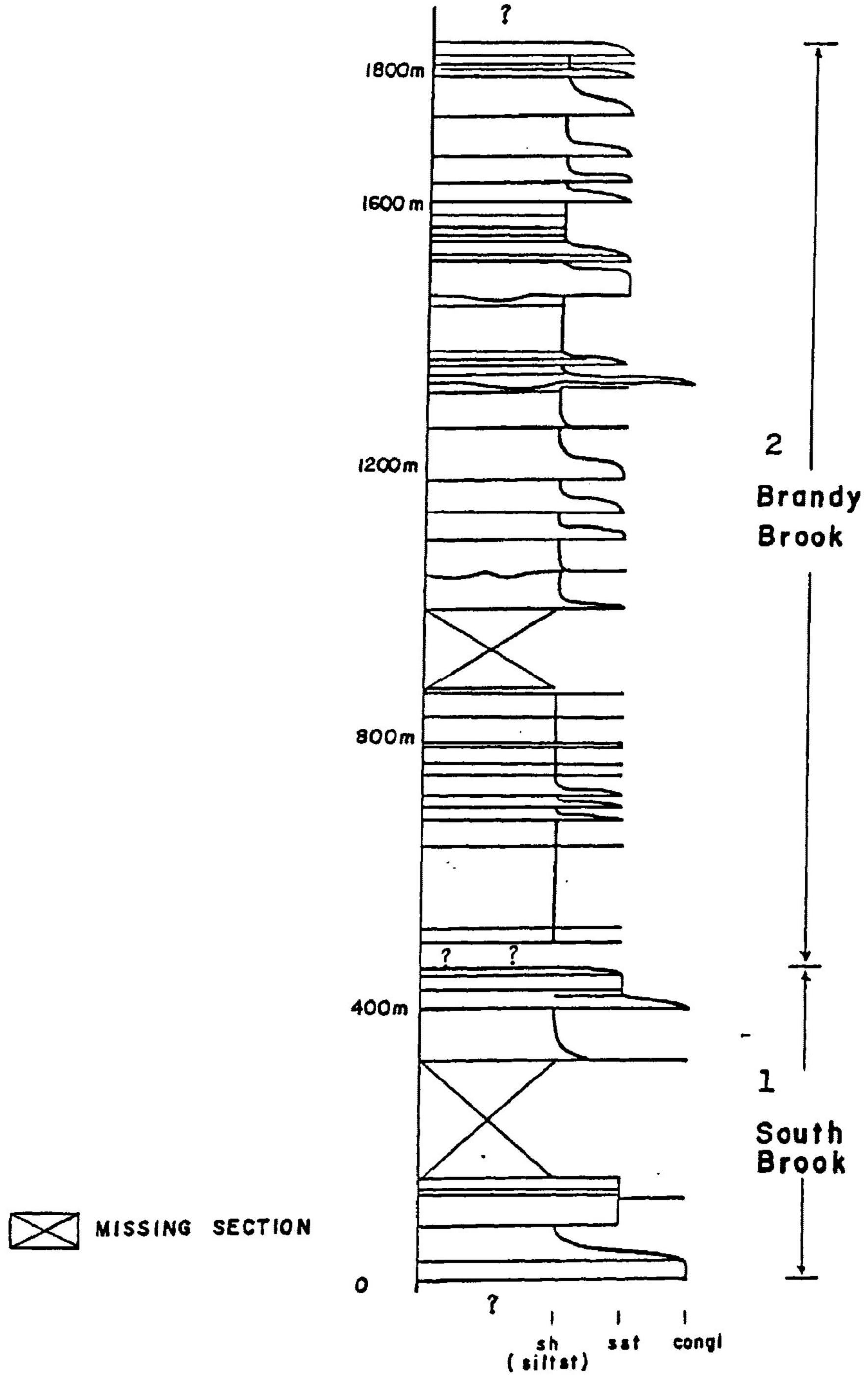


FIGURE 44. Brandy Brook Formation: partial sections (refer to FIGURE 43).

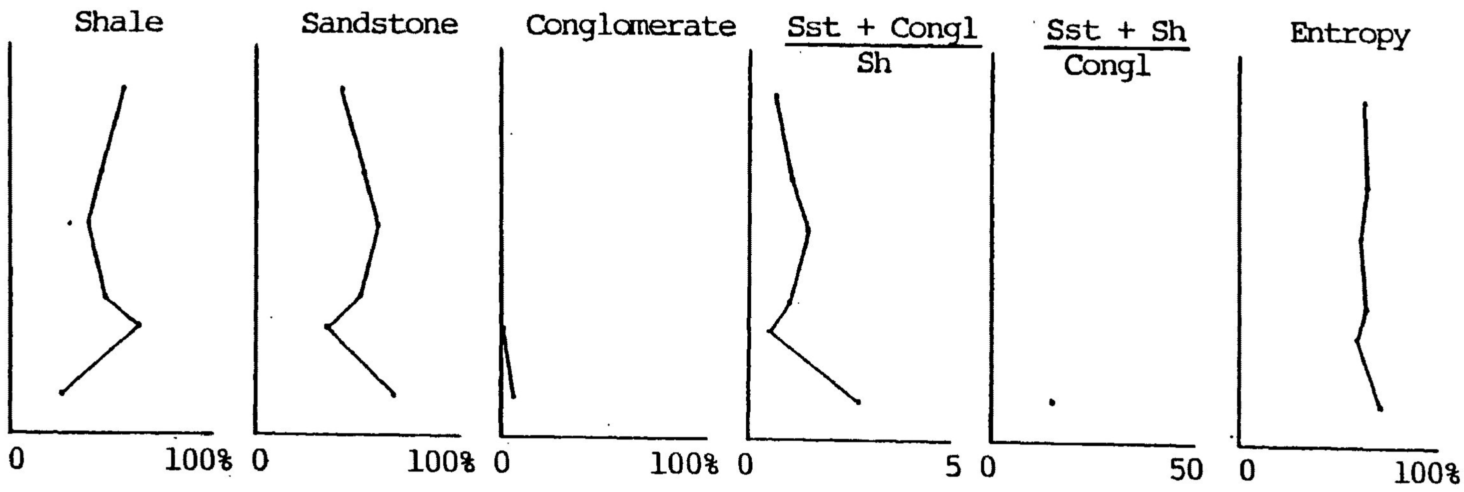


FIGURE 45. Brandy Brook Formation: per cent lithology diagrams and sand/shale ratios for the South Brook and Brandy Brook sections.

in the study area. Entropy remains relatively constant throughout the section.

Clast lithologies in conglomerates exposed in South Brook are shown as a series of three histograms in Figure 46 and several points of interest are noteworthy. No clasts of intrusive composition are observed and green quartzite is noted in only the lowermost unit. Other quartzites and clasts of sedimentary affinity comprise significant components of these units. The proportion of quartz decreases up section.

Thickness and Contact Relationships

A complete section through the Brandy Brook Formation is not available. Folding, faulting and incomplete exposure necessitates the use of two partial sections which exhibit characteristics typical of the unit. Furthermore, rocks belonging to this assemblage extend beyond the limits of the study area (refer to Figures 43 and 44).

The minimum thickness for the unit is estimated to be 1,850 metres. The lower 500 metres is exposed south of Guysborough Harbour in South Brook, and the upper 1,350 metres outcrops

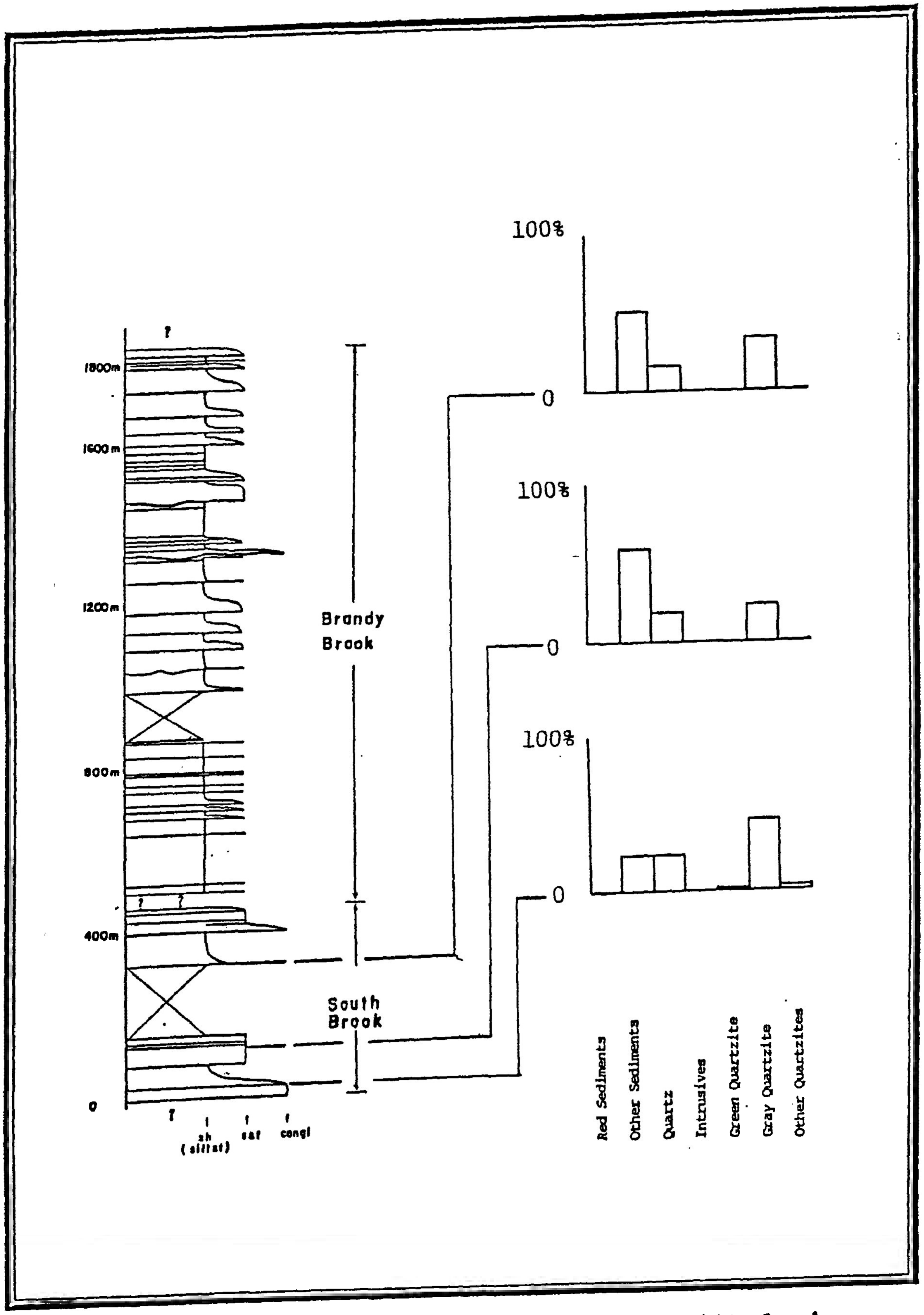


FIGURE 46. Brandy Brook Formation: clast lithologies of the South Brook section.

north of the Harbour in Brandy Brook. Schiller (1963) estimated the thickness of the Strathlorne Formation (equivalent to the Brandy and Minister Brook Formations) in the Guysborough area to be approximately 1,200 metres. It is important to note that several northeast-southwest trending and shallow plunging fold axes were located in South Brook. Repeated strata were removed from the measured section. Furthermore, rocks on the south side of Guysborough Harbour have suffered moderate deformation. Lithologically, fractured quartzites within which internal structures have been locally obliterated, predominate. Outcrops on the north side of the Harbour do not exhibit this deformation. Schiller (1963) has interpreted an east-west trending fault to underlie Guysborough Harbour but the nature of the displacement is unknown.

Neither the upper nor lower contacts of the Brandy Brook Formation are exposed in the study area. The unit is locally observed in fault contact with rocks of the underlying Tower Formation (Horton Brook, for example). Elsewhere, similar bedding attitudes measured in the Tower and Brandy Brook Formations suggest the contact to be at least locally conformable. The upper contact of the formation does not lie within the study area.

Age

Six samples were submitted for palynological analysis. Most of the samples contained woody, coaly, and exinous fragments. Spores found in these samples are vitreous black and consequently unidentifiable (pers. comm., 1989, J. Utting, Institute of Sedimentary and Petroleum Geology).

Schiller (1963) collected several samples which were examined for their fossil and floral contents. The assemblage identified from rocks of the Strathlorne Formation (equivalent to the Brandy Brook and Minister Brook Formations of this study) was indicative of an Early Carboniferous age.

Both the Minister and Brandy Brook Formations are interpreted to lie stratigraphically above the Latest Devonian to Earliest Carboniferous Tower Formation, which implies that these units are lateral equivalents of one another. Support is given to this hypothesis by similar clast lithologies in conglomerates of the two formations. Furthermore, volcanic clasts were not observed in these units. This suggests that the Brandy Brook and Minister Brook Formations also lie stratigraphically above the St. Francis Harbour River Formation. The Brandy Brook Formation is therefore assigned an age of Early to Mid-Carboniferous.

Sedimentary Lithofacies

Most of the lithofacies encountered in the Brandy Brook Formation are similar to those described for a sandy braided fluvial system by Cant and Walker (1976) and Cant (1978). The remainder are discussed with reference to facies presented by Miall, (1977) for braided fluvial deposits.

Conglomerate is more common near the bottom of the section. Clasts are rounded to subrounded, and are predominantly of pebble size. Minor intraclasts are present. Deeply scoured basal contacts (facies SS) commonly underlie pebble conglomerates but flat to slightly irregular bases are typical of very coarse sandstone. Internally, these units typically exhibit trough cross stratification (facies Gt of Miall, 1977) or horizontal stratification (facies Gm of Miall, 1977).

Normal grading to coarse sandstone (facies A and B) is common (Figure 47).

Sandstones range from very coarse to fine grained, and are moderately to well sorted. Trough cross stratified sandstone (facies A, B) occurs through a significant portion of the section and is illustrated in Figure 48. Beds are commonly stacked, with coarser and thicker beds more important near the bottom, and thinner, finer beds more prevalent near the top on a scale of several metres. Normally graded units are common. Fine sandstone beds tens of centimetres thick also occur within finer grained siltstone and shale. These units are characteristically sharp sided, normally graded, with internal structures grading from trough cross stratification near the base to ripple cross lamination to parallel lamination near the top (facies A, B, and F, respectively) (see Figure 49). Planar cross stratified sandstones in sets which average 10 centimetres thick (facies D) do not appear in the measured sections but are locally present in the formation.

Siltstones and shales in the section (see Figures 47, 49, and 50) are generally massive to parallel laminated. Thin beds rarely exhibit ripple cross lamination (facies F). These

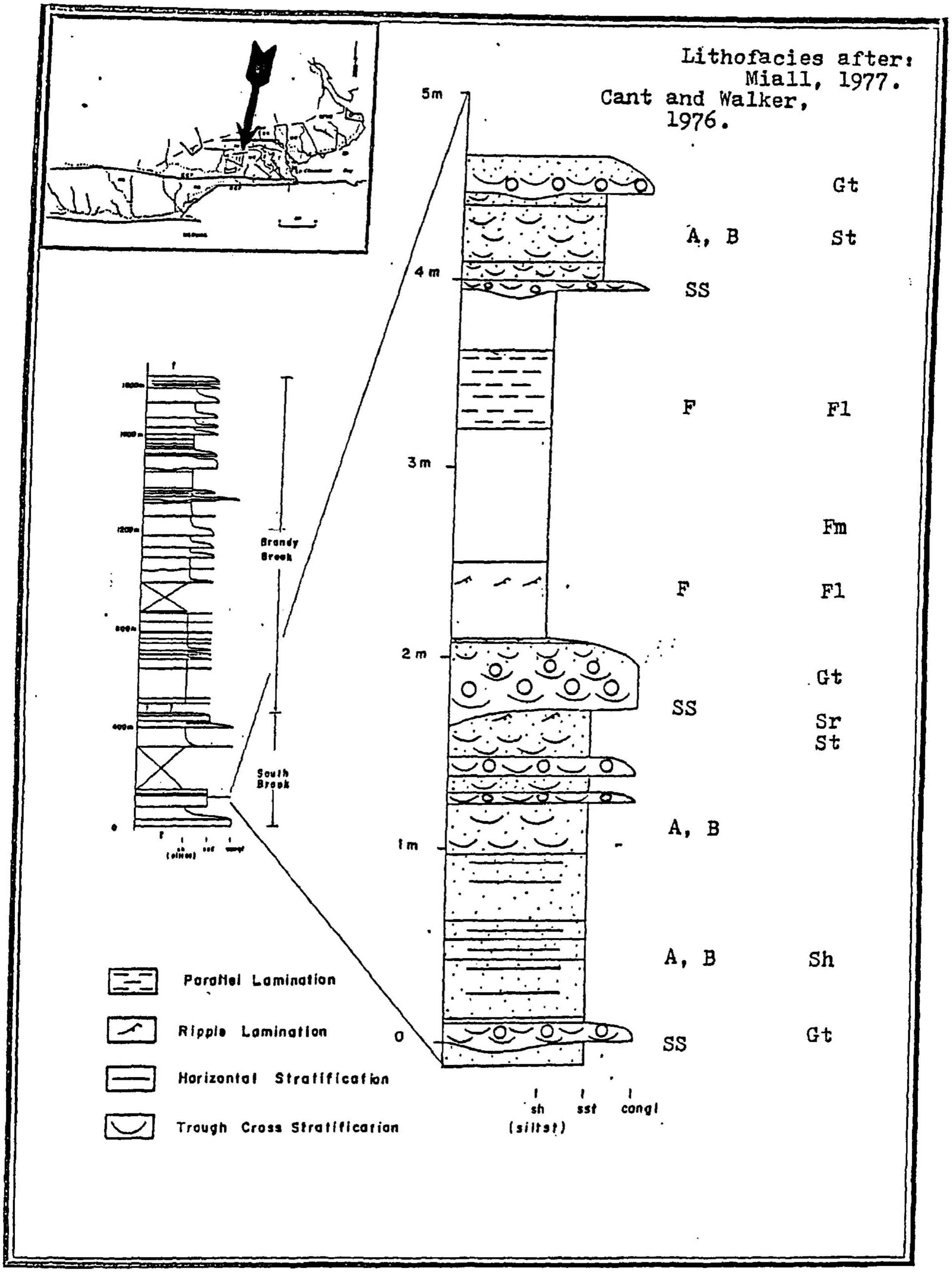


FIGURE 47. Brandy Brook Formation: conglomerate-sandstone-shale lithofacies. This section is also located on FIGURE 43.

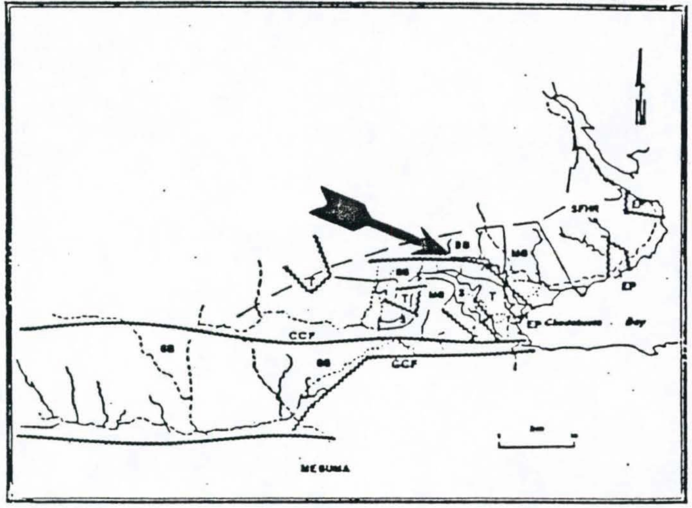


FIGURE 48. Brandy Brook Formation: sandstone lithofacies. Lensy bedded, trough cross stratified sandstone (lithofacies A, B of Cant and Walker, 1977) are commonly stacked and normally graded. This section is also located on FIGURE 43.

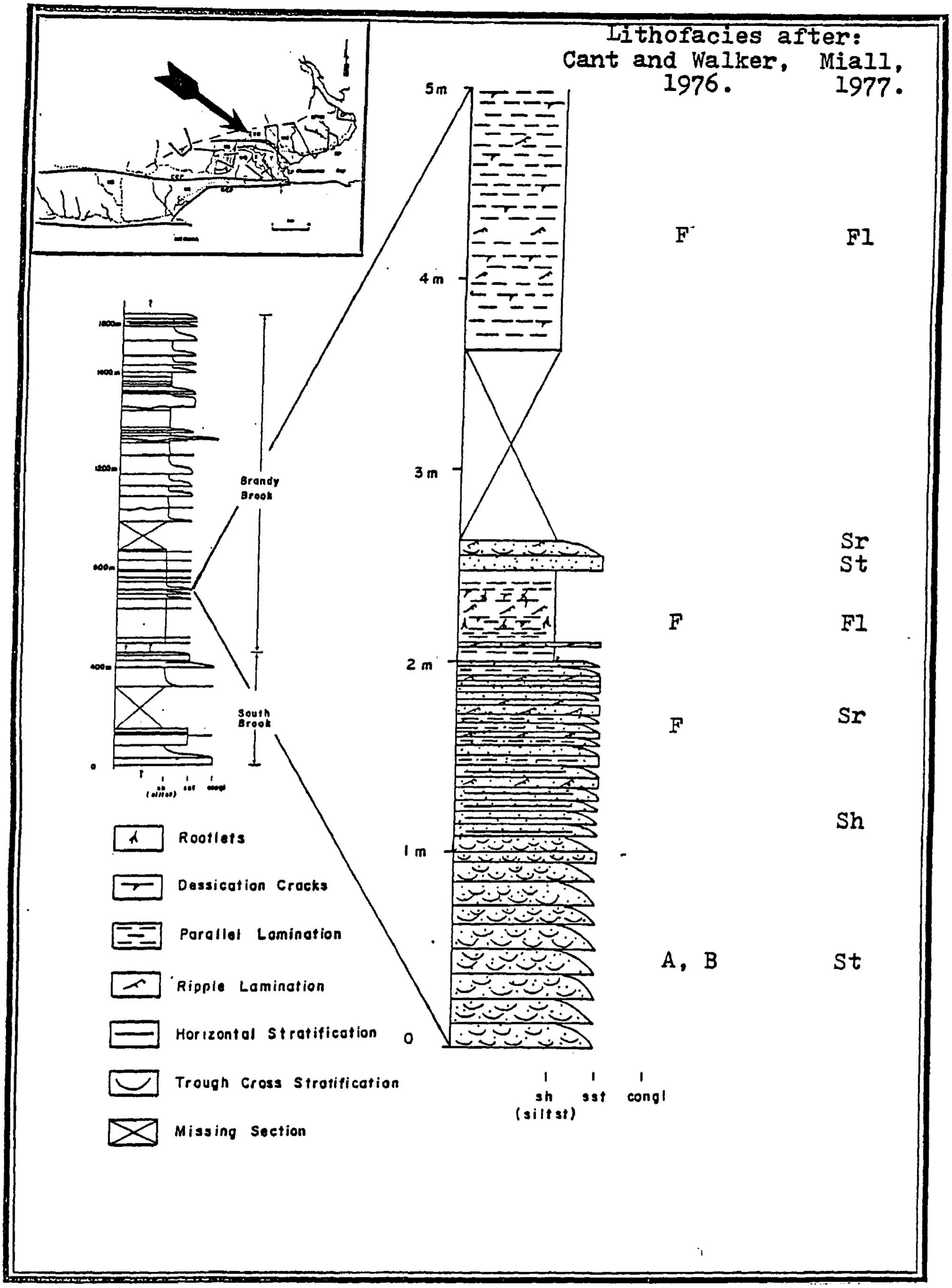


FIGURE 49. Brandy Brook Formation: sandstone-shale lithofacies. This section is also located on FIGURE 43.

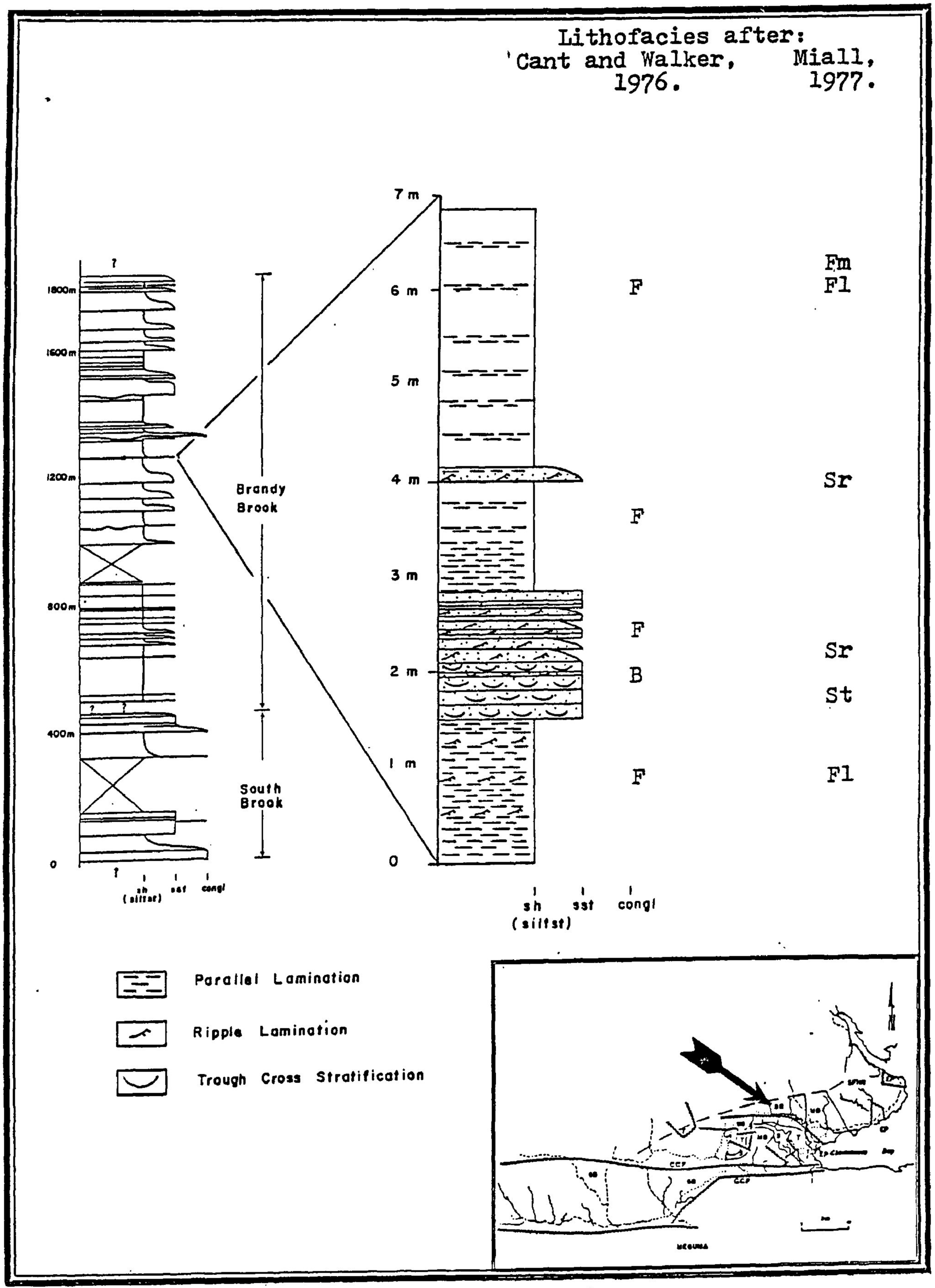


FIGURE 50. Brandy Brook Formation: sandstone-shale lithofacies. This section is also located on FIGURE 43.

sediments often contain appreciable amounts of dark organic material along bedding planes, whereas subvertical carbonaceous traces and distinct coaly fragments are occasionally evident. Poorly to moderately well developed subvertical cracks in fine units are filled with silt.

Depositional Environment

The facies association described above is suggestive of deposition in a fluvial environment. The lack of lateral accretion deposits (epsilon cross bedding) representative of point bar deposition (Allen, 1970; summary by Walker, 1981) preclude deposition in a classic meandering stream. However, several lithofacies are similar to those described by Cant and Walker (1976) and Cant (1976) for the sand dominated, braided fluvial Battery Point Sandstone (Figure 51).

The base of this sequence is marked by a scoured surface, above which abundant intraclasts occur (facies Ss). Large scale trough cross stratified units (facies A) are overlain by finer grained trough cross stratified sandstone (facies B). Facies C and D are characterized by large scale solitary and small scale planar cross stratified sandstones, respectively.

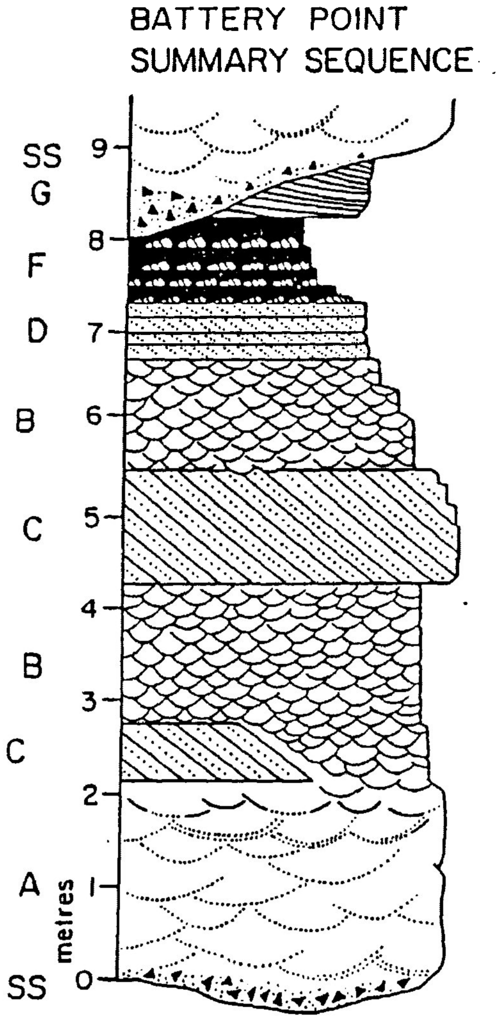


FIGURE 51. Battery Point Sandstone Summary Sequence (after Cant and Walker, 1976).

