

**A STUDY OF SEDIMENTARY STRUCTURES
IN THE LOWER CARBONIFEROUS HORTON GROUP
OF WESTERN CAPE BRETON ISLAND, NOVA SCOTIA**

**A thesis
Presented to the
Geology Department
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**by
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ABSTRACT

The occurrence of a small number of sedimentary structures in the (predominantly) continental beds of the Horton Group provides further support for the view that such structures occur in sandstones and siltstones deposited in many different environments. Currents and gravity are the agents ultimately responsible for the production of these structures.

A grouping of sedimentary structures is devised in an attempt to eliminate ambiguities and the overlapping nature of classifications appearing in ^{the} literature. For present purposes, the structures are grouped into five categories: miscellaneous pre-depositional sub-stratal markings; sub-stratal current markings, intra-stratal directional current structures; differential load structures; and intra-stratal deformational structures.

Described in detail are groove casts, flute casts, load casts and related structures, certain types of convolute laminations, ball-and-roll structures, contorted lamination, and slump-sheets. These occur only in the middle (Strathlorne) and the upper (Ainslie) Formations of the Horton. Cross-stratification is found throughout the Horton.

The analysis of available directional data reveals two paleocurrent directions, suggesting that the regime of deposition in the Ainslie Basin during Horton time comprises (1) a relatively local and lateral supply of mainly coarse and medium clastics, from the Craguish Hills, and (2) a more distant source of fine clastics transported longitudinally, and deposited in central basin areas, probably from the Cape George-Antigonish Basin, Nova Scotia.

The application of ALLEN's (1963 b) "sandstone facies scheme" to the stratigraphic distribution of cross-stratification and other sedimentary structures, in Horton sediments of Southwest Mabou River, shows some degree of contemporaneity between the Members of the lower (Craignish) Formation, and also between parts of ^{the} Strathlorne Formation. The Ainslie Formation is, however, considered as the product of a distinctly separate episode of fluvial deposition.

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CHAPTER I

INTRODUCTION

In 1961, it was brought to the author's attention that sedimentary structures, particularly those markings on the base of bed common in turbidite deposits (KUENEN, e. g. 1957b), may be present in the predominantly continental sediments of the Lower Carboniferous Horton Group in parts of northern Nova Scotia and Cape Breton Island. The purpose of this work is thus to study the occurrence of sedimentary structures in general, in the Horton Group.

The author's first observation was made in summer 1961, when remarkably developed flute casts were encountered on the basal surface of a reddish siltstone in the Lower Carboniferous exposure along the coast of Lismore, about 25 miles east of New Glasgow, Nova Scotia. The siltstone is interbedded with red shales and with fine laminated sandstones showing good parting lineations.

SHROCK (1948) has illustrated some remarkable "flow casts" (---, Fig. 117, p. 158) and groove casts (---, Fig. 122, p. 165) from the Mississippian Horton of western Cape Breton, and in correspondence later stated that these sole markings came from Southwest Mabou River.

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In the preparatory stage, the Horton exposures of Cape George-Antigonish area, Nova Scotia, and the entire western

and northwestern Cape Breton Island area were included in the field research program. However, only western Cape Breton (see inset; Location Map-) yielded sufficient data, and thus efforts were concentrated on this area. Other areas, however, were also investigated but were left out from the major program in the final stages of the fieldwork.

The fieldwork consisted of observations of type, size and shape, frequency, and stratigraphic position of sedimentary structures. Directional measurements of cross-stratification, and other structures were also made to obtain information on the paleocurrents. The scope of the fieldwork required only standard geological equipment. Maps used were the National Topographic Series, 1st Ed., scale 1:50,000*. Additional maps consist of detail sketches obtained from these and other publications on the geology of parts of the area.

Students of the Massachusetts Institute of Technology have reported upon the geology and stratigraphy of parts of northern Nova Scotia and Cape Breton Island (see M.I.T., 1957). For this reason, a visit was made to the library of Department of Geology and Geophysics of the Institute.

The author then spent June and July, 1962, working in western Cape Breton Island. About four weeks were spent in the other areas described earlier.

Laboratory work included sawing and polishing of hand specimens to reveal the more subtle internal structures.

 * Sheets: Port Hood (11K/4, $E\frac{1}{2}$); Lake Ainslie (11K/3, $E\frac{1}{2}$ and $W\frac{1}{2}$);
 Cape George (11F/13, $E\frac{1}{2}$); Whycocomaugh (11F/14, $E\frac{1}{2}$ and $W\frac{1}{2}$);
 and, partly, Margaree (11K/6, $\frac{E1}{2}$ and $\frac{W1}{2}$).

Staining by the alizarine-red method as suggested by HAMBLIN (1963) was applied to delineate the structure on some of the polished specimens. Large transparent thin sections were also made to supplement the polished surfaces. The structures on these prepared specimens were traced and presented as figures in this work.

Acknowledgement. Sincere and heartfelt thanks is extended to Dr. D.L. Dineley, of the Geology Department, University of Ottawa, for inspiring the author in selecting the subject material, and for a constant supervision of the work both in field and in writing of this thesis. Well appreciated encouragements and cooperation during preparation came from Dr. D.G. Kelley, of the Geological Survey of Canada, Ottawa, and from Prof. Shrock, of the M.I.T., Cambridge, Massachusetts.

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The author will remember the people of Nova Scotia and Cape Breton Island for their hospitality and tolerance given during his stay.

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CHAPTER II

GEOGRAPHY

Location and Extent

The areas and stream-sections covered in this thesis are distributed over some 750 square miles of the lowland of western Cape Breton, Nova Scotia (see Map: Location Map, in back pocket).

The majority of data were collected from sections of the rivers Southeast Mabou, Southwest Mabou, Graham, and Judique Interval Brook. The areas around Lake Ainslie and further north, outside the area, in the valleys of Upper and Lower Margaree were also investigated but contribute little.

Physiography

The larger part of western Cape Breton is occupied by low undulating land that generally ~~has~~^{lies} well below 700 ft. O. D., but some of the hills north of Lake Ainslie reach over 1000 ft. O. D. This lowland is actually a part of the larger lowland of western and northwestern Cape Breton extending for about 60 miles from Craguish in the south to Cheticamp in the north (see NORMAN, 1935, p. 8, and CAMERON, 1948, p. 1), bounded in the east and southeast by an almost continuous highland plateaus (the highlands east of Cheticamp, east of Lake Ainslie, and the Craguish Hills), and in the west and northwest disappears beneath the sea,

except for the Mabou Highland which rises abruptly above the surrounding area. The elevation of this highland is generally well above 800 ft., reaching in many places up to 1200 ft. The lowland is underlain by the relatively soft sediments of mostly Carboniferous age; and the highlands consist of resistant pre-Carboniferous metamorphic and igneous rocks. The boundary of the two is occasionally marked by sharp contrast in topographic relief.

Drainage

Although the highland constitutes the major region of head waters for the drainage in the area, many streams have their sources in the lowland itself (e. g. the Graham River, Skye River, and Judique Interval Brook) or originate from the hills within it (e. g. the streams north of Lake Ainslie).

The structure of the Carboniferous sediments controls the direction of flow of some of the streams as seen, e. g., in the Mabou River system (Southwest Mabou, Southeast Mabou, and Mull Rivers). The Graham River and the adjacent smaller stream flow across the structure towards the sea.

Lake Ainslie drains the norther portion of the lowland. Almost 12 miles in length and up to 4 miles broad, the lake connects via the rivers of the Margaree valleys, in the north, to the Gulf of St. Lawrence.

Population, Climate, and Accessibility

Western Cape Breton is thinly populated. Settlement is concentrated along main highways (N.S. Route 19, and Mabou-Whycocomaugh Highway), notably in and around the towns of Port Hood and Inverness, and the village of Mabou.

The climate in the area is generally temperate and humid, similar to that of the rest of the Atlantic Provinces.

Good accessibility to almost all important geological exposures in the backland is provided by a network of dirt and gravel roads represented in the topographic maps (see footnote p. 2).

Rock Exposures

The lowland is almost entirely covered by^a blanket of glacial drift which is between 40 ft. and 100 ft. thick. Over 80 percent of the area is forest covered.

For some of the local formations, the cliffs along the sea shore offer the best exposures. Unfortunately, the great majority of rocks belonging to the Horton Group are distributed inland (see: Fig. 2, and inset Map). They are exposed in river sections especially in the Southwest Mabou River, Graham River, Southeast Mabou River, and Judique Interval Brook. A few good, but scattered, exposures also occur along the shore of Lake Ainslie. Nowhere locally is a complete section available.

The Horton is exposed almost continuously and entirely in the Southwest Mabou and Graham Rivers. The larger part of the section in the Southwest Mabou River, however, is accessible only during low water.

CHAPTER III

REGIONAL GEOLOGY

Introduction

Western Cape Breton is a small part of the Appalachian geologic province where thick sediments accumulated during the Carboniferous period. After the Acadian orogeny, and early in the Carboniferous, several intra-cratonic, rapidly subsiding basins developed throughout the province. In western Cape Breton, the sediments attain a maximum thickness of over 19,000 ft., and are largely Carboniferous in age.

Two major rock divisions are thus generally recognized in the area: (1) the pre-Carboniferous, metamorphic, ^{intrusive} igneous and volcanic rocks, distributed chiefly over the highland area; (2), the Carboniferous sediments, distributed throughout most of the lowland. No Permian or younger strata, except Pleistocene glacial sediments, have been positively identified.

Previous Studies

Systematic geological studies in the region began in 1880 by FLETCHER who incorporated the results in Report of Progress of the Geological Survey for 1882 to 1884. In 1925 TRASK and MATHER, and in 1926 BELL studied the stratigraphy and structure of the Lake Ainslie region in the interest of petroleum research. Results of further systematic mapping were published in 1935 (NORMAN) in the memoir for Lake Ainslie map-area;

1948 (CAMERON) in the summary account for Margaree-Cheticamp map-areas; and, 1957 (KELLEY) in the preliminary map for Whycocomaugh map-area.

Detailed work and reports on parts of the stratigraphy, carried out in connection with these assignments, include those of ROSTOKER (1960), SMITH (1955), MURRAY (1955, and 1960), BELT (1962), COTE (1958), and MACKASEY (1963). None, however, has been specifically concerned with sedimentary structures in the Carboniferous.

The "Ainslie Basin"

The Carboniferous sediments lie in a basin, which in the terminology of KAY (1951, p. 56) is an epi-geosyncline. It is a deep, linear shaped basin developing in an old geosyncline of the Appalachian, thus in parts intra-cratonic. This basin in the western Cape Breton will be referred to as the "Ainslie Basin" (COTE, 1962). The extent of the Ainslie Basin approximately coincides with the present lowland area of western and northwestern Cape Breton. See Fig. 1.

Table I in the following page presents the classification of the relative ages of rock groups adopted for the Ainslie Basin. The table is a very generalized adaptation from the results given by NORMAN (1935), CAMERON (1948), KELLEY (1957), and COTE (1962). BELT (1962), however, uncovers evidence that leads him to conclude that the upper most Windsor, the Canso, and the Riversdale Groups were all deposited

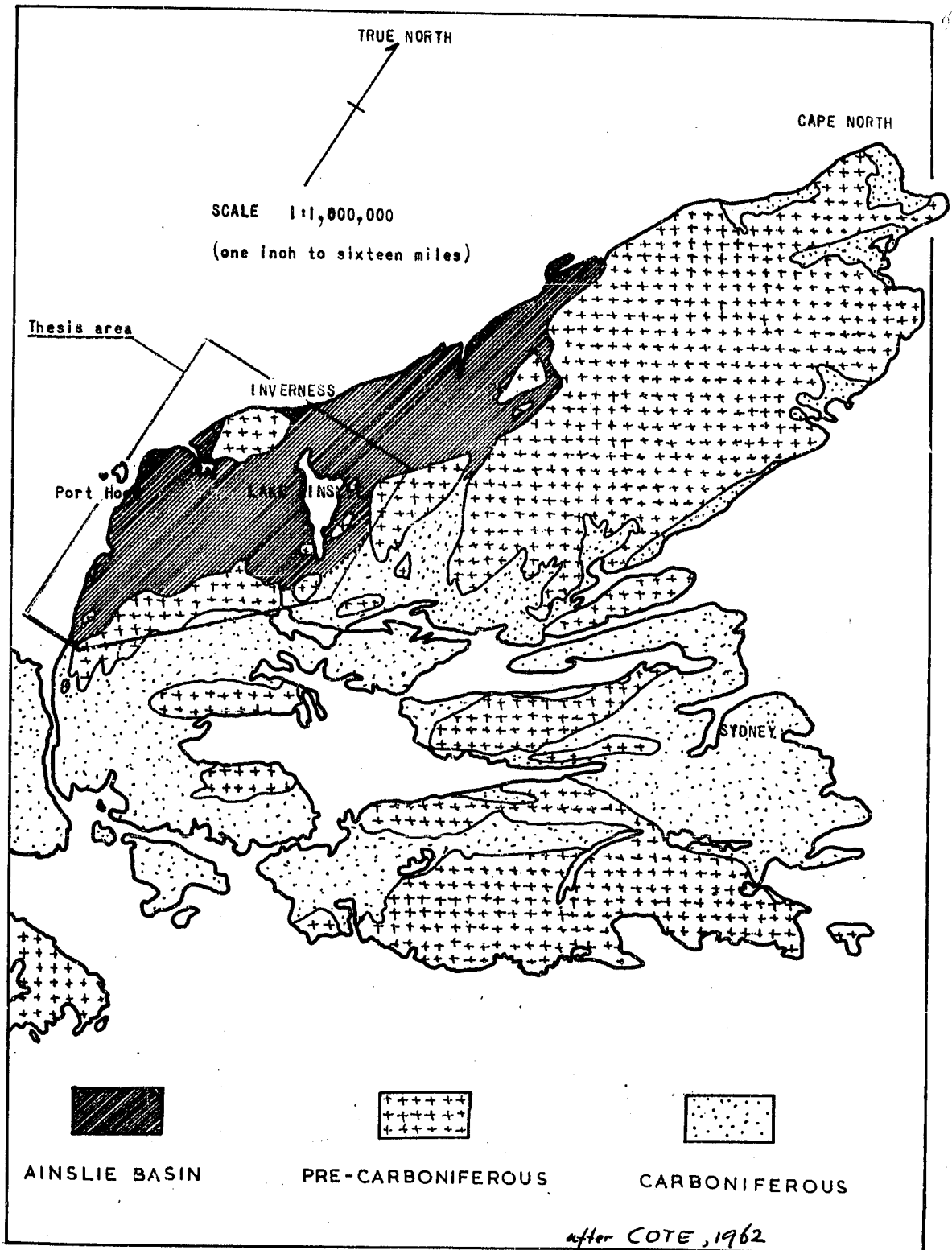


Figure 1. The Ainslie Basin and its relation to the pre-Carboniferous uplands and other areas of the Carboniferous of Cape Breton Island, Nova Scotia.

Table 1. Stratigraphy of the Ainslie Basin

After NORMAN (1935), CAMERON (1948), KELLEY (1957 and 1958), COTE (1962), and MacKASSEY (1963).

	Groups	Formation	Lithology	Thickness
CENOZOIC				
			Unconsolidated sands and gravels, boulder clay stratified sands and gravels	
			GREAT UNCONFORMITY	
	?Permian or Upp. Penn.	Broad Cove Formation	red shale, red conglomerate, a few red sandst.	
			CONFORMITY to?DISCONFORMITY?	
UPPER CARBONIFEROUS	Pennsylvanian	PICTOU GROUP		
		Inverness Formation	grey and red sandstone,arkose, grey and red shale, conglomerate, and coal	(2500 ft.)
			UNCONFORMITY	
		RIVERSDALE GROUP		
		Port Hood Formation	grey and red arkosic sandstone, red shale, coal	(4000 ft.)
			CONFORMITY to?DISCONFORMITY?	
UPPER CARBONIFEROUS	Miss. and/or Penn.	CANSO GROUP		
		Mabou Formation	red and grey sandstone, siltstone, and shale a few local thin limestone	(3000 ft.)
			?DISCONFORMITY?	
LOWER CARBONIFEROUS	Mississippian	WINDSOR GROUP		
			red and grey shale, siltstone and sandstone; gypsum, anhydrite, limestone and dolomitic limestone	(2000 ft.)
			CONFORMITY to UNCONFORMITY	
		HORTON GROUP		
			red and grey conglomerate, sandstone and siltstone, arkosic sandstone, conglomerate lenses, a few calcareous intra-formational conglomerate at top, grey and red conglomerate at base with grey and red shale	(8000 ft.)
			Includes also at base and at places some volcanic sequences (the Fisset Brook Formation)	
			UNCONFORMITY	
PRE-CARBONIFEROUS				
			Basement complex, which may include:	
			Devonian and earlier granite, syenite, and diorite	
			George River Group: quartzite, crystalline limestone, gneisses, schists, slates, some volcanic rocks	

contemporaneously and, therefore, should be grouped into a single unit for which he proposed one new name, "Mabou Group", in place of the three above. The volcanic succession occurring in the pre-Carboniferous areas east of Lake Ainslie used to be assigned to the Devonian (NORMAN, 1935, p. 24); but, reports made by MACKASEY (1963) reveals that they are Lower Mississippian-pre-Horton in age for which he applied the name "Fisset Brook Formation".

It has been previously proposed that the deposition of the Carboniferous sediments largely took place under continental conditions. NORMAN has (op. cit., p. 8) summarized this as follows:

"began under continental conditions and resulted in the accumulation of inter-fingering lenses of shale, sandstone, arkose, and conglomerate. A short period of marine conditions followed during which a group of strata consisting of shale, fossiliferous dolomite and limestone, gypsum, and anhydrite accumulated. During the remainder of Carboniferous time continental conditions again prevailed and periodically favoured the accumulation of organic matter later converted to coal".

Some volcanic activity in parts of the basin preceded the deposition of the rocks described above.

The general stratigraphic relation of the pre-Carboniferous rocks, however, is little known because of the few and poor exposures available, as well as the complexity of structure.

Tectonic activity The post-orogenic movement of the pre-Carboniferous landmass resulted in the formation of the basin where Carboniferous sediments accumulated. The movement continued periodically throughout Carboniferous and later time.

Periodic movements in the basin during the Carboniferous are recorded in the stratigraphical column. The Windsor, for instance, may be either conformable or disconformable with the underlying Horton strata. Local unconformities are found especially around the edges of uplifted pre-Carboniferous masses such as around the foot of Mabou Highland. Similar evidence of epeiorogenic movements is also apparent at the end of the Windsor time. Folding occurred at the end of the Riversdale time. The strata of the Pictou Group are believed to be unconformable to all other strata.

The present regional pattern of the Carboniferous rocks owes its development largely to the folding of the strata into gently plunging anticlines and synclines. The folds trend generally in the NE-SW direction but in the southern half of the area, where the folds are monoclinical, they trend in a N-S direction. Faulting displaced the folds and locally distorted the outcrop pattern. In the edges of the lowland, the strata are in fault contact or overlapping at an angle on the Pre-Carboniferous rocks. This condition is believed to be caused by uplifting (by faulting and warping, respectively) of the pre-Carboniferous block, which, in turn, and together with their difference in their resistance to erosion, is regionally responsible for the peripheral pattern of the Carboniferous area.

CHAPTER IV

STRATIGRAPHY OF HORTON GROUP

General features.

Since it was first described by BELL (1929) in the Horton-Windsor district of Nova Scotia, the Horton Group has been traced to Cape Breton Island, including the present western part, by NORMAN (1935), and CAMERON (1948). Earlier workers such as MATHER and TRASK (1928) made ineffective attempts to subdivide the Horton Group in western Cape Breton. In the fifties, MURRAY (1953 and 1960), who worked in close association with KELLEY (1958) and SMITH (1952), made a thorough study of the Horton stratigraphy based on the Horton section of the Southwest Mabou River. He (also KELLEY, and COTE, 1959) subdivided the Horton into several lithologic units.

The Horton Group as a whole can be defined as a series of predominantly continental beds lying over the pre-Carboniferous metamorphic, igneous and volcanic rocks and under a series of fossiliferous partially marine strata, the Windsor Group. The lower Horton contact is unconformable, but Horton-Windsor contact above is not so well defined.

The Horton sediments are an accumulation up to 10,000 ft. (KELLEY, 1958) of gravel, sand, silt, and clay in flood plains of rivers and streams under continental, often oxidizing, conditions. They contain few, poorly preserved plant remains, and rare ostracods, and fishes.

