SEDIMENTOLOGY OF THE BRADORE FORMATION,
SOUTHERN LABRADOR, NEWFOUNDLAND

R. A. WARING

SEDIMENTOLOGY OF THE BRADORE FORMATION,
SOUTHERN LABRADOR, NEWFOUNDLAND

A THESIS SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE, MEMORIAL UNIVERSITY OF
NEWFOUNDLAND

by

©

R. A. Waring, B.Sc., Hons., (Univ. Sheffield).

Abstract

The Lower Cambrian Bradore Formation in Southern Labrador consists predominantly of cross stratified subarkoses, with thin beds of conglomerate and siltstone in the basal part.

The formation is divisible into two members; the lower, named the Blanc Sablon Member, consists of a basal conglomerate and arkosic sandstones and rests unconformably on a Precambrian basement. Intercalated conglomeratic bands are frequent in the lower beds of this member. Thick to medium bedded subarkoses in the upper beds display isolated lenticular and tabular cross bedding and abundant trough cross stratification. The upper, named the L'Anse au Clair Member, consists of thick bedded quartzose sandstones and thin bedded subarkoses containing worm burrows. Here, cross stratification is less common than in the Lower Member and is mostly lenticular.

Sedimentary textures and structures indicate that the basal conglomerate was formed by a transgression, probably during the early Cambrian. The purity of the sandstone and the form of its grains suggests deposition of material which has been acted upon for prolonged periods of time, in an environment where currents have restricted the accumulation of silt or grains under a certain size.

Burrowing structures are extremely common and together with the polymodal orientation of trough cross stratification indicates a shallow water, low energy environment for the subarkoses of the Blanc Sablon Member. The facies of the L'Anse au Clair Member represents a tidal flat or beach deposit.

This thesis has been examined and approved by,

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

LIST OF ILLUSTRATIONS AND PHOTOGRAPHS

APPENDICES

(Appendixes G (Fig. 3-1b) and H to be found in the loose leaf jacket)

CHAPTER 1

INTRODUCTION

THE SETTING

The area considered in this thesis centres around Forteau, Labrador and extends 15 miles north-eastward to West St. Modeste and 12 miles westward to Bradore (Fig. 1-1). A coastal strip 3 miles wide, with an approximate length of 45 miles, was studied more thoroughly than was the inland terrain. Ile au Bois and Greenly Island lie to the south, and are included in the investigation.

Most of the inhabitants rely on the fishing industry for a livelihood and the population is restricted to small communities situated on the coast, usually in protective bays. A few families tend the lighthouse on Greenly Island.

During the summer a ferry service operates from St. Barbe on the northern peninsula of Newfoundland, to Blanc Sablon, near the Quebec-Labrador border. Canadian National operates a coastal boat service with calls at Blanc Sablon, L'Anse au Loup and West St. Modeste. Chartered flights originate mainly from Deer Lake and provide a limited air service to Blanc Sablon and Forteau.

A rough gravel road links all the coastal communities in the area. Almost all the coastal section is readily accessible with low tide being the limiting factor. Boats are available for charter from any of the fishing villages. Inland, accessibility is extremely poor and good exposures are rare.

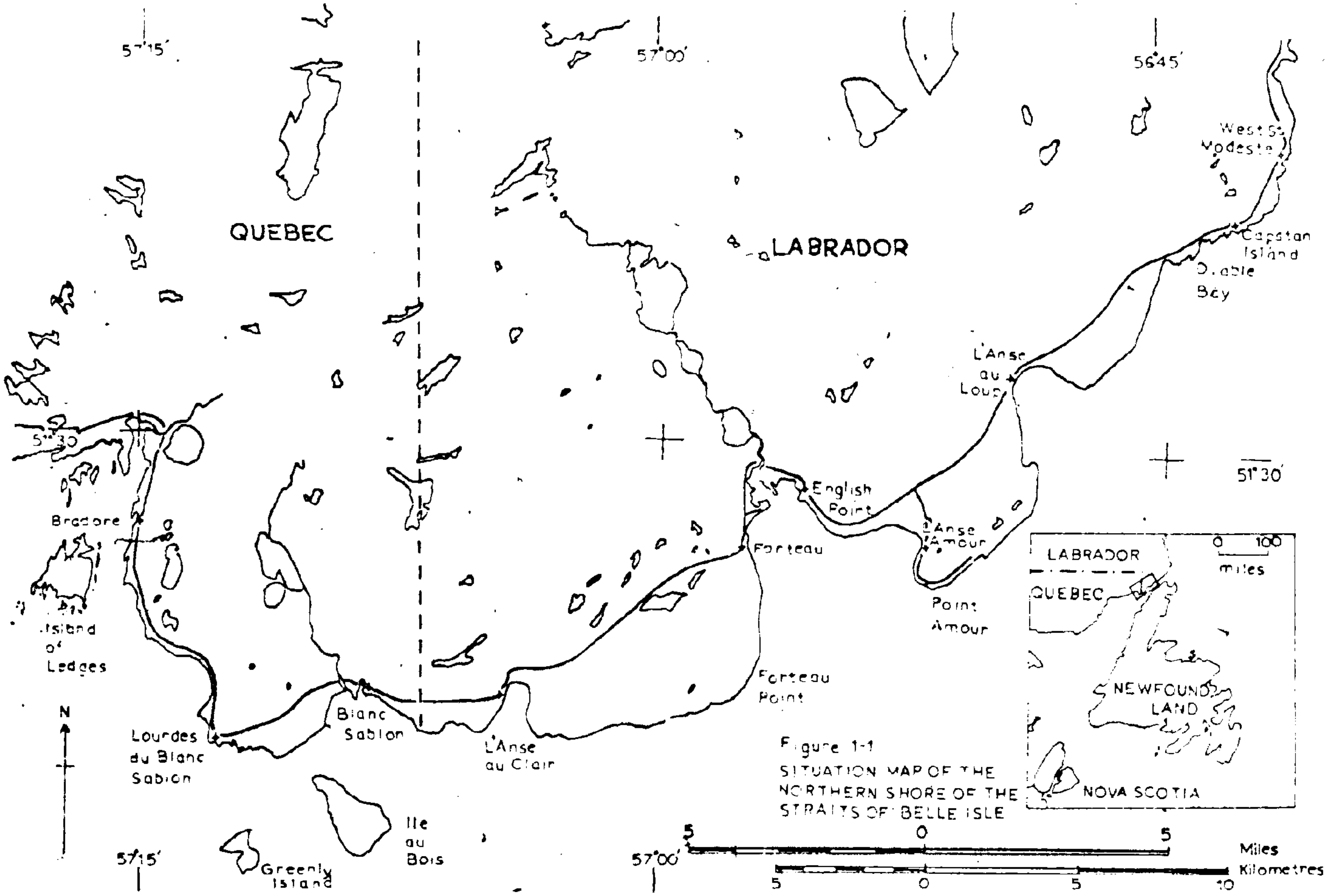


Figure 1-1
SITUATION MAP OF THE NORTHERN SHORE OF THE STRAITS OF BELLE ISLE

GEOMORPHOLOGY

Topography

The thesis area is a dissected plateau ranging in height between 250 and 1,000 feet. The region is bordered largely by coastal cliffs up to about 300 feet in height (Fig. 1-3), and by embayments at the mouth of rivers. Highlands, formed from flat-lying deposits of sedimentary rocks, are separated by low lying valleys in which Precambrian crystalline rocks are exposed. Further inland and beyond the thesis area the Precambrian basement forms very rugged topography.

Results of Glaciation

Evidence of glaciation is indicated by glacial striations, roches moutonnées, erratic boulders and valley morphology. Striae found in Blanc Sablon and further west show a south-easterly trend; roches moutonnées indicate movement to the south east. Erratic blocks of Precambrian granite can be seen in several places, for example, at Schooner Bay and north of Fox Cove. The valleys in cross section show a broad U-shape and have a very rugged floor.

Unconsolidated sediments of glacial and post-glacial origin occur in the area. The unconsolidated material, consisting of drift, peat and marine gravel, is a thin veneer largely concealed under bogs and underbush.

To the north of Blanc Sablon a remnant of a possible bay bar was observed. Initially this may have consisted of glacial moraine which formed a dam and resulted in a lake or a series of lakes and ponds.

Now the barrier, surrounded by marsh and bogland, is incomplete and crescent shaped with the focal point out to sea. The sediment shows very good rounding and was probably reworked by the sea when the latter reached further inland. Eskers can be seen nearby and these also show a seaward south-easterly trend.

Post glacial features of the area are interesting, giving evidence for both submergence and emergence. The coastline is indented with drowned river valleys which run normal to the coast. Elevated wave-cut terraces (Fig. 1-5) and raised shorelines occur and are interpreted as being the result of uplift of the coast following the removal of the Labrador ice sheet (Table 1-1), Appendix A). Grant (1969) stated that raised strand lines are present up to 500 feet above mean sea level in the region. Occasionally, elevated wave-cut terraces are more pronounced when they coincide with a continuous bed, which being both hard and resistant exerts topographical control.

Local inhabitants have reported that whale bones have been found a considerable distance inland from Blanc Sablon and Forteau, suggestive of formerly higher sea levels. They also claim that in the past a passage for boats used to exist through the centre of Greenly Island, where there is now land. Explanations for this land accumulation include oceanic current deposits, wind accretion of sand or uplift of the region caused by post-glacial rebound. This is difficult to verify as no bedrock is exposed under the sand. Large boulders were observed in the bay at West St. Modeste and are navigational hazards. However, local fishermen had been told by their ancestors that this was not always so.

In conclusion, this part of the Labrador coast exhibits features associated with a drowned coastline that has been emerging since the Pleistocene.

Drainage

The lower courses of many streams are characterised by rapids, small waterfalls and a series of ponds, suggestive of a drainage pattern in early youth. Streams draining the inland terrain west of Diable Bay frequently form small falls; larger, more spectacular falls, can be seen at the northern end of Bradore Bay, where the Bradore River drains the Precambrian Shield. Relatively large rivers in the area, namely the L'Anse au Clair and Forteau Rivers, flow into long coastal inlets and have extensive delta deposits (Fig. 1-2).

Previous Work

In 1860, Lieber made a coastal survey of Labrador, reporting little of the sedimentary sequence found in the thesis area. The following year Richardson studied and sampled (in Christie, 1951) fossils from the Cambrian strata. In 1863, Logan suggested that the sedimentary strata which crop out on the northern side of the Strait of Belle Isle were equivalent to the Potsdam group of New York. At 'L'Anse aux Blanc Sablon' he gave a thickness of 231 feet to the Bradore Formation and 143 feet to the Forteau. Logan also described

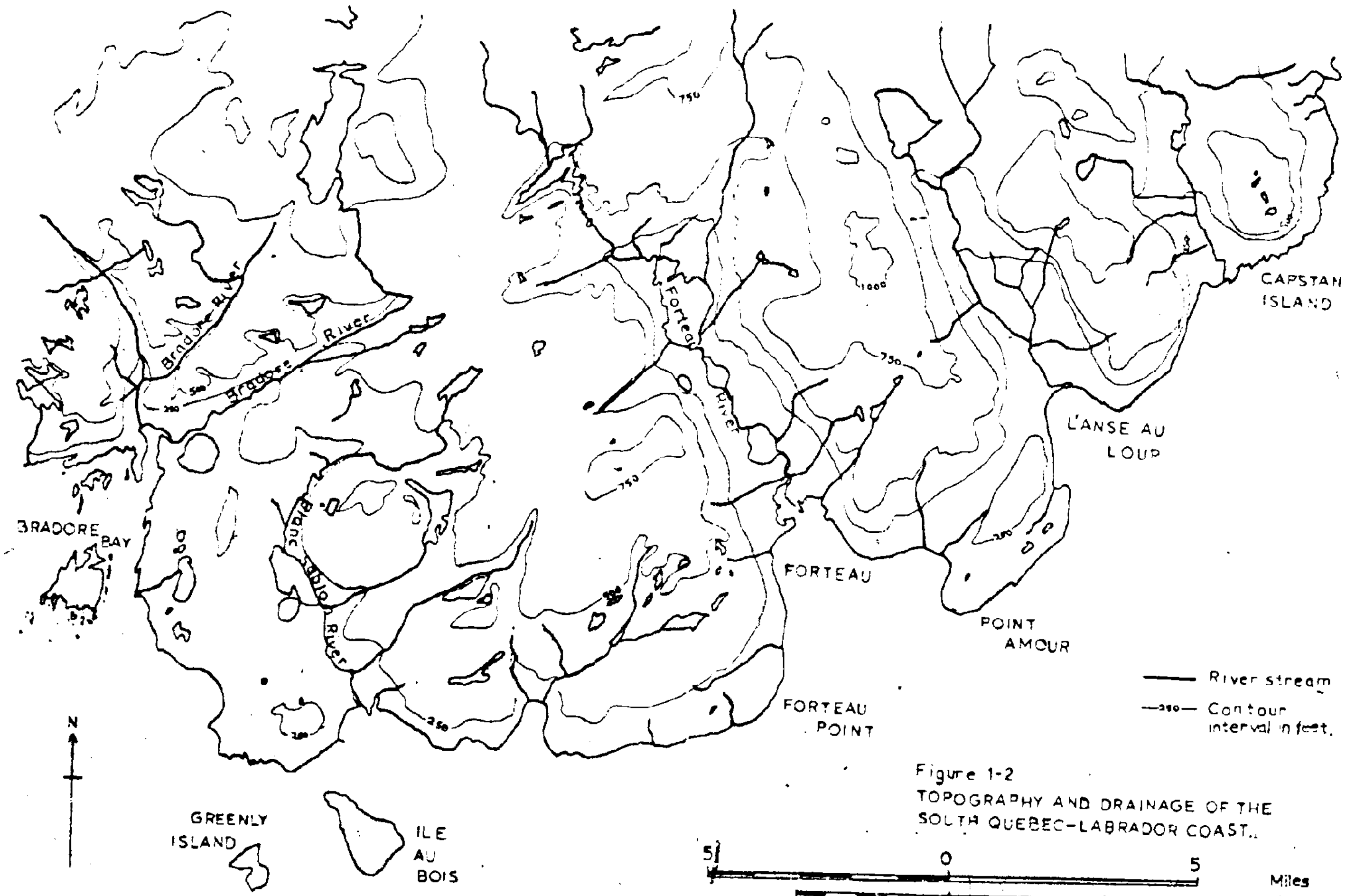


Figure 1-2
TOPOGRAPHY AND DRAINAGE OF THE SOUTH QUEBEC-LABRADOR COAST.

similar strata at Hawke Bay on the southern side of the Strait of Belle Isle. Further palaeontological work was carried out in the area by Weston in 1872 (in Christie, 1951). Bell, in 1884, made a study of the Labrador coast and considered the red coloured sedimentary rocks in the area to be of Lower Silurian age. Packard, in 1891, studied the geography of the Labrador coast and made some general geological observations. The area was visited by Daly in 1902 and ten years later by Schuchert and Twenhofel, whose collection of fossils were described by Walcott (1912). In 1920 Dunbar and Lovering carried out detailed stratigraphic studies of the Cambrian strata.

The most complete description of the regional geology was presented in a memoir by Schuchert and Dunbar in 1934, on the stratigraphy of western Newfoundland. Christie (1951) deviated little from Schuchert and Dunbar's classic description of the area, but provided palaeontological evidence of a Lower Cambrian age for the Forteau Formation (verified by the present study). He described outliers of Cambrian sedimentary strata occurring at Henley Harbour, St. Peter Islands and Table Head. He remarked that basalt present at Henley Harbour and Table Head may be related in time to deposition of the Bradore Formation.

Douglas (1953), in a very brief report of the area, mentioned that coal had apparently been seen by local residents in Blanc Sablon, Forteau and Red Bay. These alleged coal deposits were investigated and found to have been mis-identified.

In 1967, Fong made an intensive study of the Archaeocyathid-bearing Forteau Formation and briefly described the palaeontology, lithology and environment of deposition of the Bradore sandstones.

In 1969, 'Operation Strait of Belle Isle' was undertaken by the Geological Survey of Canada. D.R. Grant was responsible for studies of the Pleistocene geology, H. H. Bostock for the Precambrian gneissic rocks and L.M. Cumming for the Palaeozoic strata.

Balsam (1970) was particularly interested in the palaeoecology of the Archaeocyathids and the structure of the Lower Cambrian fossil communities.

Swett and Smit (1972) made a comparative study of the Cambro-Ordovician shelf facies of western Newfoundland, northwest Scotland and central east Greenland.

Present Study

The purpose of this investigation is to interpret the depositional and diagenetic history of the Lower Cambrian or older shelf facies on the northern side of the Strait of Belle Isle.

During the summer of 1970 field observations and measurements were made and the best exposed and most complete sections of the Bradore Formation were studied in detail. Sedimentary features, such as various kinds of cross-stratification, were noted and photographic documentation was also kept. Palaeocurrent data were plotted on rose diagrams and on a Schmidt net.

Aerial photographs at a scale of 1 inch to a mile and a topographic map at 1:250,000 were used in this study. Some local names for geographic features mentioned in this thesis are not shown on the published maps.

Examination of about fifty petrographic thin sections was undertaken together with photographic records of sedimentary and diagenetic petrographic features. Statistical analysis of petrographic detail such as composition, grain size distribution, shape and mineral alteration and other associated sedimentary features enabled environmental correlation to be carried out. Polymodal distribution of current directions, based on lenticular, tabular and trough cross-bedding in the Bradore Formation, aided in the reconstruction of the depositional environment.

X-ray diffraction was used to determine various clay minerals and to confirm the presence of glauconite. Final interpretation of the sedimentary history of the shelf facies was based upon both field and petrographic observations.

Acknowledgments

The writer wishes to express his sincere gratitude to all those who assisted in the preparation and completion of this thesis.

He is particularly indebted to Dr. A. F. King, who suggested the subject matter and under whose supervision the thesis was written, with financial support from a National Research Grant number A7052.

The faculty of the Geology Department, especially Dr. W. D. Brueckner, Dr. R. Slatt and Mr. M.M. Anderson are also gratefully thanked for their assistance.

Dr. L.M. Cumming, of the Geological Survey of Canada, his assistant S. Tella and R. Levesque, a geographer/archaeologist working in the area, are acknowledged for their help and advice in the field.

The technical and photographic staff are thanked for their co-operation.

Figure 1-3. (P. 14) Approximately 300 feet thick Bradore sandstones, conformably overlain by the Forteau Formation (extreme top of picture) East of L'Anse au Loup.

Figure 1-4 (P. 15) Raised strandlines and elevated rock benches exposed in a bay west of L'Anse au Clair Looking N.W. (Table 1-1, Appendix A, column 3)

Figure 1-5 (P. 15) Elevated rock benches in the Bradore Formation. The contact between the Precambrian and the overlying sedimentary rocks can be seen at sea level near the outer beacon light. View looking N.W. towards Blanc Sablon.

CHAPTER II

GENERAL GEOLOGY

REGIONAL GEOLOGIC SETTING

Williams (1967) divided the northern Appalachian Mountain system into three geologic provinces:- the Western Platform, the Central Palaeozoic Mobile belt and the Avalon Platform (Fig. 2-1). The thesis area is part of the Western Platform which incorporates all the terrain west of the Baie Verte-Grand Lake lineament and has an exposed basement of Grenville rocks.

The basement consists primarily of pink quartzofeldspathic gneiss (Fig. 2-7), termed 'Domino gneiss' by Leiber (1860). Pink biotite granite and sheared and foliated gneiss also occur, the latter being cut by numerous pegmatitic and aplitic veins. The gneiss passes into homogenous granite making it difficult to differentiate between the two in the field.

The Precambrian basement crops out at Blanc Sablon, and at Lourdes du Blanc Sablon, as well as in the valley floors at Forteau, L'Anse au Loup and Diable. At Bradore (Fig. 2-8) it consists of pelitic and semi-pelitic schists with a pronounced foliation dipping steeply to the east. Towards Blanc Sablon the attitude of the foliation decreases and becomes less distinctive. Kranck and Christie (1951) suggest that granitization of banded sedimentary formations accounts for the derivation of some of the rocks in the area.

Hornblende gneiss occurs to the northeast around Diable Bay and L'Anse au Loup, and is dark in colour. Betz (1939) thought that the

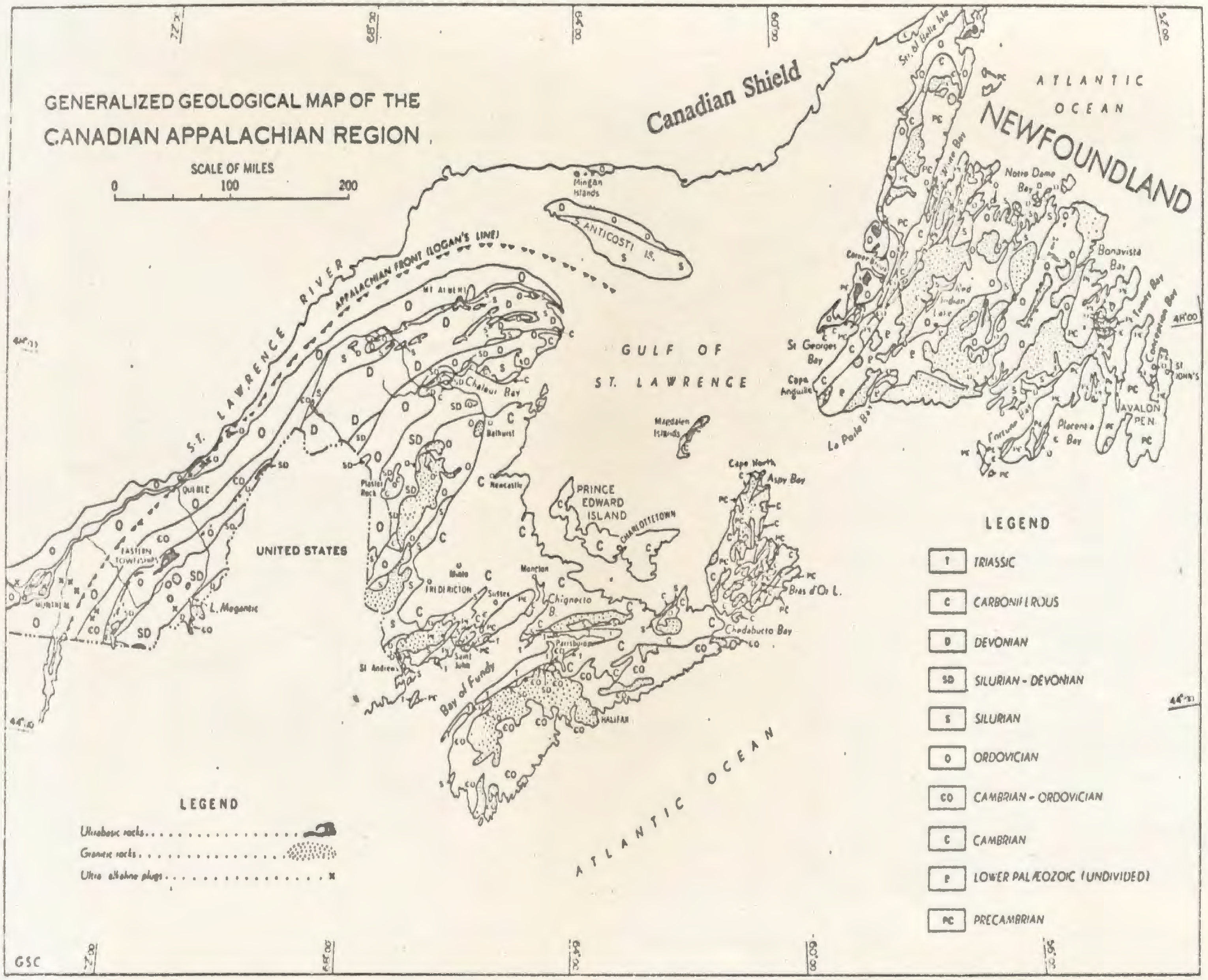


Figure 2-1 . GENERALIZED GEOLOGIC MAP OF CANADIAN APPALACHIAN REGION, (Poole,1967).

hornblende gneiss in Canada Bay was derived by metamorphism of sediments because of the high content of quartz. Piloski (1955) probably used the same logic in calling the Precambrian exposures in the thesis area 'paragneisses'.

The Lower Cambrian sedimentary rocks unconformably overlie a Precambrian basement and appear to thicken southeastward (Schuchert and Dunbar, 1934; Betz 1939). Across the Strait of Belle Isle on the northern peninsula of Newfoundland they are faulted and can be traced laterally into metamorphic rocks which probably constitute a klippe (Lilly, 1967). Local basalt flows at the base of the Lower Cambrian have been reported by Clifford (1965) in Newfoundland and by Christie (1951) and Williams & Stevens (1969) on Belle Isle, Table Head, Henley Harbour and St. Peter Island.

The flat-lying sedimentary sequence in the thesis area comprises two formations (Fig. 2-2); the underlying Bradore Formation, consisting of sandstones and conglomeratic bands, and the overlying Forteau Formation, consisting of shales and limestones. On the eastern side of Newfoundland's northern peninsula, Betz (1959), recognised a basal sandstone sequence below the Forteau Formation which he named the Cloud Mountain Formation.

The red arkosic sandstones and conglomerates of the Bradore Formation lithologically resemble the Double Mer sandstones which crop out on the north shore at Lake Melville (Kranck, 1953). The sandstones of the Bradore Formation together with the Forteau Formation have been termed the 'Labrador Series' by Schuchert and Dunbar (1934).

ERA	PERIOD	STAGE		FORMATION	DESCRIPTION
CENOZOIC	QUATERNARY	PLEISTOCENE RECENT	m.y.	-	BEACH AND RIVER DEPOSITS: TALUS, RAISED BEACHES
			1.52	-	GLACIAL DEPOSITS
UNCONFORMITY					
PALAEOZOIC	CAMBRIAN		540	LABRADOR GROUP: FORTEAU	Upper Member: REEFS WITH ARGILLACEOUS MATERIAL. CRYSTALLINE LS OCC OOLITIC Middle Member: LIMY SHALES, FOSSILIF CLASTIC LS. Lower Member: DOLOMITE AND DOL. LS. ARCHAEOCYATHID REEFS OCC ARGILLACEOUS, WITH ABUNDANT WORM TRACKS
			MINOR HIATUS		
			570	LABRADOR GROUP: BRADORE	L'ANSE AU CLAIR MEMBER: QUARTZITIC SANDSTONES THICK & THIN BEDDED BLANC SABLON MEMBER: CROSS STRATIFIED RED ARKOSE INTER CALATED WITH GREY/GREEN SILTSTONE, FREQUENTLY CONGLOMERATIC BEDS. BASAL CONGLOMERATE.
ANGULAR UNCONFORMITY					
HELIKIAN	NEO-HELIKIAN	GRENVILLIAN	935		PEGMATITES AND APLITIC DYKES, PINK GRANITE, STRONGLY BANDED GRANITIC GNEISSES AND SCHISTS

FIGURE 2-2 - TABLE OF FORMATIONS

The Lower-Cambrian Forteau Formation is named after the village where its type locality was described (Schuchert and Dunbar, 1934). It is exposed on the highlands and down-faulted blocks can be found at sea level, for example at L'Anse Amour. Fong (1967) gave a good description of these rocks and divided them into three members which are easily identifiable in the field.

The basal part consists of thinly bedded brownish weathering dolomite and dolomitic limestone (Fig. 2-14). Above this are Archaeocyathid reefs which consist of attached and fallen archaeocyathid colonies, together with fossiliferous, clastic limestones (mostly red in colour). The reefs are best developed near the present coastline (Fig. 2-16) with isolated knolls reaching up to 20 feet.

From an exposed thickness of 180 feet in the thesis area, the Forteau Formation apparently thickens eastward with a reported thickness of 386 feet in the highland of St. John (Schuchert and Dunbar 1934) and 700 feet in Canada Bay (Betz, 1939).

Faulting

Normal faults trend approximately northeast and cut both the Bradore and the Forteau Formations. One of the larger faults, named the 'Blanc Sablon Fault' (Fig. 2-17, Appendix H) can be seen just south of the hospital at Lourdes du Blanc Sablon, with the downthrown side to the north and vertical displacement of approximately 150 feet. Faults at L'Anse Amour are downthrown to the south and as a result the Forteau Formation now crops out near sea level. Numerous small displacements can be seen in the horizontally bedded strata, and can be easily traced as lineaments on aerial photographs.

A large fault, named the 'Bradore Bay Fault' trends east-northeast and can be observed in the northernmost part of Bradore Bay where it forms a distinct scarp. Cumming (1970) considered it to be one of a Precambrian set of faults. It may have been contemporaneous with Bradore sand deposition and exerted some control on the deposition of Cambrian sediments.

Bradore Formation

Name and Location

Schuchert and Dunbar (1934) named the Bradore Formation as part of the Labrador Series and described the cliffs east of Bradore Bay as the type area.

The sandstones in the thesis area form several tabular masses separated from one another by narrow valleys, exposing denuded gneiss. They are exposed along the coast, from west of the Quebec-Labrador border to West St. Modeste (Fig. 2-3) and dip gently (1-3 degrees) seaward to the southeast.

The Bradore Formation has been subdivided by the author into:-

(1) a Lower Member named the Blanc Sablon Member, which includes a basal conglomerate, thin interbedded siltstone and conglomeratic beds, with overlying red arkoses, and

(2) an Upper Member named the L'Anse au Clair Member, with mainly quartzose sandstones and subarkoses.

The boundary between the two members is transitional.

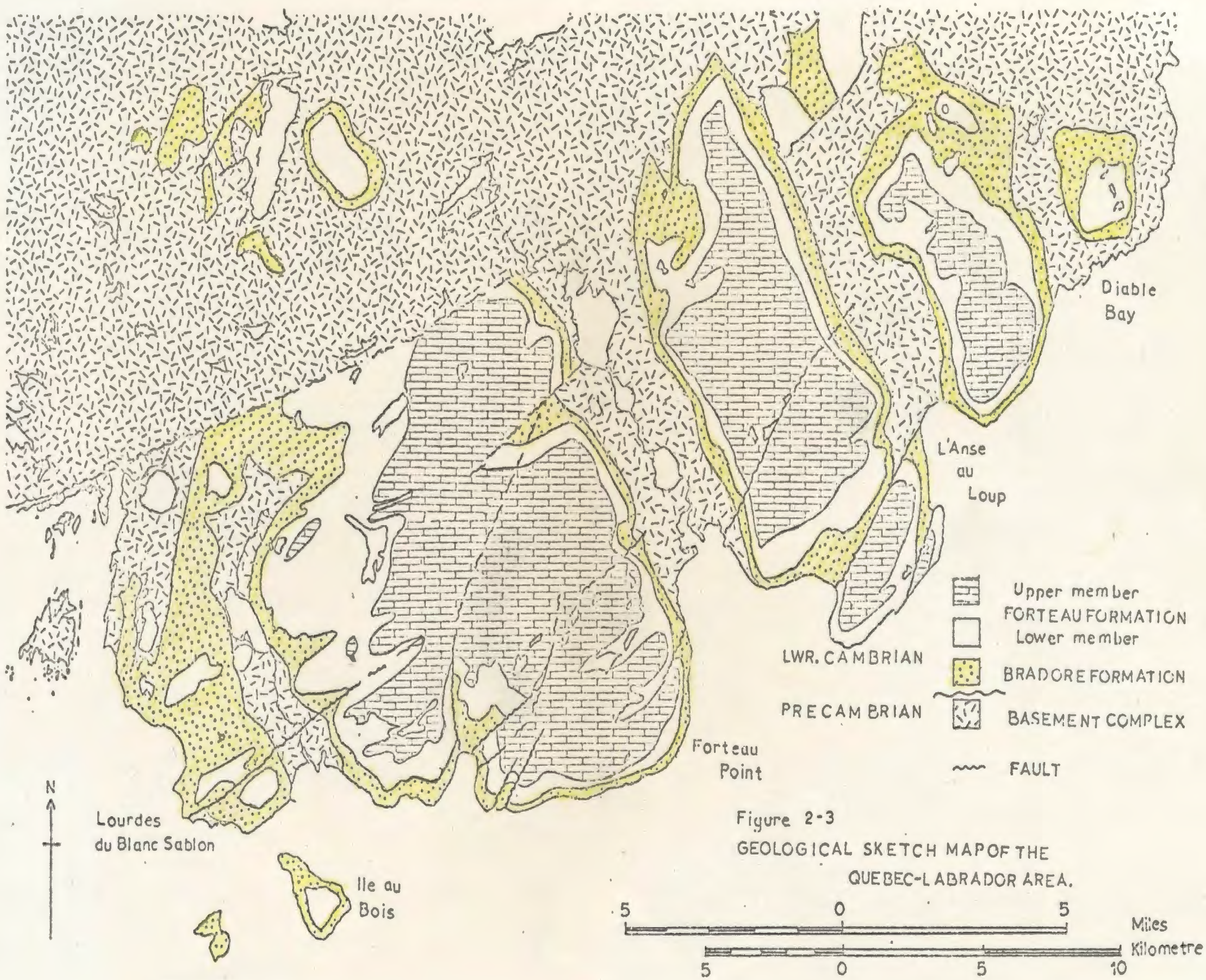


Figure 2-3
GEOLOGICAL SKETCH MAP OF THE
QUEBEC-LABRADOR AREA.

Stratigraphic Thickness

The Bradore Formation thickens from 220 feet in its type area to approximately 400 feet at Diable Bay. A comparable thickness of 300 to 400 feet has been reported from Belle Isle (Williams and Stevens, 1969); the equivalent Cloud Mountain Formation of Canada Bay has been given as 585 feet (Betz, 1939) and an apparent maximum thickness of 2,000 feet is revealed in the islands east of Cape Bauld (Tuke, 1968). The general geometry of the formation is a wedge of sandstone, thickening both east and north eastward (Fig. 2-4).

Outliers of sediments, possibly of Cambrian age, occur inland beyond the ten miles average width of the main outcrop. Some can be seen in aerial photographs to be associated with lineaments, assumed to be faults, which bring up sediments against basement. The sedimentary sequence was therefore probably preserved by being downthrown relative to the Precambrian. Other occurences are at Henley Harbour, St. Peter Islands and Table Head, all further north along the Labrador coast (Christie, 1951). No evidence was found to indicate a westward thickening wedge and the outliers are likely to indicate the proximity of the coastline during deposition.

Contact Relationship and Age

The lower boundary between the Bradore Formation and the crystalline basement is sharp and best exposed southeast of Blanc Sablon (Fig. 2-9 and 10). Fossils have not been found at this level but however the noteworthy relief on this contact surface indicates the Blanc Sablon Member to be of Lower Cambrian age.

