GEOLOGY OF THE GOOSE ARM HUGHES BROOK AREA

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by

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ABSTRACT

The regional setting for this thesis is in the central part of West Newfoundland.

The examination is concerned with an area of approximately 250 square miles more or less lying between North Mountain, in the Bay of Islands, inclusive of the southern part of the mountain, and the Humber River west of Limestone Station. A small area located south of the river is also included.

The bedrock of the area consists primarily of clastic and carbonate sediments ranging in age from Cambrian to Upper Ordovician which lie with unconformity upon earlier, more or less metamorphosed, Cambrian or Precambrian argillaceous and arenaceous rocks.

The younger clastic rocks, which may have upper members of Silurian age, are in part overlain by and, to a lesser extent, intercalated with still younger volcanic rocks. Both the volcanic rocks and upper members of the clastic rocks have been intruded by large masses of ultrabasic and basic rocks and lesser bodies of granite.

The clastic rocks are largely deltaic in character and consequently poorly fossiliferous. Moreover, the carbonate rocks have been largely recrystallized and well preserved fossils, suitable for identification, are few. Age determinations were, therefore, made by lithological correlations with adjacent areas where fossils have been better preserved. Large, easily recognized, exposures of the St.George group of Lower Ordovician age, which are abundantly fossiliferous to the south of the thesis area, provided the chief markers for these correlations.

Evidence for an early phase of orogeny occurs in the upper beds of the main sequence of Ordovician carbonate sediments. The widespread occurrence of the younger clastic sediments and subsequent volcanic activity indicate that orogeny comprised a number of phases which took place over a rather prolonged period of time.

A further orogenic phase is evidenced by the deformation of the younger clastic sequence and widespread metamorphism.

A thrust of more than 6 miles is noted, and evidence for it is submitted on the basis of the superposition of pre-St.George rocks over Lower to Middle Ordovician rocks and their relationships to the nearest possible source facies.

The occurrence of galena and sphalerite-bearing horizons in the carbonate rocks, and their possible origin, is briefly discussed.

Generalized references are made to additional work outside the area in as much as it is necessary to show the overall relationship to the environment. A brief outline of some of the problems encountered in determining the relationships of the basal metamorphic rocks to the main carbonate sequences is also provided.

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CHAPTER I

INTRODUCTION

Location and size of the area studied

The regional setting for this thesis is in the central part of West Newfoundland.

The accompanying geological map (Plate I) covers an area of approximately 250 square miles more or less lying between North Arm in the Bay of Islands, inclusive of the southern part of North Mountain, and the Humber River west of Limestone Station. A small area located south of the river is also included.

Smaller areas were studied in less detail near Lomond Village in Bonne Bay and near Port au Port, north of St.Georges Bay. Still other areas were studied with a view to correlation with strata containing better preserved fossils than those found in the thesis area.

A location map (Plate II) showing both the regional setting and many of the main features is included.

Previous Work

The writer was able to rely upon the comprehensive study of the stratigraphy of West Newfoundland which was carried out by Schuchert and Dunbar (1934). This study has provided the basis for correlation used by many subsequent stratigraphers, and is also used as a basis for the correlation of stratigraphic units in this thesis.

The stratigraphy in West Newfoundland, as described by Schuchert and Dunbar - with the exception of the Silurian, Devonian and Carboniferous strata which were also included in their work - is indicated in the following table:

Table I
After Schuchert and Dunbar (1934)

	Thickness in feet
Upper Middle and Upper Ordovician	
Humber Arm series, clastic rocks, some limestone and volcanic rocks.	5000+
Lower Middle Ordovician to Upper Middle Ordovician	
Table Head series Cow Head Breccia and Long Point series - short hiatus.	2910
Lower Ordovician	
St.George series thick sequence of dolomites and limestones.	2080+
Lowest Ordovician	
Green Point series (considered a facies of the Table Head group by the present writer).	1700+
Upper Cambrian	
March Point series long hiatus - no Middle Cambrian	1180
Lower Cambrian	
Labrador series	2600±

The area was studied for the first time by Weitz in 1946 and 1947 for his Ph.D. thesis (unpublished). His examination, although placing much emphasis on faulting, largely based on the study of lineaments on aerial photographs of the area, was primarily concerned with the clastic rocks of the Humber Arm group* and no attempt was made in his report to describe the carbonate sequence in detail.

A brief examination of the region by the Geological Survey of Canada in 1948 added little to the knowledge of the area west of the eastern end of Old Man's Pond. However, much of the area east of Old Man's Pond, which was considered to be Precambrian by Weitz, is now

* The term 'group' is used in this thesis rather than 'series'. However, where reference is made to the work of Schuchert and Dunbar (1934) the term 'series' is retained.

considered to be of Lower Cambrian age by the Geological Survey of Canada.

Physiography

Relief

The thesis area may be defined as part of a dissected and glacially modified plateau whose stream valleys show two well developed levels; the upper one dissecting the plateau surface between 800 and 1100 feet, the lower one rising from sea level to approximately 400 feet before ascending in a step-like manner to join the plateau.

On the plateau, the stream valleys vary in type from steep-sided (or youthful) to semi-mature. However, the descent from the plateau to the lower stream valleys is marked by waterfalls and deeply cut trenches. The surface, between the valleys, is irregular and marked by rounded to almost flat-topped hills and ridges trending parallel to the regional strike of the bedrock. The form of many lakes reflects both structural control and glacial modification.

Regionally, the plateau is bounded by higher features: the mountains of the Bay of Islands Igneous Complex and the Long Range, both of which are topped by peneplains and exceed 2000 feet in elevation. East of the thesis area are scattered hills exceeding 1500 feet in elevation.

The chief sea arms of the Bay of Islands, North Arm, Penguin Arm, Goose Arm and Humber Arm, are dominant, deeply indented, structurally controlled and glacially modified fiord-like features. Frenchman's Pond and Old Man's Pond are in many ways of the same erosional type and lie in deep trenches which reflect somewhat similar control. Both ponds are less than 400 feet above sea level and reputed to be very deep. Penguin

Arm Brook and Goose Arm Brook occupy the structural and erosional extensions of the fiord-like arms.

The nature of the underlying bedrock is expressed to a large extent by the topography. Areas underlain by metamorphosed clastic rocks and carbonate sedimentary rocks have sharp relief with steep hills or cliffs, usually facing northwest and following the strike of the bedrock. Nearly vertical dip-slopes are found along the southeast shore of Goose Arm and less steep dip-slopes overlook the southeast shore of Penguin Arm, east of the Penguin Hills. Southeast-facing slopes in the Penguin Arm and Goose Arm area are more gentle and, in a manner similar to those facing northwest, reflect the dip of the underlying strata.

Ridges in both the Penguin Cove and Goose Arm localities, where cut by valleys extending northwest and southeast across the regional strike of the bedrock, have well exposed sections on steep cliffs, in some places over 400 feet in height.

Areas underlain by shales and other rocks less competent and resistant to erosion than the carbonate and metamorphosed clastic sediments attain somewhat similar elevations, but have more gently rounded hills and lower cliffs toward the sea. In these areas the sharper relief is usually found to be an expression of underlying sandstone or quartzite rather than shale. Such erosional effects are found northwest of Penguin Arm where, with the exception of the sea cliffs, the country is relatively gently rolling compared to that south of the Arm, where more competent carbonate rocks underlie the area.

Most of the fiord-like sea arms of the region have developed along the contact of rocks of differing competence. The following list emphasizes this relationship and it is worthwhile to compare, and contrast, the rocks on both sides of these features. The first two sea arms are north of the thesis area.

East Arm of Bonne Bay

North shore, composed of metaclastic rocks (phyllites, quartzites) and some carbonate rocks.

South shore, mainly limestones and dolomites.

South Arm of Bonne Bay

East shore, shales and lesser sandstones with a few thin volcanic horizons.

West shore, shales and sandstones, partly intercalated with pillowed basalts, all in part metamorphosed and in contact with ultrabasic and basic intrusive rocks.

Penguin Arm

North shore, shales and sandstones, some limestones and limestone breccias.

South shore, mainly limestones and dolomites.

Goose Arm

Shows a somewhat different pattern as it has been eroded through the trough rocks of a syncline which consist of relatively incompetent limestones. The synclinal limb exposures forming the north and south shores, however, consist of rather competent dolomite.

Surface Drainage

With the exception of the Humber, no large rivers are found in the area. Generally, the streams are small and together with lakes occupy sheared or faulted zones which have been less resistant to erosion and glacial modification.

The upper courses of many streams meander through marshes occurring between the ridges and hills of the plateau surface. Stream courses leaving the plateau are often deeply trenched and have numerous waterfalls. The lower courses typically join to form broader courses which meander at irregular intervals through stream deposits consisting of silt, sand, shale fragments and large pebbles, derived locally, and in some places boulders of granite gneiss and granite derived from the Long Range complex.

Most of the streams, where deeply incised into the plateau, follow the regional strike. A notable exception is the Humber River which has cut a deep gorge of superimposed form across the strike of the metamorphosed rocks of the Long Range and the carbonate rocks of the plateau.

Underground drainage

Many of the lakes that underlie the carbonate rocks have no visible outlets and are apparently drained by subsurface streams. Near Goose Arm, many of the smaller streams have intermittent surface and subsurface courses. An excellent example of this type of drainage is found in the village of Goose Arm near the Narrows, where a small stream emerges from an outlet in limestone. The nearest source of this stream is found approximately 0.5 miles to the northwest.

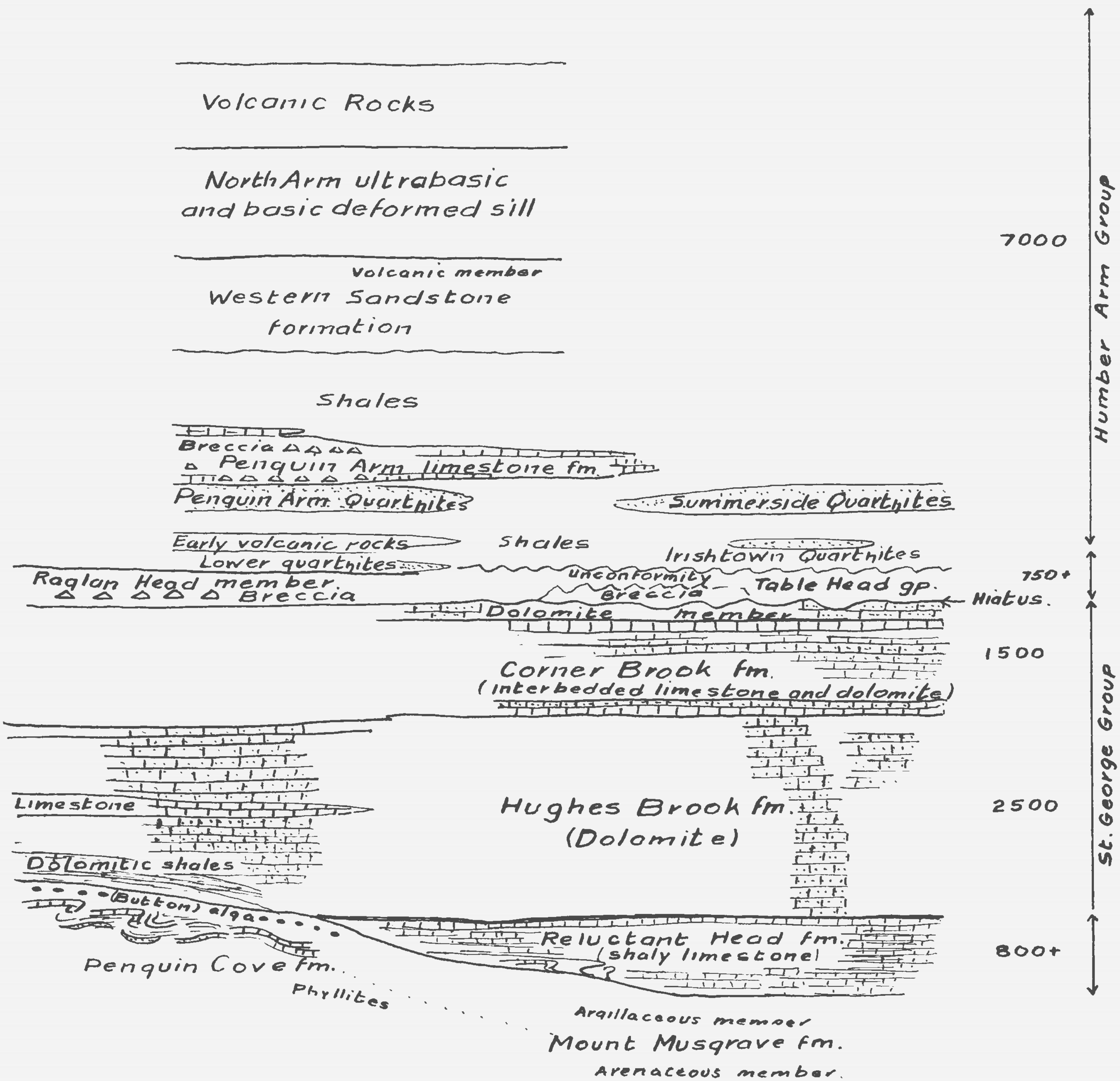
Pleistocene geology

Glacial erratics are conspicuous on the higher and more barren hill tops in the eastern part of the area. However, though less noticeable, they are equally common on hill sides and hill tops which are covered by thick vegetation. Most of the larger erratics have been derived from the metamorphic and igneous complex of the Long Range.

The remnants of raised late Pleistocene deltas are found at the mouth of most of the larger streams and form two terrace levels of approximately 40 and 135 feet above sea level. Wave-cut benches of similar altitudes occur along the shores of the fiords. The two levels indicate that the elevation of the coast (or lowering of the sea) took place in two episodes. It is noteworthy that many of the villages of the region are built either upon the wave-cut benches or upon the delta terraces.

STRATIGRAPHICAL COLUMN

Northwest | Southeast



CHAPTER 2

STRATIGRAPHY

General Statement

The bedrock of the thesis area consists of more than 12,000 stratigraphic feet of clastic and carbonate sedimentary rocks which are partly overlain by, and to a lesser extent intercalated with, a further 700 to 1100 feet of volcanic rocks. The clastic rocks which are largely of deltaic character, are practically unfossiliferous. Moreover, the carbonate rocks are mostly recrystallized and, though abundantly fossiliferous in some localities, contain few fossils sufficiently well preserved for accurate identification and, consequently, age determination.

Of the carbonate rocks, two major stratigraphic units were recognized and correlated with units distinguished by previous writers. The lower of these are correlated with the St.George group, of Lower Ordovician age, which is abundantly fossiliferous where it outcrops near Port au Port, approximately 60 miles southwest of the thesis area. The upper of these units was correlated with the Table Head group, also in the Port au Port area, however the stratigraphic limits were not as well identified in the thesis area as those of the St.George group.

Below the St.George group two other sequences, composed predominantly of carbonate rocks, have been distinguished which could not be correlated with units identified by previous workers with the same degree of certainty as the St.George and Table Head groups. One of these is an 800 feet thick sequence of shaly limestone with well defined upper and lower limits which is tentatively allocated to the Upper Cambrian age.*

* It is well worth noting that near Port au Port, there are Upper Cambrian stratigraphic units of greatly differing character and composition, and that these have been subdivided by Walthier (1949), but only because abundant fossils suitable for age determination were found in both. These divisions (the March Point and Petit Jardin formations) could not be correlated with any of the pre-St. George rocks of the thesis area.

The other sequence, composed of rocks marked by slumping, at Penguin Cove in Goose Arm, has been tentatively correlated with the upper part of the Labrador group, of Lower Cambrian age, where it outcrops on the shore of the East Arm of Bonne Bay. In both the Penguin Cove and East Arm localities this unit consists of thin to thickly bedded limestones and dolomites and also of lenticular quartzite beds and arenaceous shales.

Of the clastic rocks of the area, one sequence of great thickness lies with marked unconformity upon the Table Head group and this has been correlated with the Humber Arm series as defined by Schuchert and Dunbar (1934). Most of the Humber Arm group is of Middle to Upper Ordovician age but some of its uppermost strata may well be of Silurian age.

A second major clastic rock unit outcrops along the eastern border of the thesis area and is composed chiefly of arkosic breccias, sandstones, greywackes and shales which have undergone metamorphism of varying degrees. The degree of metamorphism has led Weitz and others to conclude that these rocks are of Precambrian age. However, they form part of a metamorphic belt which extends from a few miles south of Bonne Bay Big Pond to the southern end of the Long Range where it overlooks Cape Ray. This whole belt has traditionally been considered of Precambrian age, a conception based almost entirely on its resemblance to areas containing Laurentian gneisses in the Canadian Shield. Phair (1948) proved by a critical examination of the area north of Cape Ray that its intrusions of peridotite, gabbro and granite were all of Devonian age. Both the peridotites and gabbros have been metamorphosed, which shows that at least the southern part of the belt was metamorphosed during Devonian time. The granite,which is younger than the peridotites and gabbros, shows little of the effects of metamorphism, and this granite, or its equivalents, have been traced by the present writer as far north as the southern end of Grand Lake. Smaller bodies of granite, possibly of the same age, were also observed along the west shore of this lake and to within 12 miles of the thesis area.

The concept of these granitic rocks being relatively young intrusives, and a possible cause of metamorphism in the area, is supported by the fact that in the Corner Brook area, not only are the arkosic breccias, sandstones and greywackes around Mount Musgrave, but also Ordovician carbonate rocks and possibly even rocks as young as the Humber Arm group, metamorphosed to similar degrees although the grade of metamorphism decreases from east to west. Considering this somewhat new concept, it had to be suspected that rocks of Cambrian age would lie within the metamorphic belt which, because of the prevailing westerly dip in the whole area, would occur to the east of the Ordovician carbonate rocks. These rocks are similar in many respects to those of the Labrador group near Bonne Bay, of proven Cambrian age, as is shown in Table II. It would, however, be premature to take this correlation for granted as the total thickness of the Labrador group (approximately 2000 feet) could only account for the total thickness of the metamorphic belt under the most fortuitous of structural conditions.

Table II

Provisional correlation between the metamorphic sequences in the eastern part of the thesis area and the Labrador group in Bonne Bay and elsewhere.

Thesis area	Bonne Bay (Partly from Schuchert and Dunbar)
Upper member Calcareous shales, arenaceous shales, quartzites, phyllites at base?	Forteau formation Oolitic limestone, with button algae, sandy limestone, some quartzite, dark shales, phyllitic at base.
Lower member Arkosic breccias, coarse arkosic sandstones, some greywackes, and fine-grained quartzites (all metamorphosed to some extent).	Bradore formation Reddish arkose and sandstone, small pebble conglomerate, coarsest at base.

Summarizing, the pre-St. George rocks may be said to occur as three different sequences, represented as follows:

(1) A thinly bedded shaly limestone sequence.

(2) A highly slumped, interbedded dolomite-limestone, quartzite-arenaceous shale sequence.

(3) An arkosic breccia, greywacke, sandstone, shale sequence.

New formational names introduced in this thesis

The name Reluctant Head formation is proposed for the thinly bedded shaly limestone sequence as it outcrops for almost its entire thickness on the north face of Reluctant Head, on the south shore of Old Man's Pond.

The name Penguin Cove formation is proposed for the highly slumped sequence which is well exposed where it underlies the St.George group at Penguin Cove in Goose Arm.

The name Mount Musgrave formation is proposed, in agreement with J.M. McKillop, for the arkosic breccias-phyllite sequence which is well exposed on the west flank of this mountain. The type locality for the formation is, however, between the west shore of Hughes Lake and the main sequence of carbonate rock exposures to the west.

The name Hughes Brook formation is proposed for the lower dolomite division of the St.George group. This formation is particularly well exposed along the north wall of the Humber Gorge and along the east side of Hughes Brook. In the Humber Gorge it is approximately 2500 feet thick and consists almost entirely of thick bedded to massive buff-grey dolomite.