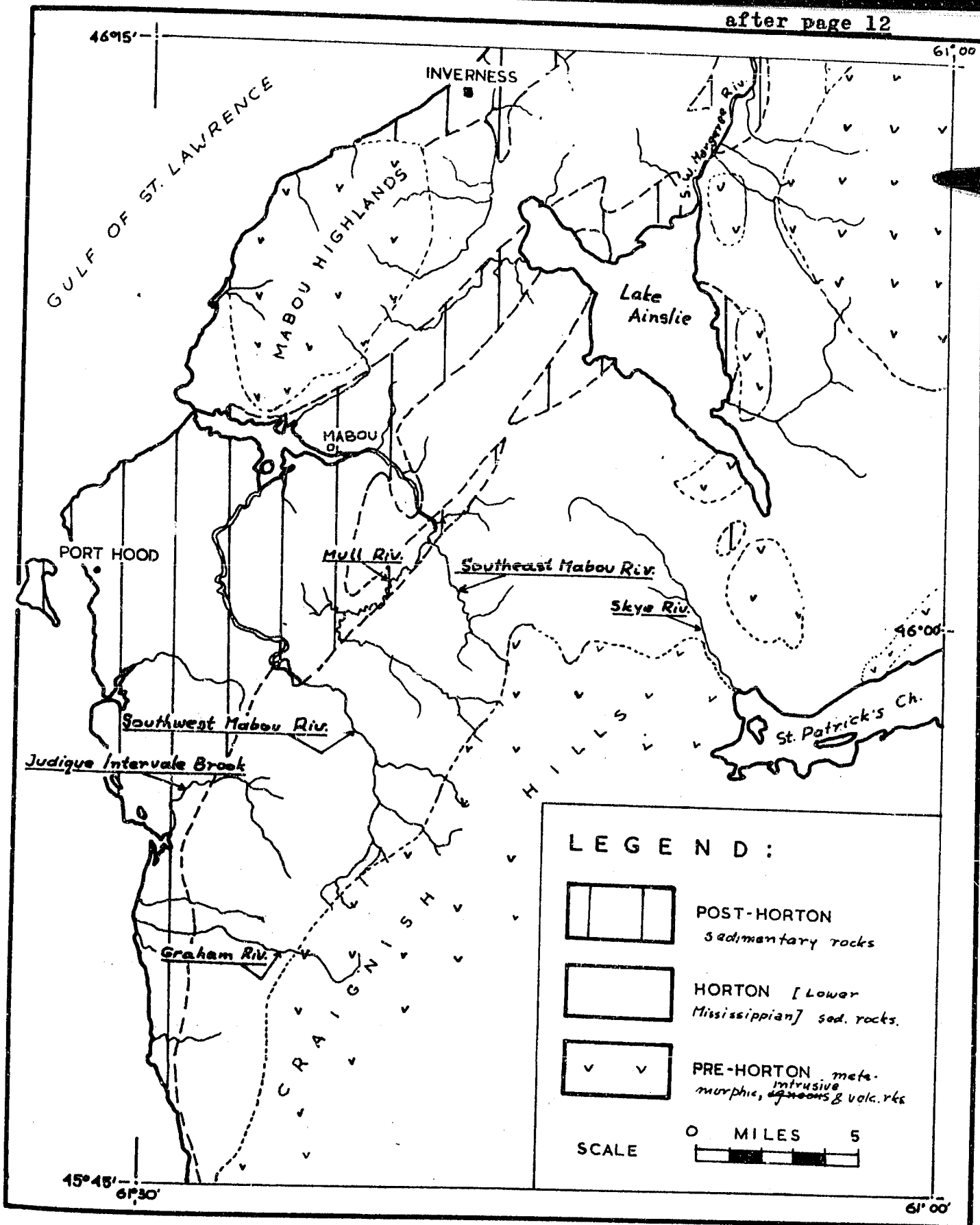


Figure 2. Distribution of the Horton Group in western Cape Breton Island, Nova Scotia (after KELLEY, 1957, and NORMAN, 1935). See also Inset Map (in back pocket) for geographical locations.

As a map unit, the Horton, underlies a NE-SW central belt stretching throughout the entire western section of the island with several additional parallel but much shorter belts west of Lake Ainslie (see Fig. 2). The strata are generally more indurated than those of the Windsor Group, so that, in these belts, the Horton forms anticlinal hills (e. g. Mull River anticline and its continuation in the northeast, and the hills north of Lake Ainslie) and the Windsor sediments occupy the narrow strips in the intervening valleys.

Description of formations,

MATHER and TRASK (1928) made the first attempt to subdivide the Horton of Lake Ainslie area into units based on lithology. NORMAN (1935) noted the difference between the lower coarse and conglomeratic beds, and the upper finer clastics in the Horton of the same region, but made no revision into new stratigraphic units.

MURRAY (1955 and 1960), in a most comprehensive study of the Horton, adopted a type section in the Southwest Mabou River where he recognized three formations, two of which are subdivided into members. These formations are, from base to top, The Caignish, the Strathlorne, and the Ainslie (see Table II).

KELLEY's (1957) division (see TABLE III) was based also on lithology, but later he (1958) adopted Murray's nomenclature.

Table II. Horton Group of SOUTHWEST MABOU RIVER.

(From: Murray, 1960, Table I, p. 11)

WINDSOR GROUP

(Limestone, gypsum, and shale)

	AINSLIE FORMATION (red and non-red fine to coarse clastics) 1820 ft	Glencoe Member (thin non-red ss. layers, shale interbed)
		McIsaac Point Member (graded sequences of red and non-red clastics)
	STRATHLORNE FORMATION (entirely non-red fine clastics with thin limestone)	
HORTON	1050 ft	
8000 ft	CRAIGNISH FORMATION (red and non-red medium and coarse clastics)	McLeod Member (red medium clastics with thin Limestone)
	5130 ft	Skye River Member (red and non-red coarse, Poorly sorted clastics)
PRE-HORTON ROCKS (igneous and metamorphic)		

Table III. Correlation of the Horton Division Made in the Western Cape Breton and other Areas

BELL	MATHER and TRASK	MURRAY	KELLEY	COTE	Others
1929	1928	1955 and 1960	1957	1959	generalized
Horton-Windsor district, N.S.	Lake Ainslie region	Southwest Mabou Riv.	Whycocomaugh	Graham River	
<hr/>					
Cheverie	Upper Dunbar	AINSLIE F.M. Glencoe Mb. ----- Pt. McIsaac Mb.	4 A	Member 3E	Upper Horton
-----	Middle Dunbar	STRATHLORNE F.M.	4 B	Member 3D	Grey beds
-----	Lower Dunbar	McLeod Mb.	4 C	Member 3C	Red beds
Horton Bluff	-----	Craig- nish Kewstone Conglo- merate series	4 D	Member 3B Member 3A	Lower Horton

Craignish Formation. The type section comprising the Craignish Formation extends from a point 200 ft. downstream from the bridge at Upper Southwest Mabou village (see inset Map), upstream to the contact with the pre-Carboniferous at the foot of Craignish Hills. The total thickness of this section is 5130 ft. which includes a lower member, i. e. the Skye River Member (2,900 ft. thick) and an upper member, i. e. the McLeod Member (2,230 ft. thick).

The Skye River Member comprises massive bedded units consisting of poorly stratified and poorly sorted, coarse arkosic sandstones and conglomerated with interbeds of red arkosic conglomerates and sandstones. This member is perhaps better exposed on the Graham River section, about 6 miles to the south of type section (KELLEY, 1958 and COTE, 1958).

The McLeod Member in its type locality consists chiefly of well stratified red, fine to coarse siltstones with interbeds of conglomerate and limestone. Further to the south, this member contains more abundant conglomerate particularly in Judique Interval Brook locality. In Graham River, however, the McLeod Member is hard to distinguish from other members of the Craignish.

The upper boundary of the Craignish is set at the upper contact of the upper-most red stratum. This red bed is conformably overlain by beds of the Strathlorne Formation.

Strathlorne Formation. The middle 1050 ft. of the Horton type section, is entirely non-red fine and medium clastics and comprises

the Strathlorne Formation. It includes generally fairly well stratified buff, greenish, or grayish thinly laminated siltstones, thick beds of dark grey fissile shale, thin bedded sandstones, and several thin interbeds of gray limestone.

In defining the formation on the basis of the supposed "entirely non-red" characteristic, KELLEY (op. cit.) noted some impracticalities in this respect. In several sections he included thin red interbeds ^{within} ~~into~~ the Strathlorne Formation. Furthermore, he continued, that neither color nor lithology changes appreciably at the boundary with the overlying Ainslie Formation. In critical sections, the exposures are generally poor. The lower boundary of Strathlorne, on the other hand, is easily defined by marked and consistent change of color from red to non-red.

The Strathlorne in the Southeast Mabou River is a little thicker (1500 ft., MURRAY, 1960, p. 45), but in the Judique Interval Brook and the Graham River localities it is reduced to a few hundred feet.

Ainslie Formation. This (upper-most) formation of the Horton is 1820 ft. in type section, and consists of fine to coarse clastic beds of both red and non-red color. The lower 1450 ft. of this formation (McIsaac Point Member) is characterized by graded conglomerate sequence. This sequence consist of conglomerates, in part intraformational, at the base, followed by a massive sandstone garding into small-scale cross-laminated siltstone at

the top. The uppermost 370 ft. (Glencoe Member) consists of thinly bedded calcareous, green sandstones and poorly bedded red, non-calcareous siltstones. The two members are generally indistinguishable from one another in sections outside the type locality.

The Glencoe, in the type section, is overlain apparently disconformably by a laminated limestone of the basal Windsor Group.

CHAPTER V

SEDIMENTARY STRUCTURES

A. CLASSIFICATION AND TERMINOLOGY.

Definition and Limitation. In reviewing the present wealth of literature, it is evident that studies in sedimentary structures rarely include the structures of entire sedimentary groups or formations. Studies are more often limited to structures found within a single bed or single sedimentation unit. (PETTIJOHN, 1957 b, p. 158). Moreover, these units are mainly sandstones and siltstones, rarely limestones, each of which is treated individually for its contained "primary" irregularities, or regularities. Thus excluded the "secondary", chemical structures and most of the "organic" structures although these two latter structures have been included in the classification of PETTIJOHN (op. cit., Table 34), as "sedimentary structures".

Development of Terminology. The studies generally include descriptions of types of structures, and their nomenclature and classification. A most important development, in more recent years, has been the mapping of directional properties inherent to some of the types. From these directional studies, a paleocurrent analysis can be made, towards a better and more advanced understanding of the depositional history of a sedimentary basin.

The development of the present state of knowledge on these structures centered largely around two most important major types: The first, the larger proportion of which were studied in North America and in England, are cross-laminations and related structures, such as ripple marks and primary lineations (STOKES, 1945), described and mapped from sandstones and siltstones of varied environments, notably: fluvial (ALLEN, 1949; STOKES, 1952; POTTER and OLSON, 1954; POTTER, 1955; FAHRIG, 1961; POTTER, 1962; POOLE, 1962; and YEAKEL, 1962), marine (SCHWABER, 1953; TANNER, 1955, 1959; FARKAS, 1960; VAN HOUTEN, 1962), aeolian (OPDYKE and RUNCORN, 1960; POOLE, 1962), and deltaic (McKEE, 1940; WALKER, 1955; PELLETIER, 1958; SHACKELTON, 1962).

The second type originated and developed in the graded turbidite deposits of the Alpine flysch of Europe, are structures collectively known as sole markings (KUENEN, 1957 b). Some of them were originally called hierolyphs or fucoids (FUCHS, 1895), and are generally referred to structures found in the underside of a bed formed by casting of irregularities on the surface of the underlying soft mud, or by impressing upon it as to produce irregularities, or both. The study of sole markings has increased tremendously in the past two decades producing a great number of types and a somewhat confusing system of nomenclature. A few of the more prevalent types that can be mentioned are: Flute casts (CROWELL, 1955); groove casts (SHROCK, 1948, p. 162) sometimes called drag-marks (KUENEN, 1957 b, p. 243); flute

casts and groove cast collectively called also "current marks" (DZULYNSKI and SANDERS, 1962). Load casts (KUENEN, 1953), are also common. They were formerly called flow casts (SHARP, 1948, p. 156) and have sometimes been referred to as flowage casts (BIRKENMAJER, 1958). Included also in the above structures are convolute lamination (TEN HAAF, 1956) and morphologically related structures such as contorted stratification (DINELEY, 1960, p. 25) and slump and slide structures (KUENEN, 1948, 1956).

Criteria for Classification In the classification of the above and many other structures, two types of criteria are commonly used: The first is descriptive, and the other is genetic.

(1). Descriptive criteria, such as used by CROWELL (1955), DZULYNSKI (1963), and, to a certain extent by PETTIJOHN (1962, p. 1471), described their usual position of occurrences of structure in a sedimentary unit, i. e.:

- a. External (stratal) structures which are either on top of beds or on base of beds;
- b. Internal (intrastratal) structures.

(a). Structures found usually on the base of beds (i. e. substratal structures) are most widely studied, and include chiefly flute casts, groove casts, and load casts.

DZULYNSKI and SANDERS (1962) gave flute casts and groove casts generic names i. e., respectively, "scour marks" and "tool marks", collectively called "current marks", and further classified them based largely upon the shape and arrangement of these structures (see op. cit., p. 68 and p. 79).

Load casts are prominently expressed on the interface of sandstones or siltstones overlying shale beds, and thus they are substratal structures. However, load casts often show internal deformation of laminae or other internal indication of flowage, and thus they transect the two categories above by being somewhat internal.

(b). Intrastratal structures include cross-stratifications, convolute laminations, contorted stratifications, and slump structures.

Cross-stratification is classified by McKEE and WEIR, see Table IV, according to: character of lower bounding surface of set; shape of sets; axial attitude of sets; symmetry of sets; arching of cross-strata; dip of cross-strata; and length of cross-strata. Similar descriptive classification of cross-strata is recently given by ALLEN (1963 c), who further recognized the genetic differences between the group and solitary cross-strata, and also between small-scale and large-scale cross-strata.

Graded-bedding is an important internal bed structure (see e. g. SHROCK, 1948, p. 64), particularly in its association with cyclic sequences.

The various forms of primary lineations (McBRIDE and YEAKEL, 1963) are internal structures of sandstone or siltstone beds.

Basic Criterion	Subordinate Criteria					
	Shape of sets of cross-strata	Attitude of axis of set of cross-strata	Symmetry of set of cross-strata	Arching of cross-strata	Dip of cross-strata	Length of cross-strata
Character of lower boundary surface of set of cross-strata						
Nonerosional surfaces (simple cross-stratification)	Lenticular	Plunging Non	Symmetric	Concave	High angle (> 20 degrees)	Small scale (< 1 foot)
Planar surfaces of erosion (planar cross-stratification)	Tabular	Nonplunging	Asymmetric	Straight	Low angle (< 20 degrees)	Medium scale (1 to 20 feet)
Curved surfaces of erosion (trough cross-stratification)	Wedge-shaped			Convex		Large scale (> 20 feet)

Table IV

Classification of Cross-Stratified Units

(After MCKEE and WEIR, 1953, Table 4, p. 386)

Convolute lamination, as described by KUENEN (1953) and TEN HAAF (1956), are intrastratal crumpling of laminae into broad troughs and narrow crests, with generally no rupture of laminae, and in which the intensity of crumpling dies out both upward and downward. They are common in turbidite beds but are found also in other, non-graded, sequences (DOTT and HOWARD, 1962).

Contorted lamination (e. g. DINELEY, 1960) generally display crumpling of all laminae within a sedimentary unit and thus called a contorted bed. The bed may be irregular or wedge-shaped, and may appear to be unconformable to unit below. The shape strongly suggest formation by sliding on a slope.

Slump structures are similar to a contorted bed, but may involve several beds and may be much larger in size. A slump unit may be appropriately called a slump sheet (KUENEN, 1949).

(2). Genetic criteria, such as postulated by VASOEVIC (1953), KUENEN (1957 b), DZULYNSKI and SANDERS (1962), and DZULYNSKI (1963), distinguished structures based upon the time relationship between the formation of the structure and the deposition of the unit, i. e.: pre-depositional, depositional, and post-depositional structures.

(a). Pre-depositional structures are formed before any deposition took place. Consequently they are preserved on the base of beds as casts. Commonly included in this category are trace fossils, dessication cracks, salt-hoppers, and a few others.

(b). Depositional structures are formed and preserved during the deposition of sands and silts. This includes some of the substratal markings, e. g. current markings and load casts, and some of the intrastratal structures such as cross-stratification, some types of ripple marks, graded bedding, primary lineations, and convolute laminations. The categories, however, may overlap.

Current markings are formed, directly or indirectly by currents before the actual deposition took place thus, in this sense, they are pre-depositional. It is generally agreed at present that these markings were subsequently filled and preserved by the sands and silts carried by the current. Thus they are intricately related to the process of deposition.

Load casts and related structures, such as flowage casts, are produced by squeezing and impressing of the sands and silts on the soft mud bottom. Some may be formed during the accumulation of the sands and silts and thus syndepositional, and others may be formed after the completion of the accumulation and thus post-depositional. They are the results of a tendency to restore equilibrium disturbed by a deposition of sands and silts upon a soft yielding substratum (DZULYNSKI, 1963, p. 96). Morphologically some of the load casts may resemble convolute laminations (HOLLAND, 1960).

Convolute laminations, in strict accordance to KUENEN (1953), are depositional structures, and are formed by crumpling generated by slight stresses due to current rippling occurring during the accumulation of the hydroplastic bed.

WILLIAMS (1960, p. 208) postulated, however, that convolute lamination is formed by lateral flow within the bed of a partially liquified group of laminae, thus it is formed after the deposition of the top-most laminae.

(c). Post-depositional structures include contorted beds, slumping, some organic structures (burrows), and some load casts and convolute laminations.

Contortion beds and slumping are genetically related in that they are both formed by subaqueous movement on a slope. Contorted bedding commonly involves one bed (i. e. intra-stratal) in which the laminae are contorted during a mass flow, usually having plastic properties (DOTT, 1963). Slumping may have involved several beds (i. e. intra-formational) which moved in both plastic and elastic flow (op. cit.). Their agent of formation was gravity where failure may be due to loading and movement may be triggered by an earth tremor.

Classification. The result of ^{the} interpolation of the genetic and descriptive criteria is presented in Table V, in the following page, in which known sedimentary structures are classified according to: Common position of occurrence; and, sequence of formation. The broken and query-marked boundaries and lines indicate overlapping of categories as mentioned in the discussion of criteria. Note that there are no pre-depositional super-stratal and pre-depositional internal-bed structures known. For general purposes, post-depositional super-stratal and post-depositional substratal structures are considered unimportant.

TABLE V. CLASSIFICATION OF SEDIMENTARY STRUCTURES
(Commonly found in beds of siltstone and sandstones)

Sequence of formation common positions of occurrences	PRE-DEPOSITIONAL	DEPOSITIONAL	POST-DEPOSITIONAL
Super-Stratal Structures		wave ripple marks current ripple marks	(some organic burrows)
Intra-Stratal Structures		laminations primary lineations cross-stratification graded bedding	----? ----(Slump-sheets) -----? -----(Contorted laminations)
Sub-stratal Structures	traces of mud-bottom dwelling animals and other organic casts desiccation-cracks	FLUTE CASTS GROOVE CASTS and other "CURRENT MARKS"	LOAD CASTS, flowage casts and related structures

B. OCCURRENCE OF STRUCTURES IN THE HORTON GROUP

All of the sedimentary structures belonging to the categories on Table V are represented in the Horton Group of western Cape Breton in some form or another. The number of occurrences is, however, generally small.

To describe the occurrences, five important group of sedimentary structures can be extracted from the classification of Table V. These are:

I. Miscellaneous sub-stratal predepositional markings: trace fossils, casts of dessication cracks, etc., the formation of which is unrelated to current or depositional activities.

II. Substratal Current Markings: flute casts and groove casts, and various other types of scour and tool marks.

III. Intrastratal directional current structures: cross-stratifications, primary lineations, and ripple marks.

IV. Differential Loading structures: load casts, flowage casts, and other load deformational structures commonly found on the base of beds.

V. Intrastratal deformational structures: various types of convolute lamination, ball and roll structures, and contorted lamination. Included here are some intra-formational subaqueous gravity slump structures (e.g. slump sheet).

I. Miscellaneous substratal pre-depositional marking. Most common are trace fossils occurring in the fissile series of inter-bedded siltstone and shale of the Strathlorne and

Ainslie Formations. Such fissile sequences can be found at Location 56 (Judique Interval Brook), Location 58 (Graham River), and Location 39 (Southwest Mabou River).

The trace fossils include excrements, coffee-bean shaped "tracks", and fin marks of fishes. Numerous other presumably organic markings were also found. Their clue to the organic origin is given by their uniformity of size and shape. No further attempts were made in identifying the structures.

Other markings include some occurrence of desiccation cracks, and rain prints from beds of the Strathlorne and the Ainslie Formations.

II. Substratal current markings. Includes: discrete, multi-directional, clustering, and reptilian-scale like flute casts; continuous and discontinuous groove casts, some are associated with flute casts.

1. Discrete and widely separated flute casts occur in few exposures. At Location 38 (Southwest Mabou River), they are present at the undersurface of a thick-bedded, massive greenish sandstone of the Strathlorne Formation. Individual flutes are in the form of oval shaped bulges with tapering, never flaring, tails. Thin sharp, discontinuous grooves, 3 to 4 inches long, indicating the same direction of lineation, are accompanying the flutes (see sketch Fig. 3).

These flute casts resemble the type E₁ of DZYLINSKI and SANDERS (1962, p. 68), which are formed by down-current scouring due to an obstacle on the bottom.

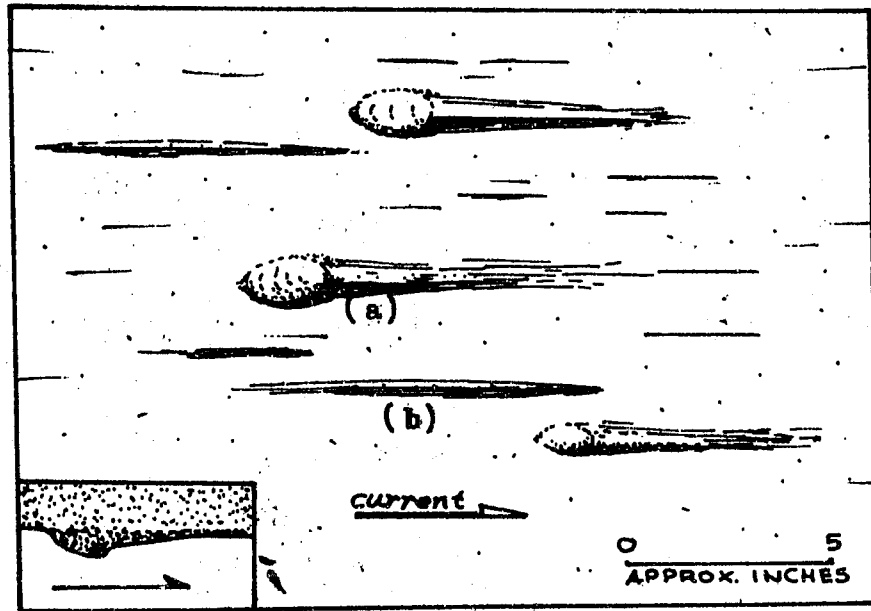


Figure 3.

Discrete, and widely spaced flute casts (a) and groove casts (b). Inset: profile of one of the flutes. Arrows indicate the implied current direction.

From greenish sandstone of the Strathlorne Fm., Location 38, Southwest Mabou River.