Interbedded ripple laminated siltstone and mudstone (facies F) and low angle horizontally stratified sandstone (facies G) are typical of the upper part of the sequence.

In Figure 47, massive to trough cross stratified conglomerates on a scoured surface are overlain by horizontally stratified, locally pebbly sandstones and trough cross stratified sandstones. Beds fine upwards rapidly and are occasionally ripple laminated at the top. These units are interpreted to represent a basal channel lag (facies Ss), and bar sediments (facies Gm of Miall (1977, 1978), overlain by deposits formed due to the migration of dunes within a channel (facies A and B). The transition to fine grained, massive to ripple laminated or parallel laminated sediment is rapid and probably reflects the adoption of another channelway for the bulk of the current flow. A second channel lag overlies a scoured surface in fine grained sediments near the upper part of the section. Normally graded units are common. Rather than a fining upward cycle which may reflect waning flow, coarse grained packages are overlain by fine grained sequences. Coarse sediments approximately equal fine sediments in this section, a feature which is consistent throughout the formation.

Figure 49 is located approximately mid-way up the exposed portion of the section. Normally graded, trough cross stratified sandstones are common and represent the migration of dunes on the channel bottom (facies A and B). These grade normally to ripple laminated and planar laminated sandstones (facies Sr and Sh of Miall (1977, 1978), interpreted to represent levee deposition. Upwards, fine sediments dominate above 2.0 metres. Features such as ripple lamination and parallel lamination, which represent overbank deposition of suspended sediment, are common. Carbonaceous traces and coaly fragments reflect the periodic establishment of vegetation on the flood plain. Silt-filled cracks in muddy beds are interpreted as filled dessication cracks. Fine sediments are occasionally interrupted by medium grained sandstones which are massive, to trough cross stratified, to ripple laminated. These units are interpreted to represent crevasse splay deposits formed when the river breached its levees during a flood event. As the water level decreased and the breach was plugged by fine sediment, waning flow was reflected in the sedimentary structures. The nature of the transition to fine grained overbank deposits is gradational and the proportion of coarse and fine sediment is still approximately equal.

Fine sediments are often dark gray to black due to the abundant organic material concentrated along bedding planes. Coaly fragments locally occur. Internally, the prevalence of parallel lamination suggests deposition occurred mainly from suspension (upper portion of Figure 50).

Though the Battery Point Sandstone provides a useful comparison for the sandy component of the Brandy Brook Formation, some of the elements in the summary sequence proposed by Cant and Walker (1976) are not present. Noticeable differences include the lack of abundant bar forms, represented by the planar cross stratified sandstones, and the significantly greater amounts of fine grained sediment in the Brandy Brook Formation.

Comparison with Miall's (1985) twelve fluvial styles based on architectural analysis provides some added insight into this depositional system. Miall (1985) considered eight architectural elements in his synthesis, each of which comprises one or more lithofacies (summarized in Miall, 1978). The lack of abundant coarse sediment, the lack of lateral accretion deposits and similar proportions of sand and mud limit the number of applicable models. Though small scale bar forms are present, element FM (foreset macroforms) such as large scale compound bar forms are not recognized due in part to the limitations imposed by narrow stream exposures. An assessment of the three dimensional variability required for the accurate determination of such macroforms (Miall, 1985) is therefore lacking. Nevertheless, the low sinuosity, sandy braided system continues to have merit (model 10 of Miall, 1985). A second possibility may be a low to high sinuosity, stable, anastomosing system (model 8 of Miall, 1985). Lateral accretion deposits form only a minor component of such a system and this may account for their apparent absence in the exposed formation. Furthermore, vegetation is typically well developed on bars within an anastomosing stream system and the floodplains may be quite wet (Smith, 1983). However, rapid elevation of downstream base level and cohesive banks are generally required for anastomosing channels to form, and large scale controls are deemed necessary (isostatic adjustment, glacial features or marine transgression, for example) (Smith and Smith, 1980; Smith and Putnam, 1980). Clearly, neither model is totally applicable, though Cant and Walker's (1976) sandy braided system seems to be most acceptable.

The association of channel and overbank sandstones with dark carbonaceous siltstones and shales suggests that flood plain conditions during Brandy Brook Formation deposition are comparable to the channel dominated system described by Flores (1981) for the Paleocene Tongue River Member of the Fort Union Formation, Powder River Area, Wyoming and Montana. In addition to sediments typical of channel deposition, siltstones and shales are common and contain abundant plant debris. Coal and carbonaceous shales are important constituents of the succession. The environment is one in which the channel system is maintained at a higher topographic level than the adjacent floodplain. Backswamps and ponds characterize this environment, in which sediment is periodically supplied during flood events and vegetation is locally well established. Coal beds up to 10 metres thick are present in the Tongue River Member and reflect the time vegetable matter had to accumulate before avulsion of the deep meandering stream occurred (Flores, 1981). We have already established that the Brandy Brook Formation probably represents a sandy braided fluvial depositional system. Given that this higher energy system is likely to interrupt the accumulation of vegetable matter as the flood plain is combed, vegetation would not have had the opportunity to produce thick peats. Swamps and ponds, where periodically established, were not long lived, as indicated by the lack of thick intervals of fine sediment in the general section (Figure 43).

Though sand/shale ratios indicate a general fining upward trend for portions of the formation, entropy for the section remains relatively constant. The scale of cyclicity is on the order of several metres and the proportions of coarse and fine sediment are approximately equal. As a result, no lithology is dominant in the section and the relative mixing of lithologies (reflected in the entropy) remains fairly constant.

The sediment source is interpreted to be similar to that which supplied the sediments which constitute the underlying St. Francis Harbour River Formation. Clasts of felsic intrusive and green quartzite are present in conglomerates of the Brandy Brook Formation and sedimentary clasts are significant constituents of both units.

Eddy Point Formation

Lithology

Black to alternating green and red shales, siltstones and sandstones are the predominant rock types. Limestone is present only in the lower parts of the section and one bed of paraconglomerate was observed. The areal distribution of this formation and the locations of partial sections are shown in Figure 52. Partial sections through the unit are provided as Figure 53.

Per cent lithology, sand/shale and clastic ratios are depicted in Figure 54. Conglomerate is present in minor amounts and is not shown in this figure. Shale and siltstone are dominant throughout the unit. Sandstone increases slightly in the lower part of the section and limestone is present only near the base of the formation. Since conglomerate and limestone are rare, the degree of mixing is inherently low and the entropy is therefore constantly low through the formation.

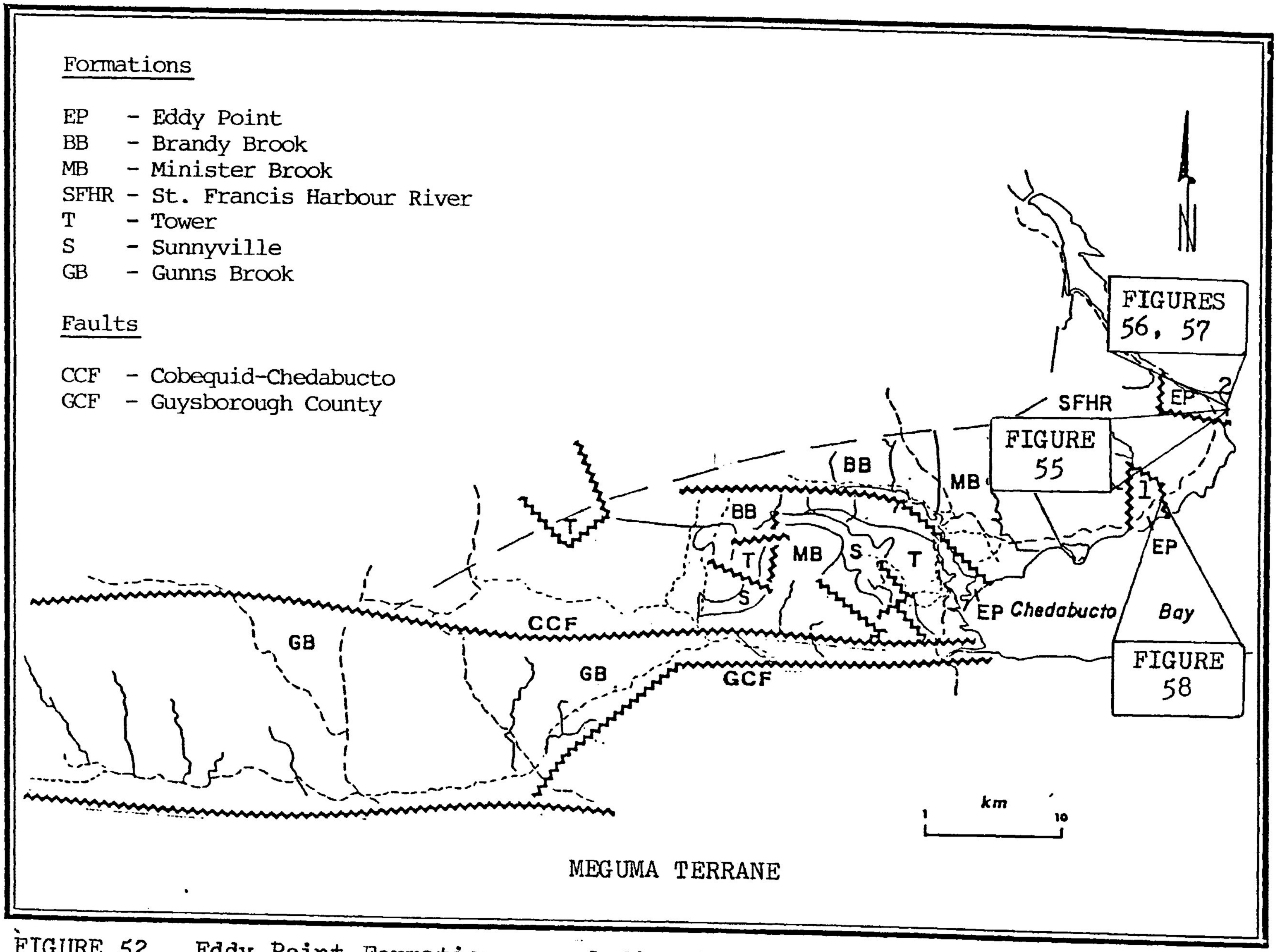


FIGURE 52. Eddy Point Formation: areal distribution and location of partial sections: 1 - Meadow Brook; 2 - Eddy Point.

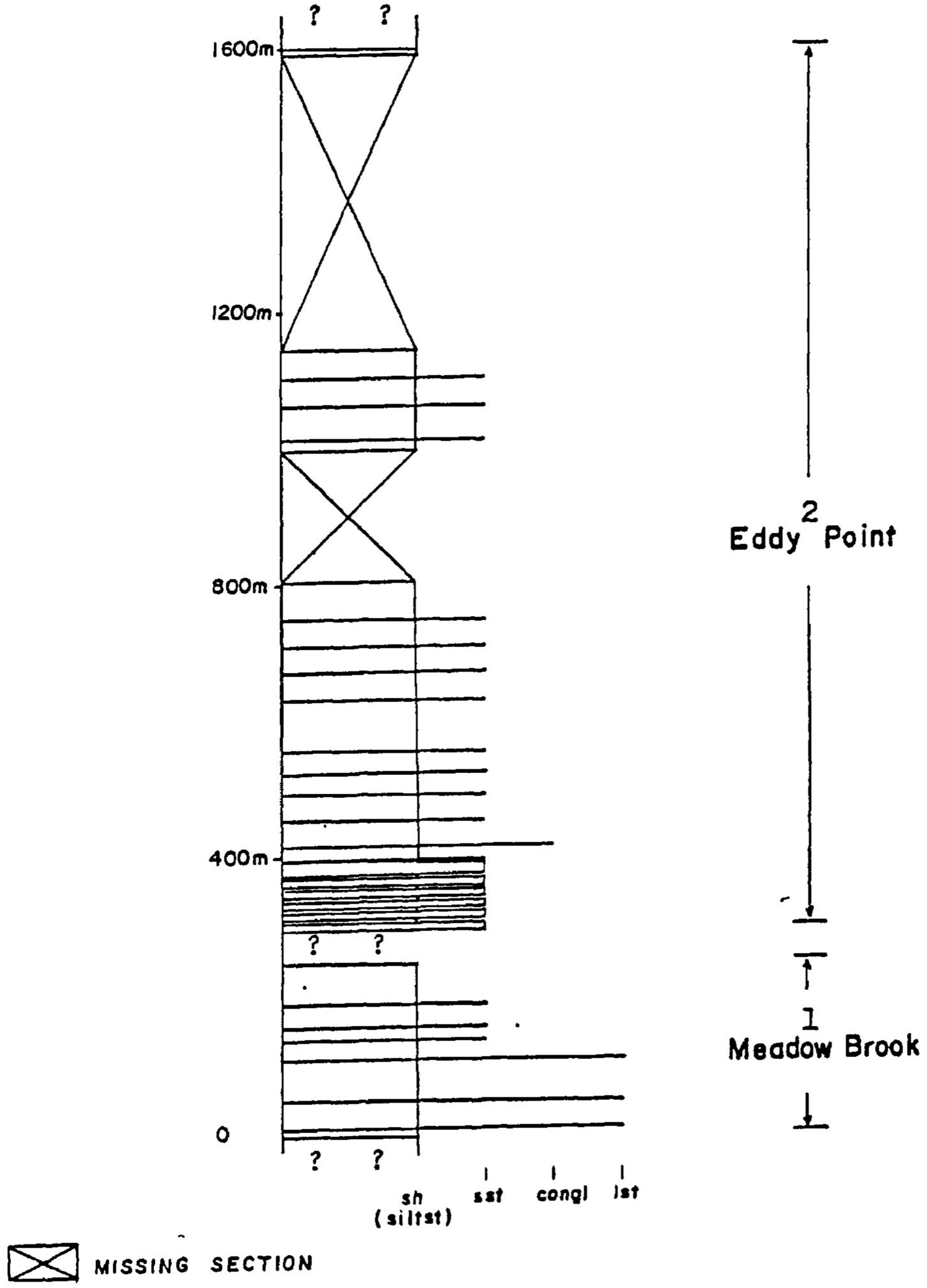


FIGURE 53. Eddy Point Formation: partial sections (refer to FIGURE 52).

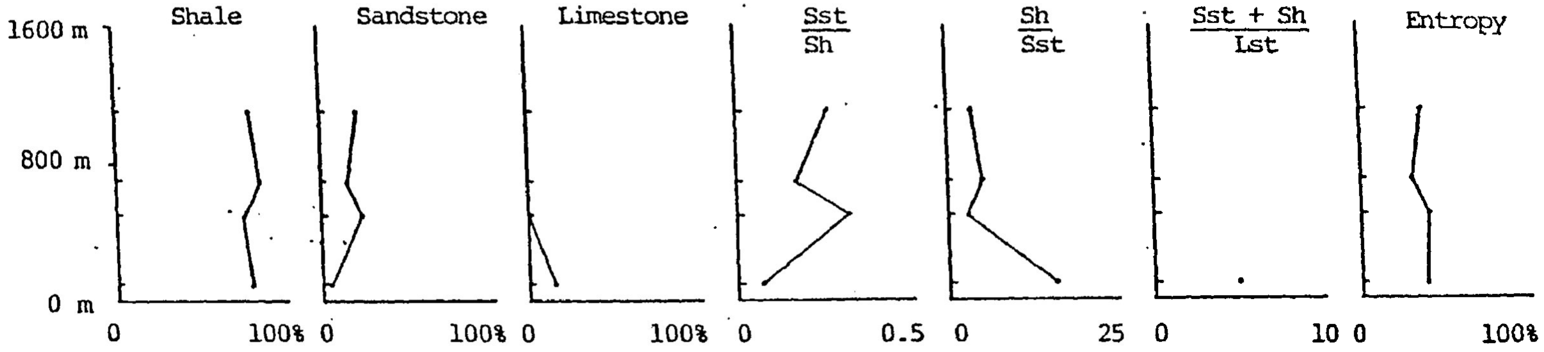


FIGURE 54. Eddy Point Formation: per cent lithology diagrams, sand/shale ratios and clastic ratio for the Meadow Brook and Eddy Point sections.

Thickness and Contact Relationships

A complete section through the formation is not available in the study area but two partial sections (refer to Figures 52 and 53), exhibit features characteristic of the unit. The Meadow Brook section grades upward from black shales and siltstones with minor interbedded limestone to alternating green and red fine grained clastic sediments without limestones. The upper Meadow Brook section is very similar to the Eddy Point section and is therefore placed at the base of the formation. The minimum thickness of this formation is estimated to be 1,600 metres.

The Eddy Point Formation occurs in fault bounded blocks (see Figure 52). The lower Eddy Point Formation is observed in fault contact with rocks of the St. Francis Harbour River and Minister Brook Formations. The upper contact is not exposed in the study area.

Age

Three samples from this formation were submitted for palynological analysis. All samples contained woody and coaly

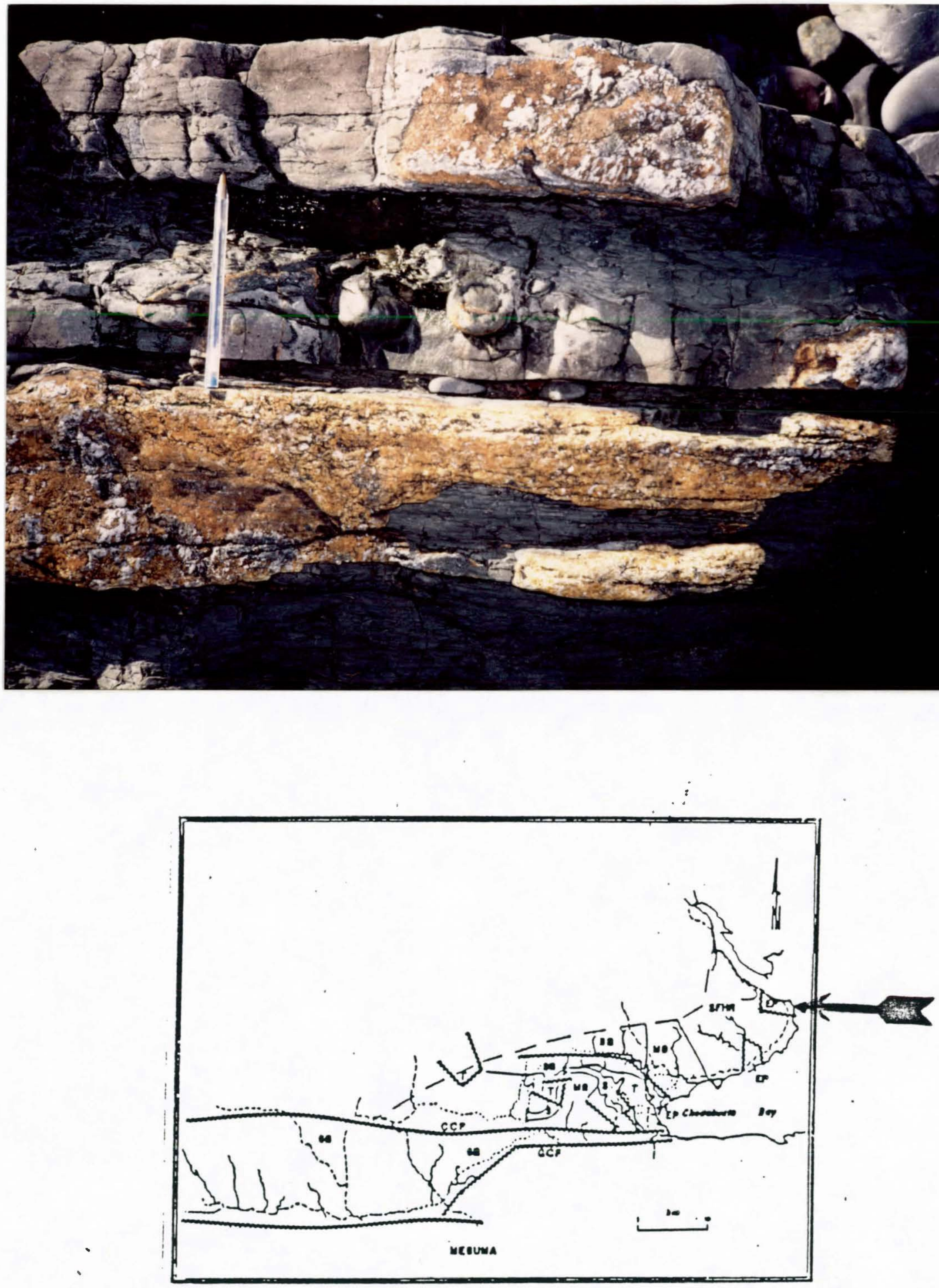


FIGURE 55. Eddy Point Formation: conglomerate lithofacies. Intraformational, matrix supported, rolled mud chip conglomerate is interbedded with parallel laminated and mud cracked fine grained sandstone. This section is also located on FIGURE 52.

fragments, though identifiable spores were present in only one sample. The following genera were identified: Punctasporites; Retusotriletes; and Discernisporites. Unfortunately, a probable age could not be determined from this assemblage (pers. comm., 1989, J. Utting, Institute of Sedimentary and Petroleum Geology).

The unit is characterized by features very similar to Belt's Mabou Group in Mainland Nova Scotia. The Eddy Point Formation is therefore assigned to the Middle Carboniferous.

Sedimentary Lithofacies

The only conglomerate observed occurs in a 12 centimetre thick bed. It is a matrix supported unit composed of green rolled mud clasts up to 5 centimetres diameter in a sandstone to siltstone matrix (Figure 55).

Sandstones, siltstones and shales are generally thin-bedded though bed thickness ranges up to 20 centimetres in the upper part of the section. Near the bottom of the section, outcrop in Meadow Brook is dominated by black to very dark gray clastic sediments. Parallel lamination is the most obvious internal structure though asymmetric ripples occur in fine grained sandstones. Oil shales are locally present.

Carbon films and local coaly fragments are typical and rare arthropod tracks?, syneresis cracks, pressure ridges, halite casts, worm trails, numerous pock marks and one possible fish scale were observed. Up section, clastic sediments alternate between green and red (Figure 56), and exhibit such internal structures as parallel lamination, normal grading, mud cracks and ripple cross lamination. Symmetrical ripples and mud cracks (Figure 57), brush marks, animal tracks and trails are all evident on exposed bedding planes.

Micritic limestone is interbedded with black to dark gray shales and sandstone near the bottom of the section (Figure 58). Lower limestone beds are green and gradually become more brownish near the top of the section. Internally, they are finely laminated and erosive truncation of these laminations are locally evident. Cubic halite casts and linear gypsum casts are evident on the bedding planes.

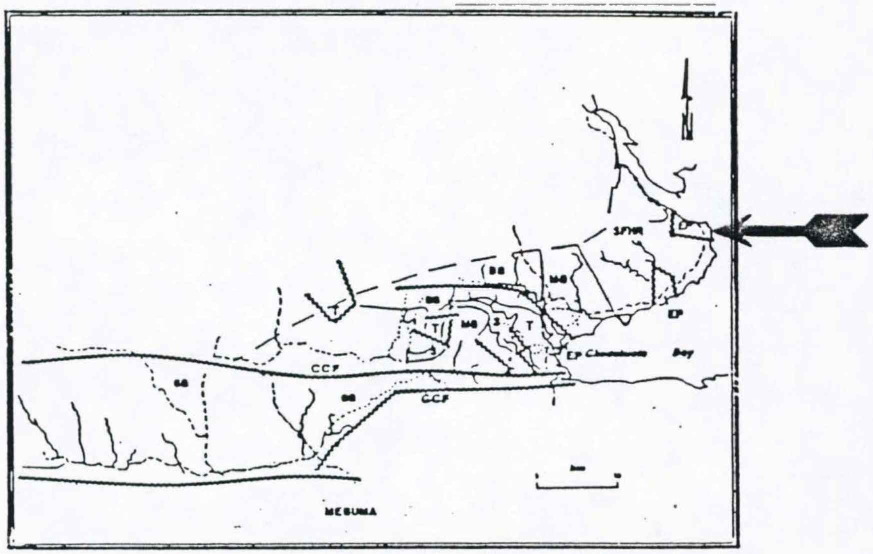


FIGURE 56. Eddy Point Formation: sandstone-shale lithofacies. Fine grained clastic sediments alternate between red and green on a scale of up to several metres. This section is also located on FIGURE 52.

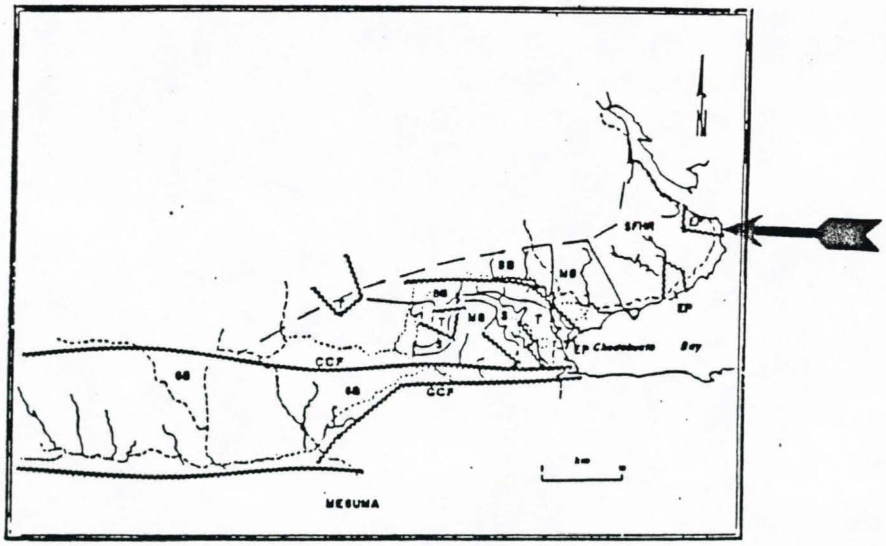


FIGURE 57. Eddy Point Formation: sandstone-shale lithofacies. Symmetrical ripples and dessication cracks are evident on exposed bedding planes. This section is also located on FIGURE 52.

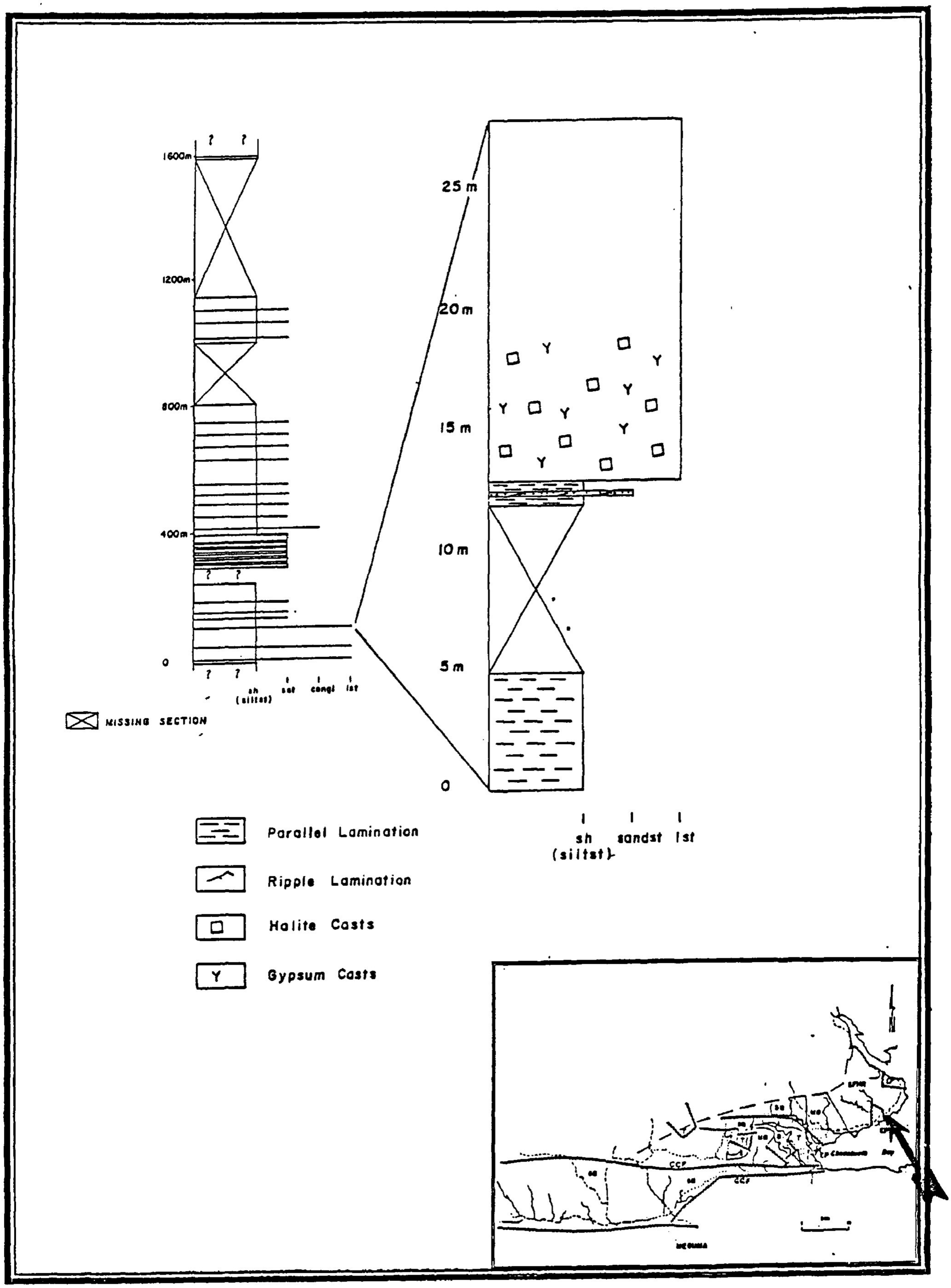


FIGURE 58. Eddy Point Formation: shale-limestone lithofacies. This section is also located on FIGURE 52.