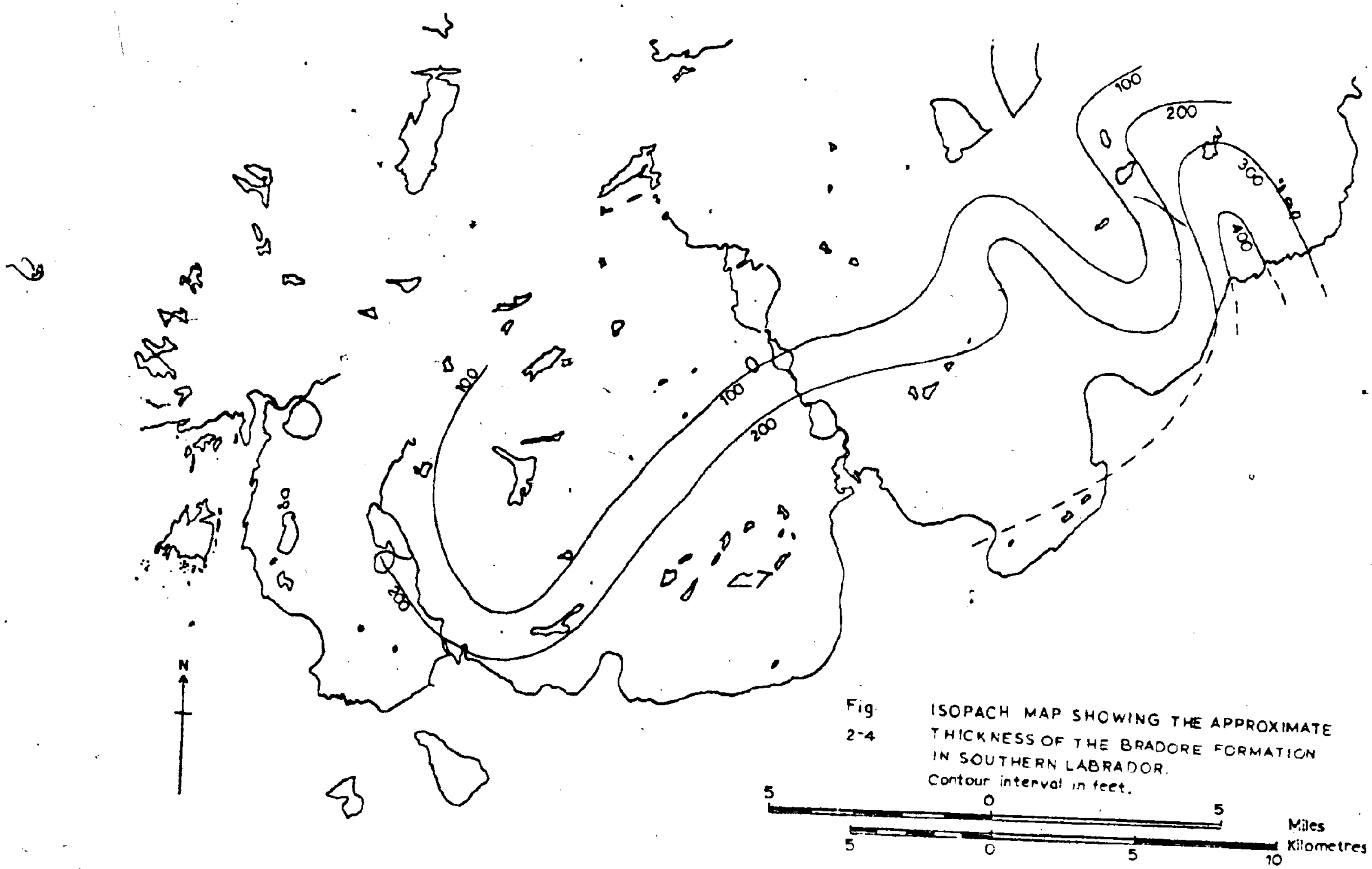


Fig. 2-4 ISOPACH MAP SHOWING THE APPROXIMATE THICKNESS OF THE BRADORE FORMATION IN SOUTHERN LABRADOR.
Contour interval in feet.

The arkosic sandstones of the Blanc Sablon Member and the overlying quartzose sandstones of the L'Anse au Clair Member show a transitional boundary with no erosional break (Fig. 3-1b, Appendix G).

At Blanc Sablon (Fig. 2-14) the upper contact between the Bradore sandstones and the overlying limestones is sharp and separated by a thin band of conglomerate, possibly indicating a disconformity, and marks a minor depositional break. Frequently interbedded with the conglomerate are lenses of fine grained, argillaceous sandstone (Fig. 3-23). The conglomerate was observed in a cliff face directly east of Blanc Sablon but appeared better cemented on the southern tip of Schooner Cover. Elsewhere in the thesis area erosion and vegetation obscure the contact. On Belle Isle a conformity or slight disconformity has been reported between the Bradore and Forteau Formations (Williams, 1969), suggesting deposition of sands followed by lime muds with probably little, if any, break for uplift and erosion.

Blanc Sablon Member

Basal Conglomerate

The basal bed is a greyish green, coarse conglomerate, with an observed maximum thickness of 27 inches at Blanc Sablon and a mean thickness of 4 inches. The conglomerate consists mainly of pebbles of quartzite with lesser granite, gneiss and chert. All are very well rounded. The ground mass is grey in colour and made up of 80 to 90 percent quartz, with smaller amounts of feldspar, mica and occasional magnetite, bound together by a siliceous cement. Feldspar is predominantly orthoclase, varying up to one-half inch in diameter;

it often shows good rounding, although is frequently fractured along its cleavages.

In one locality, just east and below the outer beacon indicator at Blanc Sablon, the basal bed is a loosely consolidated conglomerate, dark red in colour due to secondarily formed ferric oxide. Magnetite and hematite are both fairly abundant in the matrix. The pebbles are mostly quartz and quartzite, a number of which display three faceted surfaces (Fig. 2-12). They are slightly rounded and polished. The surfaces are dull and slightly pitted. Distinct edges between adjacent facets run from the apex to near the basal face, on which facet they become more rounded and smooth.

Origin of the Basal Conglomerate

The almost flat and extensive pre-Bradore topography was probably formed as a result of prolonged weathering and erosion in a marine environment. Evidence of a strong reworking is given by the well rounded quartz and the disintegrated feldspar. Under marine conditions circulation of water during rock decay resulted to some extent in leaching of the upper parts of the granite gneiss complex.

Formation of a 'pebble sheet' of material, resting on the bedrock continued until waves and currents were unable to transport the larger particles. This may have been caused by land subsidence and subsequent deeper water conditions, for a covering of finer material is present above the coarser pebble band. In a normal transgression of sea over land the trend is for sediments to gradually decrease in size on ascending the succession. However, minor regressions must have occurred after the first deposition of sand to give repetitive horizons of conglomeratic bands in the lower beds.

The faceted pebbles may be explained as wind abraded ventifacts or dreikanters, which formed from individual pieces of rock, broken off by mechanical weathering, but too heavy to be transported by the wind. Alternatively, a rectangular or rhombohedral pattern in the source area could have influenced the formation of faceted pebbles, although, the ones observed did have rough basal surfaces and considerable rounding along their edges, (Fig. 2-12).

The types of quartz and quartzitic pebbles found in the quartzo-feldspathic groundmass do not indicate a definite source or environment as irregular deposition of both rounded, egg-shaped and fragmental, angular pebbles has occurred.

A variable thickness of pebble sheet could possibly occur from shifting of the actual weathering products before and during deposition. This could have been affected in some areas by aeolian, fluvial and other continental transportation processes prior to transgression which, together with the absence of finer materials may well imply that the weathering gravel was thicker than is now represented by the basal conglomerate.

Arkosic Sandstones

The arkosic sandstones of this member are exposed throughout most of the area with good sections observed on the eastern side of Bradore Bay, near the contact with the Precambrian basement, and in the coastal cliffs at Blanc Sablon.

The arkosic sandstones are fine grained (Wentworth scale) immediately above the basal conglomerate (Fig. 2-11). One or two feet higher up the succession, gravel size layers occur and the size range is more variable (Appendix D).

Arkosic sandstones containing abundant relatively fresh pink feldspar grains are common, with frequent and extensive thinly bedded conglomerates. Intercalated with these conglomeratic bands but relatively rare, are grey and greenish coloured siltstones, which present the only abundant argillaceous material throughout the formation. They are comprised of quartz and feldspar, together with muscovite, sericite and frequently an abundance of kaolinite. The lower beds with abundant cross stratification differ from the thicker bedded, (i.e. up to 4 ft) more quartzose sandstones, higher up the succession.

The high concentration of relatively fresh feldspar in the beds immediately above the basal conglomerate may be interpreted as being derived from a proximal source or an indication of slight chemical weathering, such as in an arid environment. Quartz grains, if wind blown and in an arid climate would become well rounded.

The arkoses formed during the transgression of the Cambrian sea by the washing and sorting of the weathering products which covered the land surface. This resulted in a marked roundness of quartz grains and the lack of fine grained argillaceous material. A strong current would not favour deposition of small sized grains, except where the basal coarser materials have to some extent protected the lower parts from extensive reworking to give thin siltstone beds. The lower beds were probably formed on an open shore, where waves could freely rearrange the weathering products. The rarity of clay minerals could also be explained by assuming an arid environment in which they would quickly be broken down into powder and winnowed away (Holmes, 1965).

L'Anse au Clair Member

Arkosic-Subarkosic Sandstones (Folk, 1968)

The sandstones gradually become generally less arkosic and with less well developed cross stratification, (Fig. 3-1b, Appendix G). This vertical transition from arkose to subarkose can be followed in most places. Higher in the succession notable differences include an increase in roundness, better sorting, and a decrease in feldspar content. Probable worm burrows, common in the more arkosic beds, are rare in this member.

The sandstones tend to be white, hard and frequently quartzitic, (Fig. 2-13), although lateral variations do occur. Locally between L'Anse au Clair and Forteau, a fine grained, (Wentworth scale) pink arkose laterally passes into a white quartzitic sandstone. This change can only be observed at this locality in the topmost bed, which immediately underlies the Forteau Formation and elsewhere the topmost bed is consistently coarse grained.

Quartz, both primary and secondary, is dominant. The latter may be in such abundance that pores are completely filled, forming an interlocking texture. Feldspar is almost totally microcline. Glauconite is present mostly in the topmost bed immediately below the Forteau Formation, together with small quantities of chlorite and accessory minerals.

In several localities a calcareous and/or dolomitic cement is present in the sandstones. Its restricted occurrence in the beds immediately below the Forteau Formation suggests it formed by percolating water from stratigraphically higher limestones.

Origin and Formation

There are several probable explanations for the vertical and lateral changes in lithology:- a different source area or a more protected part of the shore could well account for lateral change; a transgression may cause vertical gradation.

Beds of uniform thickness (1-4 ft), with little variation in grain size (Appendix D), suggest that currents did not undergo strong changes characteristic of many open shore regions. Uniform sandstone thickness and extensive distribution (from 220 ft at Bradore to 300/400 ft on Belle Isle) could be due to a pre-Cambrian land surface which was strongly denuded, forming a flat peneplane with localised thickness and lithological variations caused by nondeposition, relatively excessive deposition or erosion and reworking.

The relative lack of feldspar (less than 10%) in the sandstones compared to the lower beds could indicate prolonged chemical weathering and erosion, or winnowing by currents. Deposition during this current activity as indicated by cross stratification would result in the majority of feldspar being broken down and washed away, so that the low proportion of microcline perhaps gives little indication of the feldspar content of the provenance.

The composition and lithological changes in these higher beds from the Lower Member, together with less abundant worm burrows would appear to indicate deposition at slight depth but mainly below the littoral zone.

Ichnofossils

Little is preserved of organic life from depositional times. Numerous vertical cylindrical or pipe-like structures in the sandstones (Fig. 4-17 & 19) have been referred to by many authors as the trace fossils, Skolithos linearis (Schuchert and Dunbar, 1934). Hallam and Swett (1966) in describing trace fossils from the lower Cambrian Pipe Rock in the north-west Highlands of Scotland interpret similar sediment plugged tubes as being attributable to suspension-feeding (or possibly deposit-feeding) organisms. Other writers have made modern analogies and also inferred them to be worm or phoronid burrows (Richter, 1927) although the structure gives no proof of organic origin (see Chapter IV).

The trace fossil Scolithus errans was observed, preserved in abundance on bedding planes, in the uppermost beds of the Bradore Formation at Lourdes du Blanc Sablon (Fig. 4-20).

Figure 2-7. Precambrian granitic gneiss displaying foliation and boudinage, Blanc Sablon.
(P. 24)

Figure 2-8. Steep eastward dipping foliation of Precambrian schists and gneisses. Bradore Bay.
(P.24)

Figure 2-9 (P.31) The Bradore Formation overlying the Precambrian basement (foreground) with unconformable contact at Blanc Sablon.

Figure 2-10 (P. 31) Unconformable contact between basal conglomerate and underlying Precambrian gneiss. Blanc Sablon.

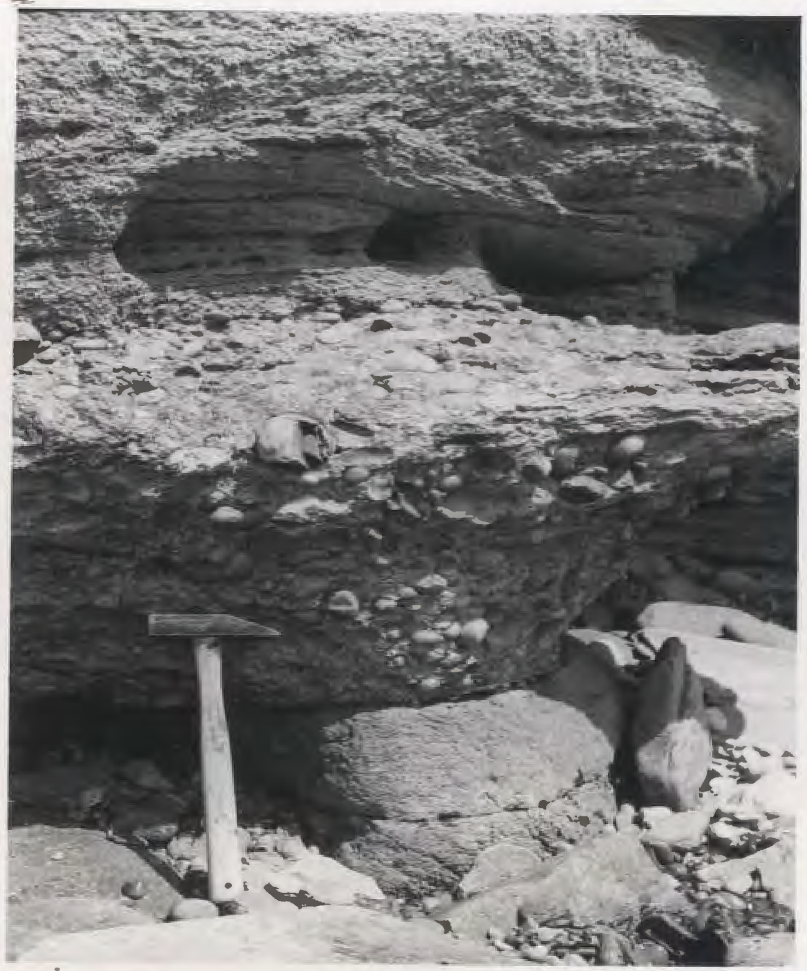


Figure 2-11.
(P. 36)
Basal conglomerate of the Bradore Formation overlain by fine grained, weathered sandstones, siltstones and conglomerates. Blanc Sablon.

Figure 2-12. (P. 35) Faceted pebbles from the basal conglomerate at Blanc Sablon.

Figure 2-13. (P. 37) White coloured, hard quartzose sandstone of the topmost bed in the Bradore Formation. Cross stratification can be seen in the block in the foreground. Overlying this thick resistant bed, the Forteau Formation is poorly exposed due to undergrowth. L'Anse au Clair.

(b)

(c)

Figure 2-14 (P. 33) (a) Disconformable contact between the Forteau Formation and the underlying Bradore Formation, exposed at Blanc Sablon. (b) Note the basal dolomitic beds of the Forteau Formation.

Figure 2-15 Rectangular jointing pattern exposed in the lower Forteau Formation at Point Amour Lighthouse.

Figure 2-16 (P.28) Archaeocyathid reef exposed at Point Lighthouse. Note transition to thinner bedded shales and limestones at base and sides of reef.

CHAPTER III

PETROLOGY OF THE BRADORE FORMATION

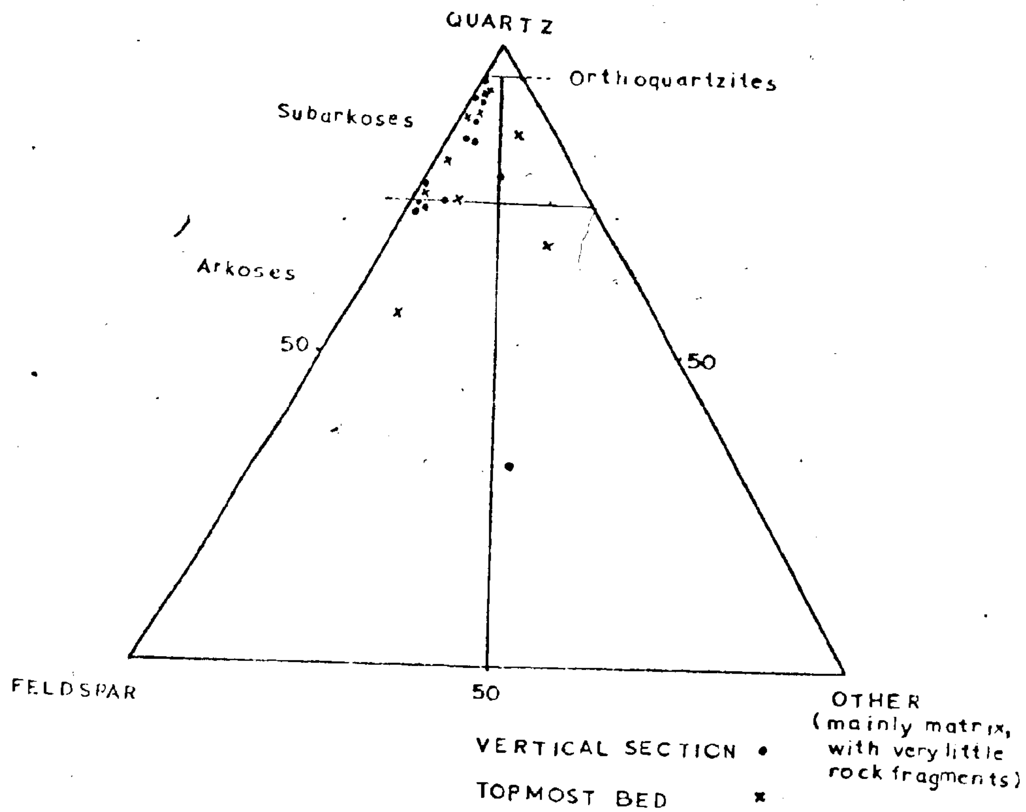
Sampling and Procedure

Rock samples were taken throughout the Formation and their stratigraphic locations are shown in Figures 3-1a and 3-1b (Appendix G) Fifty thin sections were cut and studied petrographically in order to determine both vertical and lateral changes in lithology. Analysis of composition was made by traversing across a slide and counting 1,000 points on an automated point counter at certain intervals. These were determined in order to take into account as much of the slide as possible. Size measurements were determined for 100 grains from each slide. For each grain the largest diameter (the 'A' - diameter) and the maximum diameter perpendicular to this (the 'B' - diameter) were noted. Measurements taken were established into reasonable groups to facilitate subsequent evaluation. Conversions to the phi scale were made in order that comparisons with standardised models could be made.

Fifty randomly quartz grains were studied in each thin section for determination of roundness. A similar number were used in the determination of quartz composition. A final depositional and diagenetic interpretation was based both on visual observation and comparison of table and graphic characteristics to standardised models.

Plagioclase visually appeared to be absent and was subsequently proven so by a feldspar staining technique, based upon the method described by Bailey and Stevens (1960). The test was therefore only completed on three samples, two from the basal beds and one from the

Fig.3-2. COMPOSITIONAL DIAGRAM OF THE BRADORE FORMATION.



The above descriptive classification has been plotted using the results in Table 3-1, Appendix D. Triangular plot after Folk, 1968.

topmost bed of the Bradore Formation. All proved to be negative.

The identification of clay minerals was made by X-ray diffraction on two samples. One from the topmost bed (20/505) to prove the presence of glauconite, which is difficult to differentiate from chlorite under the petrological microscope. The other came from the basal beds (15/437) and was taken for specific identification. Each sample was crushed and put into suspension with distilled water. Fractions were then pipetted onto glass slides and air dried to give orientated aggregates. In drying, particles settle down in a preferred orientation to give better instrument readings.

Mineralogy

The dominance of quartz (Table 3-1, Appendix D) is due to the source material for the Bradore Formation being derived from the basement complex of granite and granitic gneiss. Feldspar is second in abundance and occasionally predominates over quartz. The most common form of feldspar occurring in these pink arkoses is microcline.

Other minerals present can be classed as accessory components, with the exception of secondary dolomite and calcite, which occur in the topmost beds. Accessory minerals may be significant in the determination of their place of origin.

Quartz

Methodology

Blatt and Christie (1963, pp. 560-564) in their review of quartz classifications concluded that to subdivide undulatory quartz, on the basis of noting extinction by the angle of rotation on a flat microscopic stage, is insignificant in that it only gives a two dimensional extinction; three dimensional extinction can only be determined on a universal stage. In this investigation their classification of three basic types was used:

1. Non-undulatory quartz in which the crystal goes into extinction upon very slight rotation of a flat microscopic stage.
2. Undulatory quartz, where the grain shows variation of either extinction angle or interference colour.
3. Polycrystalline quartz, which consists of more than one quartz crystal unit, with different optical orientations.

Observations

The location of samples taken throughout the Bradore Formation is shown in Figure 3-1b (Appendix G). The quartz content of all samples taken averaged 77.5 percent. For the topmost bed, immediately underlying the limestone sequence, the average percentage of non-undulatory quartz in the total quartz is 80 percent compared to 53.8 percent for samples taken throughout the vertical stratigraphic succession (Table 3-2, Appendix D). These values appear unduly high (cf. Blatt and Christie, 1963, page 569) and may be due to the difficulty in distinguishing differences in interference tint, when the two axes c and c' have the same trend in thin section but different angles of plunge. A trend can be observed in Figure 3-3, where the basal beds of the Lower Member have a higher percentage of undulatory quartz which is reversed higher up the succession where a greater amount of non-undulatory quartz is present.

The following comparison of the topmost quartzitic sandstone of the Bradore Formation and the orthoquartzites of the Potsdam sandstone of New York (Blatt and Christie, 1963, page 577) can be made on the basis of percentage of quartz types:

Sandstone	Non-undulatory	Undulatory	Polycrystalline quartz
Potsdam	80.0	19.0	1.0
Bradore	80.3	19.0	0.7 percent

Inclusions of feldspar, apatite and other accessory minerals were observed in some of the quartz grains of the Bradore Formation.

Interpretation

Folk (1956) and Potter and Pryor (1961) concluded that chert and polycrystalline quartz are rare in orthoquartzites. This is true of the sandstones examined in the present study. Blatt and Christie (1963) observed a relationship between polycrystalline and non-undulatory quartz and stated that with an increase in 'mineralogic maturity', polycrystalline grains are more readily eliminated than monocrystalline grains.

Blatt and Christie (1963) refer to the differences in stability of the three types of quartz grains and observe that they may be correlated with the amount and type of transport the grains have undergone, or the number of sedimentary cycles through which they have passed. The mineralogic and textural maturity of the quartzites from the Bradore Formation, derived from the immediate underlying Precambrian basement, therefore suggest that probably more than one cycle has occurred for the Bradore sandstones. The more likely alternative is that prolonged transport and/or washing has taken place.

Conolly (1965), studying quartz types in sandstones, observed that with a decrease in grain size there is a corresponding decrease in polycrystalline quartz content. When this is low the amount of undulatory quartz also tends to be low. Both these facts agree with the present study. He states that sandstones near the base of a succession have percentage compositions of quartz types that approximate the source rocks and acknowledges the fact that post deformational effects can influence formation of undulatory quartz. He concludes that to determine origin and transportation mode, a knowledge of the constituent quartz types is necessary.

In the case of the Bradore sandstones the underlying complex, with its deformational history, contains a high proportion of undulatory quartz. Assuming that the Bradore Formation has not undergone any deformation which could affect quartz type, the topmost, thick bedded sandstones are more mature than the underlying sandstones. Both the fine grain size in these beds and the dominance of non-undulatory quartz indicate their probable depositional environment. It seems fair to conclude that either the length of time during which transportation occurred has increased or a more vigorous environment was present, or a combination of both.

Feldspar

Detrital feldspar is common in the sandstones throughout the formation and both visual absence of plagioclase and subsequent analysis by staining reveal this to be all K-feldspar (orthoclase and microcline). The abundance of feldspar in this basement complex results in a high feldspar content in the lower parts of the Bradore sandstones. The unusual high feldspar content (17.35%) in the topmost bed of the Upper Member (Table 3-1, Appendix D) either signifies a different source area or probably sand deposition under fairly quiescent conditions (Re Origin of Quartzose Sandstones, page 38).

Mica, Chlorite and Clay Minerals

Detrital grains of muscovite and chlorite, were observed in the sandstones as minor constituents (Figure 3-19). An exception was observed in the basal beds where the feldspars appear to have been kaolinised and muscovitised.

Two fractions from a basal sample were taken; one was heated at 550^{o}C. for one hour and the other was treated with ethylene glycol vapour for twelve hours at 60^{o}C. Diffraction patterns were run and revealed both strong 7 and 10 A peaks. With heat treatment, it could be seen that the 7 A peak had collapsed with no subsequent formation of a 14 A peak. This was identified as kaolinite (Molloy and Kerr, 1961). The 10 A peak appeared unaffected and supported petrological observation of the abundance of micaceous material. No change was observed with the glycolated sample.

A sample from the topmost bed gave a strong basal reflection at 10 angstroms (A), typical of glauconite and micaceous material. Very little of the latter was observed petrologically in this sample and thus the 10 A peak is unlikely to be that of the illite group. Green coloured pellets were initially presumed to be glauconite and the above data supports this. Heat treatment was applied for one hour at a temperature of 550°C. and the sample was rerun. The results showed no change either in intensity or movement of the 10 A peak. The introduction of a 14 A peak, with a disintegration of a former 7 A peak, was identified as chlorite.

Accessory Minerals

Small amount of tourmaline, epidote and rutile are present in the sandstones. The subhedral form and occurrence of rutile suggests that it may be authigenic as well as detrital. One of the basal samples (15/435, Table 3-1, Appendix D) contained abundant reddish brown coloured needles of rutile (Figure 3-20), together with opaque minerals and was probably formed during diagenesis. Apatite and zircon occur frequently as inclusions in quartz grains.

Zoisite was notably common in one sample comprising approximately 5 percent, and was probably derived from crystalline schists or from saussuritization of lime soda feldspars (Milner, 1962).

Opaque minerals which occur throughout the sequence were identified as mostly magnetite and hematite. Oxidation of the latter is the likely cause of the red colour staining which is abundant in these sandstones.

Calcite and dolomite are present in the topmost bed as pore filling replacement cement of post depositional origin. In thin section both appear relatively pure.

Textural Analysis of Sandstones

Analysis of Size Parameters

Cumulative curves were constructed using the percentage values obtained from the measuring and grouping of the maximum 'A' diameters of the quartz grains (Figs. 3-4 a-f). The curves are mostly normal indicating a unimodal size distribution from which various parameters can be calculated. Frequently complicated variations arise in the form of bimodal distribution (Fig. 3-4a) where a coarser fraction is present. This could be caused by a slight increase in transportation power and subsequent deposition of a coarser layer of material. However, if both modes were homogenous, rearrangement of material during deposition could not have been completed, otherwise a constant supply of coarser grains was present. If in close proximity to a shore line, the coarser material could be fairly evenly washed out into deeper water under certain conditions (Hadding, 1929, p.13). Deposition of coarse together with finer sand grains could be caused by the latter being carried by the larger grains or dragged along in their wake (Ibid).

The medium diameter differs considerably from the graphic mean for most samples (Table 3-3, Appendix D). Folk and Ward (1957) suggest that the median should be ignored as it is only deduced from one specific point on a cumulative curve; therefore, in this study graphic mean is used in the plotting of scatter diagrams.

The basal beds of the Lower Member are of larger grain size than those higher up the succession; a vertical profile can be seen in Figure 3-5a, and tabulation of data in Table 3-3, Appendix D. This trend is significant of a transgression with maturity increasing on going up the succession; the upper beds were thus deposited further away from the source area.

The average graphic mean for all thin sections measured was 0.6931 Ø which is classified as coarse sand on the Wentworth scale. The topmost bed has an average of 0.9979 Ø which can almost be termed medium sand, and samples taken throughout the vertical succession (Fig. 3-1b, Appendix G) have an average of 0.3881 Ø, much coarser sand. Individual samples range from -0.8667 Ø (very coarse sand) to 2.2167 Ø (fine sand).

Along the coast section the sandstones in the topmost bed show a vague decrease in size toward the east (Fig. 3-6c) which is probably again related to distance from source; current studies and subsequent determination of vectors tend to support this relationship. Size values become more meaningful for subsequent interpretation when utilised for construction of scatter plots against other parameters. Comparison of minimum and maximum grain diameters was not made as it is thought to be of little significance.

Formulae used are listed in Appendix C.

Standard Deviation

Folk and Ward (1957) suggested that their formula for inclusive standard deviation gives a more accurate overall picture of sorting. The scale for this ranges from under 0.35 (very well sorted) to over 4.00 (extremely poorly sorted). Using this classification, the Bradore sandstones are classified as moderately sorted with a mean value of 0.6636 and the topmost bed (0.5246) is better sorted (Fig. 3-22) than samples taken from throughout the vertical stratigraphic succession (Fig. 3-1b, Appendix G) which give a value of 0.8025. Vertical and lateral trends can be seen in figures 3-5b and 3-6b. Better sorting and less variability occurs from west to east whereas vertically, basal beds formed at the commencement of the transgression, are fairly well sorted but give way to poorer sorted, intermittent periods of deposition. These in turn give way to slightly better sorted material higher up the succession.

Mean Size versus Standard Deviation

Folk and Ward (1957) state that scatter bands often develop some part of an M shaped trend. Best sorting occurs in the topmost bed (Fig. 3-7) with a minimum of best sorting which coincides with the prominent mode. This occurs at approximately 1 Ø and a possible secondary mode at 0 Ø. Samples from the vertical section reveal two more distinctive modes: a coarse one at -0.30 Ø, and a finer one at 1.30 Ø. Where the two become mixed the sorting deteriorates and highest deviation values of over 1.00 are recorded.

A vague suggestion of a third, much finer mode, for the topmost bed may be present at 2.4 Ø.

Skewness

Using Folk and Ward's derivation and expansion of Inman's measures of skewness, a normal curve has a value of 1.00 and absolute limits of the scale become -1.00 to +1.00. If positively skewed the sample is imbalanced with the presence of excess fine material and vice versa when negatively skewed.

The mean value for the Bradore sandstones is -0.10, making them nearly symmetrical in size distribution. No significant trend can be seen either throughout the vertical succession or in the topmost bed (Fig. 3-5c). Laterally there is a trend in the sandstones to become more positively skewed going from southwest to northeast (Fig. 3-6a).

Mean Size versus Skewness

The majority of the samples from the topmost bed provide a normal curve (Fig. 3-9a and 3-9b), with a few exceptions of negative skewness resulting from the presence of a coarser fraction. The vertical sequence gives a more random distribution due to a larger quanity of coarser material being present. No definite trend can be observed in the latter.

Standard Deviation versus Skewness

The topmost bed can again be differentiated from the vertical succession by means of the scatter diagram (Fig. 3-10). Samples from the former tend to accumulate round the normal curve line for skewness (i.e. 0.00) and have the best sorting. Samples taken throughout the vertical succession of the Bradore Formation reveal a more dispersed grain size distribution which is slightly negatively skewed.

Kurtosis

The distribution of graphic kurtosis values is nearly normal, with a mean of 1.047 (corresponding to K_g, = 0.511). The range of values is from 0.800 to 1.401, with approximately equal frequencies of platykurtic and leptokurtic samples.

Standard Deviation versus Kurtosis

Scatter points tend to cluster around the normal curve value for kurtosis (i.e. 1.00) and the only differentiation is again based on sorting (Fig. 3-11).

Skewness versus Kurtosis

The majority of samples, taken from both the vertical sequence and laterally along the topmost bed, form scatter points which fall within the limits of a normal curve (Figs. 3-12a and 3-12b). Therefore, they have symmetrical distribution and can be seen to be slightly negatively skewed.

Methods of Moments

A more exact method of obtaining statistical parameters is the computational method of moments, in which results are affected by the distribution over every part of the cumulative frequency curve and not just by specific ranges taken between certain points. Determination of these was carried out by the setting up of 1 phi classes and computing moments on the basis of Griffith's procedure (1967) as shown in Figure 3-13. Values were then listed (Table 3-4, Appendix D) and plotted as a check on graphic parameter diagrams.

Form of Grains

Roundness

Grain shape in thin section was compared visually to standard photographic charts by Powers (1963). This procedure was preferred to Krumbein's (1941) because of its quickness and simplicity. A perfect sphere has a value of 1.0, with most sand grains having roundness values of 0.3 to 0.4. Disadvantages in the method include personal prejudice and determination of the original grain boundary if authigenic material is present.

Results were listed (Table 3-4, Appendix D) and plotted as a scatter diagram of roundness versus mean diameter (Fig. 3-14). A random distribution is observed from which the topmost bed can be differentiated from the vertical section by its higher roundess values. In Figure 3-3b, showing distribution of roundess in vertical profile, the trend is for the grains to become more rounded on going up the succession.

Sphericity

Two axes were selected for measuring sphericity in thin section; the maximum diameter, the a-diameter and the largest diameter at right angles to this, the b-axis. Sphericity was then expressed as a ratio of these, that is b/a (Griffiths, 1967). A value of over 0.75 would therefore give a very equant grain and below 0.60 a very elongated grain (Folk, 1968). Using this, the Bradore sandstones are of the intermediate type with a b/a value of 0.6906.

When plotted against mean diameter (Fig. 3-15) the grains in the topmost bed are more equant than those in the vertical section. The vertical trend can be seen in Figure 3-3a, where the values of sphericity increase on going up the succession, with the exception of a sample from the basal beds. Its sphericity value of 0.7+ probably signifies local deposition of a less forceful nature during the transgression.

In the scatter diagrams (Figs. 3-16a and 3-16b) of long versus short axes, a linear trend can be interpreted to be the mean ratio of the two axes in the sandstones, that is b:a equals 1.0:1.5.

Sphericity versus Roundness

A scatter diagram of readings from the vertical succession results in a cluster of high sphericity to high roundness values. A few value plots only give poor rounding with high sphericity. A linear trend indicates that with an increase in sphericity there is a corresponding increase in roundness but as sphericity shows less environmental sensitivity than roundness these rates of increase are not the same.

Matrix and Cement

Little matrix is present (Table 3-1, Appendix D) in the majority of the sandstones. Where alteration of the feldspars has been so intense that the original grain boundary is indistinguishable, the material has been classified as matrix. An unresolvable mixture of quartz and feldspar comprises the matrix and is frequently stained by hematite.

The sample (15/437) from the basal beds shows mineral alteration to form matrix which comprises 33 percent of the total composition. The flakes of muscovite, sericite and kaolinite bend round the quartz grains and generally tend to parallel the bedding.

Glauconite, chlorite and accessory minerals of zircon, rutile and tourmaline can be found in the matrix in small quantities.