2 Multi-directional flute casts (Plate III, Fig. A) are well developed on the undersurface of a thick bedded, massive greenish sandstone (Strathlorne) overlying a very thick shale strata at Location 102, on the northern side of Lake Ainslie. The flute casts were probably later affected by load cast because some parts appear to sag down, between which clay material is infolded. The exposure of the sandstone is largely concealed by debris from the overlying crumbly weathered, thick shale.

3 Well-developed, small scale, close rows of end-to-end aligned flute casts (Plate I) occur on the undersurfaces of several thin bedded greenish siltstone beds at Location 40 of Southwest Mabou River. The siltstones are interbedded in a thick sequence of predominantly thick bedded, dark shale of the upper part of Strathlorne Formation. The rows of these flutes are fairly parallel to each other, discontinuous and often branching, and in some parts develop into deep bulging clusters of flutes. The cross-section of the siltstone display faint grading and small-scale cross lamination (Fig. 4).

4 Similar types of flute casts (Plate II) can be found on a thin bedded red siltstone interbedded with thick red shale of the lower Ainslie Formation, at Location 42 on Southwest Mabou River. The flutes are larger and often accompanied by deep, continuous groove casts parallel in direction to the rows of flute casts. On another red siltstone bed just about 15 feet (of red shale) above the former, a similarly flute casted surface is load casted and somewhat faulted. The resulting surface has an appearance of reptilian scales (Plate III, B), a KUENEN's analogy (1957, p. 236).

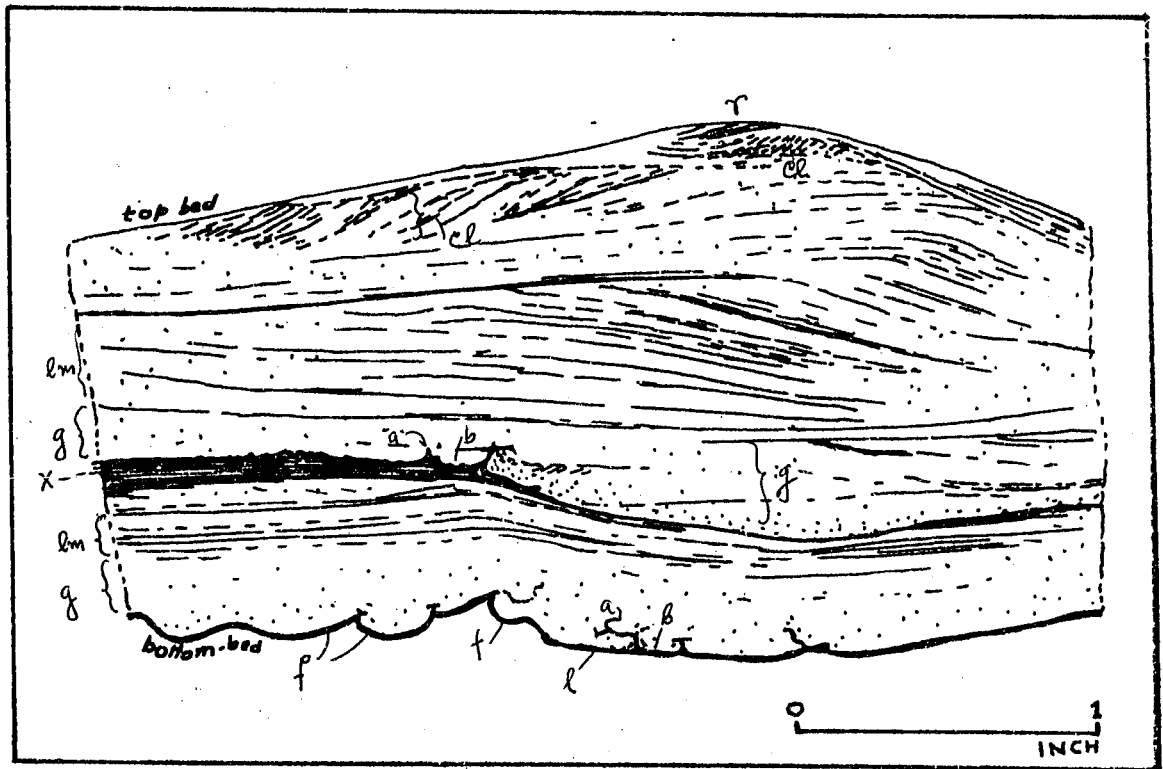


Figure 4

Internal structures of a flute casted thin bedded siltstone: (f) flute casts, (l) load-casted flute casts, (a) clay whips, (b) load pocket, (g) non-laminated sandy siltstone grading up to laminated siltstone (lm), (cl) cross-lamination, and (r) ripple crest. (X) is another load-casted horizon.

Thin siltstone unit belonging to the Strathlorne Fm., at Location 40, Southwest Mabou River.

After a thick transparent section, cut at right angles to flute casts and ripple crest.

(5) Plate IV, photo. A, shows flute casts of low relief (a) accompanied by short faint groove casts (b). This specimen is from a silty sandstone bed of Location 42 (Southwest Mabou River). The flute casts are often arranged in rows diagonal to the implied current direction (see flute casts 1, 2, and 3 of same Plate).

(6) Groove casts are more frequently found. Most common are the short discontinuous types.

Plate IV, fig. B, shows a peculiar group of short groove casts, some of which are intersecting (a) and some others are tapered at one end (b). In regard to the latter, DZULYNSKI and SANDERS (1962, p. 75) are generally of the opinion that the bulging end indicates down-current direction.

Remarkably developed groove casts, of a continuous type, are present on several undersurfaces within an 8 ft. thick series of inter-stratified thin-bedded siltstones separated by thin beds of shale. These beds belong to the Ainslie Fm., at Location 42 on Southwest Mabou River. The grooves are remarkably continuous and closely juxtaposed. They vary in size from one surface to the other between 2 to 5 inches in width, and between 1 to 3 deep. Figure 5 is one of the groove casts with fine superficial grooving (x), and the ruffled sides (Y). Internally (inset, fig. 5) they may show faint cross-lamination.

Down-current direction in these grooves is indicated by the ruffles (DZULYNSKI and SANDERS, 1962, p. 79).

III. Intrastratal directional current structures.

Cross stratification is the most abundant type of sedimentary

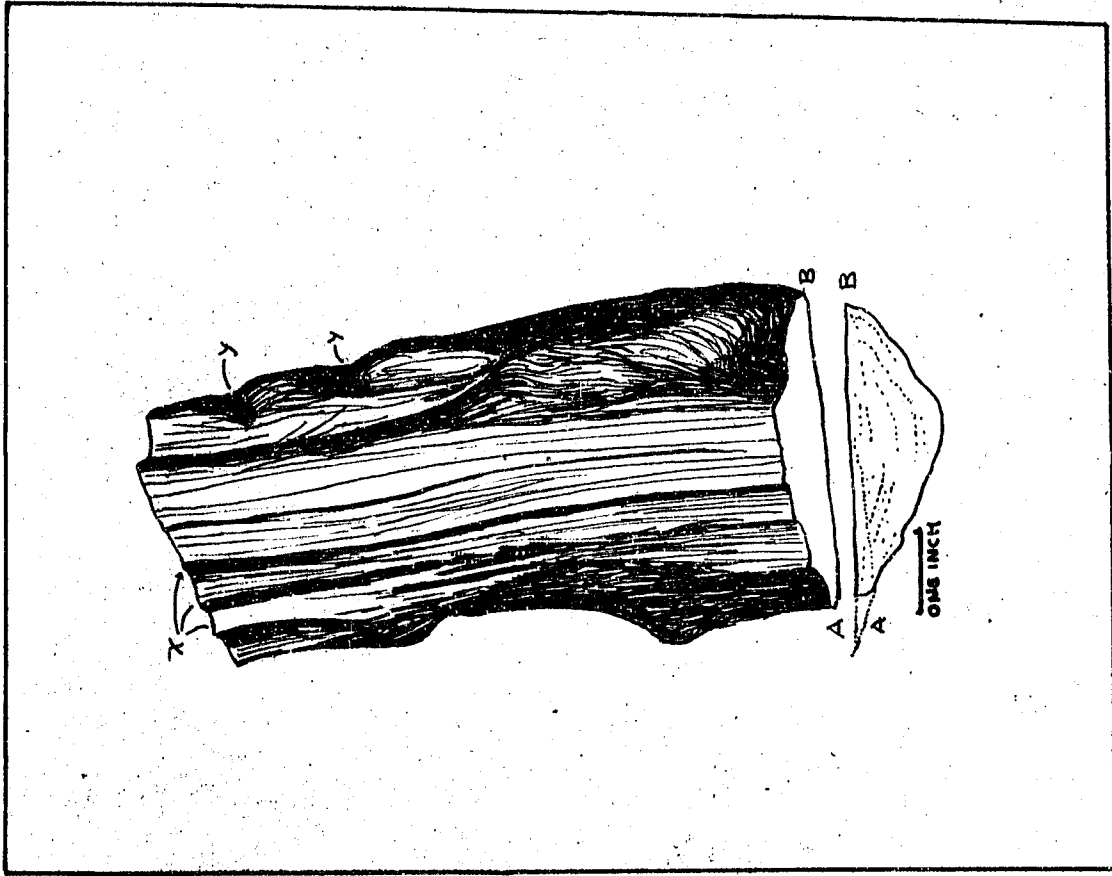


Figure 5

Ornamented large groove casts with faint internal cross-lamination (section A-B); fine parallel grooves (x) and irregular ruffles (y).

In red siltstone of the Ainslie Fm., Location 42, Southwest Mabou River.

Current is probably from top to bottom of figure. See text p. 30
After a specimen

structure present in exposures in the southern portion of the Ainslie Basin.

In describing the various types of cross-stratification, the classification of McKEE and WEIR (reproduced on page 22B), is adopted, with the exception that the term "medium-scale" is omitted throughout this work. The reason for this is given by ALLEN (1963 c) who stated that only two orders of magnitude have any genetic significance in cross-stratification. There are the small-scale cross-lamination, and the large-scale (includes "medium-" and "large-" of McKEE and WEIR). Hereupon, the terms small-scale and large-scale are used in the senses given by ALLEN (op. cit.).

The three basic types of McKEE and WEIR (op. cit.: the simple, planar, and trough cross-stratification) is also used in the following descriptions.

Small scale cross lamination, or, as described by SHROCK (1948, p. 250, Fig. 216), "choppy" cross lamination indicate a remarkably consistent direction of current within a single cross-stratified unit. They may occur in a thin-bedded, ripple-marked siltstone, which has only one zone of single sets, e. g. in many fissile sequences of the Strathlorne Formation (Locations 40 and 56), or within a relatively poorly laminated beds of siltstone or fine sandstone especially those of the Ainslie Formation.

Notable occurrences of small-scale choppy cross-lamination are in thick units of coarse siltstone, usually micaceous. These are, for example, found at Location 67 (Graham River) in strata of the Strathlorne Fm., and also Location 49A

(Southeast Mabou River) in rocks of the Ainslie Fm. These units are between 2 to 6ft. thick and entirely cross laminated, in which the bounding planes of each of the sets are commonly inclined (see Plate V.A). The upper surface of such unit may have ripple, commonly cusped, structures (see Plate V.B).

A most useful physical property of the units described above, is their large size, up to 6 inches in length, and thick laminae which also split readily, and thus help in mapping their strike and dip. Most of the data on small-scale cross-laminations (Table VII.A) comes from these units.

2. Large-scale cross stratification occurs frequently throughout the Horton sediments. Most common is the trough type, followed by the planar type, and rare occurrences of the simple type. The solitary and grouped (cosets) cross-strata (of ALLEN, 1963 c) occur usually independently.

In the Southwest Mabou River, distinct associations of cross-bedding types can be followed from one formation, or one of its members, to the other:

The Skye River Member frequently contains solitary sets of large-scale cross-strata, which are commonly lenticular in shape with curved and irregular (erosional) bottom boundaries. These sets resemble cut-and-fill structures. They are associated with conglomerate or conglomeratic beds, which are often lense shaped. In general, the bedding is rough and irregular and presumably mostly an erosional surface. Grouped cross-stratification (large-scale) also occurs, but rare. Other equivalent Skye River Member strata show similar tendencies. Poor sorting and poor bedding made attitude

measurements difficult. The McLeod Member and also the lower strata of the Strathlorne contains numerous groups of trough shaped, large-scale cross-stratification. They are occasionally associated with low-angle cross-beds, and laminated plane beds. The stratifications are usually very good, and are thinly bedded. Several occurrences of wedge-shaped, planar, large-scale cross-bedding were also observed with both straight and concave (tangential) arching of cross-strata. Small-scale cross-lamination also occur but are considered relatively uncommon.

The Strathlorne strata are generally not cross-bedded. Small-scale cross-laminations frequently occur in thin beds of siltstone as singular sets. These beds are commonly ripple-marked at the upper surfaces. Other occurrences of small-scale cross-laminations are in thick units mentioned earlier. Some planar large-scale cross-stratification occur.

The Ainslie Formation, especially the McIsaac Point Member, is characterized by "graded sequences", (MURRAY, 1960, p. 16, Table 3), which are discontinuous in the grading of both lithology and scale of cross-stratification. SHROCK (1948, pp. 32-33) counted seven of these sequences in the uppermost 2125 ft. of the Horton strata in this section (South-west Mabou River), and called them a "tripartite sedimentary cycle". The sequence usually consists of intraformational conglomerate at base, followed by massive medium sandstone with lenticular trough cross-stratification, which is of large-scale and occurring in groups (cosets). These are followed further up by finer sandstones with cosets of small-scale "choppy" cross-laminations.

They grade up to poorly laminated thick units of coarse siltstones, the tops of which, however, are well laminated.

Other internal directional current structures are a few instances of recognizable primary lineation (e. g. at Location 42, S. W. Mabou River). Ripple marks present in many siltstone beds of the Strathlorne and the Ainslie Formations. Asymmetric types are most frequent, much less so are the symmetric types. No detailed study of these features has been carried out by this writer.

IV. Differential Load Structures. Load casts and related structures in a number of forms are present in the Horton. They range in shape and size from small flat impressions or knobby protuberances one inch or less in diameter to large-scale, local collapsing which affects laterally several feet of bed. Several types of torose load casts are also present. Load casted earlier markings were seen on flute casts, groove casts, and ripple marks.

1. The simplest form of load casts are shallow flat-bottomed impressions having subpolygonal patten (Plate VI). The size of each casts is not more than 1 inch in width and less than 2 inches in length. Similar load casts are found in Location 36 (Southwest Mabou River) and Location 56 (Judique Interval Brook) in siltstone of the Strathlorne and the Ainslie, respectively.

2. Knobby casts (Fig. 6), evidently due to loading lie within a thin bed of greenish grey siltstone (of the Strathlorne) at Location 36 (Southwest Mabou River). The figure on the following page (Fig. 6) also shows well developed load

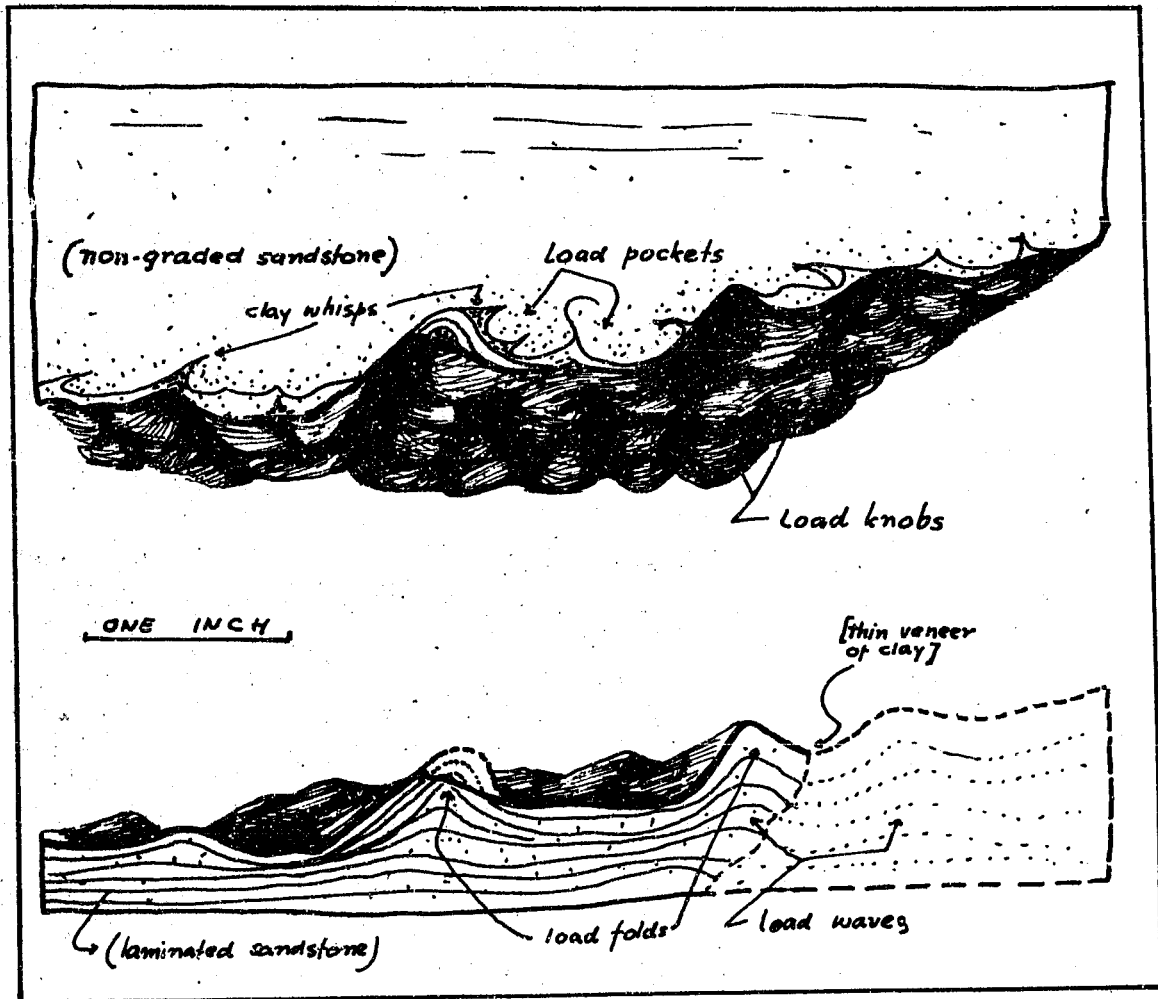


Figure 6

Knobby load casts, in greenish sandy siltstone belonging to Strathlorne Fm, Location 37, Southwest Mabou River. The terminology of internal features (clay whisps, load pockets, load fold, and load wave) are of SULLWOLD (1959). After a cut and polished specimen.

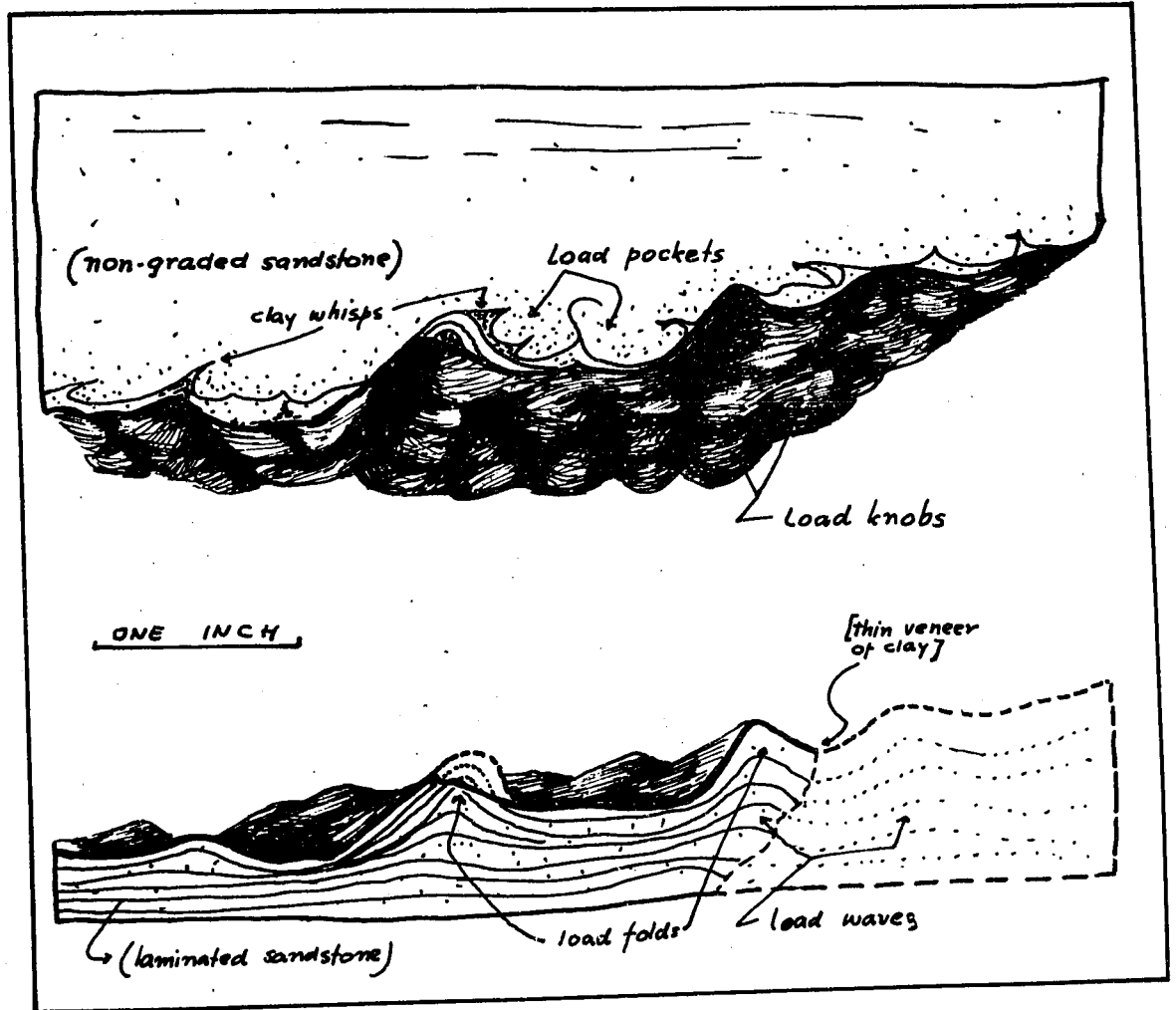


Figure 6

Knobby load casts, in greenish sandy siltstone belonging to Strathlorne Fm., Location 37, Southwest Mabou River. The terminology of internal features (clay whisps, load pockets, load fold, and load wave) are of SULLWOLD (1959). After a cut and polished specimen.

pockets, clay whishps, load folds, and load waves, all of which are internal features of load casts in the terminology of SULLWOLD (1959, p. 1248).