The name Corner Brook formation is proposed for a 1600 feet thickness of alternating limestone and dolomite sequences which extend with little variation along strike for nearly 20 miles. The uppermost part of this formation consists of closely spaced dolomite beds which have proven useful as persistent marker horizon. These beds are to be called the "upper dolomite member of the Corner Brook formation."

Both these subdivisions of the St.George group were named also in conjunction with J.M. McKillop who has mapped these formations in great detail in the area of the North Star Cement Company's quarry, near Corner Brook (McKillop 1961).

CHAPTER 3

MAINLY CLASTIC ROCKS

Pre-St. George rocks and others of unknown age outcropping mainly east of the St.George and Table Head groups.

For the most part these rocks dip to the west so that the oldest beds are exposed to the east. However, on their southeast flank occur Cambrian, Ordovician, and, with marked unconformity, Carboniferous rocks. The more arenaceous and generally more metamorphosed of the pre-St.George formations form high, partly barren ridges which extend from a little north of Deer Lake to within a few miles of Bonne Bay Big Pond. The Mount Musgrave formation lies roughly between these ridges, which in the type locality partly encompass the eastern side of Hughes Lake, and the main sequence of carbonate rocks, inclusive of the St.George and Table Head groups, to the west.

The Mount Musgrave formation

This formation may be divided into two members: a lower chiefly arenaceous one and an upper containing some arenaceous rock but consisting mainly of shale or phyllite.

The arenaceous member
Mainly arkosic sandstones, arkosic breccias* with some greywackes and shales.

The basal beds of this member are highly metamorphosed in the eastern part of the thesis area and appear to grade into the thick sequence of gneisses which form part of the metamorphic complex of the Long Range.

The arkosic breccias usually form discontinuous lenticular beds which are frequently interbedded with finer grained arkosic sandstones. The two types are easily distinguished, the finer being separated from the coarser by thin silty partings. The arkosic breccias generally weather light grey, but where well washed, as in the bed of a stream, have a faint

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* The term 'arkosic breccia' is used herein to define arkosic rocks which are composed of angular grains of quartz and feldspar ranging in size between coarse sand and small pebble conglomerate as defined by the Wentworth scale.

pink colour. Weathering surfaces are usually pitted - a feature apparently caused by the weathering out of feldspar and lesser mafic minerals. The most marked feature of the arkosic breccias is an abundance of lath-shaped feldspar fragments up to 20 mm. in length. In some places the breccias give the impression of having been dumped into or onto the finer arkosic sandstones. From place to place the silty partings between the fine and coarse beds display drying cracks. However, the areal extent of the drying cracks is in doubt as, for the most part, only in a few places is it possible to see well preserved bedding surfaces. If the drying cracks are indicative of drying in the sun, it is reasonable to assume that either repeated emergence and submergence took place at intervals during the deposition of these rocks or that they comprised part of a flood plain or somewhat similar feature.

A high proportion of the sedimentary rocks of the Mount Musgrave formation is composed of medium to thick-bedded arkosic sandstone. Invariably these rocks contain numerous veins, patches and clots of quartz. In one locality, a quartz vein, two feet thick, lies along the bedding plane and has been observed to follow it for over 400 feet.

Generally, these sandstones weather pale grey to pale yellow but are stained by brownish red iron oxide from place to place. Where somewhat sheared they tend to glisten slightly because of the development of sericite on the shear or cleavage planes. For the most part, however, these rocks weather in a manner similar to the arkosic breccias, display the same form of pitted surface, but are more evenly weathered.

Microscopically, both arkosic breccias and sandstones are seen to contain angular to subrounded quartz grains and subhedral to euhedral feldspar fragments. The arkosic breccias, however, tend to have a higher ratio of feldspar to quartz than the arkosic sandstones and also a higher proportion of groundmass.

The groundmass of the breccias is usually sericitic but frequently contains a high proportion of very fine quartz grains, grading down to silt size, which are often fused together, except where interspaced with fine sericite stringers. In addition to finely granular quartz and sericite, there are often small flecks of detrital biotite and/or chlorite and a few heavy mineral grains.

Characteristically, the larger feldspar fragments are microcline. Plagioclase fragments, which usually comprise a lesser proportion of the rock, are smaller in size and of the albite-oligoclase range in composition.

The coarse arkosic sandstones are generally similar in composition to the arkosic breccias but the proportion of feldspar is lower and seldom exceeds 15 per cent of the rock. As in the coarser breccias, microcline is the dominant feldspar. Plagioclase in the albite-oligoclase range comprises about 30 per cent of the total feldspar component. The groundmass contains more sericite and less very fine quartz grains than the arkosic breccias.

Gneissic rocks of the eastern portion of the area near Hughes Lake.

Quartz-feldspar-mica gneisses, believed to be the metamorphic equivalents of the arkosic sandstones, outcrop near Hughes Lake just east of the map area. On casual inspection these rocks have the appearance of a granite gneiss and in one or two places are associated with gneisses which have intrusive-like features. However, most of the quartz-feldspar-mica gneisses were either derived from arkosic breccias or arkosic sandstones.

It is noteworthy that these rocks appear to be richer in feldspar than the arkosic breccias or arkosic sandstones. Microscopically, the feldspars seem to impinge upon the quartz grains in a manner suggesting their growth at the expense of the quartz grains. On the other hand, the quartz grains have sutured edges as if the quartz had become mobilized and partly flowed around the euhedral feldspar laths.

Greywacke and subgreywacke.

In addition to the arkosic breccias and coarse arkosic sandstones, there are a number of horizons containing subgreywacke-pebble-conglomerates which typically contain a higher proportion of groundmass and a greater variety of detrital minerals.

These rocks have a sericitic groundmass of nearly 50 per cent in which are quartz and perthite grains up to 8 mm. in diameter as well as flakes of biotite and lesser amounts of chlorite. The heavy minerals tourmaline, zircon and spinel are also common. A higher proportion of plagioclase is present than in either the arkosic sandstones or breccias.

The argillaceous member

Mainly arenaceous shales, silt grade quartzites and some mudstones.

Stratigraphically above, and for the most part, westward of the arenaceous member is a thick sequence of mainly argillaceous rocks. These include arenaceous shales with quartz grains approaching silt grade, some mudstones and, toward the top of the sequence, shales and thinly interbedded fine-grained quartzite.

Because of the lack of outcrop in the contact zone between the coarse-grained arenaceous member and the argillaceous member, the exact relationships between them are unknown. However, in traversing from one to the other, it is remarkable that the change is almost abrupt. It is not unlikely that the two members form naturally divisible formations and, moreover, that the arenaceous member represents the Bradore formation and that the argillaceous member represents the Forteau formation, both of which are the lower formations of the Labrador group (Schuchert and Dunbar 1934).

The best exposures of the argillaceous member of the Mount Musgrave formation occur where the deeply trenched headwater courses of Hughes Brook enter Dam Pond. Here the argillaceous member commences upward from the arenaceous rocks of the lower member with a sequence of phyllites which are partly interbedded with fine-grained quartzites and small pebbly lenses of quartzite. Both phyllites and quartzites are cut by numerous quartz veins, and also contain numerous quartz pods and patches which fill openings in drag folds and crumples. The lowermost 50 stratigraphic feet of the section are highly sheared and contain disseminated pyrite.

In the brook and some other outcrops occurring along strike, the sheared zone is bounded upwards by a sequence of black shales and phyllites. The finer grained quartzites, interbedded in the lower part of this member are fairly clean and made up of 70 to 80 per cent of well sorted and rounded quartz grains and very minor amounts of microcline and plagioclase. In the groundmass, fine flakes of sericite and a few heavy minerals can be distinguished. The apparent thickness of this sequence, if the prevailing westerly dip is considered, is over 1000 feet, however repetition of beds due to tight folding or fault-slicing may have taken place, for the upper and lower parts of the sequence are very similar.

Where Hughes Brook leaves Dam Pond, also through a deep trench, there is a sequence of calcareous, sometimes nodular, shales and phyllites which stratigraphically upwards become interbedded with calcareous mudstones. This sequence may mark either the top of the Mount Musgrave formation or the bottom of the Reluctant Head formation. Above the mudstones are bluish-grey calcareous shales with intercalary limestone-cobble-conglomerates composed of well rounded, dark grey, homogeneous limestone cobbles up to 1 foot in diameter. The cobble beds are lenticular in shape and vary between 1.5 feet and 15 feet in thickness. In the Dam Pond locality the total interbedded conglomerate and shale sequence is approximately 50 feet thick. Above the conglomeratic horizons are phyllites which contain scattered lenses of angular breccia and these are in turn overlain by grey nodular calcareous shale containing numerous pods and lenses of blue-grey limestone which is commonly marked by slumping. The uppermost beds of the section are covered by overburden but farther downstream are scattered outcrops of calcareous shales and phyllites.

From place to place along the strike of the contact zone between the arenaceous and argillaceous members of the Mount Musgrave formation are thin scattered lenses of interbedded shales and silt-grade quartzites rather different from those usually found near, or at, the contact zone, which may be useful as a marker horizon for future work. Microscopically, the quartzites are seen to be composed chiefly of equigranular, well sorted quartz grains which are fused together to form a well indurated fabric. Much of the shale has been metamorphosed to the phyllite grade but contains fine laminae which are seen to consist of fine zircons with some sphene and scattered garnets. A small amount of feldspar is present in the quartzites but does not exceed 2 or 3 per cent.

In addition to the main mass of the Mount Musgrave formation, shales belonging to this formation are found in a deep valley which has eroded through the crestal rocks of the Window Pond Anticline, and here underlie the thin westerly flank of the Reluctant Head formation which, together with the shales, form part of the core rocks. Toward the axis of the anticline, the shales and phyllite equivalents are both sheared and have developed axial plane cleavage which has tended to obliterate many of their primary sedimentary features. In general, however, these sediments strongly resemble those found toward the top of the argillaceous member. In addition to the shales, or phyllite equivalents, are less metamorphosed nodular calcareous shales, also similar to those found below the limestone-cobble-conglomerates in the Dam Pond locality. No rocks resembling the limestone-cobble-conglomerates were observed in the Window Pond area.

The Reluctant Head formation.

The shaly limestones of this formation reach maximum thickness in an almost 20 mile long zone between Old Man's Pond and the Humber Gorge. In the area of the narrows of Old Man's Pond the formation is 600 feet thick and along the north wall of the Humber Gorge the thickness was estimated to be between 800 and 1,000 feet; localities in between show almost equal thicknesses. Locally, however, the shaly limestones of this formation have been reduced in thickness to as little as 100 or 200 feet where having been subjected to squeezing out by folding and/or faulting. An excellent example of such thinning out may be seen in the general locality of the Humber Gorge where, on the south side of the gorge, it is only 200 to 300 feet as compared to over 800 feet on the north wall.

Westwards of its zone of maximum thickness the formation rapidly becomes thinner. Within 3 or 4 miles to the west, the thickness diminishes to about 300 feet; in the core of the Window Pond Anticline, a few miles farther west, the formation does not exceed 50 or 60 feet in thickness. No shaly limestones, similar to those of this formation, were recognized in Goose Arm.

Variations in the shaly limestones.

The proportion of non-carbonate material varies both vertically and horizontally within the formation, and the terms shaly, or argillaceous, limestone are often misleading for in some localities the "shaly" limestones are notably high in $CaCO_3$. Assays of four bulk samples from one locality, north of the Bend in Hughes Brook, averaged less than 3.70 per cent SiO_2 and less than 1.0 per cent Al_2O_3. Another group of samples, again from this locality, averaged over 95 per cent $CaCO_3$. However, the name is somewhat valid as, in some other localities, combined SiO_2 and Al_2O_3 exceed 10 per cent. The name was originally used to describe those thin bedded limestones of the area which have clayey partings, usually less than 1 mm. in thickness. Schuchert and Dunbar (1934) also used this term in describing the southward extension of these beds where they outcrop on the north shore of the Humber River.

The Reluctant Head formation at Reluctant Head.

The most complete section of the shaly (argillaceous) limestones of this formation is exposed on Reluctant Head which is located on the south shore of Old Man's Pond, approximately 1.5 miles west of the narrows.

The lower 250 stratigraphic feet of this section consist almost entirely of slightly phyllitic, thinly interbedded brown shaly limestones and almost pure grey limestones. The argillaceous beds tend to die out towards the top of this 250 feet thickness in such a manner that the grey limestone beds become separated only by almost paper-thin clayey partings.

A distinctive feature of this basal part is a breccia, approximately 40 feet thick, which is composed of lens-shaped limestone fragments averaging between 3 and 4 inches in diameter and cemented by a sericitic silt-clay matrix. This breccia zone shows little similarity to the "cobble" conglomerates of the Dam Pond locality, or to the slump breccias of the cliffs found east of the Bend in Hughes Brook. However, it is possible that the breccia zones found near the base of the Reluctant Head formation are related to the relief of the basin in which the formation was deposited. The great variation in the thickness of the formation may well represent the filling in of an irregularly eroded basin in which, along the flanks of numerous submerged hills or ridges, slumping and associated brecciation occurred from place to place and provided several "breccia forms."

Above the basal part of the section are approximately 50 feet of irregularly bedded, reddish weathering, nodular shaly limestones. The nodular form is apparently caused by the irregular thickening and thinning of greyish weathering limestone beds varying between 5 mm and 20 mm in thickness.

The resulting depressions in these limestones are filled with reddish-brown calcareous clayey material. (Microscopically, the brown clayey material is seen to consist of sericitic clay with thin, silty, laminae). Above this 50 feet thick sequence the bedding surfaces become more even, with individual beds averaging between 1 and 2 inches in thickness and the rocks somewhat lighter in colour.

The uppermost 260 feet of the formation are again lighter in colour than those below and, for the most part, are thicker bedded with beds up to 6 inches thick. At the top are dark brownish weathering, thinly laminated, dolomitic limestones. Overlying the thinly laminated dolomitic limestones are approximately 200 feet of dolomites, belonging to the St.George group.

<u>The Reluctant Head formation east of the Bend in Hughes Brook.</u>

One of the better exposures of the Reluctant Head formation outcrops on the north side of Hughes Brook 1 mile east of the Bend, where a 250 feet thick section, containing the upper and possibly large fragments of the lower beds is exposed on a slightly overhanging cliff face.

The section commences stratigraphically upwards with a sequence of highly contorted, brown and grey weathering, thinly bedded dolomitic limestones and more or less pure limestones forming beds averaging between 5 and 7 mm. in thickness. In the lowermost beds are man-size slumped blocks of brownish weathering dolomite which apparently moved or slid into the thin bedded limestones or dolomites prior to their consolidation. Evidence of slumping is found for about 75 feet above the bottom of the sequence. Beds in the lower 200 feet of this exposure are consistently between 5 and 10 mm. in thickness, but toward the top the beds become thicker and contain poorly defined oolites which, in general, are somewhat flattened out. The oolitic beds are overlain in turn by the dolomites of the St.George group.

Relationships between the Reluctant Head formation and the upper member of the Mount Musgrave formation.

The nature of the contact between these two formations is not fully understood. Wherever the contact zone is exposed, the two formations are separated by highly contorted shales or shaly limestones which at the point of contact are crushed or shattered. Whether this type of contact zone represents a relatively slight disharmonious movement between beds due to folding, or marks a "zone of rubble" which extends beneath a thrust sheet, is unknown. The writer rather leans toward the idea that this zone marks the base of a westward slide of both the Reluctant Head formation and its burden of overlying strata. Moreover, as will be shown later in more detail, much of this "sliding" took place before intense deformation had occurred, an aspect of the structure which is based upon the fact that irrespective of the degree of deformation, whether by folding or faulting, the overall attitudes of the strata above and below the contact or deformed zone are roughly the same. Much of the confused aspect of the contact zone may be attributed to faulting which occurred later than the "sliding" and folding. These faults truncate both the earlier types of deformation. Furthermore, it is most likely that the more pronounced faults which occurred on, or close to, the contact zone between the Mount Musgrave and Reluctant Head formations, are as late as Carboniferous in age, as are those which partly separate the Carboniferous rocks of the Codroy Valley from the Southern Long Range complex (Phair 1948).

Typical contact zones were observed at Wild Cove Pond, and north of the Bend in Hughes Brook. At Wild Cove Pond the shales which mark the top of the Mount Musgrave formation are overlain by recrystallized limestones of the Reluctant Head formation. On both sides of the pond the shales display well defined axial plane cleavage which dips 80° west. The overlying limestones dip approximately 50° also to the west. Upon close examination original bedding features may be seen in the shales which indicate that they were originally crumpled against the base of the limestones prior to the development of the axial plane cleavage. North of the Bend in Hughes Brook, a rather clean contact was observed, between the shales of the Mount Musgrave formation and the base of the Reluctant Head formation, in a cave which has been developed in a part of the contact zone. In the cave are black shales which form an arch across the roof. The northwest limb of the arch dips steeply under the limestones whilst the southeast limb, after dipping southeast for a few feet, appears to be torn off by a vertical fault which truncates the less steeply northwest-dipping uplifted strata of the Mount Musgrave formation. It is noteworthy that in this locality a large part of the argillaceous member of the Mount Musgrave formation is missing, suggesting that the member was eroded off. Approximately 1 mile along the contact to the northeast, where uplift along this fault is not as great, a higher proportion of the argillaceous member consequently remains.

<u>The Humber River exposures and probable age of the Reluctant Head formation.</u>

Approximately 800 stratigraphic feet of shaly limestones belonging to the Reluctant Head formation are exposed on the north wall of the Humber Gorge near Shellbird Island.*

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* The apparent thickness of this sequence if viewed from the road is over 1,600 feet. However, drag folds exposed on these cliffs indicate that a north striking synclinal axis must lie between the eastern and western ends of the 1,600 foot wide exposure and moreover high on the north wall of the gorge, almost exactly in the centre of the exposure, occur trough rocks composed of dolomite beds of the St. George group.

These shaly limestones were considered of Cambrian age by Schuchert and Dunbar (1934). They admit, however, that their allocation to the Cambrian depended on the correct identification of a few poorly preserved trilobites. Walthier (1949) allocated these limestones and some of the shales and phyllites to the Grand Lake Brook "series", which he states is of Cambrian age. However, he presents no conclusive evidence for accurate age determination. Most remarkable is the fact that detrital limestone fragments similar to the limestones of the Grand Lake Brook group are found in the Humber Arm group and that these fragments contain well preserved Cambrian fossils.

The Penguin Cove formation.

The Penguin Cove formation occurs in the cores of both the Window Pond and Penguin Cove anticlines (see Plate I). It comprises interbedded argillaceous siltstones, quartzites, dolomites and limestones. The first two are in sharp contrast in the outcrops: the argillaceous siltstones are alternately light and dark brown in colour and grade into adjacent dolomite beds, whereas the quartzites are notably clean, weather pale yellow to pink in colour and are sharply defined. The limestones are often relatively clean, much of the silt and clay tending to accumulate in varying proportions in the dolomites. The amount of silt or clay is usually reflected in the outcrop by a change in colour on the weathered surface from pale grey or buff-yellow to dark brown.

The formation in both localities is marked by much slumping.

Relationships between the Penguin Cove and Reluctant Head formation.

Although both these formations underlie the St.George group in the same apparent stratigraphic position, they are markedly different lithologically; the Penguin Cove formation consists of interbedded clastic and carbonate rocks while the Reluctant Head formation is made up almost entirely of thinly bedded shaly limestone.

As the two formations have generally a different regional distribution and come into contact with one another only on the east flank of the Window Pond Anticline, where outcrops are poor, it is not possible to clearly establish their mutual relationships. It is the writer's opinion, however, that the most likely answer to this question is an unconformable onlap of the Reluctant Head formation over the Penguin Cove formation.

The Penguin Cove formation near Goose Arm and elsewhere.

This formation, as stated previously, is notable persistent. However, in the thesis area its exposures are confined to four localities: Penguin Cove, Penguin Harbour Brook, Old Man's Pond Brook and west of Wolf Brook, which is located on the opposite shore from Penguin Cove in Goose Arm. Beds similar in appearance to those in Penguin Cove were also observed in and near Falls Brook where it enters Old Man's Pond, but here recognition was not definite.