The cement consists of quartz and/or iron oxide. Silica cement occurs as secondary growth on the quartz grains (Fig. 3-17) and occasionally as fine crystalline matrix between them. Sutured contacts between quartz grains in some samples suggest that this secondary growth has been accompanied by solution. The original grain boundary is sometimes difficult to distinguish but is frequently defined by hematite-limonite coating and/or inclusions in the primary grain. No secondary enlargement was seen that occurred prior to deposition suggesting the quartz to be of first cycle.

Limonite and hematite cement occur on the surface of the grains and in pores. Their origin is most probably by deposition from water solution, as very little autochtonous iron rich minerals are present. An exception occurs in the basal beds where small quantities of mafic minerals could well decompose to give cement. Frequently red coloured, localised iron staining results in the formation of laminations and banding of variable thickness and number. At other times it can be uniformly located throughout the sandstones and is one of the causes of the red colouration, typical of the Bradore arkoses.

Colour in the Bradore sandstones depends upon the presence or absence of feldspar and iron oxide. If both are absent the sandstones are much purer and tend to be white in colour. The green colour of some of the basal beds is derived from chlorite and kaolinite, whereas higher up the succession glauconite and chlorite give the rocks a greenish tint, unless masked by the red colour of feldspar and ferric oxide.

Diagenesis

The most noticeable effect of diagenesis is the formation of cement. Leaching, that is the removal of salts, and compaction occurred after deposition. Percolation of water from the overlying

Forteau Formation resulted in the secondary deposition of calcite and dolomite in some parts of the uppermost sandstone beds of the L'Anse au Clair Member, (Fig. 3-18).

The sandstones have undergone only shallow burial with diagenetic reactions occurring at low pressures evidenced by lack of deformation and little interpenetration of quartz grains. Development of authigenic quartz as secondary rims on detrital grains occurs and together with the primary quartz is not replaced by carbonate except in the topmost beds.

Authigenic quartz is common. This is identified by a nucleus with inclusions or having been altered and so contrasting with unclouded secondary overgrowths. Secondary feldspar is a low temperature product (Pettijohn, 1957) and in the Bradore sandstones is probably of contemporaneous, post consolidation origin. The environment of formation for such secondary feldspar is most probably marine (Ibid).

Figure 3-17 (P.59) Photomicrograph, Sandstone with secondary quartz showing well rounding of the grains prior to secondary deposition. Transmitted plane polarised light, x 10. Sample No. 15/4310 (re Fig. 3-24, Appendix G).

Figure 3-18 (P. 61) Photomicrograph, Calcite/dolomite cement in uppermost sandstone beds. Well rounded quartz grains with authigenic feldspar. Transmitted polarised light, x 10. Sample No. 15/411 (re Fig. 3-1a, Appendix G).

Figure 3-19 (P. 51) Photomicrograph Concertina shaped muscovite accompanying abundant matrix and undulatory quartz from the basal beds. Transmitted polarised light, x 10. Sample No. 15/437 (re Fig. 3-1b, Appendix G).

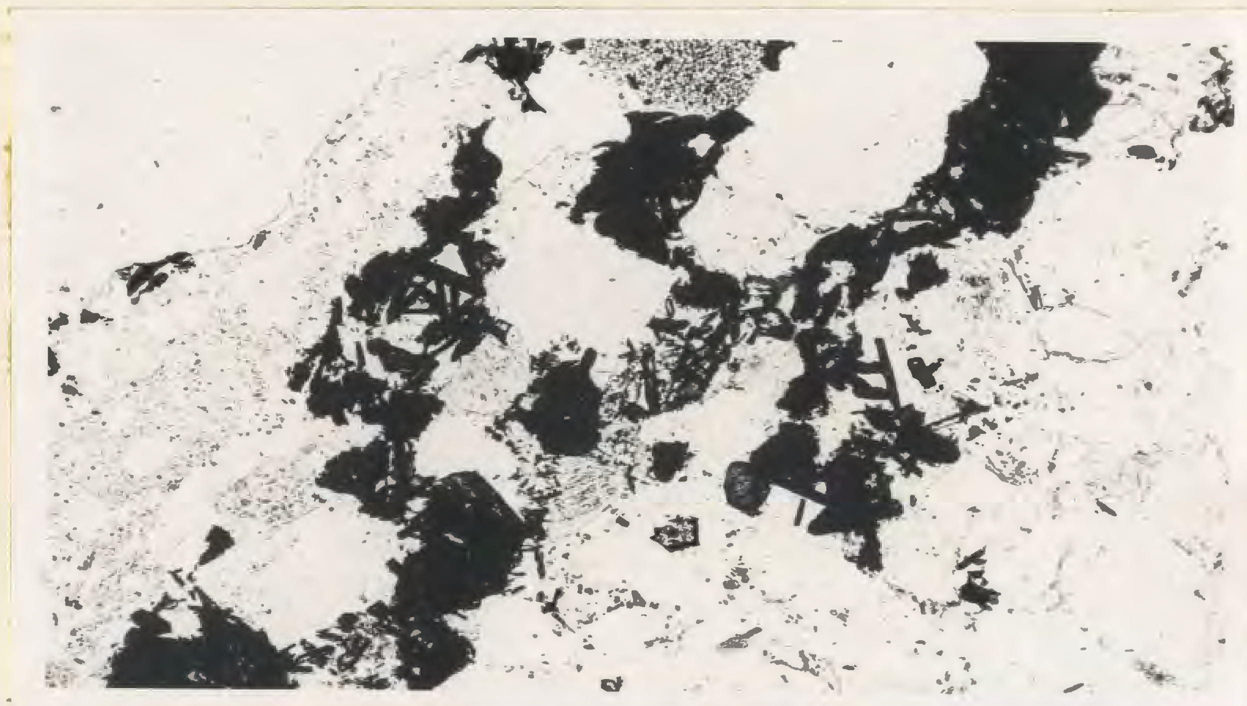


Figure 3-20 (P. 52) Photomicrograph Rutile and opaque minerals of magnetite, hematite, and limonite from the basal beds. Transmitted non polarised light, x 10. Sample No. 15/435 (re Fig. 3-1b, Appendix G).

Figure 3-21 (P.33) Photomicrograph, coarse conglomerate from the basal beds showing subrounded grains and poor sorting. Transmitted polarised light x 1. Sample No. 15/4310 (re Fig. 3-1b, Appendix G).

Figure 3-22 (P.54) Photomicrograph, well sorted, fine grained sandstone from the topmost bed with a relative high amount of feldspar. Transmitted non polarised light. Sample No. 20/5113 (re Fig. 3-1b, Appendix G).

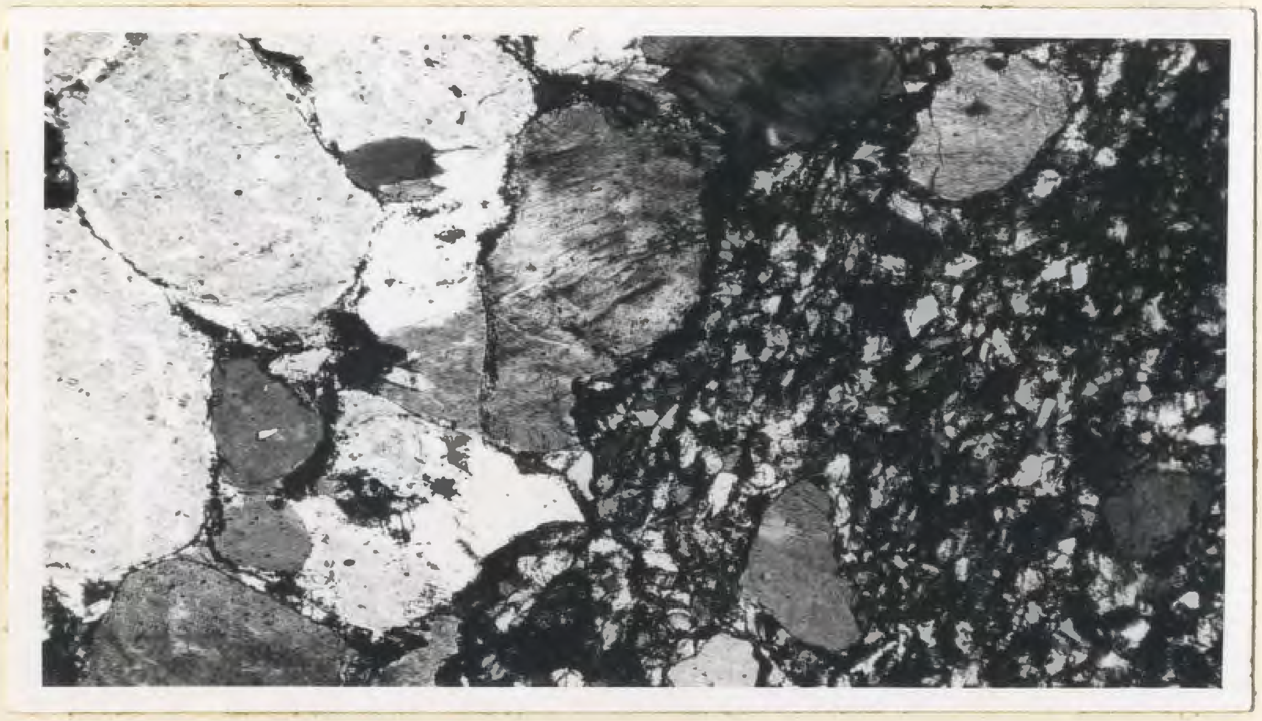


Figure 3-23 (P. 33)

Photomicrograph x 10 showing contact between the coarse interlocking texture of the topmost bed of the Bradore Formation and a lense of fine grained argillaceous sandstone. The contact marks the Bradore/Forteau Formation boundary located on the southern tip of Schooner Cove.

CHAPTER IV

SEDIMENTARY STRUCTURES

Introduction

Exposure along the coast and to a lesser extent inland, provides easy observation of primary, secondary and organic structures. The primary dip of the parallel-bedded sandstones was probably near horizontal and has been very little affected by tectonism to give gentle slopes of less than three degrees.

Sedimentary structures noted include cross-stratification, contemporaneous folding, rain drop impressions and problematical markings. Trace fossils provide evidence of organic activity.

Primary Sedimentary Structures

Cross Stratification

Methodology

The following two types of cross-stratification (McKee and Weir, 1953) occur in the thesis area.

1. Trough shaped units with curved basal contacts.
2. Tabular bodies with planar contacts (Fig. 4-3).

The azimuth of the long axis of trough cross bedding (i.e. parallel to ab) was measured and the current direction as indicated by the curvature (concave downcurrent), was noted (Fig. 4-4). Four hundred and eighty-eight readings were taken and plotted as sub areas (Fig. 4-1) in which measures of central tendency were calculated as the midpoint of a modal class and also as the vector mean (Appendix C).

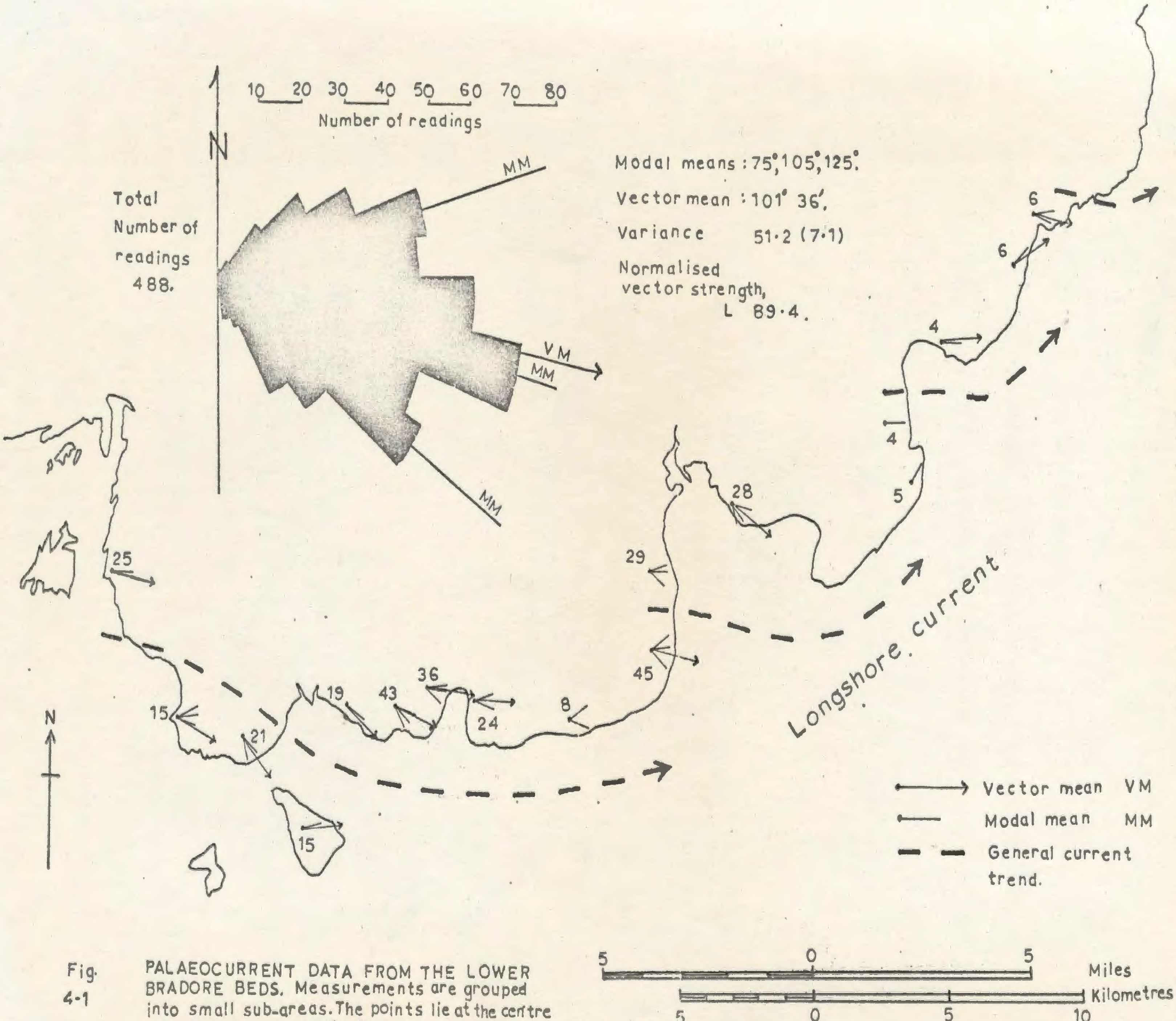


Fig. 4-1 PALAEOCURRENT DATA FROM THE LOWER BRADORE BEDS. Measurements are grouped into small sub-areas. The points lie at the centre of each sub-area, and the figures indicate numbers of readings.

Maximum dip and azimuth of foresets of tabular and large scale trough cross bedding were plotted on a Schmidt stereonet (Fig. 4-2) as poles to bedding. The result is a partial small circle from which the a and b directions can be estimated.

Readings on small scale cross stratification were taken mainly from basal beds of the Bradore Formation where the structures are exposed in planview on many bedding surfaces, whilst those of larger scale trough bedding and tabular cross bedding were taken throughout the vertical sequence.

Description

The mean thickness of the cross stratified units is 15 inches and can be termed as thinly cross bedded (McKee and Weir, 1953). There are frequent thicker cross bedded units, up to 4 feet in thickness and also thinner cross bedded strata of about 2 inches. The average length of the cross strata is 38 inches, of medium scale and the mean thickness of individual strata is 1¼ inches, termed as flaggy by McKee and Weir (1953).

Interpretation

Combining all 488 field measurements on a rose diagram reveals three modes (Figure 4-1). Tanner (1959) states that modal vectors are more significant than vector ~~sums~~ because of the separation of individual directions. Differences between the two can be seen in Figure 4-1 where the modal vectors provide a more explicit picture.

The polymodal nature of the trough beds gives modal vectors of 075°, 105°, and 125°, whereas the vector mean is 101°36'. No.

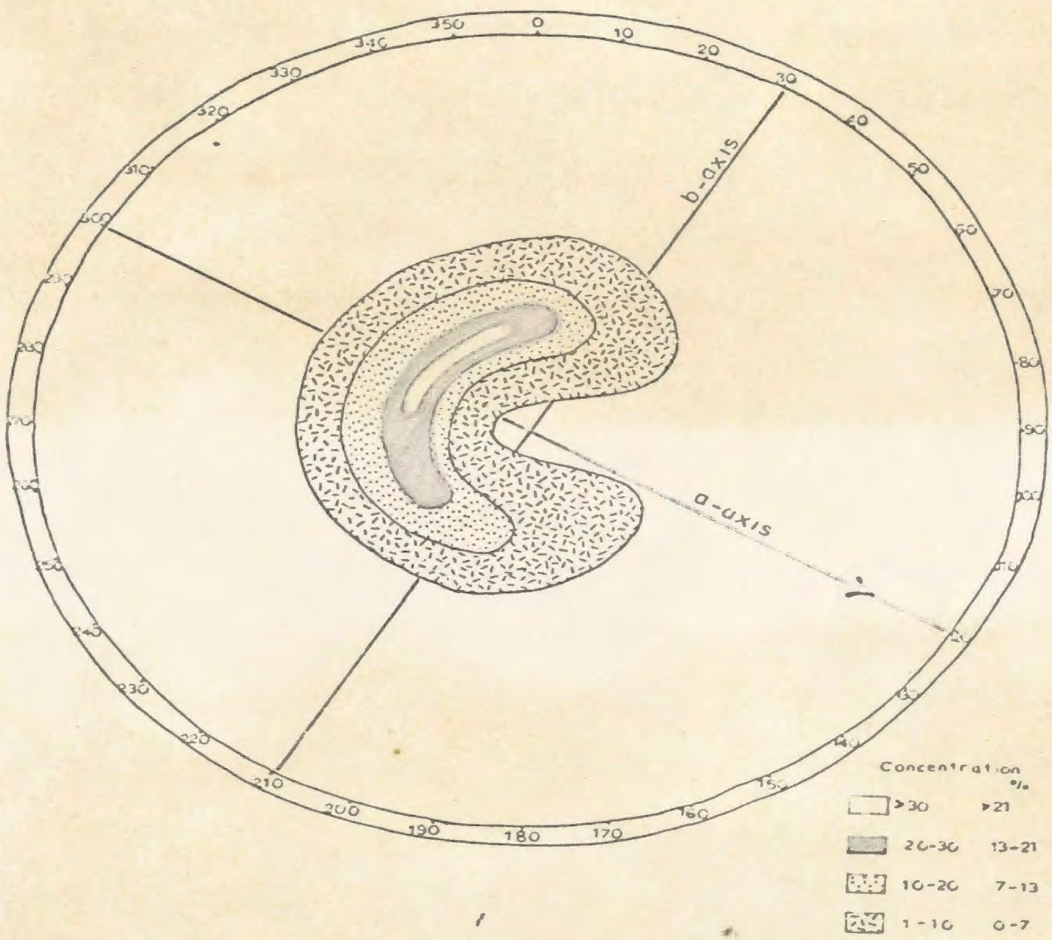


Figure 4-2. SCHMIDT NET SHOWING 141 POLES TO MAXIMUM INCLINATION OF CROSS BEDDING.

The maximum dip and the azimuth of foresets of tabular and large scale trough cross bedding when plotted give a partial small circle. From this the 'a' and 'b' directions can be determined.The readings were taken throughout the Bradore Formation,whenever a 3-dimensional view of cross stratification was available.

measurements were obtained in the arc 210^{o} to 020^{o}. Deviation from the vector mean is small, 7.1 (Appendix C).

It is clear that the modal vectors reveal paleo-current directions which are generally parallel and oblique to the present coastline. Interpretation of some plotted vectors reveals a bimodal picture, suggestive of tidal currents. The overall pattern shows easterly currents which appear to result from a southerly current much affected by long shore drift from the west. Comparison of the vector means reveals a more southerly current direction around Lourdes du Blanc Sablon than on Ile au Bois. All along the present coastline there is a trend for the preserved current readings to bend to the east and even to the north east as can be observed at Diable Bay (Fig. 4-1).

The 141 poles to bedding of tabular and large scale trough cross bedding (Fig. 4-3) give a current azimuth direction of approximately 120^{o} with considerable variability, but general indication is that large scale current structures are derived from a more northerly source than the smaller trough cross beds in Figure 4-5. The reason may be that larger structures are more stable, whereas longshore drift and local tidal currents would have greatly influenced the formation of the smaller trough cross beds.

Ripple-Drift Cross-Lamination

An exposure south east of Blanc Sablon shows a good ripple cross-lamination (Fig. 4-6) (type A of Jopling and Walker,1968) with preservation on the lee side only. According to Jopling and Walker, type A structures indicate a low suspension/traction ratio, traction as being dominant.

Ripple Marks

Observations

Longitudinal ripple marks or sand ribbons were found at two localities east of L'Anse au Clair. The ribbons were symmetrical, with an approximate traceable length of 8 feet and a width of 1 inch. Their general lineal direction was 050^{o} parallel to the long axis of a trough cross bed situated alongside (Figs. 4-7). A few were slightly convex to the south.

Interpretation

These unipolar structures are known from tidal flats and shallow seas. Allen (1968) mentions them as occurring parallel to the flow, where sediment is deposited over a flat substratum, hard or coarse enough to resist denudation under the prevailing conditions.

Kenyon (1970) described sand ribbons of greater magnitude in European tidal seas. He states that they are unlikely to be commonly preserved as they are only transitory bed features, dependent on sand supply and eventually replaced by other bed forms. As regards the probable environment, Kenyon states.

> 'If preserved, then one might expect them in basal conglomerates of transgressive seas ....'

The only other observation of ripple structures was near L'Anse Amour, where oscillation ripple marks had been preserved in the Upper Forteau Formation (Fig. 4-25).

Lamination

Description and Interpretation

The presence of a veneer of iron oxide/limonite on the surface of the grains, together with a concentration of dark minerals, probably accounts for the formation of lamination in the Bradore sandstones (Fig. 4-8). Otvos (1966) cites these two reasons, plus the presence of bituminous particles and concentration of frosted quartz grains, for the formation of parallel to sub-parallel lamination in sandstones deposited in low energy environments with little foreset lamination. Neither bitumen nor frosted grains were observed in the Bradore sandstones.

Frequently cross lamination forms web-like structures and these could be explained by Otvos (Ibid) who states;

'This outlines the flat, slightly hummocky bottom, microtopography of the ancient sedimentary basin'.

Basal beds of the Bradore Formation, both in the field and in thin section, display inclined laminae of heavy mineral concentration. This phenomenon is one of the diagnostic characters of foreshore beach deposits (Otvos, 1966).

Graded bedding and possible rill marks were other depositional features which were observed in the area. Channels in sandstones provide for erosional current structures.

Secondary Sedimentary Features

Colouration

Description

Colouration, besides that due to the presence of orthoclase feldspar, occurs throughout the succession. The colouration is represented in a veneer of limonite and hematite on the surface of the grains, as observed under a petrological microscope, and varies from very light to deep red. Frequently a false type of cross lamination, comprised of alternating coloured laminae, occurs and is caused by differential weathering of the colouration.

Interpretation

Bleaching of the red/pink laminae is the probable cause for the presence of colouration. Otvos (1966) accounts for a similar phenomenon by suggesting an arid environment in the basal layers. Colouration occurrence as a veneer suggests a secondary depositional process, whereas the presence of cross laminae infers preconsolidation.

Examples of Specific Colouration Features

An example of colour and differential cementation occurs in Figure 4-11 which displays sharp crested anticlines and wider to box shaped synclines. The structure was observed in a cliff face, exposed to the east of L'Anse au Clair, where no deformation had occurred. Vertical worm burrows were the only other structures present.

As no load deformation has occurred contemporaneously with sedimentation, the structure is demonstrably caused through differential cementation. Irregular distribution of pressure, lateral interstratal flow or the expulsion of pore water could account for the shape of the colouring, as limonite and hematite are differentially deposited. A similar explanation has been given by Migliorini (1950) for the formation of convolute lamination in which the upward expulsion of contained pore water drags the laminations in to peaked upwellings.

Figure 4-9 provides an example of interstratal current erosion. Here the foreset cross laminae display alternate colouring, which is seemingly truncated by a strongly curved lamination. If current action were the cause, the laminations would be convex upcurrent, as the outer edges of an unconsolidated bed are least resistant to a flow direction from left to right. Accompanying cross lamination reveals a south-east direction, in agreement with the above hypothesis.

Soft Sediment Folding

Description

Local deformation in sandstone was observed east of L'Anse au Clair (Fig. 4-10), and was confined to a particular bed with a very low angle of dip. No deformation occurs in the neighbouring beds either above or below and no faulting was observed on any scale. Azimuths denoting the strike of the folds were determined to be 075° and 115°.

The actual layer of deformation maintains a constant thickness. The internal folds die out laterally, being flattened against both the top and bottom of the bed, where they are most intricate.

Interpretation

The absence of deformation and faulting in the neighbouring beds infers a preconsolidation origin for the folding. Although greatest instability occurs when substrata have an exceptionally high slope, Potter and Pettijohn (1963) note evidence for movement on slopes of one or two degrees. This is due to the fact that fine grained sediments may contain a very high proportion of water when first deposited, and so may be readily mobilised.

Confinement of deformation to a particular bed is most probably caused by interstratal flowage, which does not affect the whole bed but only involves internal laminations. This readjustment is not the result of external pressure which would cause large scale deformation, lateral slumping and thickness differences of the bed.

Workers cited by Potter and Pettijohn (1963) have observed that the strike of slump folds roughly corresponds to the strike of the subaqueous slope. If this were applied to interstratal flowage the subaqueous slope at this locality would strike approximately east-west. However, lack of exposures and deposition of the Bradore sandstones on an almost flat substratum with dips of less than three degrees would not allow verification of this.

Rain Drop impressions

Structures that were interpreted to be rain drop impressions were found in the Forteau Formation at Point Amour (Fig. 4-26). They were observed on the upper surface of a calcareous mudstone and consisted of irregular grooves with a diameter of 3-8 millimeters. Edges between the impressions are shaped and uneven, and the actual grooves themselves are shallow in depth. The formation of these implies that the bedding surface has been above water.

Stylolitic suturing

Stylolitic suturing displayed by interlocking or interpenetration of the limestone was found in the Forteau Formation, east of Fox Cove. The stylolites are parallel to the bedding and have an amplitude of less than one centimetre. Pettijohn (1957) considers the origin of these structures to be pressure solution formed in a consolidated rock. They are therefore indicative of extensive interstratal solution and infer considerable reduction in rock volume.

Trace Fossils

Description

Cylindrical tube-like structures are exceptionally common throughout the Bradore Formation. They vary in diameter from a fraction of an inch to half an inch, and in length from little more than an inch to over three feet (Figs. 4-17 and 4-18). They are always straight, or nearly so, and vertical to the bedding. They have well cemented smooth walls which are often delineated by coloured laminations.

In thin section, the cylinder is more iron stained than the surrounding rock and contained a higher percentage of opaque, magnetic minerals (Figs. 4-21 and 4-22). The structures are more indistinguishable in the field, often having the same colour as their host rock.

Honeycomb like colonies often occur, in which a cross section reveals a circular shape to the structure, with an infilling, dark in colour.

Historical Review of Origin of S. Linearis

The structures have commonly been called Scolithus linearis but according to Howell (1943) in keeping with the rules of zoological nomenclature, the species first described by Haldeman should be referred to as Skolithus linearis.

Skolithus linearis

Billings (1862) noting the occurrence of Skolithus linearis in the sandstone at L'Anse au Loup, regarded them as plants, differing from the previously found Potsdam Group Structures. Later in 1869 he concluded that specimens collected by the geological survey were sponges and definitely not worm casts (cited by James, 1892).

Geinitz (1916) considers the dark infilling to be due to overlying humic, muddy water but this is unlikely considering the lithology of the Bradore sandstones. Papers by Richter (1919, 1927) favour an organic origin, although mention of a 'rising-bubble' origin is given, in which he is puzzled by how tubes remained open until filled. He also gives three observations which tend to go against an organic origin. These are:-

1. Every pipe is of equal rigid regularity
2. There is no meeting of the cylinders
3. There is no departure from the vertical

Richter suggested tube formation by upward, organic movement. The fact that the organisms are sensitive to gravity explains why the majority of the structures have almost vertical alignment. Referring to modern analogies, he cites the example Sabellaria from the North Sea. This inhabits shallow water sand deposits, subjected to occasional drying up.

Other ideas put forward for their origin include formation by pothole whirlpools giving concretionary deposits, and mobilisation of original pigment in flat lying sandstones by geyser action or rising of spring water.

Interpretation

The cylindrical structures described by Hawley and Hart (1934) and Gabelman (1955) are much larger than the ones in the thesis area. Although the depositional environment of the Bradore sandstones appears to be that of a water saturated partly consolidated silty area, formation by springs seems unlikely. This is inferred from the abundance of Skolithus linearis in association with pigmentation banding and quartzitic veining, previously stated as being of spring origin. Another factor was the caving-in appearance of the sediment in one tube structure, signifying a downward motion. However, this may be otherwise but is unlikely to be explained by a spring diminishing in velocity.

These field relationships tend to suggest that the non branching, parallel structures were formed by movement of unconsolidated material into cavities, most likely used as burrows of habitation by annelids or phoronids.

Problematic Markings/Features

Flask Shaped structures

Description

An exposure east of L'Anse au Clair in sandstones of the Bradore Formation showed flask-shaped structures related to the vertical cylinders (Fig. 4-23). The flasks have rounded base and taper upward until parallel to the tube, thus forming a neck to the structure.

The rounded base varies in diameter from 4 to 9 inches. All the structure appeared to be at approximately the same horizon in the upper part of the L'Anse au Clair Member. Frequently laminations which comprise the structure are continuous from one flask to another and occasionally were deformed around the tube. On one rock spherical laminations were associated with the flasks (Fig. 4-24) and were inferred to be vertical sections through the edges of other flask-shaped structures.

Interpretation

The cause of formation is thought to be water percolation from the depositional surface through underlying unconsolidated sandstones. Freshly dug burrows would provide less resistance to water penetration than the surrounding rock and upon reaching the basal end of the tube, iron deposition would disperse out into the sandstone so forming flask-shaped structures. The cylinders may extend through the bottom of the flask and so, if the above hypothesis were true, the lamination would be contemporaneous with the organisms. The cylinder terminates in the centre of the flask.

Dendritic-like quartz veining

Description

Dendritic-like veins were found to be common on a bedding surface in the upper part of the L'Anse au Clair Member, exposed west of Forteau. They occur as white coloured veins throughout the sandstones at this particular horizon and are commonly found with abundant cylindrical tubes. Frequently closely associated with the veins are circular structures ranging up to three feet in diameter (Fig. 4-12).

The structures were noted by Fong (1967), who described them as calcareous veins. Examination of the veins both in the field and laboratory show that they consist solely of quartz. The circular structures which generally accompany the veins are concentric colour bands. These are closely related to the shape of the dendritic veins (Fig. 4-13). The vein is always more resistant than the surrounding rock and so forms prominent ridges of clean quartzitic sandstone. In thin section the vein can be seen to be composed of large grained and well sorted material with no visible lineation. Authigenic quartz is common and the actual quartz grains are subrounded to rounded with very close packing. In contrast the country rock shows ill sorting and is heavily iron stained.

Interpretation and Significance

Water on rising would probably deposit ferrous iron compounds as continuously spreading bands, percolating through country rock. This could well account for the shape and formation of the colour banding.

Movement of water may be due to compaction of sediments and the subsequent forcing upwards of water or just simply by a fresh water spring rising due to its lower specific gravity. Absence of grain lineation indicates lack of deformation during formation and slow water movement. It can therefore be said to be post depositional and most probably preconsolidational in origin due to its colour banding character.

Large Scale Circular Structures without Veins

Introduction and Description

James Richardson, circa 1862, appears to be the first person to make reference to these structures in eastern Canada. He states in one of his field books (L.M. Cumming, personal communication),

> 'This measure is altogether arranged in rounded and oval elementary layers having a diameter of from one foot to nine or ten. Some dip to a centre while some, but fewer, dip from it.'

He then gives a general plan of their arrangement.

In 1894, Weston, in describing concretions found in Canadian rocks, states that the structures show concentric lines of various colour and some of them are a yard or more in diameter. The whole rock, he said is pierced by Skolithus Canadensis (Billings)

The structures were always found, both on Greenly Island and east of L'Anse au Clair, at a high stratigraphic horizon in the Bradore Formation. Vertical sections reveal the banding to be both basin and dome shaped, and continuous between the two (Fig. 4-15).

The colour banding is not associated with quartzitic veins, and as observed on a bedding surface, displays a round or elliptical shape (Fig. 4-14) resulting in a concentric pattern. The colour varying from red, pink to grey is due to the deposition of hematite as a veneer on the quartz grains.

Structures have variable diameters ranging up to over twenty feet in diameter, although in some very small scale of approximately one or two feet diameter, circular banding occurs with no related veining.

Interpretation

The origin of those structures is probably due to deposition of ferrous iron by water in rising. The transportation of the iron in solution does not appear to be concentrated as before in springs but is more widespread giving much larger structures. Explanation of their form is similar to that put forward for Figure 4-11 where expulsion of water caused coloured laminations to move upward and form sinous upwellings and large rounded basins.

A completely different kind of structure at the same horizon was observed east of L'Anse au Clair. This was a type of sandstone plug (Fig. 4-16) in a thick bedded, hard quartzitic sandstone. The sandstone is deep pink in colour and contrasts to the coarse grey coloured rock. The shape of the 'plug' is circular at one end, showing a certain amount of concentricity, and then it tails off.

The structure may be just an infilling of a crack in the substratum. On the other hand the circular fracturing may signify formation by a spring on a much larger scale than previously mentioned. As this was the only structure of its kind seen, its origin could not be verified.

Figure 4-3 (P. 66) Tabular cross stratification, with a planar basal surface. S.E. of Lourdes du Blanc Sablon

Figure 4-4 (P. 66) Plan (parallel to ab) view of a trough cross bed showing apparent curvature of laminations in Bradore Formation. Current from right to left. L'Anse au Clair.

Figure 4-5 (P. 70) Tabular cross stratification with small scale trough cross beds on the surface showing a different current direction. E. of L'Anse au Clair.

Figure 4-6 (P. 70) Ripple drift cross lamination of type A (Joping & Walker, 1968). Dark colour banding displays the cross lamination and shows current direction from left to right. S.E. of Blanc Sablon.

