GEOLOGY OF THE TREPASSEY AREA, AVALON PENINSULA, NEWFOUNDLAND

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GEOLOGY OF THE TREPASSEY AREA, AVALON PENINSULA, NEWFOUNDLAND

by

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ABSTRACT

This thesis presents the results of the first detailed study of the geology of the Trepassey area on the south coast of the Avalon Peninsula, southeastern Newfoundland, and includes a geological map on a scale of 1 : 8,000.

The area is underlain by a thick sequence of late-Precambrian rocks, belonging to the Conception Group and to the St.John's Formation of the Cabot Group, and at least one bed of tuff indicating contemporaneous volcanic activity. Although these rocks are well exposed along the coast, inland they are largely hidden beneath ground moraine of late Pleistocene age.

The main structural features of the area are a synclinorium and a major fault cutting its western flank. Most of the subsidiary folds of the synclinorium, the associated fracture cleavage, and many of the faults have a north-northeasterly trend although some folds and faults are cross-cutting; folds generally plunge gently to the south-southwest. An analysis of the joint pattern in the area shows its tectonic origin.

The Conception Group consits mainly of graded beds in which the coarser element is lithic or feldspathic greywacke, containing many volcanic rock fragments, and the finer-grained element is mudstone similar in composition to the greywacke. The succession also includes fine-grained very siliceous rocks, mudstones and colour-banded cherts. Conception beds are grey to green or purple; the colouring agents are dark rock fragments, iron sulphide, chlorite and hematite.

The rocks of the St.John's Formation are predominantly fine-grained and although the succession includes, in its lower part,

thin graded beds resembling those of the uppermost part of the Conception sequence, it consists mainly of mudstone (shales) interbedded with laminae of siltstone forming a repetitive sequence thousands of feet thick; the silty beds are subgreywackes. Slump zones are characteristic of the succession. Pyrites is universally present and probably responsible for the grey colour of these beds; also noteworthy is the common occurrence of authigenic carbonate.

The sediments laid down in Conception and St.John's Formation times appear, from their composition, to have come from the same northern source. A turbidity current origin is favoured for the Conception Group graded beds, hence the Trepassey area is believed to have been a deep-sea area during the greater part of Conception times. Shallowing began towards the close of Conception times and continued into St.John's Formation times when turbidity currents generally ceased. Comparison with other areas suggests that folding and faulting of these sediments took place before the close of the Precambrian although the major fault may be post-Ordovician. The Trepassey area provides no evidence of subsequent geological events until Pleistocene times apart from the presence of an upland surface (500-600 feet) believed to represent late Tertiary peneplanation of the region. During the Pleistocene the Trepassey area was probably glaciated more than once but the effects of the last, or Wisconsin glaciation, masks the effect of earlier glaciations. Ice movements modified the form of the land and when the ice melted at the close of the Pleistocene it left a blanket of boulder clay over the entire area. Vegetation soon established itself and the growth and decay of swamp plants in bogs over thousands of years has given rise to extensive peat deposits.

CHAPTER 1

Introduction

Location, Size and Accessibility of the Area

The Trepassey area borders the coast of the southeastern part of the Avalon Peninsula (Fig.1) at the head of Trepassey Bay.

The thesis area lies between 46°41' and 46°50' north latitude and 53°17' and 53°26' west longitude, an area of approximately eighty-four square miles, but because of the indented nature of the coast-line, only three quarters of this area is actually land. There are two settlements in the area, Trepassey and Biscay Bay. Trepassey has a population of about a thousand while Biscay Bay is a small community of less than a hundred people. Fishing and fish-processing are the main occupations and a fish-processing plant is located at Meadow Point on the western side of Trepassey Harbour.

Trepassey is about one hundred and five miles from St. John's, the capital of Newfoundland, to which it is connected by a daily taxi-service. Apart from the main road to St.John's that passes approximately east-west across the area and links Biscay Bay with Trepassey, another motorable gravel road runs from Trepassey down the length of Powles Peninsula to the lighthouse at Powles Head. Away from the roads, most of the area can be easily traversed on foot, but on the west side of Trepassey Harbour, above the steep cliffs, the woods are too dense to penetrate, thus making this part of the area inaccessible. The cliff section here, and around Cape Mutton, cannot be

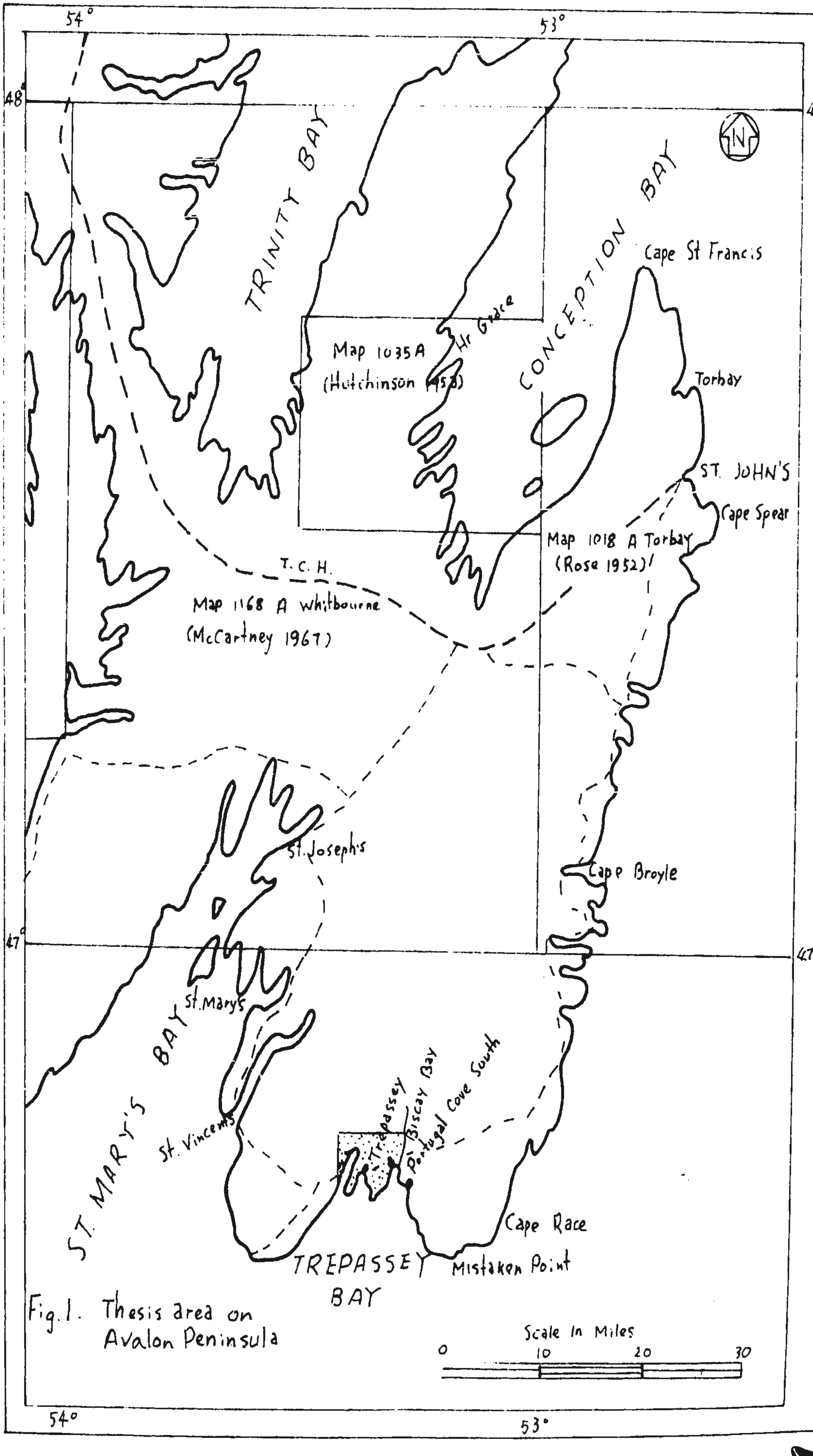

Fig. 1. Thesis area on Avalon Peninsula

negotiated on foot and their geology can only be studied from a boat.

Previous Geological Work

Prior to the present study no detailed geological investigation of the area had been carried out and no published information is available although on the latest geological map of Newfoundland prepared by Williams (1967) the whole of the southeastern part of the Avalon Peninsula is indicated as being underlain by sediments and minor volcanic rocks of the Conception Group of Late-Precambrian (Hadrynian) age. This part of William's map must, therefore, have been based on an extension of the findings of Rose, Hutchinson and McCartney who mapped the Torbay area (Rose, 1952), the Harbour Grace area (Hutchinson, 1953) and the Whitbourne area (McCartney, 1967) bordering Conception and Trinity Bays at the northern end of the Avalon Peninsula. Recently, however, Misra (1969) has completed a thesis on the coastal area immediately to the east of that studied by the author, i.e. from Biscay Bay to Cape Race. The work of Misra (1969) and of Rose (1952), whose map extends southwards from Cape St.Francis to latitude 47°00' (Fig.1) provides useful information concerning the geology of the eastern side of the Avalon Peninsula and indicates the formations that might be expected to occur in the Trepassey area.

The Torbay area, described by Rose (1952), includes both Precambrian and Lower Palaeozoic strata and since the latter are not present in the southeastern part of the Avalon Peninsula so far studied, it is necessary here to mention only his findings with regard to the Precambrian that are relevant to the present work. The Precambrian formations recognized by Rose (1952) are given in Table 1, which also includes details of their thickness and of the lithology of the beds included in each division. A brief account follows of the folds, faults, cleavage, and joint pattern that he found in the area.

Many major north-northeast striking folds are present in the strata of the Conception Group and, east of St.John's, a great syncline in the Cabot Group plunges gently north-northeastwards. Minor folds occur in both groups.

Bedding faults, strike faults, dip faults and oblique faults are all represented in the rock formations of the Torbay map area, but most of them fall into two categories, namely longitudinal faults and transverse faults. The longitudinal or strike faults trend northeasterly to northerly, and the transverse or dip faults strike northwesterly. Faults of both types are commonly steeply dipping. Most of the faults are attributed by Rose (1952) to thrusting due to compression.

Fracture cleavage is locally well developed depending on the character of the rock, the intensity of folding and proximity to faults. Fracture cleavage occurs both approximately parallel with, and at an angle to the bedding and is confined mainly to the more incompetent argillaceous and tuffaceous rocks of the area.

A rhombohedral joint pattern is evident in the sandstones and conglomerates of the Cabot Group but Rose (1952) makes no comment concerning the joint pattern of the Conception Group strata apart from stating that jointing and fracture cleavage are intimately related to folding and faulting in the Torbay map area.

Table 1 (after Rose): Precambrian Formations in the Torbay Map Area

Age	Formation (thickness in feet)		Lithology
Late Proterozoic (?)	Cabot Group	Blackhead Formation 5,500+	Red and greenish grey arkosic sandstone; minor slate, argillite and siltstone
		Signal Hill Formation 7,500	Red conglomerate, red, green, and greenish-grey, arkosic sandstone; minor slate, argillite and siltstone
		St.John's Formation 1,000	Dark grey to black slate, argillite and grit with a few arkosic conglomerate lenses and transitional zone to grey sandstone at the top
	Disconformity		
Mid-Proterozoic (?)		Basic dykes*	Small dykes of diabase and trap
	Intrusive contact		
		Holyrood batholith*	Pink and grey granite, granodiorite, syenite and aplite
	Intrusive contact		
		Meta-gabbro*	Small stocks of meta-gabbro
	Intrusive contact		

Age	Formation (thickness in feet)		Lithology
Mid-Proterozoic (?)	Conception Group	'Torbay slate' 3,000	Flinty green sandstone, green, red and reddish-brown tinged slate, argillite, siltstone and sandstone with some quartzite, quartzitic sandstones, and conglomerate
		'Conception slate' 3,000	Flinty, green to greenish grey siltstone, fine-grained green and grey sandstone, green to grey-green slate with some red slate, conglomerate, tuff, and agglomerate
	Unconformity		
Early Proterozoic (?)	Harbour Main Group		Chloritic schist, amygdaloidal andesite, rhyolite, felsite, and basalt with volcanic breccias, agglomerate, tuff and interbedded, flinty, green and red siltstone, slate, and coarse conglomerate

* May be in part, or entirely, younger than Cabot Group, and in part older than Conception Group.

Misra (1969) in the Biscay Bay-Cape Race area, correlated his rock types with those of the Conception Group and the St. John's Formation of the Cabot Group of the Torbay map area. He divided his Conception succession into three formations: the Drook, Freshwater Point, and Cape Cove (in ascending order). The rock types of each formation are given in Table 2 which also indicates that the boundaries between his divisions are transitional. Misra (1969) found fossils just west of Mistaken Point (Fig.1) in the Cape Cove Formation on ripple-marked surfaces overlain by a very thin layer of tuff indicating that minor volcanic activity occurred during late Conception times. The uppermost strata of the Conception Group pass conformably up into the lowermost strata of the overlying St.John's Formation of the Cabot Group, the transitional beds having a thickness of some 400 feet. A thicker layer of tuff was found in the St.John's Formation and this is the first record of volcanic activity during the time that these sediments were being laid down.

Table 2 (after Misra): Formations in the Biscay Bay-Cape Race Area

Age	Group	Formation (thickness in feet)	Lithology
Late Precambrian	Cabot	St.John's 1,100	Well cleaved, grey shales with sandstone laminae and sandy streaks
		Gradational boundary	
	Conception	Cape Cove 3,000	Graded beds of greywackes, siltstone, and well cleaved green argillites; purple argillites and greywackes in the upper part of the Formation
		Gradational boundary	
		Freshwater Point 1,500	Green siliceous argillites with some greywackes
		Gradational boundary	
		Drook 2,500	Banded cherts and silicified argillites and siltstones

The hard, siliceous argillites of the Drook and the Freshwater Point Formations are characterized by northeast trending broad open folds whereas the younger part of the sequence is tightly folded. These folds plunge at about 18 degrees towards the southwest.

Faults generally parallel fold axes and Misra (1969) regarded deformation along the fault planes as an integral part of a flexural slip folding process; such faults have caused vertical movement in the limbs of the folds.

Cleavage consists of closely spaced fracture planes. The attitude of cleavage and that of the axial planes of folds is similar.

Joint directions are variable with several sets occurring in a single outcrop. Some joints are vertical while others are inclined at various angles to the bedding and there are still others that parallel the bedding. Joints parallel with fold axes and fault planes appear to be related to folding and faulting.

Purpose of Study

The present study was undertaken in order to determine the stratigraphy and the structure of the Trepassey area and its relationship to the known geology of the Avalon Peninsula. It is based on field investigations carried out by the writer from June to September 1967, supplemented by a further period of fieldwork in June 1969, and a laboratory study of seventy-seven thin sections of rock samples collected during the fieldwork. The thesis area is divided between the National Topographic Series map sheets 1K/11 West Half, Trepassey and 1K/14 West Half, Biscay Bay River, prepared by the Surveys and Mapping Branch of the Department of Mines and Technical Surveys. Appropriate parts of these maps were enlarged so that mapping could be carried out on a scale of 1:10,000. The geology of the area is presented (Map 1) on a scale of one inch to six hundred and sixty feet.

Acknowledgements

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CHAPTER 2

Physiography and Glacial Geology

The thesis area covers the head of Trepassey Bay where the coast is backed, between Trepassey Harbour and Biscay Bay, by gently rolling lowland that rises gradually northwards to merge with plateau country at an elevation of about 500 feet. North of Daniel's Point there are several remnants of this level indicating that the plateau formerly extended further south than it does at present. West of Trepassey Harbour the coast-line trends south-southwestwards and the coast is cliffed. Between the cliffs and the plateau, which extends further south to the west of the harbour than it does to the east of it, there are steep slopes.

In the lowland area, bounded to the west by the Northeast Brook and to the east by Biscay Bay (Map 2), north-northeast trending ridges, reaching 250 feet or more in height, or exceptionally over 300 feet like the conspicuous hill forming Cape Mutton, separate similarly trending valleys. The bogs and ponds in each valley are linked to form a stream system. The ridges thus form watersheds between the five drainage areas that are present in the lowland area. The westernmost of the drainage areas is that of the Northeast Brook which flows into Trepassey Harbour and beyond it to the east the four other drainage areas with unnamed streams succeed one another. Although all four streams formerly flowed into Mutton Bay, only the two eastern ones now do so as the other two have become separated from the sea by a beach bar. The waters impounded by the bar have drowned the lower reaches of the two stream courses to form the lagoons present east of Trepassey.

The plateau country forms the catchment area and the divides for the main rivers draining the southern end of the Avalon Peninsula, and in the map area these are the Northwest Brook and the Biscay Bay River, both of which have their source beyond the area to the northeast. A great many of the innumerable ponds, which occupy every depression on the upland surface, eventually drain into these main rivers while the remainder are not connected with any surface drainage system. The Northwest Brook shows an unusual change in course before it reaches the sea (Map 2); it flows into the area following the usual northeast to southwest regional drainage pattern and then at a point about three miles northwest of Daniel's Point it turns through 70 degrees to flow southeastwards into the northern end of Trepassey Harbour. Where this alteration of course occurs the valley cross section changes from symmetrical to markedly asymmetrical with a steep slope on its southwestern side and a more gentle slope on its northeastern side. This lower portion of the course of the Northwest Brook does not appear to be fault controlled and since it cuts across the strike of the regional fold pattern (see chapter 3) it was probably gouged out by a glacier during the last, or Wisconsin, phase of the Pleistocene glaciation that affected the whole of Newfoundland during that period (MacClintock and Twenhofel, 1940).

Twenhofel and MacClintock (1940) in a paper describing the surface of Newfoundland commented on the slight relief of large areas of upland and they regard these as remnants of three ancient peneplains only two of which are thought to be represented on the Avalon Peninsula. These two are at elevations of about 700-800 feet and 350-450 feet respectively in the St.John's area at the northern end of the Peninsula. They did not discuss the levels to be found at the southern end of the Peninsula where the 500-600 foot upland in the Trepassey area probably represents a lowered (glacially modified) part of the 700-800 foot level at St.John's since the upland here rises gradually inland to this level only a few miles north of the map area. Twenhofel and MacClintock (1940) named the 700-800 foot level the High Valley Peneplain and they consider it was formed in late Tertiary times while the lower level, or Lawrence Peneplain, is of later date and does not appear to be represented in the map area.

The eastern side of the upland area west of Trepassey Bay is drained by the Broom River and other small streams whose short courses of two to three miles appear to be largely structurally controlled.

The coast-line at the head of Trepassey Bay is very irregular with north-northeast trending inlets and headlands alternating with one another. The inlets and headlands, from west to east, are Trepassey Harbour, Powles Peninsula with Powles Head at its southern end, Mutton Bay, the headland of

Cape Mutton, Biscay Bay and, beyond the map area, Portugal Point followed by Portugal Cove. These coastal features are due to the submergence of the coast that resulted from the Flandrian transgression in post-glacial times. The inlets are drowned river mouths or estuaries and the headlands are former divides. The inlets are, therefore, rias but it seems likely that Trepassey Harbour, at least, is a true fiord. The original valley developed probably along the line of the north-northeast trending fault (Trepassey Harbour Fault) shown on Map 1 and it was subsequently deepened by the glacier which formerly occupied the present course of the Northeast Brook at the time of the Wisconsin glacial episode.

Powles Peninsula must have been an island at the close of the Flandrian transgression but it subsequently became a peninsula as a result of the build up of a spit or tombolo of shingle and sand between the island and the mainland at the southern end of the low ridge on which Trepassey stands. This ridge ends in a rocky promontory which separates the tombolo from a bay-mouth bar that extends, a little south of east, for about three-quarters of a mile across the mouths of the rivers of the two drainage areas east of Trepassey. The bay-mouth bar, which constitutes a back beach, is made up of boulders, cobbles and pebbles that have been built up into a series of beach ridges or berms by the sea (Fig. 2-1) during successive high water levels (Guilcher, 1958). The coarse material of this back beach has a fairly steep seaward slope compared with that of the finer material, pebbles and coarse sand, of the foreshore with which it therefore makes an angle. The highest berm at the back of the beach is about twelve feet above high water level. The front part of the back beach shows well developed beach cusps. The bay-mouth bar as well as the bay-head beach of Mutton Bay are made up of material derived from the glacial drift deposits which form the low cliffs at the head of the bay between the river mouths. These cliffs are being eroded by the sea as shown by the exposure of a thick peat accumulation above the boulder clay and the presence of fallen blocks of the peat along the back of the beach. Elsewhere along the coast in the Trepassey area, retreat of rocky cliffs overlain by drift, as a result of marine erosion, also brings about the collapse of unconsolidated drift. Where the cover is thick, landslides may occur. Evidence for relatively recent landslide activity is to be found on the west side of the headland forming Cape Mutton where the rocky cliff is hidden for some distance beneath slide debris. Beach gravels are thus derived largely from glacial deposits (Fig. 2-2).

In Biscay Bay a spit occurs half way between the head and mouth of the bay. Such a spit is called a midbay bar by Johnson (1919) and, according to Zenkovich (1950), it has built up because the waves moving from the open sea into the bay are retarded to such an extent that deposition occurs before the waves reach the head of Biscay Bay. The narrowness and length of Biscay Bay are important contributory factors in this retardation. This spit does not form a complete bar as the waters of the lagoon behind the bar maintain a connection with the sea at its eastern end.

Meadow Point is a triangular spit on the west side of Trepassey Harbour and it is also an incipient midbay bar (Guilcher, 1958). This spit and the others in the area have been built up from material transported along the shore by coastal currents generated by oblique waves. The oblique waves are the result of refraction by the indentations of the coast-line. In Trepassey Harbour there has been a movement of material from south to north and, in Mutton and Biscay Bays, from west to east. The tombolo connecting Powles Peninsula with the mainland has grown through the interaction of a more complex wave refraction and diffraction pattern arising from waves passing round the northern end of the Peninsula as well as those passing down its eastern side. The waves passing down the eastern side of Powles Peninsula are also affected by the rocky promontory of the Trepassey ridge passing seawards beneath the water of Mutton Bay.

Marine erosion is active round the headlands (Fig. 2-3) and wherever the shore is backed by glacial deposits (Fig. 2-4). It is difficult to assess to what extent existing rocky cliff-lines in the map area are the result of marine erosion or the result of glacial activity. As mentioned earlier, the thesis area was glaciated, with the rest of Newfoundland, during the Wisconsin stage of the Pleistocene, and the landforms developed at that time have been little modified in the short period that has elapsed since their formation, although the submergence resulting from the Flandrian transgression and the marine erosion which has since taken place have modified the coastline. The rounded uplands, the fiords, the dominance of the consequent drainage, the presence of glacial striae on smooth rock surfaces and the blanket of glacial deposits with a very large number of ponds on its irregular surface are clear evidence of the former presence of an ice sheet covering the whole area. The ice must, in fact, have extended beyond the present land boundary because ground moraine extends beneath the sea at a number of places. These include the northern end of Trepassey Harbour, where Daniel's Point is built up entirely of boulder clay, the coast of Mutton Bay east of the lagoons and the northern end of Powles Peninsula. Glacial striae on polished rock surfaces are present on the west side of Powles Peninsula. These markings indicate the former movement of ice along the channel that now separates Trepassey Harbour from the open sea (Fig. 2-5).