Exposures similar to those in Penguin Cove are found in the bed of Penguin Harbour Brook, but here the beds are too highly contorted as well as too poorly exposed to make accurate estimates of their thickness. However, modal analysis of the quartzites from both the Penguin Cove and Penguin Harbour Brook localities provided results close enough to confirm a correlation between the two.

The beds of the Wolf Brook locality appear to be almost a direct continuation of those which outcrop in Penguin Cove.

In Old Man's Pond Brook, where beds are much contorted by movement near the core of the Window Pond Anticline, the formation is either thinner than in Penguin Cove or undergoes a facies change which makes it indistinguishable from the argillaceous member of the Mount Musgrave formation. Southeastwards of the axis of the anticline its place, which is immediately beneath the St.George group in Penguin Cove and also on the west limb of the Window Pond Anticline, is taken by the uppermost beds of the Reluctant Head formation.

Outside the thesis area, there are exposures which are almost identical in every way to those of Penguin Cove. All of these occur farther north, namely, near Bonne Bay Big Pond, Wiltondale and near Lomond, which is located in the East Arm of Bonne Bay.

The exposures near Lomond are particularly interesting in that, where they outcrop near the Narrows, 1.5 miles northeast of the village, they are only separated from the exposures of the Forteau formation by a narrow channel and the beds at the top of the Forteau formation on the north shore of the channel are identical to those at the bottom of the "Penguin Cove formation" on the south shore.

Section of the Penguin Cove formation at Penguin Cove.

The most complete sequence of exposures of this formation is found in Penguin Cove in Goose Arm.

From top to bottom, the sequence is as follows:

		Thickness in feet
Bed group No. 1	Brown and almost black weathering interbedded dolomite and argillaceous limestone containing oolites up to 2.0 mm. in diameter and "button" algae (peanut-sized), followed downwards by grey weathering black limestone with slumped fragments of light brownish weathering grey dolomite which become laminated toward the base of the group.	20.0
" " No.2	Limestone bed	2.0
" " No.3	Brownish weathering and highly contorted (slumped) limestone and shaly dolomite.	6.0
" " No.4	Greyish weathering dark grey limestone containing peanut-sized brownish weathering algal forms and numerous (slumped) dolomite fragments.	6.0
" " No.5	Reddish brown weathering dolomite with paper thin laminae, several beds lenticular in section interbedded with grey limestone. Dolomite becomes increasingly silty and argillaceous toward the base of the group and almost brick-like in colour and texture. Beds range from 2 inches to 1 foot in thickness.	44.0
" " No.6	Interbedded brownish weathering limestone and almost black weathering dolomite with beds averaging approximately 2 inches in thickness.	44.0
" " No.7	Pale yellowish grey weathering (silt grade) quartzite and numerous quartzite fragments interbedded with, or in, grey to brown weathering limestone and shaly dolomite. Quartzite beds are often lenticular in section and vary between 2 inches and 6 inches in thickness. Broken-off nose of a small slump-fold in quartzite forms a nearly perfect circle 5 feet in diameter composed of quartzite. Nose part appears to have actually rolled down a slope.	24.0

		Thickness in feet
Bed group No. 8	Brownish weathering dolomite with large numbers of slumped fragments varying in size from less than 1 inch to 6 inches thick, interbedded with scattered thinly laminated pale pink to maroon quartzite beds and greenish weathering dolomitic shale which is in part silty. The group contains clean-looking limestone beds from place to place.	128.0
	Total exposed thickness	274.0

Stratigraphically, beneath these beds is a covered interval of approximately 320 feet. Scattered outcrops apparently from this portion of the section are found in the woods nearby. These outcrops consist mainly of light and dark brownish weathering shaly dolomite with scattered quartzite beds. The total thickness of the Penguin Cove formation in Penguin Cove is estimated to be between 550 and 600 feet.

Microscopic examination of the coarser clastic rocks of Penguin Cove.

A brief summary of point counts carried out on thin sections of the quartzites shows that they have the following characteristics: approximately 80 per cent quartz grains, 4 per cent plagioclase and microcline, a groundmass of approximately 16 per cent containing zircons, leucoxene, spinel and other heavy minerals which, inclusive of possibly several others largely masked by iron oxides, comprise approximately 10 to 15 per cent of the rock. The quartz grains average slightly less than 0.1 mm. in diameter. Point counts carried out on thin sections of the argillaceous silty beds provided the following approximations: quartz grains of less than 0.5 mm. 45 per cent, sericitic and carbonate groundmass 40 per cent, fairly large flecks of biotite and muscovite 8 per cent, potash and plagioclase feldspar 2 per cent, opaque minerals and zircons 3 per cent.

CHAPTER 4

THE MAIN CARBONATE SEQUENCE

The St. George and Table Head groups.

General Description

The main carbonate sequence consists of the St.George group of Lower Ordovician age and the Table Head group of Middle Ordovician age.

As expressed in the General Statement (page 10) these two groups comprise the greatest thickness of carbonate rocks in West Newfoundland. Notwithstanding the fact that these two groups contain some clastic rocks - the St.George group having shales in some of its lower members along the western flank of its outcrop area and the Table Head group having a fairly thick sequence of shales in its upper part - the total thickness of the carbonate rocks has been recognized to vary from 2500 to over 4000 feet. These rocks, exposed over a width of from 3 to 10 miles, extend from Cape St.George, on the Port au Port peninsula, to Cape Norman, the northernmost point of the Great Northern peninsula.

In the thesis area, the great masses of the St.George group are, for the most part, easily recognized. However, carbonate rocks of the Table Head group were identified, with certainty, only in some places in the Hughes Brook area. In the Goose Arm area some sequences of beds were recognized as part of the Table Head group but the contact with the underlying St.George group was not established with an accuracy greater than 200± stratigraphic feet. Because of such poorly defined limits, the Table Head rocks and possibly some St.George rocks were allocated to a separate member, only tentatively considered as part of the Table Head group, the Raglan Head member.

The St. George group is approximately 4000 feet thick in the area of the Humber Gorge and somewhat less than 3000 feet in the Goose Arm area. The Table Head group, however, where recognized anywhere in or near the thesis area does not exceed 700 feet in thickness.

Relationships between the St.George group and the underlying Penguin Cove and Reluctant Head formations.

Throughout the thesis area, and to some extent northwards, the St.George group is underlain in the east by the Reluctant Head formation and in the west by the Penguin Cove formation. Southwards in the Port au Port area, it is underlain by the Petit Jardin formation and the March Point group, both of Cambrian age.

The contact between the Reluctant Head formation and the St. George group, though conformable, is usually sharp, the thinly bedded shaly limestones of the Reluctant Head formation often appearing to terminate directly against the thickly bedded dolomites which form the basal beds of the St.George group. In some localities, however, the contact is gradational and some dolomite beds, similar to those of the St.George group, are interbedded with shaly limestone near the contact. In both types of contact the shaly limestones and dolomites are sharply defined. Regardless of the type of contact observed in any one place, the Reluctant Head formation, together with the St.George group, appear to represent an almost continuous period of deposition.

The contact between the Penguin Cove formation and the St.George group generally appears to be conformable, but in some localities the basal beds of the St.George group give the impression of thinning and thickening over the top of the Penguin Cove formation. Some of the thickening and thinning of the beds of the St.George group may be attributed to the deposition of the lower dolomites of the St.George group onto slumped beds. However, such features occur within the main mass of the Penguin Cove formation and such a feature should not therefore be ascribed to an hiatus between the two main rock units. Nevertheless, an hiatus must have occurred between the St.George rocks and those of the Penguin Cove formation because of the fact that the St.George overlies the transgressive overlap of the Reluctant Head formation over the Penguin Cove formation.

Contrasts between the St.George group where it overlies the Penguin Cove formation and where it overlies the Reluctant Head formation.

As stated in the beginning of this chapter, the St.George group is approximately 4000 feet thick in the area of the Humber Gorge, where it overlies the Reluctant Head formation, but less than 3000 feet in the Goose Arm area where it overlies the Penguin Cove formation. In the Humber Gorge area, the lower part of the St.George group contains over 2500 feet of dolomite beds, while in the lower part in the Goose Arm area the apparently equivalent beds total less than 1400 feet. Generally, wherever the St.George group overlies the Penguin Cove formation, including the Goose Arm, Bonne Bay Big Pond, Wiltondale and Lomond areas, the lower dolomitic part of the St.George group is thinner than where it overlies the Reluctant Head formation. In further contrast in each place where the St.George group was observed overlying the Penguin Cove formation, it was found to contain shales or dolomitic shales interbedded with dolomite in its lowermost several hundred stratigraphic feet. It is evident that the St.George group received clastic material from its Penguin Cove flank for some time after its deposition commenced.

Correlation of the St.George and Table Head groups in the thesis area with the fossiliferous localities near Port au Port.

As stated previously, the basis for correlation of the St. George group in the thesis area lies in its lithological resemblance to the fossiliferous exposures of the group in the Port au Port locality. One of the better examinations of that area was made by Sullivan (1941) and as the result of this work several more fossils were found in the area, in addition to those described by Schuchert and Dunbar. From the lists of both the St.George and Table Head fauna, provided by Sullivan, the writer was able to conclude that the fauna of each is so different that even poorly preserved fossils would serve to distinguish the two groups. It will be seen in Table III, which is provided for purposes of comparison, that the fossils of the Table Head group may be divided into two facies, those occurring in shales and thinly interbedded limestone and those occurring in the massive limestones which constitute the lower beds of the group. Moreover, if the two lists are compared, it becomes apparent that any "hard shelled" animal remnants over 1.5 inches in diameter could only belong to the St.George group. As will be shown later, the presence of poorly preserved remnants, similar to those indicated by the asterisks in Table III, were useful in determining the boundary between the two groups.

Table III

Showing the comparison between the faunas of the Table Head and St.George groups as they occur in the Port au Port area.

Table Head group	St.George group
Fossils found in shales and thinly interbedded limestones.	Not indicated as belonging to any particular part of the group.
Graptolites	
* Climacograptus parvus Hall	Arthropods
Climacograptus sp.	
* Didymograptus sagitticaulus Gurley	Euchasma blumenbachi (Billings)
Ptilograptus plumosus (Hall)	Leperditia sp.
Phyllograptus quadribrachiatus (Hall)	
Tetragraptus quadribrachiatus (Hall)	Caphalopods
Fossils found in massive limestones.	Diphragmoceras
	Orthoceras explorator (Billings)
Arthropods	* Piloceras sp.
	Protocycloceras lamarcki
Megalospis huttoni	* Tarphyceras prematurum Hyatt
Brachiopods	Gastropods
Leptobolus	* Ceratopea keithi Ulrich
* Lingula n. sp.	Euconia etna (Billings)
Obolus sp.	Helicotoma tritonia (Billings)
	Lecanospira cf. L. compacta
	* Maclurites affinis (Billings)
	* Maclurites oceanus (Billings)
	Maclurites rotundatus (Billings)
	Murchisonia cf. M. obelisca Whitfield
	Ophileta nerine Billings
	Pleurotomaria hyae Billings
	* Turritoma acrea Billings
	Brachiopods
	Archeorthis hippolyte (Billings)
	Algae
	Cryptozoon sp.

* Observed by the writer but not critically identified.

The St. George group

Description of the Hughes Brook and Corner Brook formations.

The two formations of the St.George group were partly described in the General Statement. The division of the St.George group into these two units is, however, mainly for convenience as it would be difficult to prove that they each represent a particular type of deposition or environment. Moreover, each of the dolomite sequences which occur within the Corner Brook formation are, except for their size, almost identical to the great thickness of dolomites which comprise the Hughes Brook formation. Further, as these two formations change character considerably outside the areas of the Humber Gorge and Hughes Brook, sections examined in other areas are considered as part of the St.George group as a whole and the formations are referred to only for purposes of comparison.

The section for the Humber Gorge and Hughes Brook areas are given in Table IV.

Table IV

Outline of the Hughes Brook and Corner Brook formations

TOP

Corner Brook formation,	mainly alternating, stratified sequences of limestones and dolomites with a maximum thickness of 1500 feet. Contains a well defined "upper dolomite member" in its uppermost 200 feet.
Hughes Brook formation,	mainly dolomites, a 2550 feet thick sequence of dolomites in the areas of the Humber Gorge and Hughes Brook Valley, but less than 1400 feet thick in the Goose Arm area and northwards.

The Hughes Brook formation

In the Humber Gorge.

The Hughes Brook formation, in the area of the Humber Gorge, comprises a continuous 2550 feet thickness of medium to thickly bedded, in places almost massive dolomites which are in sharp contact with the underlying shaly limestones of the Reluctant Head formation.

The formation commences upwards from the top of the Reluctant Head formation with a 300 feet thick sequence of evenly bedded, almost black, dolomites with marked hematite staining on the weathered surfaces. The beds are generally thick and in places almost massive, but toward the top of this "zone" the dolomites are thinly laminated but have partings at 1 to 2 feet.

Above the 300 feet thick sequence, the dolomites are grey, weather buff-yellow and are noticeably recrystallized. Laminae, apparently due to differences in grain size become more noticeable despite the recrystallization of the rock. From place to place are sheared zones which contain secondarily introduced calcite and in these zones the dolomites have an almost glassy surface where freshly fractured. Little or no lithological variation occurs for over 200 stratigraphic feet.

The Corner Brook formation

Also in the Humber Gorge.

The Corner Brook formation, in the area of the Humber Gorge, consists of a 1500 feet thickness of alternating limestone and dolomite sequences, each sequence in turn consisting of from one to many beds of dolomite or limestone and varying from an inch to over 80 feet.

Between the Hughes Brook formation and the first limestone sequence of over 50 feet is a zone of relatively thin limestone and dolomite sequences, herein called the "transition zone", which is over 520 feet thick.*

* This zone was studied in considerable detail both chemically and lithologically. The results of assays of the limestone and dolomites are included in the part of the chapter concerning the chemical composition of the St.George group as a whole.

From the top of the high-magnesian Hughes Brook formation stratigraphically upwards for approximately 200 feet, the beds of this zone vary from 0.25 feet to 9 feet in thickness. Only a few beds exceed 5 feet and the average thickness is slightly over 3 feet. The greater proportion of beds, however, are between 1.5 feet and 2.5 feet thick. Between 200 and 250 feet, the limestone beds occasionally exceed 15 feet and one continuous sequence of limestone beds, near the top of the transition zone, measured 42 feet.

Above the transition zone are a few feet of relatively thin interbedded limestone and dolomite sequences which in turn are followed stratigraphically upward by slightly over 80 feet of limestones which are separated from a further 92 feet of limestones by 3.5 feet of dolomite. Variation occurs in this essentially calcitic sequence but it is more remarkable for its persistence along strike and laterally than for its variations and, therefore, forms one of the better prospective quarry sites where it extends into the North Star Cement quarry area.

Overlying the thick calcitic sequence is approximately 600 feet of alternating limestone and dolomite sequences, none of which are over 50 feet thick, and where only a few exceed 20 or 30 feet in thickness, but above is a limestone horizon approximately 150 feet thick which where it extends into the North Star Cement property is quarried as a cement rock.

Above the "quarry horizon" is a 170 feet thick sequence of closely spaced dolomite beds of great lateral persistence called the "upper dolomite member of the Corner Brook formation."

The upper dolomite member of the Corner Brook formation.

This member was first recognized in the Hughes Brook Valley where it outcrops approximately 0.5 miles west of Hughes Brook, and was later recognized east of the Brook north of the Gillams Transverse fault. (See Plate 1). In both localities it is 166 feet thick and consists of 85 per cent high-magnesian dolomite beds and 15 per cent of high-calcic limestone beds. This member was also recognized west of the North Star Cement quarry south of the Humber River, but here appears to contain a lower proportion of dolomite beds.

Walthier (1949) claims to have recognized an hiatus at the top of the upper dolomite member where it outcrops along the ridge east of Dormston Quarry, southward along strike from the North Star Quarry. The present writer failed to find any erosional break and a close examination convinced him that the beds above and below the supposed hiatus are almost identical. However, the limestone in this locality has been recrystallized and an hiatus could easily be overlooked.

The remarkable persistence of this member is demonstrated by its occurrence in the Port au Port area where, from excellent exposures near the Gravels, it may be traced northwest along the west flank of the Table Mountain for over 5 miles. Schuchert and Dunbar recognized an erosional surface at the top of this group from the overlying Table Head group. The writer was able to locate this erosional feature by measuring upwards for 160 feet from the base of their excellent sections but was unsure whether the hiatus persisted for any great distance northeastwards.

A number of cryptozoon reefs,which form part of the member near Port au Port, were traced easily and one reef was also seen in the Hughes

Brook exposures towards the top of the member.

Because it will be necessary to refer to this member, a detailed description is given of a section measured 0.5 miles west of Hughes Brook and 2 miles north of the seashore from where the brook enters Humber Arm.

The upper dolomite member of the Corner Brook formation.

Section from top to bottom:

Bed Sequence No.	Description	Thickness in ft.
1	Buff grey weathering evenly bedded grey dolomite with paper-thin to 1.0 mm. thick laminae, beds vary between 0.5 and 1.0 feet thick. Completely recrystallized and sugary textured.	25.0
2	Grey weathering recrystallized grey limestone with scattered horn shaped, operculated gastropod remnants. Ceratopea ?	0.6
3	Thinly bedded buff grey weathering grey dolomite becoming more thickly bedded stratigraphically downwards.	3.0
4	Thinly laminated dolomite bed, 1 foot thick followed downward by a 2 foot thick dolomite bed.	3.0
5	Greyish weathering dark grey limestone, with almost silky texture on fresh surface.	1.0
6	Thin irregularly bedded limestone and dolomite, weathering grey and light brown, beds somewhat patchy. Fragments of dolomite at the base.	2.0
7	Fossiliferous grey limestone, Maclurites? fossils poorly defined, thinly bedded in part with thin dolomitic laminae.	3.0
8	Massive looking dolomite beds with occasional noticeable laminae, up to 2 feet thick.	8.0
9	Limestone containing paper-thin to 5.0 mm. thick dolomitic laminae, are highly contorted between parallel beds.	2.0

Bed Sequence No.	Description	Thickness in ft.
10	Fractured to almost brecciated dolomite, medium bedded, indistinct laminae.	1.4
11	Almost slaty dolomite with paper-thin clayey partings at irregular intervals, weathers light brown, may be slightly silty.	7.0
12	Brownish weathering dolomite somewhat shaly toward the base.	2.0
13	Grey thinly bedded limestone with scattered cherty patches and lenses and twig-like algal pseudomorphs.	1.5
14	Dark grey sugary textured recrystallized limestone.	3.0
15	Thinly bedded dolomite with cryptozoon reef-like forms for approximately 0.6 feet in upper portion of sequence, followed downwards by thinly laminated and thinly bedded dolomite, becoming shaly toward the base of the sequence.	8.0
16	Thinly bedded shaly limestone with thin, irregularly spaced, dolomite beds less than 1 inch thick.	6.0
17	Mainly covered interval but contains scattered outcrops of dolomite with few limestone outcrops.	60.0
18	Dolomite, highly contorted bedding, weathering buff grey to light brown, sugary textured, massively bedded in part.	20.0
	Total thickness	166.5

Limestones below this sequence contain poorly preserved fossils resembling the gastropods *Ceratopea*, *Maclurites oceanus*? and a brachiopod *Archeorthis*.

The upper dolomite member has not been traced with certainty into the Goose Arm locality. It is probable that it is represented there by bed sequence No. 2 of the Wolf Brook section (to be described later), which measures 75 feet in thickness. This sequence is composed chiefly of thin to thick bedded, thinly laminated dolomite and in part contains almost massive featureless beds. Much of the massive looking dolomite appears to have had most of its primary features removed by recrystallization and the introduction of lime into numerous shears and fractures.

The St.George group in the Goose Arm area.

As stated previously, no attempt was made to subdivide the St.George group into separate formations outside the areas of the Humber Gorge and Hughes Brook. On the following pages are two detailed profiles of the St.George group where it outcrops in the Goose Arm area. The first section, herein called the White Face section, was examined along the faces of a series of cliffs which extend northwestwards from the White Face cliffs, near Penguin Cove in Goose Arm, almost to the shore of Penguin Arm. The second, called the Wolf Brook section, was measured from a short distance west of Wolf Brook, on the south shore of Goose Arm, almost to Long Point approximately 1.5 miles farther west. In both examinations the St.George group is treated as a whole.