Depositional Environment

Structures such as parallel lamination, with oscillation ripple marks observed in the lower portions of the formation suggest deposition in a subaqueous environment which was affected by wave activity. The occurrence of black sediments containing carbon films and local coaly fragments denote reducing and anoxic conditions. Pock marks are interpreted to represent loading features whereas syneresis or shrinkage cracks are indicative of water loss. Black shales and associated limestones contain gypsum and halite hopper casts which reflect the saline nature of the water column. Furthermore, halite casts are present in the black shales stratigraphically below the uppermost exposure of limestone in the formation. The presence of ripple laminated fine grained sandstones and siltstones, and of erosive truncations of laminated limestone also reflect deposition above wave base.

Several facies comparable to those noted above are described in the Eocene Green River Formation of the Western United States. This extensively studied (Bradley, 1964; Eugster and Surdam, 1973; Eugster and Hardie, 1975; Surdam and Wolfbauer, 1975; Bucheim and Surdam, 1977, for example) assemblage of ancient lacustrine sediments provides the basis for interpretation of the Eddy Point Formation.

Eugster and Hardie (1975) recognized six main lithofacies in the Wilkins Peak Member of the Wasatch Formation. The flat pebble conglomerate facies is similar to the rolled mud chip conglomerate described from the Eddy Point Formation and is interpreted to represent a lag deposit formed as the lake expanded over a low gradient mudflat.

The lime sandstone facies of the Wilkins Peak Member (Eugster and Hardie, 1975) comprises interbedded wave rippled sandstones with rare trona crystals and mudcracked dolomitic mudstones. Clastic sediments in the Eddy Point Formation are not dolomitic, though structures noted above are well developed. Sandstones are less prevalent near the base of the Eddy Point Formation, whereas wave rippled and mudcracked siltstones and mudstones are more common up section and are gradational with the mudstone facies discussed below. The facies is interpreted to represent alternating periods of exposure and inundation-deposition above normal wave base.

The mudstone facies of the Wilkins Peak Member (Eugster and Hardie, 1975) comprises laminated dolomitic mudstones which exhibit well developed mudcracks. Mudstones in the Eddy Point Formation are not dolomitic, though dessication cracks are prevalent. In addition to the parallel laminated siltstones and mudstones, oscillation ripple marks are common features in the Eddy Point Formation. The facies is interpreted to represent an exposed playa mudflat with flood events supplying coarser sediment. Oscillation ripples reflect wave activity during periods when the mudflat was inundated and red beds denote periods of extended exposure. Furthermore, alternating red and green beds reflect fluctuating water depth on the mudflat (Figure 56). Tracks and trails denote the presence of faunal activity and concentric brush marks about a coaly stem reflect rare plants which established themselves on the periodically exposed mudflat.

The oil shale facies of the Wilkins Peak Member (Eugster and Hardie, 1975) includes organic rich dolomitic laminites representative of laminated organics and silts introduced from the mudflat during high water periods, and oil shale breccias formed by reworking of desiccated ooze. Oil shales are observed in the lower portion of the Eddy Point Formation, though they are typically quite thin units. Organic films and coaly fragments are common. Organic rich laminites are present in the Eddy Point Formation though dolomite and oil shale breccias were not observed. Dessication cracks, trails and tracks indicate the periodic drying out of even the deeper portions of the lake.

The trona-halite facies of the Wilkins Peak Member (Eugster and Hardie, 1975) is commonly developed stratigraphically above oil shale. Halite occurs throughout the trona, and is locally observed as distinct beds. In the lower Eddy Point Formation, limestone overlies organic rich black shales. Halite and gypsum casts occur throughout the chemical sedimentary unit and are locally observed in the underlying shales (see Figure 58).

Additional facies noted by Eugster and Hardie (1975) but not recognized in the Eddy Point Formation include siliciclastic sandstone facies which represent braided stream deposits, volcanic tuff facies, and stromatolitic limestone facies.

Several similarities between the Wilkins Peak Member of the Green River Formation and the Eddy Point Formation have been discussed. The differences can be explained in terms of the degrees of productivity and salinity achieved in the two basins. Facies of the Wilkins Peak Member are well developed. Productive areas deeper in the basin led to the formation of thick oil shales. Evaporitic minerals form a significant portion of the unit and were deposited contemporaneously with clastic dominated facies. Extreme cases of evaporation periodically occurred, and resulted in the deposition of trona and halite. Hypersaline conditions inhibited grazing animals and allowed stromatolites to form at the lake margins.

Conversely, during Eddy Point deposition, the productivity level was lower and clastic sediment input higher, thereby allowing formation of organic rich shales interbedded with ripple laminated siltstones and fine grained sandstones. Oil shales are thin and poorly developed. Limestones analogous to the evaporites noted in the Green River Formation contain gypsum and halite hopper casts.

The water column was saline at this point but did not reach salinities indicated for the Wilkins Peak Member of the Green River Formation. Low salinities did not inhibit grazing animals and stromatolites were unable to survive. Reduced salinity during deposition of the Eddy Point Formation is indicated by the lack of a chemical component in most of the exposed sediments.

Deposition of the Eddy Point Formation is interpreted to have occurred in an environment similar to that of the marginal Wilkins Peak Member of the Green River Formation. Four depositional cycles were recognized by Eugster and Hardie (1975), (Figure 59). A modified Type IV cycle (inner mudflat) occurs at the base of the Eddy Point Formation where no trona is noted (see Figure 58). It was pointed out by Eugster and Hardie (1975) that cycles are laterally transitional and that trona deposition is confined to the central part of the basin. The bulk of the upper Eddy Point Formation is typified by the Type III cycle, though clastic sediments are not as lime rich as in the model of Eugster and Hardie (1975). Transgressive-regressive cycles reflect short term lake level fluctuations resulting from climatic change (Eugster and Hardie, 1975).

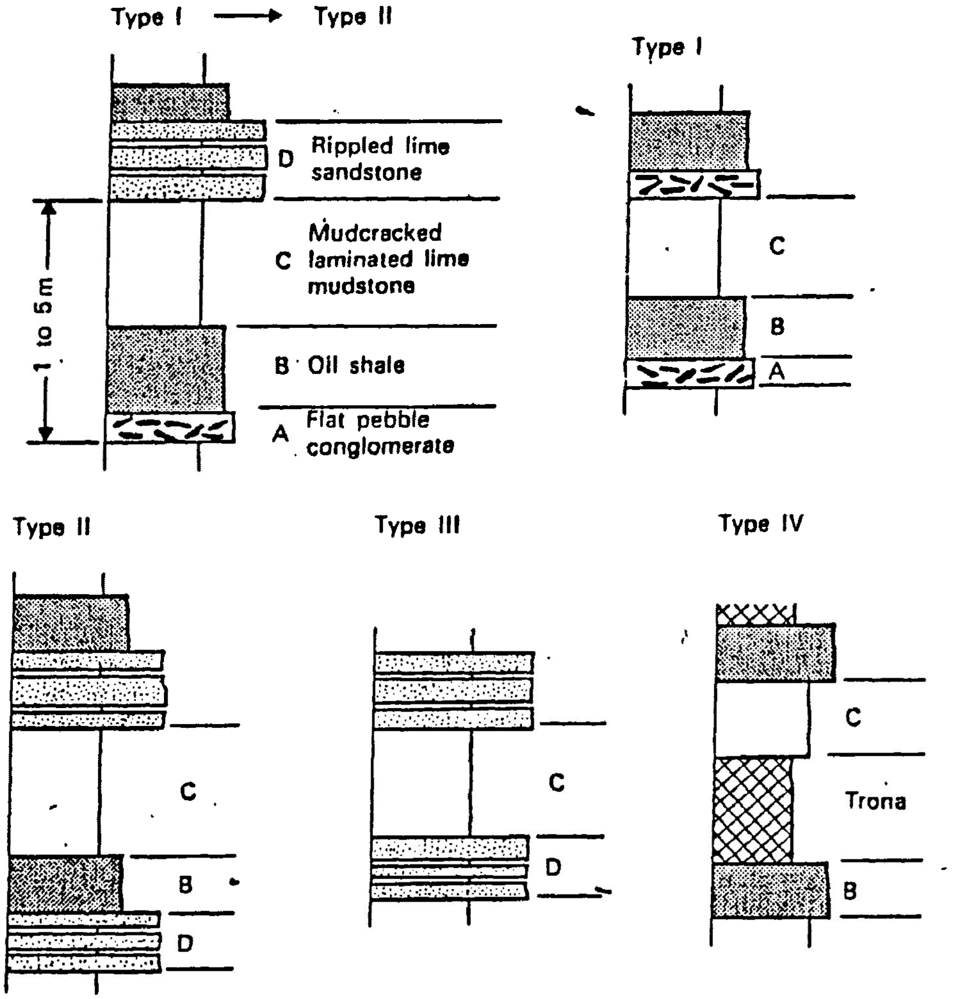


FIGURE 59. Depositional cycles of the Wilkins Peak Member, Green River Formation (Eugster and Hardie, 1975)

ST. MARY'S BASIN

Gunns Brook Formation

Lithology

Medium to coarse grained, green to gray, rarely red, micaceous sandstone is the dominant rock type in the formation. Pebble to cobble conglomerate is also present, mostly near the bottom of the section. Gray to dark gray siltstone and shale locally occur and a single three centimetre thick coal bed was observed.

The areal distribution of this formation and the location of the composite section are shown on Figure 60. The composite section through part of the formation is provided as Figure 61. Per cent lithology diagrams and sand/shale ratios derived from the composite section are shown on Figure 62. Shale, and especially sandstone, increases in importance up section, while the proportion of conglomerate decreases toward the upper part of the formation. The ratio of coarse to fine sediments in the section increases toward the upper part of the formation. The gradual dominance of sandstone in the

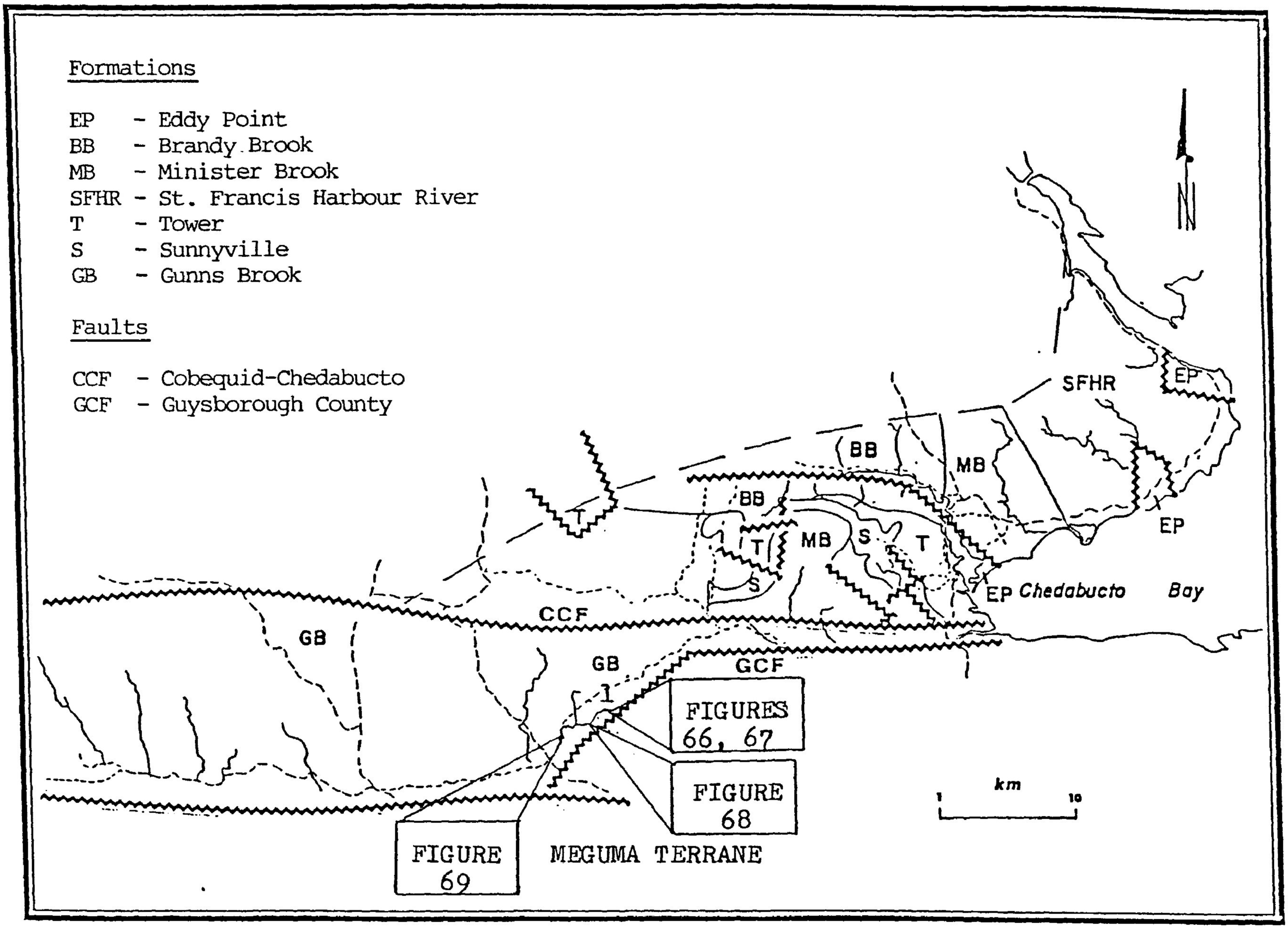


FIGURE 60. Gunns Brook Formation: areal distribution and location of partial sections: 1 - Gunns Brook.

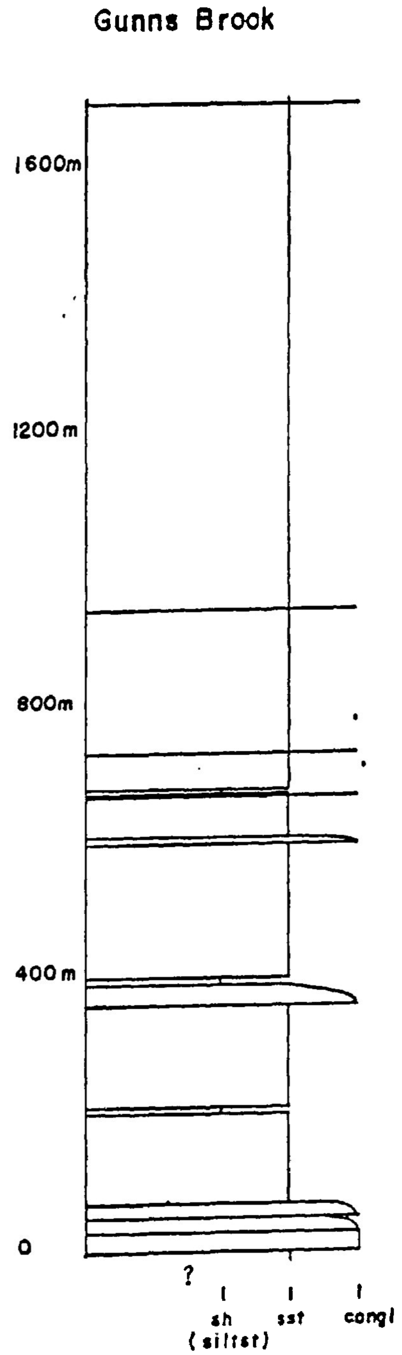


FIGURE 61. Gunns Brook Formation: partial section (refer to FIGURE 60).

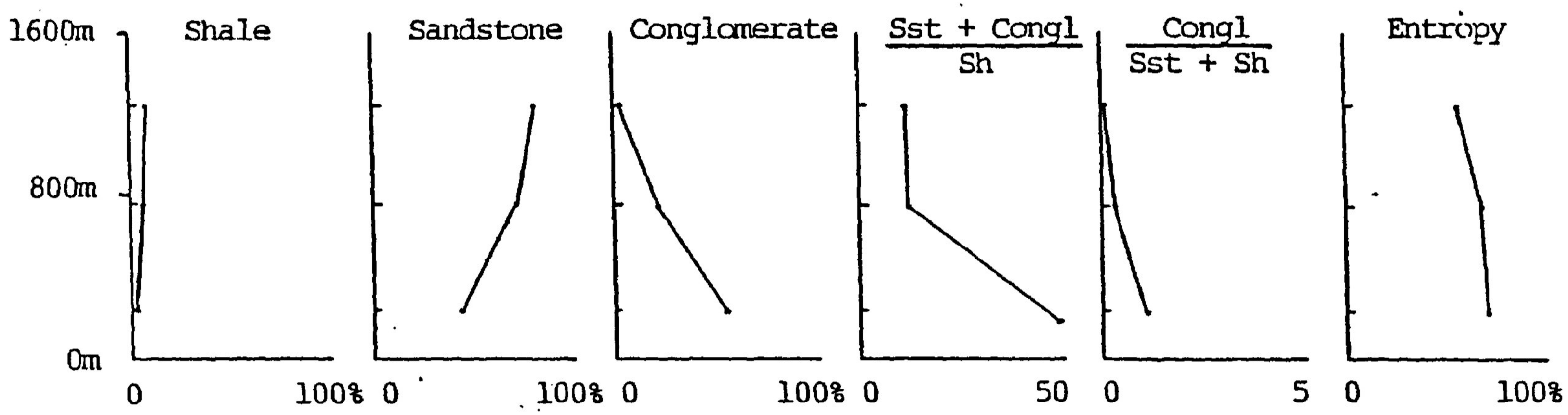


FIGURE 62. Gunns Brook Formation: per cent lithology diagrams and sand/shale ratios for the Gunns Brook section.

section is reflected by the entropy, which decreases up section.

The composition of clasts in conglomeratic units is confined to three dominant types, including green sandstone, black shale and white quartz. The sediments have been weakly metamorphosed and minor recrystallization has resulted. Both sedimentary and metamorphic characteristics are often observed so for the purposes of this discussion, clasts are referred to in terms of their sedimentary affinity. Green sandstone clasts are typically coarsest in a given unit whereas black shale clasts are typically much finer grained owing to their relatively soft nature. They commonly account for the majority of the matrix in conglomerates and coarse sandstones of the formation. White quartz is a common constituent in these units though generally to a lesser degree than the other two clast types noted above. Figure 63 depicts the narrow range of clast types observed in coarse units of the Gunns Brook section.

The percentage of black shale clasts counted at all locations is plotted and contoured on Figure 64. Note the decreasing proportion of these clasts to the north. A similar diagram is

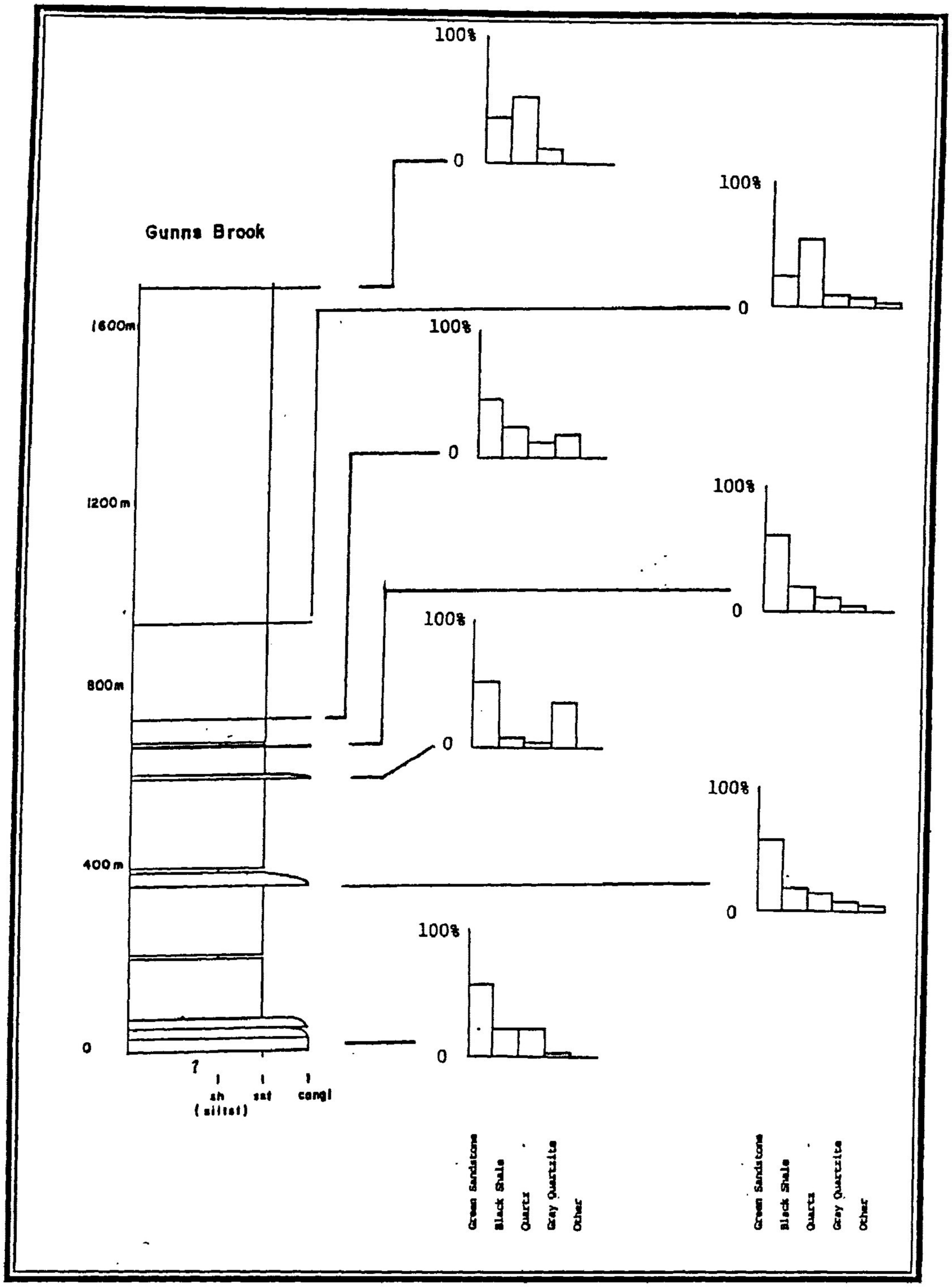


FIGURE 63. Gunns Brook Formation: clast lithologies of the Gunns Brook section.

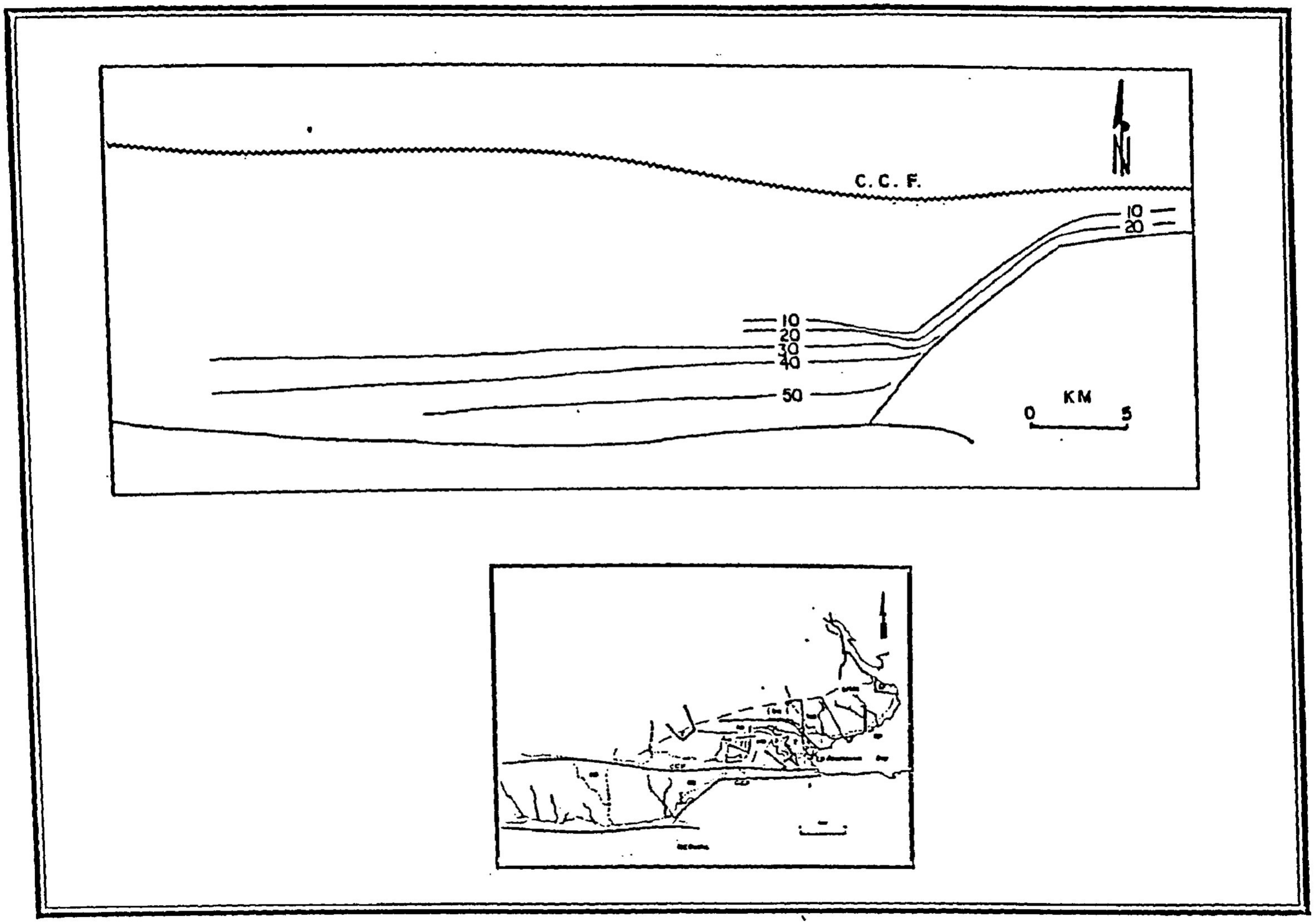


FIGURE 64. Percentage of black shale clasts in conglomerates of the Gunns Brook Formation.

presented for green sandstone clasts as Figure 65. Sandstone clasts are proportionately more important to the north. These diagrams also illustrate that outcrops of coarse grained rocks within the Gunns Brook Formation are concentrated near the south boundary of the unit.

Thickness and Contact Relationships

A complete section through the formation is not available in the study area (refer to Figures 60 and 61). Outcrop is often sparse and folding about northeast-southwest axes was observed. Dips in the central portions of the unit are commonly quite shallow, in contrast with those along the margins of the formation. The minimum thickness of the unit is approximately 1,700 metres.

Neither the base nor the top of the formation are exposed in the study area. This formation is fault bounded, with the Guysborough County Fault marking the contact with Meguma-type lithologies to the south, and the Cobequid-Chedabucto Fault delineating the contact with rocks of the Minister Brook and Tower Formations to the north.

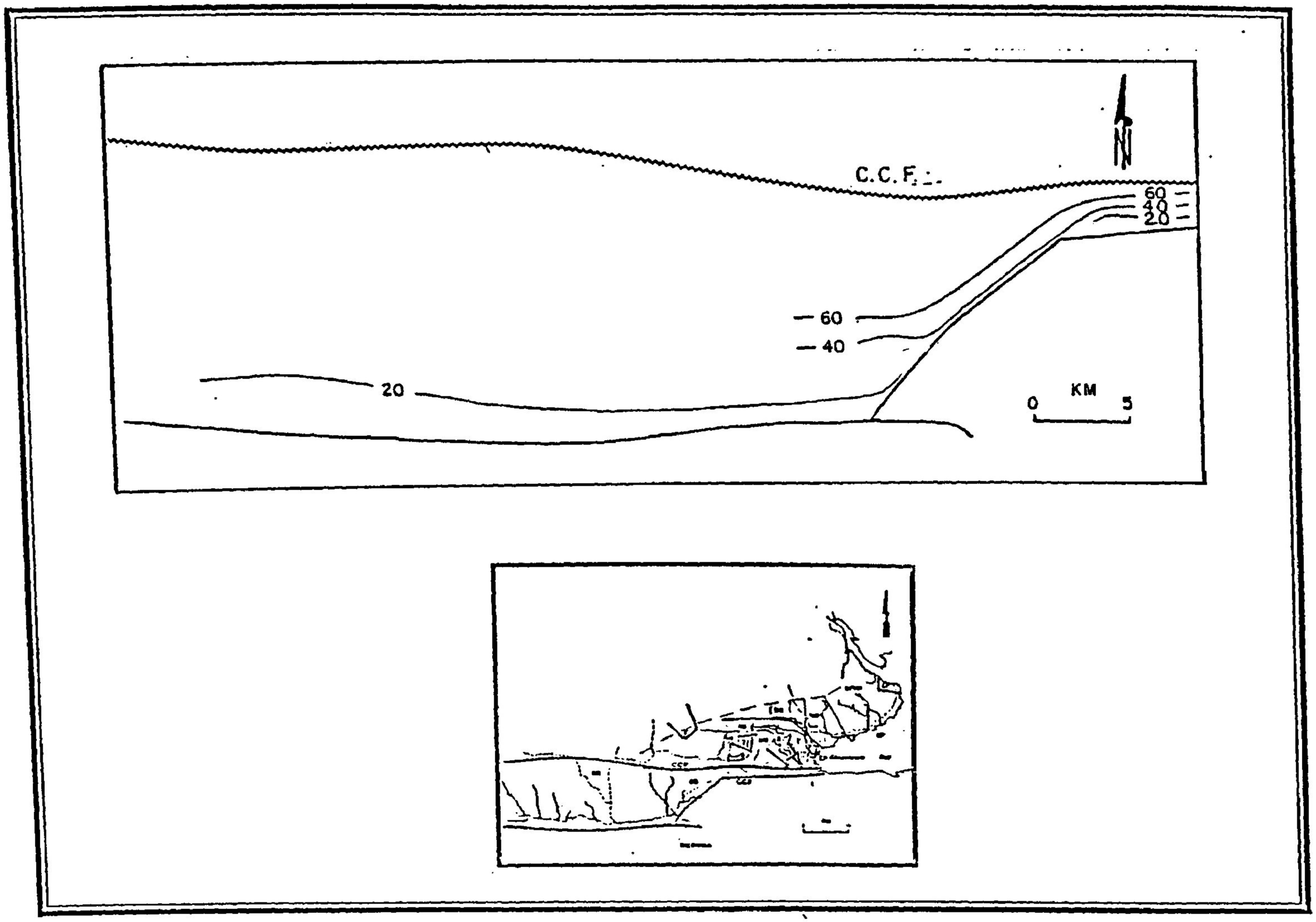


FIGURE 65. Percentage of green sandstone clasts in conglomerates of the Gunns Brook Formation.