3. Well developed load-flowage casts are found in at least two horizons at Location 38A on Southwest Mabou River. The exposure consists of several feet of thin-bedded and ripple-marked greenish grey sandstone with interbedded thin grey shales. The units alternate with thick beds of dark grey shale. The casts, (see Plate VII, A), vary in width from 3 to 6 inches, are interconnected into irregular pattern, and have flat soles with well defined rounded bounding pleats. The distinctive feature of these casts is the surfacial curvilinear grooves, which are closely spaced and roughly parallel to each other. Their pattern resembles contour lines which may well be flow contours.

In describing an apparently similar type of casts, also from the Horton of this area, SHROCK (1948, fig. 117) called the above casts "flow casts", but admitted that flowage is started by differential loading. He interpreted the "curvilinear grooves" (his own term) as . . . "shear fractures produced in the sand when it could no longer flow".

4. Remarkably developed torose-shaped load casts occur on no less than five siltstone surfaces at Location 42 (Southwest Mabou River). All these surfaces are within a 6 ft. thick, thin-bedded and ripple-marked red siltstone with intervening thin clay layers, belonging to the Ainslie Formation. The load ridges are smoothly rounded or close to subcylindrical in shape,

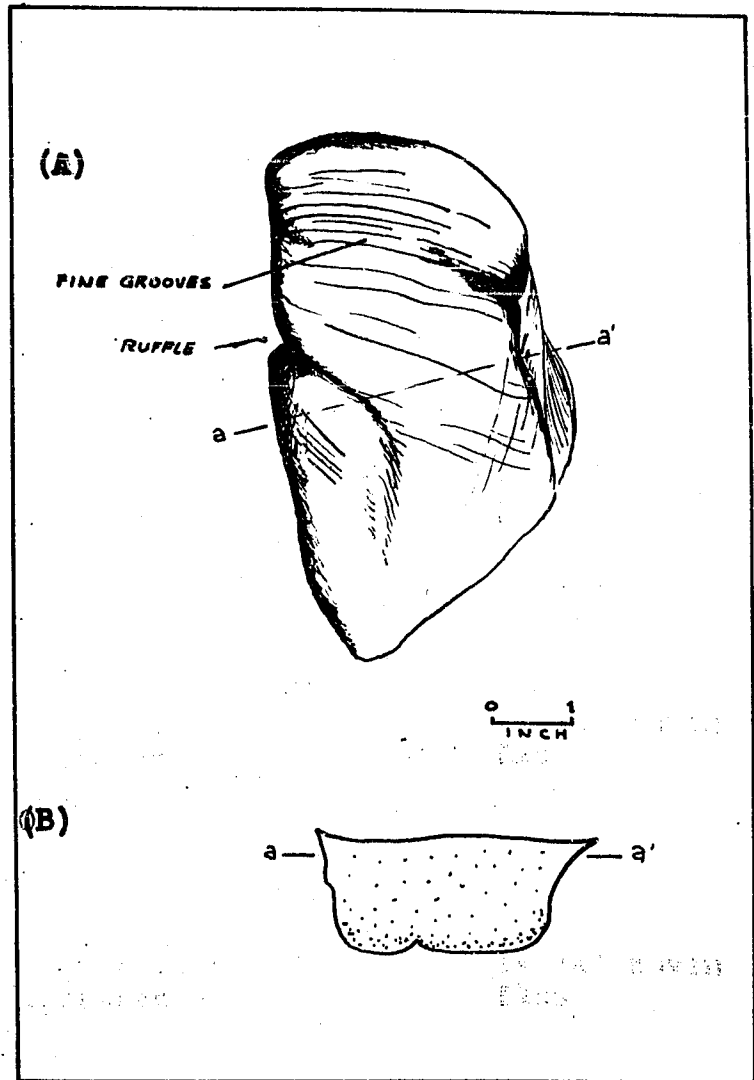


Figure 7

Large torose load casts (A) having a twisted appearance due to the ruffles on the sides. The fine curved grooves may be due to flowage. The section (B) shows profile across a-a' revealing the homogeneous internal mass.

In red siltstone bed of the Ainslie Fm. at Location 42, Southwest Mabou River. After a specimen.

with bulges at interval. They vary in size between 1 and 6 inches in width from one horizon to another. The ridges are parallel to each other, discontinuous due to intermittent bulging and pinching, and at places fusing with other prominences. See e. g. Plate VII. C. Each load ridge is occasionally ornamented (Fig. 7) with curved deep ruffles on the sides suggesting some sort of twisting, while the surficial, curved fine groovings indicate plastic flowage. The load cast surfaces can be traced throughout the entire length of the outcrop (about 30 ft.), some diminishing in size abruptly.

Torose load casts have been described by CROWELL (1955), who was not entirely certain as to their mode of formation. BIRKENMAJER (1958) is of the opinion that such oriented load casts, or, in his terminology, flowage casts, were formed by flowage of hydroplastic sands into erosion grooves (*op. cit.*, p. 142). Such explanation is highly admissible for the occurrence of torose load casts at Location 42 above, because they are closely associated with large groove casts described earlier (page 38, Fig. 5). The groove casts and the load casts, in Location 42, were found to be virtually parallel to each other, and were found in adjoining, almost alternating undersurfaces.

4. Collapsing of the bed presumably due to load was seen on a thick-bedded sandstone at Location 102 (north shore of Lake Ainslie), see Plate VIII, B. The sandstone is about $1\frac{1}{2}$ ft. thick, and the collapse affects between 1 and 4 ft. of the bed laterally. The internal lamination forms broad synclines and narrow anticlines.

5. Loading on previously marked surfaces can be observed on several samples: Plate III, A and B, shows load casted flute casts; Plate VI, load casted trace fossils; the Groove casts of Fig. 5 is probable somewhat load-casted; and Plate VIII, A, shows a probably load casted ripple marks.

V. Intrastral (and intra-formational) deformational structures. Convolute lamination in the sense of the term used by TEN HAAF (1956) and others (KUENEN, 1953, etc.) is only poorly, if at all, represented in the Horton. However, numerous other soft sediment deformational structures are present. They range in size from about one inch wide structures of convoluted laminae confined to a single thin bed of argillaceous siltstone, to contortion of all the laminae in a very thick siltstone unit. Large-scale sliding, which involved several beds, can be seen on several scales of magnitude.

1. The smallest deformed lamination structures occur within thin beds of siltstone, often argillaceous, belonging to a fissile sequence of the Ainslie Formation e. g. at Location 56 (Judique Interval Brook) and Location 68 (Graham River). The lamination in these beds is usually deformed into broad troughs measuring one to three inches wide, the crests are steep and sharp and are filled with clay from the underlying shale (see Fig. 8). Intra-stratally they may look like torose load casts, and are probably genetically related. The internal lamination of these "convolution" are often crossed.

2. Figure 9 shows roll structures from Location 56 (Judique Interval Brook). The rolls have semi-cylindrical, or elliptical cross sections, which occasionally show a similar but

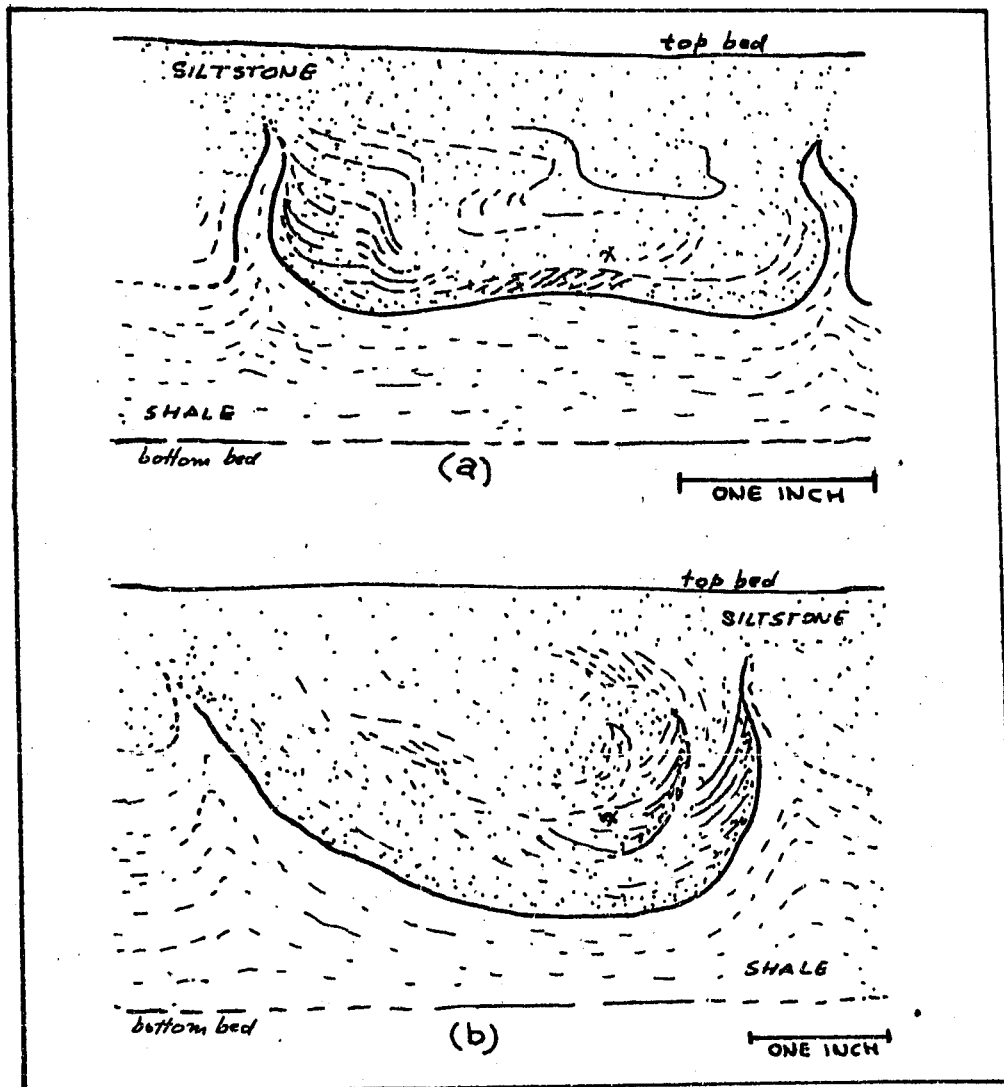


Figure 8

Cross-sections of convolute rolls (a, and b), with internal structures consisting of poorly developed convolution of cross-laminae (x). In plan view these rolls are elongated resembling torose load casts. From fissile sequence at Location 56, belonging to Ainslie Fm. of Judique Interval Brook.

After polished specimens cut at right angles to the elongation of the rolls.

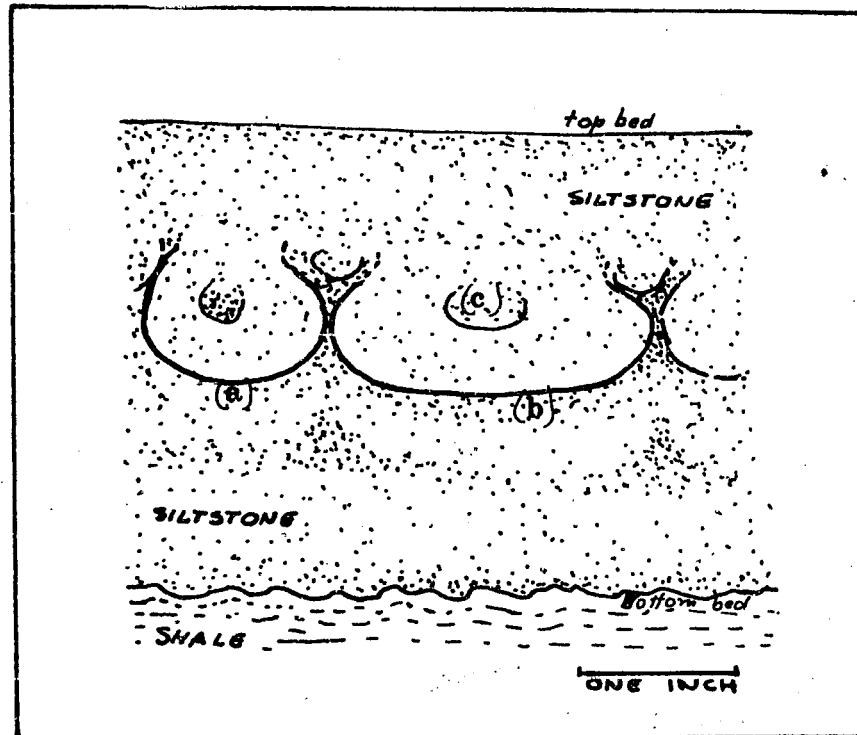


Figure 9.

Roll structures developed internally in a thin bed of red siltstone. The rolls are elipsoidal with circular or elliptical cross-sections (a,b). Inside, there may be a smaller but similar shaped rolls.

From red siltstone bed of the fissile sequence of Ainslie Fm., at Location 56, Judique Interval Brook. After specimens and field sketches.

smaller roll in the inside. A specimen of the bed may be parted around the structures, producing elongated, sometimes bended, ellipsoidal rolls. These structures were found within a 4 inch thick, red siltstone bed, at the base of the fissile sequence of the above Location (56).

The structures resemble load casts and are probably genetically related.

3. Similar to the above (2) but more irregular, rolls and balls were also found in red siltstone near Location 42 (Southwest Mabou River). The structures (see Plate IX. B.) may show the convoluted laminae within the rolls (see feature c, on the plate), and may display smaller balls above or inside the larger (see d on plate). These structures may also be formed by load casting involving partial liquifaction of the bed.

4. A remarkable development of roll and ball structures can be seen at Location 49 of Southeast Mabou River. They occur within a 2 ft. thick unit of thin bedded, greenish, calcareous siltstone (see Plate X. A and Fig. 11) belonging to the Ainslie Formation. The "deformed zone" is usually about 5 inches thick where large structure can be found, but the zone diminishes rapidly towards one side of the outcrop where small balls occur (see Fig. 10).

Well developed rolls commonly have flat soles whose plan pattern may be rhomboidal, bended, or branchingⁿ. In internal cross-sections (see Fig. 12), these large rolls display complex convoluted pattern which are marked by reddish markings within a greenish, faintly laminated matrix (see a and b on Fig. 12).

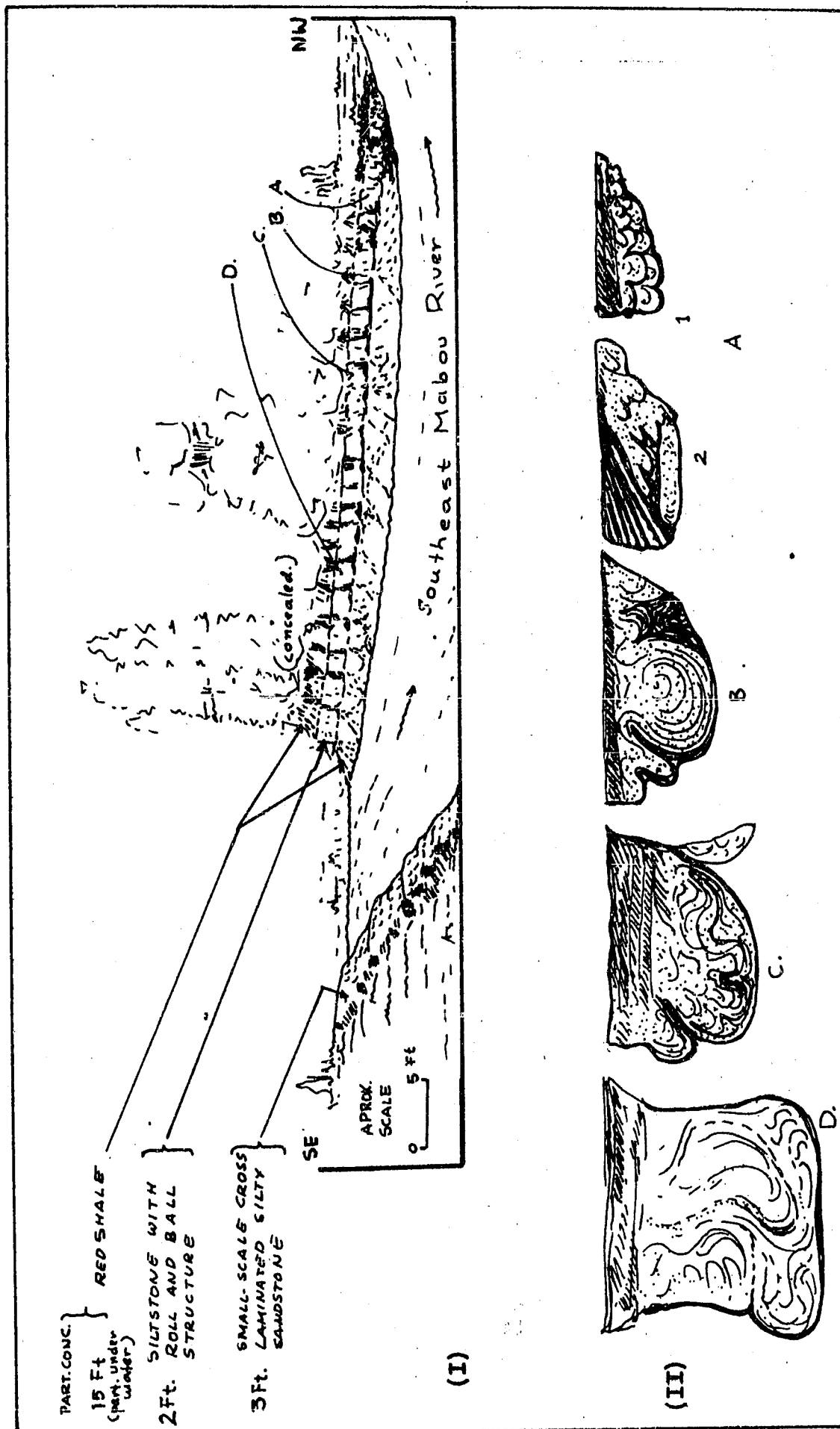


Figure 10. Roll and ball structures at Location 49, Southeast Mabou River. Fig. I is a general view of the exposure at the location. The various rolls and balls of fig. II were obtained from A, B, C, and D, respectively, in the convoluted horizon. See also Fig. 11 for close-up view at D.

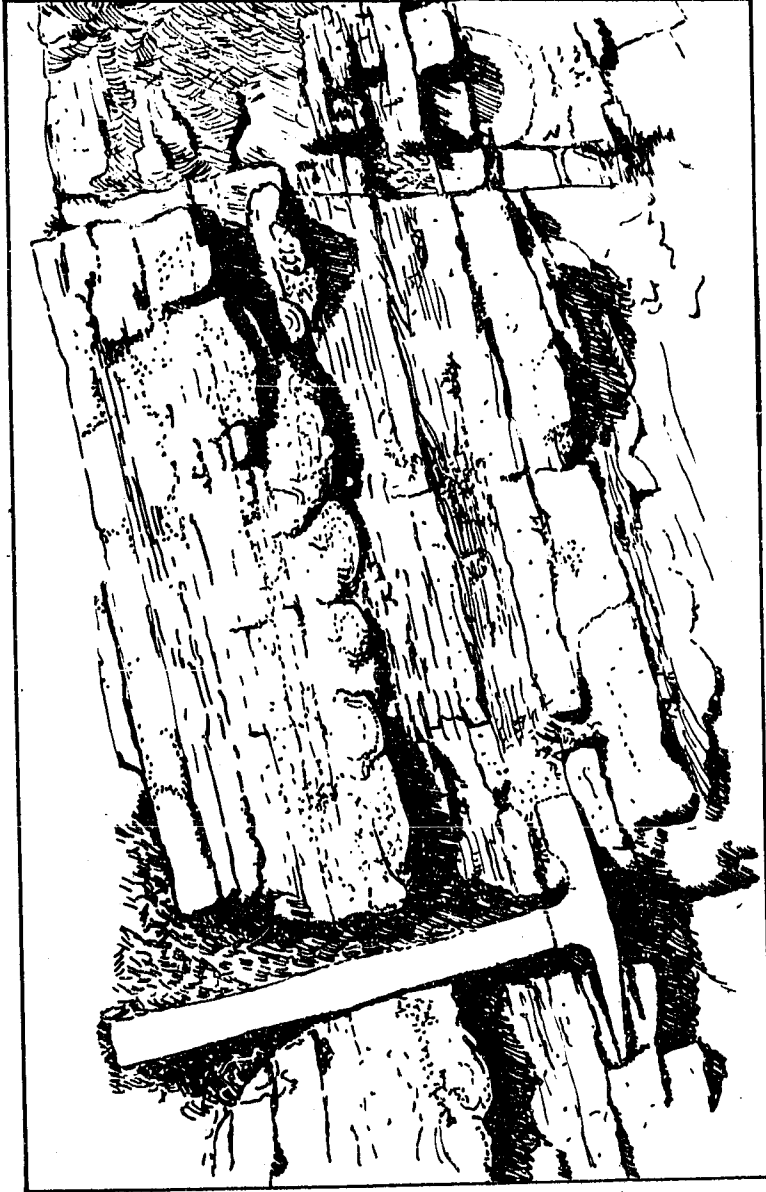


Figure 11. Roll and ball structures of Location 49, Southeast Mabou River. A close-up view at (D) in Figure 10 (I). The convolutions occur in the base of the upper quarter of a 2 ft. unit of calcareous siltstone, which belongs to the Ainslie Formation at this locality.