The White Face section.

The basal beds of the St.George group are well exposed on the White Face cliffs which overlook Penguin Cove in Goose Arm, and from there the succeeding beds of the group may be traced through intermittent exposures, northwestwards for nearly 2 miles across the west flank of the Penguin Cove Anticline. The section commences upwards from a group of finely oolitic beds which mark the top of the Penguin Cove formation.

The basal beds of this section are grey on the fresh surface, weather buff-yellow and, for the most part, possess faint brownish-weathering argillaceous laminae. Approximately 25 feet above the basal beds is a persistent 5 feet thick sequence of thin beds containing nodular to angular fragments of dolomite. The fragments appear to have been derived from the beds below while they were in a semi-consolidated to consolidated condition as both angular and nodular fragments are found in the beds above.

At approximately 40 feet above the base, the dolomite beds become thicker, and average slightly less than 2 feet. These beds contain fine, almost paper-thin brown laminae, which microscopically are seen to be composed of silt-size quartz grains and thin bands of clayey material.

Above 80 feet, the dolomites have red blotchy hematite staining, are finely crystalline and, as in the beds below, contain a small amount of silt. However, these beds are more massive and the silt, under the microscope, is seen to be unevenly distributed rather than forming laminae. At the base of the massive beds is a thin layer of dolomite fragments which have evidently been derived from the beds below.

The weathered surfaces of these beds frequently show features which resemble drying cracks and rather poorly defined current bedding.

Approximately 100 to 200 feet above the oolitic beds are found fine flecks of galena and sphalerite. Slightly higher in the section is a 30 foot thick section comprising interbedded light buff weathering dolomite and reddish weathering dolomitic shale, which appears to be entirely conformable with the overlying and underlying dolomite beds. Above the shale beds is a greyish weathering, sugary textured dolomite containing galena, sphalerite, and lesser pyrite, which is in turn followed upwards by a sequence of thin-bedded, reddish weathering, somewhat less dolomitic calcareous shale.

Stratigraphically above and occurring to the northwest of the dolomitic calcareous shales, are a number of isolated cliff faces exhibiting buff weathering, thin to thick-bedded dolomite, which possibly represent several hundred feet of dolomite, which farther west are interbedded with dark grey weathering sequences of limestone. At the bottom of the limestone beds, where they are underlain by dolomite beds, there are almost invariably 1 or 2 inch thick layers of fine to coarse, sometimes angular fragments of dolomite, similar in appearance to the underlying dolomite beds.

Toward the top of the thickness of alternating limestone and dolomite sequences is a zone containing angular blocks of dolomite and limestone varying from a few inches in diameter up to 2 x 5 x 6 feet (pianocase size) which lie within unbrecciated limestone beds. It appears that consolidated fragments, or blocks of dolomite and limestone, have slid into unconsolidated limestone mud.

The breccia zone is in turn overlain by several hundreds of feet of grey weathering, thinly bedded, fissile limestones which contain numerous, though poorly preserved gastropods toward the base, suggesting that in part these limestones belong to the St.George group. Slightly higher in the section, however, no fossils representative of either the St.George or Table Head group were found. It is not improbable that the fossils near the base of the limestone thickness are detrital and were washed or eroded out of the St.George group as were the breccias. Because of this possibility, all the limestones above the breccia zone are considered as part of a separate member - the Raglan Head member, which will be discussed later. The top of the total section is unconformably overlain by the early sediments of the Humber Arm group.

The Wolf Brock section.

This section, which was measured and examined in detail also across the Penguin Cove Anticline, has an apparent thickness of slightly over 3600 feet and was measured through beds which dip almost continuously westwards. This thickness is approximately 1000 feet greater than the estimated thickness of the section on the White Face cliffs, for parts of the section are repeated by faulting. It is noteworthy in this respect that the top and bottom limestone members, as exposed along the shore, are almost identical.

The truly representative section, derived after corrections for faulting are made, is generally similar to that on the White Face and northwestwards. The section commences downwards from a sequence of shaly limestone and calcareous shales which possibly belong to the Table Head group.

Summarizing somewhat, the section is as follows:

From top to bottom:

Bed Sequence No.		Thickness in ft.
1	Interbedded dolomite and limestone, predominantly limestone - with limestone subdivisions up to 60 feet thick and dolomite subdivisions with thinly interbedded limestones up to 20 feet thick - limestones in part shaly with thin clayey partings and containing small fragments and angular blocks of dolomite in the lower part of the sequence, apparently derived from dolomite beds immediately below.	400
2	Thin to thickly bedded dolomite, weathering buff yellow, in part thinly laminated with occasional silty laminae irregularly spaced.	75

Bed Sequence No.		Thickness in ft.
3	Interbedded dolomite and limestone, limestone subdivisions up to 30 feet thick, contains scattered cherty lenses and patches, generally similar to bed sequence No. 1.	320
4	Grey to buff yellow weathering, in part thinly laminated dolomite, with beds varying from 2 or 3 inches in thickness to just under 2 feet. Contains thin shaly limestone beds from place to place.	410.0
5	Interbedded dolomite and limestone similar to bed sequence No. 3, appears to contain a higher proportion of chert toward the top. Limestones contain numerous twig-like algal forms.	260.0
6	Dolomite similar to bed sequence No. 4	130.0
7	Chiefly shaly limestone with scattered thin dolomite beds.	65.0
8	Grey to buff yellow weathering, in part thinly laminated dolomite with beds varying from 4 or 5 inches to 1.5 feet. Some red blotchy hematite staining. Contains a few scattered thin limestone beds.	450.0
9	Interbedded dolomite and limestone, similar to bed sequence No. 5.	95.0
10	Mainly greyish weathering dolomite with brownish beds from place to place, pyrite in upper portion of subdivision, generally similar to bed sequence No. 4.	400.0
11	Dolomite, greyish weathering, with occasional sequences of brownish shaly dolomite, contains scattered patches and flecks of pyrite, sphalerite and galena, similar to dolomite on White Face Cliffs.	410.0
	Total Thickness	2,615.0

In the section described above, it is possible that bed sequence No. 7 marks the top of the Hughes Brook formation, or to elaborate somewhat, marks the changing point from an environment predominantly suitable for the deposition or formation of great thicknesses of dolomite to one generally suitable for the deposition or formation of limestone.

Breccia zones above the upper dolomite member of the Corner Brook formation in Hughes Brook and Wild Cove Valley areas and near the top of the St.George group in Goose Arm.

In the Hughes Brook and Wild Cove Valley areas, the upper dolomite member of the Corner Brook formation is overlain by breccia zones, which contain angular blocks of limestone and dolomite, bearing a strong resemblance to those occurring in the White Face section in the Goose Arm area. These breccias, however, have in many places been shattered by tectonic movement so that it is impossible to ascertain whether they originated by sliding into unconsolidated muds, as did those of Goose Arm, or not.

In the Goose Arm area, the breccias vary in size from that of a match box to several feet in length and over a foot in width. In the White Face section several breccia blocks were observed which, from their angular appearance and the random orientation of their bedding in respect to the bedding of the enclosing limestone, could not have moved far from their source. Moreover, the great variety of sizes of the blocks or fragments suggest that they slid down a rather steep slope, an idea which suggests the beginning of an orogeny. Because of this, the limestones and dolomites of the Goose Arm area overlying the breccia zones are allocated to a separate member called the Raglan Head member, after the locality where it was first examined in Goose Arm. This member is tentatively correlated with the lower part of the Table Head group. Other reasons for this correlation will be discussed later in this chapter.

The Raglan Head member

Excellent exposures of this member form high cliffs on the 1000 feet high abutment of Raglan Head where it overlooks the Narrows of Goose Arm. From a vantage point on the north side of the Narrows, it is possible to recognize evenly bedded alternating sequences of grey to dark grey weathering limestone and pale grey to light buff weathering dolomite. The dolomite, which is the more resistant of the two rock types, tends to stand out from the limestone with slight relief.

A detailed examination of the Raglan Head member shows that the strata are notably similar to those of the Corner Brook formation. The limestones in the lower part of the Raglan Head member are marked by numerous twig-like algal pseudomorphs, which because they are more resistant to weathering, stand in higher relief than the limestone containing them and, where not broken by post-diagenetic movement, lend a distinct lace-like pattern to the weathered surface of the rock.

In many limestone beds the apparent detritus from these forms gives a laminated appearance. The laminae are invariably lighter in colour than the limestone so that, as with the twig-like forms, they are easily distinguished.

Fossils other than the algal forms are rarely found in the exposures on Raglan Head and those present are too poorly preserved for accurate identification. Near, or at, the base of the member, remnants resembling Maclurites, Cytoceras and Ceratopea, among others, have been found a short distance above the breccia zone previously described, but as in the White Face section appear to die out a short distance above it.

The total thickness of the Raglan Head member is not accurately known. A thickness of 675 feet was carefully measured on the northwest face of the "head" and a further thickness of 195 feet was measured on the southwest face but here the beds have been so contorted that some measurements may have been repeated. Tentatively, one might assume that the member is approximately 800 feet thick.

The Table Head group in Port au Port and its possible equivalents in the Goose Arm areas.

The Table Head group, where it is exposed near Port au Port, is abundantly fossiliferous, and with its exposures in that locality, an attempt was made to correlate similar rock types in the Goose Arm areas. In the Port au Port area the Table Head group comprises two main rock types: a lower sequence of rather massive limestones which immediately overlies the St.George group, separated from it by a small hiatus, and a sequence of grey to black shales and thinly interbedded limestones which constitutes the upper part of the group. The fossils may be divided into two types and these, in turn, may be allocated to the two main rock types (see Table III, page 36). From the table, it may be readily seen that the fossils occurring in the limestones, which constitute the lower part of the Table Head group, could not be mistaken for the relatively large gastropods which are commonly found in the St.George group, even if they were very poorly preserved. Although no hiatus was recognized at the base of the Raglan Head group in the Goose Arm area, its place or stratigraphic position is probably marked by the breccias of the White Face and Wolf Brook sections. However, though the breccias may be the time equivalent of the hiatus found in the uppermost strata of the St.George group at Port au Port, it is unlikely that they mark the beginning of an hiatus in the Goose Arm area. This concept is somewhat borne out by the fact that none of the fossil remnants found immediately above the breccias in the Goose Arm area could belong to the Table Head group. However, at only a short stratigraphic distance above the breccias, fossil remnants which could only be ascribed to the St.George group die out. Because of such poor correlation with the Table Head group, made only on the basis of "missing fossils" and some evidence for the beginning of an orogeny, all the carbonate rocks which occur between the breccia zone, and clastic rocks of the Humber Arm group, were allocated to the Raglan Head member.

Detailed description of the carbonate rocks of the St.George and Table Head groups.

In this section the features common to the carbonate rocks of both the St.George and Table Head groups will be described. These features will be described in the following order: 1) Cyclic sedimentation 2) General and microscopic examination of the limestone and dolomite beds 3) Comparison between the results of modal analysis of quartz grains in dolomite and assay results 4) Chemical composition of the St. George group.

Cyclic sedimentation.

A form of cyclic sedimentation is evidenced everywhere the St.George group is exposed but no better exposures are found for studying its effects than on the cliffs of Raglan Head.

A close inspection of the Raglan Head exposures shows that each sequence is composed of thin to medium bedded dolomites or limestones in which the limestones in places are almost massive. In the lower part of the Raglan Head exposures and toward the base of the member, these limestone sequences average 6.2 feet in thickness whereas those of dolomite average 1.9 feet. The maximum thicknesses of the limestones and dolomites, however, are 15 feet and 6.2 feet. The distribution of the sequences in the first 300 feet of the member is fairly even, but at approximately 325 feet there is a sequence of limestone of about 75 feet in thickness which is, in turn, followed stratigraphically upward by limestones containing only thin, scattered dolomite beds.

If an examination is made of the pattern of alternating limestone and dolomite beds throughout the St.George and Table Head groups as a whole, it may be noted that there are essentially two cyclic patterns. One involves the great thickness of dolomite towards the base and the essentially calcitic thicknesses toward the top; the other involves the minor changes such as are represented by the transition zone between the mainly dolomitic and the calcitic parts.

The writer suggests that these two patterns may represent a gradual meteorological change from a high temperature to low, which involved the greater cycles and the effects of isostatic change, which involved the smaller superimposed cycles.

Detailed description of the limestones - mainly from areas where the rocks have not been greatly metamorphosed.
Chiefly in the Goose Arm area.

As partly described previously, the bases of the limestone beds where they overlie dolomite beds are commonly marked by a layer of dolomite fragments, one or two inches thick, similar in composition to the beds below them. Above the layer of fragments the limestones are frequently massive and usually several times the thickness of the dolomite beds. Generally, the limestones contain either clusters of twig-like algal pseudomorphs or fine laminae, evidently derived from broken-up algal fragments. The laminae vary from paper-thin to 1 or 2 mm. in thickness and may be a few millimeters to several inches apart but commonly join to form thicker laminae or die out altogether. Unfractured limestone devoid of shearing on both sides of these laminae indicates that the fragmentation of the algal forms was a contemporaneous or penecontemporaneous process. Moreover, where later shearing or fracturing has taken place, the shearing has ground out the algal forms and the fracturing is seen to cut across them.

Microscopically both the laminae and twig-like forms are seen to consist mainly of dolomite crystals many times as large, and of a more euhedral habit, than those which comprise the usually recrystallized matrix of calcite crystals. The proportion of dolomite crystals varies in the algal forms, for some are seen to consist almost entirely of clusters of dolomite crystals, others as little as 50 per cent. Many of the dolomite crystals are zoned. The matrix of the relatively unmetamorphosed limestones is usually rather dense but under high power it is observed that it is composed chiefly of very fine calcite crystals. Under low to medium power, it may be seen that the fine calcite crystals tend to be concentrated into rather numerous cloud-like patches of varying shape. A larger proportion of these patches have somewhat rounded outlines, however, and are interspersed by more coarsely recrystallized calcite. Numerous iron oxide stained solution cavities are found throughout, and are particularly abundant near or around the perimeters of the dolomite clusters.

Most of the cloud-like patches vary from 0.2 mm. to 0.8 mm. in diameter and have a tendency to be oriented parallel to the bedding. However, in some thin sections two directions of orientation are seen, one roughly parallel to the bedding plane; the other at about 45° to it. Some of those at an angle to the bedding are oriented along, or parallel to, very faint carbonatized shear zones. Others appear to be a form of cross lamination as if bottom currents occasionally developed miniature deltas in the limestone muds.

Interspersed throughout the limestones are scattered, often recrystallized, quartz grains, usually less than 0.02 mm. in diameter, but occasionally clusters of quartz grains are found along the solution cavities.

In one thin section from this division, the curved outline of what appeared to be a portion of a brachiopod shell was observed. The "outline" was filled largely with dolomite crystals but possibly not to the same extent as the algal twig-like pseudomorphs and contained a higher proportion of fine calcite crystals. The dolomite crystals appeared to have grown at the expense of the calcite.

Some of the limestones contain subrounded to well rounded patches of dense, very finely crystalline, calcite grains. The rounded patches vary from 0.8 to 1.5 mm. The matrix of these rounded forms is notably homogeneous and consists of calcite grains, subhedral to euhedral in shape, which are interspersed by larger recrystallized calcite grains. In some thin sections the roundness of the calcite patches appears to be more than fortuitous and bear a resemblance to fecal pellets.

Dolomite beds.

The dolomite beds are often laminated, from thin to massively bedded and weather light buff grey to light brown. In the outcrop they are in sharp contrast to the limestones which weather grey to dark grey. On the fresh surface the dolomites have usually a distinct sugary texture which is markedly different from the smooth, almost silky texture of the limestones, and being more resistant to weathering and also more competent, where both are tightly folded the limestones become contorted whereas the dolomites tend to shatter into sharp angular fragments.

From place to place the dolomite has a red blotchy staining due to the presence of hematite.

Microscopic examination of the dolomites.

In all the thin sections examined, the dolomites were completely recrystallized. Occasional vugs in some beds are often filled with secondary calcite. The range of grain sizes in the dolomites is relatively small compared with that of the limestones. Whereas grain sizes in the dolomites range from 0.07 mm. to 0.8 mm. in diameter, in the limestones they range from almost sub-microscopic to several mm. Generally, the dolomites are notably consistent as to grain size everywhere in the area irrespective of the degree of metamorphism. Quartz grains ranging from 0.05 to 0.2 mm. in diameter are found irregularly scattered throughout the dolomite beds and frequently show euhedral outlines.

Comparison of modal analysis and assay results of the dolomite for SiO_2.

Point counts carried out on thin sections of these dolomites indicated that they seldom contain more than 0.5 per cent quartz grains and in some cases even less. Assays carried out on fifty-one samples of these dolomites, however, gave an average of 4.6 per cent SiO_2. Even where assay values exceeded 10 per cent SiO_2, the number of quartz grains did not exceed 1.0 per cent of the total count in thin section.

The discrepancy between the number of visible quartz grains and the amount of SiO_2 from the assay values would indicate that much of the SiO_2 is tied up in clay minerals, not readily identifiable in thin sections, or in finely disseminated cherty matter and quartz grains too small to identify. Further, assays of the dolomite for Al_2O_3 varied between 0.67 per cent and 2.49 per cent. From the above, it is evident that the Al_2O_3 which might be incorporated in clay minerals is insufficient to account for the relatively high proportion of SiO_2.

It is notable that many of the quartz grains have sharply defined hexagonal outlines. Some of the hexagonal forms may have resulted from the enlargement of fine anhedral quartz grains into euhedral forms.

Because of the rather broad areal distribution of the dolomites, it is difficult to envision the transportation of quartz grains of 0.1 mm. to all parts of the division without the aid of turbidity currents or some kindred phenomena. Moreover, the grains have such an erratic vertical distribution in the beds that it is unlikely that turbidity was an important factor in their deposition. It is, therefore, likely that many grains grew from small quartz nuclei, probably less than 5 microns in diameter, which could be transported over large distances even by weak currents, or were derived from the recrystallization of cherty material.

Chemical composition of the St.George group as a whole.

The limestones and dolomites of the St.George group are well defined chemically and physically. The limestones seldom contain more than 2 or 3 per cent MgO, except where they include large amounts of high-magnesian fossil algae, the dolomites seldom contain less than 12 to 15 per cent MgO. Most of the dolomites contain between 15 and 21 per cent MgO, and where the proportion of MgO is less than 15 per cent, there is usually evidence for the secondary introduction of calcite near fault or shear zones. By assay, three large samples from the top of the Hughes Brook formation in the Humber Gorge area, representing a stratigraphic thickness of about 95 feet, were found to contain an average of over 21 per cent MgO, almost attaining the theoretical limit for MgO *in dolomite. A sequence of limestone beds of from 2 to 3 inches in thickness, interbedded with the dolomite at the top of the formation, averaged only 1.4 per cent MgO, suggesting that the control-factor between the formation or "precipation of dolomite" and that of the limestones, regardless of the mechanism involved, was capable of effecting very sudden changes.

The chemical relationships described above are persistent throughout the region, for assays of samples from dolomites and limestones taken from the top of the St.George group in the Port au Port area, provided almost identical results to those of the general area of the Humber Gorge. Similar results were obtained from assays of samples in the Goose Arm and Lomond areas.

Much of the information concerning the chemical and stratigraphic relationships between the dolomites and limestones was obtained in the zone stratigraphically above the high-magnesian dolomites of the Hughes Brook formation to assess the possibilities of jointly quarrying high-magnesian dolomites and high-calcic limestone. This assessment work provided much information concerning the overall relationship of the dolomites and limestones.

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* The writer acknowledges that the dolomites are an enigma, in that the process by which dolomites are formed is neither known nor understood. The process of dolomitization in some of the Pacific coral reefs is supposed to have taken place well after the depositisn of an original limestone, an idea which is supported by the fact that no dolomites are at present recognized as forming on these reefs but are found by drilling into older rocks.
Hanzawa, 1940. Hanzawa, Shoshiro, 1940. Micropaleontological studies of drill cores from a deep well in the Kita-Daito-Zima (North Borodino Island).