Age

Direct relationships between this formation and older units are not available due to the lack of exposure. Four samples from this formation were submitted for palynological analysis. Two samples contained woody and coaly fragments and no recognizeable spores. The other two samples yielded useful spore identifications as summarized below. Sample C-170937 contained the following genera-species: *Punctasporites erasus*, *Punctasporites glaber*, *Cyclogranisporites commodus*, *Vallasporites vallatus*, *Spelaeotrilites*, *Verracosisporites papulosis*, *Cristatisporites aculeatus* and *Spelaeotrilites pretiosus*. Sample C-170939 contained *Cyclogranisporites commodus*, *Vallasporites vallatus*, *Spelaeotrilites echinatus*, *Vallasporites verrucosus*, *Grandispora uncata*, *Punctasporites glaber* and *Punctasporites erasus*. These two assemblages are assigned to the *Vallasporites vallatus* Assemblage Zone of Utting et al. (in press) and are indicative of a Tournaisian (late Tn2 to Tn3) age (pers. comm., 1989, J. Utting, Institute of Sedimentary and Petroleum Geology).

Sedimentary Lithofacies

Sediments of the Gunns Brook Formation contain sedimentary structures suggestive of a fluvial environment of deposition. As with the upper Tower Formation and the St. Francis Harbour River Formation, units are discussed with reference to Miall's (1977, 1978) lithofacies summarized for modern and ancient braided streams.

Conglomerate occurs sporadically throughout the section though it is most significant in the lower portions. These coarse grained units are clast supported, poorly sorted, with clasts ranging from pebble to cobble to boulder size (Figure 66). Coarse clasts are subangular to subrounded and are surrounded by a very coarse sandstone matrix. The fine fraction is characterized by abundant black shale clasts. Boulder and cobble conglomerates are internally massive but crude horizontal stratification was occasionally observed in pebble to cobble conglomerates (facies Gm). Bed thickness ranges from 20 centimetres to several metres and stacked beds are evident at the bottom of the section. Figure 67 illustrates the character of the coarse beds exposed near the base of the formation. In the upper part of the section (Figure 66),

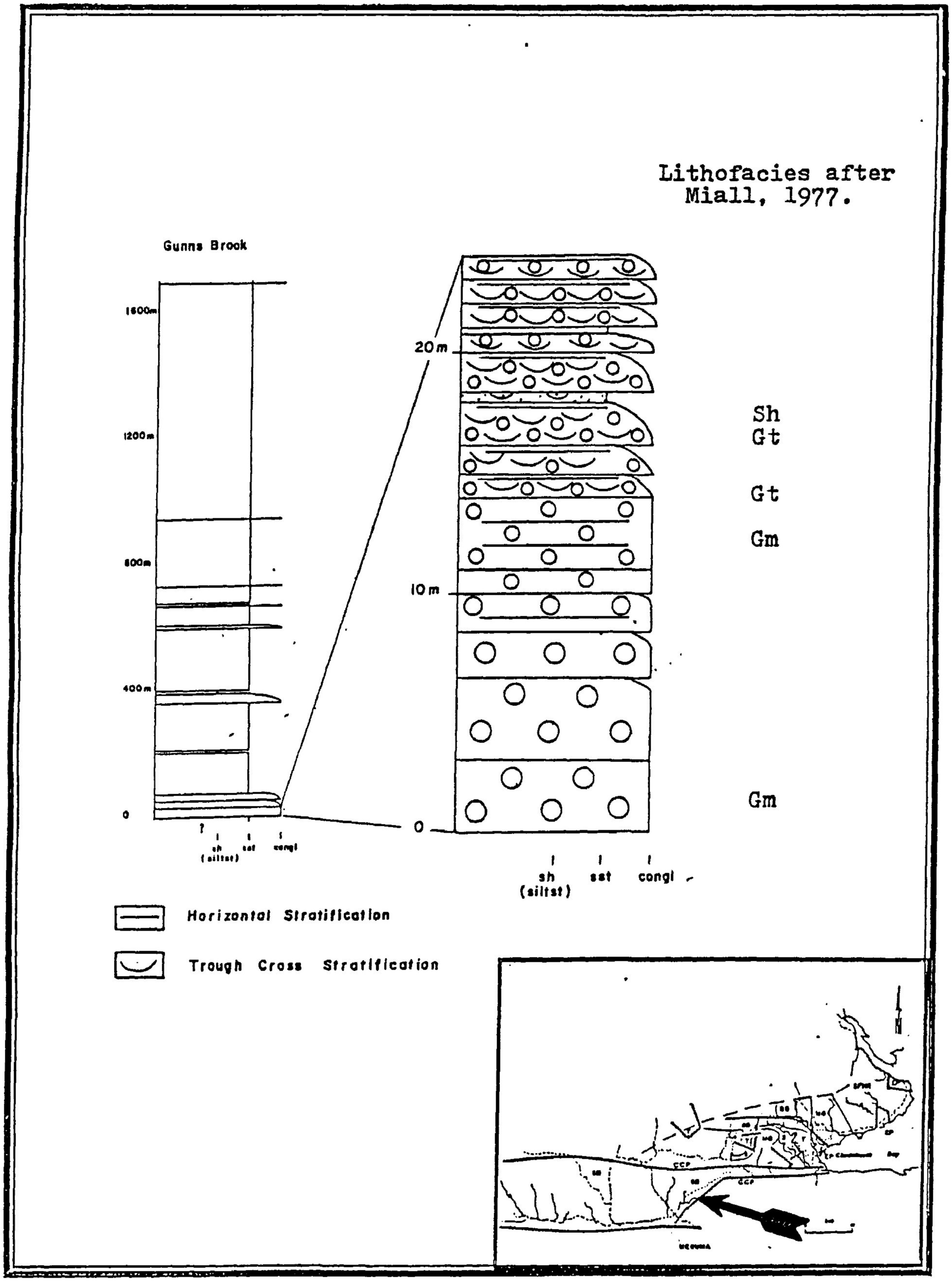


FIGURE 66. Gunns Brook Formation: conglomerate-sandstone lithofacies. This section is also located on FIGURE 60.

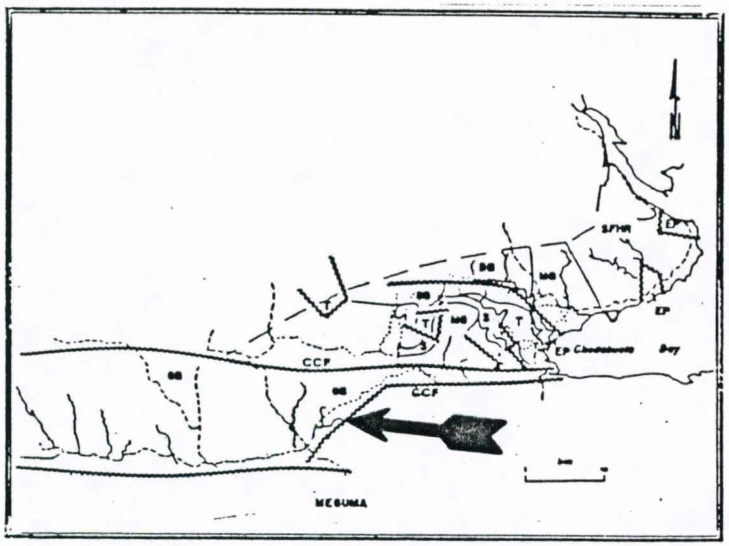
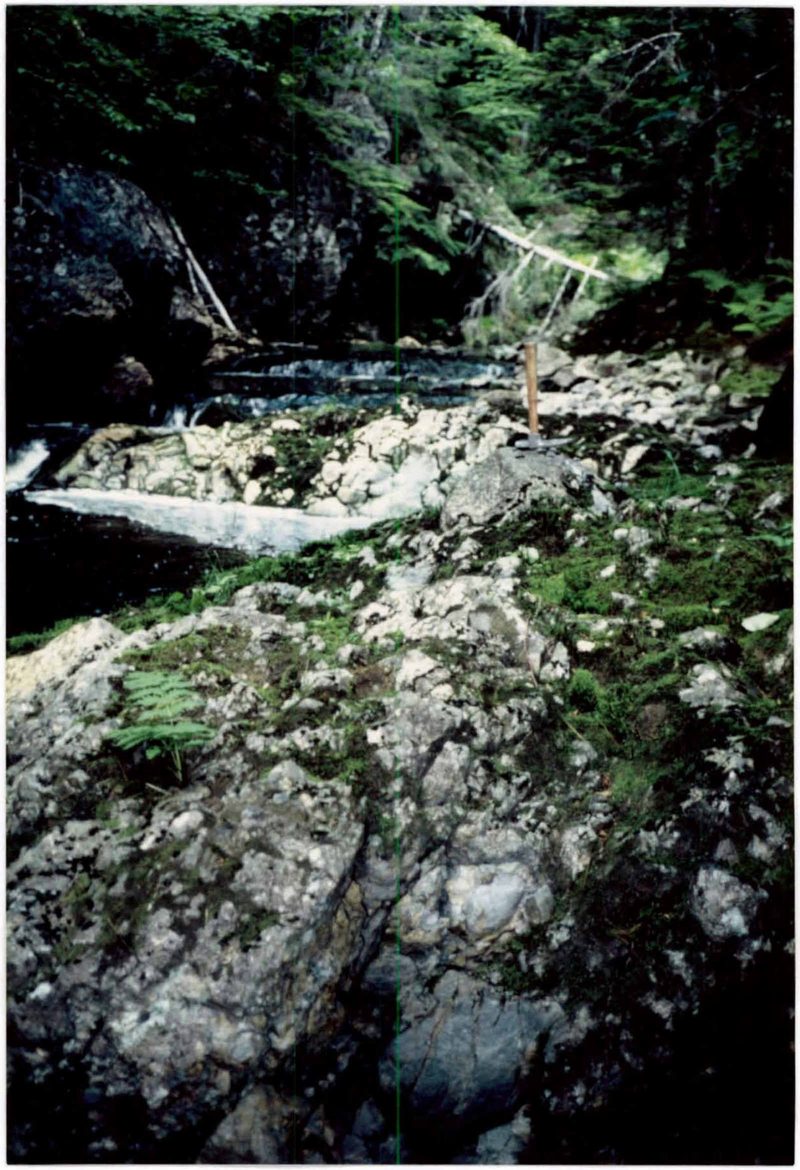


FIGURE 67. Gunns Brook Formation: conglomerate lithofacies. Boulder conglomerate (note the large clast beneath the hammer) is coarse grained and clast supported. Clasts are sub-rounded to sub-angular. Beds are poorly defined and internally structureless. This section is also located on FIGURE 60.



trough cross stratified conglomerate beds (facies Gt) grade normally to horizontally stratified pebbly sandstone to coarse grained sandstone (facies Sh). Conglomerates exposed up section are relatively more fine grained and exhibit several noteworthy characteristics. In addition to the features described above, these gravels are weakly imbricate, locally trough cross stratified, and beds are noticeably lensoid (facies Gt). Conglomerates contain a significant proportion of organic debris. Plant fragments up to 30 centimetres long and 6 centimetres wide locally occur. Striations were observed on the fragments parallel to the long axis and segments up to 10 centimetres long are defined by a distinct mark perpendicular to the long axis. A preferred orientation for the long axis of plant fragments is commonly evident.

Very coarse grained pebbly to fine grained sandstones occur throughout the section. They are characteristically very micaceous, poorly sorted, trough cross stratified units (Figure 68) which exhibit large channel structures up to several metres long with erosive truncations at their base (facies St). Figure 69 illustrates the nature of these sediments near the top of the exposed section. Bed thickness is variable though it is generally on the order of tens of

FIGURE 68. Gunns Brook Formation: sandstone lithofacies. Lensoidal, trough crough cross stratified, coarse to medium grained, micaceous sandstone characterizes the majority of the formation. Beds are laterally discontinuous and channel forms are common. This section is also located on FIGURE 60.

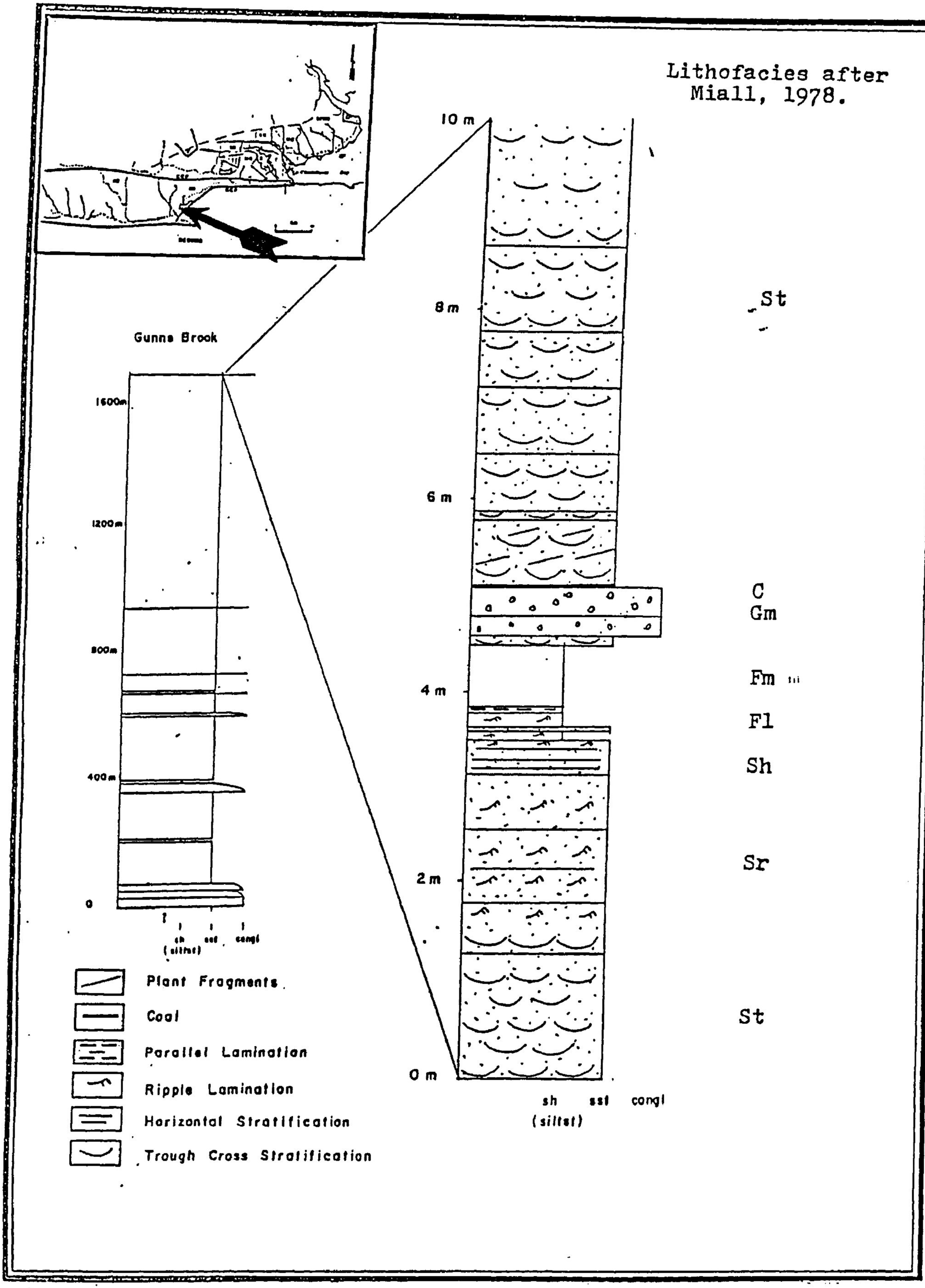


FIGURE 69. Gunns Brook Formation: conglomerate-sandstone lithofacies. This section is also located on FIGURE 60.

centimetres. Internally, trough cross stratification is prevalent. The trough cross stratified sandstones are locally normally graded to ripple and parallel laminated fine grained sandstone (facies Sr and Sh), siltstone and parallel laminated shale (facies Fl and Fm). Plant fragments as described above and organic films are common, and a single thin coal horizon (facies C) was observed in association with coarse trough cross stratified pebble conglomerate and sandstone (facies Gt and St, respectively). which contain abundant plant debris.

Siltstones and shales are rare in the section mapped on Gunns Brook (Figure 61). Where present, they occur as thin beds between coarser clastic units. Normal grading, ripple lamination (facies Fl) and parallel lamination (facies Fm) are common features of the siltstone - shale beds.

Depositional Environment

The prevalence of facies Gm and the context in which it occurs, strongly suggest deposition on longitudinal bars (Miall, 1977, 1978), which commonly contain an appreciable amount of plant debris. Facies Gt and St represent the migration of in-channel dunes (Miall, 1977, 1978), and contain abundant plant debris when associated with trough cross stratified conglomerates (facies Gt). Facies Sh is interpreted as the product of upper flow regime plane beds (Miall, 1977, 1978). Facies Sr and Sl occur in subordinate amounts and are formed by deposition from lower velocity flows than the units described above. Finally, minor fine grained sediments occur and represent the deposits of waning flow and accumulations from suspension in quiet pools of water (facies Fl and Fm, respectively). The thin coal layer is interpreted to represent transported organic debris rather than the product of swamp deposition due to its association with longitudinal bar sediments.

Six braided stream deposit profiles were proposed by Miall (1977 and 1978). Those dominated by deposition of coarse sediment include the Trollheim and Scott types and will not be discussed further. The Bijou Creek type is typified by flash flood deposition in which facies St is not developed and is also discounted as a useful model for the Gunns Brook Formation. The Platte type stream is sand dominated but exhibits no cyclicity and contains abundant planar cross stratified units (facies Sp) interpreted to represent the products of linguoid bars, transverse bars and sand waves, features which were not observed in the Gunns Brook Formation. Trough cross stratified sands (facies St) dominate in the South Saskatchewan type with minor facies including Sp, Se, Sr, Sh, Ss, Gm, Fl, and Fm (Miall, 1978). These facies typically exhibit a fining and thinning upward sequence (Cant and Walker, 1978) which is evident in Figure 69.

The South Saskatchewan River has been extensively studied (Cant and Walker, 1976; Cant, 1978). This river is straight to curving and consists of major channels up to 150 metres wide by 3 metres deep, slipface bounded bars, sand flats (complex braid bars), vegetated islands and floodplains (Cant and Walker, 1976). The slipface bounded bars are formed where the course of the river curves, and cross channel bars often occur between morphologic elements noted above (Cant, 1978). These units as well as sand flats, are characterized by planar cross stratification. Figure 70 shows the range of facies sequences found in the South Saskatchewan River. Minor planar cross stratified sandstones are found in the channel-dominated reaches of this river, and most closely resemble the sequence typical of deposition in the upper Gunns Brook Formation. In fact, deposition in the upper Gunns Brook Formation is almost exclusively within channel, with minor deposits characteristic

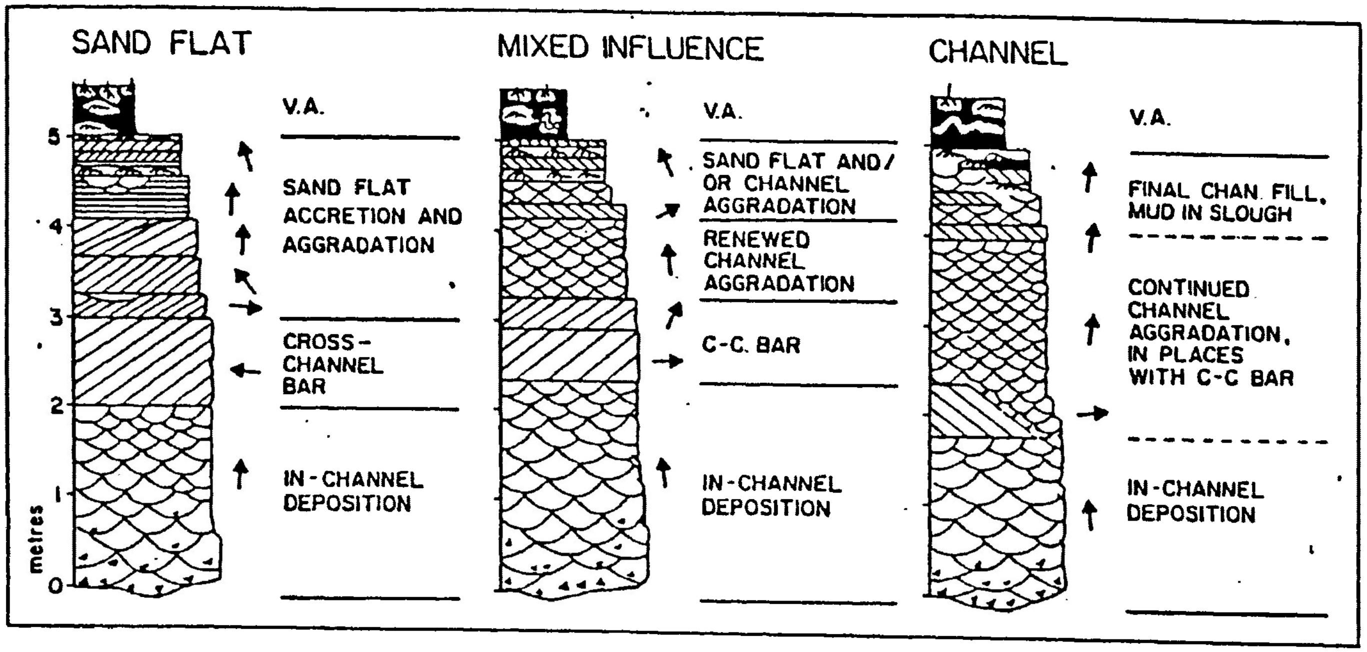


FIGURE 70. Facies sequences recognized in the South Saskatchewan River (Cant, 1978).

of abandoned channels. Upper Gunns Brook deposition was therefore predominantly within the straight reaches of a South Saskatchewan type braided stream. During periods of peak flow, vegetated islands became inundated and abundant plant debris was incorporated into coarse bar and adjacent channel deposits. With the return to normal flow velocities, deposition by the downstream migration of within channel dunes became dominant.

Cyclicity observed in the sedimentary succession can be attributed to one of two causal mechanisms. Autocyclic controls are representative of the energy distribution within a basin (Miall, 1980) and include fining or coarsening upward sequences resulting from avulsion, chute and neck cut-off and meander migration. However, extrabasinal (allocyclic) controls such as tectonics and climate strongly influence discharge, load and slope, and are reflected by large scale cycles (Miall, 1980). Furthermore, allocycles are superimposed on autocycles (Miall, 1980). Cyclicity is evident in the Gunns Brook Formation. Fining upward cycles (autocyclic) up to several metres thick are present throughout the unit (Figures 66 and 69). Sand/shale ratios for the Gunns Brook Formation exhibit a distinct fining upward trend as conglomerate beds become thinner and less frequent towards the upper part of the section (Figure 60), and reflect allocyclic controls.

The abundance of facies Gm and Gt near the base of the succession, reflecting deposition on longitudinal bars and within adjacent channels, respectively, are indicative of a higher energy depositional environment than the South Saskatchewan type proposed for the bulk of the formation. Figure 66 represents deposition in a fluvial system with abundant conglomerate and minor coarse sandstone. Miall (1978) proposed that the Scott, Donjek and South Saskatchewan type braided streams may represent a gradational downstream sequence, reflecting a decreasing gravel to sand ratio. In keeping with this theory, the lower portion of the Gunns Brook Formation is interpreted to represent deposition in a Donjek type braided stream.

CHAPTER 4

PALEOCURRENTS

Introduction

Paleocurrent analysis generates information not only about the direction of drainage and sediment transport within a basin, but indirectly allows inferences to be made regarding paleogeography, the basin geometry, the tectonic environment, and how they change (laterally and vertically) through time.

The relationship between sedimentary structures preserved in the rock record and depositional systems involving fluid flow was initially recognized by Sorby (1852) though it was well into the 20th century before the significance of the concept was realized according to Allen (1970). The importance of this type of data in paleogeographic reconstruction was well demonstrated by Potter and Pettijohn (1963). Allen (1970) stressed that recognition of the relationship between hydrodynamics and different bedforms is also of considerable value in the interpretation of depositional systems. Individual paleocurrent measurements allude not only to the general flow direction, but also to the deviations from this direction on local and regional scales (Allen, 1970). From this point, Allen (1970) proposed a hierarchical system of vector flow forms and hence of sedimentary structures representative of this flow. Lower levels in the hierarchy exhibit greater variation in paleoflow direction and define the large scale current pattern with less confidence. This concept was expanded upon by Miall (1974), who noted that sedimentary structures of higher rank (subsidiary structures) are the ones typically utilized to derive the bulk of paleocurrent data.

Variance

The directional variance within a depositional system is a composite of the variance present at all hierarchical levels, therefore the directional variance of each level must be assessed (Miall, 1974). In addition to the increasing variance exhibited with lower hierarchical levels, considerable variance is also evident within the structures of a given rank (Miall, 1974). Furthermore, certain structures within a single rank yield a more reliable indication of the flow direction than others. Sources of variance are plentiful, and include features such as the degree of sinuosity of a river (Miall, 1974), fluctuating discharge (Collinson, 1971), transverse flow within a channel (Smith, 1972), flood stage overbank spills (Potter and Pettijohn, 1963), and divergent flow from the apex of alluvial fans or deltas (Potter and Pettijohn, 1963), for example. The way in which data is collected is also a source of error. Data may be biased with respect to preservation potential by measuring and recording all possible indicators present in a given bed. Further error may result from inaccurate interpretation and imprecise measurement of the paleocurrent indicator(s) present.

Methodology

Raw data was collected in a fashion which minimized the inherent bias associated with preservation potential. For a given bed or stratum, all available paleocurrent indicators were measured. If only one bedform indicating the paleoflow direction was present, several determinations of the paleocurrent direction were taken within that bed. These azimuths were averaged and the resultant value recorded as one measurement. That is, a single measurement was recorded for one bed exhibiting useful paleocurrent indicators. This method precludes the possibility of drastically skewing paleocurrent means towards those beds which may contain numerous paleocurrent indicators available for measurement (after Fralick, 1980). This method gives a more even distribution of measurements over the entire section. A total of 773 measurements were collected on unidirectional indicators including ripple cross lamination, planar cross stratification, and trough cross stratification. A total of 99 bidirectional paleocurrent measurements were obtained from structures including symmetrical ripple lamination, groove casts, and plant fragment elongation.

Raw data was initially separated according to formation and subsequently divided into groups of up to 30 measurements according to the location along a section or perhaps for an entire section if a limited number of measurements were available. These groups were then used to calculate Local Mean Trends, according to the following formulae:

$$V = \sum_{i=1}^{n} n_i \cos x_i$$

$$W = \sum_{i=1}^{n} n_i \sin x_i$$

$$\bar{x} = \arctan W/V$$

$$R = (V^2 + W^2)^{\frac{1}{2}}$$

$$L = 100(R/n)$$

where x_i represents the mid-point azimuth of the ith class interval,

$\bar{x}$ is the azimuth of the calculated vector,

n represents the number of measurements in a given class interval,

n_i is the total number of measurements,

R is the magnitude of the length of the calculated vector,

and L represents the vector strength per cent.

The vector strength per cent is a measure of the concentration of measurements in a given sample population.

Local Mean Trends are treated in a similar fashion to generate a Regional Mean Trend for a particular formation. This nested method of treating paleocurrent data is useful in that it allows vertical trends through a formation to be more rigorously examined and compared to the regional trend generated for the formation (after Fralick, 1980).

Trends

A summary of Regional Mean Trends, vector strength per cent, and total number of paleocurrent measurements collected for each formation is presented as Table 4.