The glacial cover shows considerable variation in thickness; in some areas, such as the uplands west of Trepassey Harbour, it is thin or even absent and in other areas, notably the lowlands, it is up to 80 feet thick as, for example, on the west side of the headland of Cape Mutton. The cover is an unstratified boulder clay or till in which the boulders are entirely of local origin and erratics are rare. Apart from a few small pebbles, the only noteworthy erratic is a large boulder of granite porphyry several feet across lying at the edge of the lagoon just behind the beach east of the southern end of Trepassey. The nearest known source of granite lies about thirty miles to the north. The boulder clay is unweathered except for a small zone at the top beneath the vegetal cover where a thin podsol has developed since

Wisconsin times (Fig. 2-6). There has been insufficient time since the last ice-sheet melted for the proper development of a thick B-horizon and, normally, only the A-horizon is well developed. The A-horizon consists of an upper portion, which may be up to a few inches thick, of dark, humus-rich material with below it a lower portion of variable, but generally greater, thickness in which leaching has occurred. The boulder clay in this leached zone is, therefore, light coloured and the boulders are characteristically white. Below the leached zone is the B-horizon, rarely more than a very thin layer, in which the iron-oxides removed from the A-horizon have been deposited. Beneath the brown B-horizon the boulder clay is unweathered. Peat bogs overlying the glacial cover are a conspicuous feature of the area (Fig. 2-7).

Fig. 2-1 - Bay-mouth bar immediately east of the ridge on which Trepassey is situated (looking eastwards). The bar is made up of pebbles, cobbles and boulders up to a foot or more across; its maximum height is about twelve feet above high-water mark and it shows several beach ridges or berms on its s seaward side.

Fig. 2-2 - Gravel beach, on the west side of Cape Mutton, that has been derived from the debris washed out of the glacial deposits that form the cliff backing the beach. In the distance,shales of the St.John's Formation outcrop on the beach and in the lower part of the cliff.

Fig. 2-1

Fig. 2-2

Fig. 2-3 - Steep coastal cliffs due to marine erosion. They occur in rocks of the St.John's Formation on the east side of Cape Mutton and rise to about one hundred feet.

Fig. 2-4 - Glacial drift forming low cliffs, between three and fifteen feet high, along the east coast of Powles Peninsula. St.John's shales can be seen projecting through the beach of boulders, cobbles and pebbles derived from the drift.

Fig. 2-3

Fig. 2-4

Fig. 2-5 - Polished rock surface and glacial striae due to former ice-movement over outcrops of St.John's shales on the east side of Powles Peninsula. The pencil has been placed parallel to the striae.

Fig. 2-6 - Low cliffs in glacial material on the shore south of Trepassey showing podsol developed on boulder clay. The humus-rich layer can be clearly seen above a leached zone which forms a pocket about twelve inches thick to the left of the hammer. The bottom of the A-horizon, marked by a deposit of iron-oxide, passes through the boulder immediately to the left of that beneath the hammer.

Fig. 2-7 - Low cliffs on the east side of Powles Peninsula where peat overlying boulder clay has been exposed by marine erosion. The leached part of the A-horizon and the iron stained layer underlying it may be seen below the base of the peat.

Fig. 2-5

Fig. 2-6

Fig. 2-7

CHAPTER 3

General Geology

The Trepassey area is underlain by a thick sequence of unmetamorphosed sedimentary rocks. These rocks are separable into two groups, the lithology and sedimentary structures of which reflect the different environmental conditions under which they were laid down. However, the two groups are conformable, and since there is no abrupt change in lithology and the constituents of the beds above and below the boundary are very similar, the change from the earlier to the later sedimentary regime must have been gradual. Consequently beds above and below the boundary have certain features in common but when these beds are considered in the broader context of the sedimentary sequences with which they are associated, their affinity with one or the other formation becomes clear, and in the Trepassey area there is no difficulty in locating this boundary.

A comparison of the characters of the two formations recognized in the Trepassey area with those described for other sedimentary rock sequences mapped in the Torbay area by Rose (1952) and the Biscay Bay-Cape Race area by Misra (1969) establishes that they can be correlated with the Conception Group and the overlying St.John's Formation of the Cabot Group respectively.

Conception Group: the name Conception was first used by Walcott (1899) for one of the formations lying between the basal beds of the Cambrian of the Avalon Peninsula and the "Archaean" gneisses of Newfoundland. These Conception beds later became known as the Conception slates. Rose (1952) subsequently defined the Conception Group as a thick sequence of sedimentary rocks overlying the Harbour Main Group and underlying the St.John's Formation of the Cabot Group. He subdivided the Conception Group for convenience of description into an upper part, Torbay slate, with a predominance of red beds and a lower part, Conception slate, in which beds of tuff and conglomerate are present near the base. Hutchinson (1953) established one formal subdivision in the Conception Group to include some 500 feet of red beds present in the upper part of the Conception succession on the west shore of Conception Bay at the north end of the Avalon Peninsula. He named this subdivision the Hibbs Hole Formation. McCartney (1967) also recognized this Formation in the Whitbourne map area and he regards it as approximately equivalent to the Torbay slate division of Rose (1952).

The Conception Group outcrops along the west shore of Trepassey Bay, including Trepassey Harbour as far north as Meadow Point and, also, at the northern end of Powles Peninsula and on the shore immediately south of Trepassey. Inland, exposures are infrequent and occur chiefly in the courses of the Northwest and Northeast Brooks (Map 2) as well as on the high ground west of Trepassey Harbour where bedrock projects through the thinner covering of ground moraine in this area. Powles Peninsula and the lowland area between Trepassey and Biscay Bay, where bogs and ponds are particularly abundant, have a thick cover of boulder clay and, consequently, an almost complete absence of outcrops of Conception Group rocks.

There is neither a complete sequence of Conception Group strata in the map area, as the base of the Group is not exposed, nor is there a continuously exposed section so that only isolated parts of the succession can be studied in outcrop. However, the fact that the Conception beds at the north end of Powles Peninsula and south of Trepassey pass conformably up into beds of the St.John's Formation establishes this part of the Conception sequence as belonging to its uppermost part and corresponding to the upper beds of the Cape Cove Formation in Misra's area. The only other more or less continuously exposed sequence is present along the west side of Trepassey Bay and Harbour and this also appears, by comparison with Misra's succession and Rose's (1952) description of the Conception Group beds of the Torbay area, to belong to the upper part of the Group (Torbay slate ?) as red beds are a conspicuous feature. The red beds are succeeded by distinctly green beds. The fossiliferous horizons of Misra's (1969) Cape Cove Formation, which should be present in the succession at the northern end of Powles Peninsula and south of Trepassey, are hidden beneath glacial drift or beach material.

The Conception Group in the Trepassey area consists of greywackes, siltstones, mudstones and cherts. The greywackes and mudstones are nearly always associated in graded beds in which the lower part consists of greywacke and the upper part of mudstone; colour banding within the finer-grained rock-types and in the siliceous beds indicates that these are also graded. The greywackes range from very fine-grained to sufficiently coarse for individual grains of quartz and feldspar, as well as rock fragments, to be distinguished. The greywacke portion within an individual graded bed may be a very thin basal layer or represent the greater part of its total thickness. Graded beds are usually several inches to a foot or more in thickness (Fig. 3-1) but towards the top of the succession they are much thinner, generally between one and three inches (Fig. 3-2). These graded beds maintain their thickness laterally and even very thin layers, often distinguished by a difference in colour, are remarkably persistent. The boundaries between graded beds are sharp and distinct, very rarely showing evidence of any erosion of the underlying bed before the next one was deposited. Lamination can be seen in some cases within the greywackes. Finer-grained rock-types and greywackes may also show small-scale cross-bedding and, more rarely, slumping. Slumping of such beds must have occurred immediately after deposition since either the overlying finer-grained part of the graded bed in which slumping occurred is unaffected or, where another bed follows, it shows no evidence of movement.

Chert beds are hard, break with a conchoidal fracture and display sharp edges. They are frequently laminated and differences in grain size not apparent to the naked eye are indicated

Fig. 3-1 - Typical graded bedding displayed by Conception Group greywackes and associated mudstones on the shore along the west side of Trepassey Harbour. The individual graded units are here several inches to a foot or more in thickness. Wave action has smoothed the outcrops thus making them appear more siliceous than they really are.

Fig. 3-2 - Graded bedding in the upper part of the Conception Group Sequence near the Conception Group - St. John's Formation boundary on the east side of Powle's Peninsula at its northern end. Individual units are thin, only an inch or two in thickness and laterally persistent.

Fig. 3-1

Fig. 3-2

by a difference in the intensi[illegible] the colour of the laminae. Chert beds have also undergone slumping after deposition and the contorted nature of these beds shows up particularly well because of the colour banding (Fig. 3-3).

The incomplete and discontinuous sequences of the Conception Group present in the area, together with the fact that the section along the west side of Trepassey Harbour, where the beds are best exposed, is largely along the strike and involves only a couple of hundred feet of strata, and the further complication of tight minor folds, makes it impossible to accurately determine the total thickness of the Conception Group in the thesis area. The most that can be said, judging from its areal extent and its structural pattern, is that several thousand feet of the beds of this Group are represented.

Succeeding the Conception Group beds conformably is the St.John's Formation. The boundary can be drawn where there is a change from typically graded beds to a sequence of thinly bedded mudstones with silty or sandy intercalations (Fig. 3-4) which, in the map area, exhibit conspicuous slump features. It is not necessary here, as Misra (1969) has done in the Biscay Bay-Cape Race area, to distinguish a transitional zone, as the change from a graded to a generally non-graded sequence is clear at the three places where the boundary can be drawn, i.e. on both sides of Powles Peninsula and immediately west of the rocky point south of Trepassey.

St.John's Formation: the St.John's Formation was originally called the St.John's slate by J.B.Jukes (1843) and later the same beds were referred to as the Aspidella slates by Murray and Howley (1881) and as the Momable series by Walcott (1899). This latter term remained in general use until Rose (1952) redefined the rock formations of the Torbay map area and replaced it with St.John's Formation. Rose (1952) placed the St.John's Formation and the overlying, younger Signal Hill and Blackhead Formations in the Cabot Group which he regarded as disconformably overlying the Conception Group. There is, however, no evidence in the thesis area of any disconformity between the two Groups, and this appears to be true for the whole of the southern end of the Avalon Peninsula as Misra (1969) also found no evidence of any break in sedimentation between the rocks of the Conception and Cabot Groups in his region. Misra did, however, as mentioned earlier, distinguish a transitional zone, and Brueckner, in his description of the geology of the eastern part of the Avalon Peninsula (in Press), similarly refers to a gradational contact between the Conception-type rocks of the area and the St.John's Formation which is also contrary to Rose's (1952) opinion.

The St.John's Formation outcrops succeed those of the Conception Group on both sides of Powles Peninsula and also to the east of the rocky point south of Trepassey where they are present around Cape Mutton and along the west side of Biscay Bay as far as the eastern boundary of the thesis area (Map.1). Thus Powles Peninsula is underlain by this Formation except at its northern end and Cape Mutton is entirely underlain by the same rocks. Inland exposures are rare in both areas but the few scattered out

Fig. 3-3 - Slumping, brought out by colour banding, in laminated chert south of Meadow Point.

Fig. 3-4 - Alternating shales and thin sandstones of the St.John's Formation on the east side of Powles Peninsula. The sandstone laminae are more easily eroded than the shale layers as shown by the grooving resulting from differential erosion.

Fig. 3-3

Fig. 3-4

outcrops of the Conception Group and the St.John's Formation that are present north of Cape Hutton enable the position of the boundary between them to be fairly accurately determined in this part of the Trepassey area.

The St.John's Formation consists of light to dark grey shales in which there are intercalations of siltstone or fine-grained sandstone. The two rock-types alternate more or less regularly with one another in some parts of the Formation, but the sandy layers are nearly always the subordinate element. Sandy layers range from inconspicuous laminations to beds several inches thick although occasionally a much thicker bed is present in the sequence. Both the argillaceous beds and the sandy beds are commonly laminated. The former, since they are not fissile, are mudstones rather than shales. However, the general practice of calling them shales will be continued here. The argillaceous beds of this area appear to be less fissile and lighter in colour than the typical black shales of the Torbay map area, although the lighter colour may be due to weathering since fresh exposures in cuttings are not available locally for comparison.

The sandy beds commonly exhibit small-scale cross-bedding, and further evidence of current activity is shown by the presence of wash-outs and ripple-marks. Ripple-marks are common but they rarely form continuous lateral sequences (Fig. 3-5). This lack of continuity resulted from either partial erosion of the original ripple-marked surface prior to deposition of the overlying sediment, so that the ripples became separated from one another, or from there having been insufficient sand available at the time of deposition for the formation of a continuous series of ripples (see p.112; Fig. 3-5). Consequently completely ripple-marked bedding surfaces are rarely present in the St.John's Formation in the Trepassey area.

The sandy beds nearly all contain some calcium carbonate as shown by slight to marked effervescence when dilute hydrochloric acid is applied to them.

Slump structures are a characteristic feature of the St.John's Formation and occur most frequently within the lower part of the Formation. Slumping (Fig. 3-6) generally involved a number of associated beds so that slump zones are generally thick, in some cases many tens of feet. Shale sequences with thin sandy partings are those most commonly affected and these often display such perfect overfolding (Fig. 3-7), with little disturbance of the beds involved, that the overfolding appears at first sight to have been the result of tectonic folding. However, these slump zones are bounded above and below (Fig. 3-8) by beds displaying the normal dip of the succession so that the folding associated with slumping must have taken place soon after the uppermost layer to be affected was laid down. Other slump zones show considerable disturbance of the strata involved in the down-slope movement (see chapter 6).

Within the St.John's Formation parts of the sequence show a striking resemblance to the uppermost part of the Conception Group succession, as the beds are similarly graded and, when weathered, they exhibit the same pattern of grey-black

Fig. 3-5 - Shales of the St.John's Formation on the east side of Powles Peninsula showing sandy streaks and laminae and isolated ripple-marks at succeeding levels. A particularly clear ripple-mark is present just to the left of, and below, the head of the hammer. These asymmetrical current-formed ripple-marks show that in this illustration the current was moving from left to right.

Fig. 3-6 - Slump-folding in St.John's shales about half way down the western side of Powles Peninsula. The folds shown have their axial planes horizontal and they are, therefore, recumbent.

Fig. 3-5

Fig. 3-6

Fig. 3-7 - Recumbent slump folds showing no disruption of the strata folded during the down-slope movement of the still soft sediments on the sea floor soon after their deposition; St.John's shales on the east side of Powles Peninsula about 6000 feet south of the tombolo connecting Powles Peninsula with the mainland.

Fig. 3-8 - Slump horizon bounded above and below by undisturbed strata; St.John's shales on the west side of Biscay Bay.

Fig. 3-7

Fig. 3-8

bands alternating with pale-grey bands corresponding to the coarser and finer parts of successive graded beds (Fig. 3-9). However, the individual graded beds of the St.John's Formation are on the whole much thinner than their Conception counterparts and this difference in thickness becomes clear when figures 3-2 and 3-9 are compared with one another as there are twice as many graded beds present beneath the length of the hammer in figure 3-9, St.John's Formation beds on the east side of Powles Peninsula, as there are in figure 3-2, uppermost Conception beds at the northern end of the same peninsula.

The total thickness of the beds of the St.John's Formation in the Trepassey area is about 3,500 feet. This estimate was obtained from the practically continuous succession of beds outcropping along the eastern side of Powles Peninsula where they nearly all strike NE-SW, their dips are rarely under 30 degrees or over 60 degrees and the sequence as a whole has been little disturbed by faulting. This thickness is greater than that found in the neighbouring Biscay Bay-Cape Race area where only 1,100 feet of beds are present (Misra, 1969), or the Torbay map-area where Rose (1952) estimated the St.John's Formation to be between 1,300 amd 2,400 feet thick. Brueckner (in press) regards Rose's figure as an underestimate. The figure of 3,500 feet in the Trepassey area corresponds more closely with the thickness of the Carbonear Formation of the Hodgewater Group, 3,200 to 4,000 feet, in the Whitbourne map-area, which is considered as the lateral equivalent of the St.John's Formation (McCartney, 1967).

Fig. 3-9

Fig. 3-9 - Graded bedding in thin greywacke - mudstone beds of the St. John's Formation on the west side of Powles Peninsula. Note the continuity and uniform thickness of the individual graded beds and their sharp contacts.

Immediately below the Conception Group - St.John's Formation boundary at the northern end of Powles Peninsula, a four inch band of tuff is present in the sequence. This altered tuff was probably originally of basic composition judging from the small amount of quartz and feldspar present. The presence of this former ash indicates that volcanoes were active in late Conception times, and the tuffs found by Misra (1969) in uppermost Conception beds and in the St.John's Formation of the Mistaken Point-Cape Race area, as well as those found by Singh (1969) in the Signal Hill Formation, suggest that these sporadic outbursts of volcanic activity represent the dying phase of the main period of volcanic activity in Harbour Main and eraly Conception times.

Only a general account of the geological structure of the Trepassey area is given below and a more detailed description follows in chapter 4.

The strata underlying the Trepassey area have been folded into a synclinorium complementary to the anticlinorium of the Biscay Bay-Cape Race area recognized by Misra (1969), and its eastern flank lies largely in that area and therefore beyond the eastern boundary of Map 1. The axis of the synclinorium trends north-northeast through Mutton Head (see Map 1) and plunges gently to the south-southwest so that the beds of the St.John's Formation, that occupy the core of this composite fold, extend beneath the sea in that direction. Closure of the flanking Conception beds takes place in the northeast part of the thesis area.

Major, as well as minor folds, on the flanks of the synclinorium, generally have a similar orientation but some of the latter plunge more steeply (over 30 degrees) and, unlike the former, are asymmetrical (Figs. 3-10 and 3-11).

Only one major fault has been mapped in the area. The writer has named it the Trepassey Harbour fault and it strikes NNE-SSW below the fiord west of Fowles Peninsula where its presence is inferred from the differences in structure and succession observed on the opposing shores. Although some of the minor faults have a similar trend to the major fault, most of them have their courses aligned in other directions. The majority of the minor faults are either normal faults or bedding faults.

Closely spaced fracture cleavage striking north-northeast is present throughout the area in both the Conception Group and the St.John's Formation. In general, fracture cleavage is better developed in the St.John's Formation (Fig. 3-12) than it is in the Conception Group, apparently because the rocks of the former are softer than those of the latter group.

Joints are universally present; their abundance varies greatly from one exposure to another as does the number of sets present and the direction in which they run. Where several sets are present and the joints are closely spaced, they intersect with one another or with cleavage planes or with bedding to produce characteristic and in some cases unusual patterns (Fig. 3-12).

The north-northeast trend of the fold axes, of the major fault as well as many of the minor faults, and of the fracture cleavage is also reflected in the topography of the Trepassey area where elongate ridges, rivers, headlands and inlets of the sea generally have the same orientation. The topography of the area is thus controlled by the structure of the bedrock.

Fig. 3-10 - Asymmetrical anticline in Conception Group greywackes about two-thirds of a mile south of Meadow Point at the base of the cliffs on the west side of Trepassey Harbour. This view is from the north and shows the west limb of the anticline dipping more gently (45 degrees) than the east limb, which is vertical to slightly overturned. The axial plane of the fold is inclined towards the west.

Fig. 3-11 - The same fold as in Fig. 3-10 but viewed from the south to reveal the axis plunging southwards (down the line of the hammer) at 32 degrees. A thin layer of quartz on the exposed surface is slickensided indicating that slippage of the beds over one another took place during folding.

E

W

Fig. 3-10

W

E

Fig. 3-11

Fig. 3-12 - Closely spaced fracture cleavage in shales of the St.John's Formation on the west side of Powles Peninsula.

Fig. 3-13 - Closely spaced, nearly vertical joints, parallel to the strike of shales with sandy intercalations, cut across the dipping beds (hammer shows the inclination) as well as the fracture cleavage of this beach exposure, thus providing lines of weakness that facilitate marine erosion. The unusual outcrop pattern shown here in shales of the St. John's Formation on the east side of Powles Peninsula is, therefore, due to marine erosion opening up the joints.

Fig. 3-12

Fig. 3-13

CHAPTER 4

Structural Geology

All the rocks in the Trepassey area have undergone deformation resulting from the same compressive stresses, as the general structural pattern is the same wherever they are exposed. This is not surprising in view of the fact that the only two groups of beds represented in the area, those of the Conception Group and the St.John's Formation, are conformable. These compressive stresses gave rise first to folds and then to fracture cleavage, joints and faults in that order, since joints cut the fracture cleavage and faults in turn displace both the fracture cleavage and the joints apart from those joints that developed in association with faulting. However, where the faults are concerned it is not possible, in the absence of younger strata in the area, to state that they were all formed more or less contemporaneously as a result of the folding, and their age or ages, and that of the folding, can only be established by comparison with other areas of similar rocks, having the same structural pattern, where the stratigraphy enables the time of these events to be determined. In this case such areas are to be found at the northern end of the Avalon Peninsula, but even there the absence of Silurian or younger strata makes the dating of post-Ordovician events uncertain. Comparison with these areas is not considered further here but is dealt with in a later section on correlation.

Fold axes and many of the faults are more or less parallel and trend in a north-northeasterly direction. This trend varies locally from north to northeast. Major folds, with one exception, plunge gently to the south-southwest while minor folds, although plunging in the same direction, generally have a steeper plunge. Fracture cleavage is developed throughout, both parallel with and at an angle to the bedding. Joints are universally present.

Top and bottom structures show that everywhere the beds are the right side up.