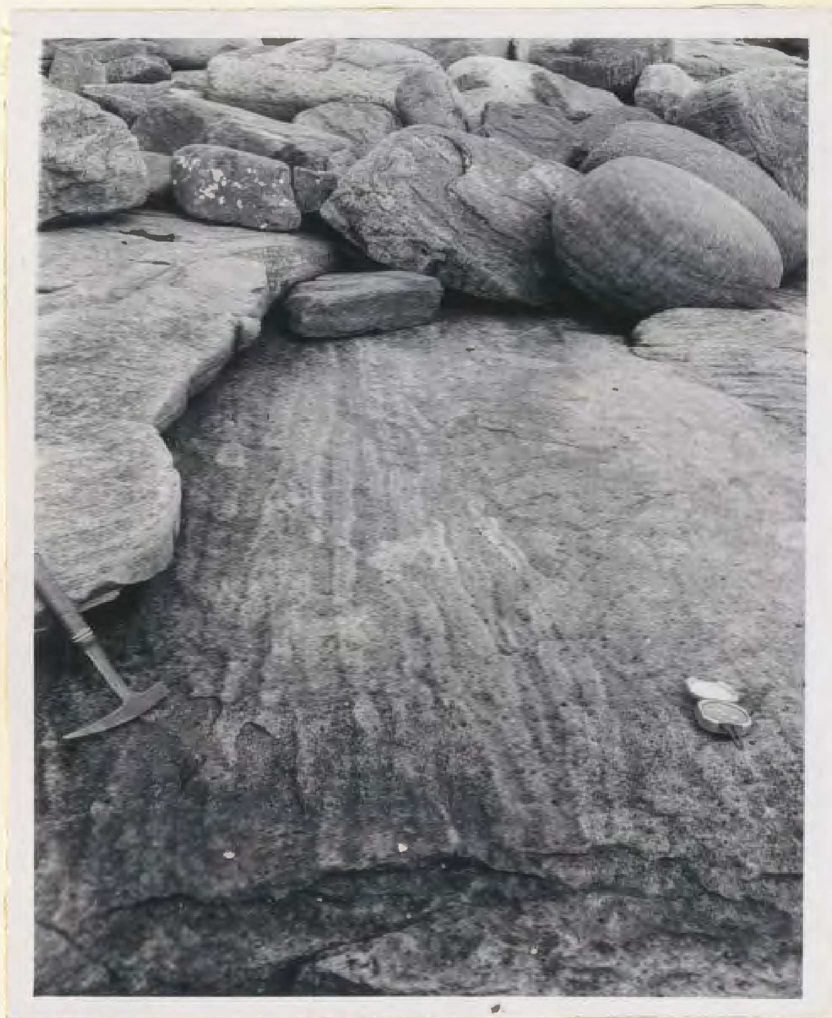


Figure 4-7
(P. 71)
Longitudinal ripple mark on a bedding surface exposed east of L'Anse au Clair
Looking East.

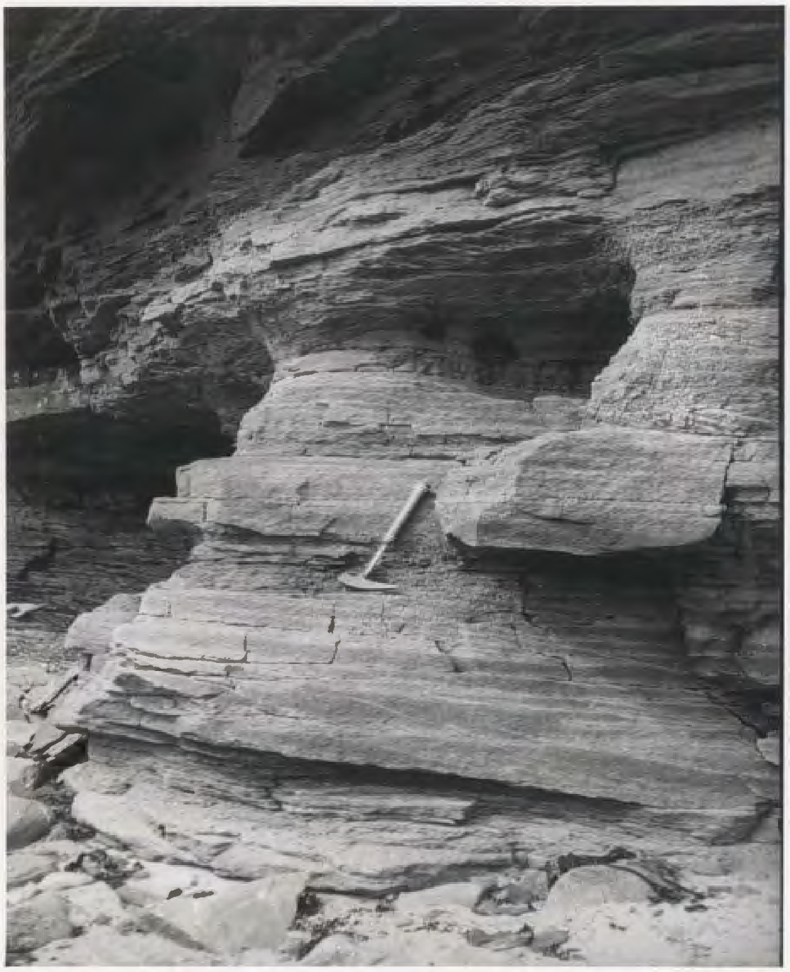


Figure 4-8 (P. 72) Lower beds of the Bradore Formation displaying horizontal parallel laminations. Frequently laminae join to form web-like patterns. Blanc Sablon.

Figure 4-9 Colour banding with the cross lamination
(P. 74) and concave shaped lamination formed by
interstratal currents, flowing from left to
right. S. of Forteau.

Figure 4-10 Contemporaneous folding exposed east of
(P. 74) L'Anse au Clair in a bed of relatively
constant thickness with underformed beds
above and below.

Figure 4-11 (P. 73) Colour and differential cementation E. of L'Anse au Clair

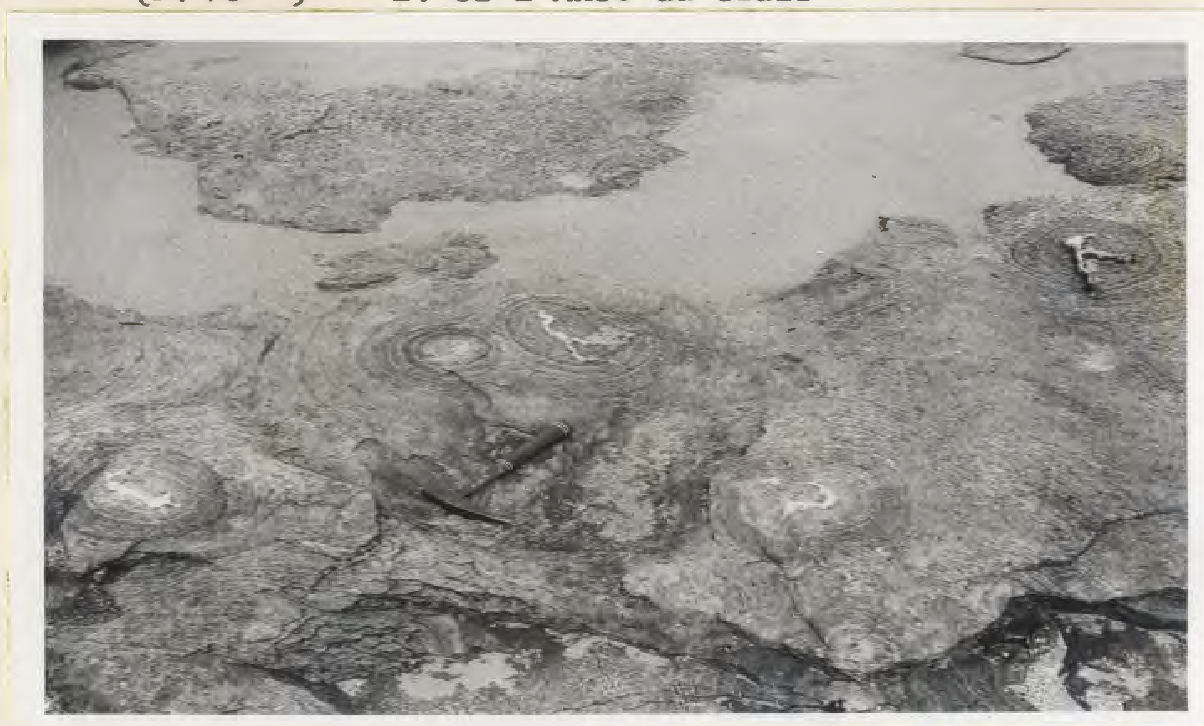


Figure 4-12 (P. 80) Quartzitic veins with associated colour banding, forming circular structures exposed west of Forteau.

Figure 4-13 (P. 80) Vertical section through the veins and circular structures showing a synclinal shape. Note the prominent quartzitic veins forming ridges on a bedding surface exposed west of Forteau.

Figure 4-14 (P. 81) Large scale colour banding forming concentric structures on Greenly Island

Figure 4-15 (P. 81) Vertical section through the structure showing continuous colour banding from one basin to another. Note vertical cylindrical tubes. Greenly Island.

Figure 4-16
(P. 82)
Pink coloured sandstone infilling, exposed in the upper sandstone beds of the Bradore Formation, west of Forteau. Note the concentric fracturing in the dyke

Figure 4-17
(P. 77)
Vertical rock face with abundant cylindrical tubes. Largest measured was over 42 inches. L'Anse Cayeux.

Figure 4-18
(P.77)

Cylindrical worm tube with a diameter of ½ inch. Located in loose boulder at L'Anse Cayeux.

Figure 4-19 (P. 39) Weathered vertical cylindrical tubes near the top of the Bradore Formation, exposed in the cliff face on the eastern side of L'Anse au Clair Bay.

Figure 4-20 (P. 39) Scolithus errans on a bedding plane, located under the topmost bed of the Bradore Formation at Lourdes du Blanc Sablon.

Figure 4-21 (P. 77) Photomicrograph, horizontal section through a worm burrow showing heavily stained and finer grained infilling. Transmitted non polarised light, x 10.

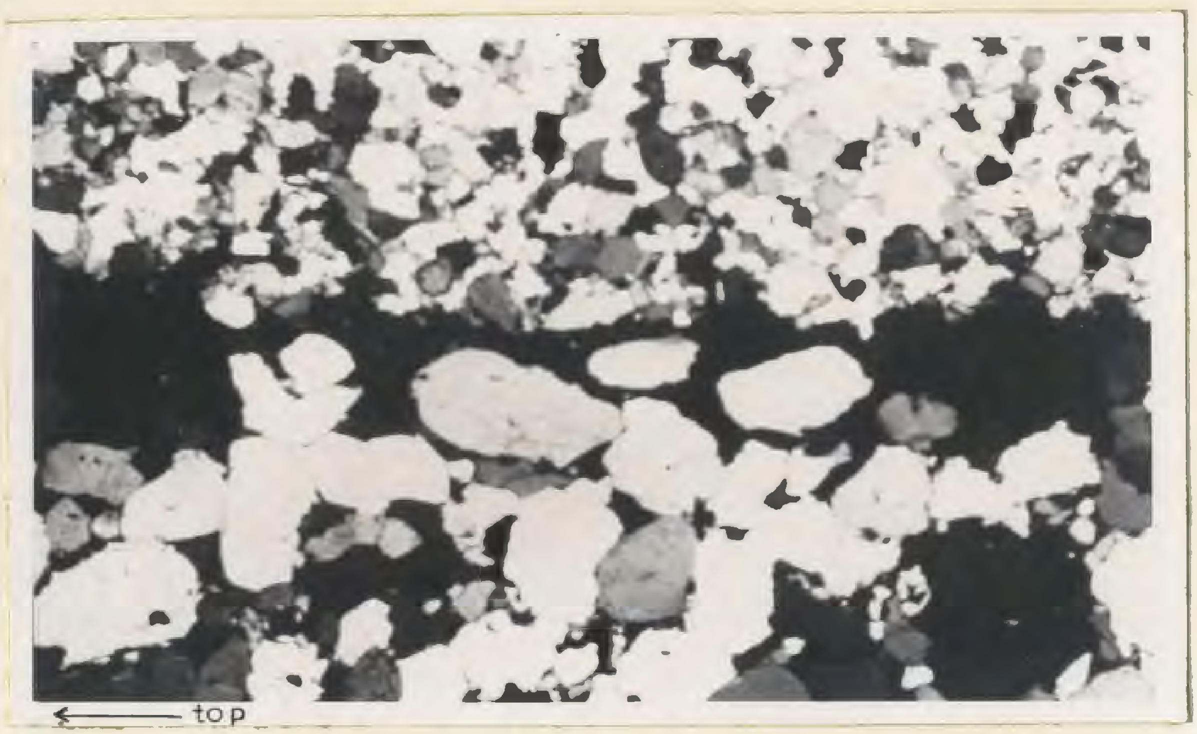


Figure 4-22 (P. 77) Photomicrograph, vertical section through a worm burrow showing finer grained infilling. Transmitted polarised light x 8.

Figure 4-23
(P. 79)
Flask shaped structures on a vertical rock face exposed east of L'Anse au Clair. Note worm burrows extending through the structure.

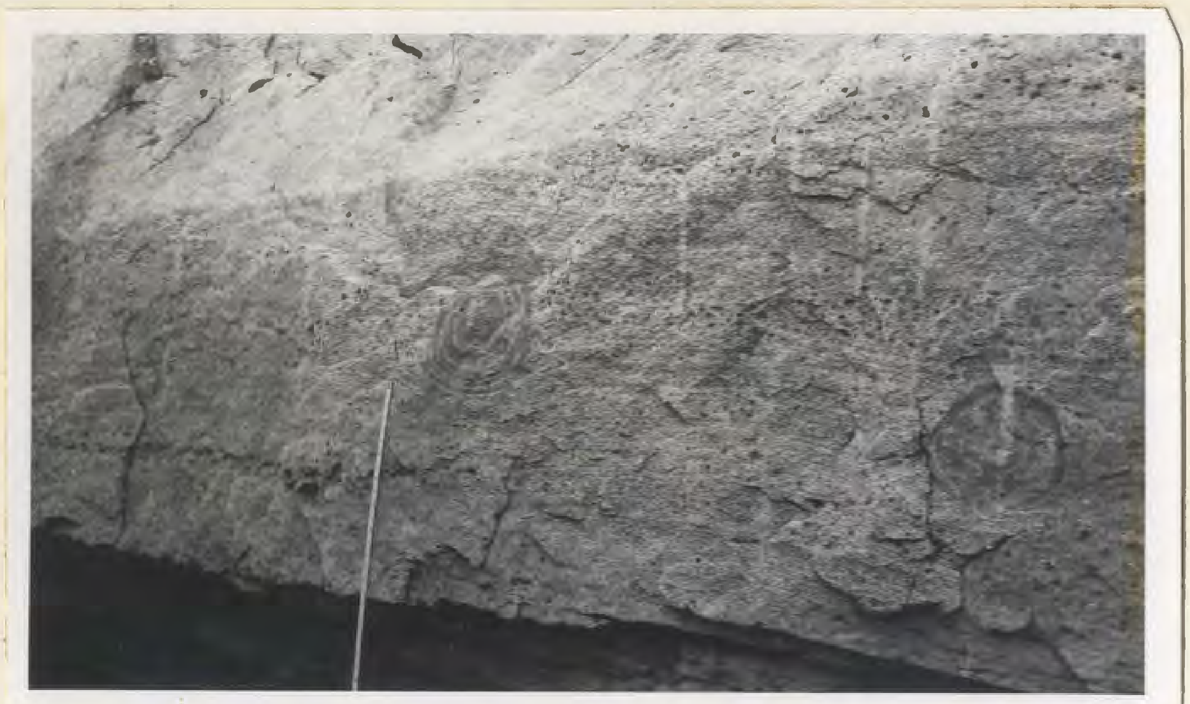


Figure 4-24
(P. 79)

Vertical rock face displaying flask-shaped structures and associated spherical colour banding. East of L'Anse au Clair.

Figure 4-25 (P. 71) Oscillation ripple marks in the Forteau Formation located at Point Amour.

Figure 4-26 (P. 76) Rain impressions on a sample from the Forteau Formation exposed at Point Amour.

CHAPTER V

ANCIENT ENVIRONMENTS

DISCUSSION

The Bradore Formation rests on a substratum which is mainly fresh and unaltered most probably due to current activity winnowing away all the loose matter with the exception of larger pebbles forming the basal conglomerate. Palaeocurrent directions and the accumulation of coarse material in the basal beds suggests an environment where wave and tidal currents dominated.

Occasional silty layers between the basal sandstones were no doubt deposited during periods of slower currents. Fine grained sandstones and siltstones immediately overlying the basal conglomerate infer a depositional environment with weak currents, such as a flat laying shore. The cause of the decrease in power is in most cases a continued depression of the land.

Worm burrows in the middle to upper parts of the Bradore Formation signify an upper shore environment. The presence of glauconite is indicative of a marine environment. The almost complete lack of argillaceous material throughout the formation is one characteristic feature of most beach deposits.

Conglomeratic bands appear less frequently towards the top of the succession and the beds are more uniform in both composition and texture. Deposition is inferred to be in less agitated waters than the lower beds, probably in near shore, shallow water, a relatively lower energy environment. The presence of intermittent conglomeratic beds and abundant cross bedding in the upper beds, however, indicates occasional strong variable currents

In conclusion the sandstones of the Bradore Formation in southern Labrador are thought to be entirely marine and of shallow water origin.

Environment with Respect to Textural Maturity

Folk (1968) states that the tectonic framework exercises an indirect control over environmental determination, which in turn controls the textural maturity of a rock. According to his four stages of maturity the Bradore sandstones would be classified as submature, since the sand grains are poorly sorted (having a value of over 0.5) and only subrounded, with under 5 percent clay. However, there appears to be more than one fraction in some of the sandstones and the rock may be bidmodal mature, with the coarse and fine mode showing poor sorting as a whole (Fig. 3-7). He also points out that immature sandstones are usually formed during crustal unrest whereas supermature ones evolve from crustal stability, although the environment has a great influence in their respective formations.

Plots of skewness and kurtosis reveal normal curves, indicating that the majority of the samples examined are unimodal in character. Bimodality would give non normal values of the two parameters. Beach sands are unimodal and give negative skewness generally, with an excess of coarse material. Folk (1968) cites the following three causes for the gravel content in beach sands:-

1. A result of past geological history, e.g. glacial
2. Hard rocks outcrop on the coastline
3. Competent rivers carry gravel to the sea

The Bradore sandstones are negatively skewed with the presence of a coarse fraction. As a hard crystalline basement is present, it is inferred that this is the source of the gravel, which mainly occurs in the beds overlying the basement.

There is a gradation from poorly-moderately sorted material in the lower beds to moderately-well sorted material in the upper ones. Grain size diminishes in the same direction and gives a fining-upward sequence.

Several environments may be inferred from the sorting values (Ibid) but the transition to more mature beds towards the top of the succession limits these to a river channel, beach and bar or aeolian and dune. The fact that sediments do become more mature is also evidenced by the increase in non-undulatory quartz content.

Environment with Respect of Mineral Composition

The mineralogical composition of sandstones is controlled by the source area and the lithology can be affected by tectonism. Folk (1968) states that textural maturity and mineral composition are interrelated.

The triangular compositional diagram (Fig. 3-2) classifies the Bradore sandstones as mostly subarkoses, with some almost orthoquartzites. In part, the very basal beds and the topmost bed (midway between L'Anse au Clair and Forteau Point) are true arkoses and infer less transporting distance. The subarkoses are thought to represent a transitional stage of maturity and mineralogy (Folk, 1968).

Feldspar content in the Bradore sandstones is relatively low in comparison with that of quartz. Initially, there must have been a great deal more feldspar, as very large crystals and a high proportion of the mineral are present in the parent rock. The freshness of the feldspar is noted especially in the basal beds. Although this is indicative of relatively slight chemical weathering, that is in an arid environment, it is interpreted as being due to a proximal source for the Bradore Sandstones. A pronounced humid climate is indicated by the weathering products being transported and deposited mainly in a disturbed position. Weathering must have been strong, crumbling the feldspar grains and washing them away with the rest of the fine silt. It is therefore likely that there was a period of prolonged abrasion of the sediments. In thin section both microcline and orthoclase are present, the latter appearing more altered.

Environment with Respect to Classification of the Bradore Sandstones

The following is a summary of the depositional history based on Folk's (1968) genetic classification:-

1. The Canadian Shield as a craton would give stability with only mild eustatic changes. Tectonics of the source area were probably quiescent and stable, with slow sediment accumulation on a peneplane consisting of granite-granitic gneiss.
2. Tectonic framework of the depositional site resulted in the formation of a wedge of sandstone thickening to the north-east of the source area, off the craton.

3. The dominant depositional environment was a transitional littoral one resulting in undaform (shallow marine) deposits.
4. Climatic effects have given rise to iron staining and both fresh and altered feldspar.

A relatively stable cratonic region would comprise on its perimeter a shelf or basin whose source of sediment would be the craton itself. This would result in the formation of a thin sheet of shallow water sediments, thickening away from the craton.

A lack of feldspar could indicate a humid and warm climate on land with low relief or tidal deposition where feldspars undergo alteration. Due to considerable transport, the presence of authigenic feldspar as overgrowths is suggestive of a marine origin. Thus, keeping these facts in mind, the arkosic sandstone could not be classed as climatic, where dry or cold conditions are necessary. The abundance of red, hematitic staining is indicative of a humid climate and so is the occurrence of both fresh and badly weathered felspar. An occasional bed of oolitic hematite (30 percent hematite) exists in the basal beds, inferring shallow agitated water. The concept of a tectonic arkose (Folk, 1968) evolving from uplift and rapid erosion is not likely in the case of the Bradore arkoses for the following reasons:

1. Apparent stability of the craton during deposition of the sands.
2. Absence of a vast thickness of sediment which would accumulate and thin outward as a wedge. The Bradore sandstones actually thicken outward from the source area.

3. The sandstones would be poorly sorted and have a clay content, although these would change with progressive maturity.

The Bradore sandstones, therefore, do not apparently fit the definitions of climatic or tectonic arkoses. However, if the large east-west trending fault occurring to the north of Bradore Bay was active during or previous to deposition, the raising of the basement to the surface would greatly influence the arkose formation and evolve a type of tectonic arkose.

SEDIMENTARY STRUCTURES

Sandstones with foreset cross lamination and trough cross lamination are abundant in the Bradore Formation. Although a polymodal nature of cross bedding orientation may indicate a fluviatile environment, the intermittant accumulation of a coarser fraction and the presence of longitudinal ripple marks signifies a tidal environment. The aximuth differences between the modes of the trough cross bedding vary from 20° to 40°. From Figure 4-1 they appear to have been greatly affected by a drift current from the south west, which prevented accumulation of seaward and landward dipping strata having larger azimuth differences.

A low energy, littoral to near shore environment is inferred from the silty basal layers with parallel to sub parallel lamination. The lack of significant amounts of clay is possibly due to intensive pre Bradore Formation wind erosion or later high energy tidal conditions.

Van Straaten (1960) points out that ripples are not generally preserved in an upper tidal flat environment where boring organisms and high wave energies exist. Frey and Howard (1969) describe the location of vertical, cylindrical worm burrows to be on an upper shore, although other types exist all over a shore profile. In Cambrian times, S. linearis appears to be restricted to the Fenno-Scandinavian and the Canadian Shields. Everywhere these ichnofossils occur in (primarily) pure marine sandstones, formed at a relatively slight depth.

Springs would occur on sandy beaches, caused by fresh water following the basement relief and then rising through saline water saturated sediments due to differences in specific gravity. Their formation may not be so complicated and may be due simply to compaction of the underlying beds and subsequent 'squeezing' out of water. No matter what their origin, water movement occurred and resulted in differential deposition of the ferrous iron to form intricate structures. From these the direction of flow of the interstratal solution may be determined but often confuses the true lamination of cross stratification.

FERROUS STAINING

The presence of iron as a veneer on the quartz grains has no doubt been brought about by precipitation. Iron compounds in the underlying gneiss, when exposed to the atmosphere would be oxidised and be put into solution. Therefore fluctuating climatic conditions might well explain the presence or absence of hematitic and limonitic staining in some of the beds.

Weller (1960) points out,

> 'Red marine strata are not common but their occurence in some formations seems to indicate deficiency of organic matter on the sea floor capable of reducing their ferric pigments.'

Interstratal solution appears to be the cause of redistribution of the iron pigmentation throughout the sandstone, forming intricate sedimentary structures. Using this source of iron, the history of deposition and the source of the secondary features could be deduced from the following future palaeomagnetic studies:

1. Stability investigations in which palaeomagnetism (viz. demagnetization) techniques may reveal the historical sequence of events, resulting in the sedimentary structures.
2. Techniques in which the rock fabric can be tied up with shape anisotrophy in rock magnetism.

The tubes of S. linearis are often strongly red coloured, even where they occur in a white coloured sandstone; and they can be white or very slightly coloured when in red coloured beds. This suggests that on the one hand the cylinder wall has been impermeable to the pigment matters and the solution for which it has been deposited, while on the other hand the pigmentation has taken place after the formation of the cylinders.

PALAEOGEOGRAPHY

An isopach map (Fig. 2-4) was made from plotting measured coastal thicknesses and approximate inland thicknesses of the Bradore sandstones. An exposed inland thickness was calculated from the intersection of the basal Bradore Formation contact with the Precambrian basement and contour height. The resulting thickness pattern from which the general direction of thickening can easily be read is thus only approximate. Compensation for faulting would have to be considered for a more exact picture.

The shoreline appears to be in the region of the most northerly exposure of the Bradore Formation and trends south-west to north-east. Figure 5-1 shows Schuchert's interpretation (cited by Wells, 1955), where the coastline is situated much further west. As the majority of the Bradore sandstones display tide dominated, shallow marine characteristics and as some show beach features, the shoreline is thought to be nearer the present one.

The source area of the sediments lay to the north-west on relatively low lying land, undergoing mild uplift. Rivers draining the land surface flowed generally south eastward to the coast. A strong south-westerly longshore current deflected local and tide currents, especially further away from the coast. This current pattern would then support Steven's observations (Williams & Stevens, 1969) on Belle Isle of a south westerly derivation. However, a possible north and north-east source area, mentioned in the same paper appears to be a contradiction, unless Belle Isle were at the meeting of the two contrary flowing currents.

The study of palaeocurrent data from the southern side of the Strait of Belle Isle might give further evidence of a north west, north east deflected current, although elsewhere in the succession paleocurrents may be from other directions.

The environment of deposition of the Forteau Formation appears to be that of a shelf margin with barrier reefs forming a little distance offshore from low land. Shales and thin bedded limestones were thus probably formed in lagoon-like conditions, with wave and current

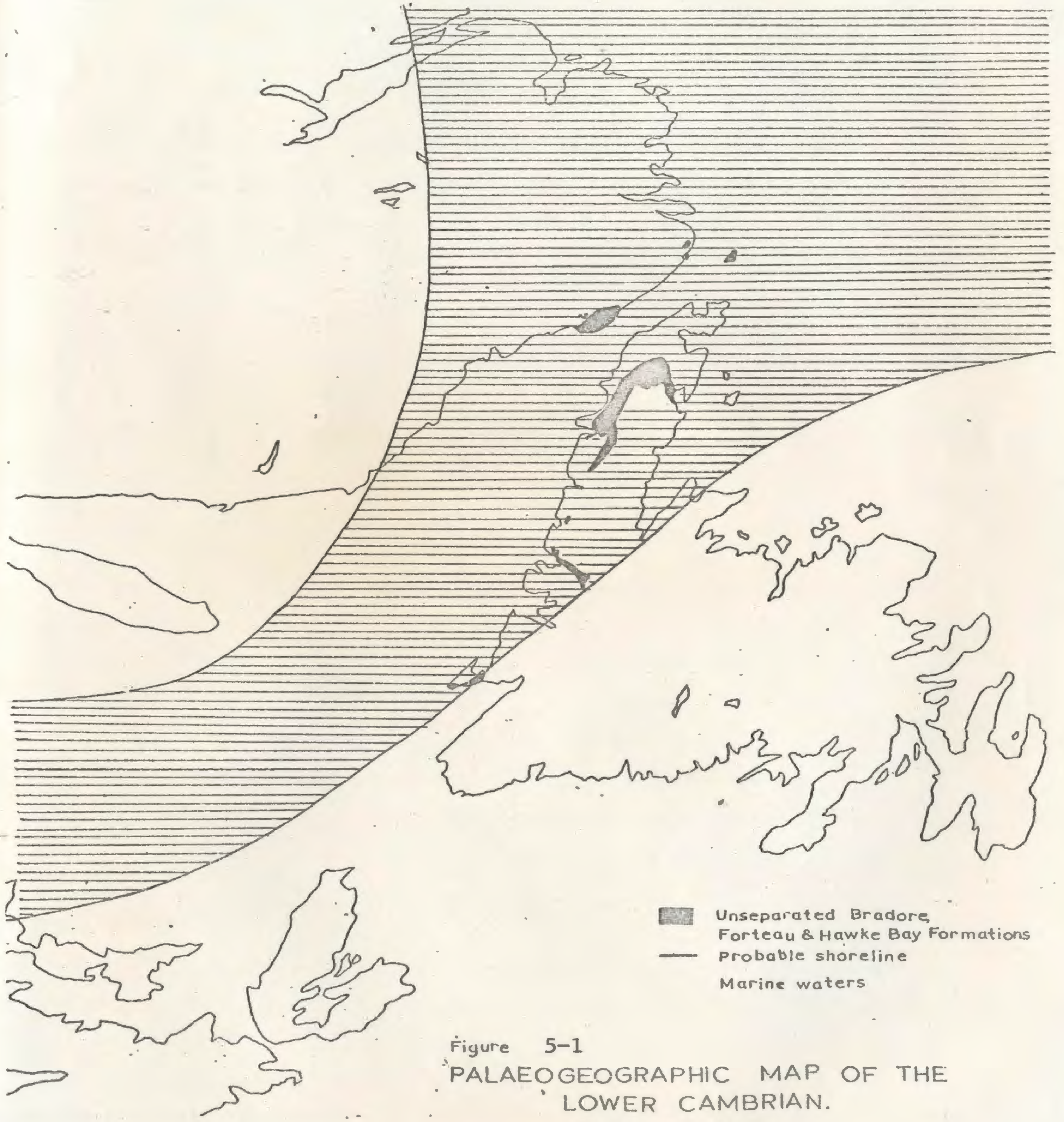


Figure 5-1
PALAEOGEOGRAPHIC MAP OF THE LOWER CAMBRIAN.
(Middle Waucoban)
Adapted from Schuchert, 1955.

agitation forming oolites and pisolites. Shallow water may be inferred by the presence of oscillation ripple marks found near L'Anse Amour (Fig. 4-25) and possible above-water sediments by the occurrence of rain impressions (Fig. 4-26).

ADDENDUM

After the first draft of the thesis was completed further studies (Swett, Klein and Smit, 1971; Swett and Smit, 1972) were made of comparable rocks to the Bradore Formation. The former concludes that the Cambrian Eriboll Sandstone of northwest Scotland, an identical deposit to the Bradore Sandstone, is also a tidal deposit, characterized by prolonged abrasion, a mineralogically maturing-upward sequence, bimodal frequency distribution of both dip angle and set thickness, together with rounded upper erosional surfaces on the cross strata. Further, they subdivided it into two members, again with similarities to the postulated subdivision of the Bradore Formation. The Lower Member comprises medium grained, well sorted mature quartzarenites and subarkosic sandstone, prominently cross stratified. The Upper Pipe Rock Member with Scolithus ichnofossils is massive bedded.

Swett and Smit (1972) infer from similarities between the Cambro-Ordovician sequences of western Newfoundland, northwest Scotland and central East Greenland that their depositional environments were juxtaposed on the western continental shelf of a proto Atlantic basin. Resemblances include stratigraphic sequences, sedimentary features and paragenetic histories.

The Bradore Formation thus represents a gradual marine transgression onto a stable craton and can be correlated with basal Cambrian sandstones from other areas in the North Atlantic. The sum total of similarities between these sandstones can hardly be fortuitous but probably necessitates deposition in the same sedimentary basin, signifying that the Proto Atlantic may have been smaller than the present Atlantic Ocean.

APPENDIX A – GEOMORPHOLOGY

LOCATION

Blanc Sablon	S.E. Blanc Sablon	Bay between Blanc Sablon & L'Anse au Clair	L'Anse au Clair	English Point	L'Anse au Loup	Diable Bay
17	17	17	17.5	17	-	-
46	46	46	46	49.5	50	-
69	69	71	68	-	-	-
84.5	84.5	-	84.5	77	-	-
90.5	-	93	92	91.5	-	-
101.5	113	109.5	112	-	-	-
116	118.5	-	-	-	-	-
127	129.5	-	-	126	-	-
136	136.5	-	-	-	-	-
145	143	-	-	-	-	153
188	-	183.5	178	172	171	-
-	202.5	-	-	198	-	-
218	-	220.5	218	211	216	-
-	228.5	-	-	247	245	-
-	-	-	-	-	269	271
-	-	-	-	-	290	-
-	-	-	-	-	311	321
-	-	-	-	-	-	427
-	-	-	-	-	-	448

Table 1-1

Rock terraces in the Bradore Formation measured above high tide (in feet)

Locations can be found on Figure 1-1 and description Page 15

APPENDIX B

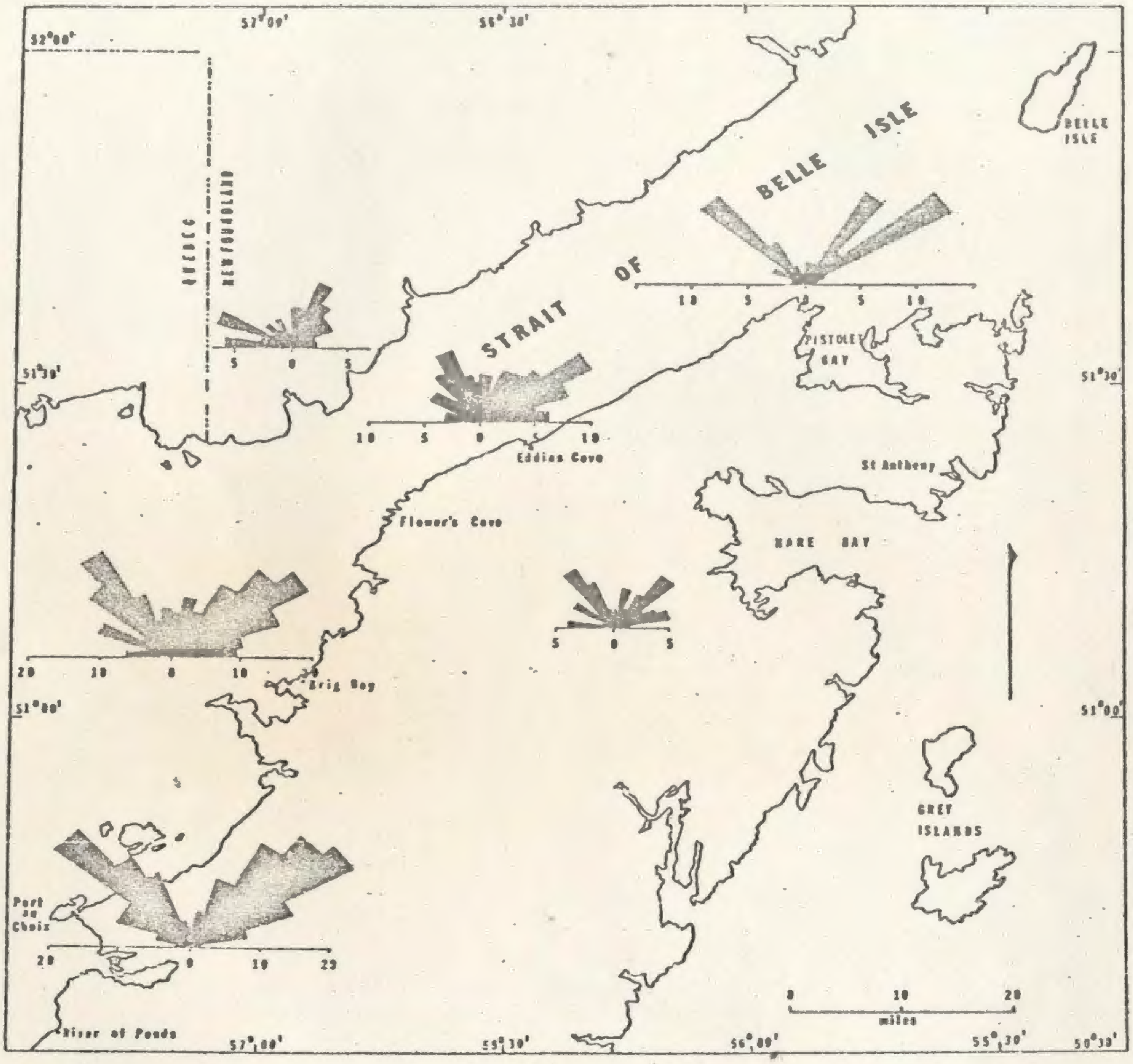
JOINTS

Cumming (1971) made a regional study of the joints on both sides of the Strait of Belle Isle (Fig. 2-5). He concluded that there was one joint system consisting of two well developed sets, representing extensional fracturing (Fig. 2-15). Results of readings taken at localities along the coast during this study tend to support this view (Fig. 2-6a and b).