Guysborough Basin

Tower Formation

Figure 71 incorporates several rose diagrams and the resultant Local Mean Trends calculated for each group of unidirectional measurements. Unimodal distributions are evident in all diagrams, which indicate a dominant direction of current flow from east to southeast to south. A single group of measurements suggest current flow to the southwest but a low vector strength per cent was calculated for these data. Vector strength per cent calculations for the remainder of the rose diagrams range from 51% to 92%. The vertical variation of unidirectional paleocurrents is shown in Figure 72. Paleocurrent Local Mean Trends are gradational from southeasterly to southerly up section in the area of Nickerson Lake. The top of the section is represented by the Tower

TABLE 4

Summary Of Paleocurrent Data

		Unidirectional			Bidirectional		
Basin	Formation	$\bar{X}$	L	n	$\bar{X}$	L	n
Guysborough	Eddy Point	124°	15%	51	74°-254°	75%	50
	Brandy Brook	66°	48%	218	99°-279°	69%	14
	Minister Brook	215°	49%	96	112°-292°	51%	6
	St. Francis Harbor River	130°	59%	189	84°-264°	57%	6
	Tower	152°	42%	54	-	-	-
	Sunnyville	-	-	-	-	-	-
St. Mary's	Gunns Brook	0°	83%	165	32°-212°	94%	12
					127°-307°	96%	11

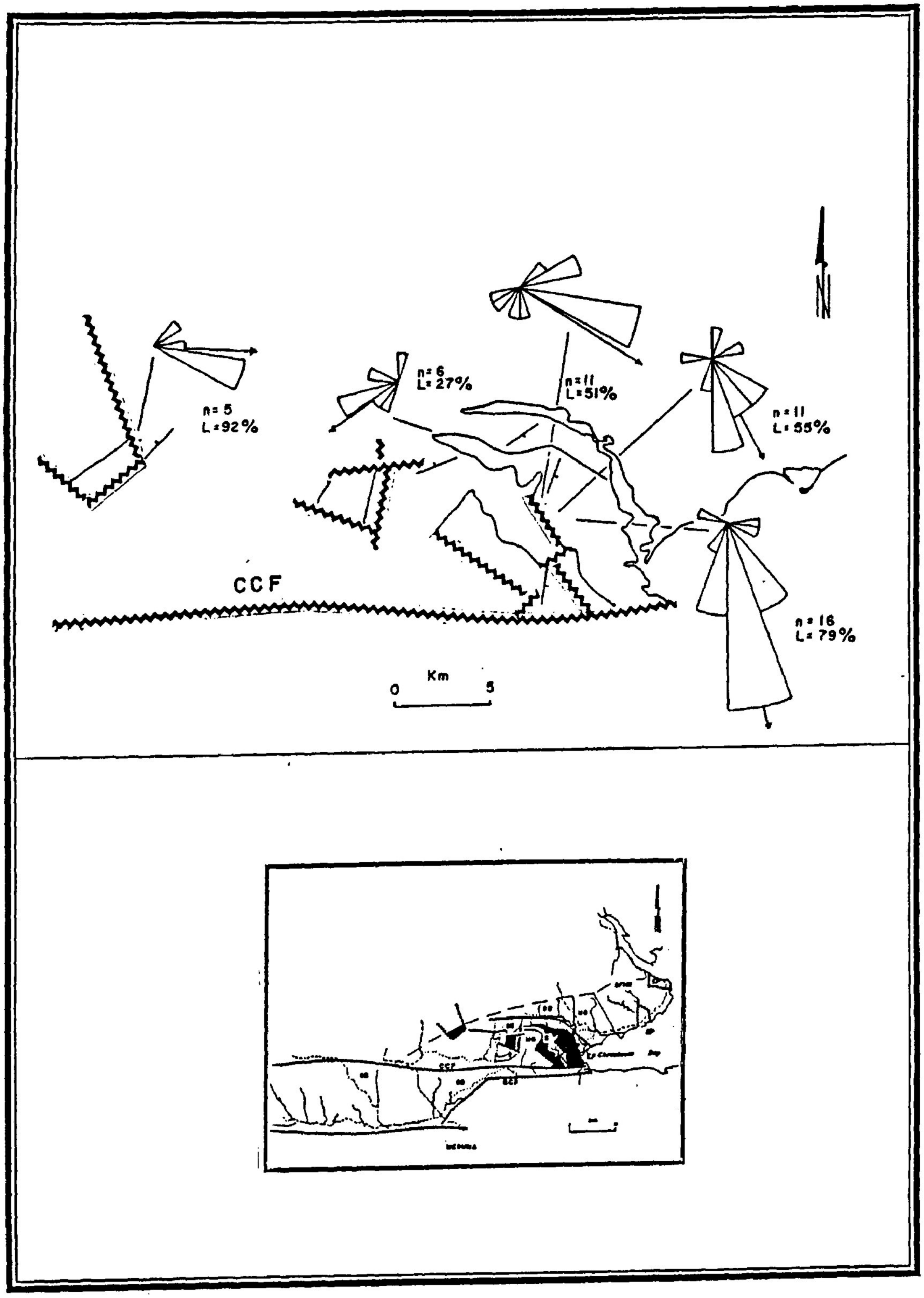


FIGURE 71. Tower Formation: Local Mean Trends for unidirectional paleocurrents (n represents the number of measurements and L represents the vector strength per cent).

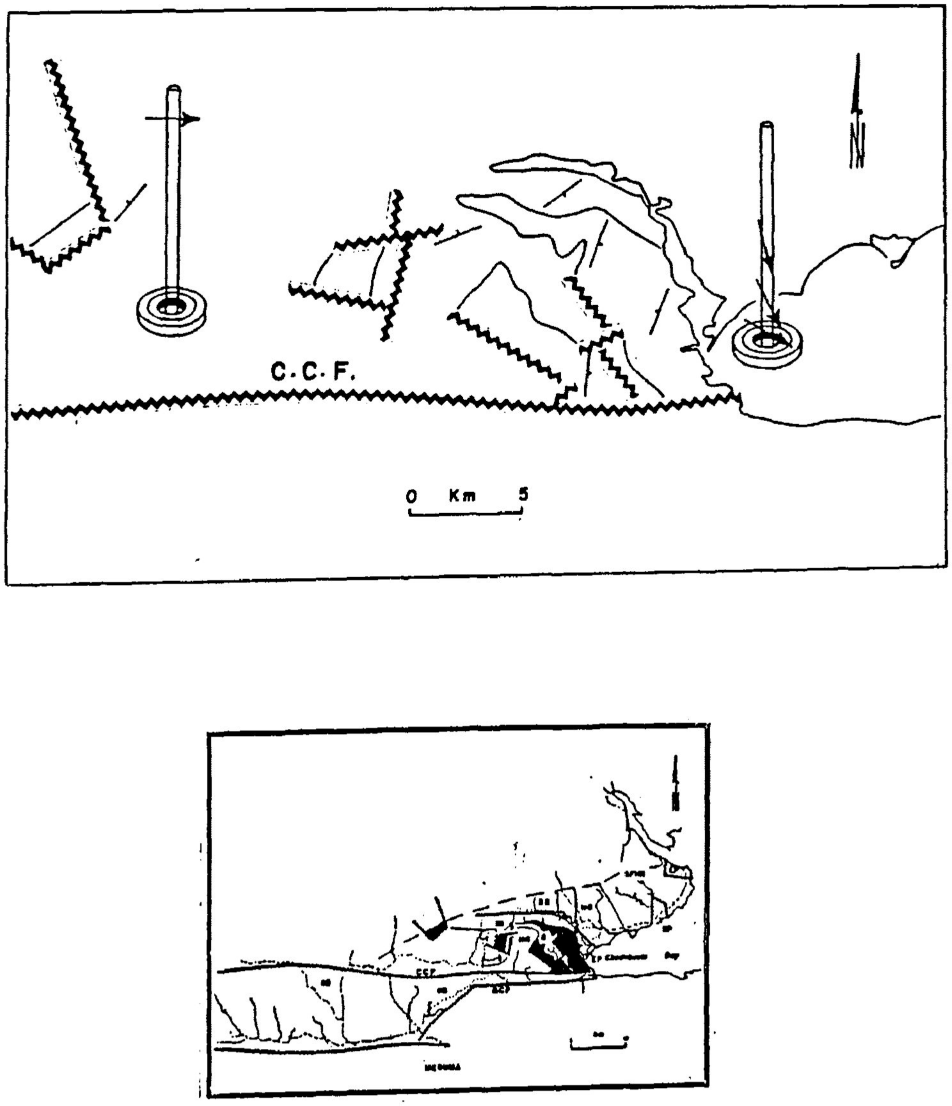


FIGURE 72. Tower Formation: vertical variation of unidirectional paleocurrents

section in the western portion of the study area. An easterly Local Mean Trend is evident here. Figure 73 shows a rose diagram representing all of the data for this formation with Local Mean Trends plotted as arrows on the accompanying map. No bidirectional measurements were collected from rocks of this formation. Unidirectional paleocurrents exhibit a unimodal distribution with a Regional Mean Trend calculated as azimuth 152 degrees. The vector strength per cent calculated for the unit is 42%. Paleocurrent indicators for the Tower Formation suggest dominant flow to the east, southeast and south.

St. Francis Harbour River Formation

Rose diagrams with calculated Local Mean Trends for unidirectional paleocurrents are depicted on Figure 74. Unimodal distributions are exhibited by all local groups of data, and calculated values of vector strength per cent are greater than 60% with one exception. The vertical variation of these Local Mean Trends is shown in Figure 75. Measurements collected from East Brook exhibit trends pertinent to the lower part of the section. Paleocurrent azimuths are gradational from southeasterly to easterly up

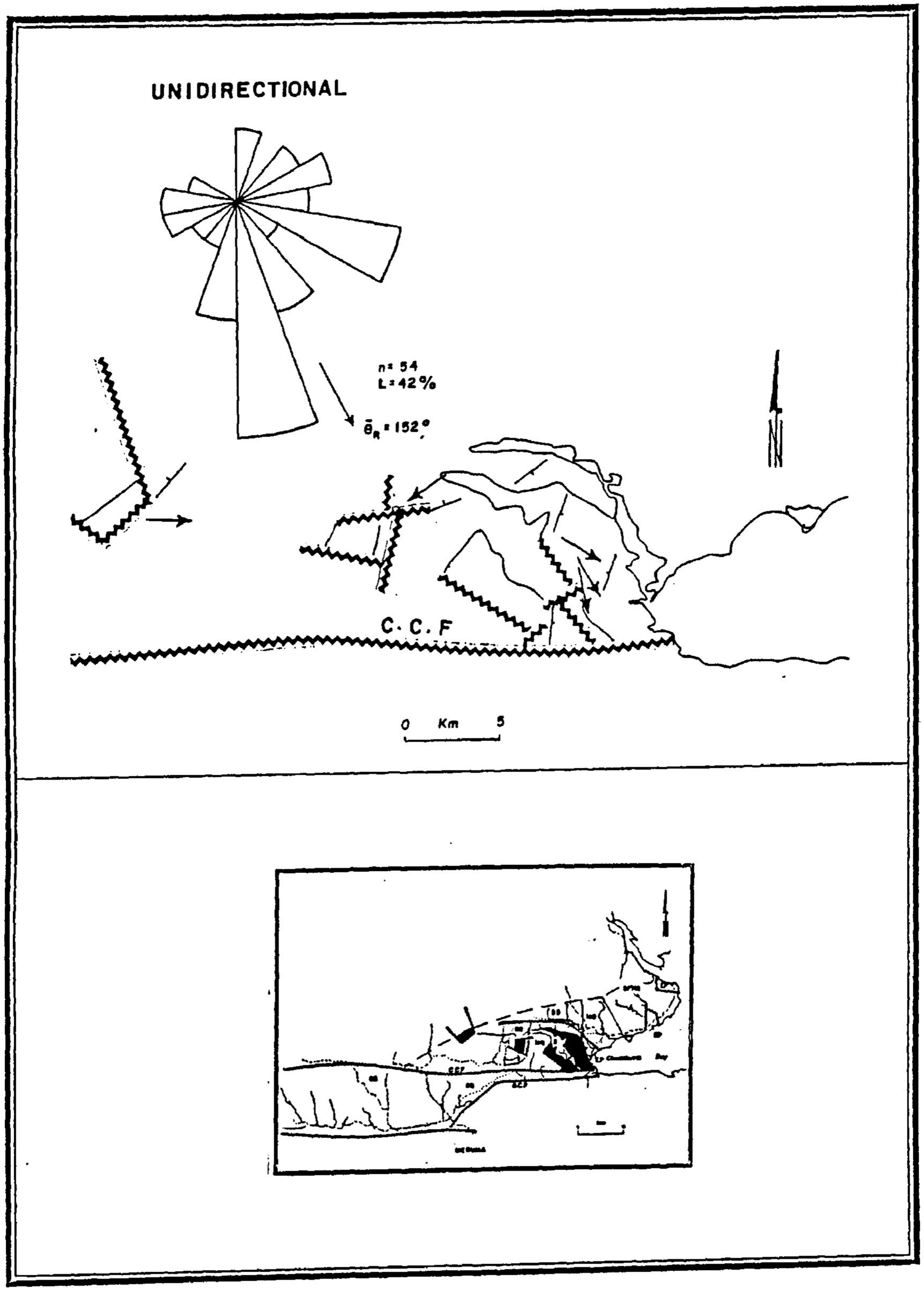


FIGURE 73. Tower Formation: paleocurrents. The rose diagram represents all of the data for this unit. Arrows represent Local Mean Trends, used to derive the Regional Mean Trend ($\overline{\theta}_R$). Paleocurrents indicate dominant flow to the south-southeast.

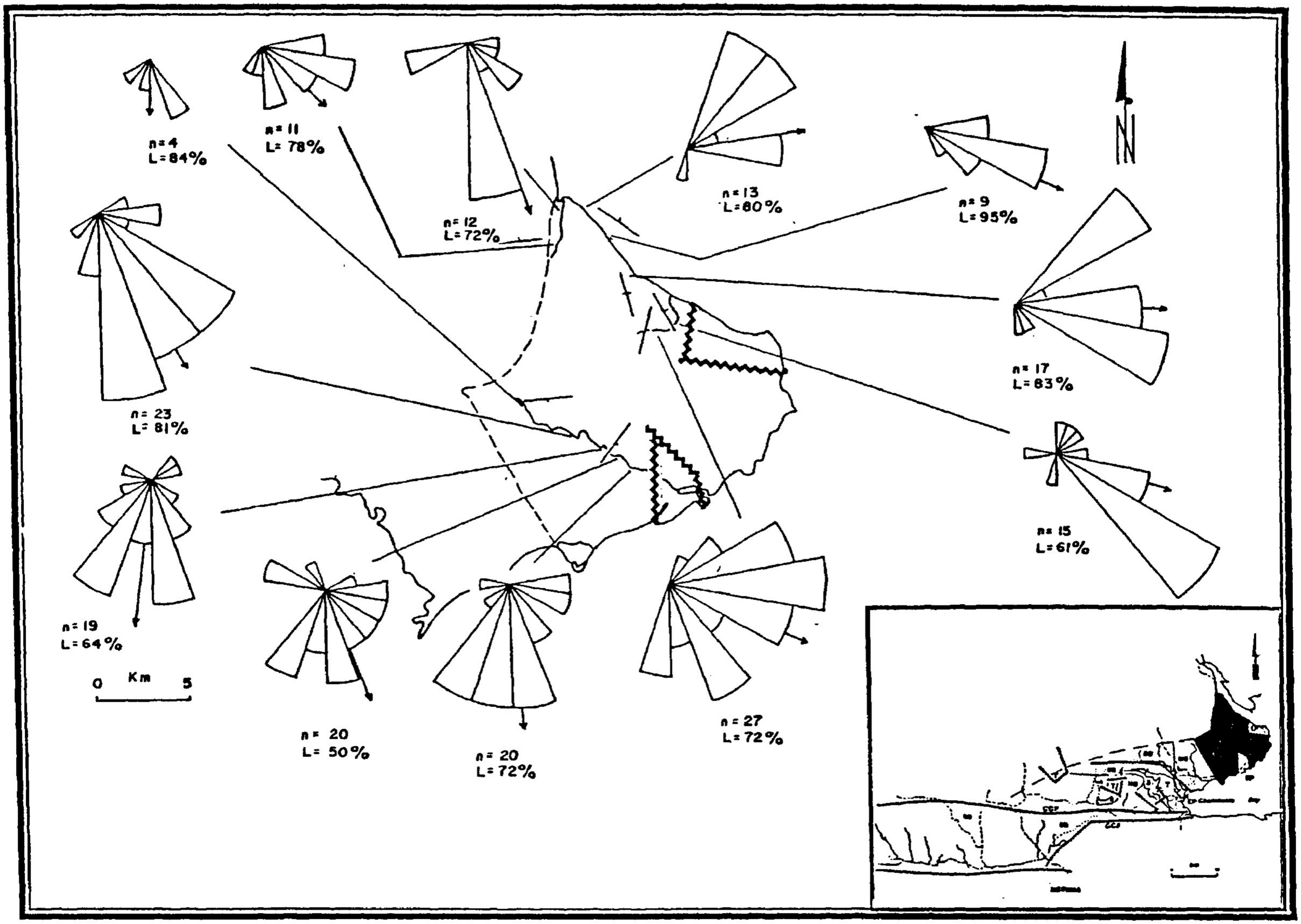


FIGURE 74. St. Francis Harbour River Formation: Local Mean Trends for unidirectional paleocurrents (n represents the number of measurements and L represents the vector strength per cent).

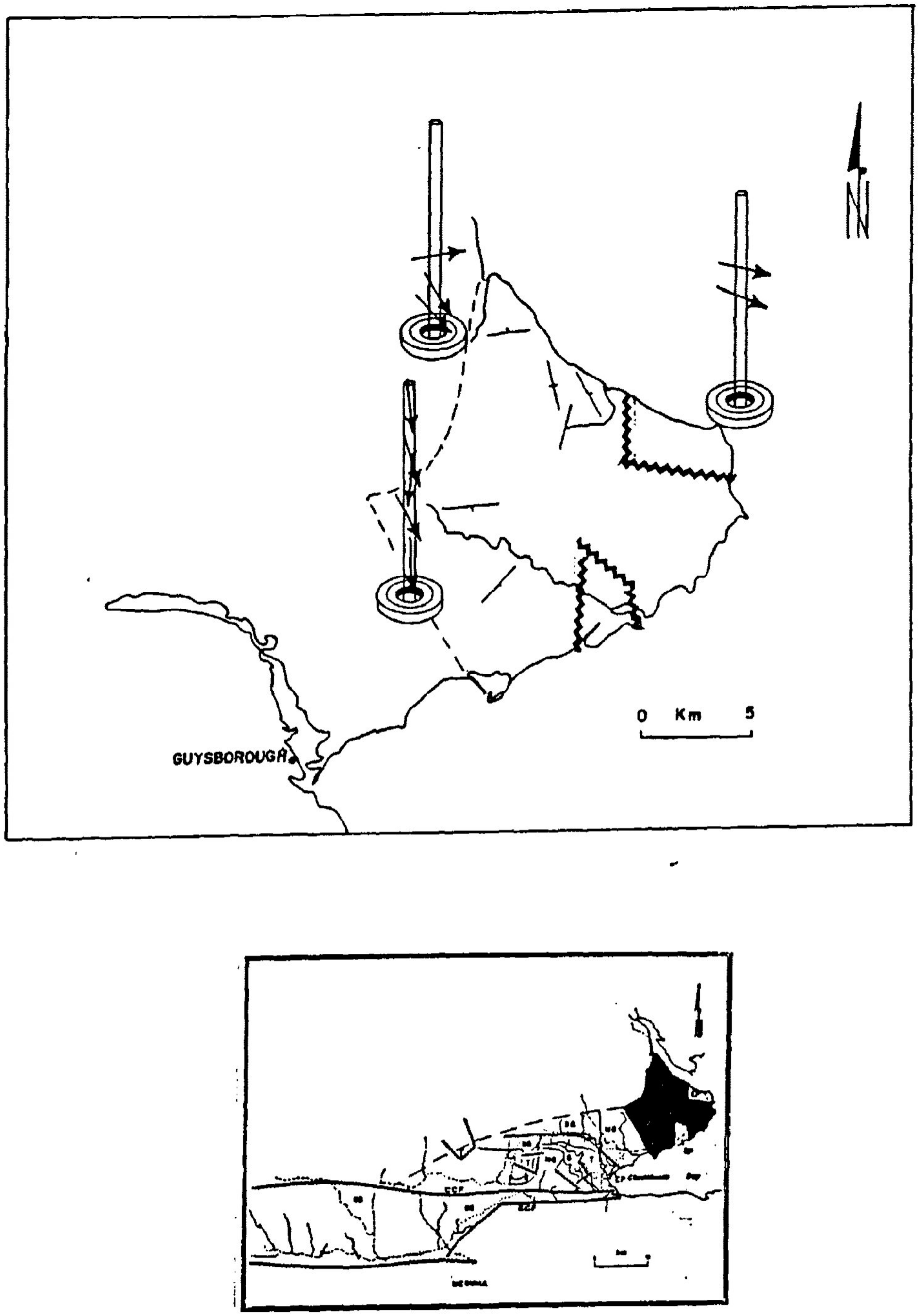


FIGURE 75. St. Francis Harbour River Formation: vertical variation of unidirectional paleocurrents.

section. The central portion of the section exposed along the coast yields paleocurrent Local Mean Trends which are oriented south-southeast, and which remain unchanged up section. The most complete section available, however, is that exposed in the St. Francis Harbour River. Upwards through the section, Local Mean Trends fluctuate on either side of azimuth 100 degrees. Figure 76 presents the total number of unidirectional and bidirectional paleocurrent measurements collected from the formation in two rose diagrams, with Local Mean Trends shown on the accompanying maps as arrows. A unimodal distribution is evident. The Regional Mean Trend calculated from Local Mean Trends is azimuth 130 degrees with a vector strength per cent of 59%. Only six measurements were collected from bidirectional paleocurrent indicators. The mean is calculated as azimuth 84 - 264 degrees with a vector strength per cent of 57%. Though unidirectional and bidirectional means are somewhat different, the mean azimuth of bidirectional indicators does correspond to a significant portion of the unidirectional current rose. Further, the small number of measurements collected does not provide an adequate data base for detailed comparison of the two groups of data. Streams depositing the sediment of the St. Francis

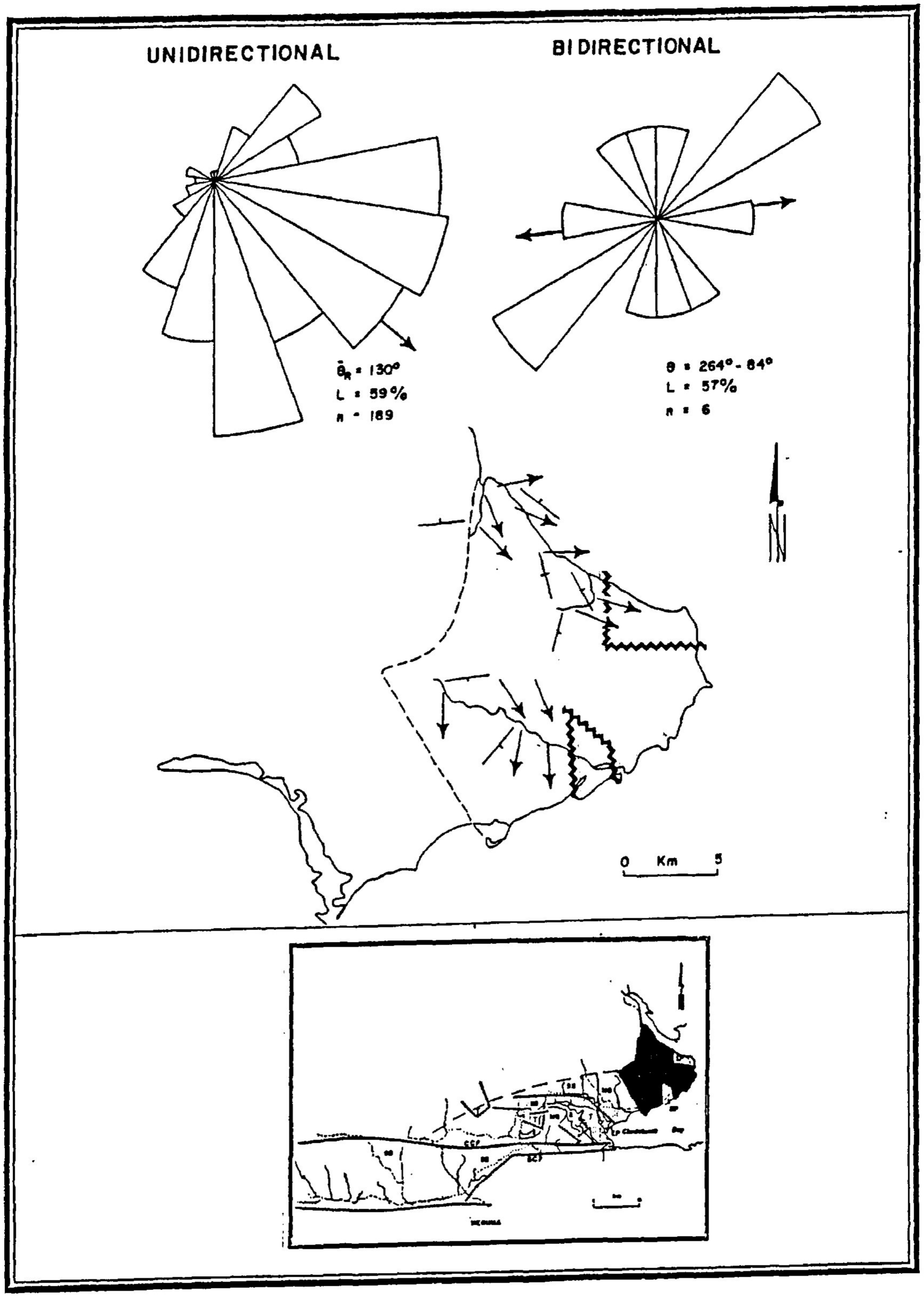


FIGURE 76. St. Francis Harbour River Formation: paleocurrents. The rose diagrams represent all of the data for this unit. Arrows represent Local Mean Trends, used to derive the Regional Mean Trend ($\bar{\theta}_R$). Paleocurrents indicate dominant flow to the southeast.

Harbour River Formation flowed to the southeast as indicated by the calculated Regional Mean Trend.

Minister Brook Formation

Rose diagrams and calculated Local Mean Trends for unidirectional paleocurrents of this unit are presented as Figure 77. Unimodal and bimodal distributions are evident with correspondingly variable values of vector strength per cent. Outcrop in the Clam Harbour River provides the only opportunity to examine the vertical variation of Local Mean Trends (Figure 78). Here, paleocurrents indicate the dominant flow was to the southwest. Isolated groups of data indicate southerly and southeasterly flow (refer to Figure 77). All of the data collected is presented in the rose diagrams on Figure 79 and Local Mean Trends are shown as arrows on the accompanying map. A unimodal distribution is evident for unidirectional current indicators though the range of values is quite variable. The Regional Mean Trend is azimuth 215 degrees and the vector strength per cent is 49%. Only 6 bidirectional indicators were measured and no trend is evident. Paleocurrents for the Minister Brook Formation are variable though a general southwesterly trend is indicated.

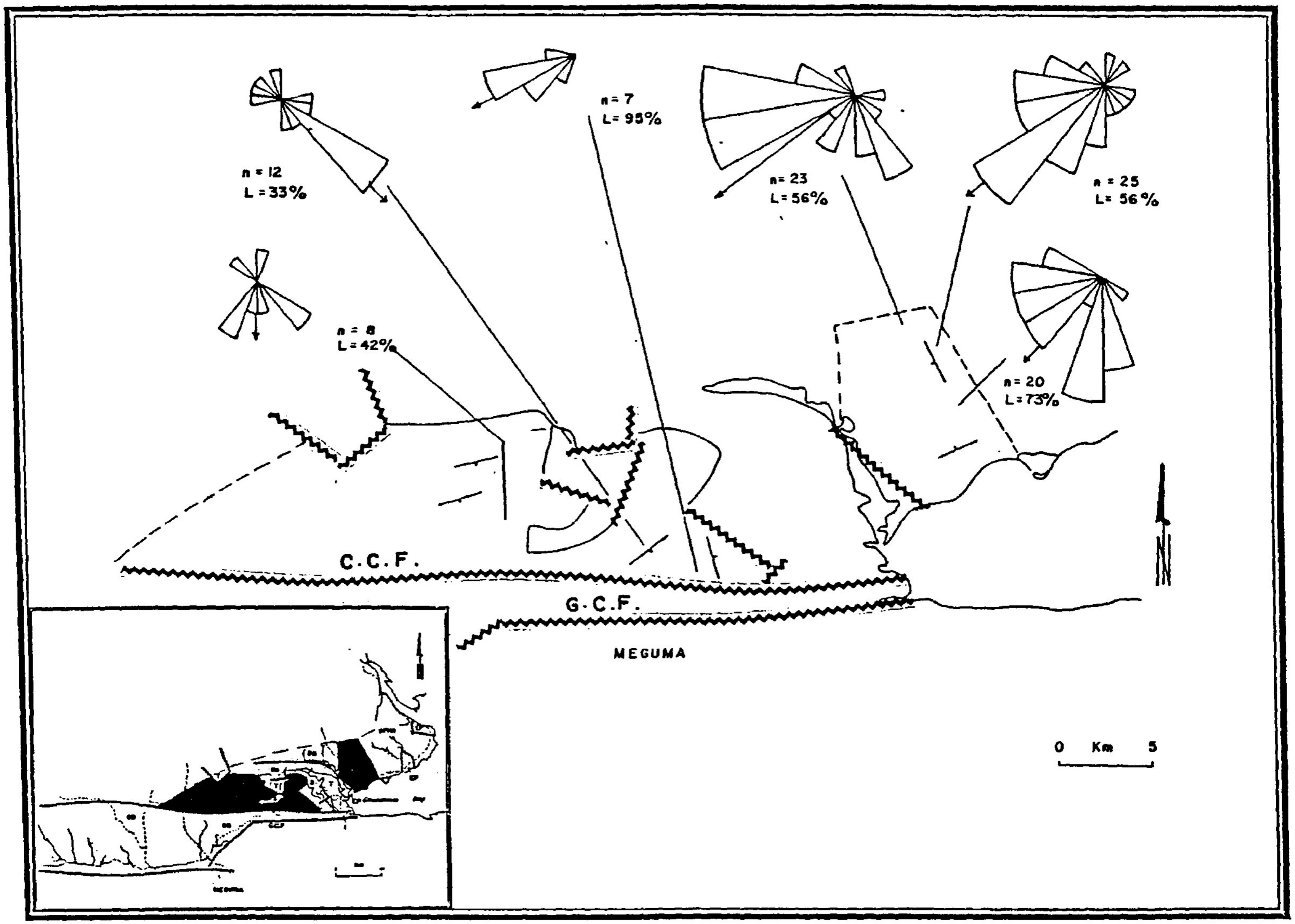


FIGURE 77. Minister Brook Formation: Local Mean Trends for unidirectional paleocurrents (n represents the number of measurements and L represents the vector strength per cent).