Folds

The most important structural feature of the thesis area is a composite fold or synclinorium, here named the Cape Mutton synclinorium. This structure underlies the entire map area and extends beyond its boundaries. The axis of the synclinorium trends north-northeast through Mutton Head and it plunges gently to the south-southwest at about 20 degrees (Fig. 4-1). This central part of the synclinorium is occupied by rocks of the St. John's Formation while the underlying beds of the Conception Group surround them on the landward side where closure of the beds occurs. Map 1 shows the axial part of the synclinorium within the Trepassey area, part only of its eastern flank, since most of it is present in the neighbouring Biscay Bay-Cape Race area where it passes laterally into an anticlinorium (Misra, 1969), and only a little more of the western flank, since this too lies largely beyond the map in the St.Shotts area which has not yet been mapped. A further anticlinorium may, however, be expected in the St.Shotts - St.Vincent's region on the basis of the large-scale structures present between Trepassey Harbour and Cape Race. The map further

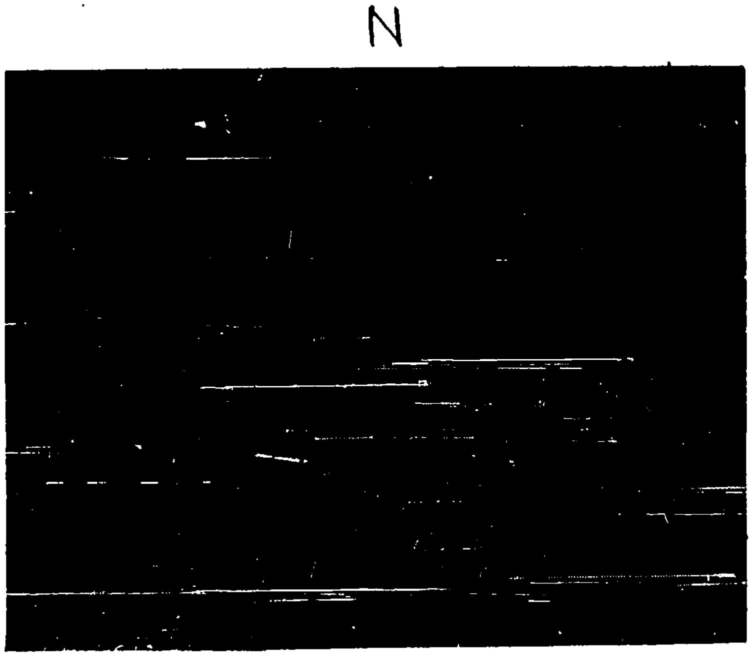


Fig. 4-2

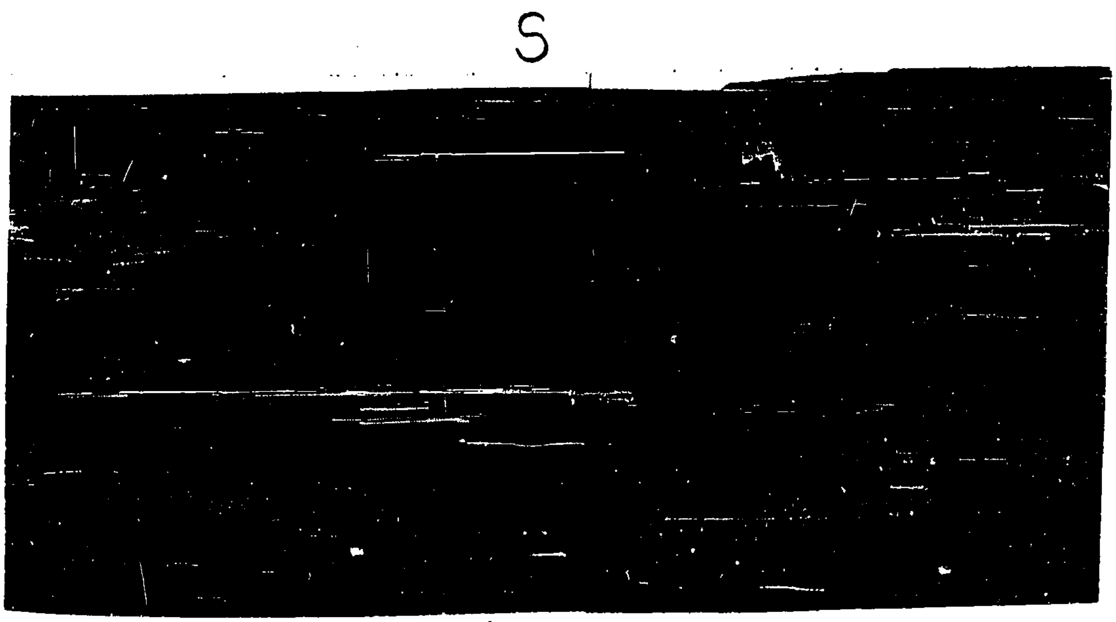


Fig. 4-3

shows that the Conception Group underlies the area to the west, northwest and north of that which is underlain by the St.John's Formation.

The Cape Mutton synclinorium includes both major and minor subsidiary folds. Three major ones can be distinguished within the thesis area and a fourth lies partly in, and partly out of, the area along its eastern boundary. The presence of a fifth major fold is inferred from the structural pattern. The most obvious of these folds is the Cape Mutton syncline. Beyond it to the west an anticline succeeded by a syncline underlie Powles Peninsula and the latter extends below the waters of Trepassey Bay. East of the Cape Mutton syncline, another syncline is present beneath Biscay Bay and consequently an anticline must be present in the intervening area immediately east of Mutton Head.

The Cape Mutton syncline, occupying the axial part of the Cape Mutton synclinorium, is the largest of the major folds. It is a broad, open fold with an essentially vertical axial plane and its axis plunges to the south-southwest at 20 degrees; the dip of the limbs is generally between 25 and 50 degrees.

The Cape Mutton syncline is followed to the west by the Powles Head anticline and syncline. The axial part of the Powles Head anticline is exposed on the shore (Fig. 4-2) and in the cliff (Fig. 4-3) below the lighthouse at the southern end of Powles Peninsula; it is also an open fold with a vertical axial plane but its axis plunges to the north at some 10 degrees which is contrary to the regional pattern. This anomalous plunge probably represents a local reversal as a little further to the north on the

Fig. 4-2 - Powles Head anticline exposed in the cliff face below the lighthouse at the southern end of Powles Peninsula. A hammer used to indicate scale is difficult to see but it is present on the cliff face directly above the plank of wood lying on the shingle; the actual height of the hammer above the beach is six feet. The fold is symmetrical and the gentle northerly plunge of the axis, exposed in the foreground, is opposite to the regional plunge. The gentle dip of the limbs on either side of the axial plane is obscured by the large number of joints (some horizontal) present in the apparently massive beds in the core of the fold. These 'massive beds' are actually thick sequences of shales with sandy intercalations belonging to the St.John's Formation.

Fig. 4-3 - Axial part of Powles Head anticline exposed on the shore at the same locality as Fig. 4-2 but here viewed from the north. The gentle landward plunge of the fold axis is evident in this photograph. A slickensided quartz layer on the exposed bedding surface indicates that the beds slid over one another during folding. Such slickensided surfaces are common throughout the area in the vicinity of fold axes.

N

Fig. 4-2

S

Fig. 4-3

west side of the peninsula the complementary syncline plunges in the usual direction. Just west of the lighthouse the western limb of the anticline is cut by a fault that traverses the south-western corner of Fowles Head disturbing the strike of the beds south of the fault so that it is not possible to trace, in the coastal exposures, the passage of the Fowles Head anticline into the succeeding syncline. However, immediately beyond the fault on the west side of the peninsula, the axial part of the syncline and its eastern limb underlie the shore and the high cliffs on this part of the coast (Figs. 4-4 and 4-5). The western limb of this fold lies beneath the sea.

Professor Anderson (personal communication) has established, largely from aerial photographs, that northeast of the Cape Mutton syncline another major syncline is present with its axis continuing southwards beneath the eastern side of Biscay Bay. This structure thus occurs between the area considered in this thesis and that studied by Misra (1969). It has a similar alignment to the other folds of the region and likewise plunges to the south-southwest. The beds of the St.John's Formation on the western side of Biscay Bay, at least towards the head of the bay, are part of this structure. The Biscay Bay syncline does not appear on Map 1 but its presence is suggested by the inferred position of the Conception Group - St.John's Formation boundary in the northeast corner of the map.

Since it is not possible to have two synclines, the Cape Mutton syncline and the Biscay Bay syncline, without an anticline between them, an anticline must be present in the northeastern part

Fig. 4-4 - West side of Powles Peninsula, north of the fault cutting across the southwestern corner of the peninsula, looking south across the fault. The fault runs more or less east-west here and its position is marked by the inlet which has developed as a result of marine erosion being able to make more rapid progress along the weak fracture zone than against the massive beds forming the cliffs to either side of it. The effect of faulting is clearly seen in the marked difference between the dip and strike of the steeply inclined beds in the background with the dip and strike of the curved beds in the foreground. The latter are part of the syncline lying to the west of the Powles Head anticline.

Fig. 4-5 - Axial part of the same syncline as seen in Fig. 4-4 viewed from the adjacent cliff top. These axial beds are plunging south-southwest. Joint sets have been opened up by marine erosion and by weathering.

S

Fig. 4-4

W

Fig. 4-5

of the map area. Unfortunately, in the critical area, the bedrock is hidden beneath glacial drift. Further south it seems likely, as there is no evidence for such a structure at the southern end of Cape Mutton, that this anticline dies out and the two synclines merge with one another.

Minor folds, tens to hundreds of feet across, are present on the flanks of the major folds and the majority of them trend northeast but notable exceptions trend west or between west and west-northwest. Minor folds with axes parallel to the regional trend are present in beds of the St.John's Formation on the west side of Powles Peninsula, about 3,000 feet south of Beach Point, and in the Conception Group on the western shore of Trepassey Harbour opposite Beach Point and further south (Map 1. Figs. 3-10, 3-11, 4-6 and 4-7). Some of these minor folds are asymmetrical with their axial planes inclined to the west and their axes plunging to the southwest.

The minor folds with a westerly trend occur in the Conception Group outcrops in the cliffs and on the shore south of Meadow Point on the west side of Trepassey Harbour, and in the St.John's Formation on the west coast of Biscay Bay about three-quarters of a mile south of Biscay Bay village. The latter, forming an anticline-syncline pair, plunge slightly north of west at a low angle and their limbs dip gently between 8 and 11 degrees. The cross-folds in the Conception Group, also an anticline-syncline pair, are larger and their limbs dip more steeply at angles between 40 and 60 degrees. The strike of the beds of the southern limb of the syncline, where the axial beds

Fig. 4-6 - Tight minor fold in greywacke-mudstone beds of the Conception Group on the west side of Trepassey Harbour almost opposite Beach Point at the northern end of Powles Peninsula. This syncline, viewed from the north, is asymmetrical and its axial plane is inclined to the west. The western limb dips at 70 degrees; the eastern one at 45 degrees. There are five minor folds of this kind succeeding one another en echelon.

Fig. 4-7 - The core of the southernmost of the five minor folds mentioned above viewed from the east side in order to show the plunge of the axis to the south-west at 30 degrees. The beds are much fractured and disturbed where the abrupt bending took place during folding. Slickensided surfaces are common. Radial tension joints and other fractures are now veins as the original cracks contain secondary quartz, feldspar and chloritic minerals. These minerals are intimately mixed with one another and they were probably derived from the rock flour produced during shearing.

Fig. 4-6

Fig. 4-7

are exposed (Fig. 4-8), is north 57 degrees east; immediately south of this exposure the strike changes to north 33 degrees east and then, as the beds are followed southwards, it becomes north 18 degrees east, i.e. the regional strike of the beds has been re-established. Where this happens a tight minor fold is present at the base of the cliff and it is succeeded to the south by four more such folds. Beyond these minor folds, at the southern end of this coastal section, the Conception beds dip southeast at 80 degrees.

Misra (1969) briefly mentions the presence of tight minor folds of the regional type in the St.John's Formation on the east side of Biscay Bay but these folds are not indicated on his geological map of the area (Plate 2-4). Rose (1952) also found, in addition to similar minor folds, some evidence of cross-folding in the Torbay map-area.

<u>Faults</u>

There are numerous faults in the area but with one notable exception, the Trepassey Harbour Fault, all appear to be minor faults. It appears, also, that most of them resulted in displacements of only a few inches or, at most, a few feet. It must be emphasized, however, that particularly where tear and bedding faults are concerned it is impossible in most cases to determine the amount of displacement that has taken place or the true relative movement. This is because (1) it is possible to observe these faults only in coastal exposures as inland they are generally hidden beneath glacial deposits, and (2) the faults observed displace only the beds of a single formation and since these formations include thick sequences of similar rock types, the beds on either side of a fault plane still resemble one another even though considerable displacement may have occurred.

The Trepassey Harbour Fault is, after the Cape Mutton synclinorium, the most important structural feature of the area. It is believed to strike north-northeastwards across the entire map area beneath the fiord west of Powles Peninsula (see Map 1). The fault cannot, therefore, actually be observed because it lies either beneath the sea floor or, beyond the map-area to the north, beneath glacial deposits, but its presence is inferred from the nature of the geology on either side of the fiord. The main differences between the geology of the two sides of the fiord are as follows:

1) Conception Group rocks underlie the entire area west of the fiord whereas east of it they underlie only the northern half of the area.
2) The rocks of the St.John's Formation, although absent west of the fiord, underlie the southern half of the area east of it.
3) The rocks underlying the northern end of Powles Peninsula belong to the uppermost part of the Conception Group succession; they are graded greywacke-mudstone beds generally only a few inches thick and characteristically grey. That part of the Conception Group underlying the area west of the fiord does not belong to the upper-

most part of the succession and although these rocks are generally graded greywacke-mudstone beds, the thickness of these beds shows considerable variation from less than an inch to over a foot. Massive greywackes, graded mudstones and cherts are also present in the sequence west of the fiord; they are typically grey-green, green or purple.

4) The structural pattern is different on the two sides of the fiord.

These differences clearly establish the lack of stratigraphical and structural continuity between the two areas, a lack of continuity that has arisen as a result of faulting in the intervening area. A detailed study of the effects of this faulting on the geology of the areas on either side of the fault, along its course to north and south of the Trepassey area, will have to be undertaken in order to determine the true nature of the faulting that has taken place.

Most of the minor faults noted in the area were observed in the extensive coastal exposures of rocks of the St.John's Formation because inland these faults are hidden beneath the mantle of ground moraine,which also obscures any topographic expression of faulting there may be in the area beneath the ground moraine. Minor faults are likely to be as common in the Conception Group as in the St.John's Formation but there was less opportunity for observing them because coastal exposures of the Conception Group are restricted to the western shore of of Trepassey Bay and around Trepassey Harbour. Minor bedding, tear and normal faults are present. Bedding faults are fairly common in both formations but it was impossible to determine their displacements (although they are probably small) because the beds above and below such faults are similar to one another (Fig. 4-9). Deposition of minerals occurred along many of the fault planes, subsequent to their formation and, in some cases, the growth of these minerals has separated the laminae of the beds bounding the fault plane. Quartz, feldspar, chlorite minerals and, to a lesser extent, calcite are found along fault planes in the Conception Group. Calcite and, to a lesser extent, quartz are present in those faults that occur in the St.John's Formation. The dominance of quartz in the former and calcite in the latter reflects the fundamentally siliceous nature of the Conception Group and the widespread occurrence of calcite in the St.John's Formation (see chapter 5).

Tear faults, similar to that seen on the western shore of Biscay Bay in a position corresponding to the southern end of the only ridge to landward (see Map 1), show much disturbance and brecciation of the strata along the line of the fault; slickensides indicate the dominance of lateral movement. The importance of faults of this kind is difficult to determine from observations made on coastal exposures. In the case of the fault just mentioned, it is possible that it continues landward for some distance and that it is responsible for an apparent topographical offset of the main Mutton Head ridge.

Normal faults have throws ranging from an inch or two to

Fig. 4-8 - Syncline in Conception beds on the west shore of Trepassey Harbour, south of Meadow Point, partly hidden by vegetation. The hammer in the centre of the picture indicates the position of the axial plane. This fold, and the complementary anticline north of it (not shown) are cross-cutting.

Fig. 4-9 - Bedding fault in Conception beds of the cross-cutting anticline immediately south of Meadow Point. Quartz is present along the plane of the fault. The beds, here dipping west at about 50 degrees, are thinly bedded, generally purple graded greywackes and mudstones. The beds above and below the bedding fault are similar.

Fig. 4-8

Fig. 4-9

greater than 50 feet, the latter figure being the maximum that is directly observable in cliff sections. A cemented fault-breccia is a conspicuous feature of these faults.

Joints

Joints are present throughout the area and they vary in number and direction from outcrop to outcrop, being sometimes easily recognizable (Figs. 3-13, 4-10) and at other times difficult to detect. This local variation appear to be due partly to the lithology and partly to the thickness of the beds concerned, but in spite of the fact that rocks of the Conception Group are, in general, more massively bedded, harder, and therefore more brittle, than those of the St.John's Formation, no generalization can be made to the effect that joints are more frequent in the former than the latter. A more obvious association was observed between joint frequency and the structural association of the beds, i.e. whether the beds are close to a fault of some kind or lie at or near a fold axis, because sub-fracturing is more extensive wherever the rocks have been subjected to a greater stress. Many of these joints are, however, nonsystematic or discontinuous, reflecting only local relief from stress, and they are frequently curved. The systematic joints tend, on the other hand, to be continuous and their surfaces are usually planar, although slight curvature may sometimes be observed. Most of the systematic joints are clean cut with smooth surfaces and appear to be shear joints.

The alignment of systematic joints was recorded outcrop

Fig. 4-10 - Conspicuous joint sets in three directions in steeply dipping beds of the St.John's Formation on the west side of Powles Peninsula at its southern end. The near vertical joints marked by the hammer on the cliff behind the beach are well developed and closely spaced. Less obvious, and not so closely spaced, is the second set of joints that cuts the first set obliquely in the cliff-face. The smooth, flat surfaces of the third set of joints, cross joints, face the observer above the exposed bedding plane.

Fig. 4-11 - Rhombohedral joint pattern in beds of the St. John's Formation resulting from the intersection of oblique joint sets. Closely spaced fracture cleavage runs parallel to the plane of the photograph and makes it easier for marine erosion to gradually strip away the rhombs. As each rhomb is removed so it leaves the acute angle of the rhomb below it exposed as an upstanding triangular peak.

Fig. 4-10

Fig. 4-11

by outcrop throughout the area and although a rhombohedral pattern (Fig. 4-11) is characteristic of some outcrops of the St.John's Formation, and joints with a northwesterly strike are the most common, no obvious regional pattern emerged from recording their direction in the field. A frequency diagram was, therefore, prepared in order to determine whether or not a regional joint pattern exists and whether there is any relationship between the joints and faults or folds, i.e. whether there are tectonic joints present. One hundred and five joint readings noted in outcrops of the St. John's Formation were used in preparing a joint rose (Fig. 4-12). The rose reveals that there are several prominent joint directions. Two of these, NW to SE and WNW-ESE, although not equally developed, show a relationship to the folding in the area as they are oblique to the regional north-northeasterly trend of fold axes and major faults, and appear to correspond to the theoretical directions of maximum shear (Read and Watson, 1962). There also appears to be a possible relationship between these directions and the strike of some of the minor faults in the Trepassey area, and in this connection it is worthy of note that 80 percent of the one hundred and five joints noted are inclined at angles of, or greater than, 70 degrees. Another prominent joint direction lies in the acute angle between the oblique joint directions and, since this direction is perpendicular to the fold axes these are cross joints. Longitudinal or strike joints are poorly represented

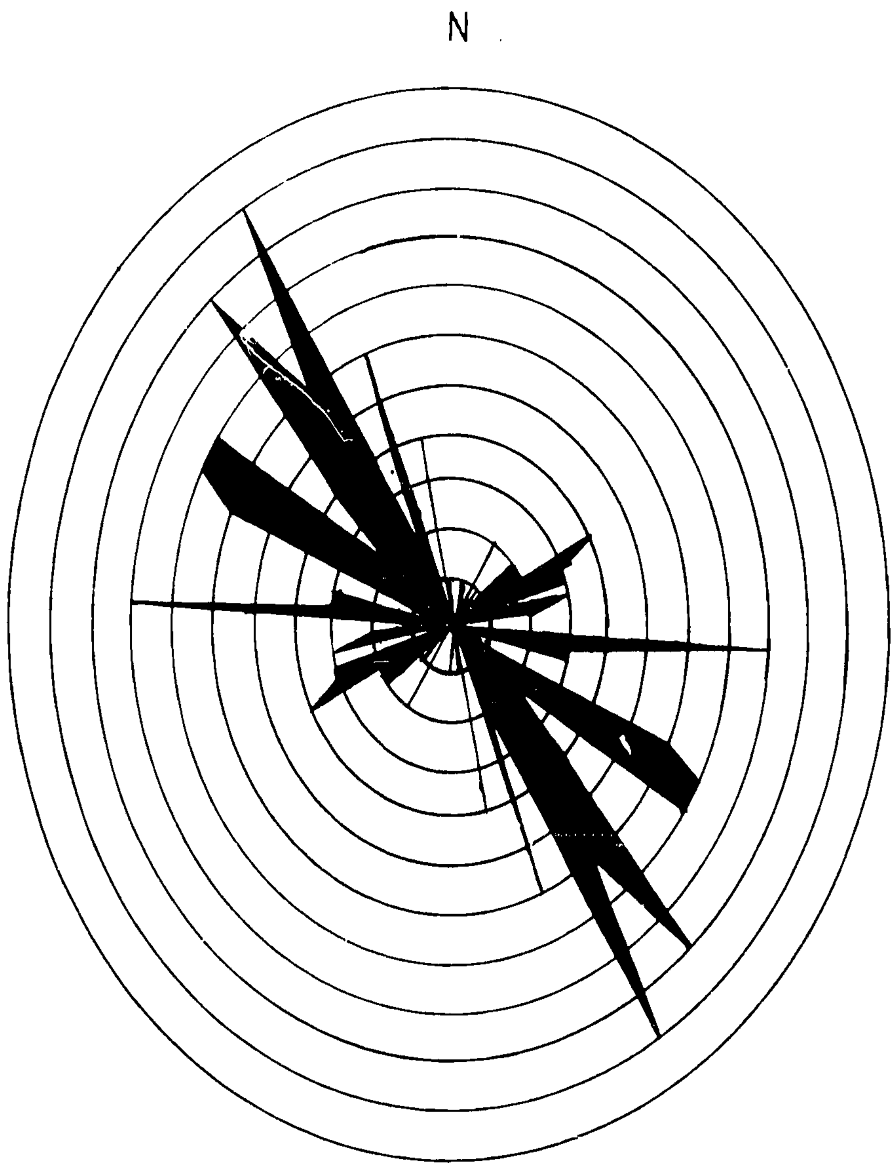


Fig. 4-12 - Frequency diagram showing the pattern of jointing in rocks of the St.John's Formation in the Trepassey area. Interval for bearings 5°; circles at unit distance apart, one joint per circle. One hundred and five readings were used in the preparation of this joint rose.

probably because of the development of fracture cleavage.

The intersection of the oblique joints gives rise, where joint sets are closely spaced, to a rhombohedral joint pattern, as does the intersection of cross joints with either set of oblique joints. Since intensity of jointing is variable, and the oblique joints are not equally developed, a rhombohedral pattern is not evident in every outcrop. Rose (1952) drew attention to the presence of a rhombohedral joint pattern in Cabot Group sandstones and conglomerates but made no reference to such a pattern being present in the shales of the St.John's Formation.