After a photograph (see Plate IXA)

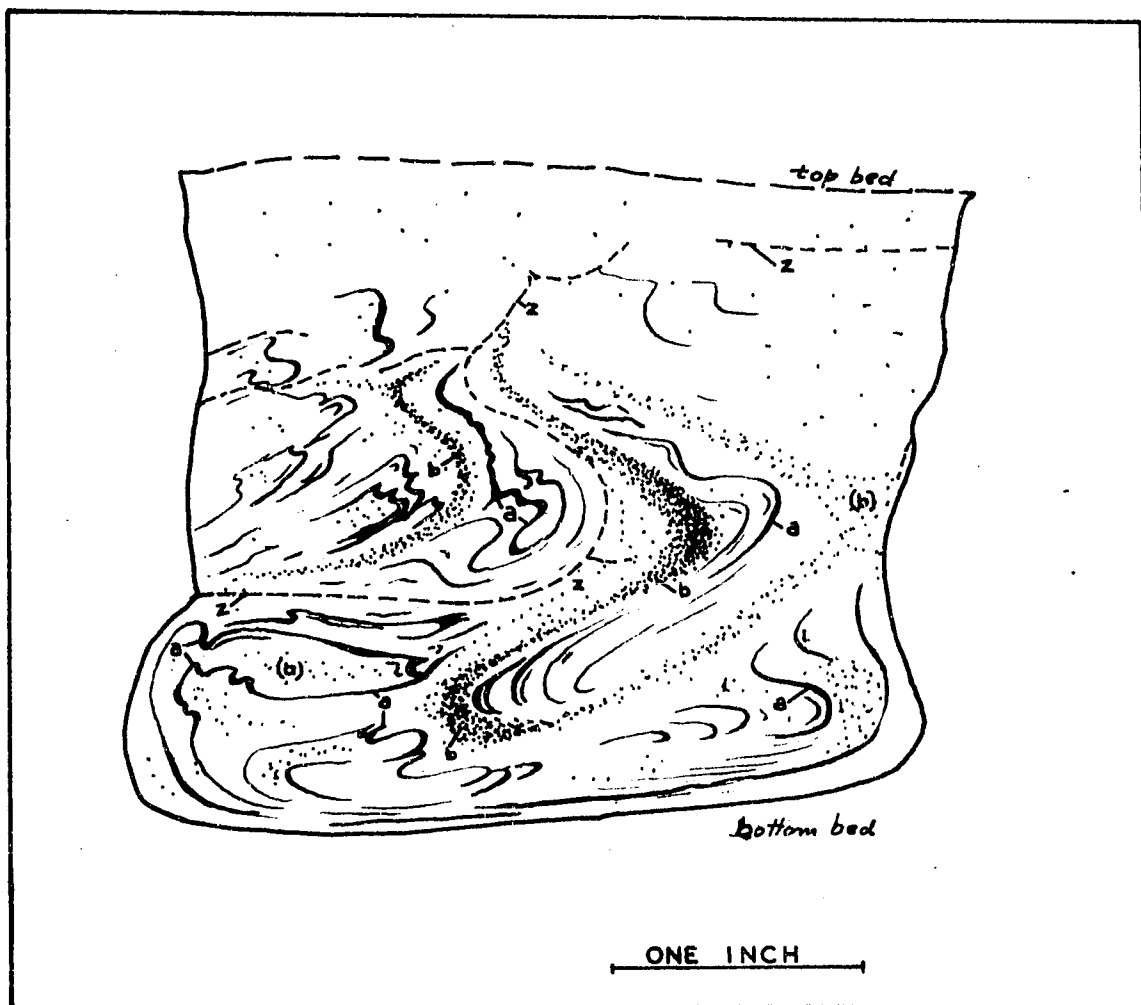


Figure 12

Complex internal convolutions of laminae in roll structure from Location 49 (see Fig 10, IID, and Fig. 11). The convolute pattern is marked by reddish marking (laminae), see a), and dark green patches (b) in light green matrix (e). Broken line z indicates a split in specimen.

After a polished specimen cut at right angles to the roll.

The smaller balls, presumably under-developed, ranges in size from about 2 inches to fractions of an inch in diameter. They may show differing convolution patterns of laminae in their internal cross-section (see A, B, and C of Fig. 10).

Small-scale cross-lamination is omnipresent in this unit, and also in the deformed zone. It is involved in the convolution especially in the smaller balls (see A of Fig. 10). This may have some genetic implication, in which the role of current is indicated in the formation of these structures. Liquifaction, flowage and gravitational action may follow in the production of the various sizes and subtypes.

4. Very large-scale, isolated slump balls, shown in Fig. 13 and also on Plate X (photo A and B), were seen within a thick sequence of shale with thin sandstone interbeds of Location 105 (Gallant River, outside the area and to the north). The balls are up to 9 ft. in length and up to about 4 ft. in thickness. They are restricted to one horizon, and individually may show some sort of exfoliation. These shells are presumably related to original stratification.

DZULYNSKI (1963) offered an explanation for similar type of balls which he called "piled and load-casted ripples" (op. cit., p. 60, see Fig. 29). However, his examples concern a very small structure less than 2 inches in size.

4. A contorted bed, or contorted lamination within a bed, can be seen at Location 44 in the Southwest Mabou River. The contortion (see Plate XI, A and B) involves a very thick laminated unit of red coarse siltstone belonging to the McIsaac

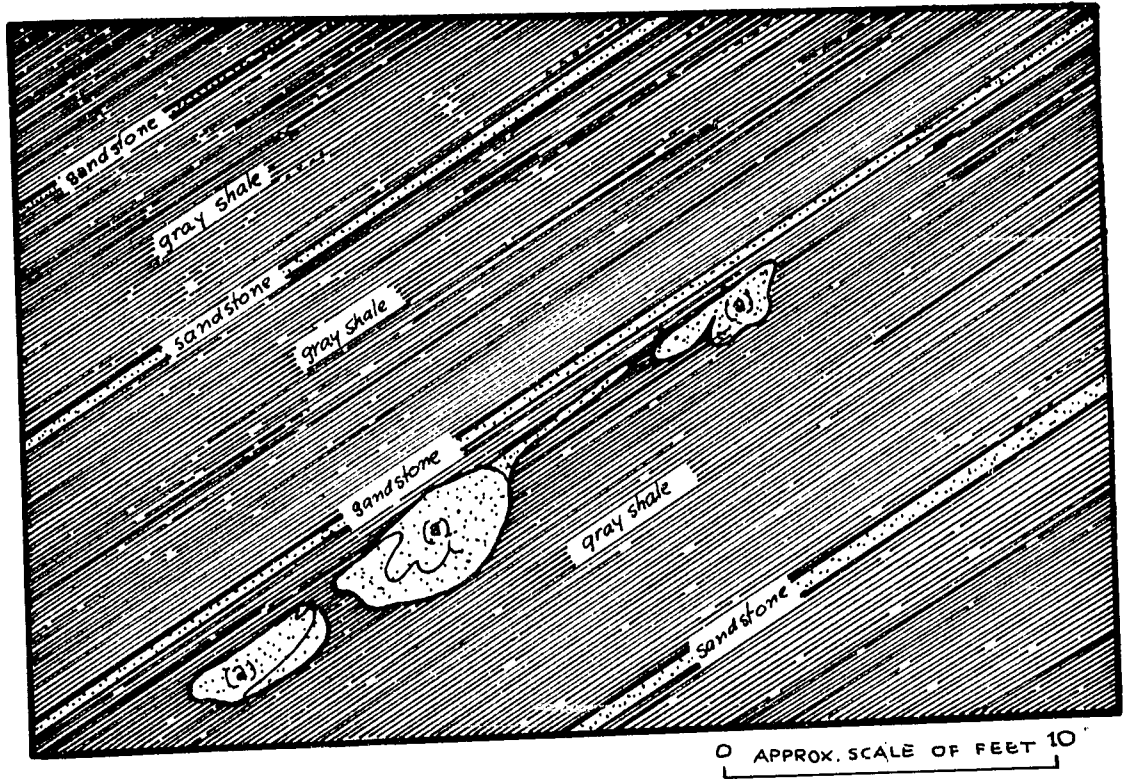


Figure 13

Slump balls, or a piled-and-load-casted bedding, in large scale. The balls developed in a predominantly grey shale sequence with thin sandstone interbeds of Upper Horton strata. In Gallant River, near Margaree Valley north of the present area.

See also Plate X,A and B.

Point Member of the Ainslie Formation. The exposure of this siltstone covers the full width of the river (about 70 ft.) and extends over 100 ft. downstream from the base of the unit. All the laminae are contorted and crumpled, but at places they are fused into a homogeneous mass (see a on Plate XI B). The deformation is entirely plastic, no elastic disruptions are seen. Gravity subaqueous slumping of material in a relatively very plastic condition, and the presence of a slope, probably account for the structure.

5. Large-scale and intraformational slumping (subaqueous) can be observed at Location 68 (Graham River), and a slump-sheet occurs near Location 40 (Southwest Mabou River). At both locations, deformation in a plastic and elastic condition is evident from the structure.

At Location 68, see Plate XII (A), the slumping involves a 4 ft. unit consisting of thin bedded, greenish grey siltstone of the Ainslie Formation. The crumpling of the strata (see a, on the plate) is accompanied by disrupting along several sliding planes, which are curved and tangential to the base of the strata (see b on the above plate). The thick grey shale units above and below the slumping show no disturbance.

The elastic deformation is shown by the brittle crumpling (see c on the Plate) and also disruptions along sliding planes.

6. Large scale slumping can be seen at the base of a steep cliff at Location 40A, see Fig. 14. The slump sheet,

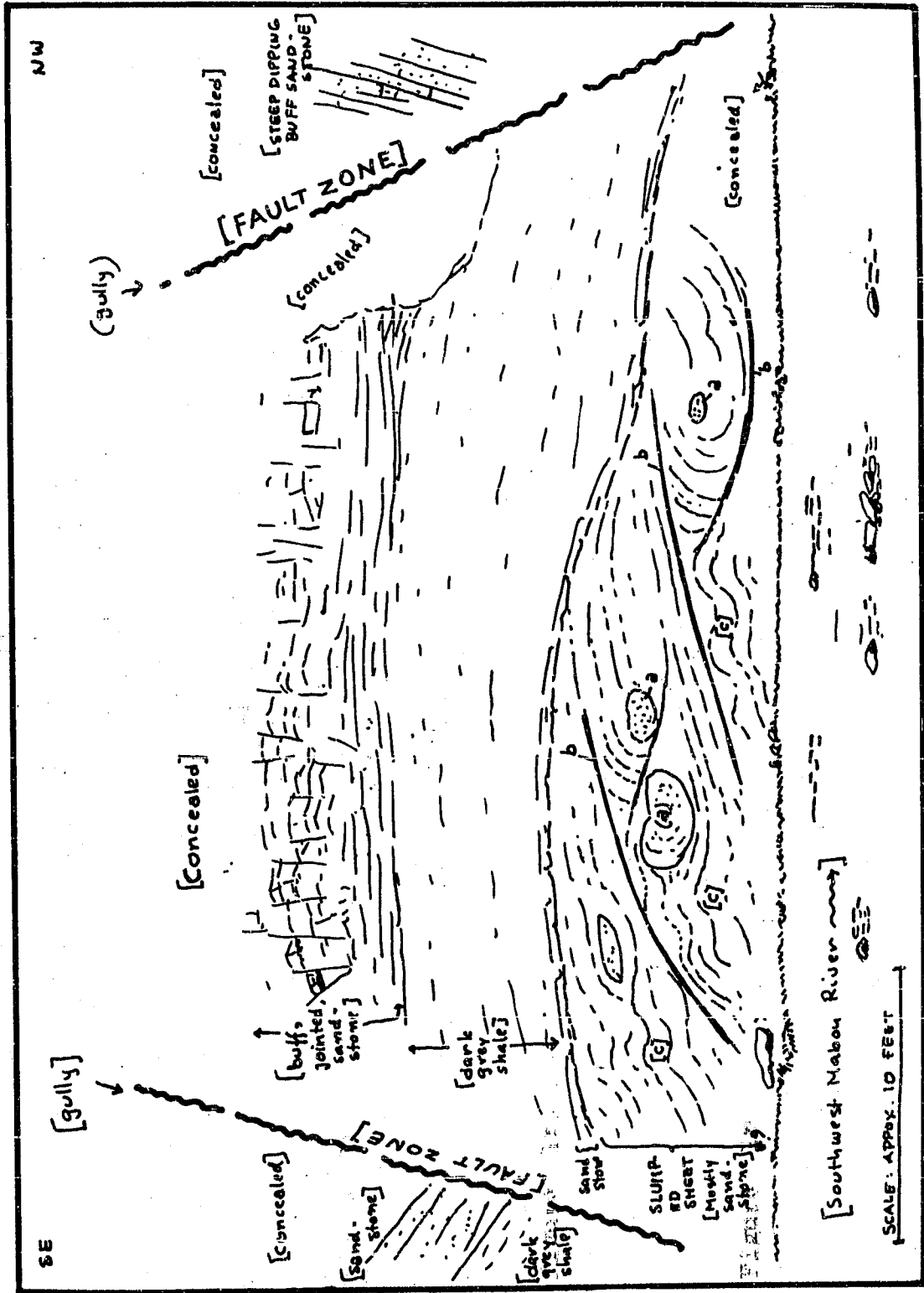


Figure 14. Slump sheet involving a series of thin bedded sandstones and some grey shale of the Strathlorne Fm., at location 40, Southwest Mabou River. The sheet is bounded by fault zones. With slump balls (a), sliding planes (b), and crumpled strata (c). After photographs and field sketches.

though partially concealed, is at least 12 ft. thick and extends between two fault zones, a distance of about 70 ft. It consists of several sandstone units and much interstitial shale. Each of the crumpled units is separated from the others by inclined sliding planes. Deformation has continued to the extent of producing sandstone slump-rolls of varied sizes and shape. The slumping may have been formed by the movement of the block bounded by the fault-zones on both sides of the sheet, but it is noted that the strata above it are relatively undisturbed. Later movements of the block brought the strata into the present relation.

The crumpling of the strata and the disruptions along sliding planes are, as in Location 68, evidence of deformation in both plastic and elastic conditions.

C. DISTRIBUTION OF OCCURRENCE

The sediments of the Horton Group are noted for their rapid changes in lithology. The changes are apparent within a section as well as between sections ⁱⁿ western Cape Breton. As a result, sandstones and siltstones are unequally distributed between the upper and the lower parts of the Horton, and between the sections in the southern half and the northern half of the area. Because sedimentary structures occur mainly in these sandstones and siltstones, they are also unequally distributed in both stratigraphical and geographical extent.

Stratigraphic distribution The lithological differences between the formations and members of the Horton

Group contributed to some degree to the variation of types or association of types of sedimentary structures present in these units. This is clearly demonstrated in Table VI (following page), in which the occurrence of various types of structures is compared with the formation and members of the Group. This, ^{is} supplemented by Fig. 15, in which the structures are diagrammatically presented with the stratigraphic thickness column based on the type section of Southwest Mabou River.

In general, the Horton Group can be divided into three units based on sedimentary structure associations. These are, starting from the base:

(1) The Lower unit, is essentially corresponds to the Skye River Member (i. e. about 3000 ft. thick). This unit contains primarily large-scale cross-bedding of solitary types. They are usually conglomeratic and poorly bedded. Poor sorting and irregular bedding are evident throughout this unit. Cut-and-fill structures are numerous, and so are erosional surfaces.

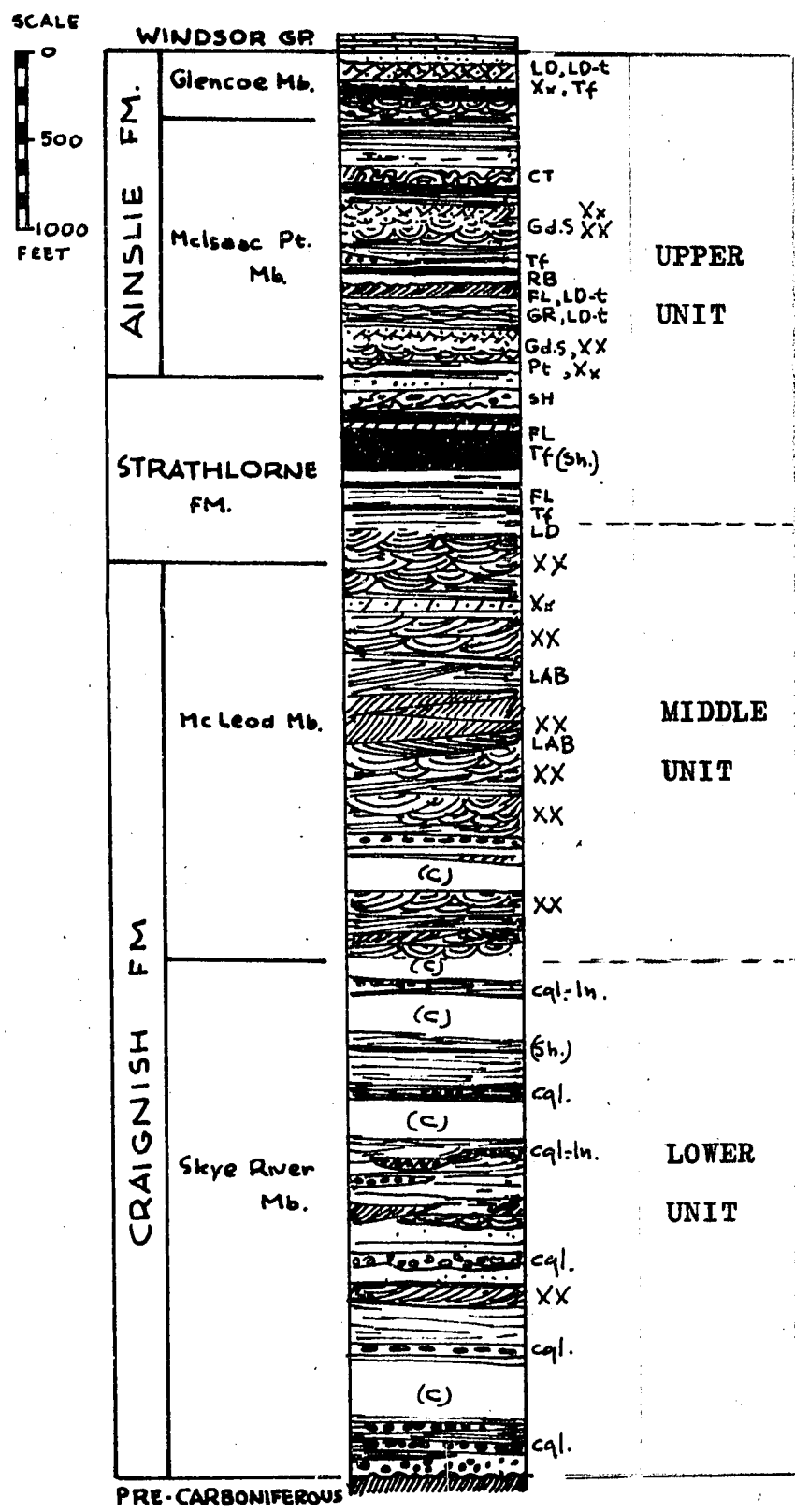
(2) The Middle Unit, about 2500 ft. thick, extends from about the base of the McLeod Member to the top of about the first quarter of Strathlorne strata. This unit contains numerous grouped, trough-shaped, large-scale cross-stratification, and low-angle cross-bedding. Small-scale cross-lamination also occurs but is less common. Practically no sole markings or any types of primary deformational structures have been found. The strata are generally well bedded, thin, and laminated.

The Middle Unit with the above characteristics is limited to the type section (i. e. Southeast Mabou River).

TABLE VI. Stratigraphic distribution of sedimentary structures in the Horton Group of western Cape Breton Island, Nova Scotia.

	desolation cracks	trace fossils	flute casts	groove casts	load casts	force load casts	"convolute lamination"	roll and ball struct.	slump sheet	"graded sequences"	primary lineations	ripple marks (asym.)	small-scale cross-lamin.	grouped	solitary	low-angled beds
Glencee Mb.	x	x	o	o	o	oo	oo	o	o	oo	(x)	x	xx	x	(x)	(x)
AINSLIE FM																
McIsaac Pt. Mb.			o	oo	oo	oo	oo	o	o	oo						
STRATHLORNE FM.	(x)	x	o	oo	o				o			x	x	(x)	(x)	
McLeod Mb.																
CRAIGNISH FM.											(x)	(x)	(x)	xx	xx	xx
Skye Riv. Mb.														(x)	xx	(x)

EXPLANATION. Number of occurrences: o, less than ten; oo, more than ten. Frequency of occurrence: (x), present; x, common; xx, very common.



EXPLANATION

- Tf trace fossils
- Fl flute casts
- GR groove casts
- LD load casts
- LD-t torose load casts
- RB roll and ball Str.
- CT contorted bed
- SH slump sheet
- Pt parting lination

Bedding:

- XX large scale cross-stratifications
- Xx small-scale cross stratifications
- LAB low angled bed
- Gd.S "graded sequences"
- cgl conglomerate
- ln congl. lenses
- (c) concealed

Figure 15. Sedimentary Structure Column, based on Horton type section of Southwest Mabou River.



Figure 15B

Fissile sequence of the Ainslie Formation
at Location 56, Judique Interval Brook.

In other sections, it is either unrecognizable (see McLeod Mb. page 16) or entirely different in structural contents.