Factors related to the deposition of the dolomite beds.

The writer is not concerned here with the physical chemistry of the dolomite beds, but hopes to show, and to some extent summarize, the relationships between the dolomites and limestones, together with some aspects of the environment of their deposition. The following factors are submitted for consideration:

1) The dolomites almost always show some evidence of having been deposited in shallow waters and for having been exposed to the sun for varying periods.

2) Where dolomites are interbedded with limestones they are separated by a sharp boundary of considerable lateral persistence.

3) Magnesia-rich algal pseudomorphs, and dolomite laminae evidently derived by the breaking up of the algal pseudomorphs, are found in otherwise high-calcium limestone.

4) Dolomite beds almost invariably show faint to well defined laminae.

5) Where dolomite crystals are found in limestone, they tend to show a preference for solution cavities in which they have apparently grown at the expense of calcite.

6) Cryptozoon reef structures are almost invariably rich in magnesia.

7) The dolomites contain, on the average, a higher proportion of SiO_2 than the limestones.

From the above, three main factors seem important; evidence of shallow water-tidal flat conditions, persistence of laminae in the dolomite and the sharp boundary between dolomite and limestone beds. The first relates the dolomite to an environment which was subjected to wave action and drying in the sun, the second suggests that the dolomites are partly detrital in origin (but not necessarily transported any great distance) and possibly derived from nearby reefs of algae which were capable of precipating dolomite or incorporating it in what were to be their fossil remains, the third, the sharp boundary between the dolomites and limestones suggests that the dolomites and limestones were deposited as separate beds and that the dolomite was not an alteration product after its final deposition. Other factors show a relationship between the faunal association and the process of dolomitization in that algal forms appear to have played a part in the original formation of the dolomite in the limestones from which the dolomite beds were ultimately derived.

The following explanation may be suggested for the higher proportion of SiO_2 in the dolomites than in the limestones. It is probable that the supply of SiO_2 was a relatively constant factor and that the ratio of SiO_2 in the limestone to its ratio in the dolomite simply represents a longer "proportion" of time for the dolomites to be deposited.

CHAPTER 5

THE HUMBER ARM GROUP

General description of the Humber Arm group.

As expressed earlier in the thesis, the Humber Arm group comprises the greatest thickness of clastic rocks in West Newfoundland. Though few recognizable fossils have been found in its strata, it is believed to be of Middle to Upper Ordovician age but some of its upper members may be as young as Silurian age.

This group overlies the main carbonate groups with great unconformity. It consists essentially from bottom to top of (a) dark shales, (b) partly interbedded quartzites, (c) thinly bedded limestones and limestone breccias, (d) shales with interbedded, partly massive, sandstones, and (e) a thick sequence of volcanic rocks consisting of basalt, andesite and lesser amounts of rhyolite.

Because of the prevailing westerly dip throughout the area, these rocks are located mainly westwards of the underlying carbonate groups. The sediments of the group, with the exception of the massive sandstones, which are relatively competent, are highly contorted and display much dragfolding and minor faults.

Contortion is so great in some localities that individual beds or horizons may be traced out only with great difficulty. Accurate estimates of thicknesses are difficult because of slaty cleavage which, in many places, has obliterated the original bedding. The thickness of the group* was, therefore, obtained by measuring the more distinctive horizons and the "bulk" of the less competent members between them.

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* It is interesting to note the great differences between the estimates of the thickness of the Humber Arm group made by different workers: Schuchert and Dunbar (1934) 5000+ feet, Walthier (1949) 4000 to 8500 feet, Weitz (1947) 12000+ feet.

The writer estimated the thickness of the Humber Arm group, including the volcanic sequence, to be over 7000 feet. The volcanic sequence was estimated to have an average thickness of approximately 1000 feet.

As shown in the General Description, the Humber Arm group has five more or less natural divisions. Only two of these, with the exception of the volcanic rocks, have recognizable limits; the western sandstones and interbedded shales, the thinly bedded limestones and limestone breccias. A third suite, the interbedded quartzites, which are easily recognized but not delineated, are given a local name. In Table V are the writer's subdivisions of the Humber Arm group for the Goose Arm-Hughes Brook areas, presented from top to bottom.

Table V

Subdivisions of the Humber Arm group in the Goose Arm-Hughes Brook area.

Top.

Humber Arm volcanic rocks	Mainly pillowed basalts and andesites, massive basaltic and andesitic flows and pyroclastics.
Western Sandstone formation	Fine to coarse sandstones and greywackes, some limestone beds and shales, intercalated with volcanic rocks towards the top.
Penguin Arm Limestone formation	Thinly interbedded limestones and calcareous shales with widespread zones of limestone slumped breccias.
Penguin Arm quartzites	Lenticular zones of clean quartzites with occasional conglomerates.
Undivided shales	Black, red, green, and grey shales interbedded with all members.

In the following pages a more or less typical section through the Humber Arm group will be described and this will be followed by a description of the lithology and relationships of each formation or important rock sequence.

The Humber Arm group in Penguin Arm and North Arm.

The most important and best exposed section of the Humber Arm group in the thesis area is found partly along the south shore of Penguin Arm near Penguin Harbour and partly along the seashore between the head of Penguin Arm and North Arm.

On the south shore of Penguin Arm, the Raglan Head member is stratigraphically overlain by dark, almost black, shales which contain large lenses and irregularly shaped blocks of sandstone and sandstone-pebble-conglomerate.

Toward the northeast, at the head of the Arm, and along the northwest shore, are almost white quartzites herein called the Penguin Arm quartzites, which contain scattered conglomerate lenses. The quartzite bodies are somewhat lenticular in shape and, with the exception of local disturbances, dip steeply northwestwards. These quartzites are notably clean and are composed of over 70 per cent quartz grains, usually fused together. The matrix, under the microscope, is seen to be composed chiefly of very fine quartz grains and a little sericite.

Stratigraphically overlying the quartzites are large masses of roughly stratified limestone breccias, which are composed of dark bluish grey and brown shaly sub-rectangular limestone fragments. These fragments appear to represent the breaking up and redeposition of thinly bedded limestones. Partly in the same stratigraphic position, but mainly above the limestone breccias, are thin bedded limestones similar in composition to those constituting the breccia fragments. The thinly bedded limestones are, in turn, overlain by more breccia. All these carbonate rocks will be discussed under the name the Penguin Arm Limestone formation.

Again, higher in the stratigraphic sequence, the breccias are overlain by highly contorted grey and green shales which contain irregularly spaced sandstone, greywacke, and limestone beds toward the top. These sandstones become successively more massively bedded and are the dominant rock type for several hundreds of feet. Because of its persistence areally, this arenaceous sequence is herein called the "Western Sandstone formation." This formation contains, in addition, grey and red shales, and intercalated volcanic rocks.

Overlying the Western Sandstone formation are approximately 1000 feet of pillowed basalts and andesites, massive andesites, agglomerates and some rhyolite breccias farther to the west.

Missing from the above section is a sequence of red and green shales and a thin sequence of volcanic flows, all of which lie stratigraphically between the black shales of Penguin Cove and the lowermost quartzites. These rocks are found along the seashore between Barachois Brook and Long Point in Middle Arm (see below). Other exposures of similar rocks are found from place to place in the bed of Penguin Arm Brook.

Basal relationships of the Humber Arm group to the Raglan Head member and Table Head carbonate rocks.

The nature of the contact between the Humber Arm group and the underlying carbonate rocks varies from place to place. Many outcrops in or near the contact show evidence for faulting. However, these faults often occur away from the contact and well within the Humber Arm rocks themselves.

In the Hughes Brook locality, south of the Gillam's Break, the carbonate rocks are represented at the contact by limestones similar to those of the Raglan Head member. Immediately above these rocks are thinly interbedded limestones, mudstones, and irregularly spaced sequences of brown limy shales. The limestones, for the most part, form thin lenses, one or two inches thick and up to 8 feet long in section.

The interbedded limestones, mudstones, and limy shales give rise by a gradational change, over approximately 100 stratigraphic feet, to grey and black shales containing numerous pyrite nodules. This contact zone has been traced for over 2 miles to the southwest. However, here the lowermost shales are interbedded with quartzite lenses, many of which have been broken up into subrounded tabular blocks. No beds are exposed immediately above these calcareous shales in the Hughes Brook locality. However, dark slaty shales, which dip steeply westwards, are exposed several hundreds of feet west of the contact zone and appear to represent stratigraphically higher beds. Similar beds are found at an equal distance above the presumed position of the contact on the south shore of the Humber River near Humbermouth, which, more or less, indicates that their stratigraphic position is within one or two hundred feet of the contact with the Table Head, or Raglan Head, carbonate rocks.

Dark shales interbedded with thin sandstone lenses are also exposed along the shore south of Long Point in Middle Arm and contain dolomite fragments which vary from walnut size to book size. These fragments are partly laminated and notably similar in appearance to some of those in the lower beds of the group exposed in Penguin Arm. With the exception of the dolomite fragments, these beds resemble those stratigraphically above the contact between the carbonate groups and the Humber Arm group in the Hughes Brook area.

Southwards of the shales, exposed near Long Point, is a 75 foot thick sequence of basaltic volcanic flows. The lowermost flows are essentially massive, notably vesicular, and have numerous flow top breccia fragments varying from a few centimeters to several inches in diameter. Scoriaceous looking patches occur from place to place.

The uppermost flows are composed of basaltic pillows which vary from less than a foot to 2 feet in length and have a little hematite staining around their selvedges. For the most part, the pillows have been moved about too much by structural deformation to provide accurate top and bottom criteria.

Although this volcanic sequence is less than 80 feet thick, it is persistent for several miles and, within its limits, provides a good marker horizon traceable along strike almost to the headwaters of Wolf Brook.

Stratigraphically above and southwards of the volcanic flows are interbedded red and grey shales, becoming predominantly grey and somewhat darker southwards. These shales, in turn, are overlain by almost white quartzites, similar to those found on the northwest shore of Penguin Arm.

Quartzites similar to those exposed along the shore outcrop upstream in Barachois Brook. Here, the dark grey shales are better exposed and are found interbedded with the lower quartzite members, as are those found at the base of the quartzites in Penguin Arm.

The section between Long Point and the mouth of Barachois Brook has many features which indicate that its stratigraphic position lies between the lowermost Humber Arm sediments and the quartzites, or their stratigraphic equivalents, which are partly exposed along the northwest shore of Penguin Arm.

Lithologically, the contact zones between the Humber Arm group and the Raglan Head member near Long Point and in Penguin Arm are quite similar and both of these zones are much like the contact zone where observed in the Hughes Brook Valley. However, shortly above the contact zone in Penguin Arm and near Barachois Brook are thin to thickly bedded sandstones and sandstone-pebble-conglomerates which were not observed in the Hughes Brook locality.

These sandstones and sandstone-pebble-conglomerates are much different from the "clean" quartzites which lie along the northwest shore of Penguin Arm. Generally, they weather grey to dark grey and show the effects of slumping so that broken off isolated portions of beds up to 6 feet long and 1 foot thick are found in the shales, usually near the larger sandstone masses. Much of the separation is directly attributable to post-consolidation tectonics. However, in many places, the sandstones have kidney-shaped bedding surfaces which represent portions of sandstone beds which evidently slumped prior to consolidation. The fracturing and shearing of later tectonic movement tends to cut across the "slump" features.

In thin section, these rocks are seen to contain two main types of sandstone or quartzite pebbles: one coarse-grained with highly altered and somewhat corroded borders so that they look like clusters of grains, the other, finer-grained showing little corrosion around their borders and thereby more easily defined. The pebbles are quite similar in appearance to the fine-grained quartzites and coarser clastic rocks of the Mount Musgrave formation which are exposed near Old Man's Pond.

Both the matrix of the conglomerate and of the grained pebbles are highly sericitized. The finer-grained quartzite pebbles, however, have closer packed grains and less sericite. The interstitial material of the conglomerate consists mainly of fine quartz grains,(less than 0.02 mm. in diameter) sericite and chlorite. Scattered throughout are isolated quartz grains up to 2.5 mm. in diameter, lesser amounts of microcline, orthoclase, perthite and plagioclase and (still rarer) leucoxene and zircon grains.

The feldspar and quartz grains in both the interstitial material and in the conglomerate pebbles are in places carbonatized. In some of the quartz grains carbonatization appears to have originated near the centre of the grain and worked outwards leaving a halo of quartz around the calcite. The pebbles in the sandstone conglomerates are too small to provide accurate modal analysis. However, their great resemblance to the eastern clastic rocks is noteworthy.

The stratigraphic thickness between the Humber Arm-Raglan Head contact and the Penguin Arm quartzite is estimated at 1100 feet and that of the section between Hughes Brook and Summerside at 1000 feet. However, a higher proportion of quartzite beds is found below the main quartzite sequence in the Summerside locality.

The Penguin Arm quartzites.

These have been briefly referred to in the description of the Penguin Arm section. As with the carbonate rocks underlying the Humber Arm group, much information concerning the quartzites must be obtained outside the thesis area. Excellent exposures of quartzites stratigraphically equivalent to those of Penguin Arm are found along the shoreline between

Irishtown and Summerside in Humber Arm.

In both localities the quartzites are fine to coarse-grained, thin to thickly bedded and weather light brown to almost white in colour. They are generally clean and composed chiefly of well sorted, rounded quartz grains with lesser amounts of potash and soda feldspar grains.

In the Summerside locality, the quartzites are commonly interbedded with green, red and dark grey shales. Conglomerate lenses with cobbles up to 1 foot in diameter were observed near the village of Penguin Arm. Pebble conglomerate lenses were commonly noted in the Summerside locality.

Where the quartzites are regularly bedded, the grain sizes of their constituents vary between approximately 0.1 mm. and 2.5 mm.

Ripple marks and current bedding were noted more frequently in the exposures near Summerside than in those of Penguin Arm. However, in Penguin Arm, the beds are more steeply dipping and bedding surfaces are less exposed.

Drying cracks were observed in both localities. Just east of Summerside, shallow depressions were observed on bed surfaces which are filled with small pebbles and tabular limestone fragments. These depressions, which are from 1 to 2 feet in width, often have smooth bottoms showing little, if any, imprint of the pebbles and suggesting that at least some drying or consolidation of the beds had taken place prior to the washing in of the pebbles. The tabular limestone fragments are usually 1to6 inches in length and resemble the limestones of the Humber Arm rather than those of the St.George group.

A short distance east of Irishtown, the quartzite sequences tend to become more widely spaced and give way stratigraphically downwards to greater thicknesses of shale. The shales are in turn followed downwards by a few fairly thin sequences of quartzite near the mouth of Hughes Brook. One of these sequences contains large blocks of limestone with twig-like algal pseudomorphs which are similar to the limestones of the St.George group.

The average composition obtained by modal analysis of 10 thin sections of the Penguin Arm quartzites in which grain sizes averaged between 0.3 mm. and 2.5 mm. are as follows: quartz grains 77 per cent; potash feldspar 2.4 per cent; plagioclase (mainly soda feldspar) 2.4 per cent; leucoxene, zircon, sphene, biotite, chlorite, calcite, in varying proportions 3.2 per cent; groundmass (sericitic and, or, with quartz grains less than 0.2 mm. in diameter) 15 per cent. (For a graph showing the composition of the Penguin Arm quartzites, see Fig. 8A).

The Penguin Arm limestone formation.

This formation consists of alternating thinly interbedded dark brown calcareous shale and dark grey limestone, the beds varying from 10 mm. to 25 mm. in thickness. Its type locality for this thesis is a short distance west of Penguin Arm village.

In this formation limestone breccias and thin bedded limestones can be distinguished.

The composition of the breccias is identical to that of the thin bedded limestones. The breccia fragments are tabular in shape and from less than 1 inch to 8 inches in length but fragments comprising several thin beds and up to 2 feet in length are occasionally found. Evidently, because the limestones are more resistant to decomposition than the calcareous shales, limestone fragments constitute by far the greater proportion of the breccias. Most of the breccia fragments are oriented parallel to adjacent bedding planes, though small zones are found with limestone fragments standing on end or at an angle to the bedding. En masse, the breccias form easily discernible beds up to 4 feet thick which are separated by calcareous shaly material, similar in appearance to that found in the thinly interbedded limestones. The limestone fragments in the breccias are only slightly rounded and most certainly have not been transported far from their source.

It is noteworthy that the breccias appear to lie stratigraphically above and below the thinly bedded limestones and are persistent along strike (through intermittent outcrops) for several miles. However, in some localities the breccias were seen to transgress the thin bedded limestones and it is likely that the brecciation of the limestones was erratic from place to place.

The limestone and limestone breccias of the Penguin Arm section have been either eroded from the Summerside locality or were not deposited there. However, south of Humber Arm, these limestones and limestone breccias, or their equivalents, are exposed near Benoit Cove and southwards. It is, therefore, likely that they have been eroded from the Summerside locality.

McKillop (1961) has mapped additional areas of limestone breccia in the area south of Corner Brook, near Bells Brook. However, these breccias have features more like the Cow Head type and contain fragments of St.George and Cambrian rocks in addition to those belonging to the Humber Arm group.

The Western Sandstone Formation.

The Penguin Arm limestones and limestone breccias are overlain by a thick sequence of dark grey to almost black shales and mudstones which give rise to alternating sequences of grey and green shales with occasional, somewhat widely spaced limestone and sandstone beds. Above the shale are thin to thickly bedded cliff forming sandstones which, opposite Brakes Cove in Middle Arm, form an uninterrupted sequence of beds 150 feet thick. Above these beds are other sequences of sandstone beds which are separated by dark grey shales and silty brownish grey shales. In North Arm, the sandstones are interbedded with dark grey shales and dark green pillowed volcanic flows. These sandstones and shales, inclusive of the volcanic flows, are herein called the Western Sandstone formation.

Generally, this formation may be taken as lying between the lowermost thick sequence of sandstone beds and the main body of the Humber Arm volcanic rocks.

The sandstones of this formation are much different from the Penguin Arm quartzites both in composition and texture in that they have a higher proportion of groundmass, more detrital rock fragments, and less rounded quartz grains than the Penguin Arm quartzites, which are more or less homogeneous. However, the "Western" sandstones have individual beds which show great deviation from what may be considered normal for the formation as a whole.

A modal analysis of a thin section made from a specimen from the lowermost beds of the formation provided the following: quartz grains up to 1.1 mm. in diameter, 24 per cent; shale fragments 9 per cent; basic volcanic rock fragments 3.0 per cent; potash feldspar 2 per cent; soda feldspar 3 per cent; chlorite 1 per cent; iron oxides 1 per cent; groundmass, in part sericitic, 57 per cent.

Averages of modal analyses of three other thin sections from a little above the previously described bed are as follows: quartz grains up to 1.5 mm. in diameter 61.6 per cent; shale fragments 13.6 per cent; soda feldspar 4.3 per cent; potash feldspar 6.0 per cent; limestone fragment 2.33 per cent; calcite 0.66 per cent; chert fragments 0.66 per cent; tourmaline 0.33 per cent; chlorite 0.33 per cent; groundmass 8 per cent.*

The Western Sandstone formation is widely distributed for, as well as in the thesis area, it outcrops intermittently along the eastern flank of the whole of the Bay of Islands Igneous Complex. Generally, however, it appears to contain less detrital shale and other rock fragments than it does in the Middle Arm locality, but variations in composition and texture are common throughout and more detailed examinations would be required to determine its regional character.

Along the eastern flank of the Table Mountain of Bonne Bay, between Sellers Brook and Trout River Pond, the sandstones of this formation weather light brown and, in part, are highly micaceous and not as well indurated as those of Middle Arm.

Arkosic and subgreywacke conglomerates are found in the headwaters of Sellers Brook and in Crouchers Gulch. In Crouchers Gulch, sandstone-pebble-conglomerates were observed which contained nothing but well rounded quartzite pebbles in a fine silty groundmass. These quartzite pebbles are singularly interesting in that they are unlike any known source rock except some facies of the Bradore formation of the

* For graph showing composition, see Fig. 8A.