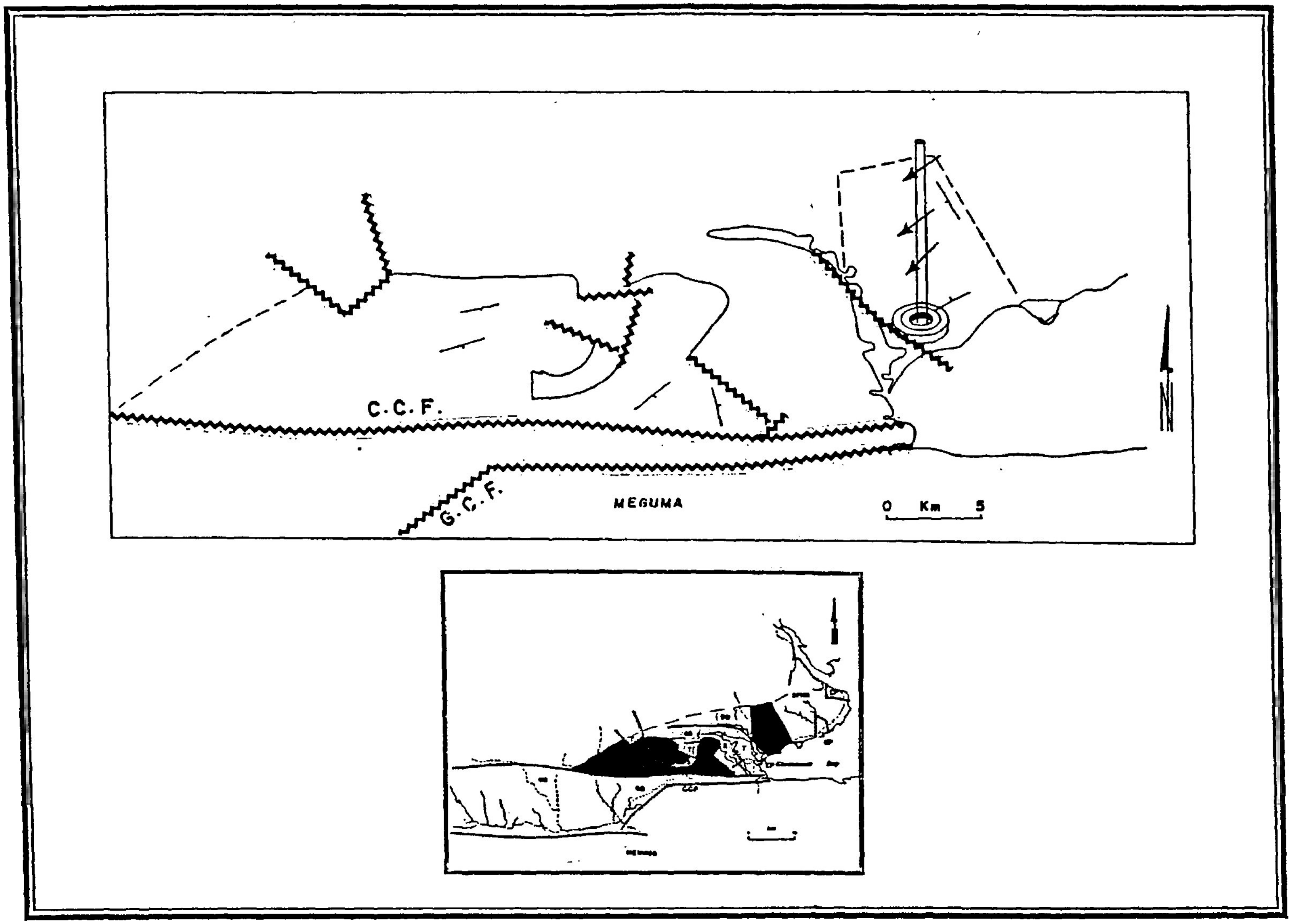


FIGURE 78. Minister Brook Formation: vertical variation of unidirectional paleocurrents.

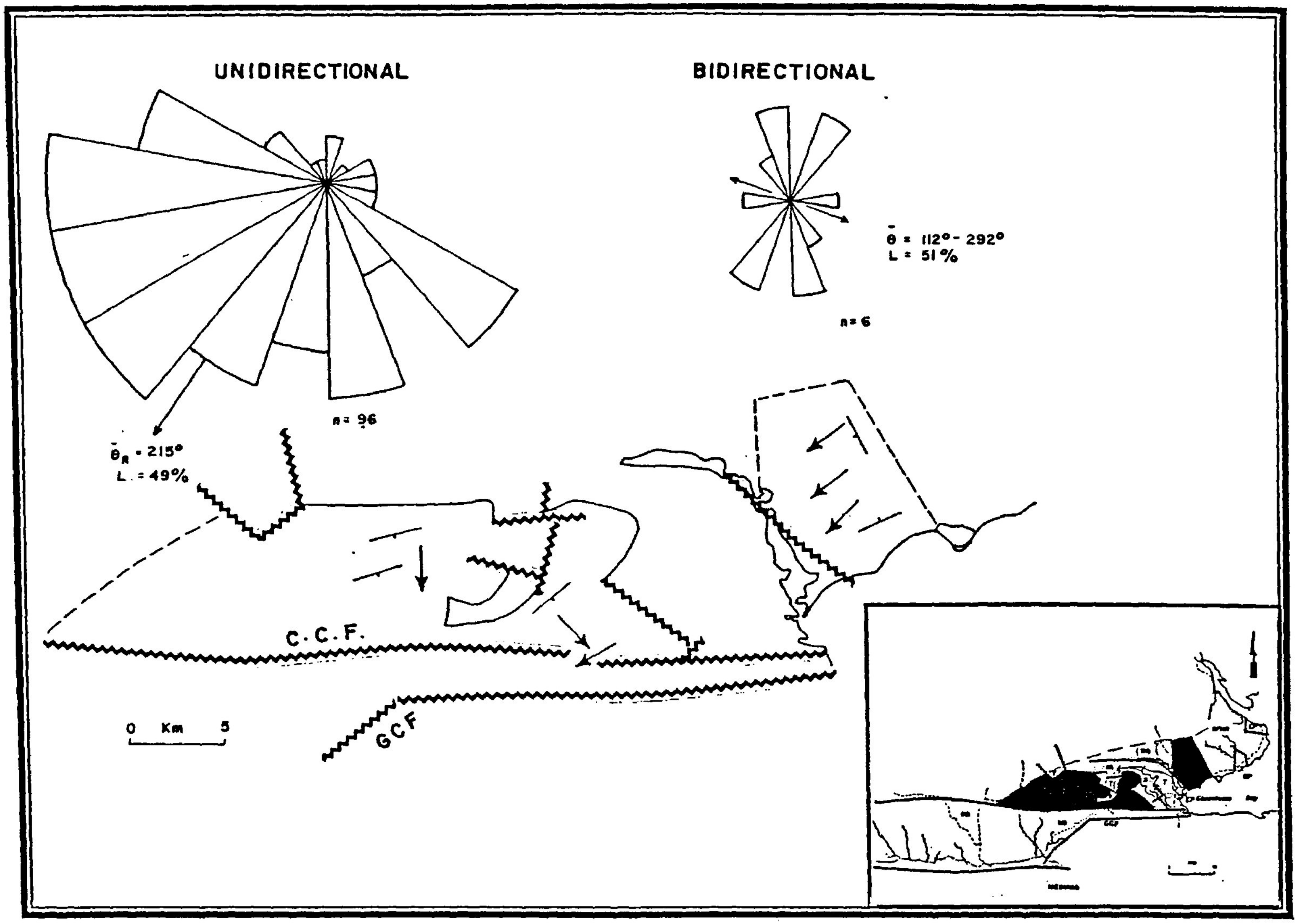


FIGURE 79. Minister Brook Formation: paleocurrents. The rose diagrams represent all of the data for this unit. Arrows represent Local Mean Trends, used to derive the Regional Mean Trend ($\bar{\theta}_R$). Paleocurrents indicate dominant flow to the southwest.

Brandy Brook Formation

Current rose diagrams and calculated Local Mean Trends for unidirectional paleocurrents are shown on Figure 80. A unimodal distribution is exhibited by all data groups and values for vector strength per cent are generally within the 50% to 80% range. The vertical variation of Local Mean Trends through the formation is shown on Figure 81. Vertical trends near the base of the section are evident in data groups collected in South Brook, where indicated paleoflow varies from southeast to southwest up section. Trends in the upper part of the section are exhibited in Brandy Brook and Brymer Brook. In the former, paleoflow becomes increasingly more southerly up section. In the latter, paleocurrents are variable, and fluctuate between southeast and southwest. Figure 82 shows all of the paleocurrent data collected in rocks of this formation. Unidirectional data shows a unimodal distribution with a calculated Regional Mean Trend of azimuth 166 degrees. The calculated vector strength per cent is 48%. Only 14 bidirectional current indicators were measured. The distribution is also unimodal, with a mean of azimuth 99 - 279 degrees and a vector strength per cent of 69%. Both data sets agree fairly well and indicate that the streams which

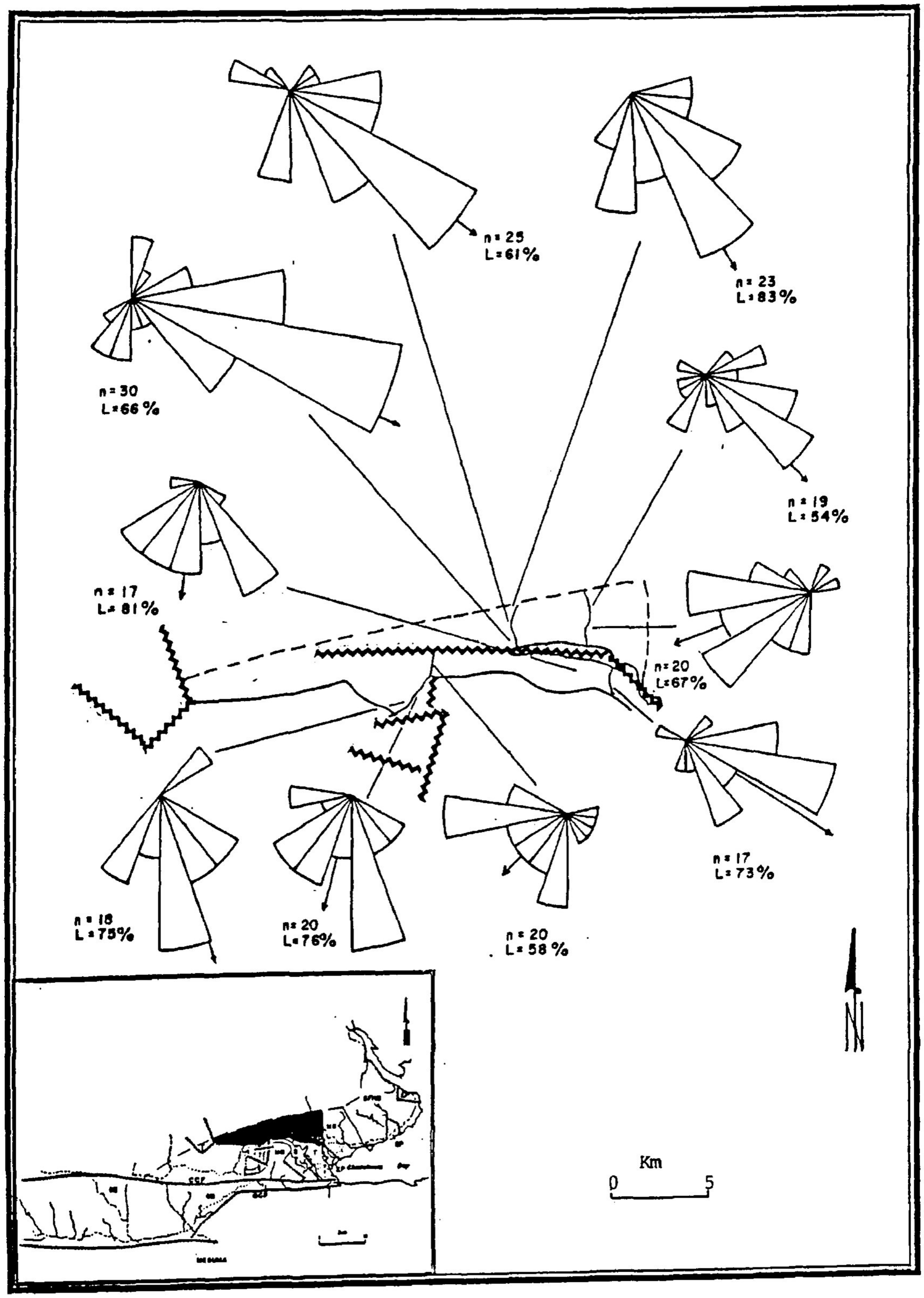


FIGURE 80. Brandy Brook Formation: Local Mean Trends for unidirectional paleocurrents (n represents the number of measurements and L represents the vector strength per cent).

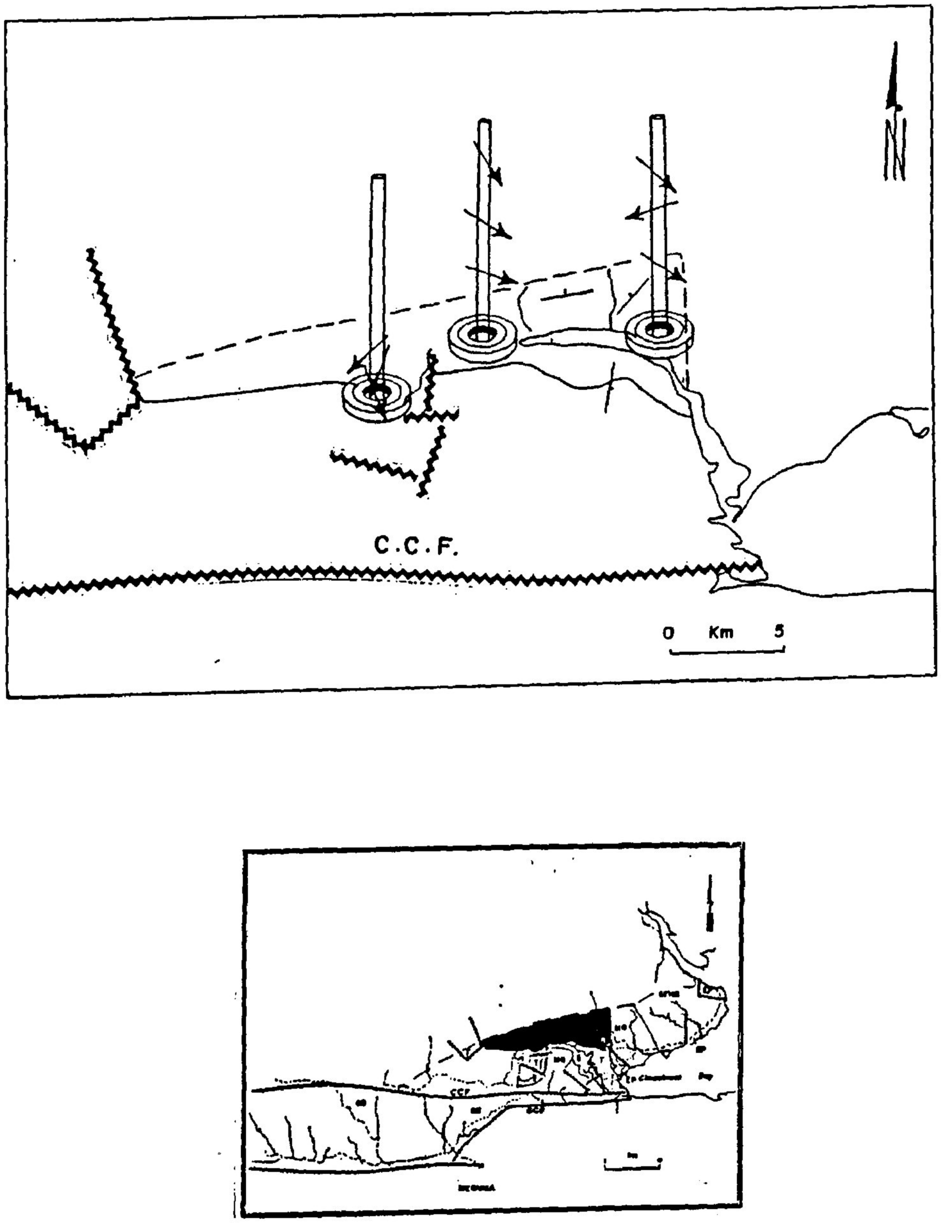


FIGURE 81. Brandy Brook Formation: vertical variation of unidirectional paleocurrents.

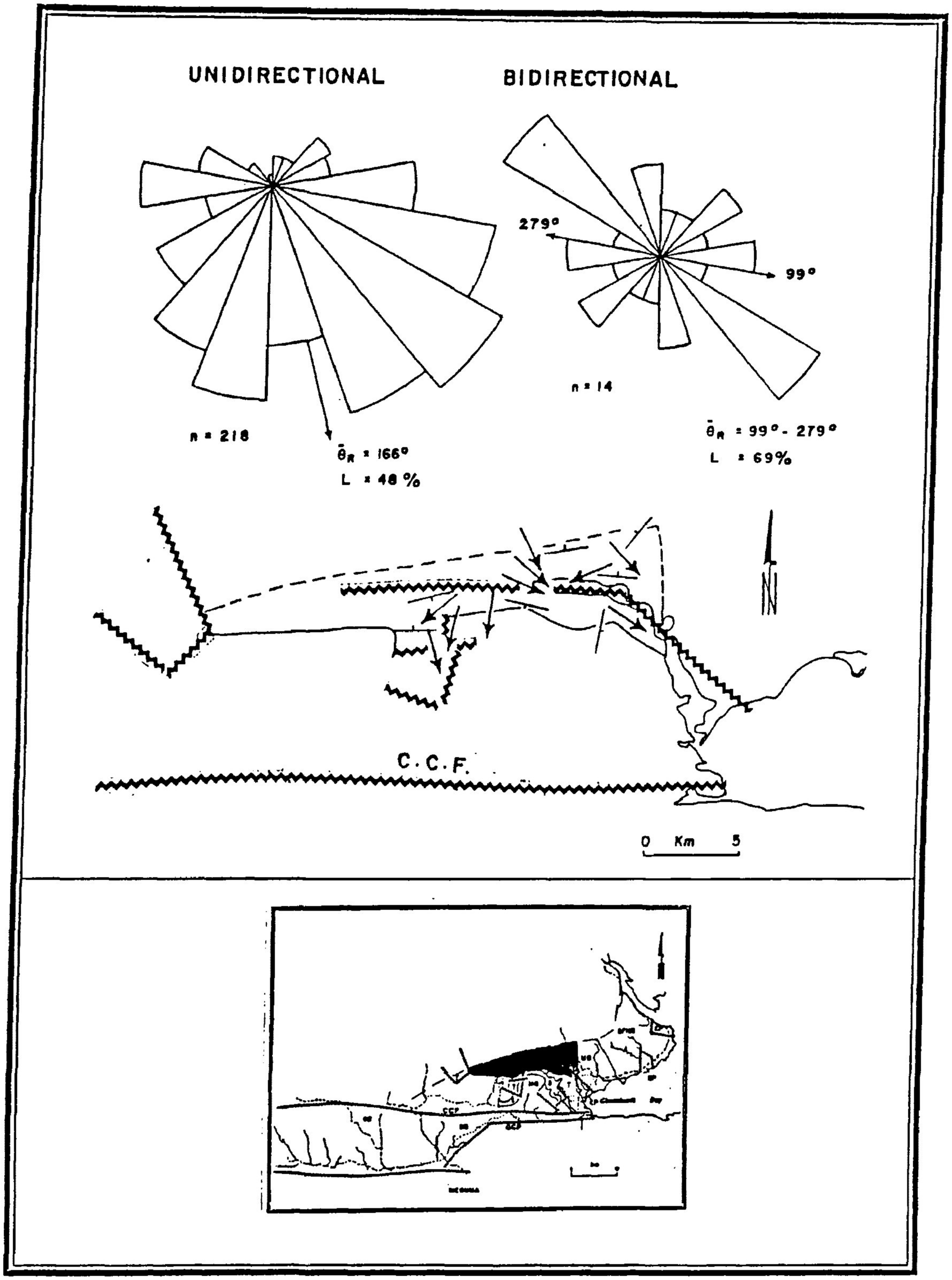


FIGURE 82. Brandy Brook Formation: paleocurrents. The rose diagrams represent all of the data for this unit. Arrows represent Local Mean Trends, used to derive the Regional Mean Trend ($\bar{\theta}_R$). Paleocurrents indicate dominant flow to the south-southeast.

deposited sediment of the Brandy Brook Formation flowed to the southeast.

Eddy Point Formation

Rose diagrams representative of Local Mean Trends for the unit are presented as Figure 83. Though a general trend to the east and south is evident, paleocurrent measurements are quite variable, an observation reflected by the low values of vector strength per cent. Vertical variation of unidirectional paleocurrents is shown on Figure 84. The two isolated groups are placed according to their interpreted position in the general section (refer to Figure 53). Unidirectional paleocurrents suggest flow to the southeast near the bottom of the formation, and to the east in the upper portion of the section. All of the paleocurrent data collected for this formation is presented as Figure 85. The Regional Mean Trend of unidirectional paleocurrents is azimuth 124 degrees though the vector strength per cent is low. The dominant flow direction suggested by bidirectional current indicators is azimuth 74 - 254 degrees and the vector strength per cent is 75%. Mean flow directions are not in agreement for unidirectional and bidirectional current indicators and rose

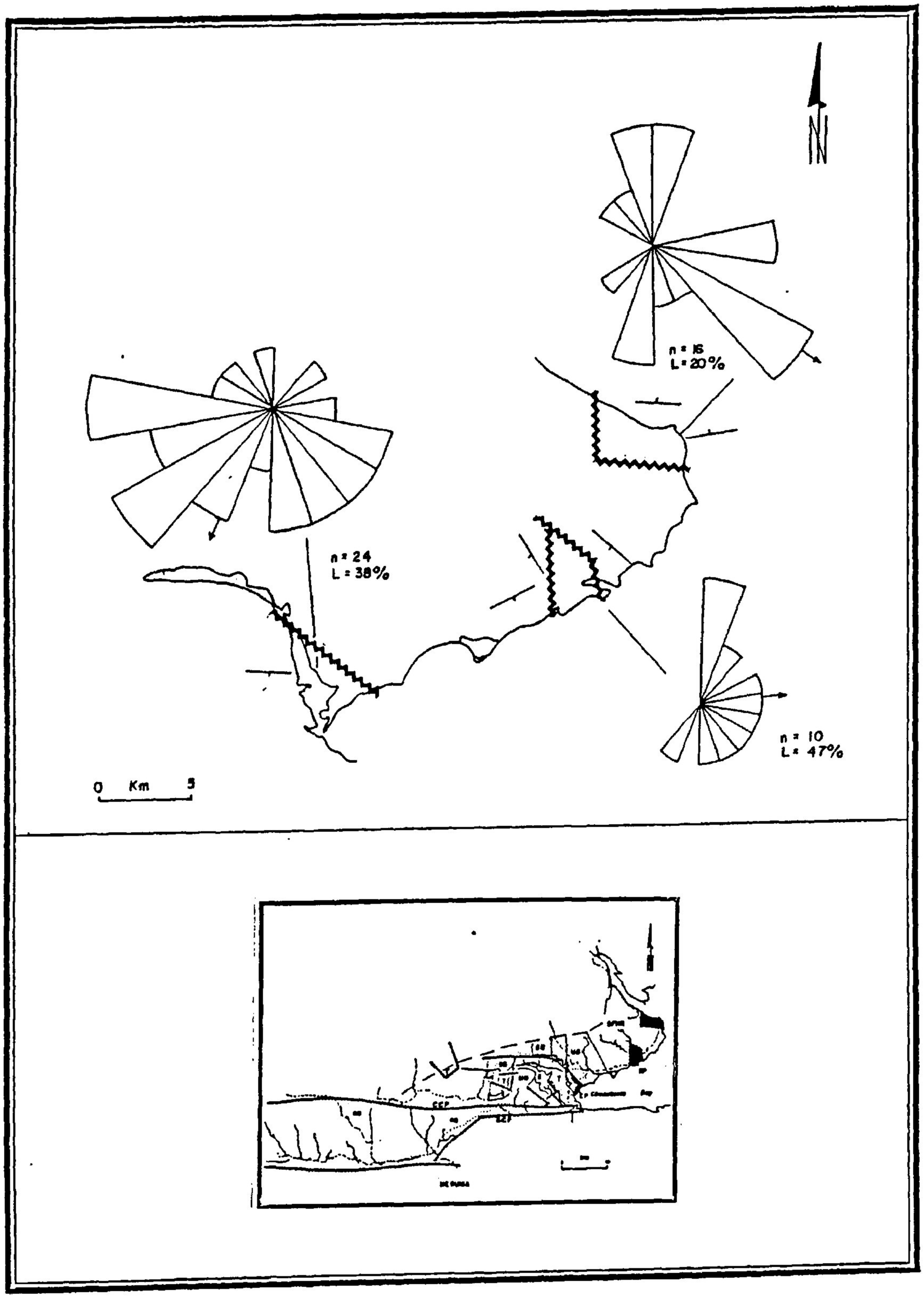


FIGURE 83. Eddy Point Formation: Local Mean Trends for unidirectional paleocurrents (n represents the number of measurements and L represents the vector strength per cent).

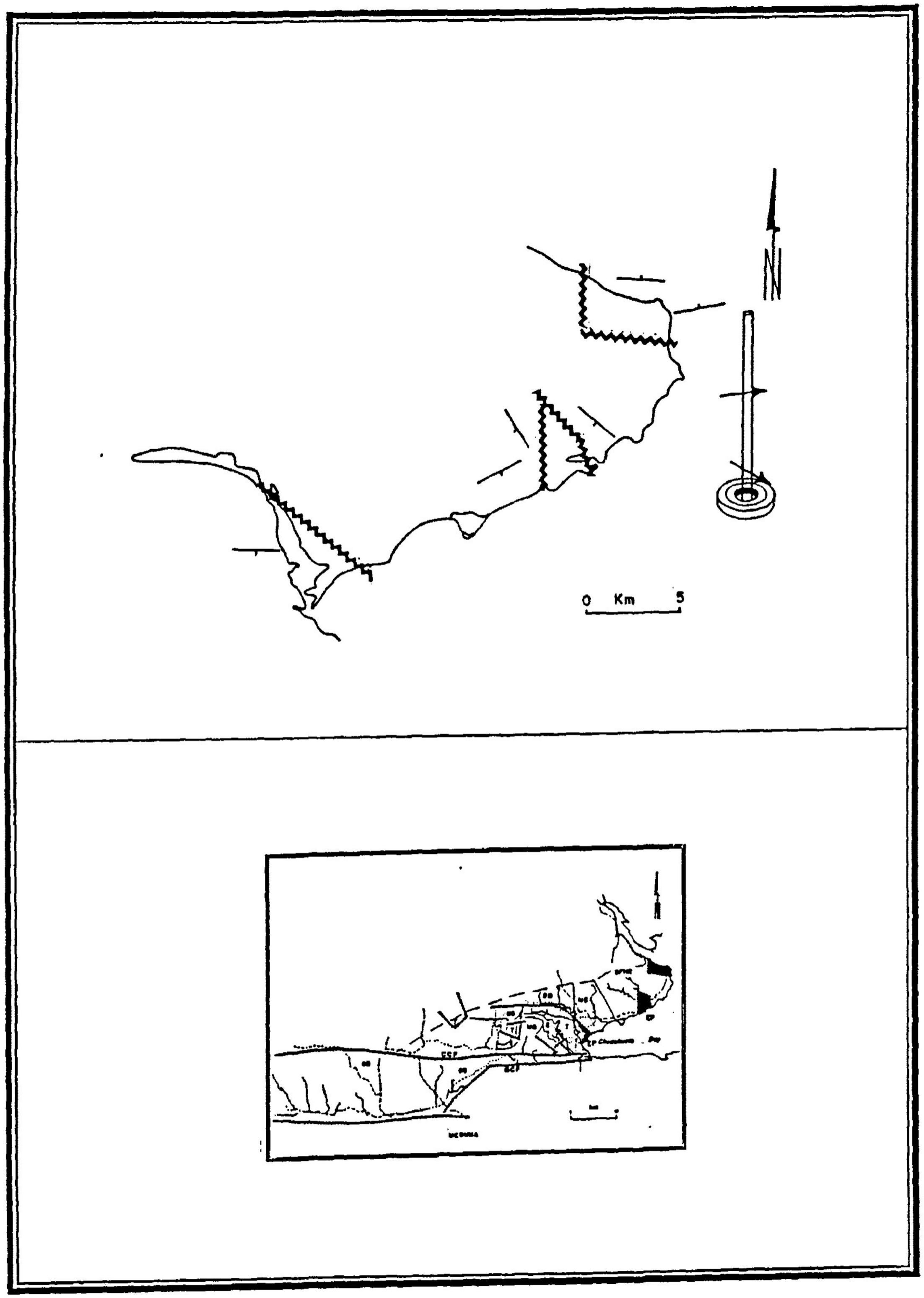


FIGURE 84. Eddy Point Formation: vertical variation of unidirectional paleocurrents.