(3). The Upper Unit, about 2500 ft. thick, extends from the top of about the first quarter of the Strathlorne up to the top-most bed of the Horton (i. e. includes all of the Ainslie Fm.). This is the most important unit because it contains most of the structures belonging to Groups I, II, IV and V. Cross-stratification is also frequent. It has many fissile sequences consisting of thin bedded sandstones and siltstone, interstratified with thin bedded shales. These fissile sequences (see Fig. 15B) often contain numerous trace fossils, in association with ripple marks (symmetric types), small torose load casts, small convolution (e. g. Fig. 8 & 9), small-scale cross-lamination, some flute and groove casts, and occasional dessication cracks. Examples of these associations are Locations 40, 56 and 68. Another association is of large groove casts and large torose load casts of Location 42. Thick units of small-scale cross-lamination (Locations 43B, 49 and 67) also belong to this Unit.

In the type section, the McIsaac Point Member is characterized by the occurrence of several "graded sequences" (MURRAY, 1960, p. 16), also described and called "tripartite sedimentary cycles" by SHROCK (1948, pp. 32-33). Large-scale cross-stratifications are common also outside the above graded sequences.

Geographical Distribution The greater majority of data on the observed occurrences of sedimentary structures came from the southern half of the area, i. e. the river sections

of Graham, Southwest Mabou, Southeast Mabou Rivers and Judique Interval Brook. Only a few were observed in the area around Lake Ainslie.

The discrepancy is mainly due to the distribution of sandstones and siltstone, a large percentage of which occurs in the southern half of the area. There is, upon calculation, a rapid decrease in the sand (including silt)-shale ratio between the sections in the south and exposure areas in the north. The sand-shale ratio in the Southwest Mabou River is about 4, as calculated from MURRAY's data (1960, p. 13B, Fig. 7). Approximately the same ratio is also found in the Graham River Section (COTE, 1962). Around Lake Ainslie, however, the number and the thickness of shale beds are decidedly larger in comparison to sandstone or siltstone beds. In many stratigraphically broken sections in this area, the ratio is generally less than 1. Further to the north, e. g. in Gallant River, outside the area, the sand-shale ratio is close to .2 (COTE, 1962).

CHAPTER VI

DIRECTIONAL ANALYSIS

Directional sedimentary structures in the Horton Group of western Cape Breton were measured and analyzed. This work includes: One hundred measurements of cross-stratification from ten different locations; and, fifteen measurements of current markings and other types of directional structures.

The computed data are summarized in appropriate diagrams but only a few are plotted on maps. The number of obtained data and the regional spread of localities from which these data came do not allow a decisive construction of a paleocurrent map for the entire Horton area. Local analyses of cross-stratification, together with the analysis of a handful of other directional structures can only at most suggest the nature of current activities on a regional scale.

Cross-stratification

Measurements of cross-strata were carried out for the Horton sediments of western Cape Breton in the manner employed by authors such as PETTIJOHN (1957a), PELLETIER (1958), YEAKEL (1962) and others. Most of the cross-bedding available in the exposures in Southwest Mabou River and Mull River was measured. Small scale "choppy" cross-laminations are generally difficult to measure due to their minute sizes, but data on these were obtained from Southeast Mabou, Southwest Mabou and Graham Rivers. Table VII, A lists all the measurements

and the computation thereof which also includes the stratigraphic positions and the descriptions of the cross-strata.

Each measurement of a cross-stratum plane is made either directly or with the help of a note book or a clipboard placed in a visual position of the plane represented by two intersecting lines (traces) on two different rock surfaces, see e. g., YEAKEL, 1962, p. 1517, Fig. 2. In each exposure the cross-stratified unit was first determined and the true stratum plane bounding this unit measured. The number of measurements in each unit depends on the number of available sets: generally, one measurement for each set was made. The data obtained from the above measurements were further corrected for tilt granted during deformation. A standard equal-area net was used on which poles of cross-strata were rotated about the strike of the true stratum plane to the amount of its dip. This brought the strata and the cross-strata into the position which they are assumed to have originally.

The results of the above procedure are: (1) Dip direction (azimuth) of cross-strata indicating a down-current direction; (2) "Inclination" (foreset dip) of cross-strata which, as defined by PETTIJOHN (1957, p. 472), is the dihedral angle between the plane of cross-lamination and the plane of true bedding. The inclination is related to the original angle of repose, but not exactly so due to shearing action took place during the folding. Rotation of azimuth due to plunge of fold (YEAKEL, 1962, p. 1517) is believed to be minimal from what can be seen of the structure locally (see Chapter III, p. 7).

Table VII A. Data on cross-stratification

Location:		Attitude of		Tilt		Description, lithology	
Formation or Member	Loc.	strata: strike-dip	cross-strata: "strike"- "dip"	corrected azimuth and inclination of cross-strata	$\bar{\theta}$ = resultant azimuth		
Southwest Mabou River:							
Ainslie	43A	N212E 57NW	N227E	72NW	349	21	Large scale cross-strata in red fine siltstone $\bar{\theta} = 330$ Small-scale choppy cross-lamination in non-red and red fine silty sandstone $\bar{\theta} = 54$
			210	67NW	290	11	
			220	80NW	321	24	
			210	80NW	297	23	
			227	80NW	337	26	
			210	80NW	297	23	
			230	70NW	357	22	
			225	55NW	45	10	
			225	55NW	45	10	
			250	55NW	47	30	
			240	42NW	77	26	
			232	55NW	47	16	
			245	65NW	25	30	
			230	47NW	70	17	
			222	50NW	73	10	
Strath-lorne	37	N210E 20NW	232	27NW	10	12	Large scale cross-bedding in greenish gray coarse siltstone $\bar{\theta} = 335$ (for Loc.37)
			242	45N	345	30	
			263	35N	25	28	
		N215E 17NW	155	12W	170	15	
			175	20W	205	14	
			253	32W	10	21	
		N210E 15NW	232	35NW	336	22	
			222	25NW	324	22	
			102	15S	155	25	
			195	35W	276	21	
McLeod	35	N227E 22NW	227	40 NW	227	18	Fairly well cross-bedded red fine grained sandstone; all large scale cross-bedding good cross-bedding (large-scale) poor cross-bedding (large-scale)
			240	35 NW	346	14	
			272	15 NW	93	15	
			257	10 N	118	15	
			220	32 NW	295	11	
			212	50 NW	294	19	
			215	40 NW	293	19	
			145	20 W	185	27	
			245	40 N	345	20	
			260	25 N	62	14	
			280	25 N	79	22	
			127	15 NW	89	22	
		N235E 22NW	252	35 NW	7	11	
			212	27 NW	225	10	

(continued next page)

(cont.)	35	N230E 20NW	N250E	40NW	359	20	Good, large-scale cross-bedding in red siltstone.				
			220	30NW	289	9					
			275	10N	114	15					
			232	35NW	324	14					
	46	N238E 30NW	232	60NW	318	30	Good, large-scale				
			260	50N	10	30					
			255	50N	2	23					
			200	55W	270	25					
			210	45NW	270	23					
			262	20 N	112	14					
			220	35NW	259	11					
			232	45NW	314	15					
<u>Southeast Mabou River</u>											
Ainslie	49	N238E 35NW	N275E	30N	87	20	Good, small-scale choppy cross-lamination in greenish, calcareous micaceous sandstone.				
				282	30N	88		23			
				265	40N	56		18			
				277	40N	62		24			
				257	55N	9		25			
				265	45N	40		20			
				265	45N	40		20			
				270	30N	88		18			
				267	50N	32		25			
				257	50N	16		19			
	49A	N225E 65NW	247	53 NW	81	22	$\bar{\theta} = 51$ (for Locations 49 and 49A)				
			255	70NW	41	27					
			240	70NW	23	14					
<u>Mull River</u>											
undiff.	52	N260E 15NW	N290E	35N	37	23	Cross-bedding (large scale) in poorly bedded coarse sandstone				
				240	55N	164		20			
				307	35NE	60		27			
				315	30N	73		25			
				305	25N	70		19			
				317	35N	70		29			
				350	10E	130		16			
				310	25N	77		17			
				295	30N	50		20			
				282	30N	32		19			
				280	27N	32		14			
				297	15N	90		8			
				53	N 35E 15SE	335		10NE	345	13	(similar to Loc. 52)
						285		25N	357	30	
						60		25S	180	15	
			335	25NE	354	20					

(continued next page)

(cont.)	35	N 35E 15SE	N307E	15N	354	20	Poorly-bedded, greenish grey coarse sandst. Large scale cross- stratification	
				320	35NE	27		20
				312	32NE	18		33
				280	10N	31		21
				85	15S	242		12
				305	20NE	0		25
				235	15NW	45		5
				15	25SE	82		12
			$\bar{\theta} = 45$ (for Locations 52 and 53)					
<u>Graham River</u>								
Strath- lorne	67	N205E 60NW	220	60NW	21	14	Small-scale choppy cross-lamination, well laminated, in greenish, medium grained sandstone	
			217	58NW	18	10		
			223	57NW	40	16		
			212	57NW	67	7		
			220	65NW	2	15		
			220	70NW	350	17		
			230	55NW	45	22		
			217	70NW	342	15		
			272	50NW	57	16		
			220	70NW	350	17		
$\bar{\theta} = 23$								
----- REGIONAL RESULTANT OF AZIMUTHS= $\bar{\theta}_r = 25$ -----								

For each location, or, several locations considered as one, the resultant azimuth ($\bar{\theta}$) is calculated trigonometrically (CURRAY, 1956). The regional resultant azimuth ($\bar{\theta}_R$) is calculated for all the available data from the Horton Group. In some local interpretations, the azimuths are summarized in rose diagrams (circular histograms) having twelve 30-degree classes. The magnitude of the resultant vectors (in percentage) are also calculated and plotted as current arrows on maps.

Summary of results The diagram-map of Figure 16 shows good indications of a north-northeasterly paleocurrent direction. These indications, however, are exhibited chiefly by the small-scale "choppy" cross-lamination (ch, on map). Larger scale cross-strata in Southwest Mabou River indicate northwesternly direction of paleocurrent. This is shown on Diagrams in Figure 17, where the histograms for the McLeod Member, Strathlorne Formation, and Ainslie Formation are given. Although these histograms are markedly different in pattern, the resultant azimuths ($\bar{\theta}$) for each of the rock group points consistently towards the northwest (N 330°-335°E). The "choppy" cross-lamination from the Ainslie Formation of Southwest Mabou River (see Table ^{VII}A) points also towards the northeasterly direction.

The regional resultant azimuth ($\bar{\theta}_R$), calculated from all the available cross-stratification data of the Horton Group is N 25°E.

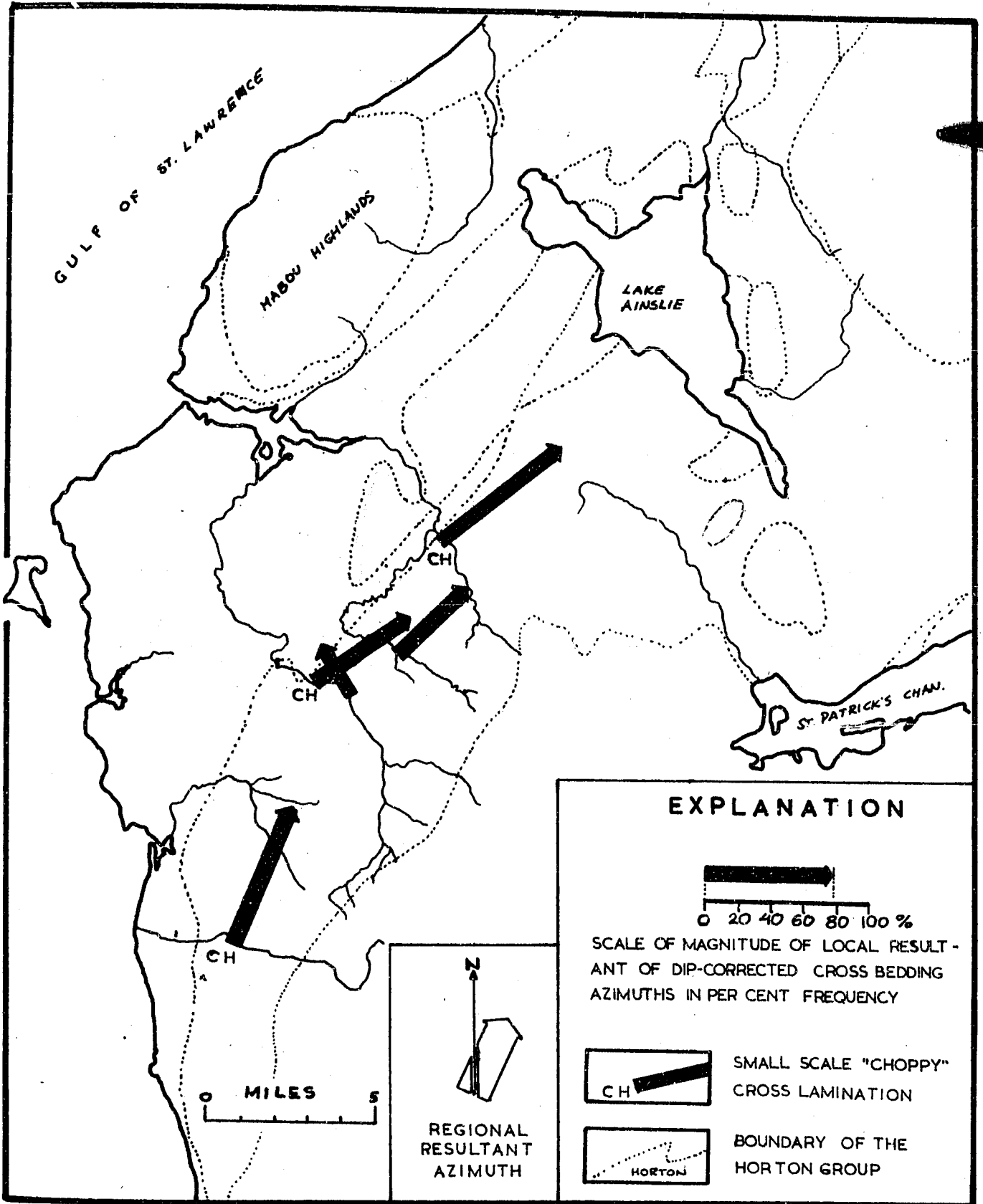
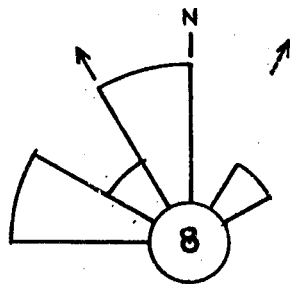
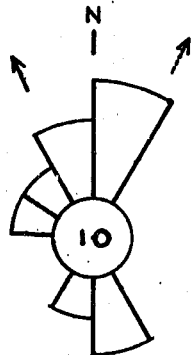


Figure 16. Current Arrow Map. The arrows are resultant vectors of cross-stratifications. Note those of small-scale cross-laminations (CH)

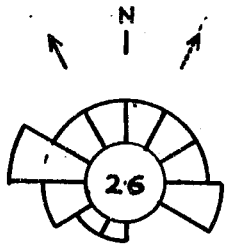
SOUTHWEST MABOU RIVER



AINSLIE FM.
 McISSAC POINT MEMBER
 LOCATION No. 43A.
 $\bar{\theta}$ 330°
 ($\bar{\theta}_r$ 25°)

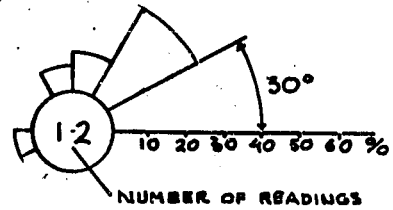


STRATHLORNE FM.
 LOCATION No. 37
 $\bar{\theta}$ 335°
 ($\bar{\theta}_r$ 25°)



CRAIGNISH FM.
 McLEOD MEMBER
 LOCATION No. 35 & 46
 $\bar{\theta}$ 332°
 ($\bar{\theta}_r$ 25°)

EXPLANATION



HISTOGRAM OF DIP-CORRECTED
 CROSS BED AZIMUTH WITH 30° CLASS-
 ES. CLASS LENGTH BASED ON
 NUMBER PER CENT FREQUENCY

$\bar{\theta}$ LOCAL RESULTANT AZIMUTH
 $\bar{\theta}_r$ REGIONAL RESULTANT AZ.

Figure 17. Vertical variations of shape of rose-diagrams and the resultant azimuths ($\bar{\theta}$) of cross-stratification in the Southwest Mabou River. Note the consistency of $\bar{\theta}$ despite the differing patterns of diagrams.

Current Markings and other Directional Structures

Groove casts, flutecasts, parting lineations, load casts, convolute laminations, and slumping structures are recorded directionally. Although they are small in available and recognizable number, the data and their results of computation are listed on Table VII B, which also includes geographical and stratigraphical locations, and the description of each structure.

Measurements of these structures in the field were based on taking the apparent bearing of lineations where, if possible, the implied down-current directions were also indicated. To obtain the true bearing, each of these data was later corrected for tilt. On a standard equal-area net, the field bearing was rotated about the strike of the strata to the amount of the dip. The plunge of folds rotates the bearing in the vertical axis but the effects are considered negligible as also applied to cross-stratification (page 39). The corrected bearings obtained from above are summarized as vectors in a circular diagram similar to that used by CROWELL (1955, also HSU, 1958). The small number of existing data permits the computation of the resultant directions by graphical method. It is important to note that because some of the lineations (e. g. groove cast, partly lineations), are bi-polar, (two-directional), only half (eastern-) of the circle is considered and each angle of vector within this half has to be doubled in computation of the resultant. This resultant will be twice as large as the actual resultant vector. The purpose of this procedure, KRUMBEIN (1939), is to

Table VII B. Data on directional bottom, and other structures.

Location: Formation or Member; Loc.-	Attitude of strata: Strike-Dip	Apparent bearing of linear directions	Tilt correct ed bearing	Descriptions
Southwest Mabou River:				
Ainslie	42 N227E 15NW	N 10E	N 10E	parting lineations
		25	25	parting lineations
		35	35	parting lineations
	N210E 15NW	35	35	groove casts
		22	22	large groove casts
		40	40	large groove casts
		35	35	large torose load casts
		60	60	large torose load casts
Strath- lorne	43 N210E 15NW	35	35	small groove casts
	38 N245E 22NW	80	80	large flute casts
	40 N200E 20NW	300	300	small flute casts
		60	60	small flute casts
		40	40	axis of convolute rolls
Southeast Mabou River:				
Ainslie	49A N225E 65NW	60	60	groove casts
	51 N250E 40NW	70	70	groove casts
		70	70	groove casts
		70	70	groove casts
Judique Interval Brook:				
Ainslie	56 N240E 65NW	20	10	groove casts
		0	350	groove casts
		70	75	groove casts
		90	150	groove casts
		70	75	groove casts (large)
		140	140	torose load casts
		90	95	axis of convolute rolls
Strath- lorne	58 N230E 40NW	90	100	groove casts
		70	75	groove casts
		0	357	groove casts
Graham River:				
Ainslie	68? N215E 65NW	240	260	axes of slump balls
		245	270	axes of slump rolls
Lake Ainslie shore				
	102 N260E 60S	35	10	groove casts

obtain a non-symmetric periodic distribution or otherwise will not reflect a true central tendency (CURRAY, 1955).

Summary of results Regionally, there is a good suggestion of current towards the NNE to NE. The overall resultant shown by the diagram on Figure 18 is N31E for about 60 percent of all the vectors: This figure breaks down into 65 percent of the lineations indicating N40E, and 60 percent of the flute casts indicating a N25E direction.

The widely separated locations from which the data came, can be suggested as an explanation for the high degree of scatter in the distribution of the vectors on Figure 18. This results in the relatively low percentage, (although more than 50 percent) of the total vector in the resultant.

Paleocurrent Interpretations

Directional analysis has shown that there were two current directions apparently prevailing during the deposition of the Horton Group in the Ainslie Basin. These paleocurrent directions intersect almost at right angles. To some degree, they are also intersecting in the sense of the time and place of their deposition.

The ultimate implications of the paleocurrent directions are the directions of sedimentary supply and thus the sources of sediments carried by these currents. In this regard KUENEN (1957 a, and 1958) is of the opinion that two directions of sedimentary supply are present in many basins. In an elongate basin there are: (a) lateral supply of sediments from

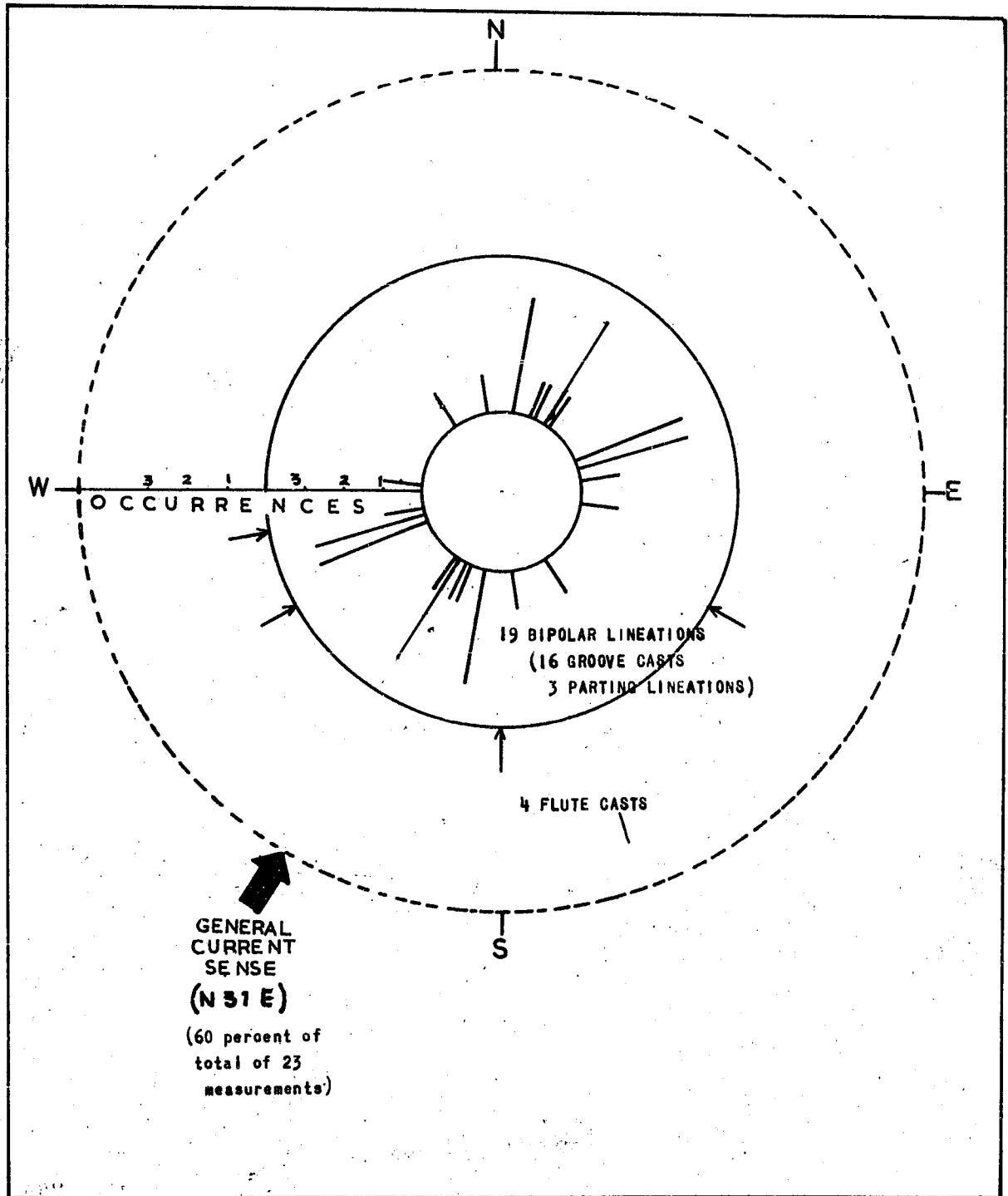


Figure 18. Rose diagram for linear directional features in the Horton Group.

local sources; and (b) longitudinal supply from distant sources.