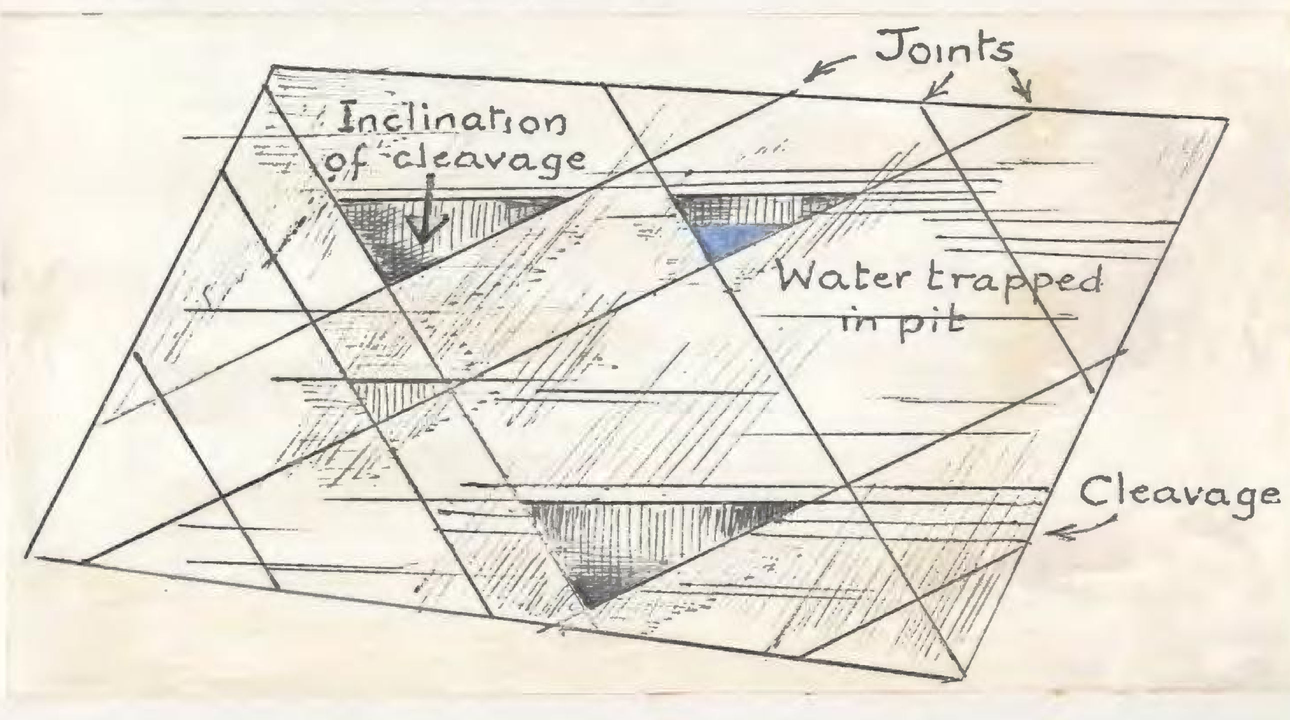
Intersection of joints with cleavage gives rise to a remarkable pattern of triangular pits on the bedding planes of Conception Group cherts and greywackes outcropping in the waterfall where the Northeast Brook flows into Trepassey Harbour (Map 2; Fig. 4-13). The pits have been produced by river erosion. The surfaces of some of the chert beds in the sequence show only these triangular indentations because the joint planes have not been opened up to the same extent in these beds as in the softer greywackes.

Cleavage

Closely-spaced fractures are present throughout the whole of the thesis area. This fracture cleavage is, however, best developed in the softer, fine-grained rock types, where the cleavage planes may be only millimetres apart (Fig. 3-12),

Fig. 4-13

Fig. 4-13 - Bedding surface of a Conception Group greywacke bed exposed in the waterfall at the mouth of the Northeast Brook south of the road bridge. Sets of oblique joints intersect the cleavage which is inclined in nearly the same direction as the bedding surface. The river has scoured out the down-slope corners of such intersections to produce triangular pits - see sketch below.



and it is difficult to detect or even apparently absent in coarser or harder rock types. It is more apparent, therefore, in shales of the St.John's Formation and in the mudstones of the Conception Group, and it is less onvious, or undetectable, in siliceous mudstones, cherts and greywackes of the latter Group, particularly where these are thick bedded. The cleavage is sometimes refracted as it passes from softer to harder beds where a reduced number of planes may be evident.

The fracture cleavage developed during folding of the beds, probably when further lateral shortening of the beds by folding became impossible (DeSitter, 1956); consequently, it more or less parallels the axial trend of the folds. The strike of the cleavage planes ranges from north 10 degrees east to north 40 degrees east and dips are steep to east or west. Fracture cleavage thus occurs both approximately parallel with, and at an angle to, the bedding and since cleavage planes converge upwards towards the tops of anticlines and downwards towards the bottoms of synclines, their relationship with bedding provides a very useful aid in determining the structural pattern of an area.

A very common feature of many exposed bedding planes is the presence of pseudo-ripples due to micro-faulting on a limited number of convex cleavage planes (Hills, 1963). Pseudo-ripples are particularly well displayed by beds of the St.John's Formation in coastal exposures at the southern end of Powles Peninsula and on the east side of Mutton Bay.

The fracture cleavage pattern of the thesis area is shown in Map 2.

Chapter 5

Petrography

Hundreds of rock specimens were collected in the field for laboratory examination and, of these, seventy-seven were thin sectioned for study under the polarizing microscope. Map 3 shows the site at which each rock was collected for thin-sectioning. All the rock types in the Trepassey area are of clastic or pyroclastic origin and some appear to be clastic with an admixture of pyroclastic material.

Rock types of the Conception Group

In the thesis area the Conception Group beds are conspicuously graded, and non-graded beds are the exception. The coarser element is greywacke and the finer element mudstone, although in certain parts of the succession grading within finer-grained sediments is also apparent, e.g. silty mudstone passing upwards into chert. However, most of the succession consists of a monotonous repetition of the greywacke-mudstone units which, in outcrop, differ from one another only in thickness, the extent to which greywacke or mudstone is the dominant component, and in their colour.

Rock types represented in the Conception Group succession are thus limited to greywackes (coarse to fine-grained), silty mudstones, mudstones and cherts (using the term purely to indicate a fine-grained, highly siliceous rock).

Of the six thin-section descriptions that follow, five are of representative greywackes and one is of chert. The chert has been included, in spite of the fact that little information regarding the mineral composition of the finer-grained rocks is revealed by thin-section studies, in order to demonstrate the nature of the colour-banding which is a conspicuous feature of some Conception Group cherts.

KNW - 1A: Very fine-grained feldspathic greywacke (Fig. 5-1) from first outcrop in the Northwest Brook north of the river bridge. In hand-specimen this rock would be regarded as a siltstone because of grain size; dark grey with widely scattered, tiny specks of pyrites which can hardly be seen without the aid of a lens. In thin section angular grains of quartz, mostly strained, feldspars and rock fragments of variable size grade down to the rock flour of the matrix. Minor constituents include scattered grains of iron-ore, occasional flakes of chlorite and muscovite, and a little calcite, probably secondary. Feldspar (microcline, albite and possibly oligoclase) is particularly abundant. Sericite has grown, in places, in fine approximately parallel zones and is probably an indication of incipient cleavage. The rock fragments are mainly fine-grained aggregations of volcanic origin.

KNW - 3B: Thinly bedded chert (Fig. 5-2) taken from an outcrop on the Northwest Brook 1.3 miles upstream from the road bridge. This is a hard, greenish-grey siliceous rock, breaking with a conchoidal fracture, marked by bands of grey and darker green. Fine laminations are present in some of the lighter coloured

Fig. 5-1 - Fine-grained greywacke of the Conception Group in which there are a few larger grains similar in size to the conspicuous feldspar in the centre of the figure. Other plagioclase feldspar grains can be recognized by their twinning but some of the cloudy grains are also feldspar. Quartz grains showing undulose extinction can be seen in the upper half of the figure. The rock fragments, which form a conspicuous element of this greywacke, are mostly fine-grained aggregates of volcanic origin.
Crossed polars, X30.

Fig. 5-2 - Laminated chert (Conception Group) in which the individual laminae are distinguished by microscopic differences in grain size. This figure shows a silty streak of larger grains (quartz, chlorite and iron-ore) grading up into mudstone in which grains can still be identified, and overlying, with a sharp boundary, a chert lamina below.
Crossed polars, X70.

Fig. 5-1

Fig. 5-2

layers. In thin section the grey-green bands of chert alternate either with darker bands of mudstone containing tiny scattered grains of angular quartz or with grey bands of siltstone consisting of quartz, chlorite and iron-ore in a finer matrix. These silty laminae sometimes have a coarser basal layer of quartz and chlorite grains which grades up into finer material (Fig. 5-2). Finely divided iron-ore occurs in all the laminae and defines the base of the silty layer seen in the figure wherever the coarser grains of quartz and chlorite are absent.

KFP - 1D: Fine-grained feldspathic greywacke (Figs. 5-3a and 5-3b); first outcrop of Conception beds south of Meadow Point, west side of Trepassey Harbour. In hand-specimen a grey-green siltstone with grains barely visible to the naked eye. In thin section abundant grains of quartz, feldspar and rock fragments are associated with a minor amount of iron-ore, scattered flakes of chlorite and muscovite, all set in a finer, generally indeterminate, matrix. Most of the quartz grains show undulose extinction and the feldspar is typically albite; some of the quartz and feldspar grains appear to be corroded and encroached upon by the matrix and, in other cases, by chlorite. Sericite and chlorite can be identified in the matrix. Rock fragments are difficult to determine in greywacke thin sections unless they are fairly large and characteristic. This difficulty is increased by the fact that under crossed polars the boundaries of many of the darker, fine-grained aggregates seen distinctly under plane-polarized light

Fig. 5-3a - Fine-grained feldspathic greywacke (Conception Group) with both angular and moderately well rounded grains. Quartz and feldspar grains can be readily identified in the figure (some of the former show undulose extinction) as can large fragments of quartzite. Fragments of volcanic origin (felsite) account for the bulk of the darker grains. Corrosion of the margin of the large, roughly triangular, quartz grain towards the bottom of the photograph can be clearly seen; other quartz grains also appear corroded (see the upper part of the figure).

Crossed polars, X38

Fig. 5-3b - Same greywacke as in Fig. 5-3a but under plane-polarized light in order to show the boundaries between the grains (which become indistinct under crossed polars). The poor sorting and lack of orientation of the variously sized constituent grains and rock fragments typical of greywacke is apparent in this microphotograph.

Plane-polarized light, X30.

Fig. 5-4 - Very fine-grained greywacke (Conception Group) enclosing part of a pebble of purple mudstone. The boundary between the pebble and the enclosing greywacke is sharp.

Plane-polarized light, X30.

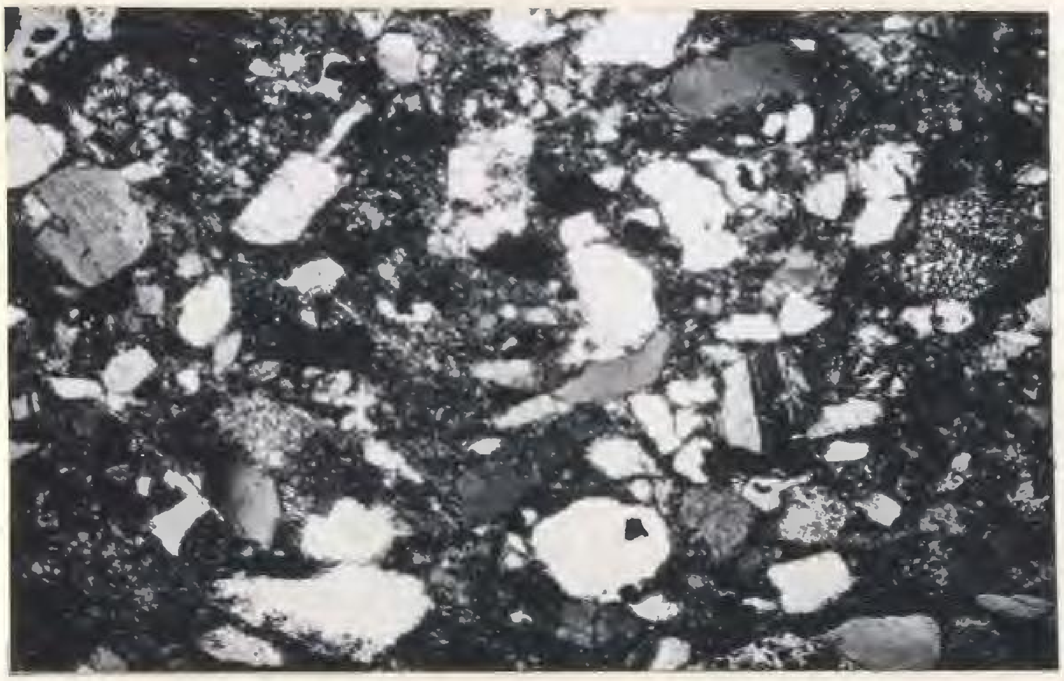


Fig. 5-3a

Fig. 5-3b

Fig. 5-4

cannot be distinguished because they appear to merge with one another and with the matrix (compare Figs. 5-3a and 5-3b). Rock fragments include quartzite, probably of metamorphic origin, devitrified glass, trachyte, andesite and other fragments of volcanic origin.

KPC - 3C: Very fine-grained greenish-grey greywacke with purple, oval pebbles (Fig. 5-4) from an outcrop a quarter of a mile south of Meadow Point on the west shore of Trepassey Harbour. The pebbles, an inch to 1.5 inches across, are well separated from one another by the enclosing greywacke matrix and the conglomerate is generally only a single pebble thick. In thin section the pebbles are found to consist of mudstone with irregularly scattered, tiny quartz and iron-ore granules suggestive of slumping in the original bed from which the pebbles were derived. This mudstone is similar to the purple mudstones of the greywacke-mudstone, graded bed sequence in which the conglomerate occurs and it is, therefore, intraformational (see chapter 6). The greywacke matrix is similar in general to the greywackes already described except for having a greater abundance of recognizable chlorite and iron-ore.

KFW - 5A: Medium-grained grey-green lithic greywacke associated in graded bed with a green mudstone (Figs. 5-5a and 5-5b); collected from first tributary of the Broom River that is crossed by the road between Meadow Point and St.Shotts. Rock and quartz fragments are the dominant constituents; feldspar (mainly albite) is less abundant. Sericite and chlorite can be

Fig. 5-5a - Lithic greywacke of the Conception Group in which quartz and rock fragments, mostly of volcanic origin, are the dominant constituents. Grains of quartz, some showing undulose extinction, and of feldspar, as well as fragments of quartzite (which is particularly abundant in this rock), devitrified glass and other fine-grained aggregates of volcanic origin are set in a chlorite-sericite matrix. Crossed polars, X30.

Fig. 5-5b - Same thin section as Fig. 5-5a showing the angularity of most of the smaller grains contrasting with the well-rounded, much larger fragment of trachyte (?). The clear, wavy area in the centre of the fragment is a hole. Plane-polarized light, X30.

Fig. 5-6 - Greywacke of the Conception Group with very similar composition to that illustrated in Fig. 5-5a. The larger pieces of quartz are particularly obvious. The dark, finer-grained fragments of volcanic origin are moderately well rounded.
Crossed polars, X30.

Fig. 5-5a

Fig. 5-5b

Fig. 5-6

readily identified. A few scattered grains of epidote, secondary with chlorite, are also present. Grains are noticably variable in size; some are angular, others are moderately well rounded as, for example, the large grain of trachyte (?) seen in Fig. 5-5b. Most of the larger grains have been derived from acid volcanic rocks. Rock fragments identified include felsite, quartzite, andesite and a quartz-epidote rock.

KFW - 5C: Green greywacke-mudstone (graded bed) (Figs. 5-6 and 5-7; Broom River near KFW - 5a. The thin section shows that in addition to the obvious grading seen in the hand-specimen, the mudstone exhibits complex micro-graded bedding, i.e. distinct laminae within the mudstone. The medium grained greywacke below passes up, along a fairly sharp boundary (Fig. 5-7), into mudstones speckled with tiny quartz and iron ore grains, giving the layer a dark colour, and in turn it is succeeded by another lamina of mudstone in which the grains cannot be distinguished. The sequence of coarser mudstone followed by finer mudstone is then repeated by the succeeding laminae. This whole micro-sequence is only a few millimetres thick. The greywacke of the basal part of the graded bed (Fig. 5-6) is of variable grain size grading down to rock flour. Grains range from angular to well rounded. Constituents present are quartz (mostly strained), albite, quartzite, trachyte, felsite and other volcanic sand grains and minor amounts of secondary epidote. This rock type is green because of the chlorite in the matrix. Sericite is marked along certain grain boundaries, in a more or less parallel pattern, possibly indicating incipient cleavage.

Fig. 5-7

Fig. 5-7 - Boundary between greywacke below and mudstone above in graded bed. The boundary is a fairly sharp one as far as the coarse grains are concerned but the rock flour of the matrix can be seen passing up without a break into the mudstone which originally had the same composition. Some of the darker grains below the boundary are epidote which, in this particular thin-section, is concentrated at this level. Plane polarized light, X30.

Conception Group beds exhibit great variation in colour and range from grey to green or purple (so-called red beds). The colouring agents are as follows:

grey beds: dark rock fragments, chlorite in the matrix, iron sulphide; where chlorite is abundant grey-green colours are dominant;

green beds: chlorite (abundant large flakes);

purple beds: hematite; may be partially or completely oxidized in surface outcrops which are grey or green where the ferrous iron has been retained in the rock.

The chlorite is probably largely secondary, as is also much of the sericite, in these rocks.

The Conception succession in the Trepassey area is very largely made up of graded beds in which the coarser-grained element, greywacke, represents resedimented, land-derived, material carried from shallow water by turbidity currents. The finer-grained element, mudstone, also appears to have been derived from the same source because the minerals identified by X-ray diffraction (see Misra, 1969) are merely smaller particles of those seen in the greywacke. Whether or not there is any pelagic material in these ancient sediments has not yet been determined.

Finer-grained rock types in the Conception succession are often very siliceous. The high silica content may be (a) entirely primary, due to an originally high silica content, or (b) entirely secondary, resulting from a later impregnation with silica, or (c) partly primary and partly secondary. Contemporaneous volcanic activity, particularly in lower Conception times, provided a ready source of silica.

Rock types of the St.John's Formation

The rocks of the St.John's Formation are predominantly fine-grained; the main rock type is mudstone and the subordinate type siltstone. Deposition of mudstones and siltstones was cyclic or repetitive through thousands of feet of strata. In the Trepassey area the mudstones are thinly bedded or laminated but they are not fissile and cannot, therefore, be classified as shales even though they are commonly referred to in the literature as shales.

The separation of silt and clay particles from one another depends on the maintenance of currents of slightly different strengths: (1) strong enough to carry silt and prevent deposition of the clay → silt deposited, and (2) too weak to carry clay → clay deposited, and it follows that graded bedding (silt to clay) will occur wherever current (1) weakens and continues as current (2). This explains why graded laminae are commonly associated with non-graded laminae in the succession. In addition to this micro-grading, thicker graded units are present in the lower part of the St.John's Formation and they appear to have been deposited from turbidity currents and to represent a temporary return to the conditions of deposition that prevailed during Conception times.

Apart from these graded bed sequences the nature of the remainder of the succession depends on the extent to which the siltstone is represented in each cycle. Thus the sequence is dominantly mudstones wherever the silt is present only in continuous or discontinuous laminae or is reduced to mere laminations. With increasing thickness of the siltstone layers, silty shales take the place of the laminated mudstones, and if the silty layers predominate, the beds may then be described as shaly siltstones or sandstones.

Unweathered, these rocks vary from light to dark grey, but on weathered surfaces the silty layers may be light to dark brown as a result of oxidation of iron released from finely disseminated iron sulphide which is the colouring agent in the St.John's Formation.

Five thin sections of rocks from the St.John's Formation are described below. They include two subgreywackes typical of the formation, a laminated siltstone, a calcareous mudstone showing cone-in-cone structure and a fault breccia in which the fragments are held in a matrix of secondary calcite.

KPP - 43A: Fine-grained, calcareous siltstone (Fig. 5-8) from about 2000 feet north of Powles Head at the southern end of Powles Peninsula. In thin section, under plane-polarized light, this siltstone was identified as a subgreywacke composed of grains of quartz and felspar together with mostly indeterminate rock fragments, some of which are cloudy and brown in colour, cemented in a fine-grained matrix.

Subgreywackes differ from greywackes in having a higher percentage of quartz (up to 80%), a smaller percentage of feldspar (less than 10%), less matrix (about 10%), and a preponderance of sub-rounded particles. Subgreywackes are also generally finer-grained.

When the thin section was examined under crossed polars, the constituents of the subgreywacke were found to have been replaced by authigenic calcite to such an extent that the greywacke has become a calcareous siltstone. A great many of the quartz and feldspar grains, many of the rock fragments, and the matrix have been replaced by calcite which has developed as metacrysts that interfinger with one another to give a characteristic patchy extinction (Fig. 5-8). The residual fragments appear to float in calcite. They include quartz, feldspar and the brown fragments seen under plane-polarized light that represent an alteration product, leucoxene, which does not undergo replacement by calcite. Large flakes of secondary muscovite are also present. Some of the quartz grains are moderately rounded whereas others are very angular indicating that they are sutured grains from a quartzite.

Replacement of constituents (grains and matrix) by authigenic calcite is characteristic of the silty or sandy beds and laminae of the St.John's Formation in the Trepassey area and although some of them do not appear to have been affected, the majority show partial to almost complete replacement. Grains of quartz, of feldspar and rock fragments alike can be seen at all stages of replacement. Grains that have undergone partial replacement have characteristically embayed margins. Where replacement proceeded further, all that is left of the original particles are corroded patches embedded in calcite, and where the process was carried through to completion the replaced grains are preserved in carbonate pseudomorphs. These pseudomorphs are

Fig. 5-8 - Fine-grained calcareous subgreywacke of the St.John's Formation from the east side of Powles Peninsula. The calcite is secondary and has grown by replacement of many of the original constituent grains of this siltstone. The calcite is locally in optical continuity thus forming metacrysts; their presence results in the patchy extinction seen here under crossed polars. X35.

Fig. 5-9 - Fine-grained feldspathic greywacke of the St.John's Formation from the east side of Mutton Bay. This siltstone is notable for the unusual angularity of its quartz grains which has resulted from the growth of secondary silica. The secondary quartz has, in some cases, grown around other grains so that they now lie in embayments of the quartz - two examples in Fig. 5-9 are indicated by the red arrows. Crossed polars, X56.