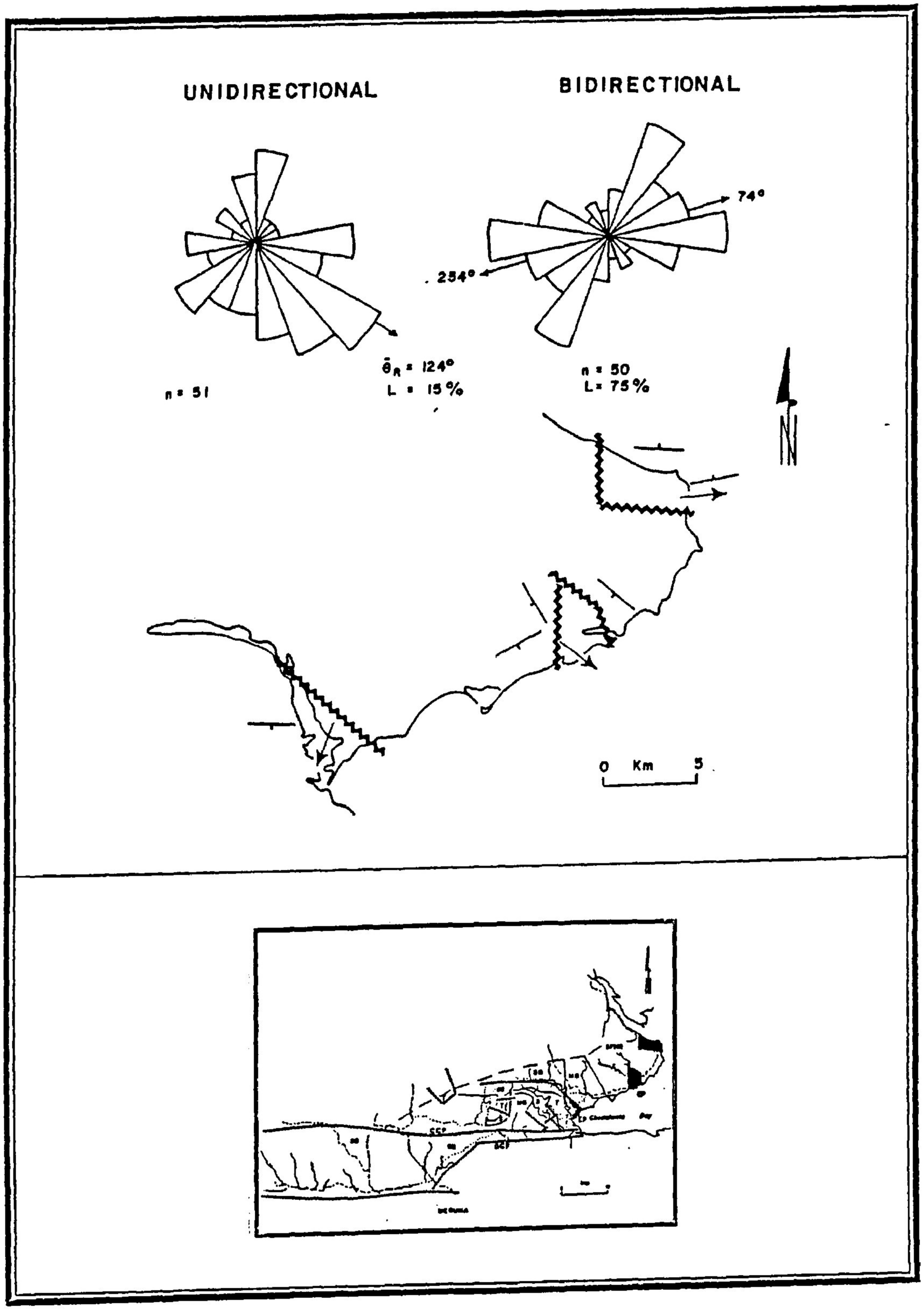


FIGURE 85. Eddy Point Formation: paleocurrents. The rose diagrams represent all of the data for this unit. Arrows represent Local Mean Trends, used to derive the Regional Mean Trend ($\bar{\theta}_R$). Paleocurrents indicate dominant flow to the southeast.

diagrams exhibit considerable variability with respect to the range of paleocurrent measurements collected for this unit.

St. Mary's Basin

Gunns Brook Formation

Rose diagrams and calculated Local Mean Trends are presented as Figure 86. Diagrams are strongly unimodal with high values for vector strength per cent. Vertical trends through the formation are shown in Figure 87. Only minor fluctuations on either side of azimuth 0 degrees are evident. All of the data collected for this unit is presented on Figure 88 with Local Mean Trends shown as arrows on the accompanying map. Unidirectional data is strongly unimodal with a high vector strength per cent. The Regional Mean Trend calculated for the Gunns Brooks Formation is azimuth 0 degrees. Bidirectional current indicators exhibit a bimodal distribution. One trend is consistent with unidirectional data whereas the second is oriented perpendicular to this trend. Most of the measurements were taken on the orientation of plant fragments in coarse clastic units. Plant debris lodged at the upstream end of gravel bars may not reflect the general flow direction

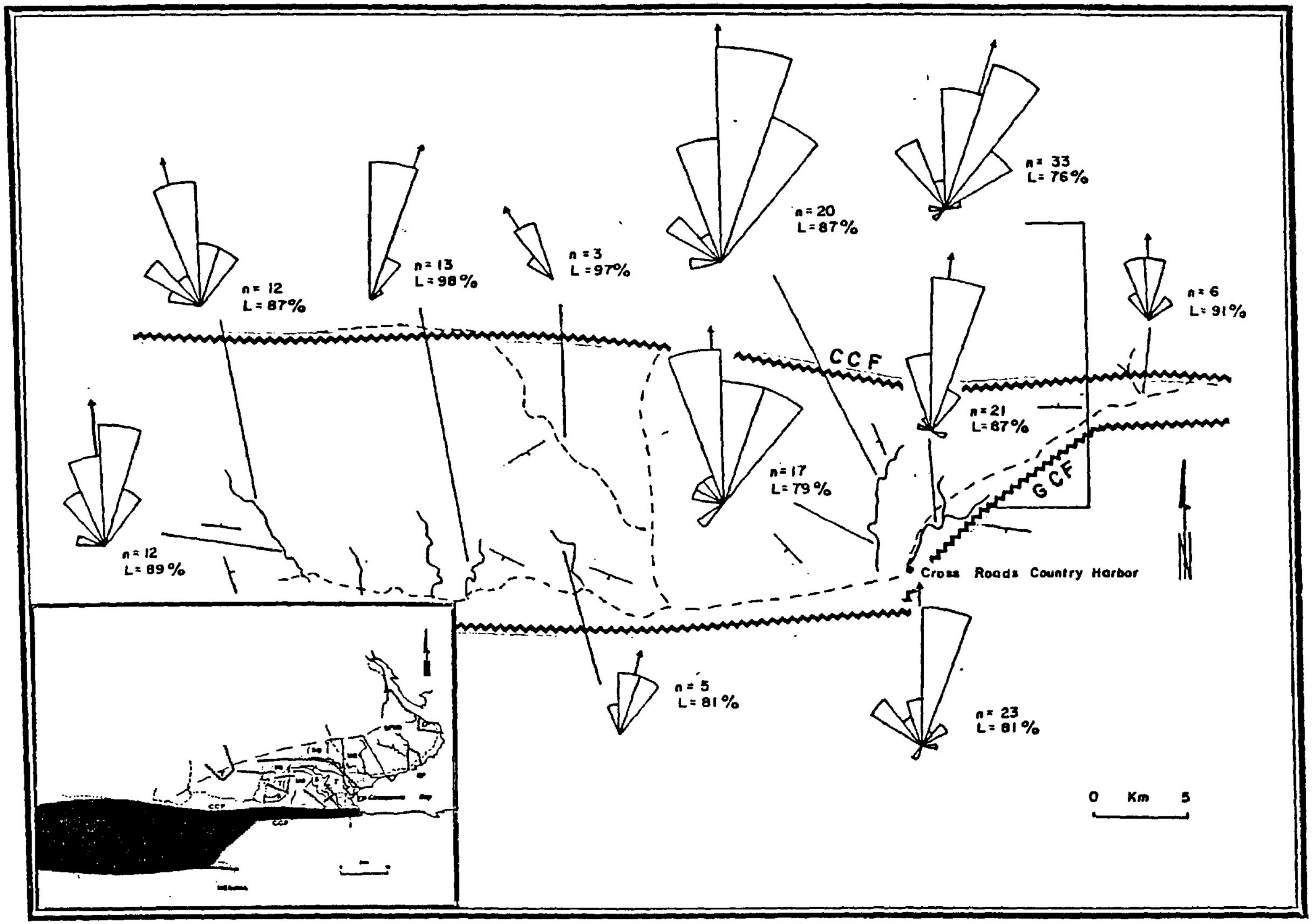


FIGURE 86. Gunns Brook Formation: Local Mean Trends for unidirectional paleocurrents (n represents the number of measurements and L represents the vector strength per cent).

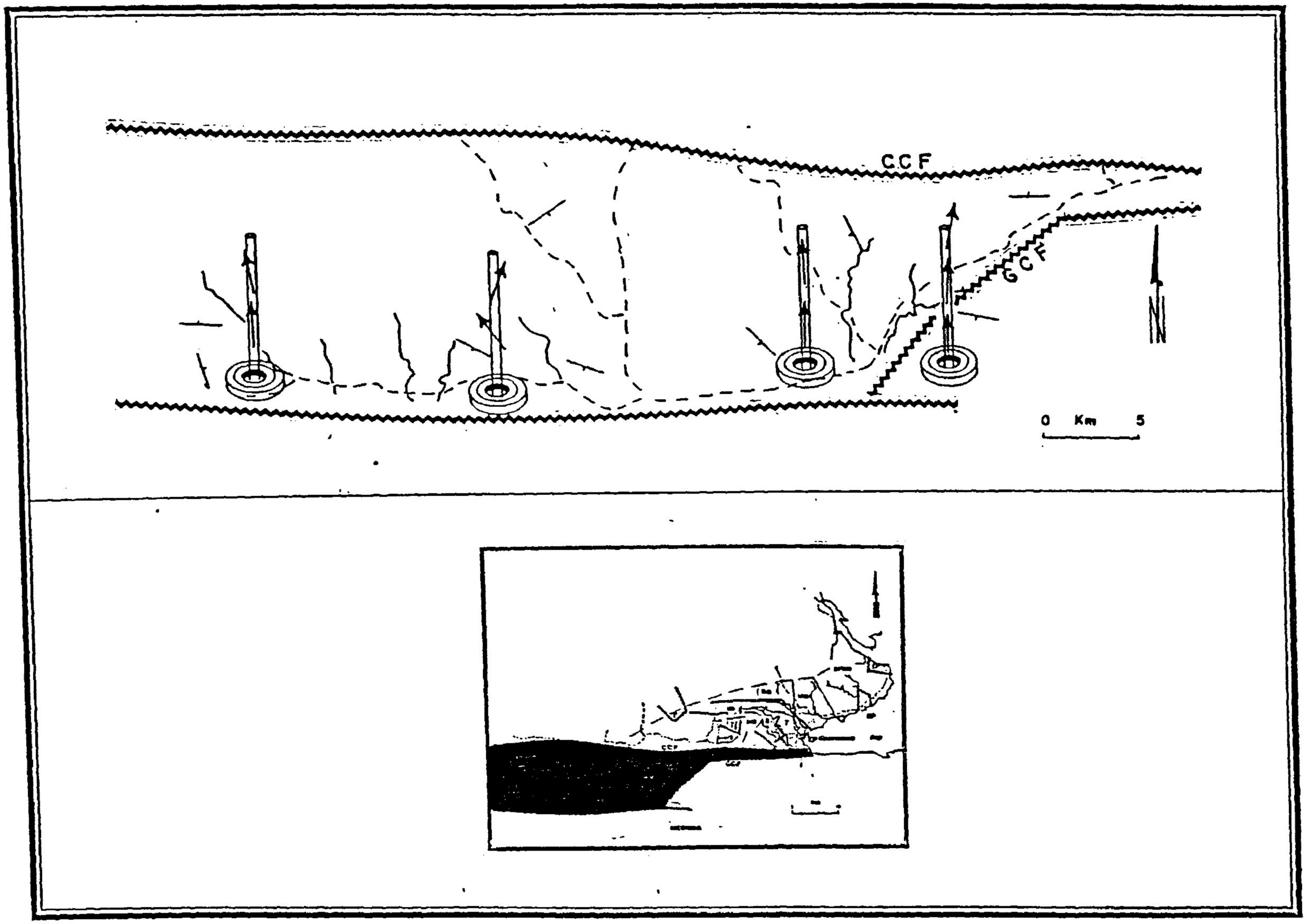


FIGURE 87. Gunns Brook Formation: vertical variation of unidirectional paleocurrents.

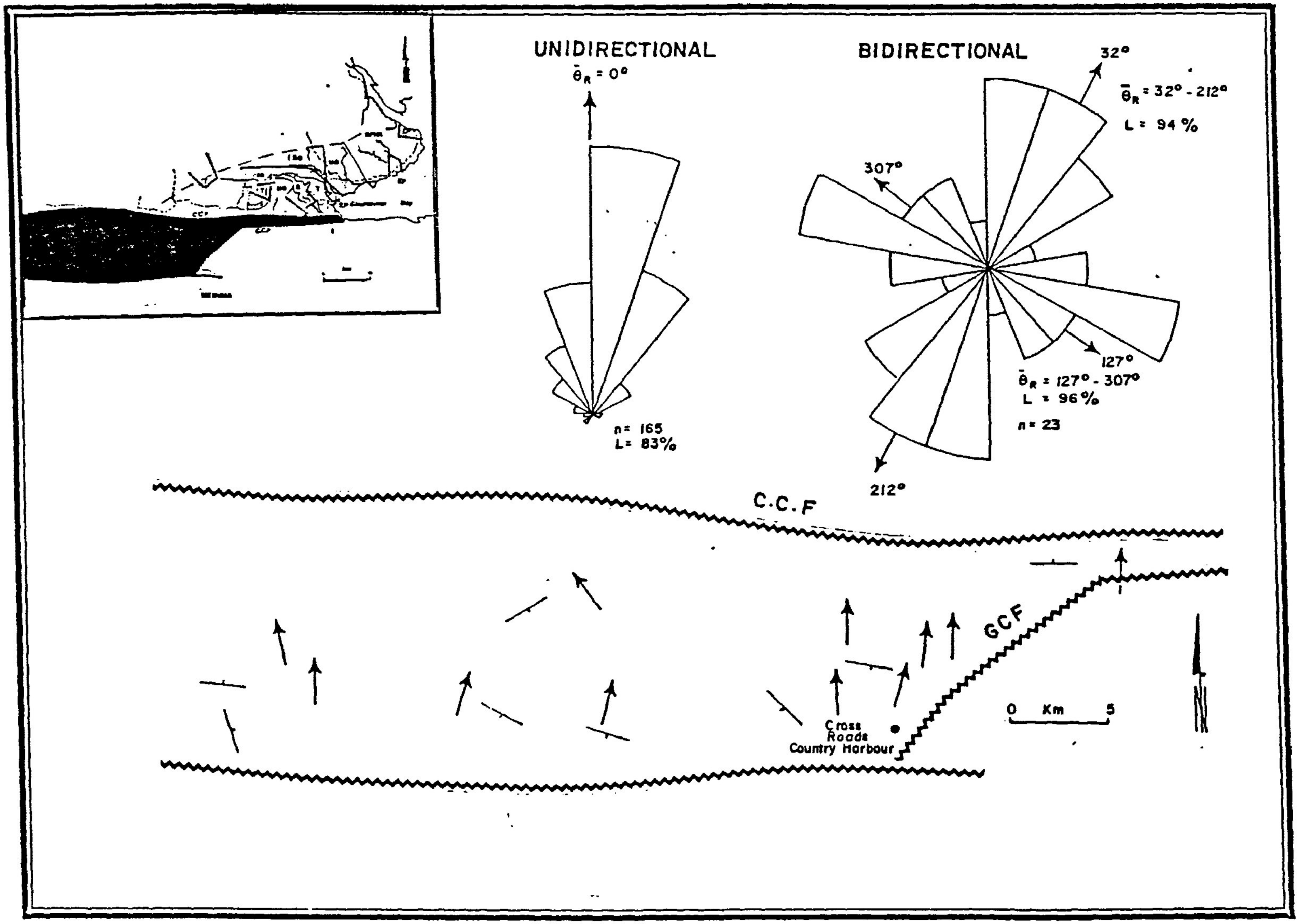


FIGURE 88. Gunns Brook Formation: paleocurrents. The rose diagrams represent all of the data for this unit. Arrows represent Local Mean Trends, used to derive the Regional Mean Trend ($\bar{\theta}_R$). Paleocurrents indicate dominant flow to the north.

and is here used to explain the group of bidirectional data oriented transverse to the flow direction suggested by unidirectional data. Streams which deposited sediment of the Gunns Brook Formation flowed to the north.

Figure 89 shows the variation of maximum clast size in conglomerates of the Gunns Brook Formation. The average of the five largest clasts observed was utilized in the generation of this figure. Coarsest clasts are found proximal to the southeast faulted contact with the Meguma Terrane. To the west, fewer coarse beds are exposed and boulder conglomerates are not present. Conglomerates in the Gunns Brook Formation generally fine to the north in keeping with the paleocurrent data presented above. Exposures in Barren Brook near the west boundary of the study area coarsen to the north but reflect folding about northwest-southeast axes.

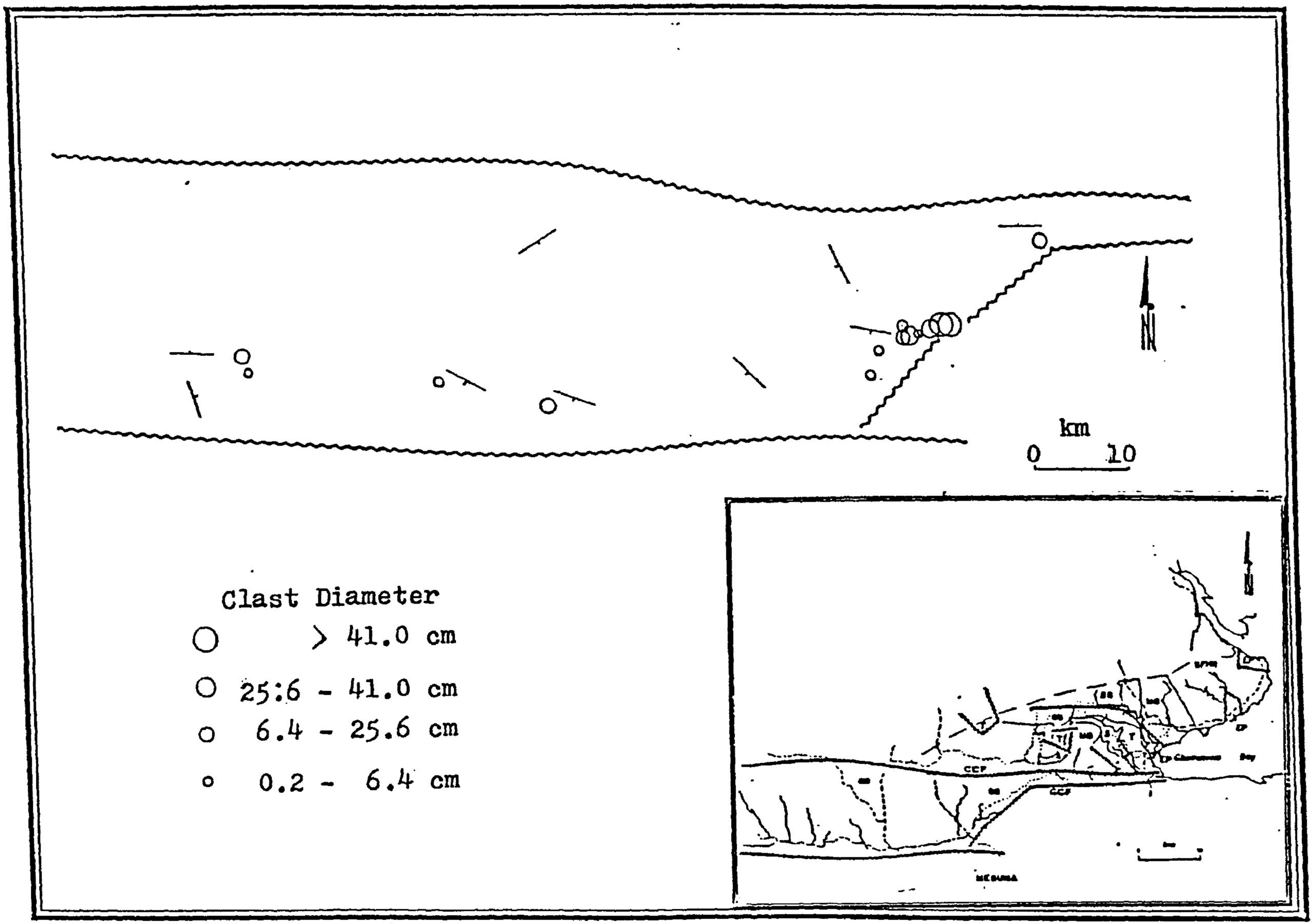


FIGURE 89. Gunns Brook Formation: clast size variation in conglomerate illustrates a fining upward trend away from the southeast, present day basin margin. To the west, conglomerates fine upward to the southeast and reflect folding along northwest-southeast axes. Coarse grained clastic units are not evident to the north and northwest, consistent with current flow in this direction.

CHAPTER 5

DEPOSITIONAL SYSTEMS

Introduction

The depositional systems approach to stratigraphic interpretation has been successfully employed by several workers (Fisher and McGowen, 1967; Embry and Klovan, 1976; Miall and Gibling, 1978; Hanford and Dutton, 1980; Casey, 1980). The concept requires integration of the observed lithofacies in terms of description, distribution, geometry, and relationships to associated lithofacies, and the subsequent recognition of large scale genetic units similar to modern systems (Fisher and McGowen, 1967). Several depositional events (lithofacies) comprise a single depositional episode and the resultant sedimentary complex formed is described as the product of a single depositional system (Embry and Klovan, 1976). Contemporaneous systems may be linked to form systems tracts which evolve through time as a function of tectonics and source area variability (Brown and Fisher, 197). This hierarchical organization of stratigraphic units facilitates the application of the concept to very large scale basins (Embry and Klovan, 1976).

Eight depositional systems comprising two systems tracts are recognized in the study area. With one exception, the informal lithostratigraphic units described in Chapter 3 correspond to the product of a single depositional system. The Tower Formation includes lithofacies typical of fluvial and lacustrine environments and therefore represents two depositional systems combined to form a systems tract. Systems identified in Guysborough Basin are discussed first followed by consideration of the single depositional system exposed in St. Mary's Basin.

Guysborough Basin

Sunnyville Formation

This formation constitutes the base of the succession in Guysborough Basin. Though dominated by volcanic flows and pyroclastics, interflow sedimentary lithofacies suggest accumulation of fine clastic material in a quiet marine or lacustrine environment (Figure 90a). Deposition by mass flow processes occurred when sediment accumulation on either inter basin slopes (perhaps the flanks of volcanic centres) or basin margin slopes became unstable. Clast lithologies in

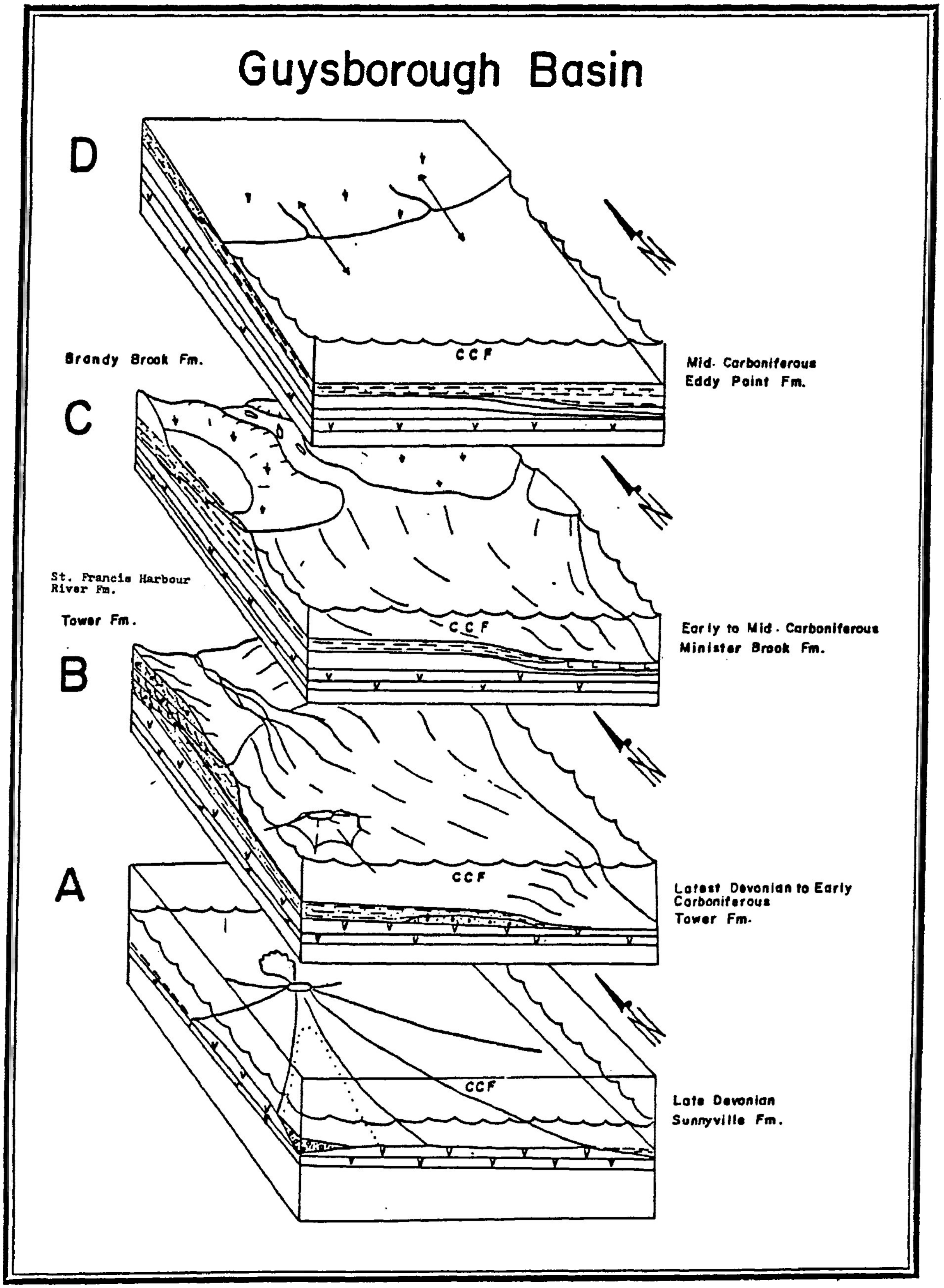


FIGURE 90. Depositional systems in Guysborough Basin.

conglomerates are exclusively of volcanic derivation and indicate the local nature of the sediment source for this unit. No age determinations were made for the formation but comparison with similar units in the Maritimes (Mackasey, 1963; Blanchard et al., 1984) suggest a Late Devonian age. No paleocurrent measurements were collected from these rocks.

Tower Formation

As noted above, this formation represents two environments of deposition, and therefore, two depositional systems (Figure 90b). In the central portion of the study area, mass flow sediments are interbedded with fine sediments which accumulated from suspension, in a quiet subaqueous environment similar to that which existed during deposition of the Sunnyville Formation. Grain flow deposits are common here. High depositional slopes such as those on the flanks of volcanic centres are required for deposition by this process to occur (review by Middleton, 1980). To the north, northwest and northeast, the Tower Formation is characterized by the deposits of a braided fluvial depositional system. Clast lithologies in conglomerates near the bottom of the formation indicate the predominance of a local source area. A non-local source area is more important in the upper part of the formation as indicated by the abundance of intrusive clasts. Sand/shale ratios increase slightly up section. The age of this formation is estimated to be Latest Devonian to Earliest Carboniferous and paleocurrent measurements for the formation suggest dominant flow to the southeast. The relatively low to moderate vector strength per cent reflects the amalgamation of paleocurrent populations from fluvial and lacustrine strata.

St. Francis Harbour River Formation

Lithofacies in this formation are interpreted to reflect deposition in a Donjek type braided fluvial environment (Figure 90b). This depositional system was laid down in part contemporaneously with the upper portion of the Tower Formation as indicated by the presence of volcanic clasts in conglomerates of the unit. Intrusive clasts constitute a significant proportion of coarse clastic units throughout the formation and sedimentary clasts are more abundant up section. Detritus for the upper part of this formation was supplied primarily from an external source area. Coaly fragments incorporated into bar and channel sediments of the unit reflect the establishment of vegetated areas. Sand/shale ratios show a general fining upward trend through the formation. The unit is assigned an age of Earliest Carboniferous based on stratigraphic relationships. Paleocurrents suggest streams depositing sediments of this formation flowed to the southeast. A moderate vector strength per cent was calculated for the measurements collected from rocks of this formation.

Minister Brook - Brandy Brook Formations

The Minister Brook Formation is interpreted to represent deposition in a lacustrine environment. Conglomerates near the base of the section contain abundant sedimentary clasts and clastic ratios indicate an increasing amount of dolomitic limestone up section. Clasts in conglomerate are predominantly of sedimentary affinity. The formation is assigned an age of Early to Mid-Carboniferous. Unidirectional paleocurrents are quite variable though a southwesterly Regional Mean Trend is evident. The vector strength per cent is comparable to that calculated for the Brandy Brook Formation.

The Brandy Brook Formation is interpreted to reflect deposition in a sandy fluvial environment (Figure 90c). Conglomerates near the bottom of the section contain abundant clasts of sedimentary affinity. Sand/shale ratios indicate a general fining upward trend through the formation. Fining upward cycles are also evident on a scale of several metres with coarse sediments approximately equalling fine sediments. This relationship is reflected in the entropy values, which remain quite constant through the section. Clast lithologies in conglomerates are similar to those in the Minister Brook Formation. The unit is assigned an age of Early to Mid-Carboniferous based largely on stratigraphic considerations. Paleocurrents indicate that stream flow was dominantly to the southeast. The vector strength percent for this data set is lower than that calculated for the underlying St. Francis Harbour River Formation.

Both formations are in conformable contact with the underlying Tower Formation. Furthermore, clast lithologies in conglomerates near the base of these units are comparable. Based on these considerations, the two formations are interpreted to represent lateral equivalents, and are therefore linked to form a fluvial-lacustrine systems tract.

Eddy Point Formation

This formation is interpreted to represent deposition in a lacustrine-mudflat environment subsequent to the Windsor incursion of the sea (Figure 90d). Chemical sediment occurs in the lowest part of the section and sand/shale ratios indicate a slight coarsening upward trend. The formation is assigned an age of Mid-Carboniferous based on paleobotanical data reported by Bell (1944) and Rostoker (1960). Unidirectional paleocurrents indicate flow to the east and southeast. Bidirectional paleocurrents are quite variable and do not exhibit a distinct trend. For both sets of data, calculated values of vector strength per cent are low.