Cumming (1971) reported the regional joint pattern in the Cape Norman area on the northern peninsula predates the faulting. In the present study no time relationship between joints and fault systems was found, although evidence of movement along some of the joints was clear.

During the early part of the Taconian Orogeny (post Early Ordovician) Southern Labrador, situated on the eastern St. Lawrence Platform and bordering the St. Lawrence geosyncline, underwent extensive erosion attributed to the occurrence of epeirogenic uplift and the following southward retreat of the sea (Poole, 1967). These movements are the probable cause of the structural pattern which occurs in the area. The overall deformation effects in the area are slight compared to those on the eastern side of the Strait of Belle Isle.

APPENDIX B - JOINTS



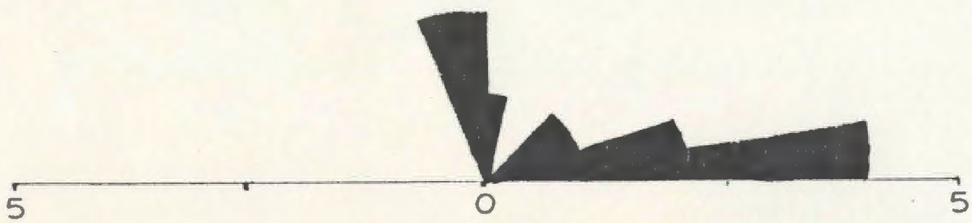
Rosette diagrams, proceeding from south to north, represent measurements at:

207 localities from Port Saunders area (12 I/11);
204 localities from Brig Bay (12 P/2) and Flower's Cove (12 P/7) areas;
59 localities from Salmon River area (12 P/1);
97 localities from Eddies Cove (12 P/8) and Big Brook (12 P/9). areas;
61 localities from Labrador (12 P/6, 12 P/7) and
65 localities from Raleigh area (2 M/12 west half).

Figure 2-5. Distribution of joints in Palaeozoic rocks in the Strait of Belle Isle region.
(Cumming,1971)

APPENDIX B - JOINTS

Figure 2-6a DISTRIBUTION OF JOINTS IN THE PRECAMBRIAN ROCKS.



(14 Readings, with angles of over 60° from the horizontal for the joint faces, taken from Lourdes du Blanc Sablon, Diable Bay and English Point.)

APPENDIX B - JOINTS

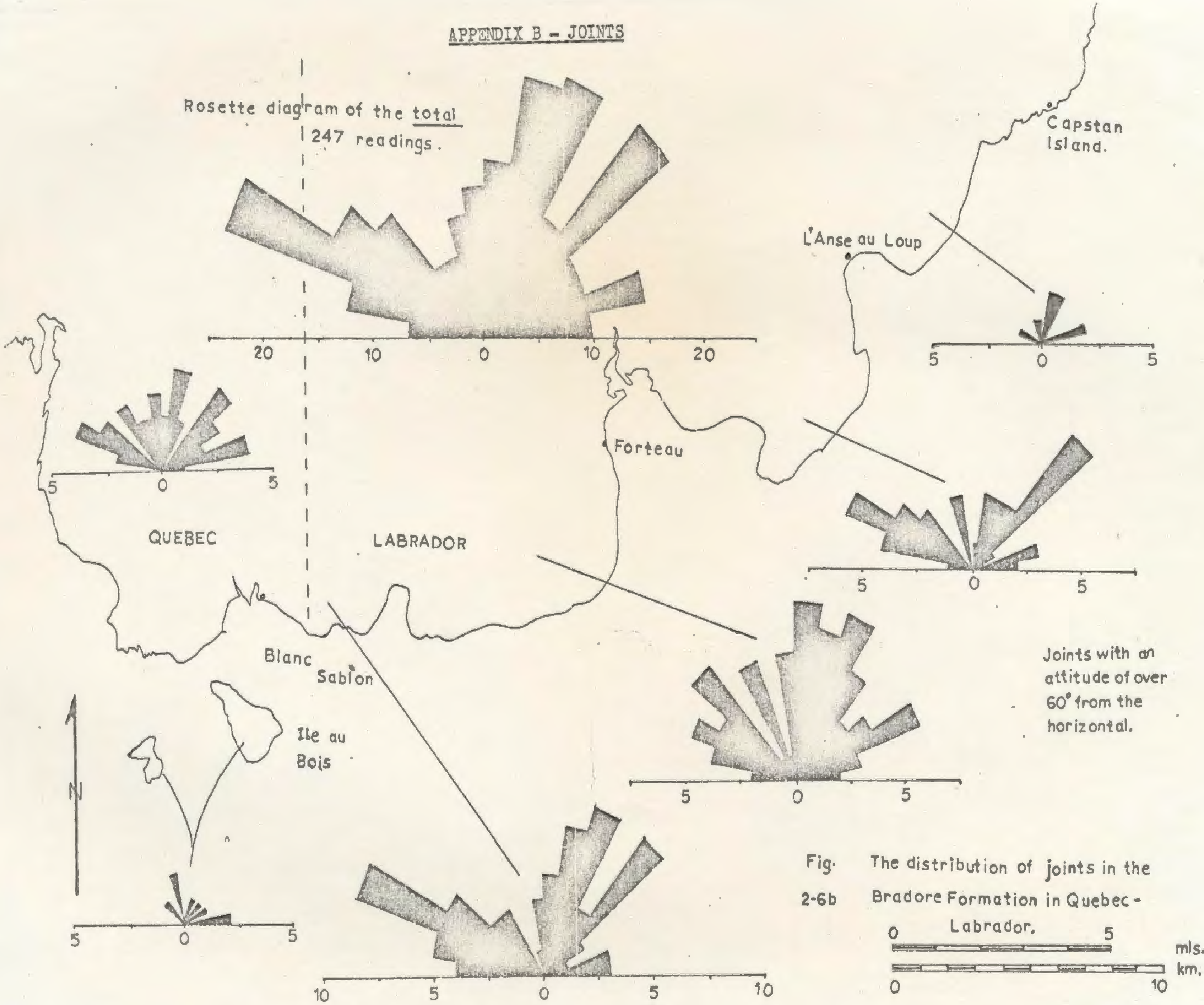


Fig. 2-6b The distribution of joints in the Bradore Formation in Quebec - Labrador.

APPENDIX C - STATISTICAL MEASURES

Statistical Measures	Symbol	Formula and How Derived
Millimeter Median	Md	Graphically: the 50% diameter on a Cumulative Frequency Curve
Phi Median	Md_ϕ	
Millimeter Arithmetic Mean	$\bar{X}$	For ungrouped values: $\frac{\Sigma X_i}{N}$
Graphic Mean (Folk)	M_z	$\frac{P_{16} + P_{50} + P_{84}}{3}$
Inclusive Graphic Standard Deviation	σ_i	$\frac{P_{84} - P_{16}}{4} + \frac{P_{95} - P_5}{6.6}$
Inclusive Graphic Skewness	Sk_i	$\frac{P_{16} + P_{84} - 2P_{50}}{2(P_{84} - P_{16})} + \frac{P_5 + P_{95} - 2P_{50}}{2(P_{95} - P_5)}$
Graphic Kurtosis	K_G	$\frac{P_{95} - P_5}{2.44\ (P_{75} - P_{25})}$

Formulae for Statistical Measures

APPENDIX C - STATISTICAL MEASURES

Formulae used in the calculation of cross stratification parameters

Vector mean was calculated by the formula:-

$$\Theta = \text{ARCTAN} \frac{W}{V}$$

Where Θ is the vector mean,

$$W = {}_{i=1n}E_{N_1} \quad \text{SIN } \Theta_1$$

$$V = {}_{i=1}E_{N_1} \quad \text{COS } \Theta_1$$

Θ is an individual azimuth

N is the total number of azimuths

Deviation from the vector mean was calculated from:-

$$S^2 = E(\Theta_{1M} - \Theta_V) \quad (N - 1)$$

Where S^2 is the variance

Θ_{1M} is the mean class azimuth

APPENDIX D - DATA

	Sample No.	Quartz	K.felds.	Matrix	Opaque	Calc./Dol.	Rock frag.	Chlorite	Musc.	Zircon	Rut.	Glau.	Others present
12	15/4377	89.6	8.6	0.2	1.1	-	-	-	0.3	0.2	-	-	-
12	15/4373	85.2	13.3	-	1.2	-	-	-	-	0.1	0.2	-	-
10	15/4366	75.5	22.8	0.1	1.3	-	-	-	-	0.2	0.1	-	-
9	15/4359	90.5	7.0	-	0.3	-	2.1	-	-	0.1	-	-	Tour
8	15/4355	90.9	8.8	-	0.2	-	-	-	0.1	-	-	-	-
7	15/4326	73.2	26.00	-	0.3	-	0.2	-	0.2	0.1	-	-	-
6	15/4318	74.5	19.7	0.2	-	-	0.8	-	-	-	-	-	4.8 zoisite
5	15/4314	78.2	21.7	-	-	-	-	-	0.1	-	-	-	-
4	15/4310	84.9	11.9	1.3	1.7	-	-	-	-	-	0.2	-	-
3	15/437	30.9	30.2	33.5	3.6	-	-	-	1.8	-	-	-	-
2	15/435	78.1	8.0	5.4	6.1	-	0.6	-	0.5	0.6	0.7	-	Apat/Tour
1	15/434	74.1	24.6	0.6	0.3	-	-	-	0.2	-	0.2	-	Apat/Tour
1	15/361	87.7	10.8	0.4	0.3	-	-	-	-	0.1		0.7	Tour
2	15/385	89.0	8.2	1.6	0.3	-	-	-	0.2	0.1		0.6	-
3	15/411	74.5	17.9	-	-	7.2	-	-	-	0.1		0.3	-
1	15/441	67.9	9.9	13.3	8.6	8.6	-	-	-	0.2		0.1	-
5	15/391	92.6	5.6	0.9	0.3	0.3	-	0.2	0.2	0.1		0.1	-
6	15/4387	93.0	5.8	0.7	0.5	0.5	-	-	-	-		-	-
7	20/493	85.0	4.8	-	1.9	8.3	-	-	-	-		-	-
8	20/507	94.5	5.4	-	0.1	0.1	-	-	-	-		-	-
9	20/505	76.3	22.7	0.7	0.2	-	-	-	-	0.1		-	-
10	20/5113	56.3	35.2	6.5	0.5	-	-	0.7	-	0.2		0.6	Epid.
11	20/5119	37.6	51.5	3.7	3.5	2.4	-	0.3	-	0.2		0.8	-
12	22/563	80.7	17.0	0.9	0.1	0.8	-	-	0.1	0.1	-	0.3	Apat/Epid.

Table 3-1 Percentage mineral composition of the Bradore Formation

Sample numbers are indicated on maps, Figures 3-1a(page 136) and 3-1b(Appendix G)

Matrix includes indistinguishable quartz and feldspar

APPENDIX D - DATA

Sample Number	Total Quartz	% Non Undulatory	% Undulatory	% Polycrystalline	
12 15/4377	89.6	87	13	0	Vertical Section
11 15/4373	85.2	86	14	0	
10 15/4366	75.5	72	28	0	
9 15/4359	90.5	52	42	6	
8 15/4355	90.9	72	27	1	
7 15/4326	73.2	42	56	2	
6 15/4318	74.5	22	62	16	
5 15/4314	79.2	54	44	2	
4 15/4310	84.9	40	50	10	
3 15/437	30.9	66	32	2	
2 15/435	78.1	26	72	2	
1 15/434	74.1	26	66	8	
1 15/361	87.7	88	12	0	Topmost Bed
2 15/385	89.0	80	18	2	
3 15/411	74.5	86	14	0	
4 15/391	92.6	62	36	2	
5 15/4387	93.0	74	26	0	
6 20/5113	56.3	92	8	0	

Location of samples is indicated on Figures 3-1a (Page 36) and 3-1b (Appendix G).

Table 3-2 Percentage of Quartz Types in the Bradore Formation

APPENDIX D - DATA

Group	Sample Number	Median diameter mm. Md	Median diameter phi Md ϕ	Graphic mean phi M_z	Arithmetic mm.	Arithmetic phi $\bar{X}$	Inclusive Graphic Standard Deviation σ_i	Inclusive Graphic Skewness Sk_i	Graphic kurtosis K_G	Graphic kurtosis K_G' $\frac{KG}{K_G+1}$
Vertical Section	12 15/4377	0.58	+0.80	+0.69	0.71	+ 0.50	0.81	-0.18	0.86	0.46
	11 15/4373	0.44	+1.20	+1.18	0.49	+ 1.05	0.73	-0.08	1.40	0.70
	10 15/4366	0.44	+1.23	+1.17	0.53	+ 0.90	0.88	-0.15	1.08	0.52
	9 15/4359	0.52	+0.95	+0.82	0.76	+ 0.40	1.08	-0.22	0.89	0.47
	8 15/4355	1.25	-0.33	-0.27	1.22	- 0.30	0.72	+0.12	1.11	0.53
	7 15/4326	0.32	+1.65	+1.53	0.38	+ 1.35	0.71	-0.27	1.06	0.52
	6 15/4318	1.83	-0.88	-0.87	1.93	- 0.94	0.73	+0.05	0.87	0.46
	5 15/4314	1.10	-0.13	-0.14	1.77	- 0.85	0.70	-0.02	0.89	0.47
	4 15/4310	0.79	+0.33	+0.13	1.20	- 0.25	0.96	-0.16	1.13	0.53
	3 15/437	0.48	+1.05	+1.13	0.54	+ 0.90	1.00	+0.09	0.82	0.45
	2 15/435	1.10	-0.18	-0.27	1.33	- 0.40	0.62	-0.28	1.40	0.58
	1 15/434	1.32	-0.43	-0.45	1.49	- 0.55	0.69	-0.10	1.06	0.52
Topmost Bed'	1 15/361	0.55	+0.88	+0.87	0.57	+ 0.80	0.54	-0.01	0.80	0.44
	2 15/385	0.60	+0.73	+0.58	0.79	+ 0.35	0.72	-0.36	0.84	0.46
	3 15/411	0.40	+1.30	+1.18	0.45	+ 1.15	0.48	-0.39	1.13	0.53
	4 15/441	0.47	+1.08	+1.00	0.65	+ 0.61	0.81	-0.32	1.38	0.58
	5 15/391	1.05	-0.05	-0.09	1.04	- 0.10	0.52	-0.14	1.01	0.50
	6 15/4387	0.46	+1.10	+1.09	0.47	+ 1.10	0.41	-0.08	0.98	0.49
	7 20/493	0.60	+0.75	+0.77	0.61	+ 0.70	0.50	-0.00	1.21	0.55
	8 20/507	0.75	+0.38	+0.38	0.81	+ 0.30	0.54	+0.01	1.00	0.50
	9 20/505	0.52	+0.93	+0.94	0.54	+ 0.90	0.42	-0.01	1.05	0.51
	10 20/5113	0.31	+1.70	+1.73	0.30	+ 1.70	0.54	+0.03	0.87	0.47
	11 20/5119	0.22	+2.20	+2.22	0.19	+ 2.38	0.38	+0.07	1.25	0.56
	12 22/563	0.39	+1.30	+1.31	0.40	+ 1.30	0.43	-0.00	1.04	0.51

Table 3-3 Grain size parameters of the Bradore Formation

Sample numbers are located on maps, Figures 3-1a (Page 136) and 3-1b (Appendix G).

APPENDIX D - DATA

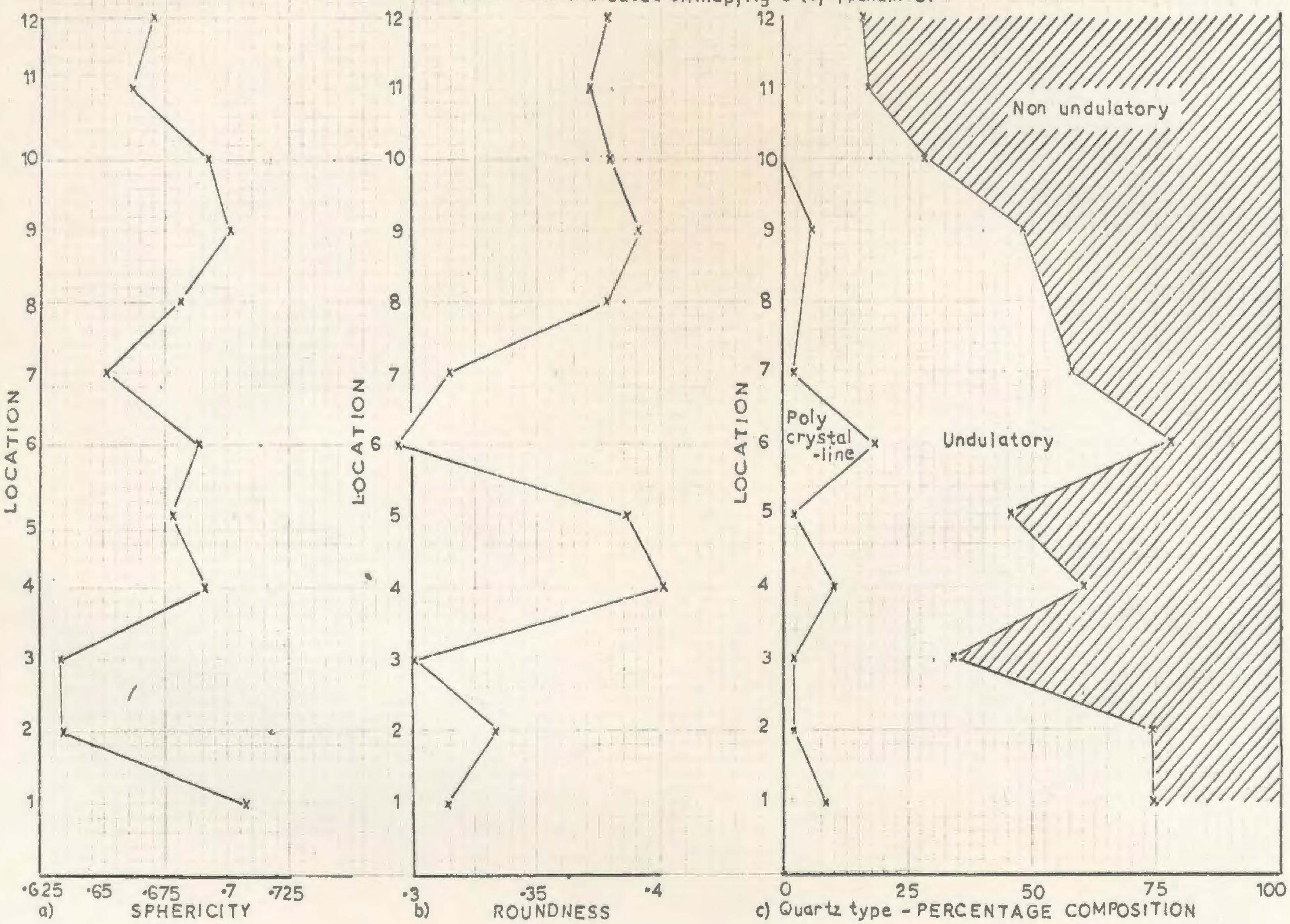
	Sample No.	Mean phi units	Standard dev. phi classes	b_1	b_2	Skewness SK	Kurtosis K	Sphericity b/a	Roundness
Vertical Section	12 15/4377	+0.74	0.86	-0.09	2.41	-0.04	-0.59	0.67	.38
	11 15/4373	+1.23	0.85	+0.09	2.93	+0.05	-0.65	0.66	.37
	10 15/4366	+1.25	0.92	-0.43	2.80	-0.21	-0.20	0.69	.38
	9 15/4359	+0.79	1.13	+0.60	2.74	-0.30	-0.26	0.70	.39
	8 15/4355	-0.06	0.81	+0.58	3.51	+0.29	+0.51	0.68	.38
	7 15/4326	+1.61	0.79	-0.40	2.79	-0.20	-0.21	0.65	.32
	6 15/4318	-0.77	0.77	+0.26	2.67	+0.13	-0.33	0.69	.29
	5 15/4314	+0.03	0.83	+0.10	2.93	+0.05	-0.07	0.68	.39
	4 15/4310	+0.30	1.21	-0.93	3.00	-0.47	+0.01	0.69	.40
	3 15/437	+1.30	0.94	-0.15	2.87	-0.07	-0.13	0.63	.30
	2 15/435	+1.20	0.95	-0.56	4.46	-0.28	+1.46	0.63	.34
	1 15/434	-0.12	0.87	0.45	4.12	-0.23	+1.12	0.71	.31
		-0.31							
Topmost Bed	1 15/361	+0.95	0.61	-0.04	2.61	-0.02	-0.39	0.72	.43
	2 15/385	+0.60	0.68	-0.23	2.39	-0.12	-0.61	0.69	.45
	3 15/411	+1.19	0.54	-0.47	3.93	0.23	+0.93	0.69	.44
	4 15/441	+0.96	0.96	-0.72	3.30	-0.36	+0.30	0.71	-
	5 15/391	+0.09	0.42	-0.29	3.03	-0.15	+0.03	0.76	.47
	6 15/4387	+1.15	0.50	-0.13	1.74	-0.07	-1.26	0.67	.46
	7 20/493	+0.78	0.57	-0.03	2.48	-0.01	-0.52	0.71	-
	8 20/507	+0.39	0.65	+0.06	2.36	+0.03	-0.64	0.73	-
	9 20/505	+0.94	0.54	+0.08	1.84	+0.04	-1.16	0.73	-
	10 20/5113	+1.80	0.57	+0.05	2.41	+0.03	-0.59	0.69	.44
	11 20/5119	+2.43	0.51	-0.03	3.67	-0.02	+0.67	0.70	-
	12 22/563	+1.38	0.52	-0.06	3.00	-0.03	0.00	0.68	-

Table 3-4 Grain size parameters based on moment measures and shape analysis

Sample numbers are indicated on maps, figures 3-1a (P.136) and 3 - 1b (Appendix G)

APPENDIX E - DATA PLOTS

Fig. 3-3 DISTRIBUTION OF PARAMETERS IN VERTICAL SECTION
(Locations indicated on map, fig 3-1b, Appendix G)



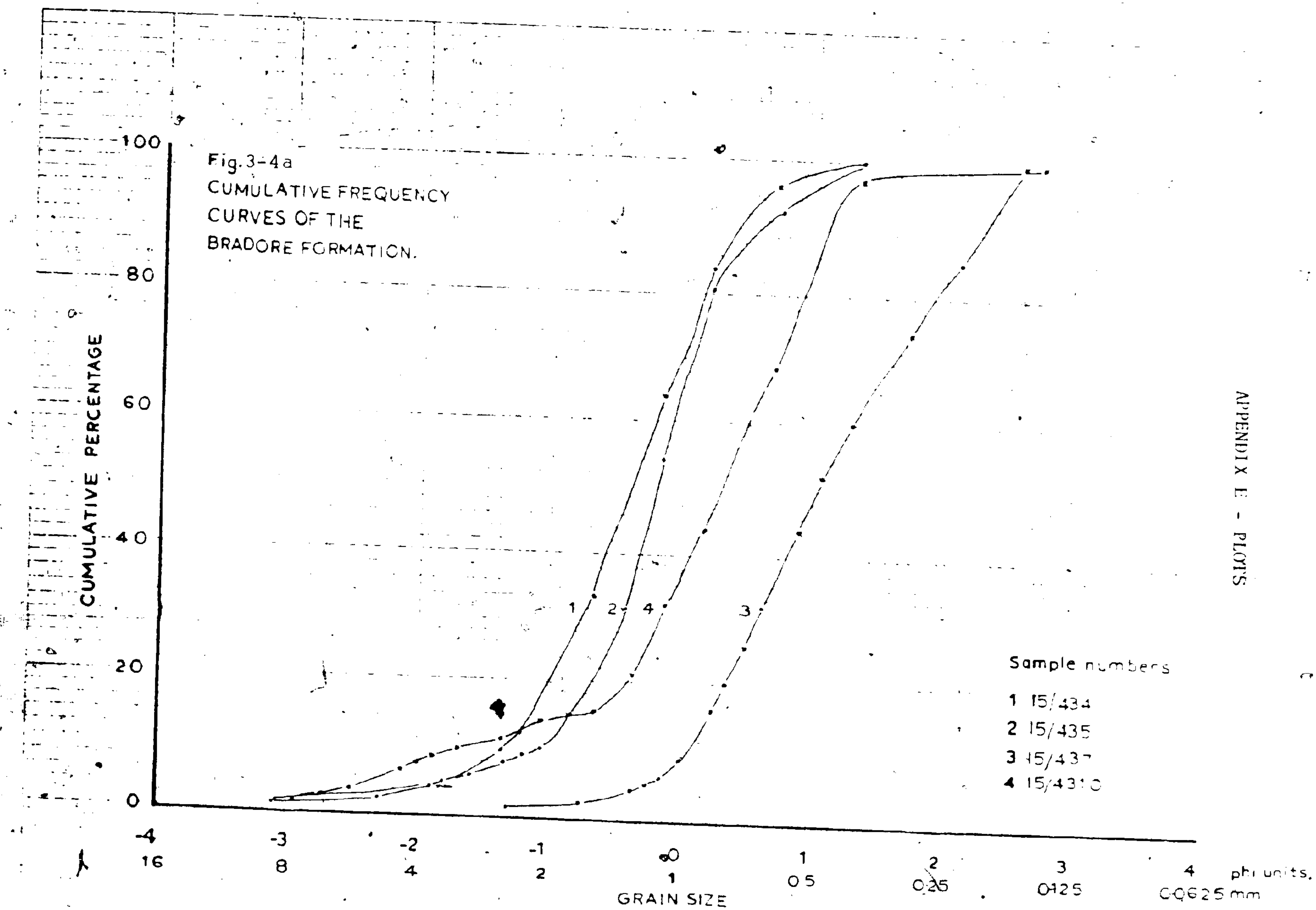


Fig.3-4a
CUMULATIVE FREQUENCY CURVES OF THE BRADORE FORMATION.

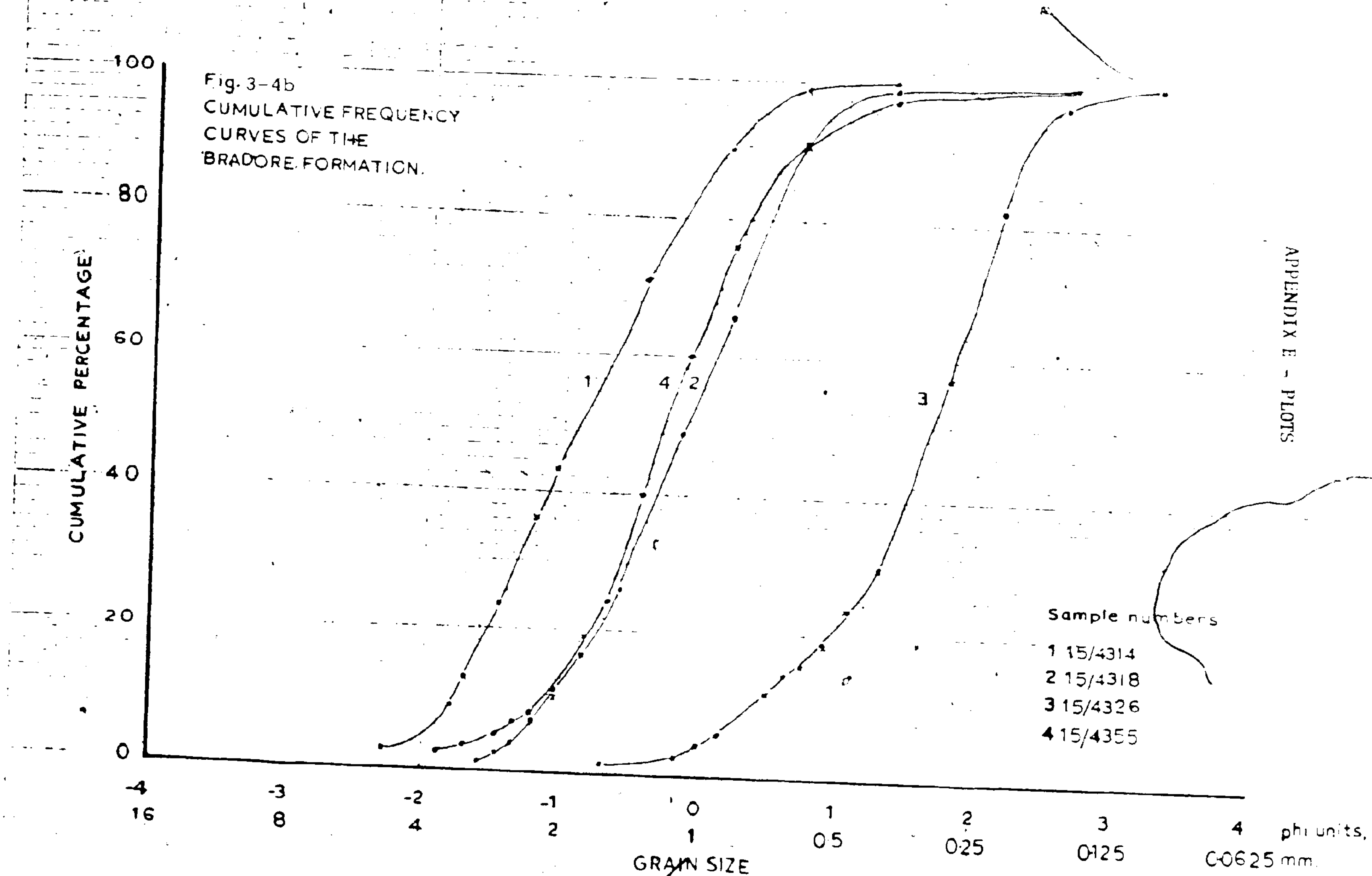


Fig. 3-4b
CUMULATIVE FREQUENCY
CURVES OF THE
BRADORE FORMATION.
CUMULATIVE PERCENTAGE
100
80
60
40
20
0
1
4
2
3
Sample numbers
1 15/4314
2 15/4318
3 15/4326
4 15/4355
-4
16
-3
8
-2
4
-1
2
0
1
1
0·5
2
0·25
3
0·125
4
0·0625
phi units,
mm.
GRAIN SIZE

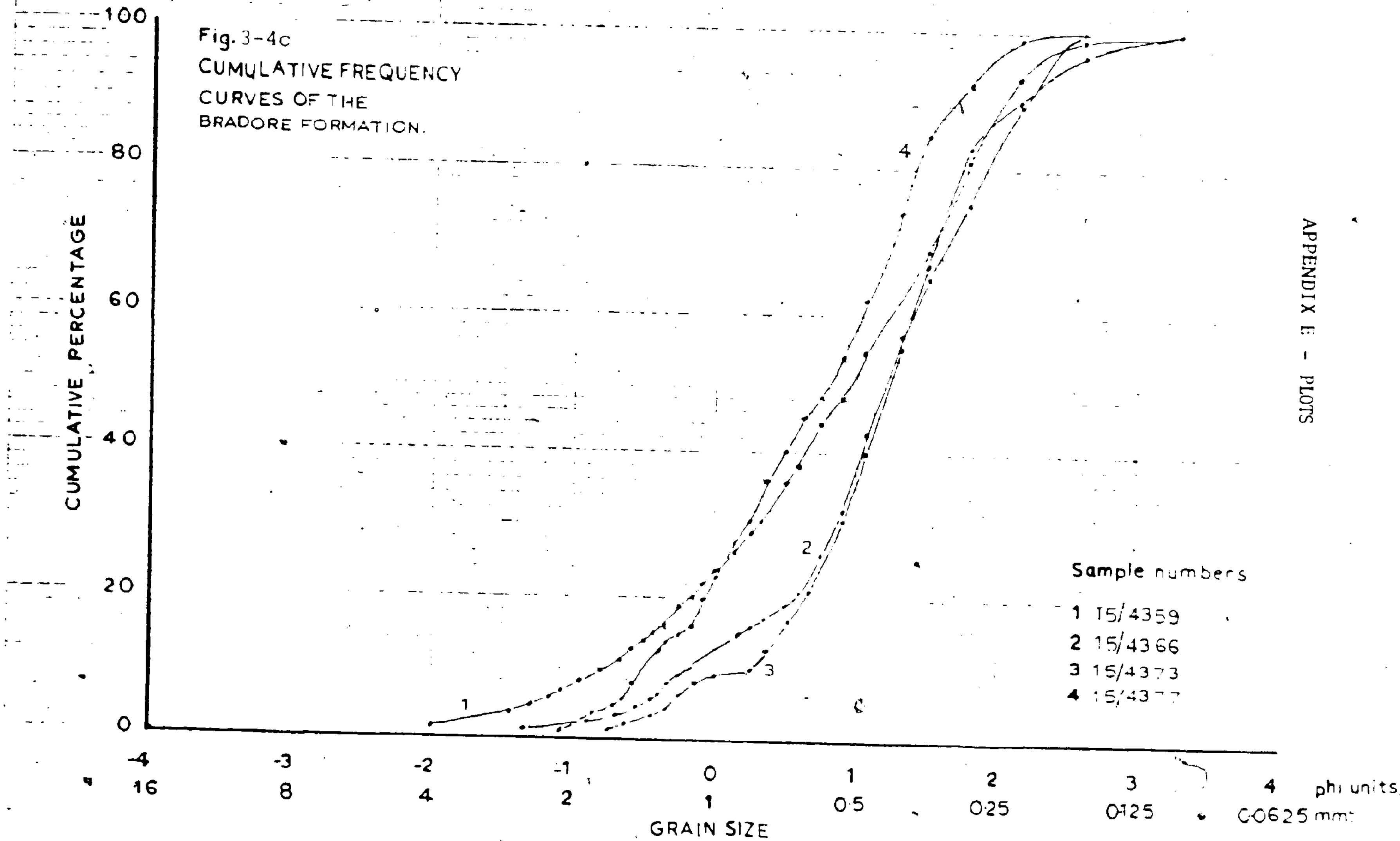


Fig. 3-4c
CUMULATIVE FREQUENCY CURVES OF THE BRADORE FORMATION.