Fig. 5-8

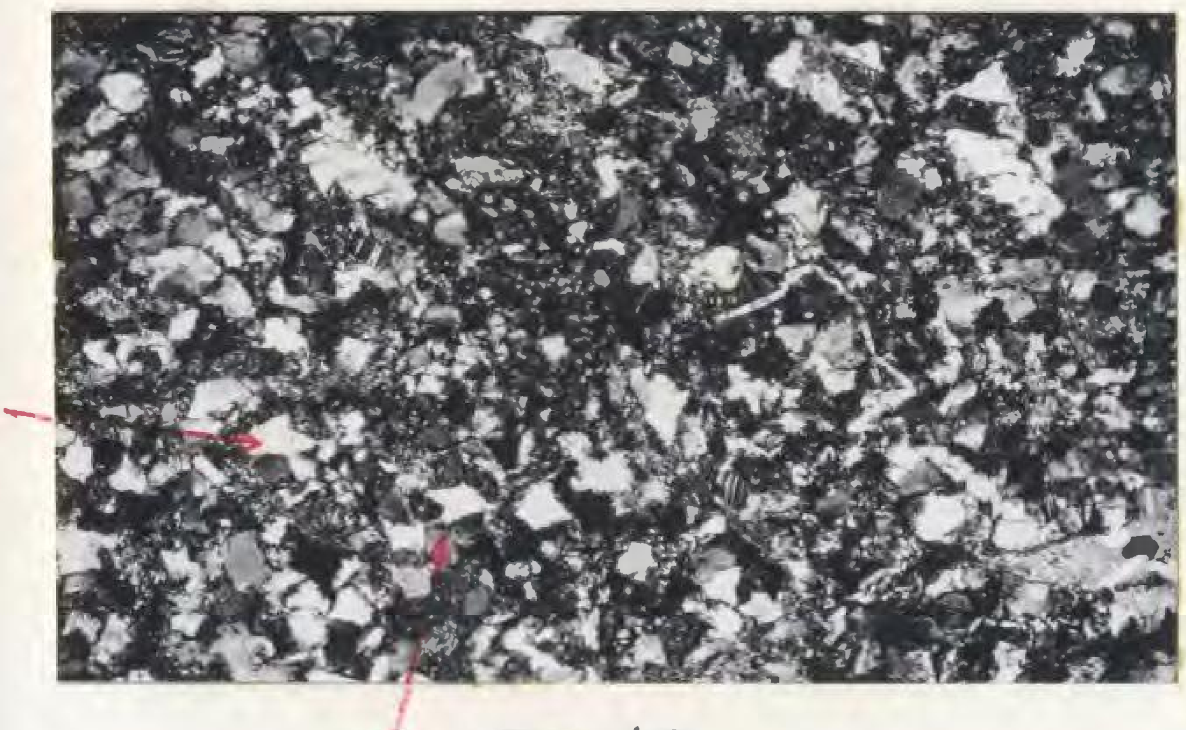


Fig. 5-9

obvious only under plane polarized light where they can, nevertheless, be mistaken for grains of clastic carbonate.

KMB - 10F: Laminated siltstone (Fig. 5-9) from the small headland on the east side of Mutton Bay north of Cape Mutton. In thin section the rock was identified as a lithic subgreywacke made up of grains of quartz, an appreciable amount of feldspar (albite) and an abundance of fine-grained rock fragments, probably of volcanic origin. The matrix is inconspicuous and appears to constitute less than 10% of the rock. An unusual feature of this subgreywacke is the development of secondary quartz that has grown in optical continuity with the original grains, which are subrounded. Their boundaries can be distinguished under a higher magnification than that used for Fig. 5-9.

KBB - 19B: Calcareous mudstone (Figs. 5-10a and 5-10b) from the west side of Biscay Bay. Under plane-polarized light the mudstone exhibits cone-in-cone structure. The coned layers of fibrous calcite are separated by residual lenses of mudstone, which is probably largely siliceous in composition, as the calcite is authigenic and has replaced practically all the original constituents with the exception of tiny scattered quartz grains that can be seen embedded in the cones above the lower boundary of Fig. 5-10a. The coned structure is made evident by the dust layers (fine argillaceous matter) and the tiny quartz grains that have been trapped between the cone-cups that lie one within the other. The cone-in-cone structure has a striking and characteristic appearance under crossed polars (Fig. 5-10b) - for explanation see the caption on page 94.

Fig. 5-10a - Calcareous sandstone, St.John's Formation, showing well-developed cone-in-cone structure. Plane-polarized light, X14.

Fig. 5-10b - Layers of cone-in-cone structure in the same calcareous sandstone as shown in Fig. 5-10a but under crossed polars. The 'spherulitic' effect is due to the points of one coned layer lying opposite the points of the cones of the overlying layer so that the fibrous calcite of these opposed cones produces this striking radial pattern.
Crossed polars, X14.

Fig. 5-10a

Fig. 5-10b

Cone-in-cone structure owes its origin to the growth of calcite during early diagenesis of the containing sediment. It is only at that time that the muddy sediment attains the required physical conditions for crystallization in a stress field appropriate for the development of cones of fibrous calcite (Woodland, 1964).

KPP -32A: Laminated siltstone (Fig. 5-11) from nearly half way down the east side of Fowles Peninsula. The laminae within this rock are only a few millimetres thick. They consist of either very fine-grained siltstone or of mudstone; such layers are, in some cases, quite distinct from one another, but in other cases a coarser one may grade into a finer one to produce a graded lamina. Some of the thicker laminae show distinct laminations. A number of the latter were found to consist of tiny spheres of iron pyrite. Spherulites of iron pyrite are also scattered throughout the laminae and, in some of them, they are associated in strings or clusters. Cleavage is apparent in this thin section and there appears to have been some recrystallization in the argillaceous layers as the flaky minerals are aligned parallel to the cleavage and extinguish together under crossed polars.

KPP - 9B: Fault breccia (Fig. 9-12) from fault on the west side of Fowles Peninsula. The breccia contains angular fragments of silty mudstone and fine-grained greywacke in a matrix of large, interlocking crystals of calcite.

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The grey to black colour of the beds of the St.John's Formation does not appear to be due to the presence of carbonaceous material. This observation is supported by the findings of Misra (1969) who used X-ray diffraction to determine the mineral content of the shales. As mentioned earlier, the colour is accounted for by the presence of disseminated pyrite and, in coarser-grained beds, dark rock fragments contribute to the grey colour.

The universal presence of pyrite and the common occurrence of carbonate are noteworthy features of the St.John's Formation. The former may have developed from amorphous iron sulphide that was deposited concurrently with the sediment (Pettijohn, 1949) or it may, like the carbonate, be a product of authigenesis. A hypothesis proposed by Krynine (1940) to explain the presence of pyrite in a Devonian greywacke provides not only an explanation of the pyrite but also the carbonate. He considered the pyrite a product of the earliest penecontemporaneous diagenesis when the sulphate-reducing bacteria were thought to have attacked the sulphate,that was dissolved in the water between the particles, forming sulphides. These sulphides,in turn, reacted with carbon dioxide to form carbonates, and in this way calcium was precipitated in the pore space in the mud.

The carbonate observed in the thin section studies described above has been called calcite but it may prove, on further investigation, to be ankerite,which is the carbonate commonly associated with some greywackes.

Fig. 5-11 - Laminated siltstone of the St.John's Formation showing: (1) alternation of siltstone and mudstone layers, (2) grading from fine silt to clay size particles within some laminae as a result of deposition from gentle currents of waning strength, (3) fracture cleavage which is refracted by the silty layers, and (4) evidence of recrystallization in the mudstone layers where the micaceous minerals are now oriented parallel to the cleavage direction.
Crossed polars, X14.

Fig. 5-12 - Fault breccia from fault in the St.John's Formation on the west side of Powles Peninsula. The rock fragments produced as a result of movement along the fault plane are embedded in a matrix of secondary calcite.
Crossed polars, X30.

Fig. 5-11

Fig. 5-12

CHAPTER 6

Sedimentary Structures

The sedimentary structures observed in the Trepassey area are entirely of inorganic origin. Fossil representatives of the Metazoa have been found in the neighbouring Biscay Bay-Cape Race area in the Conception Group (Anderson and Misra, 1968, 1969; Misra, 1969a & b), and since these strata continue into the Trepassey area, similar animals must have been living there at the time the sediments were laid down. A careful search has, however, failed to reveal any evidence of the former existence of organisms. The particular part of the upper Conception sequence in which fossils occur elsewhere is not exposed either at the northern end of Powles Peninsula or south of Trepassey although uppermost Conception beds outcrop at both localities.

The inorganic structures observed are all primary in that they were formed either during sedimentation (graded bedding, ripple-marks etc.) or so soon thereafter that they are regarded as contemporaneous with sedimentation (load casts, slumping etc.). Cone-in-cone structure (see chapter 5), is a secondary feature, but because it is evident only in thin section, it is not treated here as a secondary structure.

Sedimentary structures noted in the thesis area and discussed here are: bedding (laminae, lamination), graded bedding, cross-bedding, ripple-marks, ripple-drift lamination, intraformational conglomerates and breccias, convolute lamination, load casts and slump structures.

Bedding

Laminae, Laminations

Sedimentary rocks (and one, or possibly more thin beds of tuff) underlie the whole of the Trepassey area and consequently all outcrops display bedding, i.e. discrete sedimentation units set off from one another by bedding planes. Each recognizable layer deposited is, technically, a bed but for convenience of description three terms are used to indicate layers of different thickness: bed - layer over half an inch in thickness

lamina - layer under half an inch in thickness

lamination - smallest recognizable layer (one to several grains thick) within a larger unit.

Laminae may also be present within a bed and their presence then indicates that although deposition was continuous, fluctuation in current velocity led to deposition of layers or laminae differing slightly from one another. Laminations are accounted for by momentary fluctuations in the current velocity. Laminae and laminations are present in most of the beds of the St.John's Formation, but they are less common in beds of the Conception Group where they are generally associated with the finer-grained rock types although laminations are also to be found in the upper part of some greywacke layers.

A graded bed is one in which the size of the grains making the bed varies regularly from coarse at the bottom to fine at the top. However, some graded beds show variations and in such cases laminae and laminations, recognizable by differences in grain size, are apparent in them. Hills (1963) refers to the former as simple graded beds and to the latter as complex graded beds.

Cross-bedding is true bedding that resulted from interrupted or variable sedimentary deposition on inclined surfaces (Weller, 1960). Cross-bedding and graded bedding are considered in more detail below.

Beds are variable in thickness in different parts of the Conception Group (Fig. 6-3). They range from laminae in bedded cherts to massive greywacke beds over four feet thick on the west shore of Trepassey Harbour. The St.John's Formation is mainly built up of thin beds of mudstone generally interbedded with sandy or silty beds, laminae or laminations. Thick sequences of these thin beds (lacking parting planes) are characteristic of the upper part of the succession where they resemble very massive beds (Figs. 6-1 and 6-2).

Graded bedding

Graded bedding is present in both the Conception Group and the St.John's Formation; it is characteristic of the former and fairly common in the latter.

In the Conception Group it generally occurs on a macroscopic scale (Fig. 3-1) in beds, several inches to a foot or more in thickness, in which the lower part is greywacke and the upper part mudstone, but it is also present on a microscopic scale within the thin beds or laminae of finer-grained rock types. Although the minute differences in grain size in the graded beds of the finer-grained rock types are undetectable in hand specimen, the grading is reflected by variation in the intensity of the colour of the lamina concerned, e.g. light green to dark green (silty mudstone to chert). The thicker, graded beds are of two kinds in the thesis area: (1) those in which the coarser element merges with the finer, so that no boundary can be drawn between them (Fig. 6-4) and (2) those in which the finer part is clearly separated from the coarser part of the bed (Fig. 3-2) in the same way as the summer and winter layers of varves are clearly separated from one another. The latter variety is, in fact, sometimes referred to as 'varved' in the literature but the use of this term has genetic implications and is best avoided in this case since there is no evidence that these beds were associated with glacial melt waters. The proportion of greywacke to mudstone within a graded bed varies widely in the Conception Group sequences examined in the Trepassey area (Figs. 6-4 and 6-5). Misra (1969) separated his Cape Cove and Freshwater Point Formations on the basis of their having more, or less, than 20 percent greywacke in the graded beds which make up these formations. While it may be possible to separate them where thick sequences are exposed, and the average proportion of greywacke to mudstone can be assessed visually, it is not feasible where outcrops are scattered or of limited extent. This criterion alone, therefore, does not provide a satisfactory basis for these subdivisions of the Conception Group.

Graded bedding does not appear to have been recognized previously in the St.John's Formation where it is present on a macroscopic and a microscopic scale. The former belongs to the second type noted earlier in Conception beds and, apart from being thinner (Fig. 3-9), these beds resemble those of the upper part of the Conception Group. Micro-grading is present in the sequences of shale with sandy intercalations where it may not be recognizable in outcrop but if slabs are polished or thin-sectioned, the generally cyclic nature of the beds is revealed as well as the presence of graded laminae of siltstone or silty mudstone passing up into mudstone (Figs. 5-11 and 6-3b). These graded laminae are, in some cases, only a millimetre or two in thickness.

Single graded beds result from (1) storms that stir up unconsolidated bottom material, and (2) currents of slackening speed (decreasing competency). The micro-grading in both formations in the thesis area is on too small a scale and is too frequent to be attributed to (1) and it is, therefore, the result of sedimentation from gentle currents of waning strength (Fig. 6-3b).

Graded beds associated in repetitive sequences result from (1) seasonal alternations of conditions (varves), and (2) turbulent currents. It is doubtful that any of the thicker graded beds of either formation are varves. Turbulent currents are, therefore, considered to have been responsible for their formation. Turbulent currents are associated seasonally with fluvial and deltaic environments, and they also develop on the sea floor as a result of submarine slumping. In the latter case they are referred to as turbidity currents. The grain size of the graded beds in the Trepassey area, their generally sharp non-erosional boundaries and absence of cross-bedding strongly favour

Fig. 6-1 - Evenly bedded shales with very thin sandy intercalations of the St.John's Formation outcropping at the southern end of Bowles Peninsula. These thick sequences without parting make the beds appear massive. The upper two feet of the fourteen foot sequence figured here shows slump structures.

Fig. 6-2 - Outcrop face of silty shales with sandy lenses showing a massive appearance in spite of the fact that they are thinly bedded or laminated. The sandy lenses indicate the presence of ripple-marked horizons; they have weathered out as a result of differential erosion. St.John's Formation at the southern end of Bowles Peninsula.

Fig. 6-1

Fig. 6-2

Fig. 6-3

Fig. 6-3 - Steeply dipping 'beds' of variable thickness at the base of the cliffs on the west shore of Trepassey Harbour about threequarters of a mile south of Meadow Point. The outcrop shown is about 15 feet high. Some of the layers observed are actually beds whereas others include a number of beds within them and consequently the observed partings in this graded bed sequence do not indicate the true thickness of the beds present a turbidity current origin.

At any particular locality where a repetitive graded bed sequence is present, graded beds may exhibit (a) different thicknesses, due to variation in the amount of sediment carried by successive turbidity currents, (b) sole markings, (c) various features (see below) in the upper part of the bed which reflect the strength* of the current at the time it flowed past the area being considered, and (d) convolute lamination or slump bedding (that may be restricted to the coarser element, see p.127).

The graded beds of some sequences are remarkably uniform in thickness. The uppermost Conception beds and some of the graded beds of the St.John's Formation are of this kind (Figs. 3-2 and 3-9), whereas other sequences, for example, the Conception beds of the western shore of Trepassey Harbour (Fig. 6-3), show considerable variation in the thickness of the individual beds.

Sole markings, downward and upward projecting lobes of various kinds that developed along the common boundary between two associated beds after their deposition, are restricted in the thesis area to load casts. In the neighbouring Biscay Bay-Cape Race area, Misra (1969) found flute casts and prod marks associated with the graded beds of his Cape Cove Formation at Cape Cove, but such structures have not been recognized, to date, in the Trepassey area.

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* It is probably an over-simplification to ascribe these features solely to the strength of the current because turbulence, or lack of it, and the nature of the sediment being transported are other factors that influence this development.

(Actual size)

Fig. 6-3b

Fig. 6-3b - Surface of polished slab of silty shale from the St.John's Formation showing laminations in the upper part and laminae in the lower part; some of the laminae are graded, see also Fig. 5-11. Note the presence of erosional surfaces(marked by arrows)indicating current activity.

The features associated with the upper part of graded beds are either erosional (scouring) or depositional (notably lamination and cross-lamination) and the latter, in particular, can be seen associated with Conception beds in coastal exposures south of Meadow Point. Convolute lamination and slump structures are also associated with this part of the succession.

The sedimentary structures of various kinds mentioned above, with the exception of lamination, which was discussed earlier in this chapter, are considered below in more detail.

Cross-bedding

Cross-bedding is an internal bedding inclined to the principal surface of accumulation and is the result of current activity. It is characterized by sets of beds that are similarly shaped and approximately parallel.

Cross-bedding has been observed at many horizons in both the Conception Group and the St.John's Formation. These beds range in thickness from two or three millimetres to some two or three feet. Cross-bedding is also present, on a small scale, in ripple-marks and ripple-drift lamination (formed by migrating ripple-marks); these sedimentary structures are discussed separately in subsequent sections of this chapter.

Cross-bedding is a generally inconspicuous feature in greywacke beds of the Conception Group where it occurs mainly in the upper part of these graded sandstone units. It rarely affects more than a few inches at the top of such beds and in this zone, laminae, a few millimetres thick, and thin beds, an inch or two in thickness, exhibit various kinds of cross-bedding.

Fig. 6-4 - Graded bedding in Conception beds exposed on a wave-smoothed outcrop on the west shore of Trepassey Harbour south of Meadow Point. The greywacke element in the beds illustrated is some 80% of the total thickness of each bed. The boundary between greywacke and mudstone elements within each graded bed is indistinct but the boundary between one graded bed and another is sharp and regular.

Fig. 6-5 - The same sequence of beds as seen in Fig. 6-4 above, some 15 feet lower down in the succession, showing graded beds in which it is the mudstone that is the dominant element. A bedding fault is indicated by the layer of quartz beneath the head of the hammer.

Fig. 6-6 - Unusually coarse, graded greywacke, some 9 inches thick, in which the decrease in grain size from bottom to top of the layer can clearly be seen with the naked eye. The greywacke bulges downwards into the underlying thin bed of laminated silty mudstone forming load casts. A sharp junction separates the silty mudstone from the finer-grained mudstone below. A fairly sharp junction also separates the greywacke from an overlying mudstone.

Fig. 6-4

Fig. 6-5

G – Greywacke M – Mudstone

Fig. 6-6

Within the laminae the cross-lamination is planar and very gently inclined at an angle of about 10 degrees to the normal bedding planes; other kinds of cross-bedding are absent from this association. This observation is in accord with those of Harms and Fahnestock (1965) who regard such fine planar cross-stratification as a product of an upper flow regime whereas they consider the more steeply inclined trough or tabular sets, also occurring in the upper part of other graded sandstone units of the Conception Group, as resulting from a lower flow regime. The latter appear to have been formed during the infilling of erosional scours on the greywacke surface; the orientation of these sets is variable, even within the same scour, so that this cross-stratification cannot be relied upon for determining the source of the sediments that were being deposited in Conception times (Fig. 6-7).

Cross-bedding (excluding ripple-drift lamination) on a moderately large scale is uncommon in the shales (with sandy intercalations) of the St.John's Formation (Fig. 6-8). These occasional sets may indicate the local development of banks on the sea floor.

Allen (1963) classified cross-stratified units on their physical properties, and related each type to a possible method of formation in a particular environmental association (or associations), but establishing which of Allen's fifteen types one is dealing with at a given locality is difficult because it is rarely possible to view them in the three dimensions required for establishing their physical properties

Ripple-marks

This section is concerned only with ripple-marks that can be recognized by their characteristic shapes when viewed either in outcrop faces or on exposed bedding surfaces.

No ripple-marks of any kind were observed in the Conception Group with the possible exception of the uppermost Conception beds on the east side of Powles Peninsula, not far below the Conception Group - St.John's Formation boundary. At this locality, two poorly exposed bedding planes of limited areal extent have wavy, iron-stained, surfaces resembling the large ripples that are found well exposed in uppermost Conception beds of Misra's (1969) Cape Cove Formation. Ripple-marks are also absent in those parts of the St.John's Formation that exhibit obvious graded bedding. However, in the remainder of the succession, where thick sequences of thin shaly beds are inter-bedded with sandy or silty horizons, current ripple-marks are commonly associated with the latter. Although these ripple-marks are commonly seen in outcrop faces they are very rarely ever seen on exposed bedding surfaces.

The sandy or silty intercalations range from beds, exceptionally over a few inches in thickness, down to laminae and even to laminations. The thinner layers may be discontinuous. The sandy lenses of the discontinuous laminae are often found, on closer inspection, to actually represent ripple-marks within which fore-set lamination can be distinguished and this clearly

Fig. 6-7 - Small scale cross-bedding in Conception beds. Sets are both planar and trough-shaped and one form sometimes appears to grade into the other in places (see below light spots). The relationship between sets is generally erosional and the cosets are inclined in different directions indicating considerable local variation in current direction.

Fig. 6-8 - Large scale cross-bedding, i.e. sets greater than 5 cm. in thickness (Allen, 1963), in shales with sandy intercalations of the St.John's Formation on the east coast of Mutton Bay. Note the penecontemporaneous erosion surface at the base of the overlying undisturbed beds truncating the upper end of the cross-strata below to give angular discordance.

Fig. 6-7

Fig. 6-8

indicates their current origin (Fig. 3-5). The ripple-marks are, in some cases, so well preserved that the original shape of these sand ridges can be recognized without difficulty in outcrop faces, but, in other cases, their outline may not be so clear because the tops of the ridges are missing as they were removed by current scour before the next layer of sediment was deposited.

Discontinuity of ripple-marks on some bedding surfaces, where there is evidence of erosion contemporaneous with sedimentation, resulted from removal of previously deposited material by fluctuating currents, but this explanation cannot apply in the many cases where the shape of the discontinuous ripple-marks is perfectly preserved as they must have literally been 'frozen' in the surrounding shale. This perfection of preservation, coupled with the fact that they rarely form continuous trains for any distance, indicates that only a limited amount of sand was available and they, therefore, represent impoverished current ripple-marks that formed on a clay surface and were subsequently blanketed by an influx of clay. The fact that ripple-marks in beds of the St.John's Formation in the Trepassey area are nearly always impoverished and rarely in continuous trains explains the scarcity of ripple-marked bedding surfaces to which attention was drawn at the beginning of this section.

Ripple-drift lamination

(Ripple laminae)

Ripple laminae are internal structures as opposed to ripple-marks which are surface forms; they are built up in sand or silt by either currents or waves (McKee, 1965). Sets of such lenses may be superposed with ripple-crests either one above the other, stationary ripple-lamination, or they appear to be advancing up slope, ripple-drift lamination.

Neither ripple laminae nor ripple-drift lamination was observed in the Conception Group in the thesis area although the former have been observed in uppermost Conception beds on the eastern side of Portugal Cove Point. In the St.John's Formation ripple laminae are common in incomplete ripple-profiles as well as in isolated ripple-lenses (Fig. 6-8), and small thicknesses of ripple-drift lamination are occasionally present in the sequences of silty shales.

Continuous ripple lamination can develop only where sand or silt is being brought into an area in excess of the amount required to produce a ripple-marked surface. When the supply is continuous and widespread they evolve both laterally and vertically into distinctive types of ripple-drift laminae according to the fluctuating changes in flow regime (McKee, 1965). The lack of sand available for the development of continuously ripple-marked surfaces in parts of the St.John's Formation noted earlier, accounts for the discontinuity of the ripple lamination and the absence of ripple-drift lamination from these sequences. Ripple lamination may be more common in the silty parts of the St.John's Formation than has hitherto been recognized because (a) it is not readily apparent in outcrop surfaces that are not parallel to the direction of ripple migration, and (b) it is inconspicuous in the fine, silty beds and may be revealed only in polished blocks.