St. Mary's Basin

Gunns Brook Formation

This formation is interpreted to represent deposition in a South Saskatchewan type braided stream environment (Figure 91). Clast lithologies in conglomeratic units are dominantly green sandstone, black shales and white quartz. A fining upward trend is exhibited by the sand/shale ratios through the

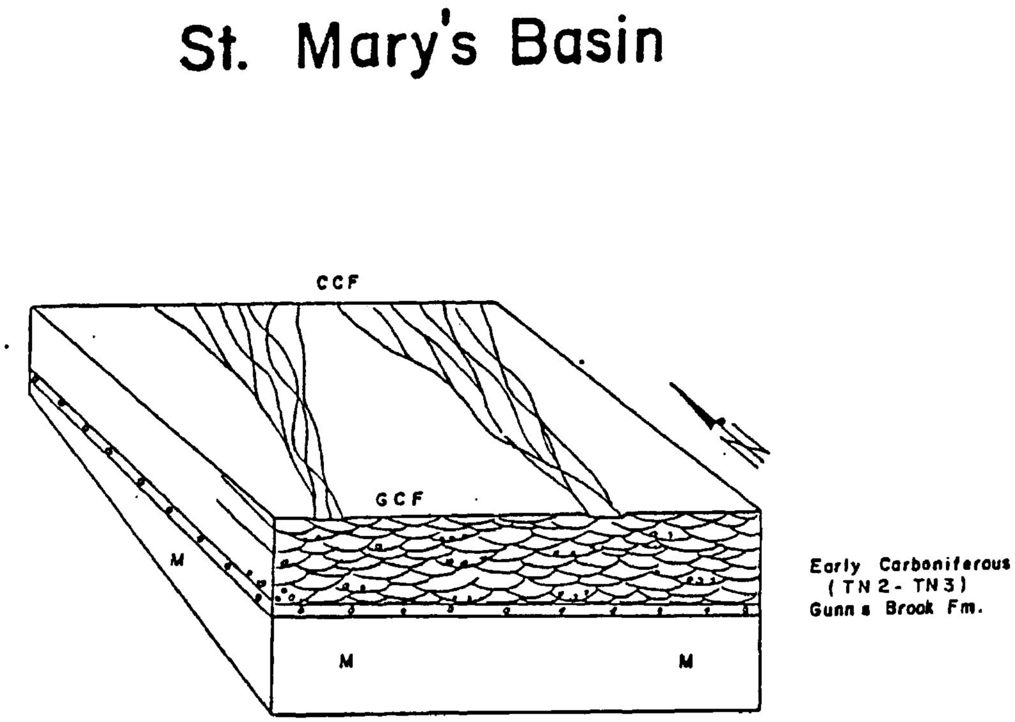


FIGURE 91. Depositional system in the St. Mary's Basin.

succession. Palynological analysis yielded an assemblage indicative of a Tournaisian age (late Tn2 to early Tn3). Paleocurrents and the average clast size indicate streams flowed to the north during deposition of the Gunns Brook Formation. The vector strength per cent calculated for the unidirectional data set is high.

CHAPTER 6

INTEGRATED BASIN ANALYSIS - DISCUSSION

Introduction

The Mid-Devonian Acadian Orogeny caused widespread basement fragmentation and subsequent formation of the Maritimes Carboniferous Basin system (Belt, 1968). A braided strike-slip tectonic environment formed as a result of oblique continental collision between cratonic North America and the Avalon Microcontinent (Kent and Opdyke, 1978, 1979). Periodic adjustment along wrench faults controlled basin formation and sedimentary evolution through Devono-Carboniferous time (Webb, 1969), when the Maritimes Carboniferous Basin was no longer able to contain the sedimentary assemblage (Belt, 1968).

Basin Formation In A Strike-Slip Tectonic Environment

Tectonic conditions which are conducive to the formation of strike-slip basins are satisfied in several plate tectonic environments, including intracontinental settings (Christie-Blick and Biddle, 1985). Though a component of oblique movement is required for basin formation, the lateral fault displacement of adjacent crustal blocks is dominant (Christie-Blick and Biddle, 1985). Basins formed in this environment may be subject to variable tectonic influence. Wilcox et al. (1984) noted that oblique movement of adjacent blocks or changes in strike of the main wrench fault dictates whether the system is dominantly convergent or divergent in nature. Furthermore, convergent and divergent wrenching are commonly developed along a single system and result in the magnification of compressive structures (folds, conjugate faults, reverse faults, and thrusting) and tensile structures (normal faults), respectively (Wilcox et al., 1984). The terms transpression and transtension were coined by Harland (1971) to denote the conditions found in tectonic zones of oblique slip.

Early models for the formation of strike-slip basins and their subsequent sedimentological evolution relied on the geometry of boundary faults to a large degree (Kingma, 1958; Lensen, 1958; Quennell, 1958; Burchfiel and Stewart, 1966; Clayton, 1966; Belt, 1968; Freund, 1971; Crowell, 1974a, 1974b; Burke et al., 1982; Crowell and Link, 1982; Fralick, 1982; Mann and Burke, 1982; Mann et al., 1983; Mann and Bradley, 1984).

However, Christie-Blick and Biddle (1985) caution that post sedimentation deformation, including late faulting, may obscure features typical of the original basin and somewhat limit present day geometric reconstructions of strike-slip basins. They divided the available basin formation models into theoretical and empirical types. The derivation of theoretical models is initiated by defining a set of assumptions based on the properties of the lithosphere. These models are subsequently compared to existing basins which formed in this environment (Rodgers, 1980; Segall and Pollard, 1980; Aydin and Nur, 1985; Giraud and Seguret, 1985; Pitman and Andrews, 1985; Royden, 1985). Empirical models are those which represent the collation of data from several basins (Crowell, 1974a, 1974b; Aydin and Nur, 1982; Mann et al., 1983; Nilsen and McLaughlin, 1985; Sengor et al., 1985).

Generalized basin types are formed at two scales (Reading, 1975) and include comparatively small basins of pull-apart (Crowell, 1974a, 1974b), fault wedge (Kingma, 1958), and fault termination (Kingma, 1958; Chinnery, 1966; Moore, 1979; Fralick and Schenk, 1981) origin, and larger basins formed due to block rotation around sub-horizontal axes within the braided fault zone (Moody and Hill, 1956; Crowell, 1974a; Fralick and Schenk, 1981).

The Cobequid-Chedabucto Fault zone marks the contact between the Guysborough Basin, floored by rocks of the Avalon Microcontinent, and the St. Mary's Basin, which lies on Meguma type basement, and is recognized as a major terrane boundary. Studies conducted on this fault zone support dextral strike-slip (Eisbacher, 1968, White, 1983) on the order of at least 160 kilometres (Donohoe and Wallace, 1979) through the Late Carboniferous (Sneck and Nance, 1987). Displacement along this deformation zone played a vital role in the formation of basins in Nova Scotia and particularly those basins which are partially exposed in the study area. Further, tectonism controlled depositional episodes now preserved in the rock record and described in terms of depositional systems in Chapter 5.

Guysborough Basin

Basin Formation

Guysborough Basin is bounded to the south by the Cobequid-Chedabucto Fault, to the northwest by the Hollow Fault (refer to Figure 2) and constitutes part of Keppie's (1982) Antigonish Terrane. The distribution and sense of displacement along faults in and proximal to the study area are similar to that described by Crowell (1974a, 1974b) for his example of strike-slip fault divergence. In this case, bounding faults define a block rotation basin which has rotated counterclockwise and east end down (Figure 92). This interpretation is supported by the distribution of depositional systems and systems tracts through the Devono-Carboniferous and by paleocurrent data which indicate a dominant current flow to the southeast and east.

Basin Evolution

Depositional systems at the base of the succession in Guysborough Basin reflect the dominance of tensile tectonic

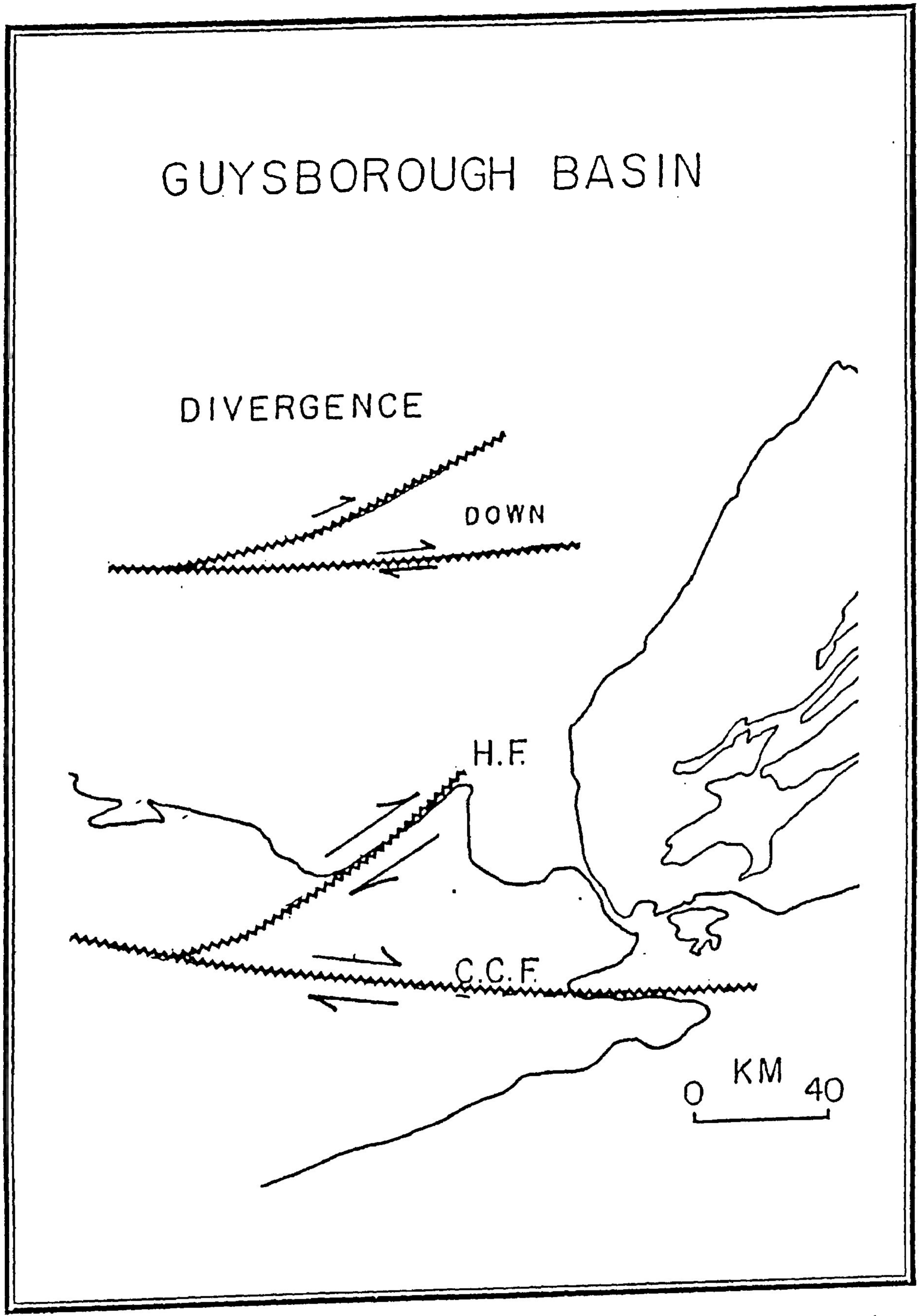


FIGURE 92. Basin formation model for Guysborough Basin. Bounding faults define a block rotation basin which rotates, east end down according to Crowell's (1974) case of divergence of strike slip faults.

conditions during the early stages of basin development. Extrusion of volcanic flows and pyroclastic eruptions occurred as a response to basement fragmentation associated with the Mid-Devonian Acadian Orogeny. The oldest clastic sediments were deposited as interflow units within the Late Devonian Sunnyville Formation. Sedimentation continued through the Early Carboniferous within fluvial and lacustrine environments of deposition. Vertical variation of unidirectional paleocurrents in the Tower Formation show a distinct trend from southeasterly to southerly directed current flow. This clockwise rotation of paleoflow directions may reflect oblique tilting and/or counterclockwise rotation of the crustal block on which sedimentation was occurring through the Latest Devonian to the Earliest Carboniferous. Furthermore, since the block is interpreted to have rotated toward the Cobequid-Chedabucto Fault, continued transtensional conditions are suggested. Near the end of Tower Formation deposition, intrabasinal volcanic source areas became less important and extrabasinal source areas to the west and northwest supplied an increasing proportion of the detritus. Paleocurrents measured from the Minister Brook and Brandy Brook Formations exhibit southwesterly and southeasterly trends. During this depositional episode, current systems supplied detritus from source areas to the northwest and northeast. This flow direction may reflect a late component of block tilting southwards, towards the Cobequid-Chedabucto Fault.

Deposition of the St. Francis Harbour River-Tower Formations systems tract and of the Minister Brook-Brandy Brook Formations systems tract record fluvial environments of deposition. The sedimentary fill of the latter is slightly finer grained and reflects lower energy sedimentation, probably on depositional slopes of reduced gradient. However, sand/shale ratios fail to exhibit a pronounced general fining upward trend through these depositional systems. This suggests a sustained gradient reflecting continuous block rotation and/or eustatic adjustment in the depocentre.

Basin Architecture

Coarse fluvial sediments are primarily exposed in the northwestern and northeastern part of the study area. Fine grained lacustrine sediments of the Tower and Minister Brook Formations are exposed in the central portion of the area. These sediments outcrop close to the Cobequid-Chedabucto Fault and pose an interesting problem, assuming that this segment of the Cobequid-Chedabucto fault was active through the Earliest Carboniferous. Within a strike slip deformation zone, crustal blocks adjust to tectonic influence by rotation relative to adjacent blocks. Detritus in the Guysborough Basin was shed from the upraised portions of an individual block, north and west of the study area. However, coarse detritus, which might have prograded from the northern edge of an adjacent block to the south, is not present. The lack of these marginal lithofacies suggests that the Guysborough Basin may be incomplete.

St. Mary's Basin

Basin Formation

The St. Mary's Basin is bounded to the north by the Cobequid-Chedabucto Fault and to the southeast and south by the Guysborough County Fault. This basin probably formed in a similar tectonic environment as Guysborough Basin. The Cobequid-Chedabucto Fault defines the northern limit of the basin and the present day southern limit is delineated by the Guysborough County Fault. If the Cobequid-Chedabucto Fault was in fact active during sedimentation, a tensional tectonic regime is suggested by 1) paleocurrent trends, which indicate current flow to the north; 2) clast size data, which show a fining trend to the north; 3) provenance data, which reflects the dominance of Meguma type lithologies in coarse clastic units of the Gunns Brook Formation, and which implies a source area to the south.

Coarse cobble to boulder conglomerate only outcrops near the base of the exposed section at the southeast end of the present-day St. Mary's Basin. To the west, boulder conglomerates are not observed.

Basin Evolution

The St. Mary's Basin is described here in terms of a single braided fluvial depositional system. Donjek type braided streams near the base of the succession are gradational to South Saskatchewan type braided streams up section, and may reflect downstream fining and reduction in the gradient of the depositional slope. A distinct fining upward trend is exhibited by sand/shale ratios, and the maximum clast size in conglomerates decreases away from the southern basin margin. Vertical variation of unidirectional paleocurrent Local Mean

Trends is low and fluctuates about azimuth 360 degrees, suggesting a nearly northward depositional slope. Once the basin formed and began receiving sediment, there is no evidence for sporadic tectonic adjustment. Current flow into the depocentre remained relatively constant and progressive basin filling is reflected by the pronounced fining and thinning trend within the Gunns Brook Formation.

Clasts within conglomerates of the Gunns Brook Formation are exclusively of Meguma Terrane derivation. The metamorphic grade of these clasts is sub-greenschist, although that of the exposed Meguma Terrane is greenschist with amphibolite grade rocks near the east end of the Cobequid-Chedabucto Fault. This implies that higher levels of the Meguma Terrane supplied the majority of the detritus to the St. Mary's Basin.

Basin Architecture

Coarse grained, Donjek type braided stream sediments exposed at the base of the succession are gradational to sand dominated, South Saskatchewan type braided stream deposits which are exposed over the bulk of the basin. No downslope evidence exists to indicate the presence of distal environments of deposition in this basin. However, fine grained, dark sediments are exposed in south Horton Brook, within the deformation zone associated with the Cobequid-Chedabucto and Guysborough County Faults (Figure 93). Their mode of deposition is questionable as sedimentary structures have been largely obliterated due to the deformation they have suffered.

Streams carrying and depositing sediment in the St. Mary,s Basin flowed northward into some form of distal environment which we no longer see in its original position. Two possibilities exist to explain this problem. The St. Mary's Basin could have been asymmetrical during deposition such that these environments were concentrated at or near the present day north margin. If this is strictly the case, then poor exposure may explain the discrepancy. Alternatively, the basin was much larger than what is exposed today and the distal environment(s) were removed by faulting along the Cobequid-Chedabucto Fault (Figure 94). One such fault wedge may be represented by the slice of fine grained sediment exposed between the Cobequid-Chedabucto and Guysborough County Faults (Figure 93).

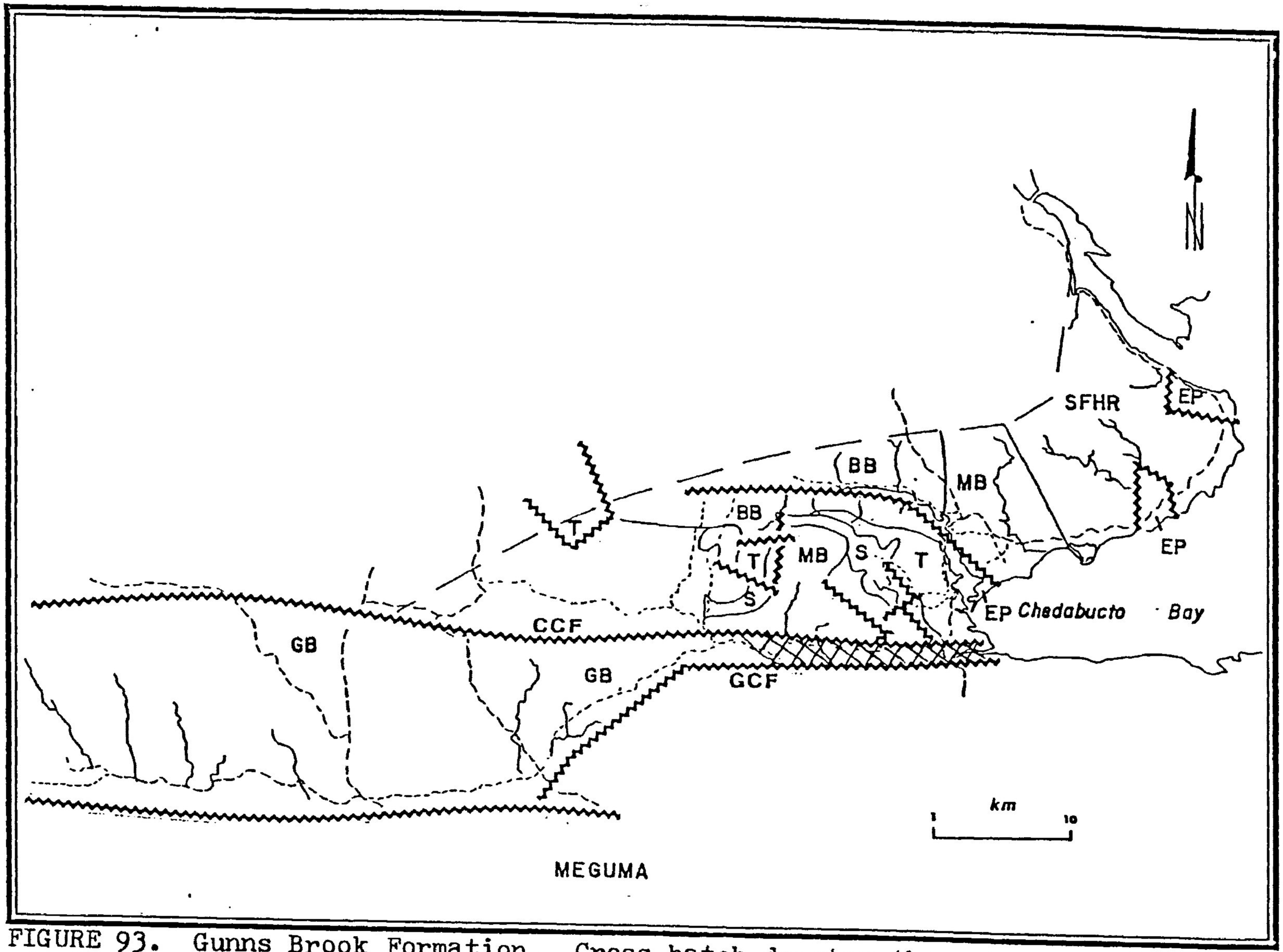


FIGURE 93. Gunns Brook Formation. Cross hatch denotes the outcrop distribution of fine grained sediments bounded by the Cobequid-Chedabucto Fault to the north and the Guysborough County Fault to the south.

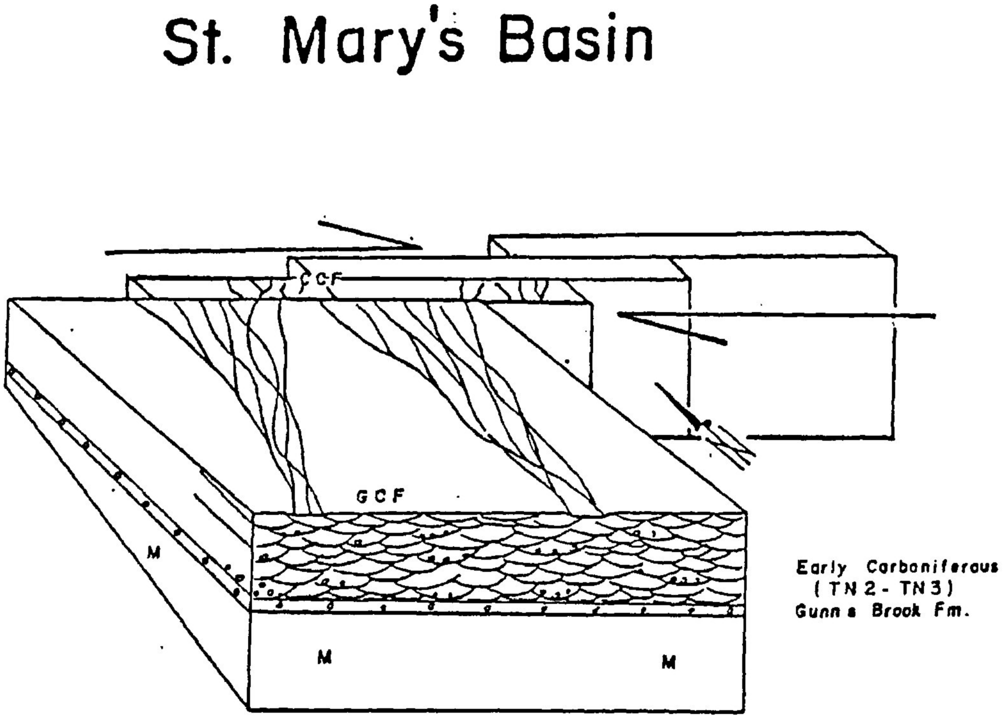


FIGURE 94. St. Mary's Basin: tectonic evolution. Dextral displacement along the Cobequid-Chedabucto Fault resulted in removal of basin slices.

Implications

Both basins discussed above were more extensive during their respective periods of active sedimentation and probably required the existence of transtensile tectonic conditions for their formation and subsequent sedimentary evolution. Clast lithologies in sediments of the Guysborough and St. Mary's Basins are mutually exclusive and paleocurrent data indicate that independent drainage systems operated for each depocentre. The Meguma Terrane was not in a position to supply detritus to the Guysborough Basin during Early Carboniferous sedimentation, and hence, could not have been in its present position during this time interval.

Depositional episodes in the two basins occurred, in part, simultaneously. Stratigraphic considerations suggest Late Devonian volcanism was followed by sedimentation through the Mid-Carboniferous in Guysborough Basin. Palynological data from the St. Mary's Basin indicate the sedimentary assemblage accumulated during the Early Carboniferous (Tn2 to Tn3).

Collision of the Meguma Terrane with cratonic North America probably occurred at some point east of its present position along the Cobequid-Chedabucto Fault at the time of, or immediately subsequent to the Acadian Orogeny (Figure 95). By Mid-Carboniferous time, dextral strike slip faulting along the Cobequid-Chedabucto Fault resulted in en echelon folding about northeast-southwest axes in both basins and incorporation of slices from both basins into the deformation zone. Fault removal of basin slices not only explains the lack of distal environments of deposition within the St. Mary's Basin; it also resolves the problem of apparently missing lithofacies at the south margin of the Guysborough Basin.

Fine grained sediments exposed between the Cobequid-Chedabucto Fault and the Guysborough County Fault are probably related to sedimentation in the St. Mary's Basin. Their fine grained nature attests to deposition in a lower energy environment than the sediments described in this basin. These rocks may represent a faulted slice of sediment which accumulated at some point more distal from the south basin margin than the exposed coarse sandstones and conglomerates typical of the Gunns Brook Formation.

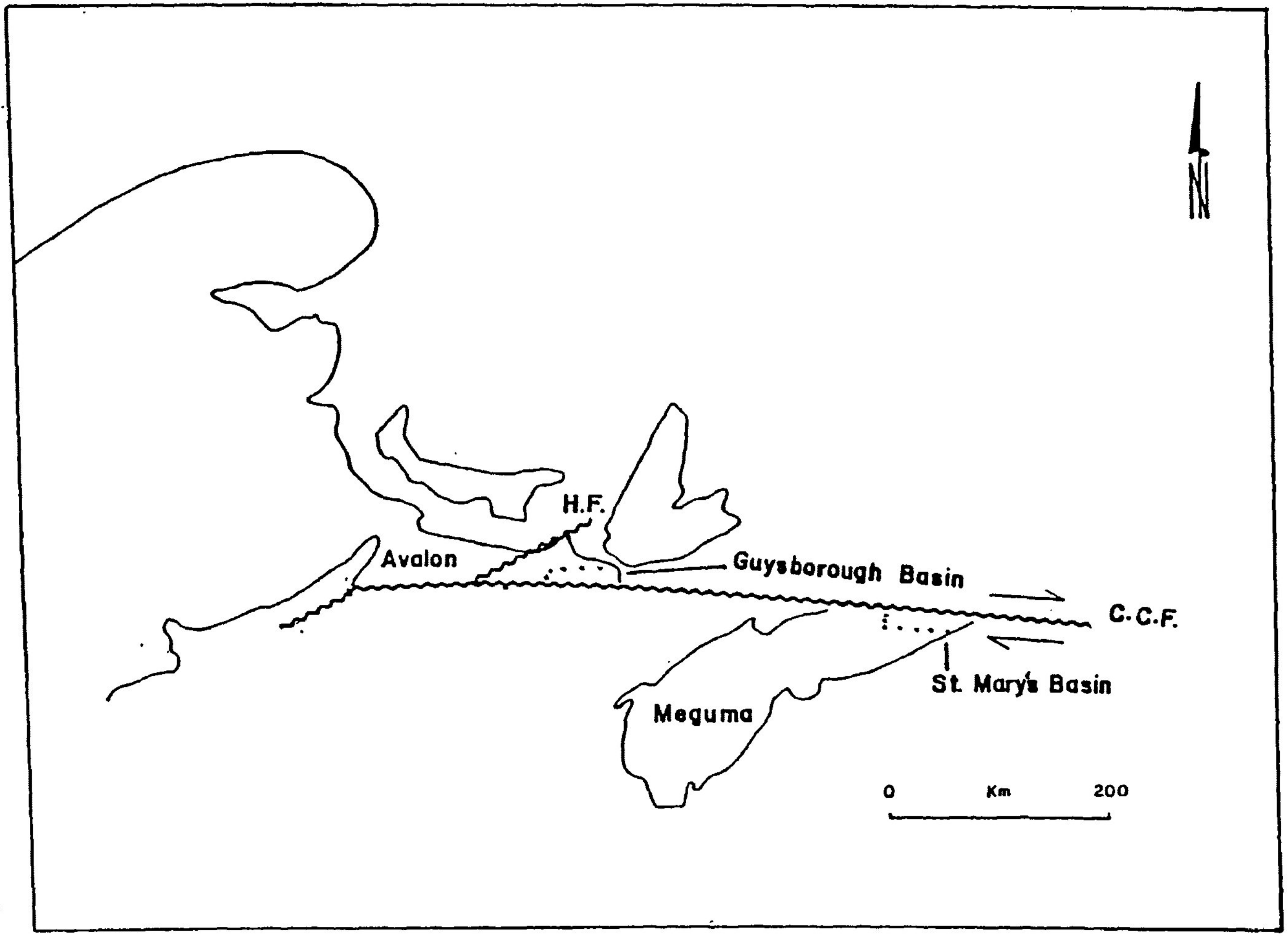


FIGURE 95. Collision of the Meguma Terrane occurred at some point east of its present position along the Cobequid-Chedabucto Fault.

CONCLUSIONS

The Mid-Devonian Acadian Orogeny signalled initial collision between the Avalon Microcontinent and cratonic North America. Resultant basement fragmentation ant tectonic adjustment in a transtensile environment led to basin formation by block rotation, counterclockwise and east end down, in the area north of the Cobequid-Chedabucto Fault (Guysborough Basin). This is initially manifested by volcanism (Sunnyville Formation) and sedimentation (Tower and St. Francis Harbour River Formations). South of the Cobequid-Chedabucto Fault, the St. Mary's Basin has yet to form. The Meguma Terrane may have still been undergoing minor movement toward North America at this time. Collision of the Meguma Terrane occurred at some point east of its present position along the Cobequid-Chedabucto Fault.

By Early Carboniferous time, depositional slope in the Guysborough Basin was reduced and a sand dominated fluvial system (Brandy Brook Formation) fed lacustrine environments (Minister Brook Formation). Palynological data indicate that braided stream sediments accumulated through the Early

Carboniferous (Tn2 to Tn3) within the St. Mary's Basin (Gunns Brook Formation). The low metamorphic grade of clasts within conglomerates of the Gunns Brook Formation (sub-greenschist) suggests derivation from higher levels of the Meguma Terrane, since Meguma type rocks now exposed range from greenschist to amphibolite grade (Schenk, 1980).

Subsequent to the Windsor, marine incursion of the sea, Eddy Point Formation sediments record a sequence of deep to shallow water lacustrine to mudflat environments in the Guysborough Basin.

The Guysborough and St. Mary's Basins are distinct in terms of their lithologies, clast lithologies within conglomerates and paleocurrents. Both basins are incomplete with respect to lithofacies which should be exposed proximal to the Cobequid-Chedabucto Fault. They have been juxtaposed by late dextral displacement along the Cobequid-Chedabucto Fault and slices of both basins were removed during this tectonic event.

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