Labrador group.

West of Blow-me-down Mountain, near the Bowaters woods road to Serpentine Lake, the sandstones of this formation are almost green in colour and display excellent graded bedding. North of the road are tuffaceous sandstone beds which are locally interbedded with reddish shales.

Micaceous sandstones, somewhat similar to those of the Bonne Bay locality, were noted by the writer in the southern headwaters of Fox Island River south of the Lewis Hills.

The Humber Arm Volcanic Rocks.

With the exception of a few outcrops located along the shore of North Arm, these rocks lie almost entirely outside the main thesis area. However, because they represent an important phase during the deposition of the Humber Arm group, they are briefly described and discussed here.

The main sequence of "extrusive rocks" may be taken as the stratigraphically highest "layered" rocks in the whole area. These rocks are found on the north and west flanks of the Table Mountain of Bonne Bay, west of North Arm Mountain on the Gregory Plateau and in the stream valleys of Crabbe Brook and the Gregory River. South of the Bay of Islands they occur partially east of the igneous massifs of Blow-me-down Mountain and the Lewis Hills but their greater proportion lies on or near the western flanks of these features. The extrusive rocks and their associations are strikingly similar throughout the whole of the Bay of Islands Igneous Complex.

The extrusive rocks consist primarily of intermediate to basic pillowed lavas, some ropy lavas, massive flows, flow breccias, pyroclastics and, in some places, water-worked ash beds. Some of the pillowed lavas and associated pyroclastics contain rounded sandstone pebbles. To a lesser extent are found rhyolite flows, rhyolitic pyroclastics and flow breccias, which are generally younger than the intermediate to basic extrusive rocks.

Toward the base of the extrusive assemblage, pillowed flows and pyroclastics are intercalated with red, green and dark grey shales of the Western Sandstone formation.

The upper and lower contacts of the intrusive masses warrant attention because of their metamorphic aureoles.

The contact between the ultrabasic rocks, peridotite and dunite, and the Humber Arm rocks is marked by a distinct but relatively narrow metamorphic aureole varying in composition from a well-baked quartzite, where the sandstones lie in contact with the peridotite, to a slightly garnetiferous amphibolite gneiss. The exact nature of the contact-rock from which the amphibolite gneiss is derived is in doubt, but nearby are usually found basic extrusive rocks, shales and intercalated sandstones. Some diopside is commonly present near the contact, the chief mafic minerals, however, are hornblende and actinolite. The garnets appear to be almandite, though near the contact in one locality the magnesian garnet, pyrope, seemed to be present. The fact that the grade of metemorphism decreases away from the contact suggests that the aureole belongs to the ultrabasic rocks.

In contrast to the thin contact aureole of the peridotites, the upper contact between the gabbro (bytownite gabbro in part) and the basic flows is marked by the fairly widespread development of granulite amphibolite, often retaining crude outlines of pillows and volcanic breccias. Stoping is a common feature near the gabbro contact.

The contact aureole between the ultrabasic rocks and the Western Sandstone formation is faulted off along the line of the Trout River Fault so that the extension of the metamorphosed zone is found approximately 6 miles to the northeast near the Head of Trout River Lake.

CHAPTER 6

SUMMARY AND CONCLUSIONS
(Based on lithology and stratigraphy)

This chapter is concerned with those lithologic and stratigraphic features of the previously described rocks which the writer considers to be diagnostic of the environment in which they were deposited and also what may be inferred from these features regarding their sources of supply and to what extent they reflect orogeny.

There is considerable evidence to suggest that the Mount Musgrave formation represents the lower part of the Labrador group, but further studies are needed to confirm this assumption. Moreover, it is apparent that these rocks strongly resemble those occurring southwards in the Long Range and that, irrespective of the degree of metamorphism shown from place to place, they are one and the same formation. Because of their widespread occurrence it is most important that their relationship to the Labrador group be proven, or disproven, for if these rocks are part of the Labrador group, a firm base is provided for the study of the rocks of Central Newfoundland.

The Penguin Cove formation has many features similar to those of the Forteau formation of the Labrador group, including the ubiquitous "button" algae which occur at or near the top of both. The formation was not recognized with certainty in the eastern part of the thesis area and where lithologically similar beds are found, such as in Falls Brook, they are not slumped. However, in other localities, such as north of Wiltondale and near Bonne Bay Big Pond where the Penguin Cove formation is easily recognized, some outcrops also show little evidence of slumping. It is, therefore, likely that slumping was not widespread throughout the formation but rather followed; 1) the foresetting of a delta, on which slumping occurred from time to time, 2) the line of a slight uplift or 3) the flank of a basin which developed during Forteau? and, or, Penguin Cove time. The presence of well sorted silt-grade quartzites and the lack of a conglomerate facies indicate that the source of the clastic material of the Penguin Cove formation was either far removed from its site of deposition, or that the profile of the attendant river courses was gentle and incapable of providing the forces necessary to move relatively large pebbles or grains. Tending to support this concept is the widespread occurrence of oolites in the upper beds of the formation, which suggest large expanses of very shallow waters over the site of deposition.

It is likely that the supply of clastic material for the Mount Musgrave and Penguin Cove formations came from the west as it did for the Labrador group (Schuchert and Dunbar 1934). Moreover, in view of the westerly onlap of the Reluctant Head formation over the Penguin Cove formation, it also received a great part of its clastic material from the same direction. Further, because of the thicknesses of shale in the lower part of the St.George group, where it overlies the Penguin Cove formation, there seems to be little doubt that these beds,which occupy the western flank of the thesis area, also received their clastic material from a westerly source and continued to do so during the greater part of the time during which the Hughes Brook formation was deposited.

On the basis of the above, it would be safe to conclude that after the filling in of a relatively narrow basin by the Reluctant Head formation, the St.George group commenced to encroach upon the Penguin

Cove flank of this basin and thenceforth continued to grow westwards as in a gradually deepening and widening basin with its surface of deposition never far from sea level and, if the abundance of drying cracks on the surface of the dolomite beds are considered, repeatedly exposed to the sun. At approximately the time the upper member of the Corner Brook formation was deposited, there commenced a period of orogeny, marked by the sliding of large blocks of dolomite into unconsolidated calcareous muds of the late St.George and, to a lesser extent, early Table Head sediments in the Goose Arm-Hughes Brook area, and by an erosional surface in the Port au Port area. After this period of orogeny commenced, the source of clastic material was from the east and, subsequently, this eastern "hinterland" supplied the clastic material for the upper part of the Table Head and practically the whole of the Humber Arm group.

The early Humber Arm rocks contain pebbles which were evidently derived from the Mount Musgrave formation, indicating that erosion had either cut deeply into the St.George group and exposed the Mount Musgrave formation, or that it was uplifted in such a manner that its strata were subjected to erosion. It is also evident that some erosion had started in the Goose Arm area prior to the deposition of the Table Head group cutting rather deep troughs or trenches. The fact that much of the Corner Brook formation is missing from the locality a short distance south of the Penguin Hills and that the Table Head group there is deposited directly upon the Hughes Brook formation supports this view.

The graptolite-bearing shales of the Table Head group were not recognized as such in the Goose Arm-Hughes Brook area. Even if the shales were graptolitic at one time, it is hardly likely that such a fauna would be found in the beds of this area, because of their great deformation. Moreover, in the same approximate stratigraphic position of these shales, in the Goose Arm-Hughes Brook locality, are sandstone-conglomerates and coarsely arenaceous shales, which seem to belong to the Humber Arm type of sedimentation rather than that of the Table Head group. Because of these differences, those clastic rocks which overlie the Raglan Head member are allocated to the Humber Arm group.

The unconformity between the Table Head group, including the Raglan Head member, and the Humber Arm group marks an abrupt change from what may be termed a tidal-flat or lagoonal type of environment to an essentially deltaic environment, for the change from carbonate rocks to shale, and shortly after to very coarse material, was accomplished quickly and distinguished by large limestone fragments from the St.George group and then followed the deposition of sandstone conglomerates containing pebbles derived, in all probability, from the Mount Musgrave formation. If the Mount Musgrave formation lay in the same approximate relationship to the Humber Arm group, as it does at the present time, it must have been either rapidly uplifted to provide a mountain chain, or erosion was extremely rapid. The occurrence of large slide breccias indicates that some degree of uplift must have taken place and, because of their presence in the early Table Head sediments, this uplift must have started well before the Humber Arm sediments were deposited. An attempt will be made later to show that erosion was well advanced before the rocks of the area were tightly folded.*

* See the description of the Shellbird Island Syncline in the chapter on Structural Geology.

The Cow Head breccias, near the gravels of Port au Port, have evidently slid over both Table Head and Humber Arm shales and contain fragments derived from the St.George group and possibly even the Humber Arm group. It is suggested that the breccias of the Port au Port and Goose Arm-Hughes Brook area are all related to the same stage of one orogeny.

The character of the Humber Arm sedimentary rocks reflects the development of a large delta system which obtained its supply of clastic material from at least two main sources. One of these sources, composed at least in part of the Mount Musgrave formation, provided much of the early material of the Humber Arm group and possibly a considerable proportion of the later quartzites. The other source, not in evidence until the delta system had considerably grown, provided the material for the Western Sandstone formation, including fragments of volcanic rocks and quartz and feldspar grains.

The earlier sediments and those of the Western Sandstone formation probably reflect different phases of orogeny. The earlier sediments consisting of shales, arkosic sandstones, greywackes and pebble-conglomerates, including large blocks of limestone from the St.George group, indicate an orogeny which began during, or slightly prior to, Table Head time. The sediments of the Western Sandstone formation suggest a second orogenic phase associated with volcanism but also with the exposure of a source of arkosic sediments.

The depositional environments of the earlier Humber Arm sediments have many features which are similar to those of the Western Sandstone formation with the important exception that the earlier sediments contain the large "landslide blocks" which indicate to some extent a cliffed shore environment, a concept which is supported by the fact that these blocks slid or fell into sediments deposited near the surface. The earlier environment may be considered as a complicated one, the later one as more or less straightforward.

Any attempt to determine the character of the early Humber Arm environment must account for the following factors: 1) the almost simultaneous deposition of black shale in one locality and coarse, poorly sorted material in another;2) the rapid deposition of greywackes and their protection from currents capable of winnowing them;3) the presence of almost pure sandstones interbedded with shales and greywackes; 4) the inclusion of large subangular to angular blocks of St.George limestone in both the shales and sandstones; 5) the presence of both drying-cracks and current bedding in the sandstones.

Taken together, these factors indicate a predominantly slow rate of supply of the fine clastic material of the shales, which was interrupted from time to time by the flooding-in of coarser material such as are contained in the pebble conglomerates and greywackes, from a nearby source. In some localities at certain times, the predominating greywacke type of sediments was subjected to wave action which had the effect of both sorting the grains and winnowing out a high proportion of fine-grained material and, or, detritus from the carbonate rocks of the St.George group.

After the initial stages of development, the delta system took on a more characteristic aspect. Channels were eroded out and into these cobble conglomerates were deposited, in other localities the topset beds were well preserved, for numerous drying-cracks are found in nearly any of the larger quartzite sequences. Some beds show evidence for both erosion and consolidation during intervening periods, after which sedimentation recommenced.

Generally, the whole aspect of the Humber Arm sediments suggests that near-surface conditions prevailed for most of its development and, if so, therefore because the thickness of the Humber Arm sedimentary rocks is over 6000 feet, and therefore the basin of deposition must have subsided ~~as~~ by that ~~much~~ amount. It is possible that the orogenic phase suggested by both the sediments of the Western Sandstone formation resulted from the disrupting force of this great thickness of sedimentary rock.

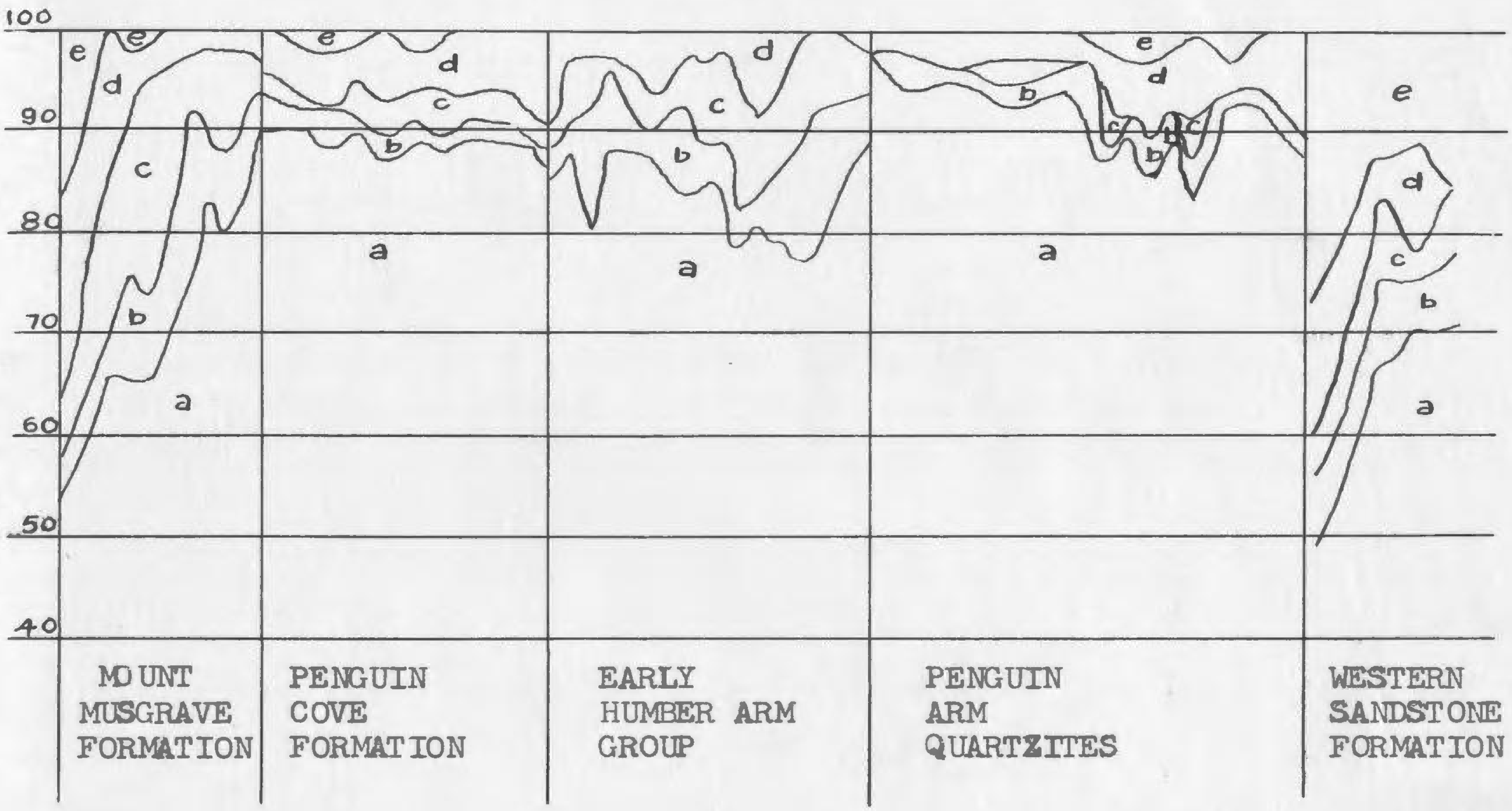
Between the deposition of the Mount Musgrave formation and the final stage of Humber Arm sedimentation, a number of paleogeographic changes occurred and these are reflected in the type of sediments deposited. The graph on page 83 shows the results of the modal analysis of thin sections from each of the main clastic divisions. Inasmuch as was possible the results are represented in stratigraphic order, the left side of the graph representing the bottom and the right side, the top.

Fig. 8A

MODAL ANALYSIS OF THIN SECTIONS

OF THE ARENACEOUS ROCKS SHOWING THE PROPORTIONS OF THE CHIEF COMPONENTS

Proportions by percentages in stratigraphical order from bottom to top. Approximate thicknesses over which specimens were collected are indicated in feet for each formation or sequence.



Bottom. Top

LEGEND

Percentages of minerals or rock fragments

a, Quartz grains

b, Potash feldspar grains

c, Plagioclase feldspar grains

d, Aggregate of heavy minerals and mafic minerals, some rock fragments

e, Rock fragments

All points plotted for grains of over 0.1 mm.

* Last 5 specimens collected within approximately 50 feet of each other and in no particular order.

CHAPTER 7

STRUCTURAL GEOLOGY

An attempt is made in this chapter to describe the essential structural features observed in the thesis area and, to some extent, outside. Toward the end of the chapter the history of the development of these structures is tentatively outlined.

The following should be read in conjunction with a study of the map and sections. The features 1 to 6 are structural elements in the belt of carbonate rocks and will be described in order from northwest to southeast. Features 7 and 8 refer to structures near and in the area occupied by the Humber group. Features 9 and 10 are of a linear nature:

1. The Goose Arm Arch, which includes the Window Pond anticline, Penguin Cove anticline and Goose Arm syncline.
2. Old Man's Pond syncline and thrust.
3. Penguin Hills klippe and overthrust.
4. Wild Cove Valley anticline.
5. High Knob syncline.
6. Shellbird Island syncline and related anticlines.
7. The North Arm and Middle Arm structures.
8. The North Mountain intrusive wedge.
9. Gillam's Transverse Fault and lineament.
10. The Lomond shearing.

Some other structural features are recognized but the examination of those listed above will provide a fairly adequate picture of the overall structure.

The Goose Arm Arch.

This name is given to the general structure between Old Man's Pond and Penguin Arm. The structural trend of the arch is northeast and southwest. Along the southeast limb of the arch are interbedded limestones and dolomites of the St.George group which, in part, are overlain by rocks belonging to the Penguin Hills "Overthrust." The northwest limb is composed mainly of rocks of the Raglan Head member. Older rocks of the St.George group are uplifted toward the axis of the arch. Superimposed upon the overall structure are the anticlines of Penguin Cove and Window Pond, and the Goose Arm syncline. The entire arch appears to plunge under the Humber Arm group to the southwest.

The Window Pond anticline.

The core of this anticline is composed mainly of highly deformed shales and slates, in part with well developed axial plane cleavage. These sediments were first believed to belong to the Humber Arm group but, upon further investigation, were allocated partly to the basal beds of the Penguin Cove formation and partly to the argillaceous member of the Mount Musgrave formation.

These shales are overlain on both limbs by a thin sequence of interbedded limestones and dolomites which, in turn, give rise stratigraphically upwards to the "button" algae beds which occur toward the top of the Penguin Cove formation. These beds were used to determine the structure of the anticline.

The northwest limb of the Window Pond anticline is overturned and dips between 70° and 80° southeast, the southeast limb between 25° and 40°, and together, these attitudes indicate the asymmetry of the structure. Northeast along the axis of the anticline, towards the head of Goose Arm, the Penguin Cove formation plunges under the St.George group. Northwest of the overturned limb, the interbedded limestones and dolomites of the Raglan Head member have been squeezed outwards from the west flank of the anticline. East of Old Man's Pond Brook, along the line of Window Pond, the clastic rocks of the Penguin Cove formation have been squeezed upwards and much of the limestone has been thinned out so that, in places, only a relatively thin veneer is left to mark their original stratigraphic position below the St. Georges dolomite. Also, along the northwest limb, the overturned beds are marked by numerous small faults which strike in a NNE direction and at an angle of about 25° to the axis of the anticline. The less competent shales have been partly squeezed into these faults so that in places the shales have been brought into contact with the lowermost dolomites of the St. George group.

The Goose Arm syncline.

No exposures of the Penguin Cove formation are found between those of Old Man's Pond Brook and Penguin Cove. However, small outcrops of the Hughes Brook formation are found toward the base of Raglan Head, indicating that the dolomite passes under the waters of Goose Arm. It is unlikely that Goose Arm represents a fault of any great displacement. The sediments on both sides of the arm are similar and of approximately the same stratigraphic position.

The Penguin Cove anticline.