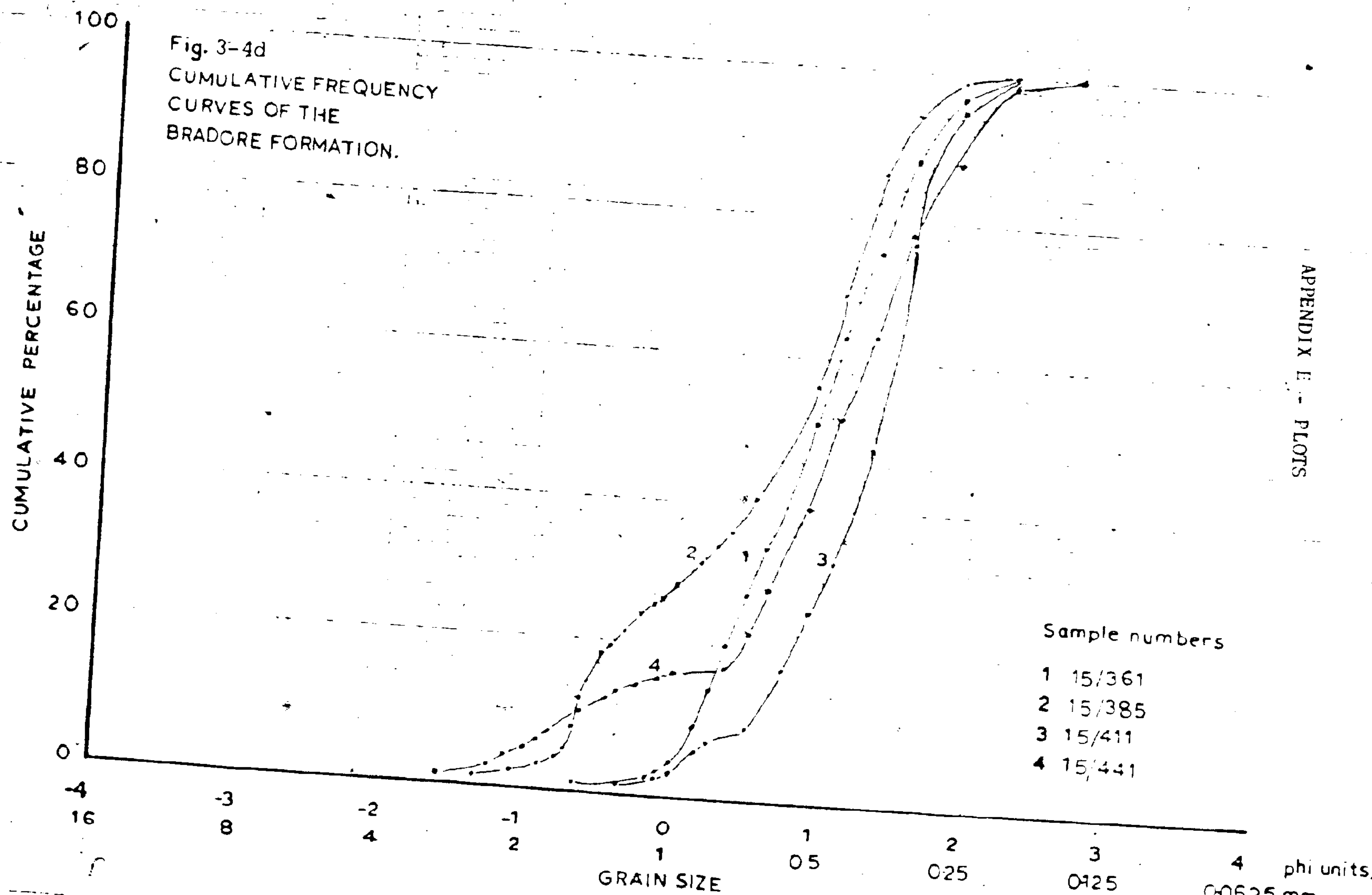


Fig. 3-4d
CUMULATIVE FREQUENCY CURVES OF THE BRADORE FORMATION.

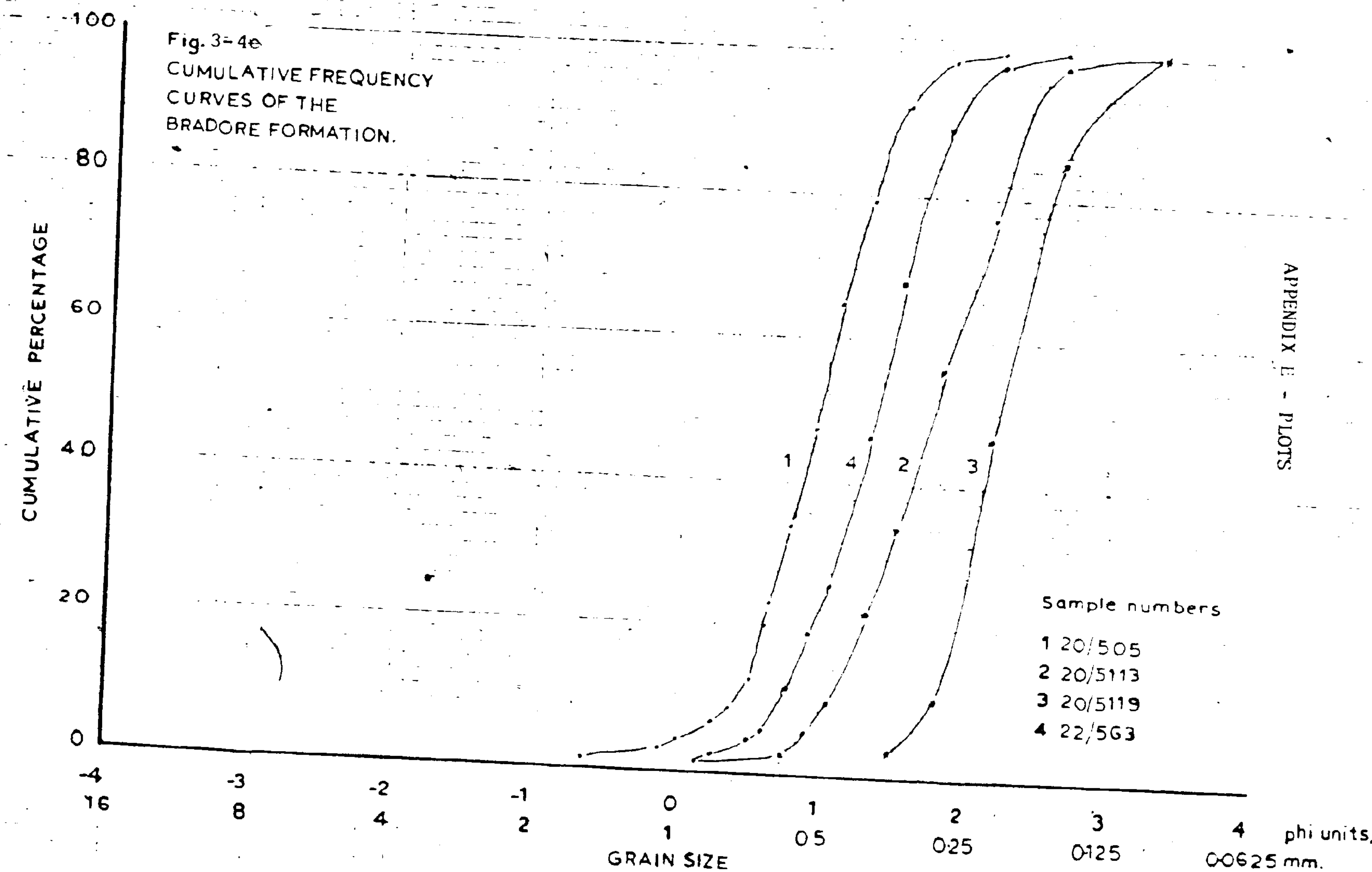


Fig. 3-4e
CUMULATIVE FREQUENCY CURVES OF THE BRADORE FORMATION.

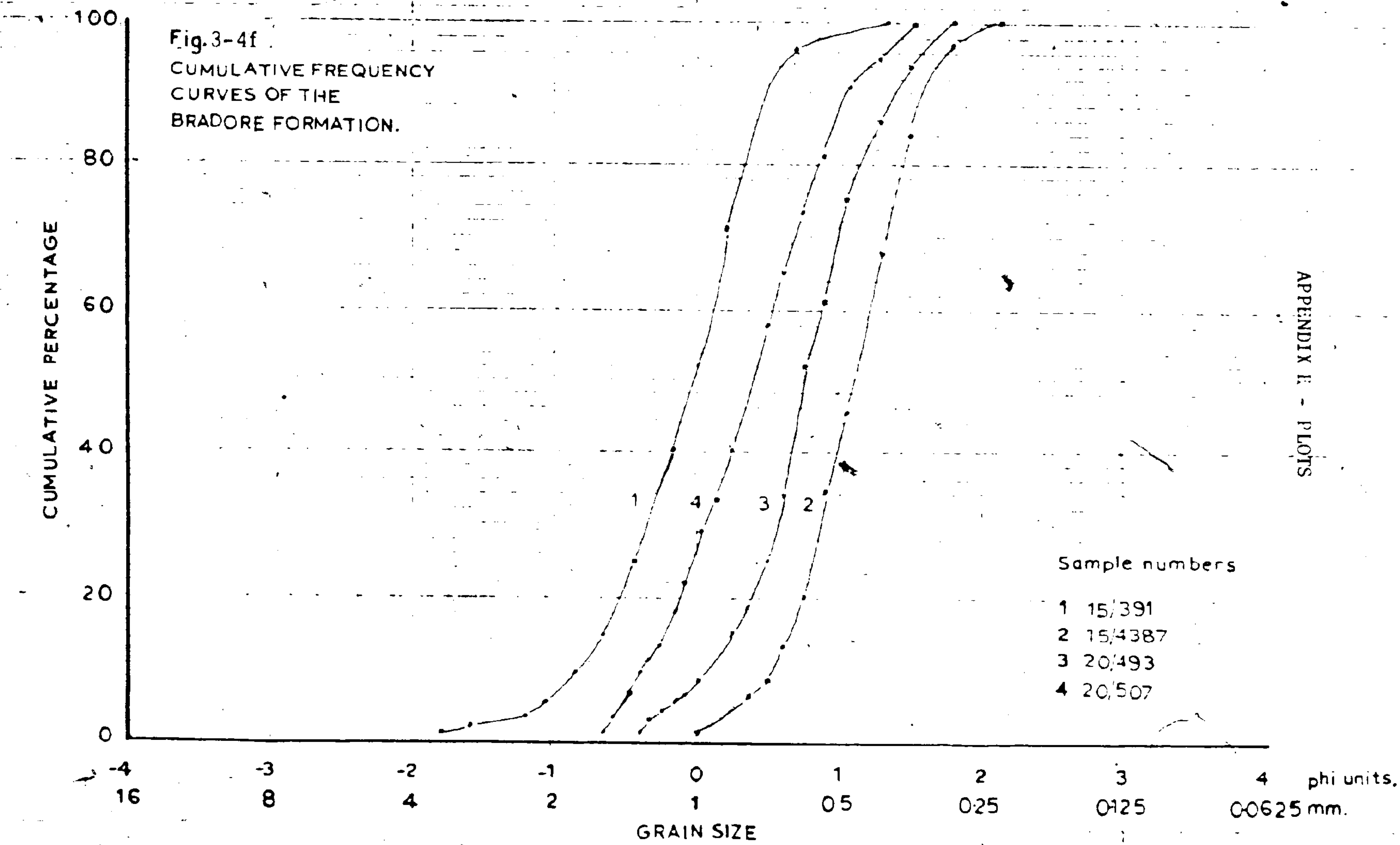
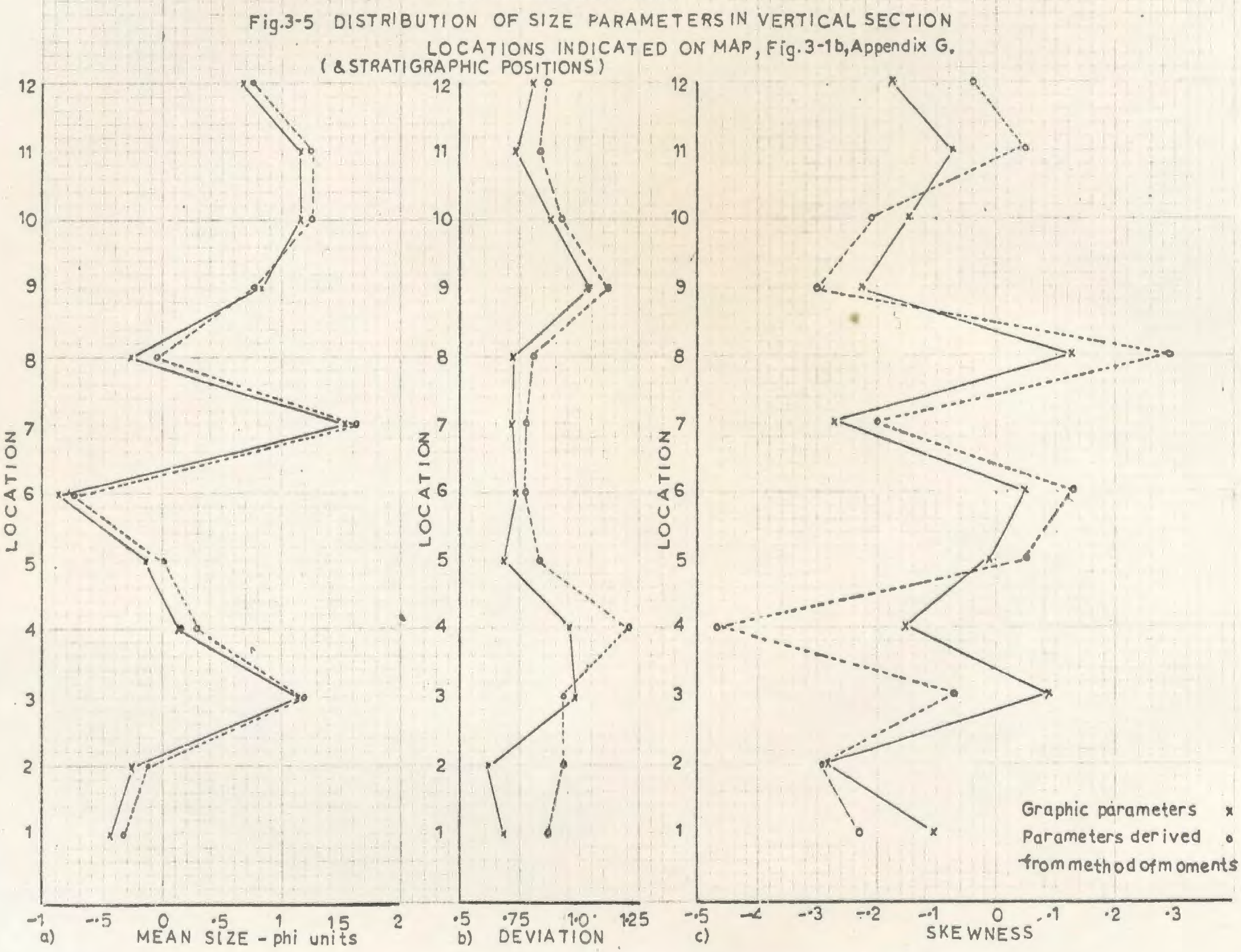


Fig. 3-4f
CUMULATIVE FREQUENCY CURVES OF THE BRADORE FORMATION.

APPENDIX E - DATA PLOTS



APPENDIX E - PLOTS

Fig. 3-6a

DISTRIBUTION OF SIZE PARAMETERS AGAINST LOCATION
(Locations indicated on map, fig. 3-1a, p.42).

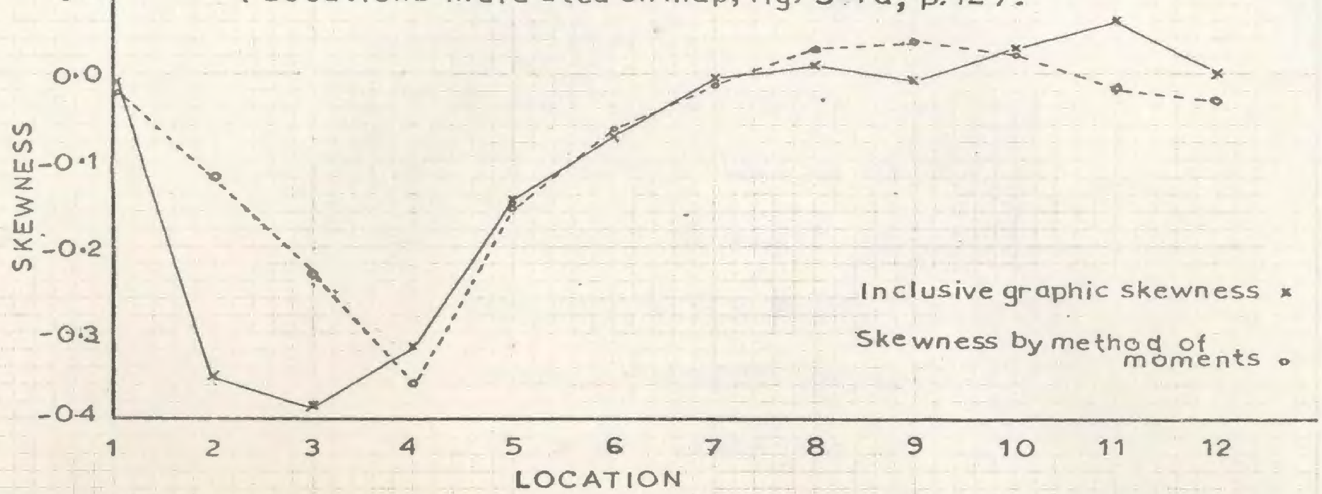


Fig. 3-6b

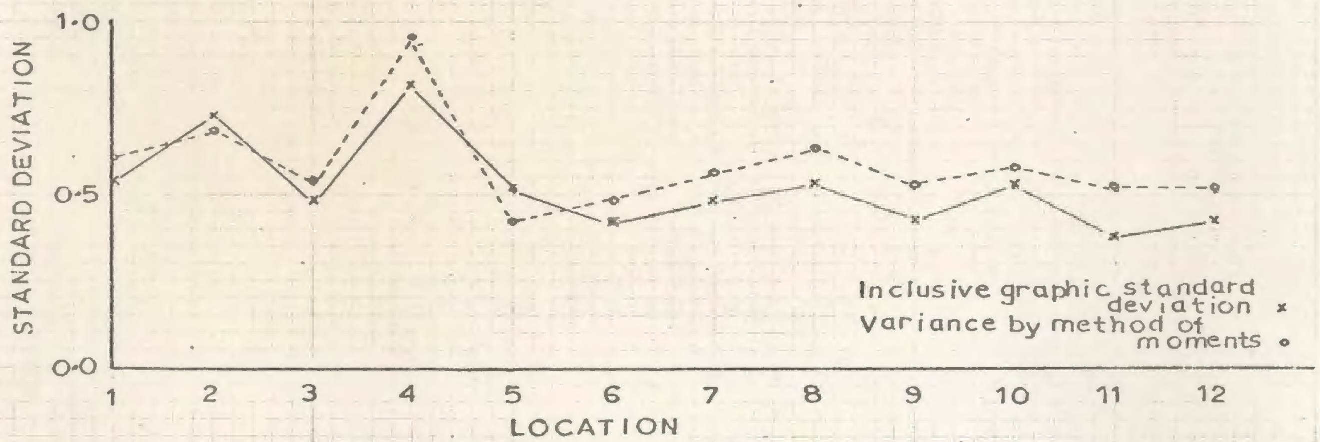
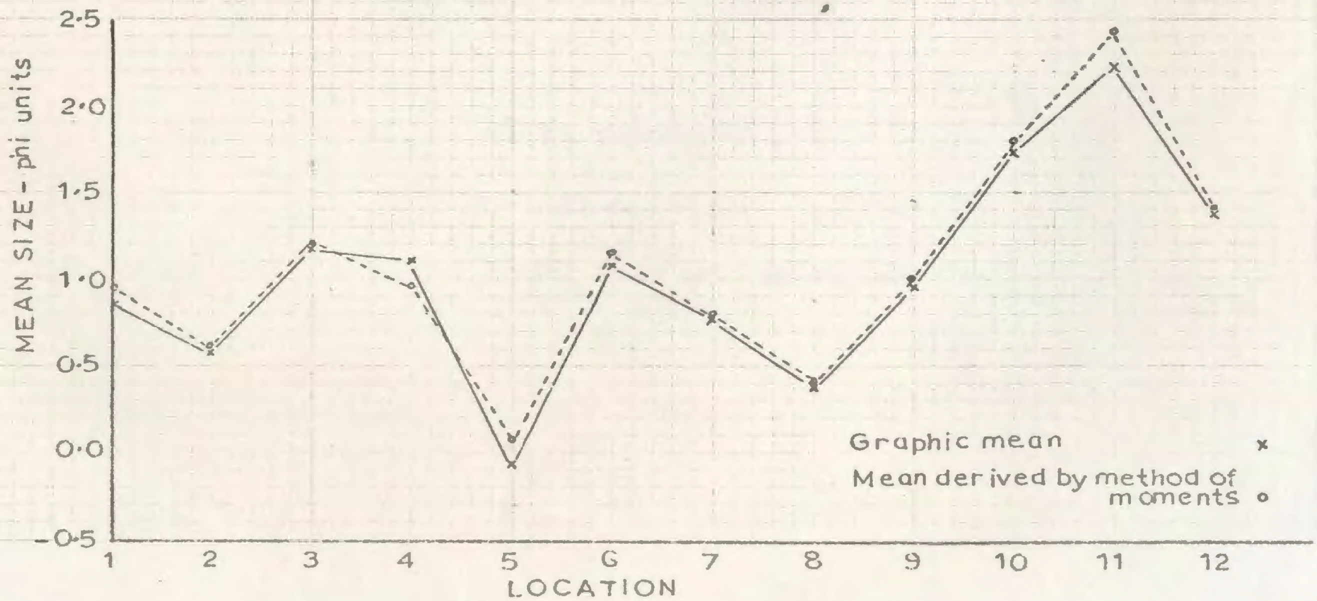


Fig. 3-6c



APPENDIX E - DATA PLOTS

Fig.3-7 SCATTER PLOT OF MEAN SIZE VERSUS DEVIATION

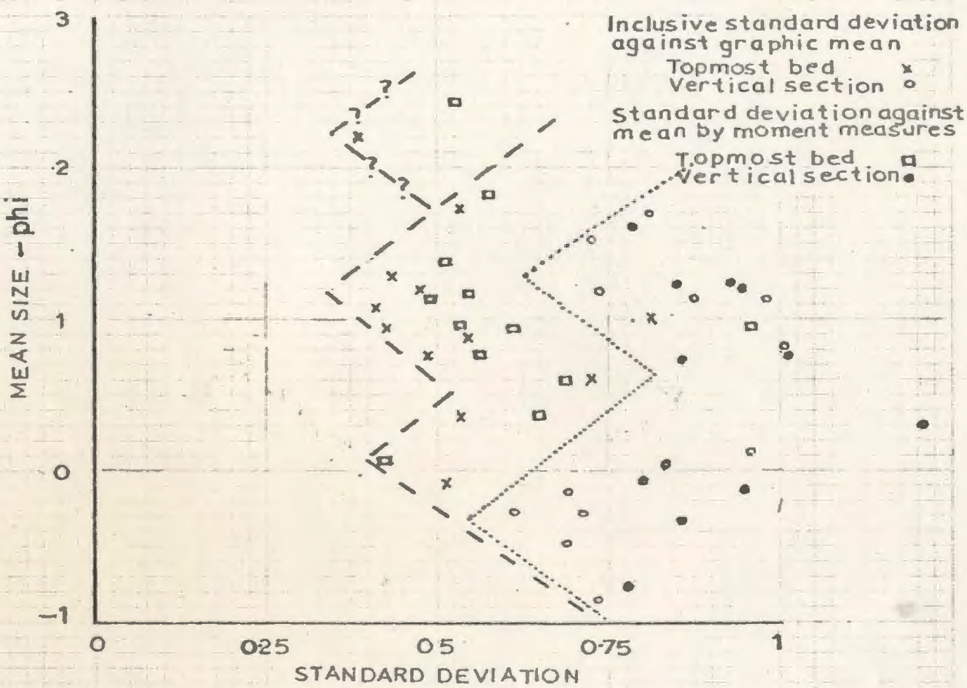
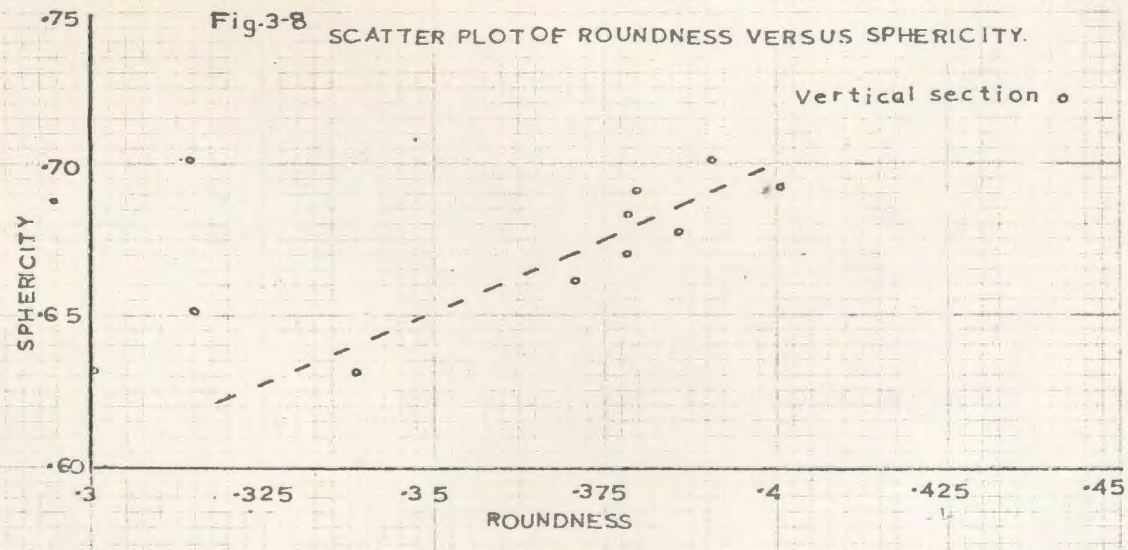


Fig.3-8 SCATTER PLOT OF ROUNDNESS VERSUS SPHERICITY.



APPENDIX E - DATA PLOTS

Fig. 3-9

SCATTER DIAGRAM OF SKEWNESS VERSUS MEAN SIZE

OF a) Topmost bed

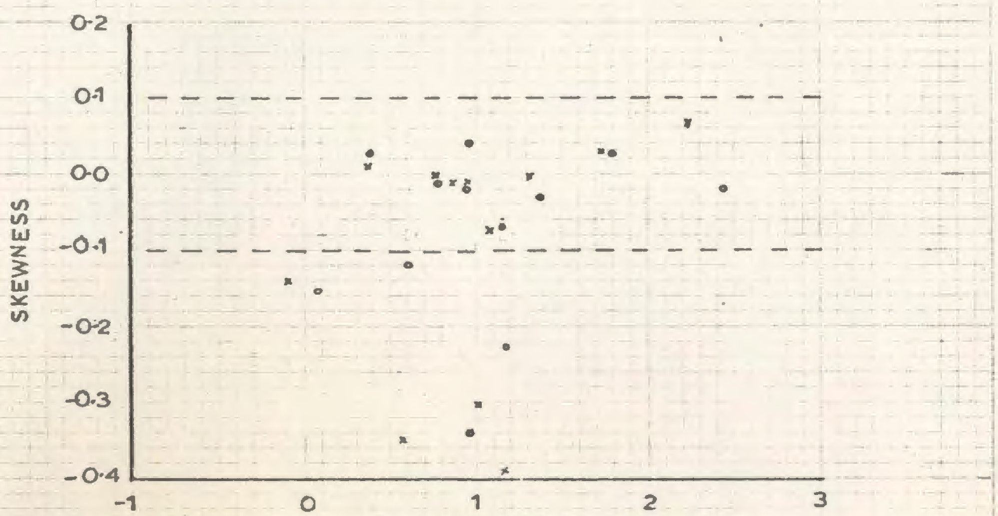


Fig. 3-9a

b) Vertical section

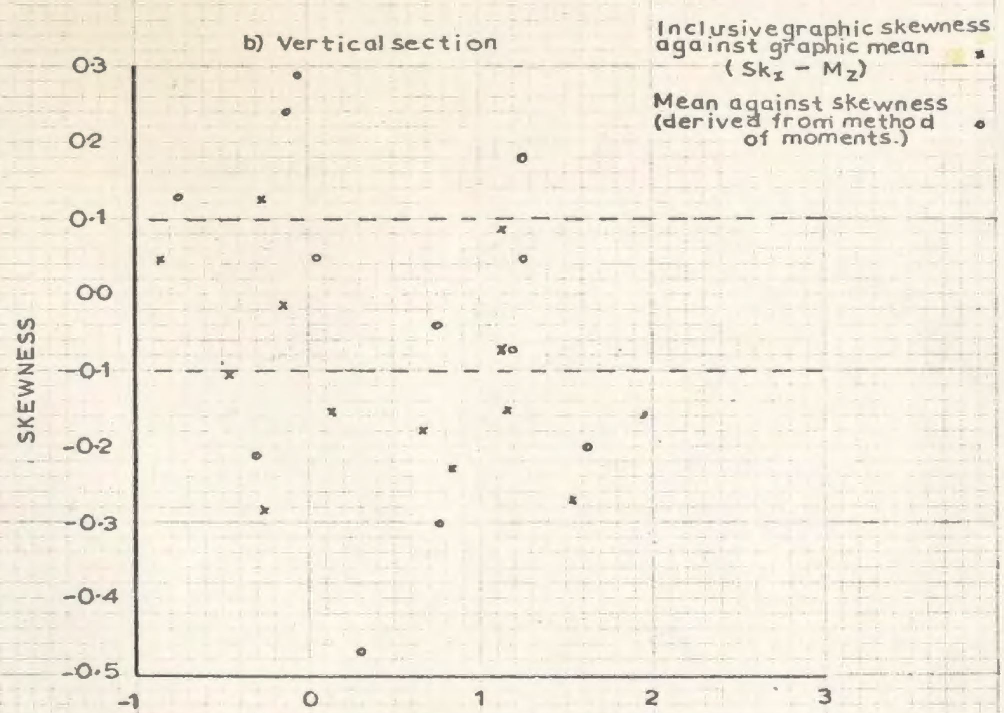


Fig. 3-9b

Area shaded is within the range of the normal curve
(FOLK & WARD, 1957)

APPENDIX E - PLOTS

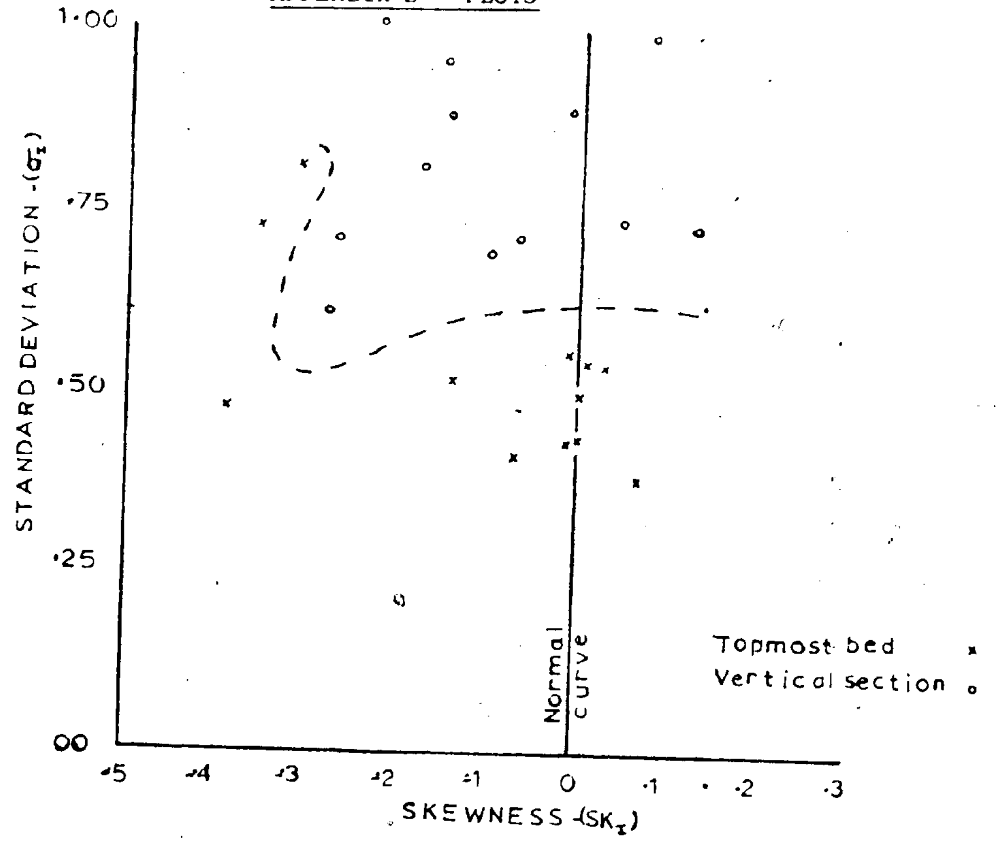


Fig. 3-10 SCATTER PLOT OF SKEWNESS VERSUS STANDARD DEVIATION

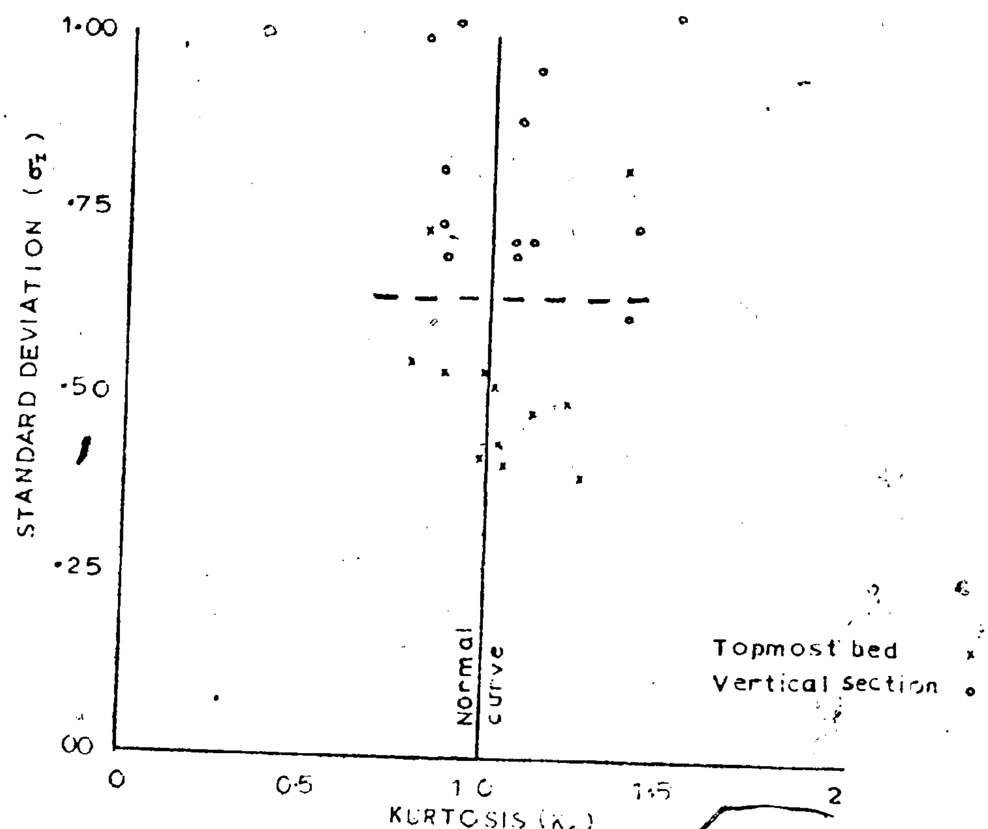
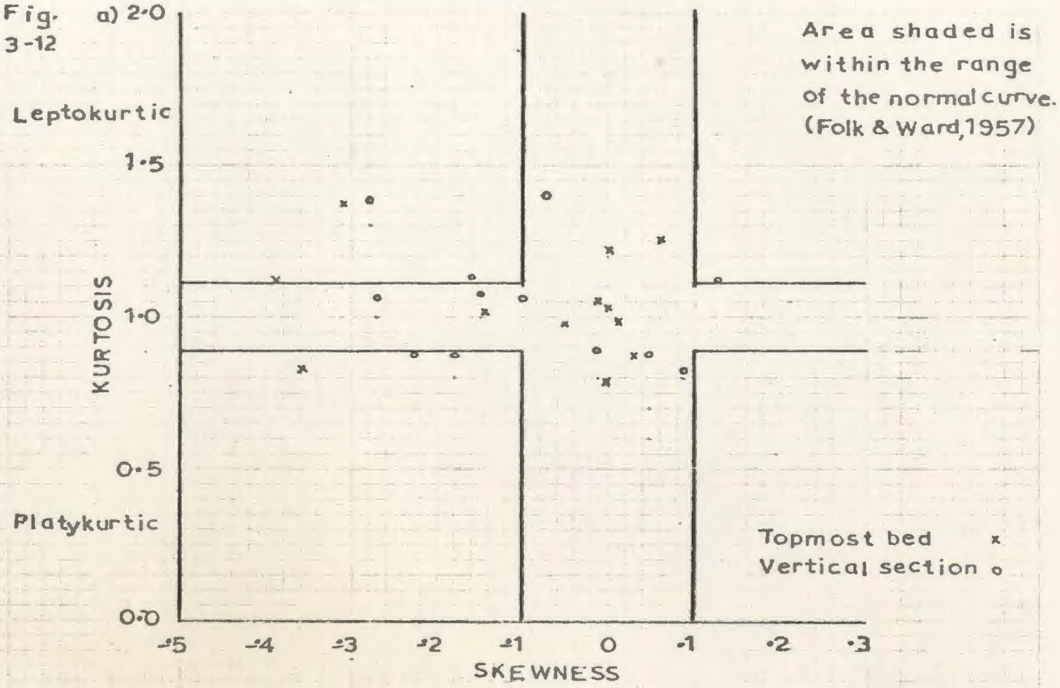


Fig. 3-11 SCATTER PLOT OF KURTOSIS VERSUS STANDARD DEVIATION

APPENDIX E - DATA PLOTS

Fig. 3-12 a)

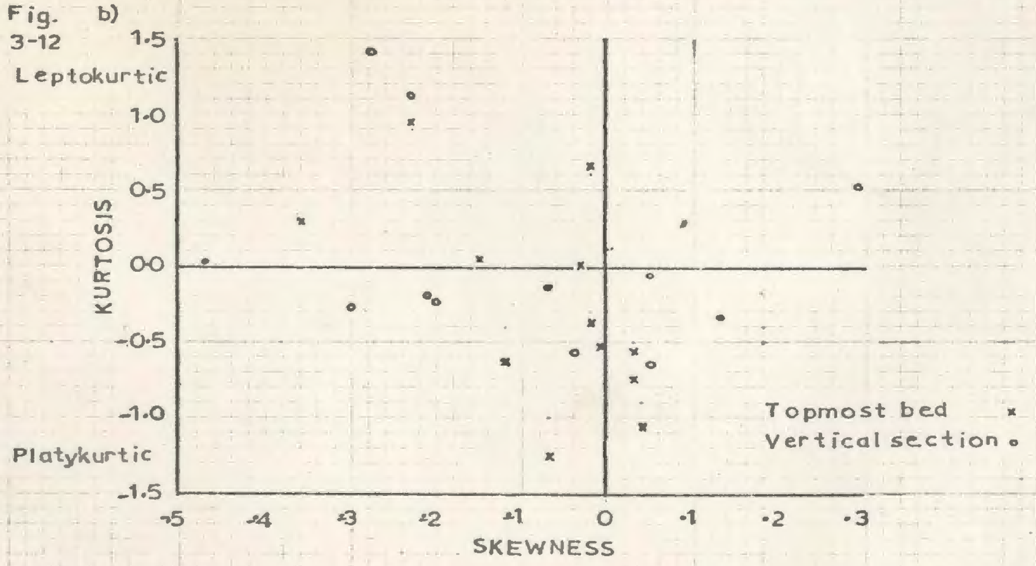


SCATTER PLOTS OF SKEWNESS VERSUS KURTOSIS

a) Graphic kurtosis against inclusive graphic skewness.

b) Kurtosis against skewness derived by the method of moments.