In the Ainslie Basin this relationship is strongly suggested, with the northwesterly direction of paleocurrents being lateral, and the northeasterly directions longitudinal in relation to the NE-SW elongated shape of the basin.

Previous authors have suggested (see Chapter III), that the pre-Carboniferous highland is an important source of the Carboniferous sediments in western Cape Breton. The presence of northwesterly paleocurrent directions support the admissibility of a lateral, however, local supply of sediments from the adjacent Craignish Hills. These directions, indicated by the large-scale cross-bedding (see Fig. 17), and thus these lateral currents are probably responsible for the transport of the greater volume of sediments now accumulated in the Ainslie Basin. Furthermore, the shapes of the rose diagram for these cross-bedding (Fig. 17) are multi-, if not tri-, modal which TANNER (1959) believed indicates a shore or transitional (land-water) environments. Therefore it is suggested further that the lateral accumulation of sediments progressed in the manner of "delta-building". The shorelines during the various stages were probably approximately parallel to the elongation of the Craignish Hills.

The northeasterly, longitudinal paleocurrent directions are primarily suggested as sorting currents. Their role in the transport of sediments is limited to finer clastics, and may be held responsible for the greater percentage of shale

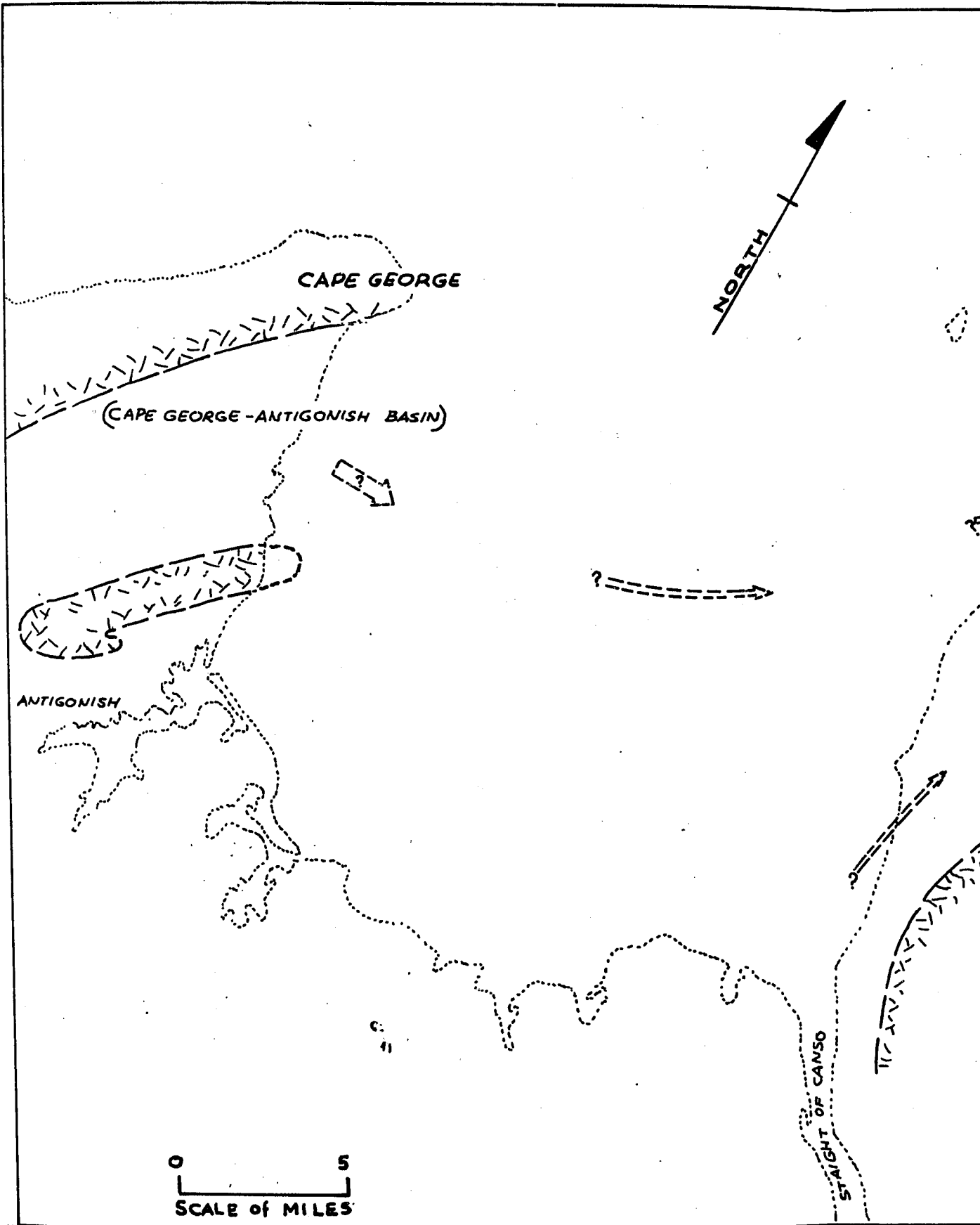
beds in the northern parts of the area (see page 45). Such may be the case, their direction (northeasterly) being highly consistent during the greater part of Horton deposition.

The consistency of the longitudinal direction of currents are indicated by small scale cross-lamination analyses (see Fig. 16). The cross-laminations came from both the Strathlorne and the Ainslie Formations. These currents may or may not be responsible for the formation of other directional structures (current marks, etc.) merely because they indicate congruent directions of currents (see Fig. 18).

In comparison to the lateral current, the longitudinal currents are relatively weak, i. e. in the lower flow regime (ALLEN, 1963 b), as evident from the structure they produced.

Although the fine clastics carried by the longitudinal current are primarily obtained from the sorting of the laterally supplied sediments, there remains the possibility of a distant source. Such may be the Cape George-Antigonish Basin in the mainland of Nova Scotia, about 25 miles west and southwest of western Cape Breton. This basin has been postulated by MURRAY (1960) as being connected to western Cape Breton during Horton deposition (op. cit., pp. 67-90, and p. 116).

As a conclusion, Fig. 19 on the following page presents the relationship of the lateral and longitudinal paleo-current direction in the Ainslie Basin during the deposition of the Horton Group. It is not necessary to designate the paleogeographic picture to any one formation of the Horton, because, as believed by CAMERON (1948, p. 5) and also by MURRAY (1960, p. 94), their continuity of relationship is not entirely certain.



after page 58

**Figure 19 Map of Paleocurrents during the Horton deposition
in the Ainslie Basin of western Cape Breton
Island and the Cape George-Antigonish Basin,
Nova Scotia.**

CHAPTER VIISUMMARY AND CONCLUSIONS

(1) Until recent years, some types of sedimentary structures, especially sole markings, have been regarded as structures of turbidite deposits or formed under turbidite environment. It is now well established that sole markings and other types of "turbidite structures" are known from other types of sediments deposited in varied environments. Flute casts and groove casts have been described from fluviatile and shelf deposits (CUMMINS, 1959), and from deltaic deposits (MURPHY and SCHLANGER, 1962). Convolute laminations has been maintained as inherent ~~of~~^{to} turbidite deposits (e.g. SANDERS, 1960), but occur in non-turbiditic sediments (DOTT and HOWARD, 1962). DOTT and HOWARD (1962) believed that only repetitious graded bedding, and not convolute lamination, is to be regarded as characteristic of turbidite sequences. In general, the outstanding characteristic of turbidite deposits in regard to sedimentary structure occurrence, is not the kind but the abundance of the structure present. This is so admitted by KUENEN (1957 b, p. 232).

The occurrence of nearly all types of sedimentary structures in the predominantly continental sediments of the Horton Group provides further evidence in support of the modern view which states generally that no single type of structure indicates any one form of depositional environment.

(2) The study on the development of sedimentary structures is now concerned with the interpretation of their

mechanisms of formation, i. e. the agents and the processes involved in the production of the structures. These are: Currents, which through the processes of scouring and marking of the mud-bottom produce current (scour-, and tool-) markings, and by deposition and fall-out, structures such as cross-stratification, current-ripples, lamination, and graded-bedding are produced; gravity, which through the processes of unequal loading, collapsing, sliding, in a subaqueous condition, produces load casts, flowage casts, contorted laminations, slump structures and slump sheets; and, the interaction of both currents and gravity, in a complex manner, is held to be responsible for the production of certain types of convolute lamination.

a). Currents Hydrodynamic studies have shown the behavior of currents in the transport of particles and grains to be by traction, saltation, and suspension. The transportation patterns differ accordingly during the various "flow phases". These phases are governed by the ranges of velocities, which in an increasing intensity are (DZULYSNKI, 1963, p. 100):

1. First smooth phases;
2. Transportation in ripples;
3. Second smooth phases;
4. Antidune phases.

In the basin, where deceleration and deposition took place, various sedimentary structures were formed during each phase.

The antidune phases are responsible for the scouring of ^{the} basin floor, on which scour marks (flute casts) were

produced. Some of the tool marks, especially the short and discontinuous ones (Plate IV, B), were probably formed during this erratic phase. Other tool marks, however, were probably produced during the next, second smooth, phase. For this latter reason, the relatively continuous groove casts (tool marks) on Plate II were evidently formed after the flute casts (scour marks) of the same surface.

The filling of these markings may have taken place during fall-out of particles from "second smooth phases", from which a thin layer of massive or thinly laminated sands or silts were deposited. The deposition continued with one or several sets of cross-laminated siltstones ("transportation in ripples phase"), and may end with another set of flat laminae ("first smooth phases"). The sequences of formation of the features shown in Fig. 4 (after p. 29) ideally follows the above succession.

b). Gravity The effects of gravity may become apparent during accumulation of the sediments. Some load casts and convolute lamination may be formed during this time, but some others are evidently formed after the accumulation of sands and silts are completed.

The process involved is initially a partial or whole liquifaction of the freshly deposited and cohesionless sediments, after which displacement of mass or flowage occur due to loading, current, or the presence of slope. The process of loading involves a differential vertical flowage of sediments into the soft yielding mud substratum, in which further flowage may take place horizontally resulting in the formation of flowage casts. The

loading may have induced local collapsing and disrupting of parts of a bed and produced certain type of convolution (see DZYLYSNKI and SMITH, 1963, p. 625). Other convolution of laminae may be generated by current rippling (see e.g. TEN HAAF, 1956) and other forces acted upon laminated bedding during its sedimentation (DZULYSNKI and SMITH, 1963, p. 622).

The convoluted laminae in the structures of Fig. 8 and 9 may be due to collapsing of a bed generated by current ripples merely because of the uniformity of width of these structures and their axial shape which are arranged in subparallel pattern.

The convolute balls and rolls of Fig. 11 (also Figures 10 and 12) may also form in the same way as above, i. e. by the interaction of currents and gravity. But they may involve a further flowage as is evident from the complex internal convolution of one of the rolls shown in the Fig. 12. The heeling of these rolls (the flattening of the "sole", see Fig. 12), may indicate the lower limit of the liquified horizon.

The presence of a slight slope, which, according to DOTT (1963, p. 104), can be as little as half a degree, may help in the production of the intra-stratal and intra-formational deformational structures.

DOTT (1960, p. 110) classified the different types of subaqueous gravity movements according to their flow behavior: Subaqueous rock fall (elastic flow); subaqueous slump and sliding (both elastic and plastic flow); subaqueous mass flow

(plastic flow); and, subaqueous turbidity flow (viscous fluid flow). All of which took place in the presence of a subaqueous slope.

The contorted bed of Plate XI (A, and B) was most likely produced by ^aflow having plastic behavior (a subaqueous mass flow). The slump structure of Plate XII (A), and the slump sheet of Fig. 14 were the results of a flow having both elastic and plastic behavior (i. e. a subaqueous slump and sliding).

(3) The Horton Group contains different types of sedimentary structures at different parts of its stratigraphic section (see Chapter IV, pp. 42). In the section in Southwest Mabou River, for instance, each of the formations and their member, or parts thereof, is characterized by different types of cross-stratification. To follow some of the significance of these differences, ALLEN's (1963) "scheme of sandstone facies" is considered.

ALLEN (op. cit.) produce^d the scheme experimentally, which in an increasing intensity of fluid flow, is: Small-scale cross-stratification -- large-scale cross-stratification (cosets) --- flat bedding with primary lineations. Most important is his application of this scheme in interpretation of such facies in sediments of fluvial origin. The "cyclothem" begins with erosion of channel floor and accumulation of conglomerates, both are indications of an uppermost regime of fluid flow; then, the accumulation of top-set beds consisting of plane beds with primary lineations; after which, accumulation of thick units of

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large scale cross-stratified sediments, progressing in the manner of "delta building"; the cycle ended with the deposition of a small-scale cross-stratified unit which grades up into fine siltstones with no bedding.

Parts of the above "facies" were found to be typical for some of the units of the Horton. With this and other properties of these units, it is possible to envisage some aspect of the depositional history of the Horton; LOWER UNIT (i. e. equivalent to the Skye River Member), contains numerous beds^{of} conglomerates in lens shapes or filling irregular scoured surfaces. In these cut-and-fill structures the conglomerates or the conglomeratic beds are cross-bedded. The bed roughness and the conglomerate beds indicate deposition in an upper flow regime, and are recorded throughout this unit. It is feasible to suggest an accumulation of alluvial fan and alluvial plain deposits (MURRAY, 1960, p. 30). It is not exactly known how extensive these deposits are across the basin, i. e. whether they cover the entire basin floor or grade horizontally into the next upper, but not necessarily younger, unit. It can be said, however, with a fair degree of certainty that the build up of these sediments took place along the foot of the Craignish Hill and progressed north-westernly across the basin, towards the central basin area.

MIDDLE UNIT (i. e. McLeod Member and lower part of the Strathlorne Formation), particularly in the Southwest Mabou River, contains numerous cosets of large-scale cross-strati-

fication, plane beds, and low-angle cross beds. The unit can be interpreted as the product of a concentration of fluvial activities in the form of delta building. During most of the time of accumulation, the basin floor was maintained at constant depth allowing a constant level flow regime, and therefore, allowing a thick accumulation of large-scale cross-stratification throughout most of this unit. Some variations in the level of flow regime are evident from the presence of some plane beds and small-scale cross-stratification.

Paleocurrent studies have shown that the deltas building progressed towards the northwest, thus verifying the inference that the source area for this unit was also the pre-Carboniferous area in the southeast, i. e. the Craignish Hills.

Unfortunately this unit is difficult to recognize beyond the section at Southwest Mabou River. In the Judique Interval Brook, a series of red-beds occurs below the non-red series of strata of the presumably Strathlorne Formation. But there the similarity ends, because these beds contain thick masses of conglomerate, siltstone, and shale, none of which are cross-bedded.

UPPER UNIT (i. e. the middle and upper parts of the Strathlorne Formation, and the Ainslie Formation) contains numerous trace fossils, sole markings, intra-stratal deformational structures, cross-stratification, and ripple marks. Thick units of small-scale cross-laminated siltstone and sandstone were observed in numerous places in the exposure of this unit in Southwest Mabou River as well as in other river sections.

The siltstones belonging to this unit are frequently massive, non-bedded, with occasional ripple marks (symmetrical types) on their upper surfaces. Some of the load casts were found on the base of these beds. Very thick shale beds are common for this unit.

The numerous occurrences of small-scale cross-laminated units and non-bedded siltstone units implies a low level of flow regime of current during most of the depositional history of this unit.

The graded sequences in the McIsaac Point Member of Southwest Mabou River (see page 33) correspond closely to ALLEN's cyclothems (op. cit., Fig. 4). Their appearance indicates a renewed activity in fluvial deposition. This is probably related to the rejuvenation which, according to MURRAY (1960, p. 117), occurred at the beginning of Ainslie time. In other areas of the Horton, this renewed activity is generally less evident.

Analysis of large-scale cross-stratification in this unit shows a paleocurrent direction towards the northwest, and thus conforms to the directions indicated in the Lower Units. The greater volume of the sediments was probably also supplied from the Craignish Hills. The lithological association implies deposition in a central basin area, relatively far from the source. This is also shown from the present geographical position of this unit in the area, which is relatively undisturbed by orogenic displacement.

However, small-scale cross-lamination and

directional bottom structures have been shown to indicate a northeasterly direction of paleocurrent. This is a longitudinal direction in relation to the basin shape, and in contrast to the direction indicated by other cross-bedding, which proved to be a direction of a laterally transported, local supply of sediments. The longitudinal direction of currents is primarily maintained as a sorting current which also transported the finer clastics towards the deeper parts of the basin, i. e. towards the northwest. The circumstances pointing to the possibility of a distant source of additional fine clastics is provided by the presence of the Cape George Antigonish Basin (see page 56).

(4) Throughout the discussion above, one question remains unanswered. This is the problem of contemporaneity of the successive units of the Horton. MURRAY (1960, p. 94) concluded that no important time transgression across the sequence as a whole is involved. Then, how exact is the contemporaneity between the units?

ALLEN (1963) has shown the genetic and sequential importance of bedding roughness, plane beds with primary lineations, and associations of cross-stratifications.

In the Horton Group, it is possible that due to distribution through time and space, the present exposed units of the Group are characterized by accumulation of one type of sandstone facies in one unit, and another type in the next.

However, the concordant succession between units and sandstone facies points to a further possibility. This is

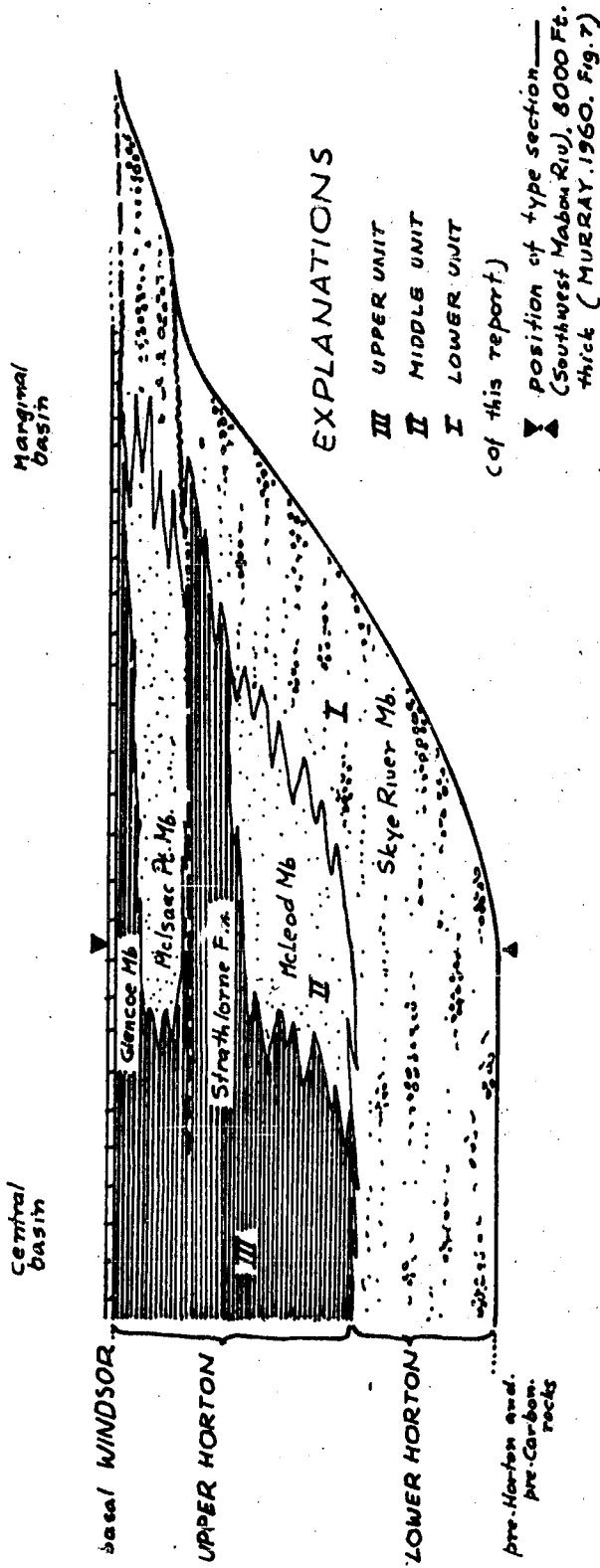


Figure 29

Continuity of relationship between the units of the Horten Group in western Cape Breton Island, Nova Scotia.

to say that conglomerates with rough bedding features tend to characterize the Lower Unit (Skye River Member, 2900 ft. thick); the next facies, the plane beds and cosets of large-scale cross-strata tend to typify the Middle Unit (McLeod Member and part of Strathlorne Fm., about 2500 ft. thick); and, small-scale cross-lamination, including also those siltstone beds devoid of bedding, were found frequently in the Upper Unit (e.g. the remainder of the Strathlorne Fm.).