The structure of this feature is less complex than that of the Window Pond anticline. As in the latter structure, the Penguin Cove formation appears in the core, but with only the upper members of the formation exposed in Penguin Harbour Brook.

Along the axis, and toward the core of the anticline, axial plane cleavage and minor faulting has developed. The faults are reflected to some extent in the overlying dolomites of the St.George group but show less displacement. The maximum observed displacement occurs on the northwest side of the White Face cliff, where the dolomites are upfaulted for 86 feet on the northwest side.

The crest of the anticline, which is largely represented by more gently folded thickly bedded dolomite, is cut by numerous small faults. Into these faults, approximately along the axis of the anticline, have been squeezed small portions of the uppermost beds of the Penguin Cove formation. Such a feature is indicated along the crest by small exposures of highly disturbed oolitic limestone and shaly dolomite which have been "poked" up through almost undisturbed dolomite beds.

The uppermost beds of the St.George group have been eroded from the southeast limb of the anticline whilst nearly the whole of the St.George group and the Raglan Head member are exposed on the northwest limb. For the most part, the dip of the beds is fairly regular throughout the section. However, on Penguin Head, the Raglan Head member and the underlying St.George rocks are highly contorted and broken by several northwesterly dipping faults.

These faults divide Penguin Head into three parts, the two westerly portions representing small fault slices. An examination of these "slices" indicated that movement occurred in succession from the southeast to northwest. This faulting was evidently followed by later movement in which the southwest side moved upwards and toward the southeast. Here, we have apparently ambiguous criteria for determining the direction of movement, i.e. indications of a northwesterly movement on the basis of folded beds, the other, a southeasterly high angle movement on the basis of slickensides and dragfolding. It is the opinion of the writer that both sets of criteria are acceptable inasmuch that some movement of the fault slices post-dated the main phase of fold activity.

An explanation is offered for the high degree of contortion of the ~~Penguin~~ Raglan Head rocks on both Penguin Head and a short distance east of Long Point. An examination of the accompanying geological map (Plate I) will show that east of Long Point the axis of the Penguin Cove anticline swings toward the south. It is probable that the high degree of contortion in the rocks of Penguin Head represents a "tightening" up of structures around the nose of the curving anticline.

These structures may be taken as the result of the change from the rather homoclinal structure of the Hughes Brook Valley to the south to a combination of thrusting, folding and faulting in the Goose Arm area to the north. Further, it may be seen that the logical extension of the homoclinal structure of Hughes Brook is disrupted by the uplifting of the eastern clastic rocks and the uplifting and northwestward thrusting of the Reluctant Head formation.

<u>Old Man's Pond syncline and thrust.</u>

A partial effect of the overall uplift in this locality has been the development of a syncline approximately along the line of the Falls Brook and another between the southeastward extension of Frenchman's Pond and Old Man's Pond.

The southeast limb of the syncline at the Falls Brook is composed largely of steeply west to northwesterly dipping beds of the Mount Musgrave formation which have been disrupted by faulting along the line of the Narrows. The vertical displacement along this fault is about 600 feet, where estimated at the Narrows, and has resulted from the rocks on the northeast side having been lifted into a higher and more steeply westerly dipping attitude than those on the south side. Southwest of the Narrows, the shaly limestones and lower members of the Reluctant Head formation, which are much less competent than the rocks of the Mount Musgrave formation, do not reflect this displacement to the same extent but are dragfolded and warped in such a manner as to conform to the break in the clastic rocks without complete disruption to themselves.

Erosion has cut relatively deeper in the trough of the Falls Brook syncline on the north side of Old Man's Pond than on the south side. The trough beds exposed on the north side consist, for the most part, of the lower members of the Reluctant Head formation, whilst those on the other side consist of beds of the middle to upper part of the formation and, upon some of the higher hills south of the Pond, lower St.George dolomites.

The clastic rocks of the Mount Musgrave formation southwest of the Narrows of Old Man's Pond and the limestones of the Reluctant Head formation have similar northwesterly dipping attitudes on both sides of their contact zone. However, farther to the southwest, the attitude of the Reluctant Head formation changes to dip between 20° and 25° south.

It is noteworthy that from a point a short distance east of the island in Old Man's Pond, the beds dip almost continuously between 20° and 35° southwards along the east side of the Hughes Brook Valley for nearly two miles and only near the contact between the clastic rocks and the limestones do the beds appear to dip northwest.

A second syncline is found between the southeast extension of Frenchman's Pond and the west end of Old Man's Pond. The northwest limb of this structure is composed of carbonate rocks of the Reluctant Head formation which have been partly thrusted over the carbonate rocks of the St.George group, the latter forming the southwest extension of the Window Pond anticline. The southeast limb of the syncline is composed of tightly folded rocks of the Reluctant Head formation which give way stratigraphically upwards to the southeast to the dolomites of the St.George group. In the trough of the syncline, at the western end of Old Man's Pond, are small scattered outcrops of the lower St.George dolomites.

The Penguin Hills Klippe and Overthrust. (See Plate 4, section F).

The Penguin Hills on the southeast side of Penguin Arm consist of northwesterly dipping, thinly bedded limestones of the Reluctant Head formation, which are overlain by dolomites of the lower St.George group. Both the limestones and dolomites overlie sandstones and shales of the Humber Arm group which dip steeply in the same direction.

The present position of the limestones and dolomites was first attributed to a nearly vertical uplift. However, an examination of the shales and sandstones around the base of the limestone, disclosed the presence of a thrust plane, dipping from 15° to 20° to the northwest, between the shales and carbonate rocks. Further examination showed that in places the thinly bedded limestones had been partly overthrusted by the more competent dolomite beds and, in part, provided gliding surfaces over which the dolomites had moved.

The nearest possible source for the overthrust limestones and dolomites was at first considered to be the crest of the Penguin Cove anticline, now located approximately 1.5 miles to the southeast. This zone, however, while providing a match for the dolomites, contains no limestones similar to those found stratigraphically underlying the dolomites. The only recognizable source for the limestones of the Penguin Hills feature, known at present, is found near Reluctant Head in the Old Man's Pond locality. The minimum overthrusted distance in such a case would be approximately 7 miles. However, if the Penguin Hills feature is part of the Old Man's Pond thrust and not a simple "slide", such as some of the larger fragments of the Cow Head Breccia, it becomes necessary to invoke a massive overthrust sheet with its possible source even "tens of miles" to the eastward. In addition to the possibility of the Penguin Hills being a klippe, it is interesting to note the distribution of the nearby St.George and Raglan Head rocks.

It will be seen from the geological map that much of the Corner Brook formation, or its equivalent, is missing from the locality immediately southeast of the Penguin Hills and that the early rocks of the Humber Arm group are separated from the dolomites of the Hughes Brook formation by a relatively thin sequence of beds belonging to the Raglan Head formation. Needless to say, the Raglan Head rocks could only have been deposited upon the Hughes Brook formation because, at the time of their deposition, the limestones were eroded off. These limestones are present only a short distance southwest of the klippe and are again present shortly northeast.

It is the writer's opinion that the present rock distribution reflects a trough or submarine canyon which was eroded out shortly prior to, and partly during, Raglan Head time, and further that the Penguin Hills Klippe slid into this trough and was thereby protected from later erosion.

The Wild Cove Valley anticline (See Plate 3, section I).

This section was first outlined by drilling in the quarry area of the North Star Cement Company, which is located south of the Humber River a short distance east of Corner Brook. In the quarry area, the crest of the anticline is marked by dolomite beds of the Hughes Brook formation of the St.George group. North of the Humber River, erosion has cut deeper into the anticlinal structure so that along the north wall of Wild Cove Valley the crest of the anticline is marked by the upper members of the Reluctant Head formation. The east limb of the anticline in this locality is composed of shaly limestones of the Reluctant Head formation, which are in fault contact with interbedded limestones and dolomites of the Corner Brook formation. In order for these two formations to have been brought into contact, the Reluctant Head formation must have been uplifted more than the thickness of the Hughes Brook formation - a distance of more than 2000 feet. However, much of the movement which has taken place between the shaly limestones of the Reluctant Head formation and the more competent dolomites and limestones involves squeezing out of the shaly limestones rather than a clean break along the fault plane. It will be seen from the geological map that the dip of the west limb of the anticline, north of Wild Cove Valley, varies between 15° and 60°. Dips, taken on outcrops of the Reluctant

Head limestone on the crest of the anticline are, for the most part, too erratic, however, to be significant except where statistical studies have been carried out. For the most part, the attitudes of beds on the crest of the anticline indicate a squeezing out of less competent limestones between relatively more competent dolomite beds - a feature similar to that described on the crest of the Penguin Cove anticline. It is possible that the apparently great displacement along this fault may be attributed to the thickening of incompetent limestones on the broken crest of the anticline and that subsequent distortion may have brought the St.George limestones and the pre-St.George limestones together.

The High Knob Syncline

This feature has been traced from shortly south of the Humber River northwards as far as the Hughes Lake Road. The most perfect exposure of the syncline is found on the cliffs north of the Ballam Bridge which crosses the Humber River near Humbermouth. Here, it is readily seen that the syncline is asymmetrical and that its axial plane dips approximately 50° to 60° southeast. The eastern limb of the syncline is formed by the transition zone between the dolomites of the Hughes Brook formation and the limestones of the Corner Brook formation, whilst the western limb lies in fault contact with the east limb of the Wild Cove Valley anticline. The trough rocks (which may be observed from the highway south of the Humber River) consist of the lower to middle members of the Corner Brook formation.

The faulting along the west limb of the syncline is of special interest as it reflects a common deformational pattern found throughout the area. Further, it has special economic implications where it extends into the North Star quarry area. North of the Humber River, it is estimated that more than 30 feet of the second 75 feet thick sequence of limestones in the Corner Brook formation have been apparently sliced off or squeezed out approximately along the plane of this fault. In the North Star quarry area, this sequence has not been located despite considerable drilling across the projected strike.

Northwards across the Wild Cove Valley, the east limb of the High Knob syncline is relatively intact. However, the west limb is almost completely sheared off against the dolomites and, or, limestones of the east limb of the Wild Cove Valley anticline.

The Shellbird Island syncline and related anticlines.

The axis of this syncline strikes approximately northeast and southwest and crosses the Humber River about 1000 feet southeast of Shellbird Island.

The syncline, where exposed north of the Humber River, consists almost entirely of shaly limestones of the Reluctant Head formation. The syncline here is tightly folded so that dips on both limbs, with the exception of where the beds are highly dragfolded, are nearly vertical. The effect of the tight folding is to present an almost continuous apparent thickness of over 1600 feet. However, the trough beds of the syncline, which are exposed near the top of the cliffs, consist of dolomites of the St.George group and these, as well as an analysis of the drag folds, revealed the presence of the tightly folded syncline.

South of the Humber River, the dolomites of the trough are more widespread and the shaly limestones of the Reluctant Head formation are exposed only for a short distance south of the river bank and on the limbs of the syncline. This area has been described by McKillop (1961).

North of the river the limbs of the syncline give rise to tightly folded anticlines. The northwest limb, within a very short distance, turns sharply and dips steeply under the rocks of the lower dolomite division of the St.George group. The southeast limb similarly turns to form a tightly folded anticlinal structure near the river but farther south the anticline broadens and here the limestones of the east limb of the anticline are overlain by large erosional remnants of the St.George group.

The Reluctant Head formation and the lower dolomites of the Hughes Brook formation are in fault contact east of the Shellbird Island syncline. The pattern of faulting here is quite similar to that found wherever breaks occur in anticlinal structures, and where the competent dolomites formed the crest rocks over the rather incompetent shaly limestones. The displacement along this type of fault usually takes place within the limestones and appears to be the result of "squeezing out" along bedding planes or shaly laminae. Almost invariably, a small portion of the limestones continues to adhere to the bottom of the dolomite beds.

Generally, it seems as if this type of faulting and deformation has occurred where the confining load over the limestones was either much reduced, removed altogether, or non-existent when folding took place.

If the structure of the Reluctant Head formation and the lower dolomites of the Hughes Brook formation are examined on both sides of the Humber River, it will be seen that the vertical displacement of the trough rocks of the Shellbird Island syncline must exceed several hundreds of feet. An examination of the relative positions of the crest rocks of the anticline to the east indicates a somewhat similar displacement. The trough rocks in the south end of the syncline south of the Humber River belong to the lower dolomites of the Hughes Brook formation. Here, the dolomites are more widespread than on the north side of the river and provide an apparently effective confining load. On the north side of the river only a small, steeply-dipping dolomite remnant marks the position of the synclinal trough and here the shaly limestones have been squeezed upwards around the dolomite in such a manner that in places they almost envelop it. From these observations, it is evident that the confining load on both limbs of the Shellbird Island syncline, where exposed north of the Humber River, must have been almost non-existent and, further, that the volume of dolomite in the trough could not have been great at the time of folding.

It is tentatively suggested that the Reluctant Head formation was exposed from place to place during, and possibly prior to, the later stages of folding, so that their rocks could be "extruded mechanically" through the erosional gaps. These "mechanical extrusions" were often accompanied by faulting along the walls of the confining rocks and also by the breaking away and uplifting of thin portions of the more competent crestal rocks.

The North Arm and Middle Arm structures (See Plate 3, section A).

The Western Samdstone formation contains the greatest accumulation of relatively competent beds in the generally incompetent

Humber Arm group. Underlying this formation along the north shore of Middle Arm toward the mouth, is a thick sequence of shales which are occasionally interbedded with limestones, mudstones and, more rarely, sandstones.

The attitudes of the shales underlying the sandstone formation are difficult to relate to the overlying structure, largely because of numerous drag folds, minor faults and a great degree of contortion in general. The shales immediately beneath the sandstone formation, however, for the most part, show a more or less normal sedimentary gradation upwards into the more competent beds. Further, if the attitudes of the contorted shales were intergrated, it is highly probable that the shales and sandstones were conformable. However, if the shortening of the shales, due to folding and faulting, is considered, one might accept a shortening of at least 25 per cent more than that of the sandstone.

The overall attitude of both the sandstone formation and the shales is more or less gently synclinal so that the contortion of the shales cannot be accounted for by compression such as would be found in the core of an anticline. It is, therefore, suggested that the deformation of the shales is the result of an overall westward migration of the more competent sandstone formation across the shales and that the necessary displacement was accommodated for within the shale horizon by numerous minor faults, drag folds and shears.

The North Mountain Intrusive "Wedge".

This feature is one of four large ultrabasic and basic intrusive masses which constitute the chief rocks of the Bay of Islands Igneous Complex.

The North Mountain and Table Mountain parts of the Igneous

Complex were studied by the writer in 1955 and 1956 (before he began his thesis work) and a geological map of the area, on a scale of 1 inch equals 1000 feet was prepared for the British Newfoundland Exploration Limited. Nevertheless, a brief description may be included here as certain information gained from this study of the intrusive masses throws light upon the overall structure of the area and, particularly, upon the structure of the rocks surrounding the intrusive masses.

The North Mountain Intrusive Wedge dips between 40° and 60° northwest and, as stated in the chapter on the Humber Arm group, has intruded approximately between the Western Sandstone formation and the main sequence of volcanic flows, pyroclastics and breccias, which form the uppermost members of the Humber Arm group. The bottom of the igneous mass may be taken as that part which lies almost "stratigraphically" upon the Western Sandstone formation, and the top, that part which lies beneath the volcanic rocks.

The bottom portion of the igneous mass consists chiefly of peridotites but numerous zones of dunite are found from place to place. Below the peridotites and dunites is a contact aureole varying in thickness from a few feet up to 150 feet. The degree of metamorphism decreases rapidly away from the contact. The metamorphosing effect of the gabbroic portion of the mass is much more widespread and the volcanic rocks around it have been converted to granulite amphibolites over an area of several square miles and possibly to a thickness of several hundred feet.

From bottom to top, the intrusive mass near North Arm and westwards may be divided as follows:

8000 feet (approximately) of somewhat banded or layered peridotite and dunite - the whole weathering light brown. The banded aspect is chiefly due to thin lenticular concentrations of enstatite - in part pseudomorphous, the enstatite having been altered to antigorite. Thin coatings of serpentine are commonly found on joint planes, often in conjunction with 1 to 10 cm. thick clusters and layers of bronzite. The layering (or bordering) in places shows a high degree of contortion, remarkably similar to the slumping of sedimentary beds. The banding is commonly disrupted and often lies within undisturbed relatively enstatite-free peridotite or dunite. The overall aspect of the ultrabasic rocks is that of a pseudostratified mass dipping northwest.

Toward the contact zone between the ultrabasic rocks and the gabbros, a definite, but not altogether noticeable, change in composition occurs. At a pseudostratigraphic distance of about 1000 feet beneath the main gabbroic portion of the intrusive mass, the ultrabasic rocks become occasionally feldspathic, and apparently associated with the development of the feldspars are pods and lenses of chromite.

The nature of the peridotite-gabbro contact zone varies from place to place. Commonly, the composition of the contact zone may be classified as that of a troctolite. In some areas, however, pyroxenite or anorthosite occurs. The most notable feature of the contact zone, and to some extent of the entire thickness between the chromite zones and the main gabbroic masses, is the change from orthopyroxene (enstatite) to clinopyroxene (augite) and an increasing amount of plagioclase (bytownite).

Above the contact zone, there are 2000+ feet of gabbro, roughly in the form of a thick cap over the ultrabasic rocks but, where it intrudes the deformed structure of the volcanic rocks, it takes the form of tongues, sills, lenses and sheets. Numerous xenoliths of originally volcanic material are found in the gabbro from place to place. Some of the larger xenoliths retain the outlines of flow structures and breccias but have the composition of a granulite amphibolite.

Both the ultrabasic and gabbroic masses show varying degrees of alteration. The ultrabasic rocks are often highly serpentinized, a feature not commonly recognizable in the outcrop but most noticeable in thin section. The gabbros away from the contact zone are commonly seen under the microscope to be composed of a matrix of bytownite, in which are found intergrowths of olivine, magnetite, augite and hornblende. The olivine is usually altered to antigorite but retains well defined pseudomorphic outlines. In shear zones, the gabbros are saussuritized and chloritized. Steatitization is common in shear zones both in the troctolites and peridotites.

Most important to this thesis are features which may be related to deformation in the intrusive rocks. They can be summarized as follows:

(a) The disruption of banding in undisturbed peridotite and dunite suggests that the "bands" were in a semiconsolidated or consolidated state while the enclosing material was still liquid.

(b) Such disruption indicates that movement was taking place during a period of fractional crystallization, in which case the enstatite-rich bands crystallized prior to their surrounding material.

(c) Any folding of the igneous intrusives after consolidation would tend to take place along serpentinized glide planes.

(d) The mechanical problems involved in folding consolidated rather homogeneous plutons of the shape of the North Arm Wedge are obvious. It is, therefore, likely that folding took place, for the most part, prior to consolidation.

(e) If the banding in the ultrabasic rocks is attributed to crystal settling, it would be logical to assume that the resulting pseudostratification was primarily horizontal and that the present westward dip is a subsequent feature - the result of folding. If so, the whole mass must have remained in a semiplastic state for some time.

Outside the igneous masses, to the east, the sedimentary rocks are folded to some extent around the perimeter of the intrusive. If a comparison is made between the axial planes of folds in the sediments and the attitudes of the pseudostratification* within the intrusive masses, a remarkable resemblance is noted. It is herein suggested that both the sedimentary attitudes and igneous attitudes are related.

The Gillams Transverse Fault and Lineament.

This name is given to a fault which is associated with a well defined lineament extending from the mouth of Gillams Brook almost to Deer Lake. From the geological map it will be seen that this lineament tends to follow a series of stream valleys of east--west trend.

Two of these streams drain into Hughes Brook from opposite sides. The stream entering from the west lies between two markedly different topographic forms. To its south are exposures of the upper St.George and Table Head groups which are somewhat tightly folded. North of the stream, the sediments are, for the most part, younger and outcrops of the Table Head group are more widespread. Here, the structure is less well understood but the high proportion of Table Head limestone in conjunction with relatively shallow dips in the more isolated outcrops, suggests less deformation than south of the stream.