Fig. 3-12 b)



—— represents kurtosis and skewness values for a normal curve. (Griffiths,1967)

Example of the procedure for

Computation of Statistics from the Moments of a Frequency Distribution

(Griffiths, 1967)
Sample No. 15/4355.

Fig. 3-13

X = midpoint of each class f^{*} = frequency

$\bar{X}$ = arithmetic mean $\bar{X}'$ = assumed mean =

c = class interval = 1 phi $d = \dfrac{X - \bar{X}'}{c}$

Class limits, phi units	X_ϕ	f	d	fd	fd^2	fd^3	fd^4
-5 - -4	-4.5						
-4 - -3	-3.5						
-3 - -2	-2.5						
-2 - -1	-1.5	11	-1	-11	11	-11	11
-1 — 0	-0.5	48	0	-	-	-	-
0 — 1	0.5	30	+1	30	30	30	30
1 - 2	1.5	8	2	16	32	64	128
2 — 3	2.5	3	3	9	27	81	243
3 — 4	3.5						
4 — 5	4.5						
5 — 6	5.5						
TOTAL		100		44	100	164	412

Moments around the arbitrary origin

$$n_1 = \frac{\Sigma fd}{\Sigma f} = 0.44 \qquad n_2 = \frac{\Sigma fd^2}{\Sigma f} = 1.00$$

$$n_3 = \frac{\Sigma fd^3}{\Sigma f} = 1.64 \qquad n_4 = \frac{\Sigma fd^4}{\Sigma f} = 4.12$$

Moments around the true mean corrected for grouped data

$$m_1 = \bar{X} = \bar{X}' + cn_1 = -0.5 + 0.44 = -0.06$$

$$m_2 = \delta^2 = c^2(n_2 - n_1^2) = 1.0 - 0.1936 = 0.8064$$

$$\delta = \sqrt{\delta^2} = 0.898$$

$$m_3 = c^3(n_3 - 3n_2n_1 + 2n_1^3) = 1.64 - 3(0.44) + 2\,(0.085184)$$

$$= 0.490368$$

$$\sqrt{b_1} = \frac{m_3}{\delta^{3/2}} = \frac{0.490368}{0.851} = 0.5762256$$

$$Sk = \frac{\sqrt{b_1}}{2} = 0.2881128$$

$$m_4 = c^4(n_4 - 4n_3n_1 + 6n_1^2n_2 - 3n_1^4)$$

$$= 4.12 - 4(1.64)\ (0.44) + 6(0.1936) - 3(0.0374809)$$

$$= 4.12 - 2.8864 + 1.1616 - 0.1124427 = 2.2827573$$

$$b_2 = \frac{m_4}{\delta^4} = \frac{2.2827573}{0.6502873} = 3.5104$$

$$K = b_2 - 3 = 0.5104$$

Summary statistics

$$\bar{X}_\phi = -0.06 \qquad \delta_\phi = 0.8064$$

$$\sqrt{b_1} = 0.5762 \qquad b_2 = 3.5104$$

Fig 3-14 SCATTER DIAGRAM OF AVERAGE ROUNDNESS AND GEOMETRIC MEAN SIZE

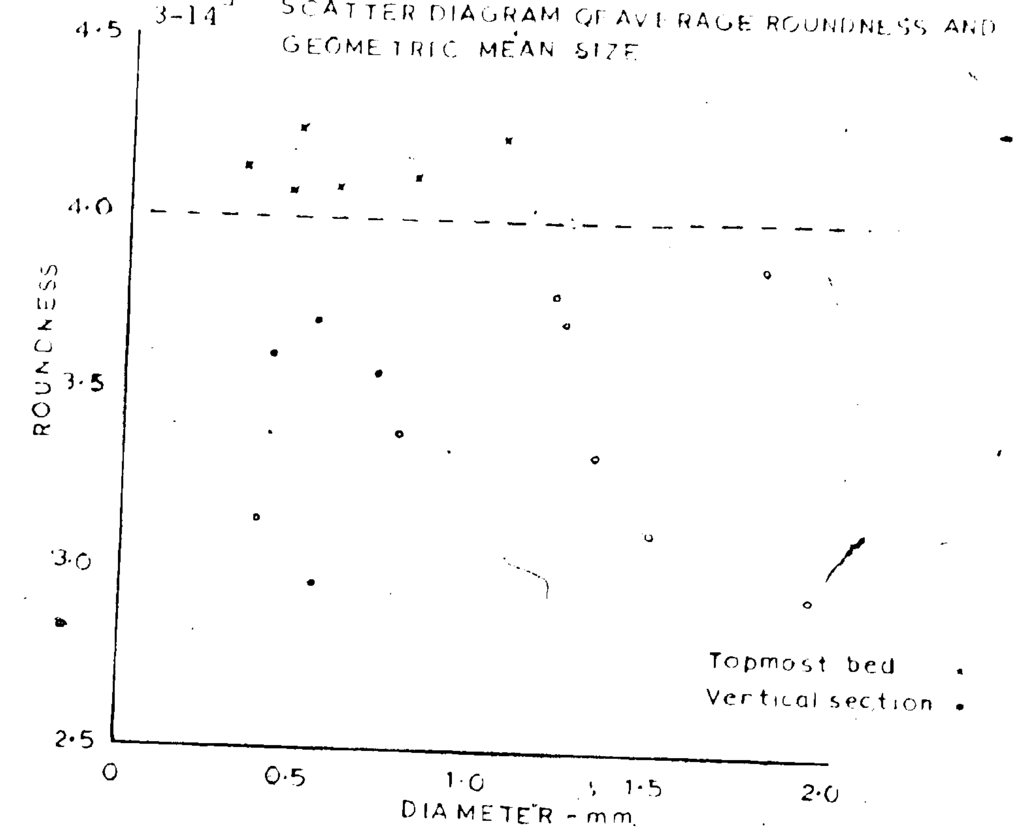
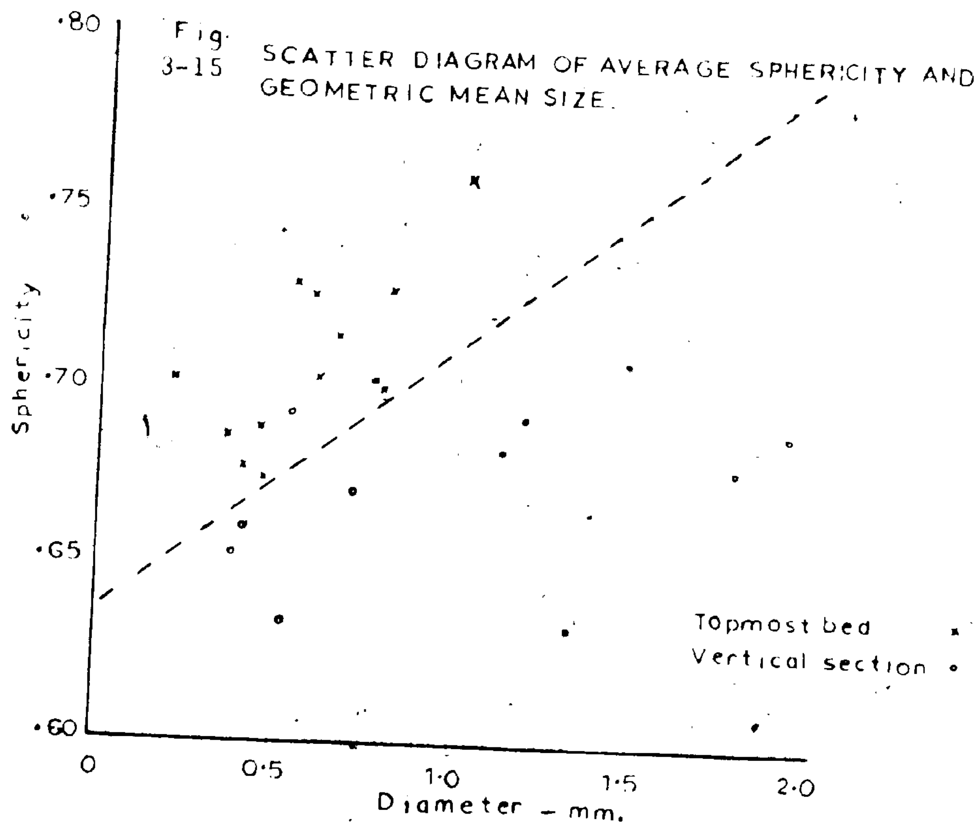


Fig. 3-15 SCATTER DIAGRAM OF AVERAGE SPHERICITY AND GEOMETRIC MEAN SIZE.



APPENDIX E - PLOTS

Fig 3-16a SCATTER DIAGRAM OF LONG AXIS-a AGAINST SHORT AXIS-b, MEASURED IN THIN SECTION

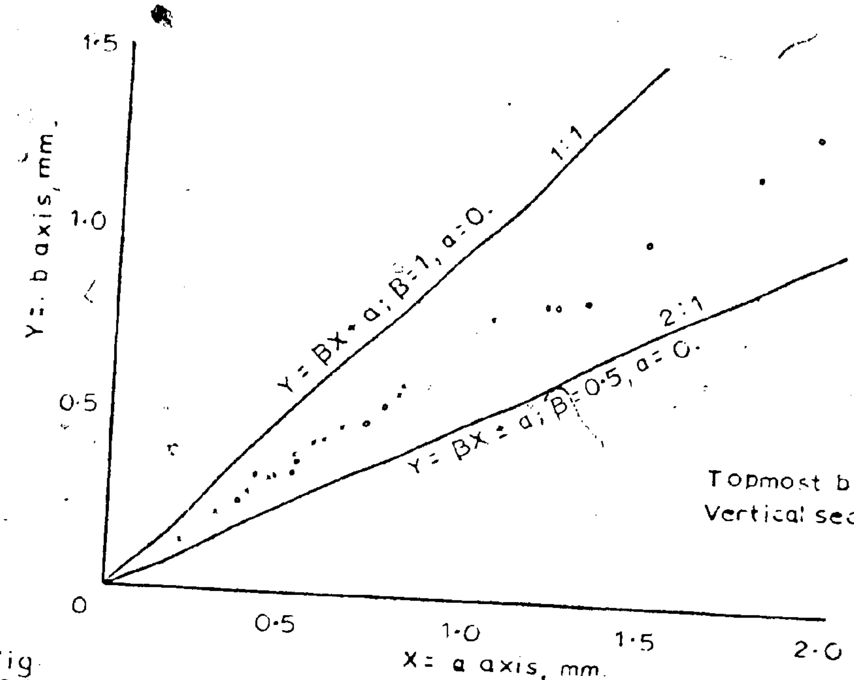
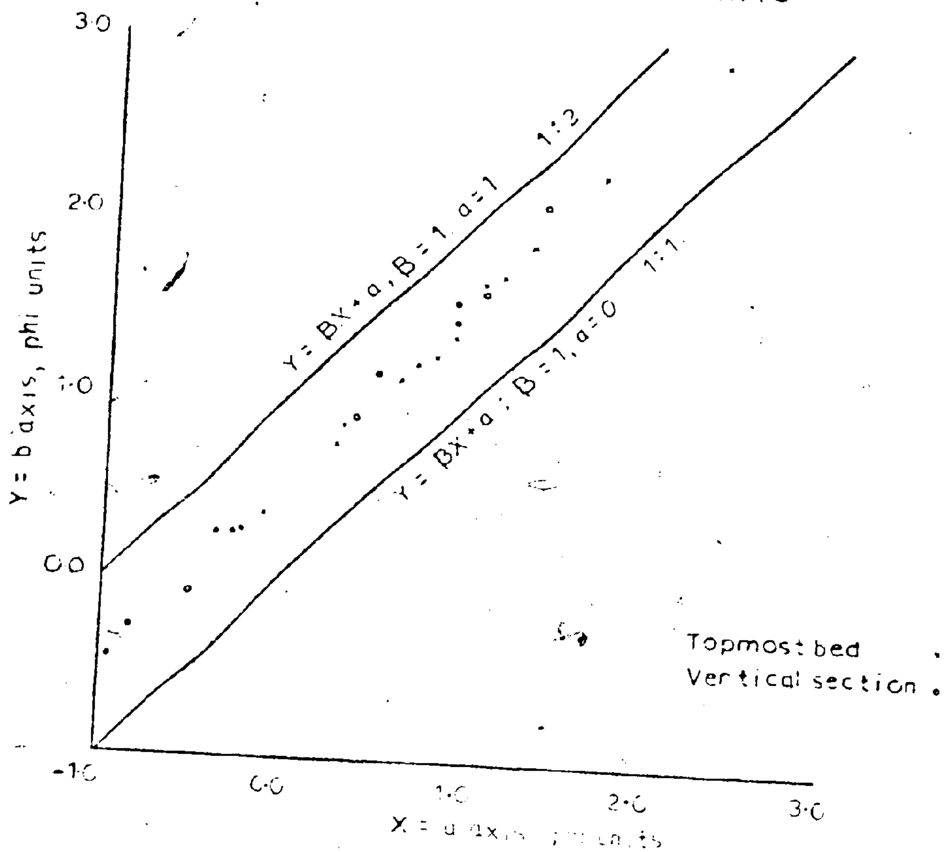


Fig 3-16b SCATTER DIAGRAM AS ABOVE, IN PHI UNITS



APPENDIX F - PALAEONTOLOGY

Palaeontology of the Forteau Formation

The Archaeocyathid fauna of the Forteau Formation was described by Fong (1967). Other fossils found and mentioned by him include inarticulate brachiopods, molluscs, trilobites, and various calcareous algae. Amongst the trilobites identified was Olenellus thompsoni (Hall), a time stratigraphic fossil for the Lower Cambrian.

Besides undetermined archaeocyathids, the present writer collected the following, from exposures at Point Amour and Fox Cove:-

Phylum Brachiopoda	Nisusia sp.
Phylum Mollusca	Salterella sp.
Phylum Arthropoda	Bonnia sp.
Plant fossils	Division Schizomycophyta
	Girvanella sp.

APPENDIX 3

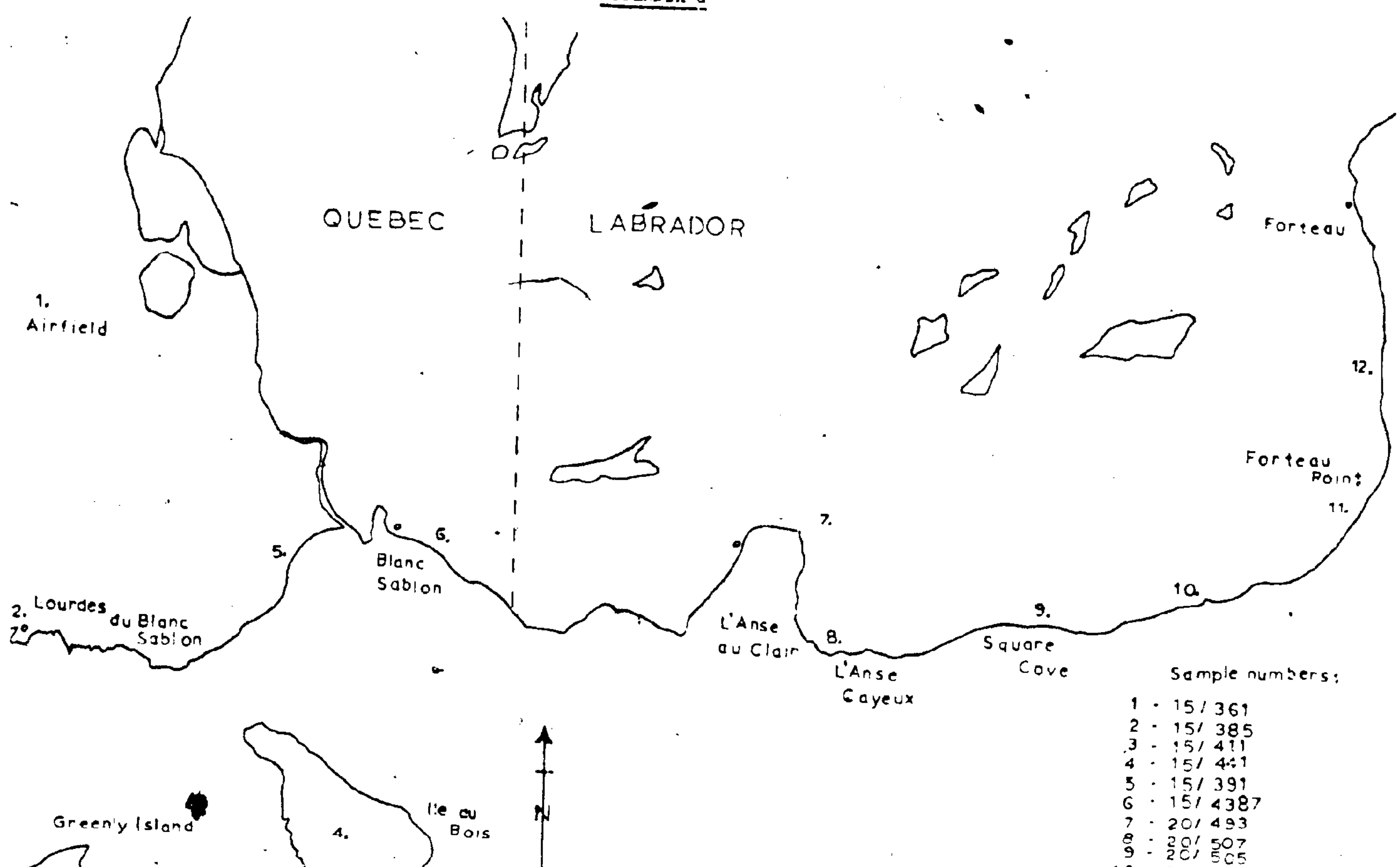


Fig 3-1a SOUTH COAST OF QUEBEC-LABRADOR: SAMPLE LOCALITIES OF THE TOPMOST BED OF THE BRADORE FORMATION.
Scale 1:65,000.

SELECTED BIBLIOGRAPHY

Allen, J.R.L.
1968 — On the Character and Classification of Bed Forms; Geol. En Mijnbouw, V. 47, No. 3, p. 173-185.

Bailey, E.H. and Stevens, R.E.
1960 — Selective Staining of K. Feldspar and Plagioclase of Rock Slabs and Thin Sections; Amer. Min., V45, p. 1020 - 1024.

Balsam, W.L.
1970 — Personal Communication, July 27th.

Bell, R.
1884 — Observations on Geology, Mineralogy, Zoology and Botany of Labrador Coast, Hudson Strait and Bay. Can. Geol. Natural History Surv. Annual Report, 1885, pt. D.D. Pub. Dawson Bros.

Betz, F.
1939 — Geology and Mineral Deposits of the Canada Bay Area, Northern Newfoundland, Geol. Surv. Nfld. Bulletin 16.

Billings, E.
1962 — Further Observations on the Age of the Red Sandrock Formation (Potsdam Group) of Canada and Vermont. Amer. J. Sci., V.33, 2nd Ser., p.101.

Black, R.F.
1964 — Palaeomagnetic Support of the Theory of Rotation of the Western Part of the Island of Newfoundland. Nature V. 202, No. 4936, p. 945-948.

Blatt, H. and Christie, J.M.
1963 — Undulatory Extinction in Quartz of Igneous and Metamorphic Rocks and its Significance in Provenance Studies of Sedimentary Rocks J. Sed. Pet. V 33, No. 3, p. 559-579

Bostock, H.H.
1971 — Precambrian Geology, Strait of Belle Isle, Newfoundland. G.S.C. Paper 71 1A, p. 122-123.

Christie, A.M.
1951 — Geology of the Southern Coast of Labrador from Forteau Bay to Cape Porcupine, Newfoundland. G.S.C. Paper 51-13.

Clifford, P.M.
1965: Palaeozoic Flood Basalts in Northern Newfoundland and Labrador. Can. J. Earth Sc., V. 2, p. 183-187.

Connolly, J.R.
1965: The Occurrence of Polycrystallinity and Undulatory Extinction in Quartz in Sandstones, J.Sed.Pet., V.35, No. 1, p. 116-135.

Cumming, L.M.
1970: Operation Strait of Belle Isle, Quebec and Newfoundland-Labrador. Project No. 680130. G.S.C. Paper 70-1A, p. 3-8.

Cumming, L.M.
1971: Operation Strait of Belle Isle, Newfoundland and Labrador, Project 680130. G.S.C. Paper 71-1A. p.2-6.

Daly, R.A.
1902 Geology of the Northwest Coast of Labrador. Bull.Mus. Comp.Zool. Harvard, V. 38, Geol. Ser. V. 5., No. 5.

Douglas, G.V.
1953: Notes on Localities Visited on the Labrador Coast in 1946 and 1947, G.S.C. Paper 53-1.

Folk, R.L.
1956: The Role of Texture and Composition in Sandstone Classification. J.Sed.Pet., V. 26, p. 166-171.

Folk, R.L.
1961: Petrology of Sedimentary Rocks, Austin, Hemphill's Bookstore, p. 154. Cited by Blatt and Christie 1963.

Folk, R.L.
1968 Petrology of Sedimentary Rocks. Hemphill's Austin, Texas.

Folk, R.L. and Ward, W.C.
1957: Brazos River Bar: A Study in the Significance of Grain Size Parameter. J.Sed. Pet., V.27, No. 1, p. 3-26.

Fong, C.C.K.
1967 Paleontology of the Lower Cambrian Archaeocyatha-Bearing Forteau Formation in Southern Labrador. M.Sc. Thesis, M.U.N.

Frey, R.W. and Howard, J.D.
1969: A Profile of Biogenic Sedimentary Structures in a Holocene Barrier Island - Salt Marsh Complex, Georgia. Trans. Gulf Coast Ass. Geol. Soc., V. 19, p. 214-227.

Gabelman, J.W.
1955: Cylindrical Structures in Permian (?) Siltstone, Eagle County, Colorado. J. Geol., V, 63, p. 214-227.

Geinitz, E. (Rostock)
1916: Zur Scolithus - Frage. B. Geol. Instit. of Univ. Upsala, V, XIII, 2, p. 409.

Grant, D.R.
1969: Surficial Deposits, Geomorphic Features and Late Quaternary History of the Terminus of the Northern Peninsula of Newfoundland and Adjacent Quebec-Labrador, Maritime Seds. V.5, N.3, p. 123-125.

Griffiths, J.C.
1967: Scientific Method in Analysis of Sediments. McGraw-Hill.

Grim, R.E.
1953: Clay Mineralogy. McGraw-Hill.

Hadding, A.
1929: The Pre-Quaternary Sedimentary Rocks of Sweden. Part III. The Paleozoic and Mesozoic sandstones of Sweden. Lunds Univ. Arsskrift, Avd. 2, Bd. 25, Nr. 3. Kungl. Fysiograf. Sallskapets Handlinger, N.F. Bd. 40, Nr. 3.

Hallam, A. and Swett, K.
1966: Trace fossils from the Lower Cambrian Pipe Rock of the north-west Highlands. Scott. J. Geol., V. 2, No. 1, p. 101-106.

Hawley, J.E. and Hart, R.C.
1934: Cylindrical Structures in Sandstones. B.G.S.A., V.45 p. 1017-1034.

Holmes, A.
1965: Principles of Physical Geology. Nelson & Co.

Howell, B.F.
1943: Burrows of Skolithus and Planolites in the Cambrian Hardyston Sandstone at Reading Pennsylvania. Publications of the Wagner Free Institute of Science, V.3.

James, J.F.
1892: Studies in Problematic Organisms - The Genus Scolithus. B.G.S.A., V.3, p. 32-44.

Jopling, A.V. and Walker, R.G.
1968: Morphology and Origin of Ripple-Drift Cross-Lamination, with Examples from the Pleistocene of Massachusetts, J. Sed. Pet., V.38, No. 4, p. 971-984.

Kenyon, N.H.
1970: Sand Ribbons of European Tidal Seas, Marine Geology, V. 9, p. 25-39.

Kranck, E.H.
1953: Bedrock Geology of the Seaboard of Labrador between Domino Run and Hopedale, Newfoundland, G.S.C. Bull.26.

Krumbein, W.C.
1941: Measurement of Geological Significance of Shape and Roundness of Sedimentary Particles. J. Sed. Pet., V. 11, No. 2, p. 64-72.

Krynine, P.D.
1940: Petrology and Geneisis of the Third Bradford Sand. The Penn. State Collete Mineral Industries Expt. Sta. Bull. 29, p.134. Cited by Blatt and Christie, 1963.

Krynine, P.D.
1946 Microscopic Morphology of Quartz Types. Pan-American Cong. Mining and Geol. Engineers, Annals of 2nd Comm., p.36-49 Cited by Blatt and Christie 1963.

Kuenen, Ph., H.
1947: Water Faceted Boulders. Amer. J.Sci., V.245, p.779-734.

Lieber, O.M.
1860: Notes on the Geology of the Coast of Labrador. U.S. Coast Survey.

Lilly, H.D.
1967: Some Notes of Stratigraphy and Structural Style in Central Western Newfoundland. Geol. Ass. Can.; Sp. P.No. 4, p.201-211.

Logan,
1863: Geology of Canada, Report of Progress from its Commencement to 1863. Dawson Bros., Montreal, p. 287 and 288.

McKee, E.D. and Weir, G.W.
1953: Terminology for Stratification and Cross-Stratification in Sedimentary Rocks. B.G.S.A., v. 64, p. 381-390.

Migliorini, C.I.
1950: Dati A Conferma Della Risedimentazione Della Arenarie Del Macigno. Mem. Soc. Toscana Sci. Mat., V. 57, p. 1-15. Cited by Potter and Pettijohn 1963.

Milner, H.B.
1962: Sedimentary Petrography. George Allen and Unwin.

Molloy, M.W. and Kerr, P.F.
1961: Diffractometer Patterns of A.P.I. Reference Clay Minerals Amer. Min. V. 46, p. 583-605.

North, F.K.
1971: The Cambrian of Canada and Alaska, in Cambrian of the New World, ed, C.H. Holland, p. 219-325.

Otvos, E.G.
1966: Sedimentary Structures and Depositional Environments, Potsdam Formation, Upper Cambrian B.A.A.P.G. V. 50, No. 1, p. 159-185.

Packard, A.S.,
1891: The Labrador Coast; A Journal of Two Summer Cruises to That Region. Pub. N.D.C. Hodges, New York. P. Kegan, Trench, Trubner, London.

Palmer, A.R.
1971: The Cambrian of the Appalachian and Eastern New England Regions, Eastern United States; in Cambrian of the New World, ed.C.H. Holland, p. 169-219.

Pettijohn, F.J.
1957: Sedimentary Rocks. Harper and Row, pub.

Piloski, M.J.
1955: Geological Report on Area 'E', Labrador Concession. British Newfoundland Corp. Ltd., unpub., Report D8.

Poole, W.H.
1967: Tectonic Evolution of Appalachian Region of Canada. G.A.C.Sp. Paper 4, p. 9-51.

Potter, P.E. and Pettijohn, F.J.
1963: Paleocurrents and Basin Analysis. Academic Press Inc.

Potter, P.E. and Pryor, W.A.
1961: Dispersal Centers of Paleozoic and Later Clastics of the Upper Mississippi Valley and Adjacent Areas. B.G.S.A., V. 72, p. 1195-1250.

Powers, M.C.
1953: A New Roundness Scale for Sedimentary Particles. J. Sed. Pet., V. 23, No. 2, p. 117-120.

Richardson, J.
1862: Cited by L.M. Cumming, (Personal communication, April, 1st, 1970).

Richter, R.
1919: Ein Devonischer 'Pfeifenquarzit'. Verglichen Mit Der Heutigen 'Sandkorallen'. (Sabellaria Annelidae). Senckenbergiana 11. p. 215-235. Lethaea, Fr. Furt.

Richter, R.
1927: "Sandkorallen" - Riffein Der Nordsee. Nature and Museum 57.

Schuchert, C.
1955: Atlas of Paleographic Maps of North America, J. Wiley & Sons.

Schuchert, C. and Dunbar, C.O.
1934: Stratigraphy of Western Newfoundland. G.S.A. Mem.1, p. 123.

Schwartzbach, M.
1963: Climates of the Past. D. Van Nostrand Co.

Smit, D.F.
1970: Personal Communication, April 29th.

Swett, K. Klein, G.D. and Smit, D.E.
1971: A Cambrian tidal sand body - the Eriboll sandstone of northwest Scotland an ancient - recent analog. J. Geol., V.79, p. 400-415.

Swett, K. and D.E. Smit,
1972 Cambro-ordovician Shelf Sedimentation of western Newfoundland, northwest Scotland, and central-east Greenland. 24th International Geological Congress, Section 6, p. 33-41.

Tanner, W.F.
1959: The importance of Modes in Cross Bedding Data. J. Sed. Pet., V. 29, No. 2, p. 221-226.

Tuke, M.F.
1968 Autochthonous and allochthonous Rocks in the Pistolet Bay Area in Northernmost Newfoundland. Can. J. Earth Sci., V.5, p. 501-513.

Van Straaten
1960 Sedimentation in Tidal Flat Areas. J. Alberta Soc. Pet. Geol., V.8, p. 203-226.