Intraformational Conglomerates and Breccias

At several horizons within the Conception Group there are greywacke beds that contain either angular pieces or rounded pebbles of mudstone similar to the mudstones of the graded-bed sequence in which they occur. These intraformational breccias and conglomerates (sometimes called auto-breccias and conglomerates) may have originated as a result of the break up of a previously deposited layer by strong currents which then carried the fragments to some other place where they were incorporated in the sediment being laid down at that place, or they developed almost in place either by the pulling apart of cohesive clays in deposits that had slid a little after deposition, or by the injection of sand-water slurries along bedding planes with consequent disruption of the clay layers (Hills, 1963). The two latter processes result in a breccia of tabular, angular fragments; therefore either of them may have been responsible for the formation of the intraformational breccia noted in a thick greywacke south of Meadow Point on the west side of Trepassey Harbour (Fig. 6-11).

The intraformational conglomerates, of the kind seen in a greywacke on the west side of Powles Peninsula at its northern end (Fig. 6-12), and elsewhere, cannot have been formed in place because (a) the rock fragments are rounded, which implies

Fig. 6-9 - Pattern on outcrop face resulting from the weathering out of sandy lenses interbedded with shales of the St.John's Formation at the southern end of Powles Peninsula. These lenses of sand show ripple-lamination, and the regular spacing of the lenses, both along the bedding surface and at successive horizons, indicates their origin from ripple-marks whose spacing and size varied with the strength of the current and the amount of sand available.

Fig. 6-10 Slab, from an outcrop of the beds shown in Fig. 6-9, polished to reveal the ripple-lamination and other features of the bedding. Current direction is indicated by an arrow. Note the conspicuous erosion surface on the third sandy layer from the top.

Fig. 6-9

Fig. 6-10

abrasion during transportation, (b) the pebbles are generally strung out in a line rarely more than two pebbles thick, (c) the pebbles vary considerably in size, some only millimetres across, and (d) in some cases they display imbricate texture which requires current activity for its production. Consequently, the first of the processes mentioned earlier in this section is most likely to have been responsible for the production of these intraformational conglomerates, especially because only a fairly strong current is likely to carry the fragments far enough for them to become perfectly rounded during transportation.

In some greywackes of the Conception Group there are intraformational breccias that may not have formed in one of the three ways mentioned above. They are readily recognizable by the haphazard arrangement of peculiarly-shaped fragments that are indented and drawn out suggesting that the sediment from which they were derived was still soft when disruption occurred (Fig. 6-13). Break-up of the plastic clay may have been brought about in one of two ways, both of which probably result indirectly from the sudden vibration of unconsolidated sediment beneath the sea floor by an earthquake (possibly caused by volcanic activity in the region):

(1) a disrupting upsurge of water from the underlying water-filled sediment due to the compacting effect of a sudden shock (grains become more closely packed, pore space is reduced, and water is squeezed out);

(2) a rapid upward movement of the underlying water-

saturated sediment (greywacke) that has been transformed into a state in which it behaves as a liquid (thixotropic effect - liquefaction by shaking).

Convolute lamination

Convolute lamination somewhat resembles slump bedding but the complexity of convolution increases from the bottom to the top of the bed (Fig. 6-14) so that basal laminae are much less disturbed. According to Dzulynski and Smith (1963) convolute lamination is produced by the drag of currents of waning strength flowing over loosely consolidated sand and clay laminae on the floor of the basin of deposition. The joint action of eddies within the currents, surface drag and the migration upwards of pore waters within the laminae causes the contortion. Potter and Pettijohn (1963) stated that convolute lamination may also result from load deformation simultaneous with deposition. Unlike slumping, only one bed is normally involved, lateral movement is not the cause of contortion and slabs from earlier formed layers are never associated with the disturbed bed.

Load casts

These structures develop by exaggeration of an initial depression on a plastic mud bed, as a result of unequal loading by the superincumbent bed. The material of the latter sinks downward to form load casts of various kinds. If the downward movement is not very great the casts are little more than bulges of the overlying sediment into the underlying mud (Fig. 6-6). Greater downward movement leads to the formation of bulbous

Fig. 6-11 - Intraformational breccia of angular mudstone blocks several inches across in thick greywacke of the Conception Group on the west side of Trepassey Harbour south of Meadow Point. The surface of the rock was wetted in order to show the fragments more distinctly but unfortunately, apart from the tabular fragment above the compass case, they do not show up at all clearly.

Fig. 6-12 - Intraformational conglomerate (drawn natural size from field sketch) in graded beds of the Conception Group on the west side of Powles Peninsula at its northern end. These small, well rounded pebbles of mudstone are enclosed in a matrix of greywacke. The arrow indicates the direction of the current (approximately northwest to southeast) that caused the pebbles to overlap one another.

Fig. 6-13 - Irregularly-shaped fragments of mudstone (up to several inches across) in a greywacke of the Conception Group. These peculiarly, drawn-out pieces differ from the angular fragments seen in Fig. 6-11 and this suggests a different method of fragmentation. In this case the intraformational breccia appears to have resulted from the break-up of plastic clay by a sudden upsurge of water released from underlying beds possibly as a result of thixotropy (see text).

Fig. 6-11

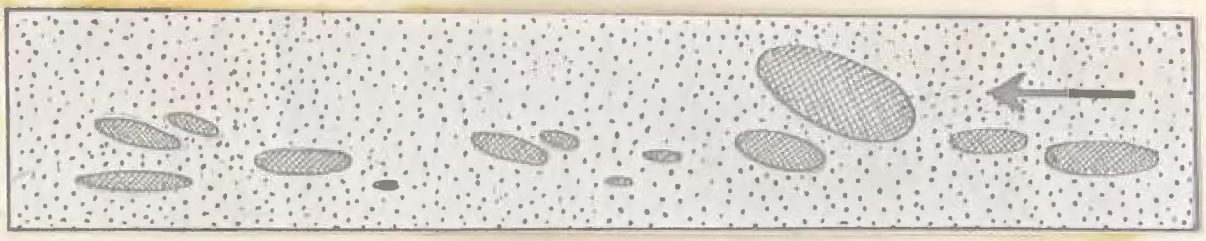

Fig. 6-12

Fi

structures like that illustrated in Figs. 6-15 and 6-16. These occur in uppermost Conception Group beds on the west side of Fowles Peninsula at its northern end, close to the boundary of the St.John's Formation. The load casts are preserved in thin graded beds in which the lower part of each bed is siltstone and the upper part is mudstone.

In this case a silty layer sank down at places into the mud of the underlying graded bed and, as sinking proceeded, the surrounding silt and overlying mud were drawn downwards eventually forming bulbous structures of the kind shown in Figs. 6-15 to 6-17. While the sinking was taking place, the underlying mud was squeezed upwards between the descending lobes and it is, in fact, the upward movement of the mud that enables load casts to develop. The perfect symmetry of the load casts in the Conception beds shows that they were not involved in any lateral movement after their formation. Although the sediment was plastic at the time the load casts developed, it remained remarkably cohesive during flowage as demonstrated by the load cast shown in detail in Fig. 6-17 where the lamination within the silt is generally beautifully preserved and it has been disrupted only where contortion of the sediment occurred in the core of the load cast and on the flanks of the structure where the uprising mud broke through the silt.

<u>Slump structures</u>

In the Trepassey area the deformation caused by slumping,

Fig. 6-14 - Convolute lamination in Conception Group beds on the west side of Trepassey Harbour, south of Meadow Point. The lower part of the bed, where lamination is still clear, is much less disturbed than the upper part, which is irregularly contorted.

Fig. 6-15 - Load casts in graded Conception Group beds on the west side of Powles Peninsula at its northern end. The boundaries between the graded beds, as well as between their coarser and finer elements, are all quite sharp. The load casts at this horizon, although they vary somewhat in shape, have the same general size and they are all symmetrical.

Fig. 6-14

Fig. 6-15

Fig. 6-16 - Bulbous load casts at the same horizon as those illustrated in Fig. 6-15. Differential weathering of the outcrop face has revealed these structures which are less readily seen on unweathered surfaces. The siltstone of the load cast weathers more easily than the surrounding mudstone, and it has become brown in colour,instead of grey, due to oxidation of the iron released from finely disseminated iron pyrites.

Fig. 6-17 - Slab with load cast,from the same outcrop face as seen in Fig. 6-16 above, polished to reveal details of its structure. The plastic nature of the sediment at the time it was formed is demonstrated by the fact that even in the core of the load cast, where maximum movement must have occurred, the silty layers were contorted with little loss of identity. Note that before load-casting ended, the uprising mud had already begun to 'pinch' the base of the load cast and that it had pierced the silty layer to the left of the structure.

Fig. 6-16

Fig. 6-17

or down-slope gravity induced sliding of sediment after it has been laid down (involving one or more beds), is rare in the Conception Group, and widespread at a number of horizons within the St. John's Formation.

In the Conception Group, slump structures are usually confined to individual beds but sometimes a small number of neighbouring beds have been slump-folded together so that disturbed zones are commonly only a few inches to two or three feet in thickness (Fig. 6-18). The slump zones, which occur in a sequence of graded greywacke-mudstone beds, are generally widely separated from one another by undisturbed beds.

In the case of individual contorted beds it was the instability of the greywacke element of a graded bed at the time of deposition on the sea floor that led to its sliding down slope under the influence of gravity. This is demonstrated by the fact that although these graded beds are made up of two layers, one coarser-grained and the other finer-grained, it is always the coarser-grained layer that has undergone folding; the finer-grained layer may or may not be similarly disturbed. Slumping, therefore, affected the whole bed in some cases and apparently only half a bed in other caes. These two situations are explained by a difference in the tining of events. Where both layers were involved, slumping took place after deposition of the muddy layer, but where only the sandy layer was disturbed, slumping occurred before deposition of the muddy layer.

Slump structures are a characteristic feature of the St.John's Formation where disturbed zones are present throughout the succession. These zones differ from those in the Conception Group, that have already been described, in that they always involve several layers (Fig. 6-19), and in some cases very large numbers of beds were associated in the deformation. As a result individual slumped zones vary greatly in thickness. Thus, some are only a few inches thick while others are many tens of feet thick. In all cases, varying thicknesses of sediment on the sea floor became unstable and moved-off down-slope. Some of the masses were thrown into a series of tight folds, often recumbent, in which there is no obvious disruption of strata, and such folds have been mistaken for tectonic structures (Fig. 6-19). That the deformation was penecontemporaneous is, however, confirmed by the presence of (a) undisturbed beds underlying and overlying the disturbed zones (Fig. 3-8), and (b) a penecontemporaneous erosion surface overlying, and cutting off, the disturbed beds. Other masses show greater deformation of the layers involved, possibly as a result of sliding a greater distance, accompanied by fragmentation of the more resistant sandy layers. Fragmentation of the sandy layers gave rise to irregularly-shaped blocks and slabs that were bent or folded into various hook-shaped and rolled-up structures (Fig. 6-21).

Slumping on a small scale, associated with cross-bedding or ripple-drift lamination, may also be seen in the thesis area.

Fig. 6-18 - Slump horizon in Conception Group graded bed sequence south of Meadow Point, west side of Trepassey Harbour. The mudstone and greywacke elements are intimately mixed with one another in complex folds; pillows and balls of greywacke can be recognized within the deformed layer which is underlain and overlain by undisturbed graded beds. The overlying greywacke (above the hammer) is lenticular because it occupies a depression in the surface of the slump zone.

Fig. 6-19 - Relatively thin slump zone in beds of the St.John's Formation on the east side of Powles Peninsula. Lateral movement of the shales (with interbedded sandstone) has folded them into tight recumbent folds. That deformation was penecontemporaneous is demonstrated by the presence of undisturbed beds above and below the deformed zone. Note the truncation of the folded laminae by an erosion surface.

Fig. 6-18

Fig. 6-19

Fig. 6-20 - Large-scale, recumbent slump folds in the St.John's Formation on the west side of Powles Peninsula, close to the Conception Group - St. John's Formation boundary. Deformed beds of this kind, which retained their coherence during movement, probably did not travel very far, possibly only a few tens of feet.

Fig. 6-21 - Slump zone in the St.John's Formation on the east side of Powles Peninsula. The shaly layers are folded while the more competent, originally interbedded, sandstone is fragmented and folded. Fracture cleavage masks the folding and crumpling in the shaly layers but the folded sandstone blocks or slump balls are picked out by differential erosion.

Fig. 6-20

Fig. 6-21

CHAPTER 7

Correlation, Age and Stratigraphy

The strata underlying the Trepassey area are similar to those of the neighbouring Biscay Bay-Cape Race area. They are also in structural continuity and, therefore, in the absence of any recognizable facies difference, the stratigraphy of the two areas appears to be the same. Misra (1969) related the rock types in his area to those recorded by Rose (1952) in the Torbay map area, some twenty miles to the north, and established that the succession he mapped includes beds belonging to the Conception Group and to the St.John's Formation of the Cabot Group as defined by Rose. In the Trepassey area, as in the Biscay Bay-Cape Race area (Misra, 1969), the St.John's Formation conformably overlies the Conception Group.

A much closer correlation between the strata of the two areas can be established using slump zones, fossil horizons, tuff beds and parts of the sequence having a distinctive lithologic appearance as, for example, the silty shales of the upper part of the St.John's Formation that are interbedded with sandy lenses can be recognized wherever differential erosion has hollowed out the sandy lenses (Fig. 6-2).

The slump zone in the St.John's Formation at Fishers Point, near Cape Race, that Misra (1969) correlated with the slump zone near Shingle Head also outcrops at Portugal Cove Point, on the shore south of Trepassey and on both sides of Powles Peninsula at its northern end. In each case it lies immediately above the Conception Group - St.John's Formation boundary. The Conception

Group graded-bed sequence below the boundary is equally distinctive and is readily recognizable wherever it is exposed between Powles Peninsula and Cape Race. These examples suffice to show that a more detailed study of coastal outcrops, than could be undertaken during the present study, should enable a more precise correlation to be established between the discontinuous exposures of both Conception Group and Cabot Group rocks at the southern end of the Avalon Peninsula.

The rocks of the St.John's Formation in the Trepassey area do not appear to be as shaly, or as dark, as their counterparts in the Torbay map-area. A careful comparison of the succession in the two areas may, therefore, reveal that they are different facies.

The Conception Group and the St.John's Formation of the Cabot Group are regarded as Precambrian on the basis of their stratigraphic relationship with Cambrian strata in southeastern Newfoundland.

The lowest division of the Cambrian in Newfoundland is the Bonavista Formation, a pre-trilobite faunal zone characterized by hyolithids and inarticulate brachiopods, that has been correlated with a similar faunal zone at the base of the Cambrian succession of Shropshire, England, and the Boston region of the U.S.A. (Hutchinson, 1962). The Bonavista Formation lies disconformably on the Random Formation or, in Conception Bay, rests with angular unconformity upon the folded volcanics and interbedded sediments of the Harbour Main Group, or upon the sediments of the Conception Group.

The Harbour Main Group includes the oldest rocks of the Avalon Peninsula. It is overlain by the Conception Group which, in turn, is succeeded in the northeastern part of the Avalon Peninsula by the Cabot Group, and elsewhere by the Musgravetown and Hodgewater Groups (time equivalents of the Cabot Group). The Random Formation lies unconformably on the Musgravetown and Hodgewater Groups in the Avalon Peninsula and is overlain disconformably by lowermost Cambrian strata so that it is very late Precambrian.

Stratigraphic relations thus indicate a Precambrian age for the Conception and Cabot Groups. No absolute ages have been established for these Groups although an isochron age of 574 ± 11 million yr. has been determined by McCartney et al (1966) for the Holyrood granite which intrudes the Harbour Main Group in the northeastern part of Newfoundland. Because the Conception Group is partly, or wholly, post Harbour Main, and the Cabot Group is even younger, they must be less than 574 ± 11 million yr. old. However, this places their age too close to the generally accepted figure of 570 million years for the base of the Cambrian, and such an age is considered by Rose (1952), and also by Anderson and Misra (1968), to have left too little time for all the events that must have taken place between the time of emplacement of the Holyrood granite and the transgression of the Cambrian sea. This problem, which is discussed more fully by these authors, is beyond the scope of this thesis.

The presence in the thesis area of only two, closely related, late Precambrian Formations, and the absence of younger strata, apart from late-Pleistocene and Holocene deposits, limits what can be said regarding the geological history of the area to pre-Cambrian and post-Tertiary events. Furthermore, because the folding and faulting of the Precambrian strata could, in the absence of any local evidence to the contrary, have taken place at any time after the close of the Precambrian, this restricts comments on the geological history of the area during late Precambrian times to a consideration of the changes that took place in the environment of deposition. However, if evidence from other areas where similar rocks showing the same structural pattern have been investigated, is taken into consideration, then tentative ages can be assigned to the folding and faulting. According to the information contained in Brueckner's (1969) summary of the geology of the eastern part of the Avalon Peninsula, based on his findings as well as those of other workers, deformation of Conception and Cabot Group strata ceased before Cambrian times although some of the faults in the region, e.g. the Topsail fault on the eastern side of Conception Bay (Fig.1), are attributable to post-Lower Ordovican faulting because they affect strata of this age. It is tempting to consider the Trepassey Harbour fault as a southward continuation of the Topsail fault but this possibility cannot be verified or discounted until the geology of the areas south of Rose's (1952) map-area and west of the fault have been more thoroughly investigated and the nature of the fault determined. The Topsail fault has vertical and horizontal components of considerable magnitude and it is possible that the Conception beds west of the Trepassey Harbour fault are very much younger than those found east of it. They have been assigned here to the upper part of the Conception Group but this may be incorrect because although red beds have not, so far, been observed within the lower Conception succession at the southern end of the Avalon Peninsula, both Rose (1952) and McCartney (1967) found red beds not far above the base of the Conception Group in their respective areas at the northern end of the Avalon Peninsula. The less significant faults in the thesis area probably formed earlier than the Trepassey Harbour fault as a result of the post-Precambrian deformation.

The sediments of the Conception Group and of the St.John's Formation appear from their composition to have been derived from the same source area because the greywackes of the former, and the subgreywackes of the latter, are composed dominantly of quartz, feldspar and rock fragments, largely of volcanic origin, but including pieces that have come from metamorphic and igneous terrain. The currents that distributed these sediments in the Trepassey area came, according to the evidence provided by current ripple-marks, ripple-drift lamination and cross-bedding observed in outcrop faces, from a northerly direction. The source area thus lay somewhere to the north but whether it was actually to the north, or to the northeast or to the northwest, was not determined. Misra (1969), using sole marks and cross-stratification for determining palaeocurrent direction concluded from only sixteen observations that the source area of the sediments in the Biscay Bay- Cape Race area lay to the northeast. This conclusion, based on so little evidence, can only be regarded as tentative, and another, more detailed, palaeocurrent study will have to be undertaken before its validity can be ascertained.

As mentioned earlier in the discussion on graded bedding, a turbidity current origin is favoured for the graded beds of the Conception Group which may, therefore, be called turbidites. Turbidites are regarded by most workers as deep-sea deposits. Bouma (1964), Keunen (in Bouma, 1964) and other workers have studied recent deep-sea turbidites and applied their knowledge to the recognition of turbidites in ancient deposits. A comparison of the sedimentary features asscciated with deep-sea turbidites and those recognized in Conception Group graded-bed sequences (see chapter 6) supports the theory of a deep-sea origin for the latter. During the greater part of Conception times the Trepassey area was, therefore, a deep sea area (bathyal ?). Shallowing began towards the close of Conception times as shown by the much thinner graded beds of this part of the sequence and the general decrease in grain size of the sediments. This shallowing continued into St.John's Formation times when turbidity currents ceased to operate except during temporary deepenings. The latter are indicated by the graded-bed sequences within the St.John's Formation which are similar in character to the graded beds of uppermost Conception times. The shallower-water environment of St.John's Formation times, judging from the fine-grained nature of the sediments that were deposited from gentle traction currents and the extreme thinness of most of the beds, was probably some distance from the coast-line of the period. It seems likely, therefore, that at that time the area belonged to the outer part of the neritic zone; the area certainly lay below wave base as there is no evidence of any disturbance of the sediment by waves, even during storms, and also beyond the reach of strong currents as shown by the bedding features and the absence of coarse sediments. There is no evidence of the further shallowing and encroachment of thick sands that subsequently took place in later Cabot Group times in other areas as deposits of this age, although probably laid down in the Trepassey area, have since been removed by erosion. Mention must be made here of tuff beds (only one was definitely identified in the Trepassey area but others are known from the adjoining Biscay Bay-Cape Race area (Misra, 1969)) indicating contemporaneous vulcanicity in the region. Vulcanicity was probably more widespread than has hitherto been recognized (Anderson, personal communication).

The Trepassey area provides no record of geological events that affected the region between the Cambrian period and late-Tertiary times apart from the fact that at some time prior to the latter the strata had been uplifted to form part of the landmass now called Newfoundland.

Between late-Tertiary times and the Pleistocene, the Trepassey area was peneplanated, probably more than once, but the only peneplain represented is that which occurs at an elevation of about 500-600 feet. It is believed to be of late-Tertiary age (see chapter 2). During the Pleistocene the Trepassey area suffered glaciation during the advance and retreat of ice-sheets. However, the effects of the last, or Wisconsin glaciation, mask the effects of earlier glaciations. During Wisconsin times an ice-sheet lay over the region. The movement of the ice-sheet as a whole brought about a rounding and a general lowering of the land surface. Glaciers deepened the valleys that they occupied and the deeper parts of these are now the fiords and other inlets that are a characteristic feature of the present coast-line. Henderson (1959) carried out a detailed study of the Pleistocene geology of the northern half of the Avalon Peninsula and he considers that the glacier that covered the central part of the peninsula, its southern extensions and the St.John's Peninsula originated as a local ice-cap, independent of the main Newfoundland ice-sheet.

Changes of sea-level relative to land have taken place since Wisconsin times but their effects have not been studied in the Trepassey area.

After the ice retreated, prior to the beginning of the Holocene about 7,400 years ago (Olson and Broecker, 1958), it left a blanket of boulder clay resting upon the eroded and, in some places, glacially polished surface of all the consolidated rocks in the area. Vegetation soon established itself, not only on the boulder clay, but also in the many lakes and ponds that filled depressions in the ground moraine. The growth, decay and accumulation of the decayed remains of swamp plants over many thousands of years has given rise to peat deposits. Peat moss is still growing in most bogs although some are well advanced in development and a few are even suffering erosion. Boulder clay still mantles most of the area, although it has been eroded from some of the higher ridges and, under the influence of weathering and a cover of vegetation, soil is gradually accumulating.