In other words, it is possible that, given accepted names, the Skye River Member is contemporaneous with the McLeod Member and also with, perhaps, the Strathlorne Formation. The Ainslie strata, however, as also maintained by MURRAY (1960, pp. 95-96), show little contemporaneity with those of other parts of the Horton. Evidence to this effect is even strongly suggested in Southwest Mabou River, where the beds of McIsaac Pt Member consist largely of cyclothemic "graded sequences" and thus, are a distinct episode of fluvial deposition.

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THE PLATES

PLATE I

Flute casts arranged end-to-end longitudinally. Later load casting is obvious in the upper left hand corner of the specimen. Internally, beds with these flute casts may show small-scale cross-lamination (see text Fig. 4).

Arrow indicates implied current direction.

From thin bed of greenish siltstone of the Strathlorne Fm., Location 40, in the Southwest Mabou River.

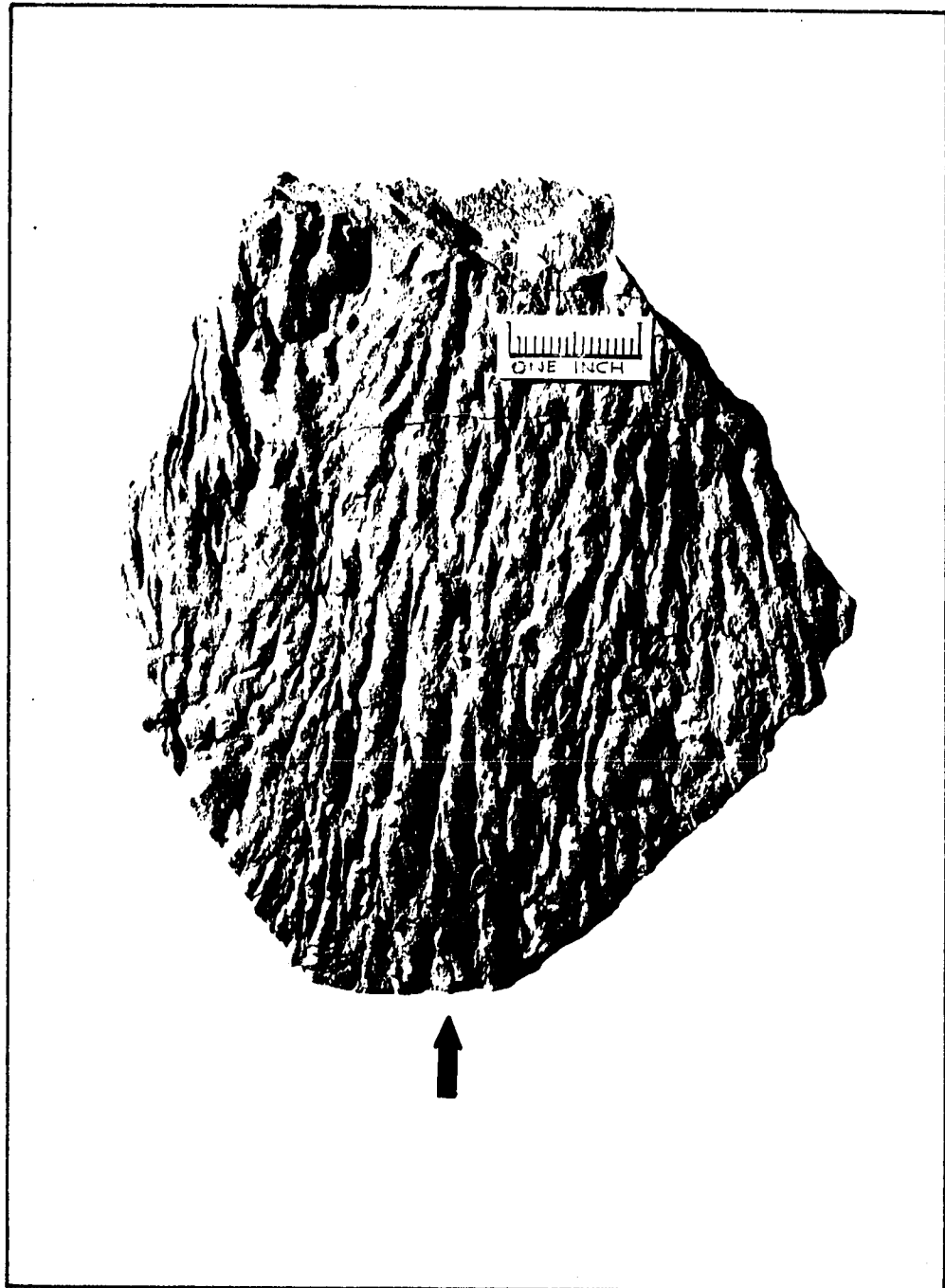


PLATE II

Flute casts, small-scale, arranged end-to-end (a) but occasionally in alternating position (b). Two prominent, continuous type groove casts (g) can be seen in the lower right hand of the photograph.

The base of thin bedded red siltstone of the Ainslie Fm., Location 42, in the Southwest Mabou River. Arrow indicates implied current direction.

Note: The groove casts appear to transect and delete the flute casts (e.g. at x). This may indicate the priority of formation of flute casts to groove casts.

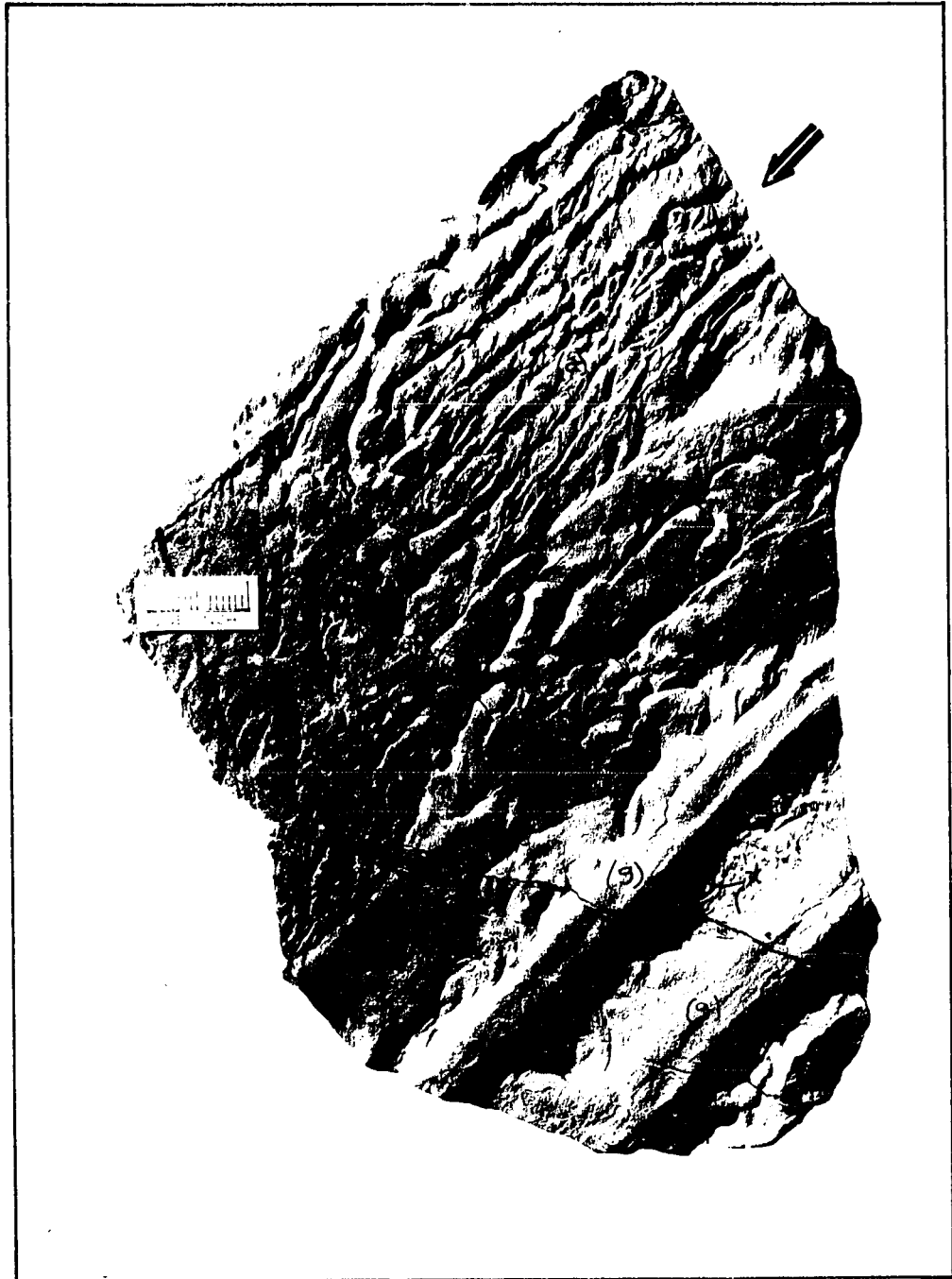


PLATE III

A. Reptilian scale-like small flute casts. The flutes are similar to those on Plate II developed in groups at intervals. The groove cast (g) was probably also formed later. Load casting and slight faulting (at f) contributed to the peculiar pattern of the surface.

Arrow indicates implied current direction. Scale is indicated by a one cent piece (x).

A slab of thick bedded red siltstone from the Ainslie Fm., Location 42, in the Southwest Mabou River.

B. Multi-directional flute casts, intensely load casted; in thick bedded greenish silty sandstone belonging to the beds of Upper Horton, Location 101, north shore of Lake Ainslie.

Scale indicated by one cent piece (x).

PLATE III.



(A)



(B)

PLATE IV

(A). Flute casts (a) of low relief and varied sizes, arranged occasionally in diagonal position (see 1, 2, 3); with faint groove casts (b).

Arrow indicates implied current direction. Scale is indicated by one cent piece (x).

Greenish siltstone, with reddish patches, of the Ainslie Fm., Location 42, Southwest Mabou River.

(B). Groove casts, discontinuous type, with occasional intersecting arrangements (at a). Some of the groove casts are tapered (B) in one direction: This may imply an upcurrent direction.

Scale is indicated by the pen (at x: approx. 5 inches).

Greenish siltstone of the Ainslie Fm., Location 42, Southwest Mabou River.

(A)



(B)



PLATE V

SMALL-SCALE CROSS-LAMINATION

(A). Cross-section of a cross-laminated bed displaying inclined boundaries of sets (e.g. b). This type of boundaries are often gradational, or non-erosional, and are invariably planar.

Greenish micaceous sandstone of the Ainslie Fm., Location 49, Southeast Mabou River.

Scale indicated by one cent piece. Arrow indicates implied current direction.

(B). Cuspate ripple marks typically found on the upper-surface of cross-laminated sandstone of (A).



(A)



(B)

PLATE VI

Load casts, small-scale, each having sub-polygonal pattern bounded by shallow furrows. Minute markings distributed randomly over the surface are probably organic in origin.

Thin bed of red siltstone from the Ainslie Fm., Location 42, Southwest Mabou River.

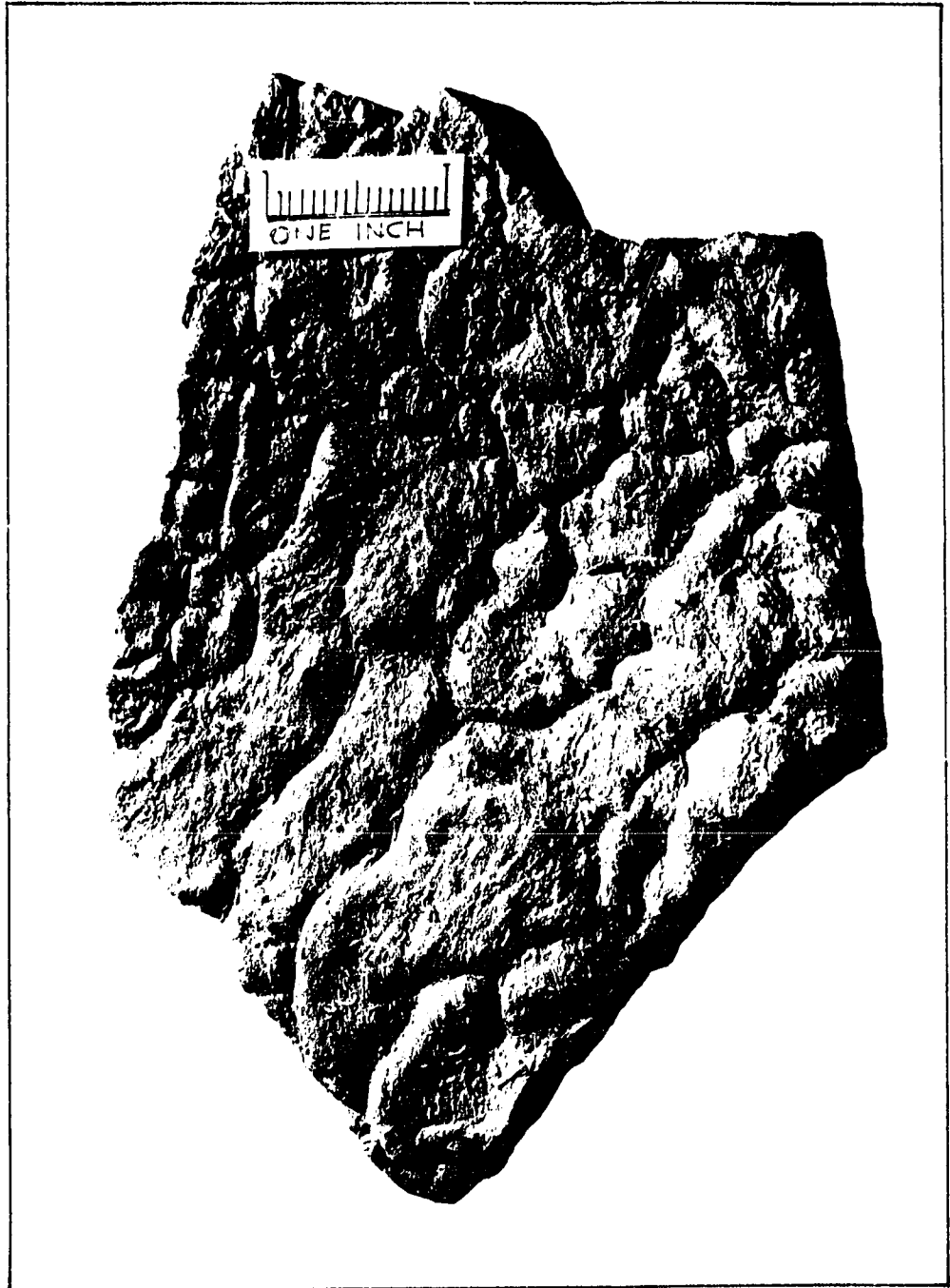


PLATE VII

(A). Load casts, or multi-directional flowage casts (BIRKENMAJER, 1958, p. 142), with curved linear fine grooves relative to flowage.

Greenish siltstone bed of the Strathlorne Fm., Location 38A, Southwest Mabou River.

Scale indicated by one cent piece (x).

(B). Torose load casts (a and b) where they bulged and fused forming into a knee-shaped load casts (a + c)

Red siltstone of the Ainslie Fm., Location 42, Southwest Mabou River.

Scale indicated by pen (x, approx. 5 inches).

PLATE VII.

(A)



(B)

PLATE VIII

(A). Load-casted ripple marks (a) and counterparts (b) in red siltstone of the Ainslie Fm., Location 42, Southwest Mabou River.

The pen (about 5 inches) indicates scale.

(B). Collapsing of bed, in large but local scale. The laminations are thrown into broad trough (a) and narrow crest (b).

Greenish grey laminated sandstone of the Upper Horton, Location 102, north shore of Lake Ainslie.

The hammer (x, approx. 13 inches) indicates scale.

PLATE VIII.



(A)



(B)




PLATE IX

(A). Ball and roll structures in greenish calcareous siltstone of the Ainslie Fm., Location 49, Southeast Mabou River. See also Figures 10, 11, and 12.

The hammer is about 13 inches long.

(B). Ball and roll structures with internal convolution of laminae (c) and smaller rolls in the upper horizon (d).

Red siltstone of the Ainslie Fm., Location 42A, Southwest Mabou River.

PLATE IX.

(A)



(B)

PLATE X

SLUMP BALLS, ^{of} ~~in~~ very large scale (photo A and B), developed within a grey shale sequence with thin sandstone interbeds belonging to Upper Horton Strata of Gallant River, near Margaree Valley (north of the thesis area). See Also Fig. 13. They may be appropriately called piled-and-load-casted bed.

Hammer in photo B indicate scale (approx. 13 inches).

PLATE X.



(A)



(B)




PLATE XI

CONTORTED BED

Views of intra-stratal contorted lamination (A, and B) at Location 44, Southwest Mabou River. The contortion affected all lamination within a thick unit of red siltstone of the Ainslie Formation. At a, the laminations fused into a homogeneous mass. Hammer is 13 inches long.

PLATE XI.



(A)



(B)



PLATE XII

(A). Slump sheet, small scale, at Location 68, Graham River. The slumping affected a thick unit of thin bedded sandstone of the Ainslie Formation. The crumpling (a) and disrupting (b, sliding planes) of bed imply a plastic and elastic deformation.

Hammer is 13 inches long.

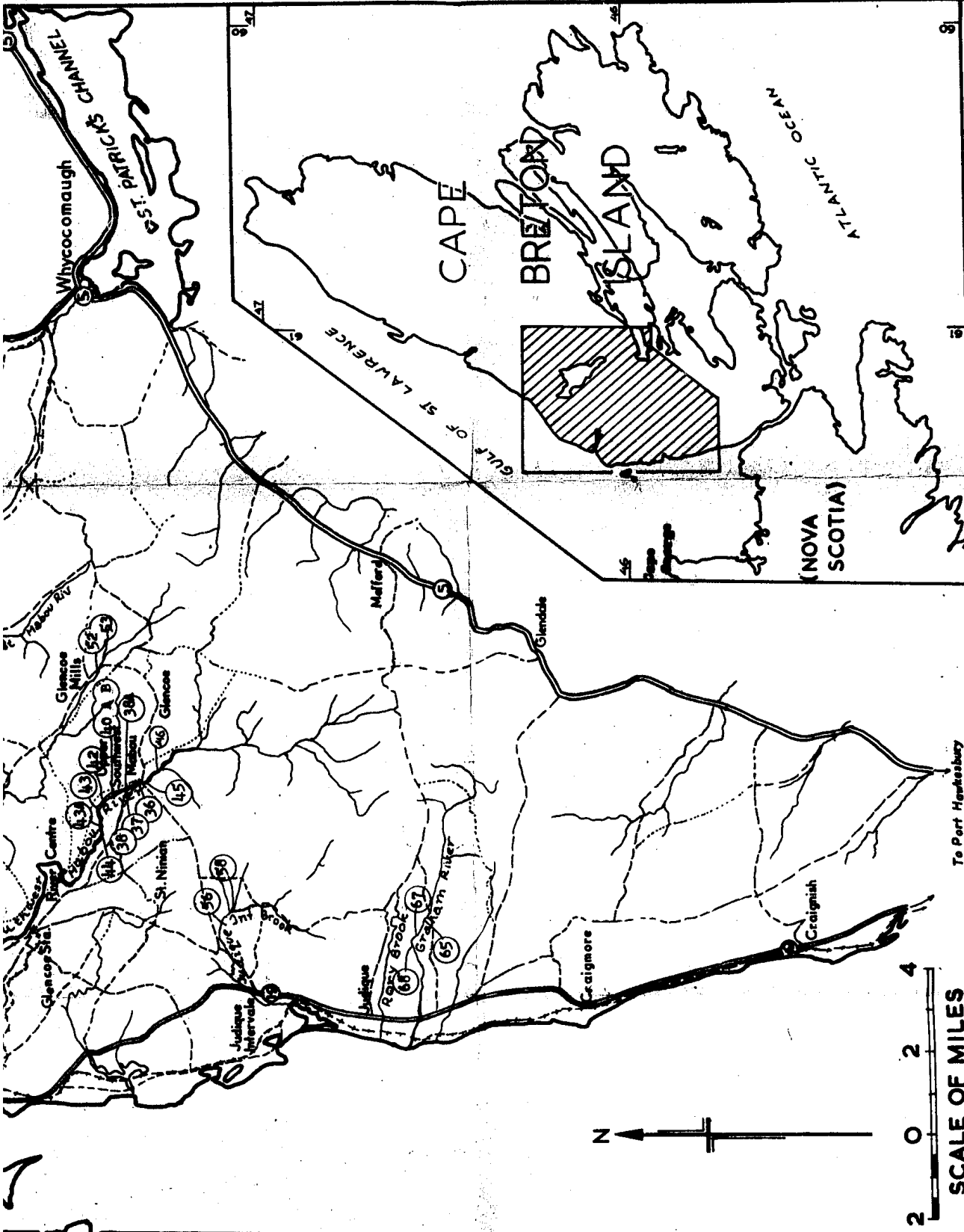
(B). Slump ball of sandstone developed in slump sheet of Location 40 (see Fig. 14), Southwest Mabou River.

PLATE XII.





(A)



(B)



WESTERN CAPE BRETON ISLAND GEOGRAPHICAL LOCATIONS

-  Paved Highway
-  Gravel roads
-  LOCATION NUMBER referred to in TEXT
-  Area covered by large map, and TEXT

INSET: CAPE BRETON ISLAND, Nova Scotia;