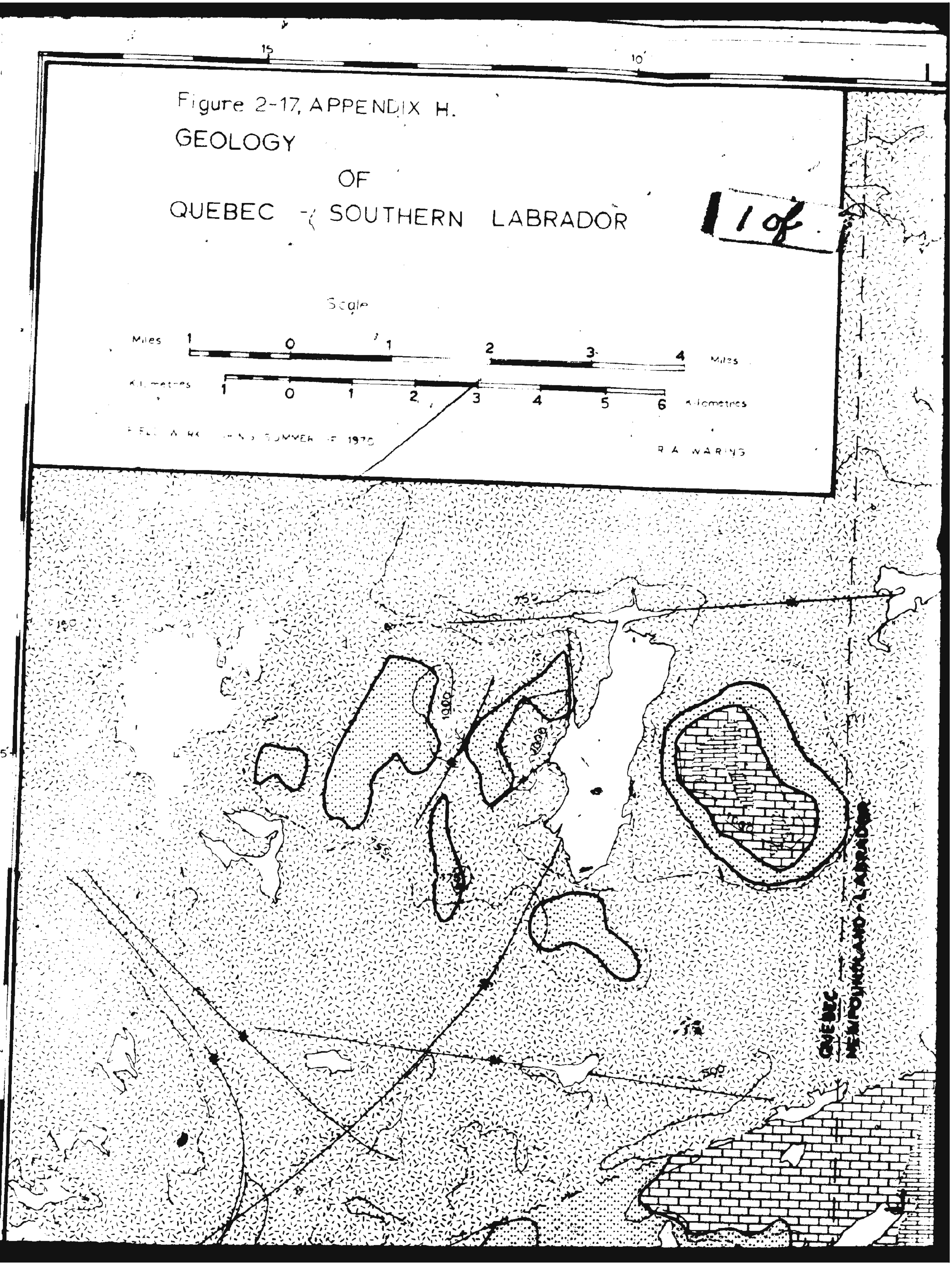
Walcott, C.D.
1912 Cambrian Brachiopoda. U.S. Geol. Surv., Monog., V. 51. Cited by Christie, 1951.

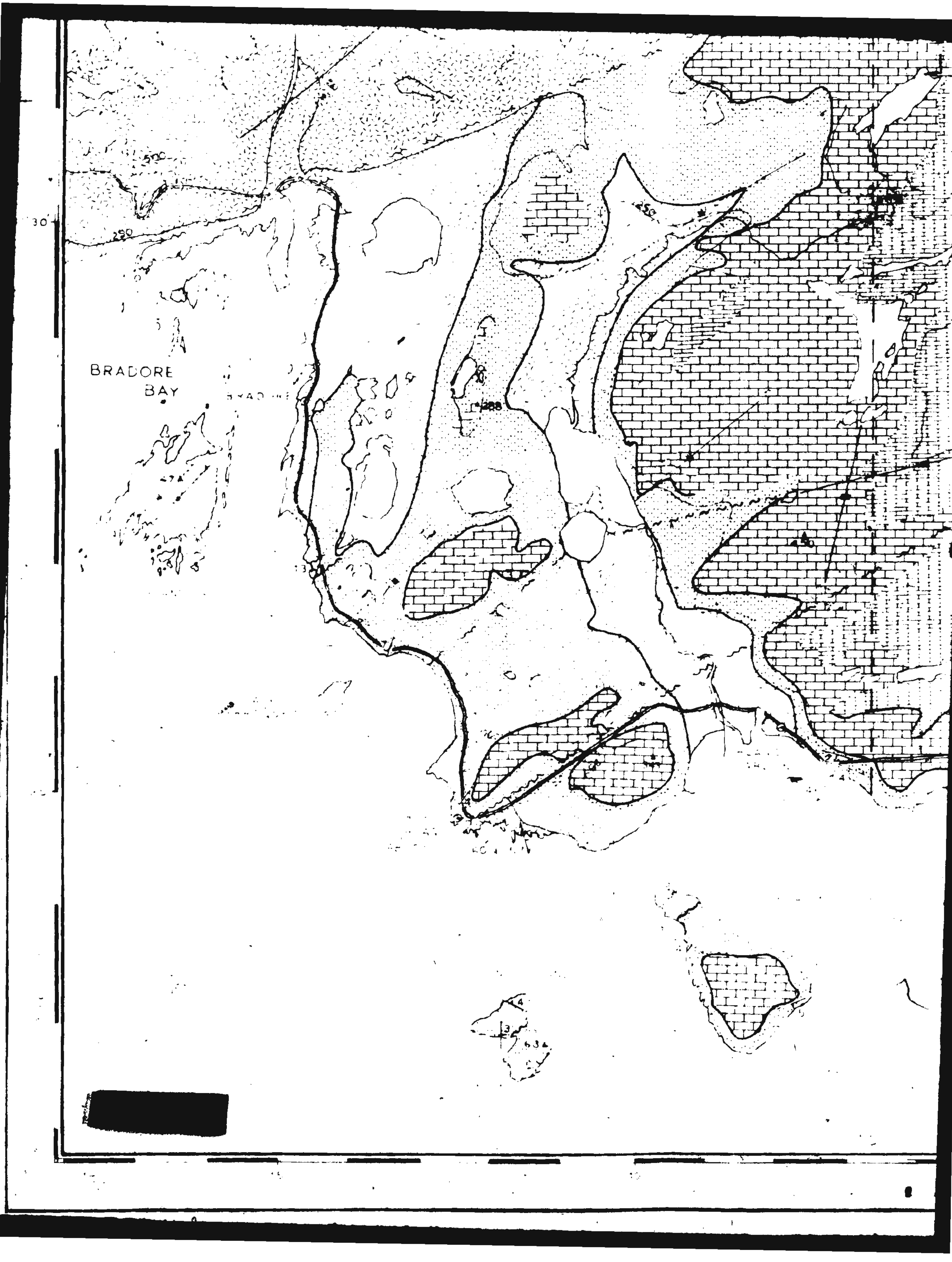
Weller, J.M.
1960 Stratigraphic Principles and Practise. Harper Bros.

Weston, T.C.
1895 Notes on Concretions Found in Canadian Rocks. Trans. Nova, Scotia Instit. Sc. 1894/1895.

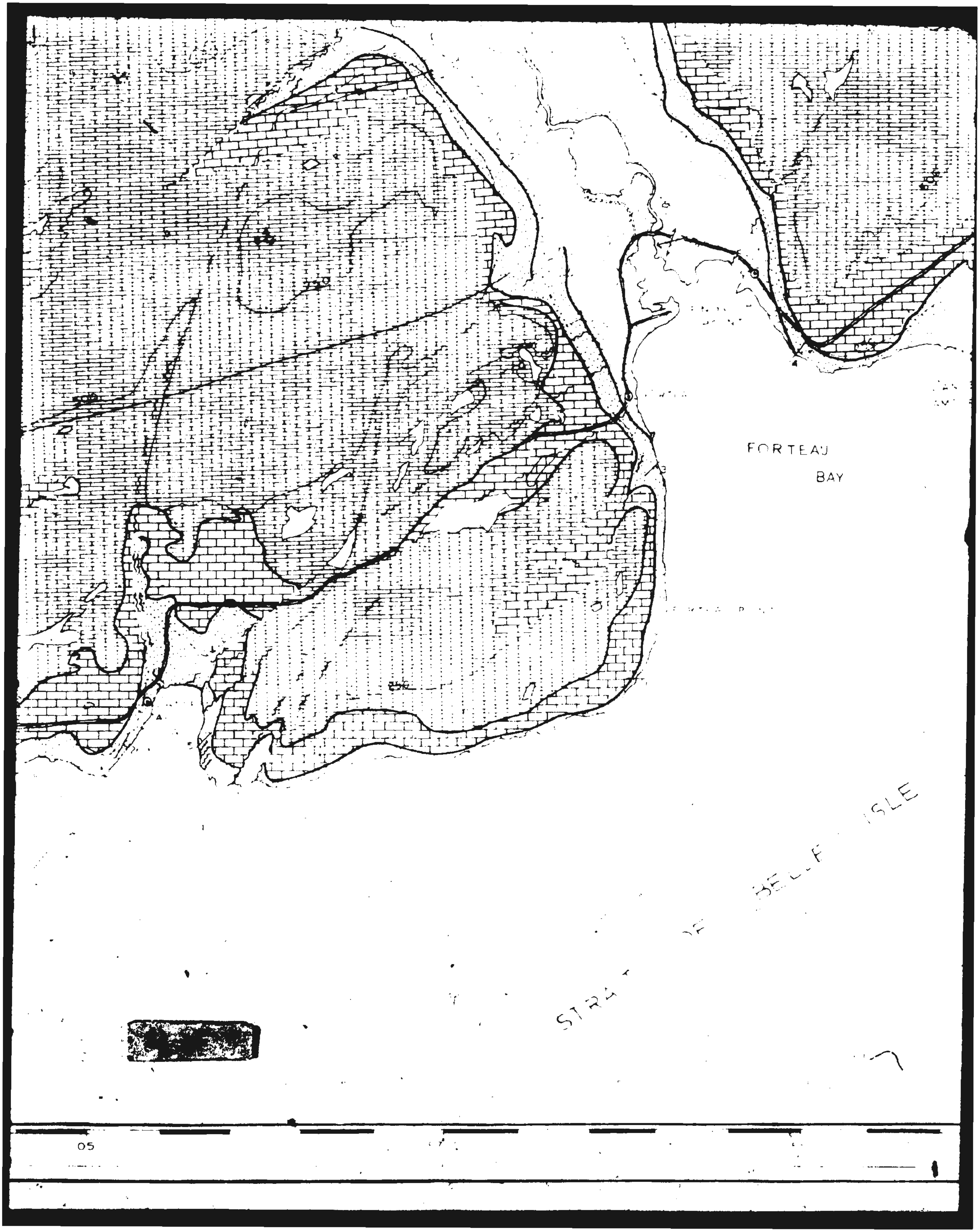
Williams H.
1969 Precarboniferous Development of Newfoundland Appalachians. N. Atlantic Geol. and Cont. Drift Mem. 12, Pub. A.A.P.G. p. 39.

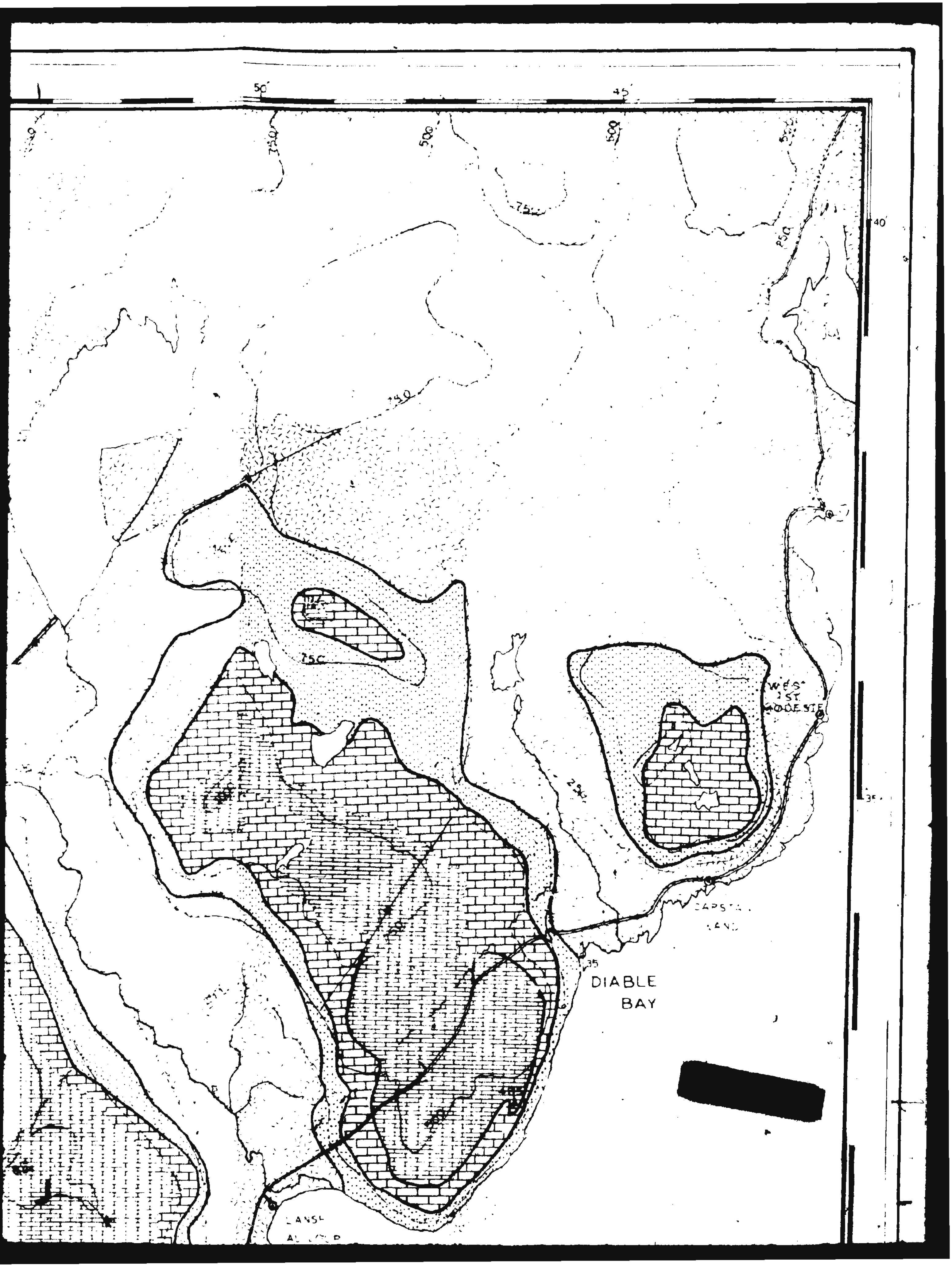
Williams, H. and Stevens, R.K.
1969 Geology of Belle Isle - Northern extremity of the Deformed Appalachian Miogeosynclinal Belt. Can. J. Earth Sci., V.6, No. 5, p. 1145-1157.

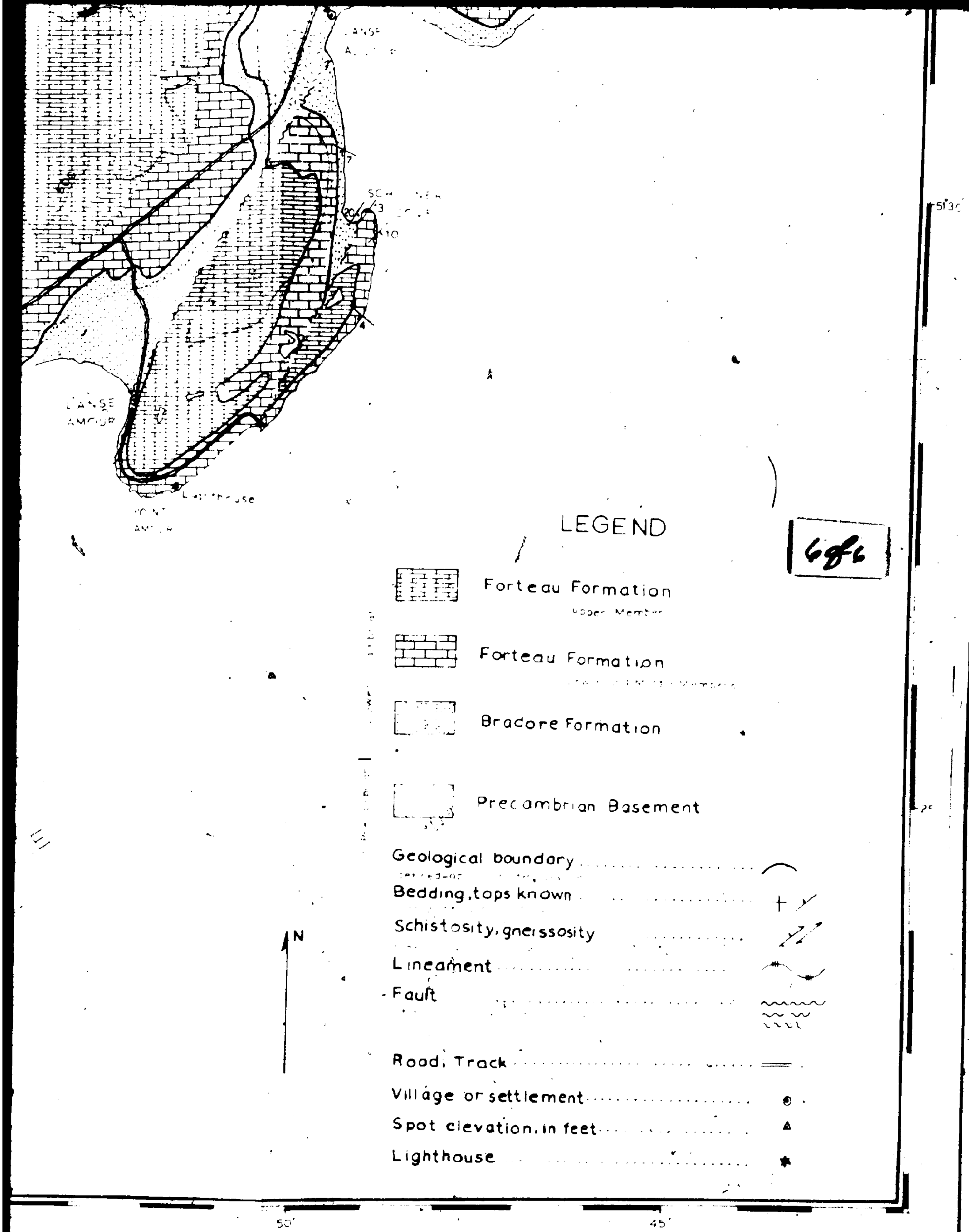

15
10'
Figure 2-17, APPENDIX H.
GEOLOGY
OF
QUEBEC - SOUTHERN LABRADOR
1 of.
Scale
Miles 1 0 1 2 3 4 Miles
Kilometres 1 0 1 2 3 4 5 6 Kilometres
R. A. WARING
1000
1000
35'
QUEBEC
NEWFOUNDLAND - LABRADOR
500


BRADORE
BAY
30
500
250
250
288


05'
57'
55'


FORTEAU
BAY
STRA
BELLE
ISLE

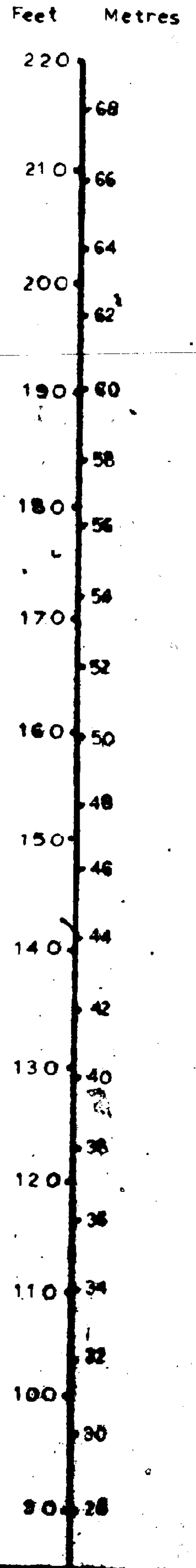

50'
45'
40'
750
DIABLE
BAY
[redacted]

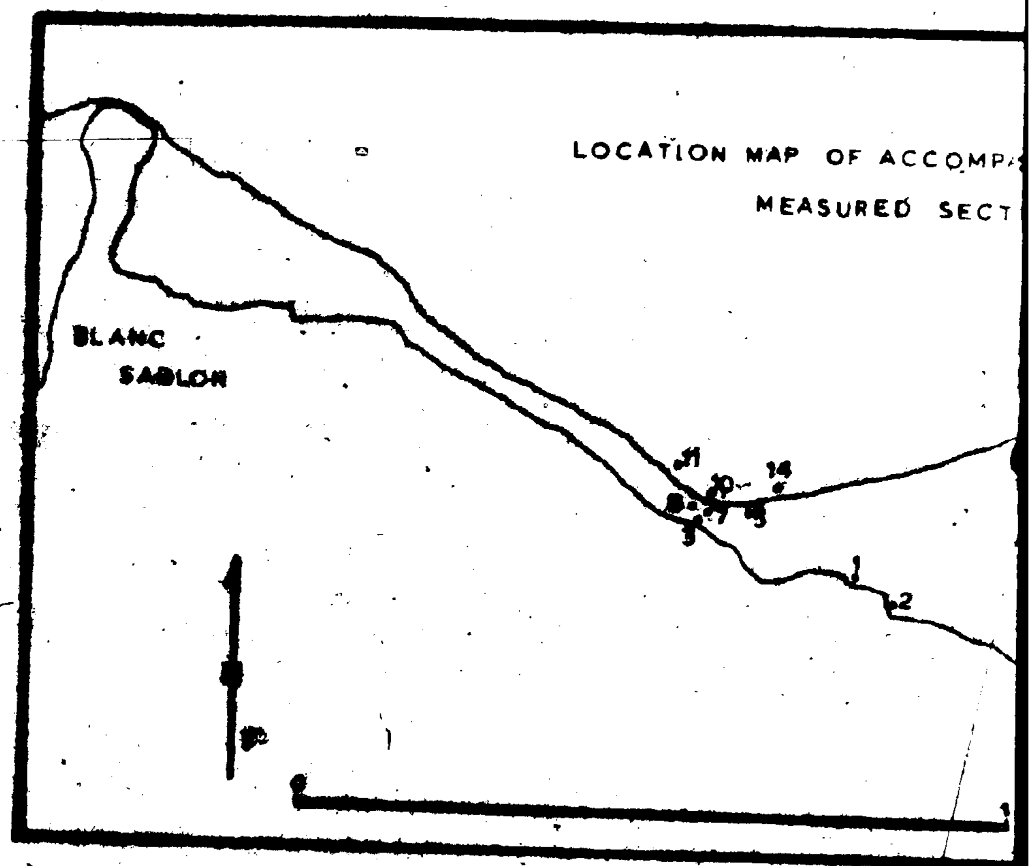


L'ANSE AMOUR
Lighthouse
51°30'
6 of 6
LEGEND
Forteau Formation
Upper Member
Forteau Formation
Bradore Formation
Precambrian Basement
Geological boundary
Bedding, tops known
Schistosity, gneissosity
Lineament
Fault
Road, Track
Village or settlement
Spot elevation, in feet
Lighthouse
N
50'
45'

Figure 3-1b, APPENDIX G.

LITHOLOGICAL CHARACTER OF THE BRADORE FORMA

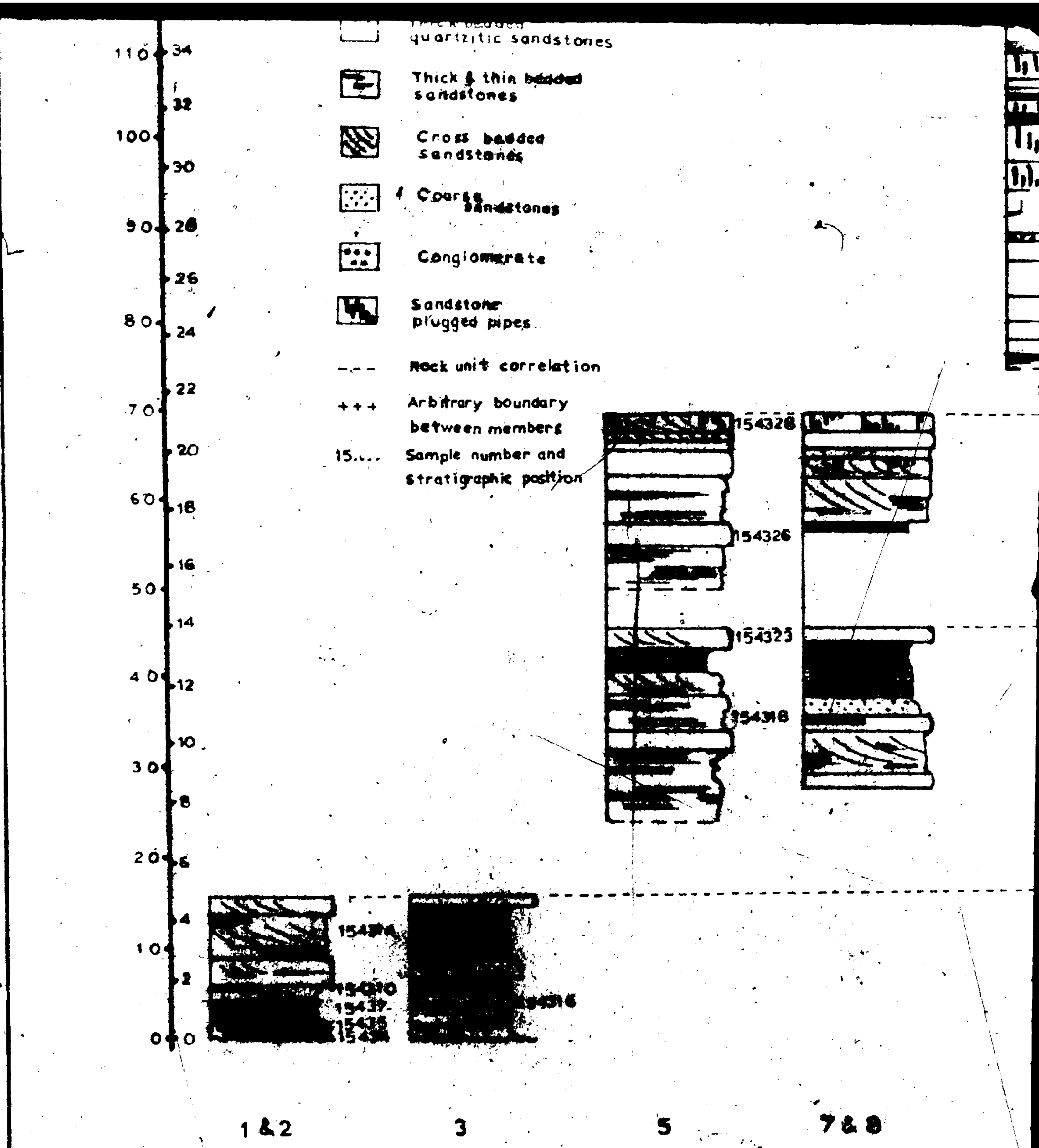




LEGEND

- Thinly bedded sandstones & siltstones
- Thick bedded quartzitic sandstones
- Thick & thin bedded sandstones
- Cross bedded sandstones
- Coarse sandstones
- Conglomerate

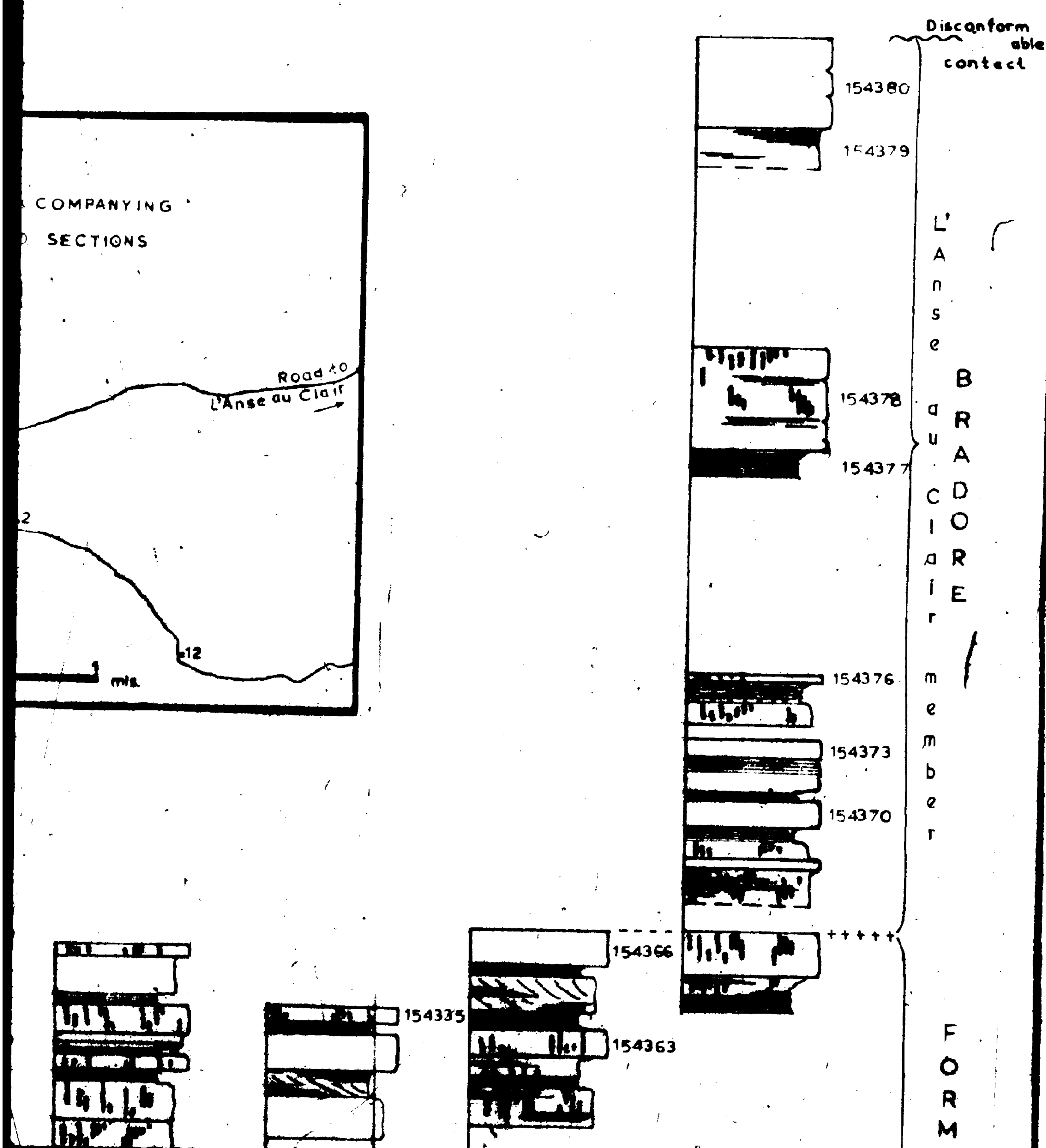
10

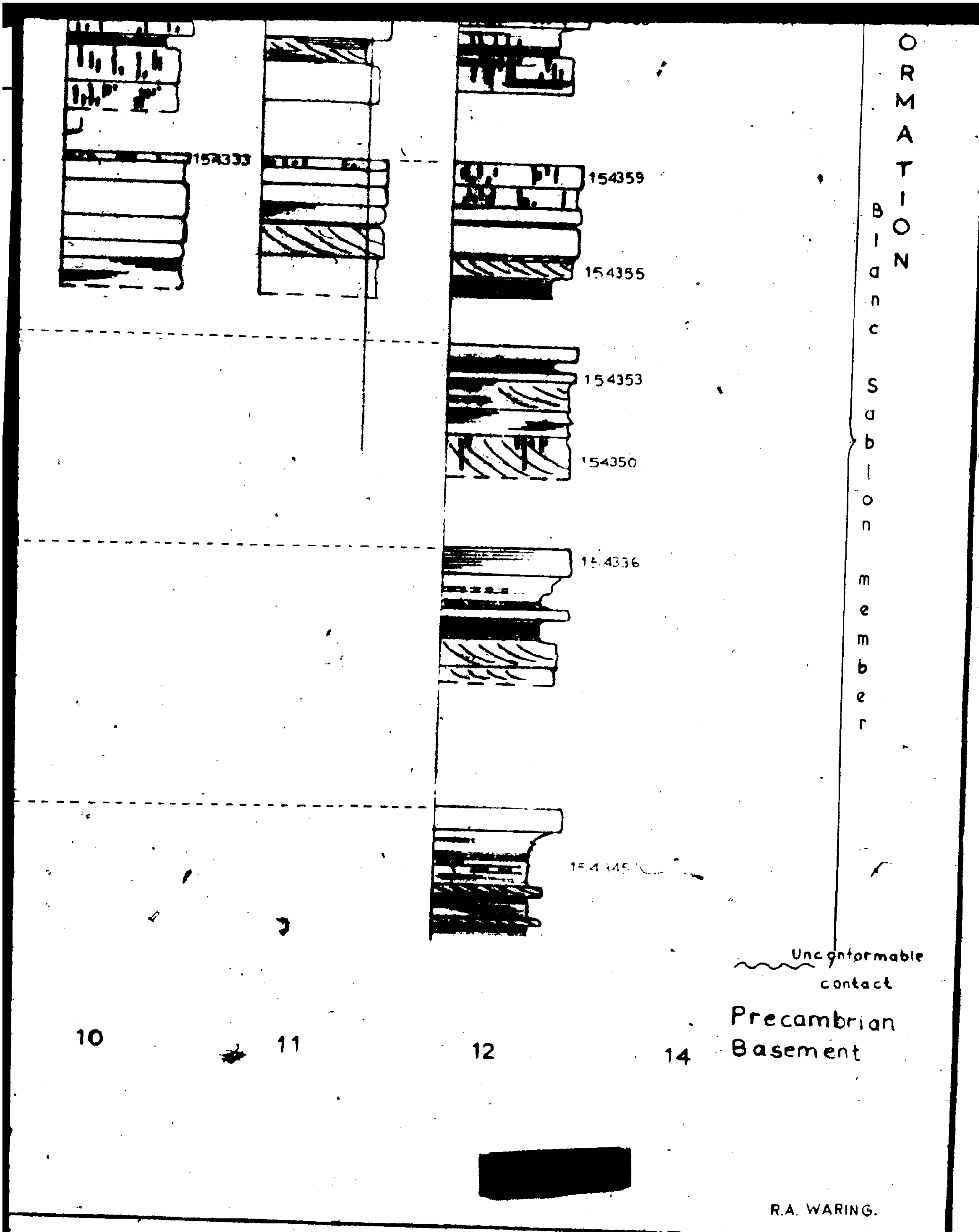


quartzitic sandstones
Thick & thin bedded sandstones
Cross bedded sandstones
Coarse sandstones
Conglomerate
Sandstone plugged pipes
Rock unit correlation
Arbitrary boundary between members
15.... Sample number and stratigraphic position
154328
154326
154323
154318
154314
154316
0
10
20
30
40
50
60
70
80
90
100
110
1 & 2
3
5
7 & 8

[redacted]

FORMATION IN SOUTHERN LABRADOR





ORMATION
Blanc Sablon member
154333
154359
154355
154353
154350
154336
154345
Unconformable contact
Precambrian Basement
10
11
12
14
R.A. WARING.