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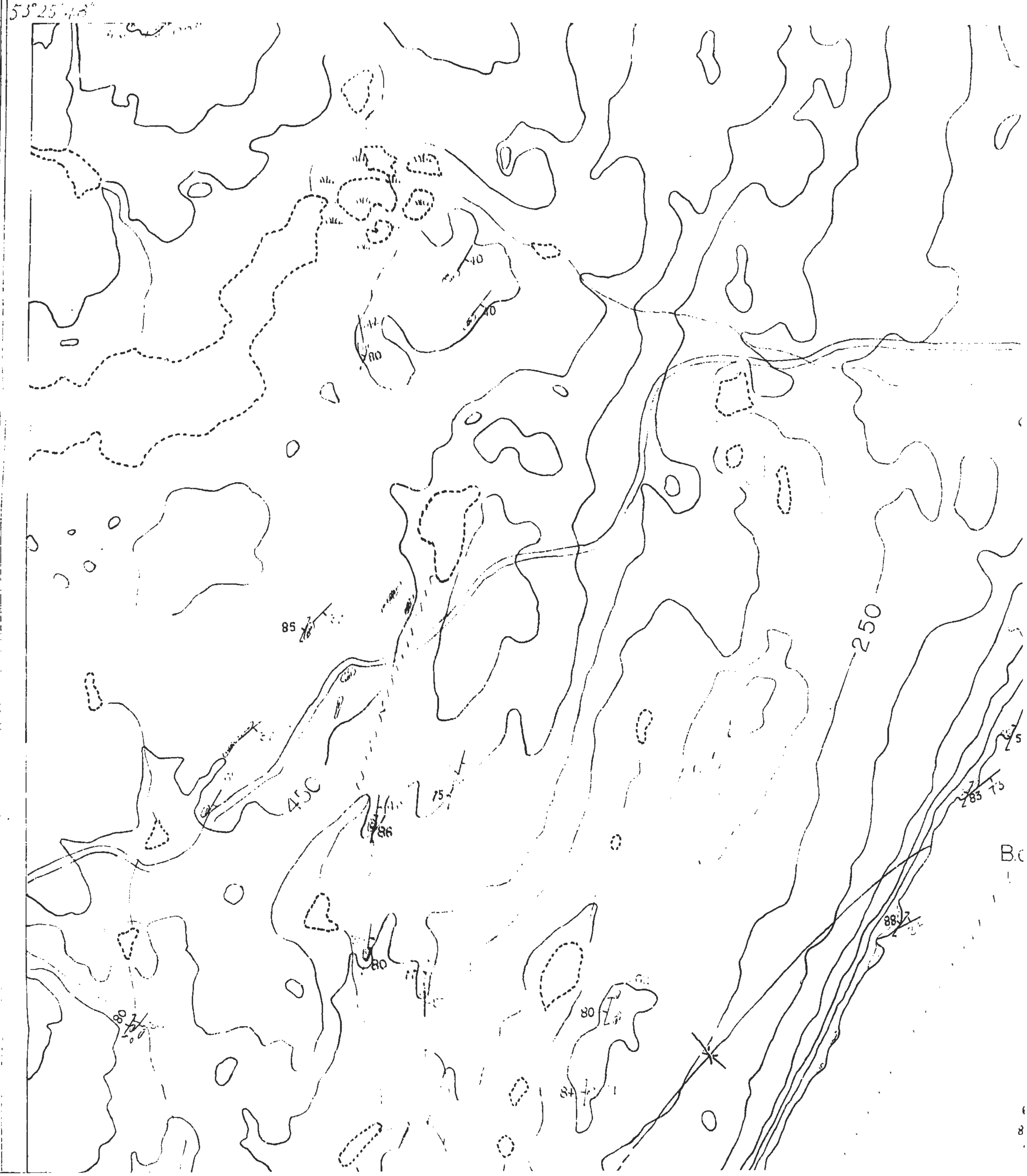
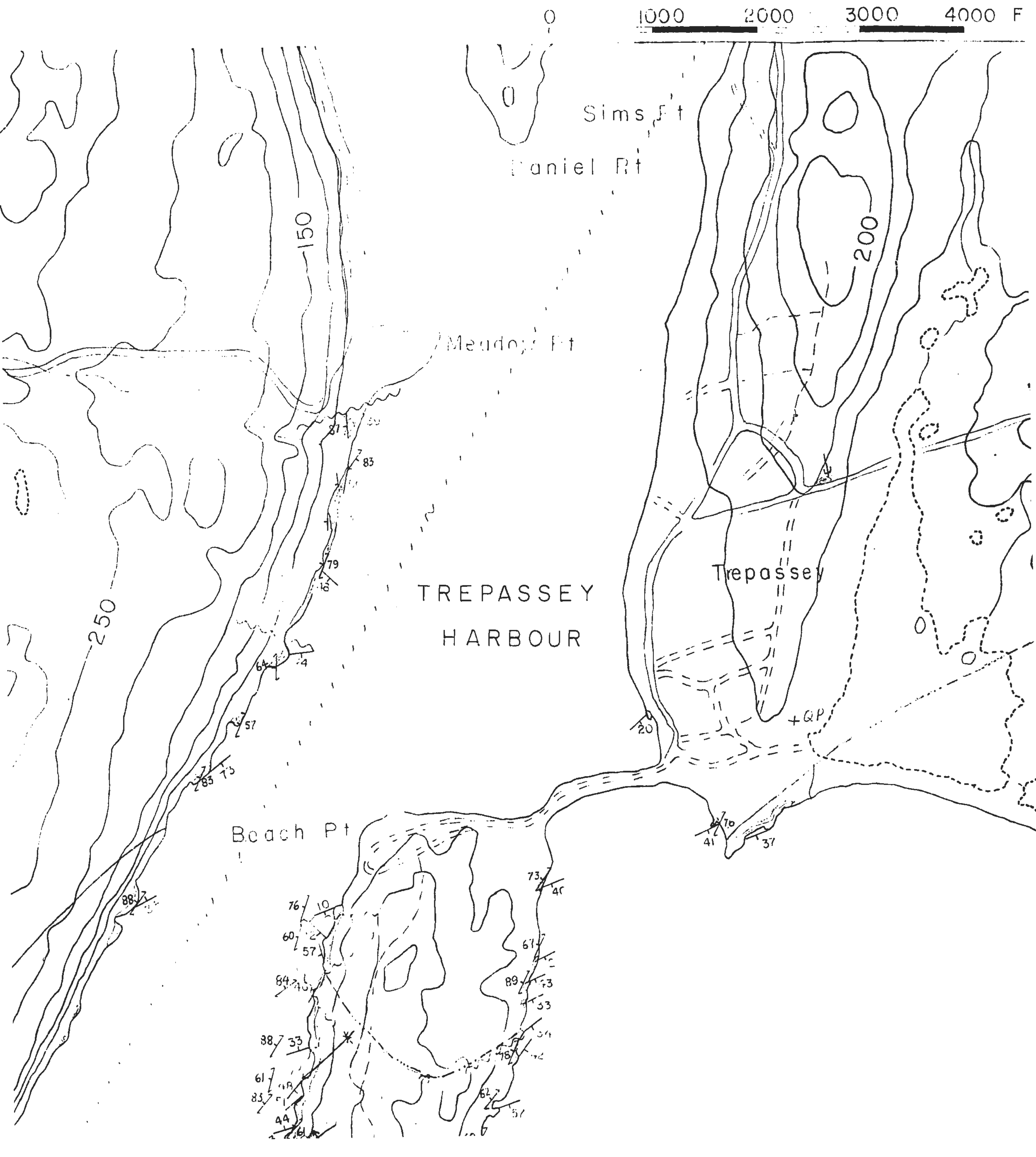


GEOLOGY OF THE TREPAS

SCALE

ONE INCH TO APPROXIMATELY 660 FE



THE TREPASSEY AREA

SCALE

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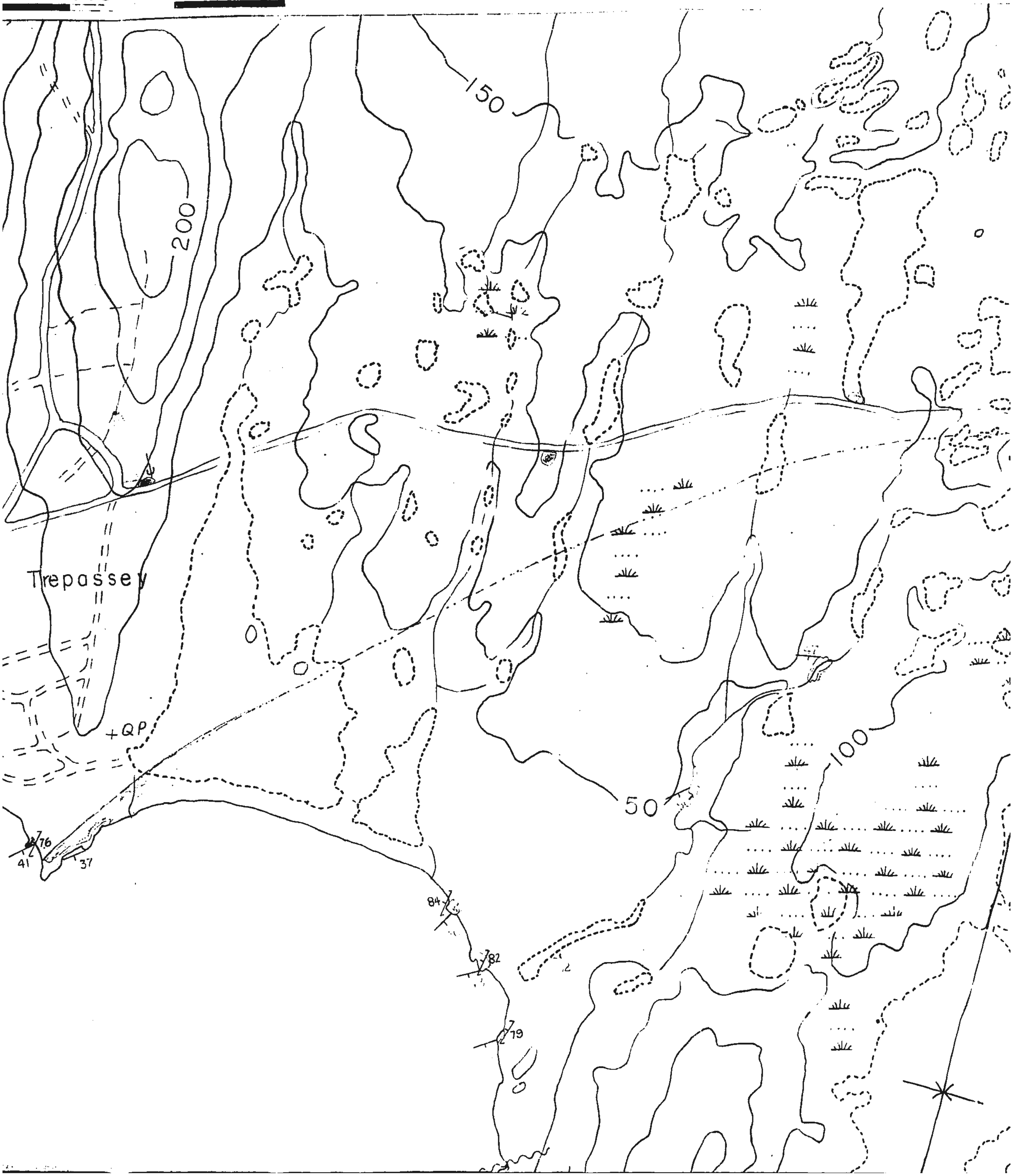
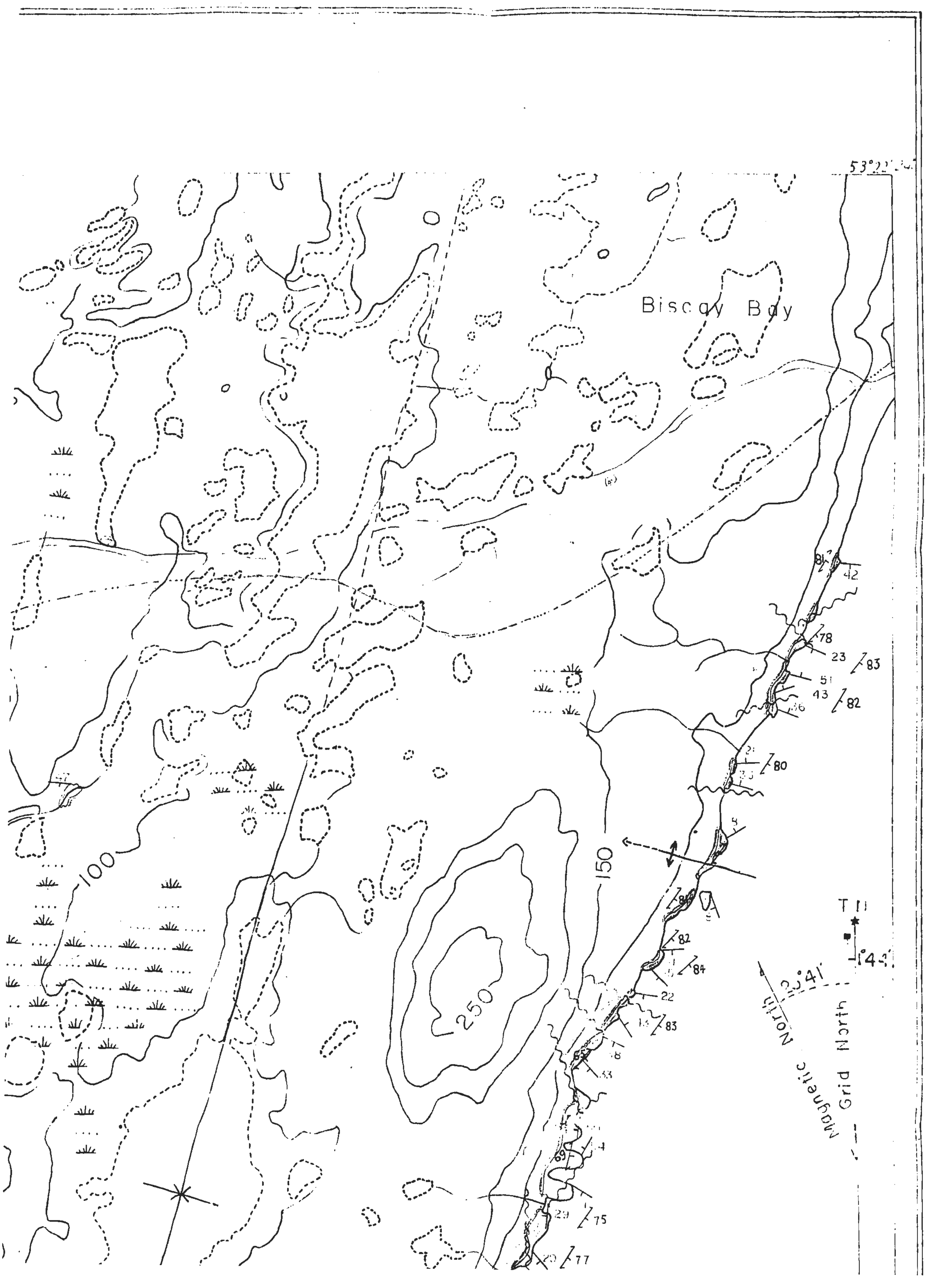
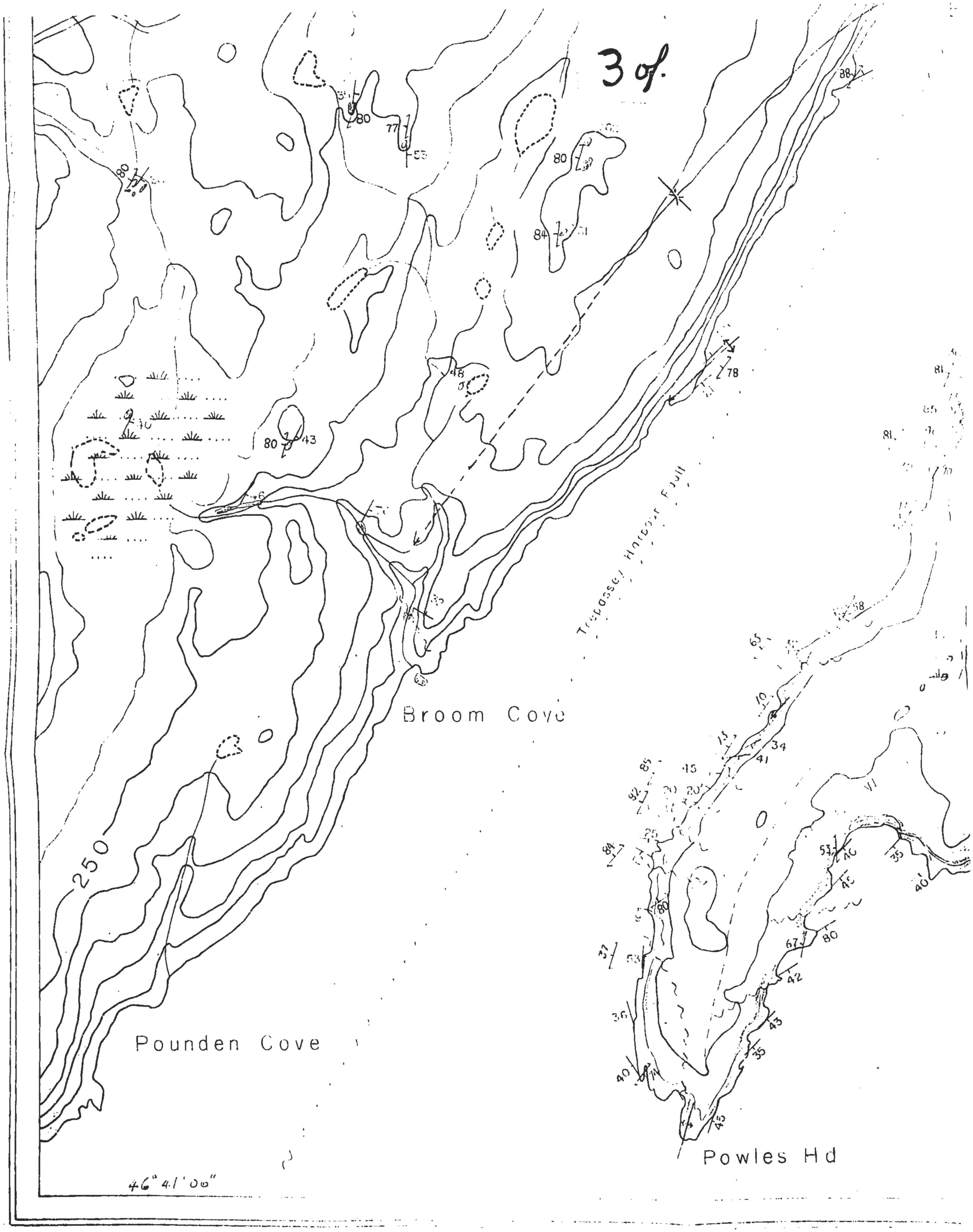
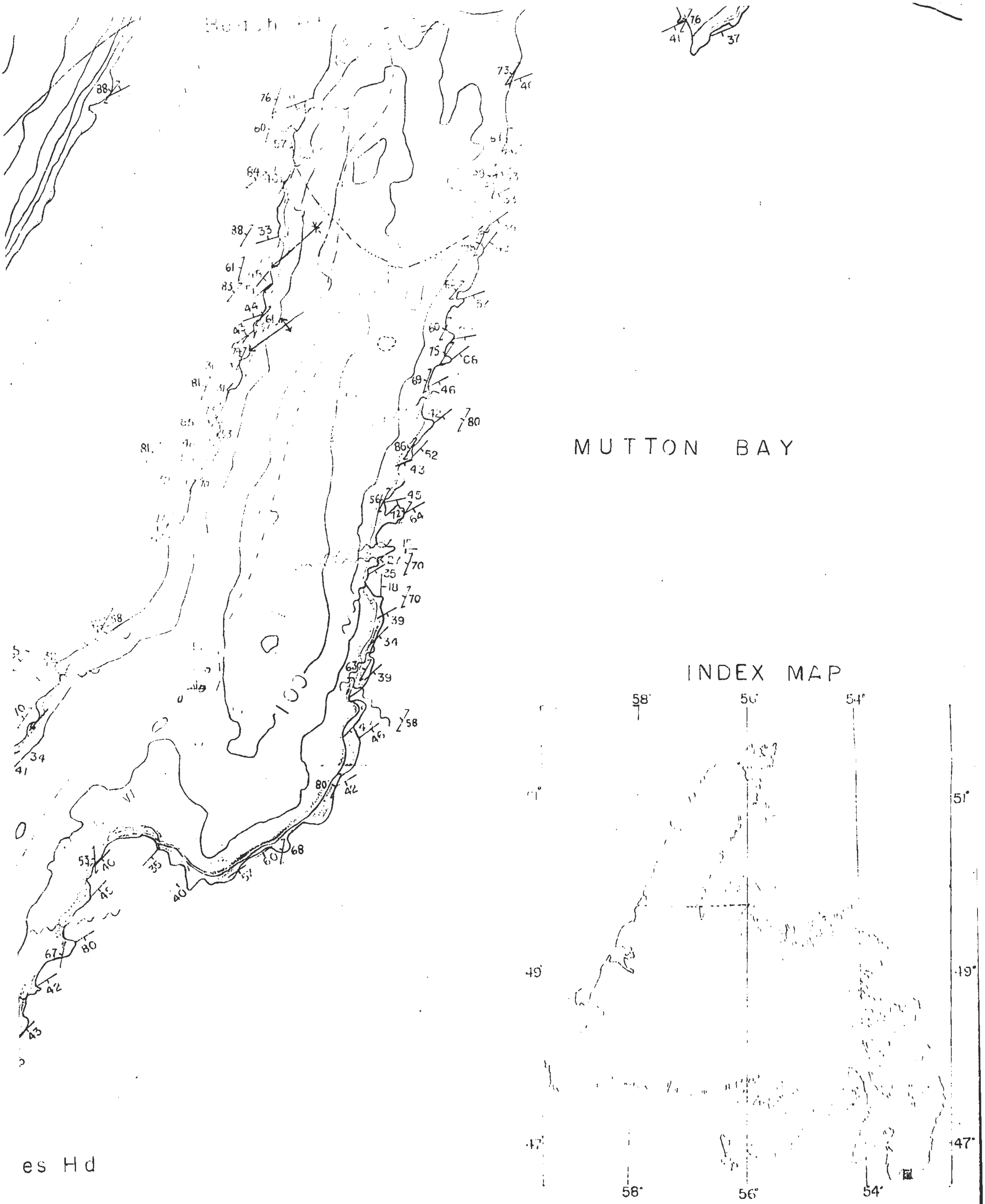
2000 3000 4000 FEET

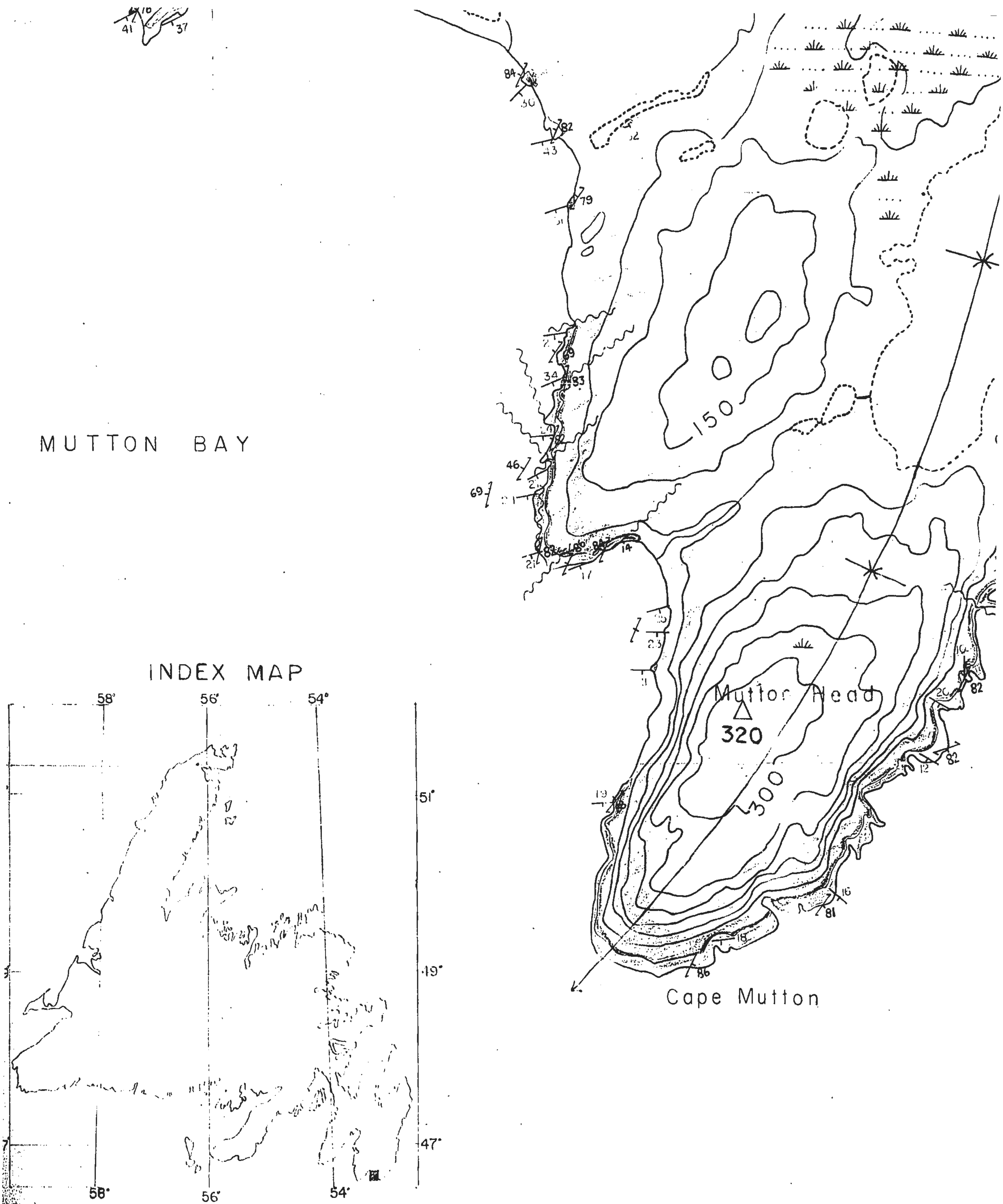




53°22'
Biscay Bay
100
150
250
T N
Magnetic North
Grid North


3 of.
Broom Cove
Pounden Cove
Powles Hd
Trepassey Harbour Fault
250
46°41'00"


MUTTON BAY
INDEX MAP
58°
56°
54°
51°
49°
47°
es Hd


MUTTON BAY
150
Mutton Head
320
300
Cape Mutton
INDEX MAP
58°
56°
54°
51°
49°
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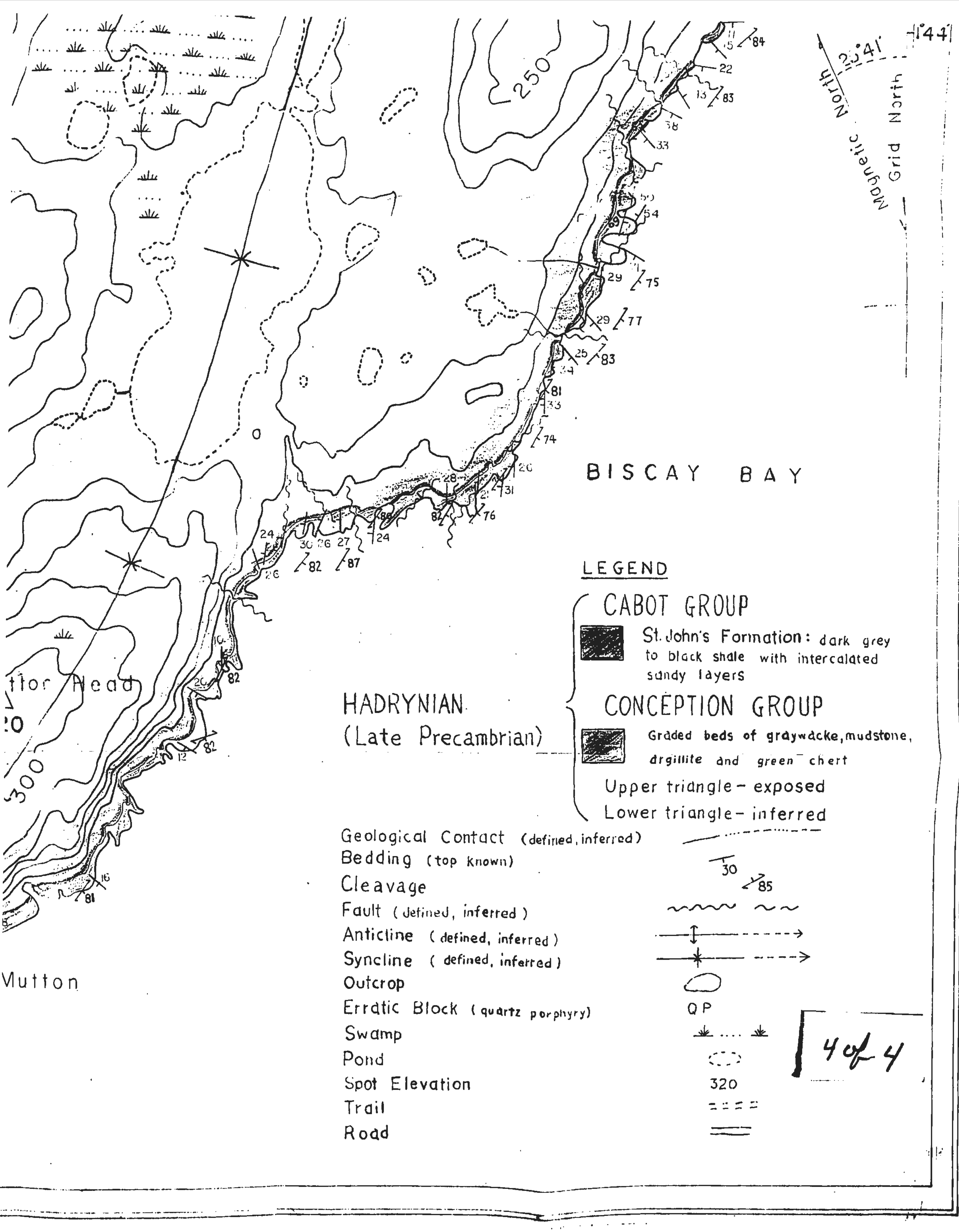
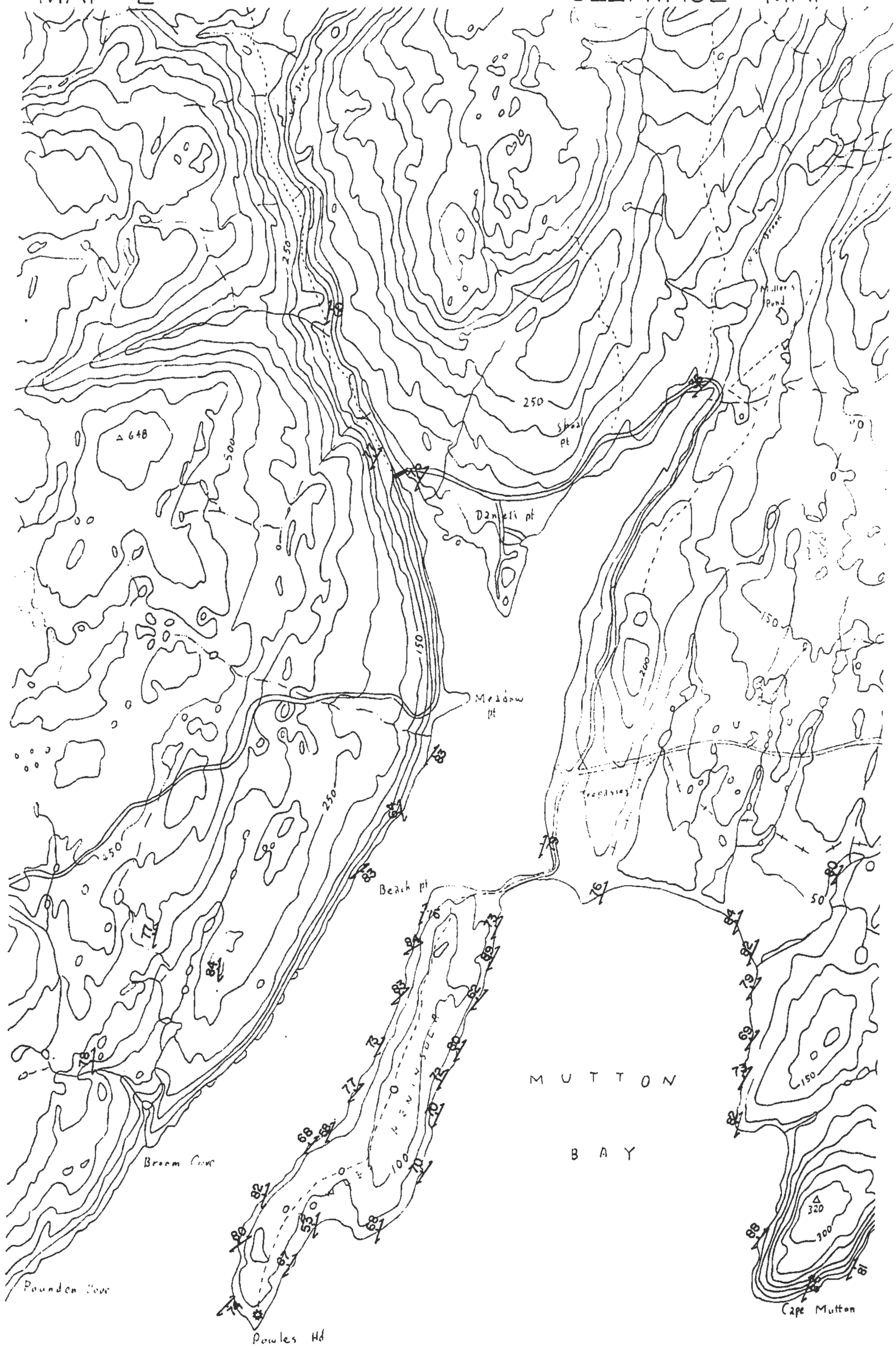


BISCAY BAY
250
300
ttor Head
Mutton
North
Magnetic North
Grid North
23°41'
LEGEND
HADRYNIAN
(Late Precambrian)
CABOT GROUP
St. John's Formation: dark grey to black shale with intercalated sandy layers
CONCEPTION GROUP
Graded beds of graywacke, mudstone, argillite and green chert
Upper triangle - exposed
Lower triangle - inferred
Geological Contact (defined, inferred)
Bedding (top known)
Cleavage
Fault (defined, inferred)
Anticline (defined, inferred)
Syncline (defined, inferred)
Outcrop
Erratic Block (quartz porphyry)
QP
Swamp
Pond
Spot Elevation
320
Trail
Road

4 of 4

MAP 2 CLEAVAGE MAP



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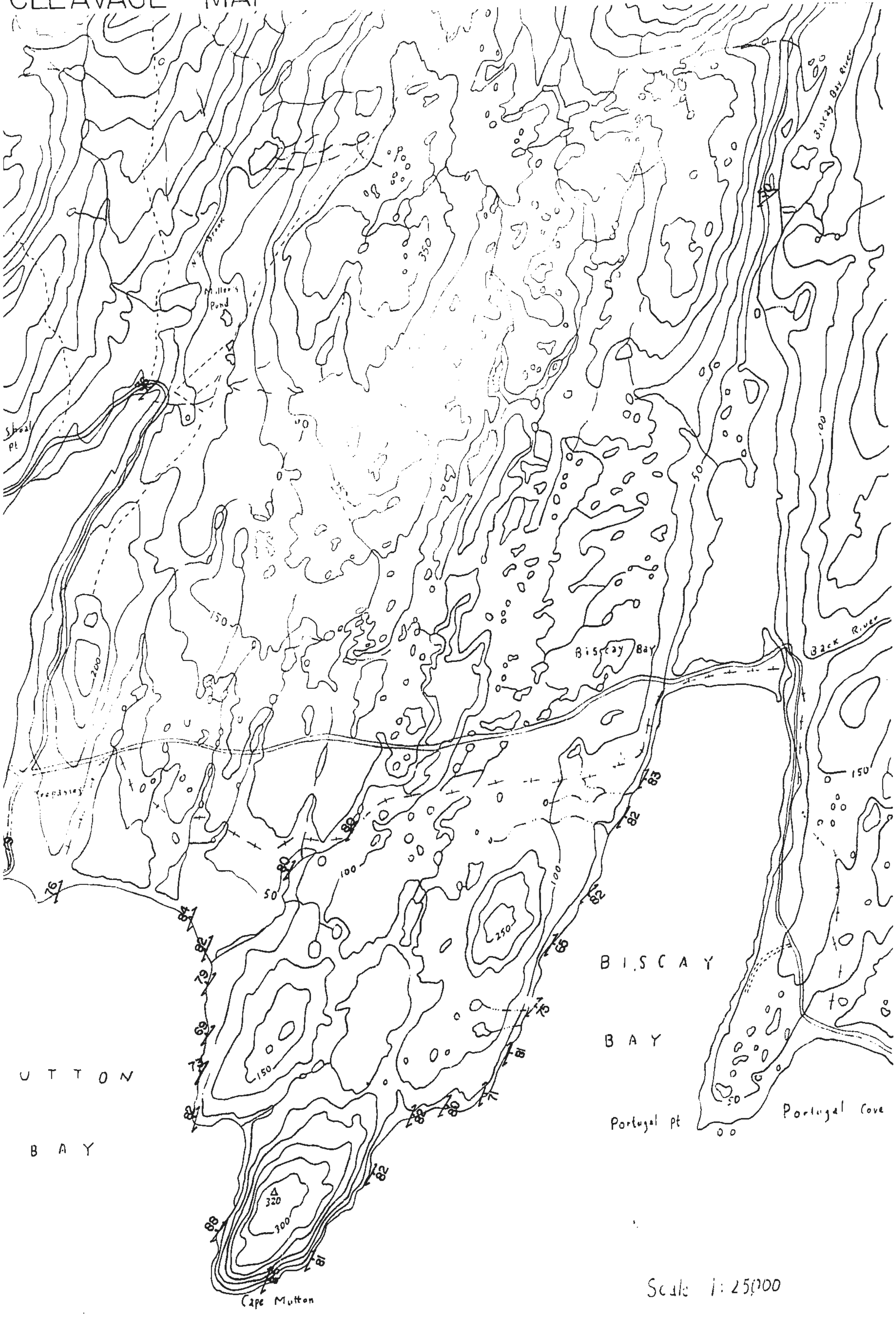
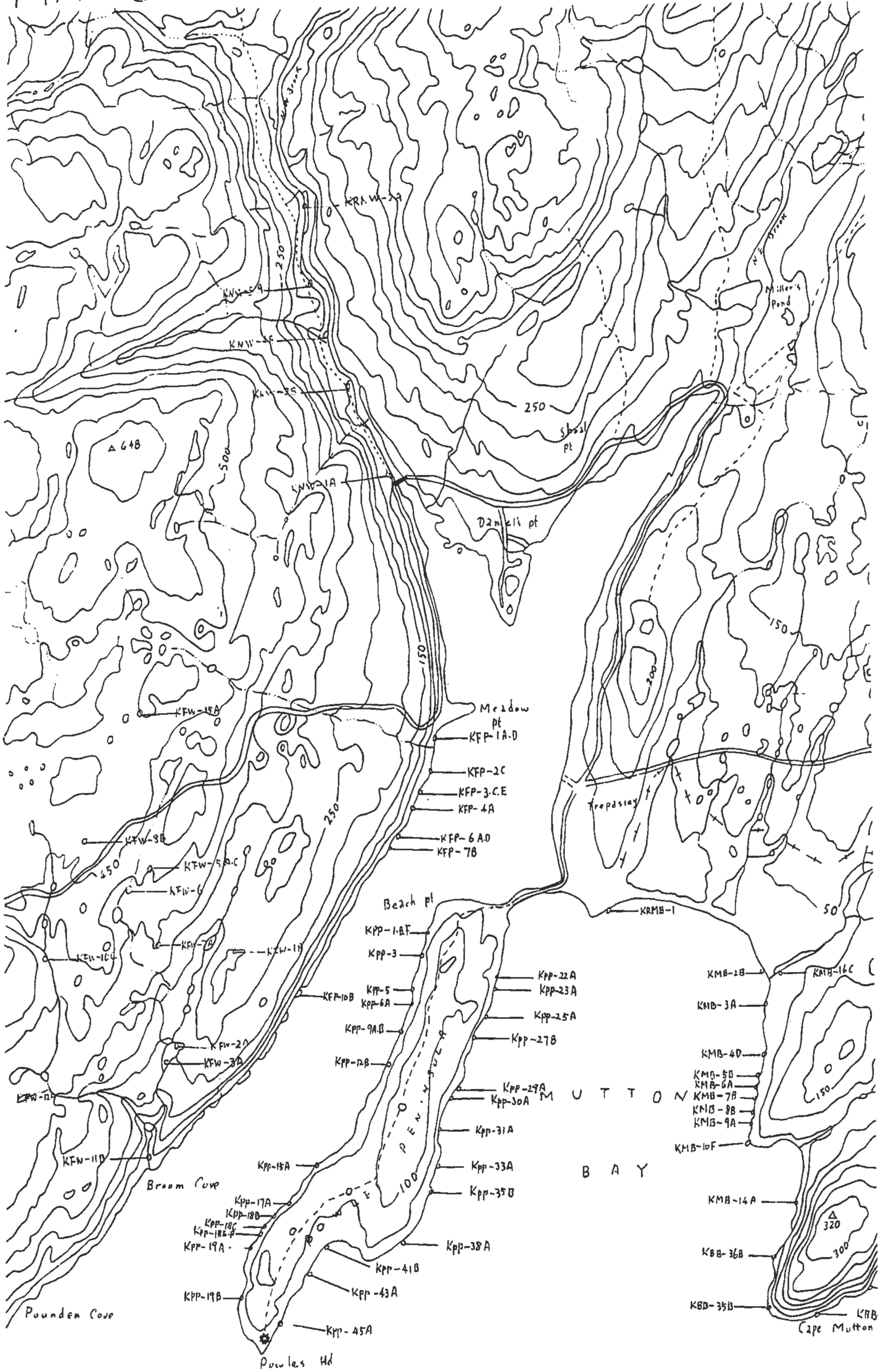


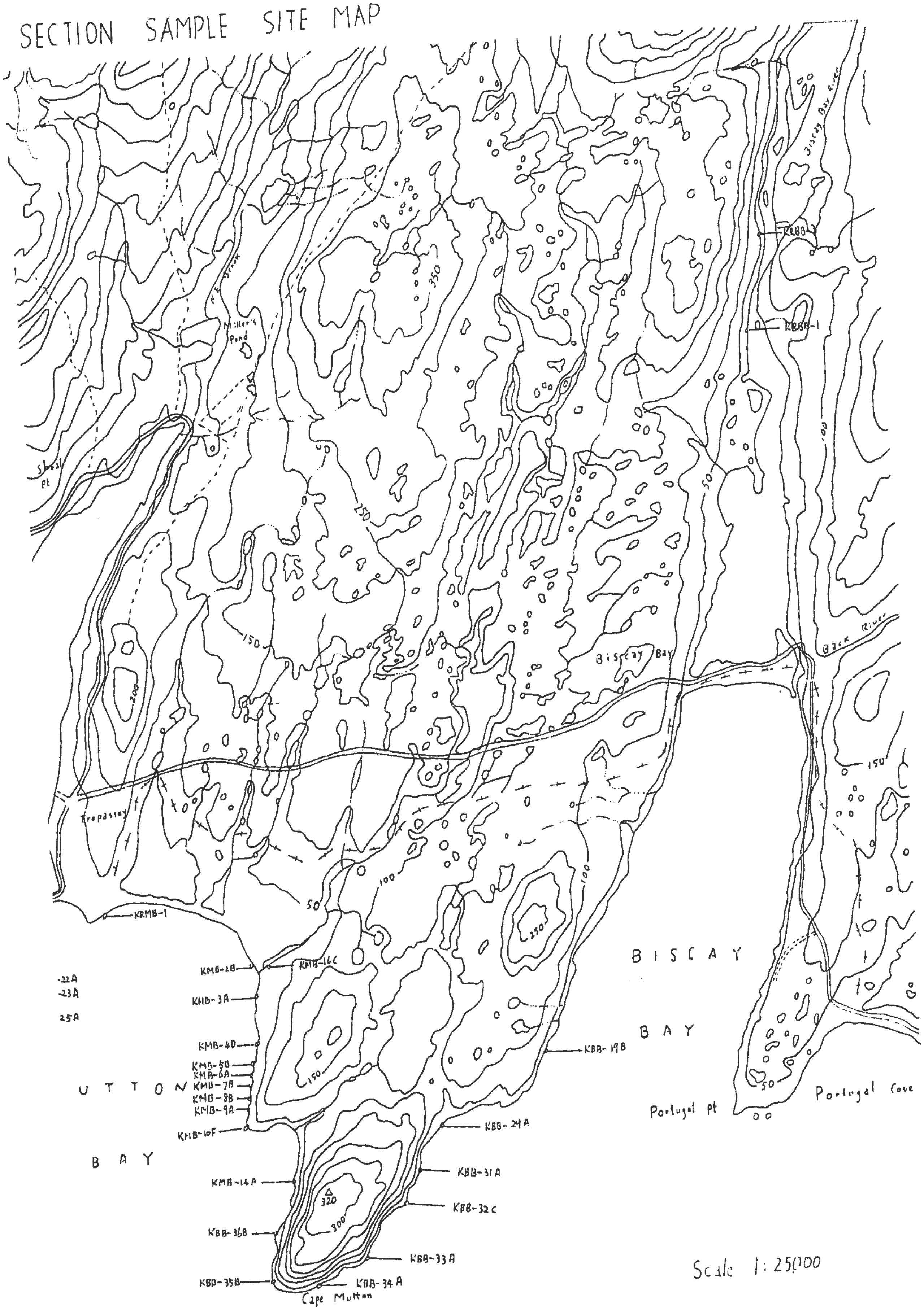
1 of 1

MAP 3

THIN SECTION SAMPLE SIT



SECTION SAMPLE SITE MAP



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