* The pseudostratification (flow layering) was studied as part of an attempt to predict the position of chromite bodies in the ultrabasic mass and, consequently, many attitudes of pseudostratification were recorded.

East of Hughes Brook, the lineament is seen to cut through the dolomites and limestones of the St.George group and, farther eastward, through both the limestones and clastic rocks of the Reluctant Head and Mount Musgrave formations. South of the lineament in this area the older dolomites of the St.George group and the shaly limestones of the Reluctant Head formation are exposed, whereas on the north side, and almost directly opposite, are younger rocks, those of the Corner Brook formation including the upper dolomite member.

Farther east, where the Reluctant Head limestones are exposed, chiefly east of the dolomite outcrops, they dip conformably under the dolomites of the St.George group on the south side of the lineament, and somewhat similar structural relationships are seen on the north side. The only apparent horizontal displacement is approximately 300 feet. However, a short distance east of this locality and on the north side of the lineament, shaly limestones and shales of the Reluctant Head formation occur, which are stratigraphically several hundreds of feet below.

From the above observations, it is possible to conclude that the rocks south of the lineament were uplifted in relation to those on the north. However, the apparent displacement of the upper dolomite member a little east of Hughes Brook indicates a westward movement on the south side of the lineament. The actual displacement of the south side is, however, unknown, for only in a few localities was the fault zone itself observed. In the stream west of Hughes Brook, it is marked by a 25 feet wide calcite vein in which are disrupted dolomite and limestone beds. East of Hughes Brook, the fault zone is marked only by occasional slickensides on vertical fault planes.

Miscellaneous east-west faults.

On the geological map several other faults similar in many ways to the Gillams Brook Transverse Fault are indicated. All these faults are probably related to relatively late periods of deformation such as have disrupted the Carboniferous rocks in southwest Newfoundland. In rocks less competent than those of the thesis area, these faults are reflected as numerous shear zones, rather than sharply defined dislocations. In these sheared zones much of the overall movement is taken up by small displacements of 1 or 2 feet. This type of movement is common in the Lomond area of the East Arm of Bonne Bay.

The Lomond shearing.

In the Lomond area the folded St.George rocks have been uplifted toward the north in such a manner that the overall structure plunges to the south and away from the Long Range igneous and metamorphic rocks.

Superimposed over these southward plunging folds are numerous sheared zones which strike approximately N 80° E and dip between vertical and 70° north. Minor displacement of one or two feet have been observed along the sheared zones from place to place. This shearing is also reflected by the development of small stream valleys which trend N 80° E and by the modification of others.

Generally, where the shearing is most intense, the dolomites of the St.George group are shattered, whilst the limestones with which they are interbedded are sheared into small, one or two inch thick lenses. Variations occur locally in the attitudes of the shear planes and these variations can be attributed mainly to variations in competence between the dolomites and limestones. Shearing is most intense along the south shore of the East Arm of Bonne Bay and decreases southwards from the shore. North of the East Arm, the shear effect on the area is represented by small localized fault zones, which, in conjunction with numerous though localized shears, impart a secondary cross-schistosity to the overall area.

On the basis of conventional stress analysis such an overall shear effect would not be attributed to a simple uplift of the crystalline rocks of the Long Range but to a northwestward movement of the crystalline rocks which possibly carried with them a portion of the Labrador series overlying them.

Summary of the history of deformation

Theoretical considerations.

Before summarizing the history of deformation, it is necessary to make certain logical assumptions concerning the relationships between each phase of orogeny and the type of sediments involved.

Because each phase of orogeny in the thesis area is related to sediments which have specific stratigraphic positions, it is possible within fairly fixed limits to relatively date each phase and to some extent, where composition and distribution allows, tentative conclusions as to the types of deformation which occurred. In addition to dating deformations by related sedimentary types, it is also possible to date later phases of orogeny by structural superposition.

Factors and conclusions.

From the character of the sedimentary rocks in the thesis area it is possible to trace three phases of orogeny: one reflected by the Wolf Brook breccias, which separate the Corner Brook formation from the Raglan Head member, a second by the pebble conglomerates of the early part of the Humber Arm group, and a third by the Western Sandstone formation with its volcanic rock fragments.

The first phases of orogeny reflected by the breccias of the White Face type may have taken place in a number of ways among which are: 1) thrust faulting, possibly including the development of nappe structures, 2) uplift by block faulting and, or 3) folding. On the basis of the available data either of the above could have provided the type of relief necessary for the erosion and subsequent deposition of the breccia blocks. Though not discounting the possibility of uplift by thrust faulting and, or block faulting, the writer favours folding as the dominant type of deformation for the following reasons. From the distribution of the sedimentary rocks south of the Penguin Hills, and the fact that the greater part of the Corner Brook formation had been eroded before the Raglan Head member was deposited, it must be concluded that an erosional channel existed in that area either below or above sea level during the period of time between the deposition of the White Face breccias and the deposition of the early Humber Arm sediments. In order for the Penguin Hills Klippe to have come to rest upon the early Humber Arm sediments it must have moved or slid into its resting place in the channel after their deposition, in which event the movement either occurred prior to the deposition of the greater part of the Humber Arm rocks or that they had been eroded from the mouth of the channel prior to a "later" movement of the Penguin Hills Klippe. However, where rocks of the Penguin Hills or the Old Man's Pond overthrust are found to the east, near Old Man's Pond, they are almost always parallel with the underlying strata, and where folding has occurred, the strata on both sides of the thrust plane appear to be folded to the same extent, showing that the greater degree of folding took place after the Penguin Hills Klippe moved to its present resting place. That the Mount Musgrave formation had been uplifted and subjected to erosion prior to the westward thrusting of the klippe is proved by the fact that pebbles derived from it constitute part of the early Humber Arm sediments.

Generalizing, it may be said that the White Face breccias mark the beginning of an orogeny and that the pebble conglomerates of the early Humber Arm sediments mark the end of a rather vigorous phase of its development.

During the period of time between the deposition of the Humber Arm sediments and the first extrusions of volcanic rock marked by the volcanic rock fragments in the Western Sandstone formation, it is possible that only a small amount of deformation occurred. That some deformation occurred is evidenced by the erosional surfaces which are found in the Humber Arm quartzites, features which because of their erratic distribution possibly reflect deformation in localized zones rather than isostatic change.

The volcanic fragments of the Western Sandstone formation reflect the beginning of an orogenic phase which was marked by volcanism and possibly culminated in the deformation of the whole region. From the nature and distribution of the main volcanic rock types of the Gregory Plateau and its environs, it seems likely that the volcanic rocks were first extruded through fissures in the ocean floor as pillowed basalts, but after an interval they were succeeded by massive flows which extruded upon the land surface of small volcanic islands, for almost everywhere the flanks of the areas covered by massive flows are marked by pillowed flows, usually of the same apparent composition as the massive flows. Roughly beneath the lower boundary of the volcanic flows were intruded the large differentiated masses of the Bay of Islands Igneous Complex which were, in turn, folded a short time after their intrusion. The length of the time interval between the extrusion of the volcanic rocks and the intrusion of the plutonic masses is unknown, but assumed to be rather short. Some of the more intense phases of folding may be much younger, perhaps Devonian.

Possibly as late as Carboniferous time the region was subjected to normal faulting and block faulting. These faults,which cut across all the main structures of the area, possibly belong to an entirely separate orogeny from that which, during Middle to Upper Ordovician time and probably including Silurian time or later, deformed the bedrock of the area.

CHAPTER 8

ECONOMIC GEOLOGY

Metallic Mineral Deposits

Galena and sphalerite are the only metallic minerals of economic importance found in the area. They commonly occur in thin widespread zones within the lower dolomite beds of the St.George group where they overlie the Penguin Cove formation both in and to some extent north to northeastwards of the Goose Arm area. Two types of mineralized zones are found; one, which is the more widespread, consists of sphalerite and galena in dolomite with no associated gangue minerals; the second type, observed only in two localities, consists of sphalerite and galena in a gangue of pyrite with lesser marcasite and limonite.

The more widespread of the two types varies in width from a few inches to 8 feet, but in these zones aggregates of more than 5 or 6 per cent lead and zinc were not found comprising widths of more than 3.5 feet. Moreover, in nine occurrences in the Goose Arm area only two were found where lead and zinc in excess of 5 per cent occur over a width of more than 2 feet. In this type of occurrence none of the lead-zinc mineralization appears to be associated with any particular form of shearing or faulting, and little or no alteration is found within the mineralized zone or nearby. Both the lead and zinc sulphides occur as small patches or veinlets, with the exceptions that the galena in some places occurs as isolated cubes and the sphalerite in small vugs. The host rock throughout the whole area is almost invariably finely recrystallized, sugary textured, grey to buff weathering dolomite which has a fine vuggy porosity from place to place.

The second type of occurrence, containing the gangue minerals pyrite, marcasite and limonite, was observed in only two localities; on the south side of Goose Arm, east of Raglan Head, and on the north bank of Goose Arm Brook about 1.5 miles from its mouth.

In the locality east of Raglan Head, the mineralization comprises a near-vertical northeast striking zone with a total width of 14 feet which has been traced along strike for approximately 300 feet. Most of the mineralization, however, is confined to an inner zone 4.5 feet wide and only small patches of galena and sphalerite are found over the remaining thickness. In the inner zone, the galena and sphalerite occur as small veinlets and pockets with marcasite formed around the sides of largely irregularly shaped patches of pyrite. The limonite appears to be a weathering product of the pyrite and related to the action of surface waters. A small amount of irregularly scattered cerussite is also present.

The mineralized zone at Goose Arm Brook comprises a roughly conformable lens in gently dipping dolomite about 60 feet wide which is exposed above the bed of the brook for almost 10 feet up the steep bank. The bottom of the zone is beneath the level of the brook. The mineralization of this zone is quite similar to thatin the locality east of Raglan Head, but more limonite and marcasite are present.

Evidence of considerable development work is present in and about the Goose Brook showing. The remains of a well-timbered shaft are found on the north bank of the brook about 60 feet above the water level and other remains indicating the presence of an adit, apparently aimed at the shaft, are found about 4 feet above the brook. A partly overgrown road about 12 feet wide runs from the head of the shaft to Goose Arm. The age of trees overgrowing the road and near the shaft, indicate that the work was carried out prior to 1925.

Methods of prospecting employed.

Geochemical prospecting is well suited to the regional environment and has proven useful in locating new lead and zinc occurrences and in delineating those previously known. The zinc being the more mobile has a relatively wide dispersion in contrast to the lead which shows little dispersion and is seldom anomalously enriched except over the mineralized zones or nearby. This difference in *dispersion has been a useful factor in prospecting for the lead and zinc over large areas. In any area where silt sampling has been carried out, an increase in the grade of zinc anomalies in any direction almost invariably has led to zones with high lead anomalies. Having obtained high lead anomalies, trenching or detailed prospecting could be done successfully in areas which are masked by overburden.

Generally, geochemical prospecting in this area was carried out in two stages; one which, more or less, determined the possibility of lead and zinc occurrences within the overall area, the other which led to the immediate locality of a showing. This procedure involved silt sampling in the major streams and, to some extent, in their tributaries

* Work by the U.S.Geological Survey at the Union copper mine, Gold Hill district, North Carolina, showed that the Zn:Cu:Pb ratio derived from the weathering of sulphide mineralization is about 10:10:30 whereas the ratio of the same elements in the unweathered zone is 10:0.6:2 with an absolute decrease in the zinc content from 4 to 0.04 per cent. Hence the order of increasing mobility of these metals is lead, copper, zinc. The relative immobility of lead may be an effect of the relative stability of galena as compared with other sulfides. Also, lead sulfate is less soluble in dilute sulfate solutions. Moreover, factors restricting the mobility of zinc do not make themselves felt until the solutions have passed well beyond the acidic environment created by the oxidation of sulfides. (U.S.G.S. Bull. 1000-F 1957).

and finally, if anomalous conditions were found, detailed soil sampling on the sides of nearby hills. Several zones in the Goose Arm area were found by these methods and, though none of these occurrences were of economic grade, they served to prove the usefulness of the geochemical technique.

Possibilities of higher grade lead-zinc deposits in the thesis area and beyond.

The known lead-zinc deposits are too thin and too low grade to be mined economically. However, economic deposits may yet be found in which the lead and zinc minerals have been concentrated in one or more of the following ways:

1) By tight folding involving a repetition of the host beds and, consequently, doubling the thickness of a number of zones.

2) By mechanical concentration in intraformational conglomerates which passed through mineralized locality.

3) By epithermal veins in fracture or shear zones.

4) By supergene enrichment.

Because of the widespread occurrence of the lead-zinc mineralization, the possibility of finding enriched or thickened zones is not remote, and if the geochemical methods which were effective in the Goose Arm area are used, little difficulty should be encountered in locating them.

Origin of the lead-zinc deposits.

In an attempt to explain the origin of the lead-zinc deposits of the thesis area the following observations have to be taken into consideration.

The lead-zinc deposits were only found above the Penguin Cove formation and either immediately above or below the dolomitic shales which occur within the St.George group where it overlies the Penguin Cove formation. The more widespread mineralization shows no evidence of having replaced any part of the dolomite beds and is confined within definite stratigraphic limits. Mineralization in the same stratigraphic position occurs near Bonne Bay Big Pond, Wiltondale and near Gallants. Near Gallants, however, the lead and zinc occurs in veins which fill fractures in the dolomites of the lower beds of the St.George group, and in the Cambrian limestones.

From the inspection of polished sections of the gangue-type mineralization, it can be seen that pyrite has replaced dolomite but it may be also seen that numerous calcite veins in turn cut the pyrite. In part at least, the pyrite was introduced after diagenesis.

No igneous bodies occur near the mineralization.

In reviewing the possible methods by which the lead and zinc was concentrated into zones, one might consider the following:

1) Primary deposition from the sea.
2) Primary deposition from sea water, but modified and concentrated by regional metamorphism.
3) Original scattered deposition but later concentrated by circulating waters either moving upwards or downwards.
4) Deposition from fluids of igneous derivation involving hydrothermal solutions, volatiles or metallic vapours.

Considering the above, deposition from the sea would appear likely except for the tendency of the lead and zinc mineralization to comprise zones in which are found, in addition to patches and pods of sphalerite and galena, small veinlets comprised of both metallic minerals. Again, considering modification by circulating ground water, this method does not seem likely because of the tightness of the dolomite beds.

However, in favour of this method, it is not improbable that the dolomite beds were relatively porous for some time after the deposition. As stated previously, deposition from fluids of igneous origin is unlikely to have occurred because of the great distance from the nearest igneous masses. Moreover, it is further unlikely that solutions of igneous origin would have deposited the lead-zinc within such well defined stratigraphic limits over several hundreds of square miles. Of the above methods the writer favours sedimentary deposition and subsequent concentration by solid diffusion resulting from low grade metamorphism. The solid diffusion would possibly have taken place in a somewhat similar manner to that described by J.E.Gill (1960). However, even if the method of dry ion migration (or solid diffusion) as shown possible by Gill's experiments on copper, was a factor in the deposition of the lead-zinc mineralization, it is difficult to envision such a deposit being free of cognate waters.

Industrial Minerals and Materials

Riprap

The limestone in the locality of Dormston Quarry, located to the east of Corner Brook, has been used successfully as riprap. The stone, which is a dark grey to black recrystallized limestone (marble), has been successfully broken into blocks with dimensions of over 8x10x10 feet with only a relatively small proportion of small unusable blocks. The same type of stone outcrops in the Corner Brook formation not far from the mouth of Hughes Brook and would probably break into blocks of similar dimensions. Some of the massively bedded dolomites of the

Corner Brook formation in the Humber Gorge and Hughes Brook Valley, though probably of slightly different specific gravity, would also provide stone of similar dimensions and suitable for similar purposes.

Rubble.

Practically all the limestones and dolomites of the area, after crushing, could be used successfully as rubble. In view of the present rather unsuccessful use of glacial material for this purpose in West Newfoundland, the extra cost of crushing and general preparation of limestone would probably even out costs in a relatively short time.

Dimensional, building and ornamental stone.

The limestones in some localities may be suitable as dimensional stone, the darker limestones of the Hughes Brook locality might be used successfully for the cruder building stones when taken from the less sheared and contorted areas.

Marble from the Dormston Quarry locality was reported by Walthier (1949) to take a good polish.

Chemical uses.

The limestones of the Corner Brook formation in the Hughes Brook-Goose Arm area and the Table Head group in the Port au Port area are in part chemically suitable for the production of cement. In Goose Arm, however, the attitudes of the limestone beds and high proportion of interbedded dolomite would make quarrying costs too high for transshipment to nearby ports. Other localities in the Hughes Brook area provided suitable thicknesses of limestone which might be used if low cost transportation was available.

The most likely sources of high grade limestone, low in MgO, were found in the Table Head group near Port au Port. This area has already provided limestone for the manufacture of calcium bisulphite dissolving liquor for use in the pulp and paper industry, and dolomite and limestone for use as fluxes in iron and steel manufacture.

Other likely sources of limestone and dolomite for chemical uses are found in the upper beds of the St.George group in the East Arm of Bonne Bay.

Pottery Clays.

Clays suitable for pottery manufacture occur as outwashings from late Pleistocene deltas in the general area of Humber Arm.

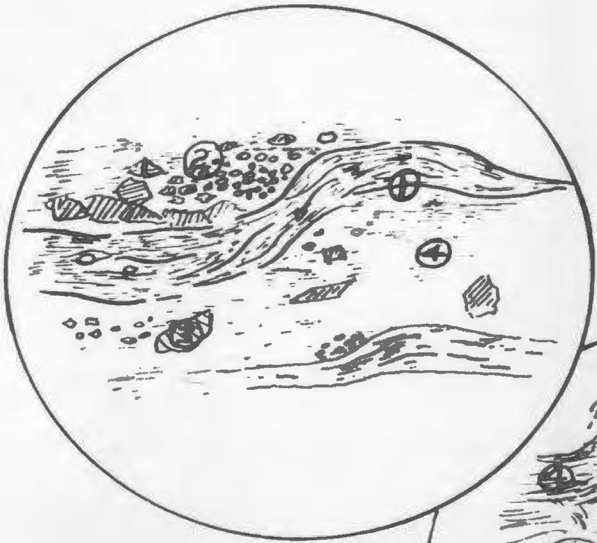


Fig 1A

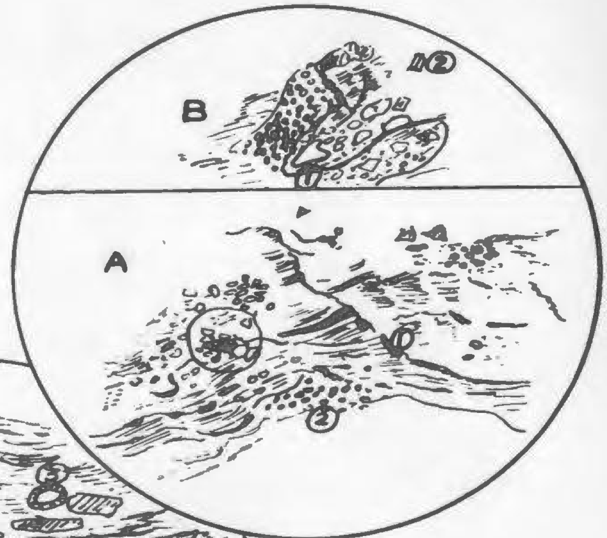


Fig 3A

Calcareous shales
and shaly limestones

Fig 2 A

Fig 1 A Shaly limestone - Old Mans Pond Locality, Reluctant Head formation. ① Sericitic clayey partings. ② Small cluster of quartz grains ③ Calcite ④ Finely crystalline limestone.

Fig 2A Calcareous shale - Penguin Hills locality
① Calcite in small slumped feature ② Quartz grains ③ Small fossil.
④ Calcareous clayey matrix. ⑤ Iron oxide staining around groups of opaque minerals

Fig 3A-A Shaly limestone - Penquin Harbour Brook
① Sericite in microfaults, ② Small clusters of quartz grains
B. Detail from A. ① Quartz in nose of small fold
② Feldspar grain.

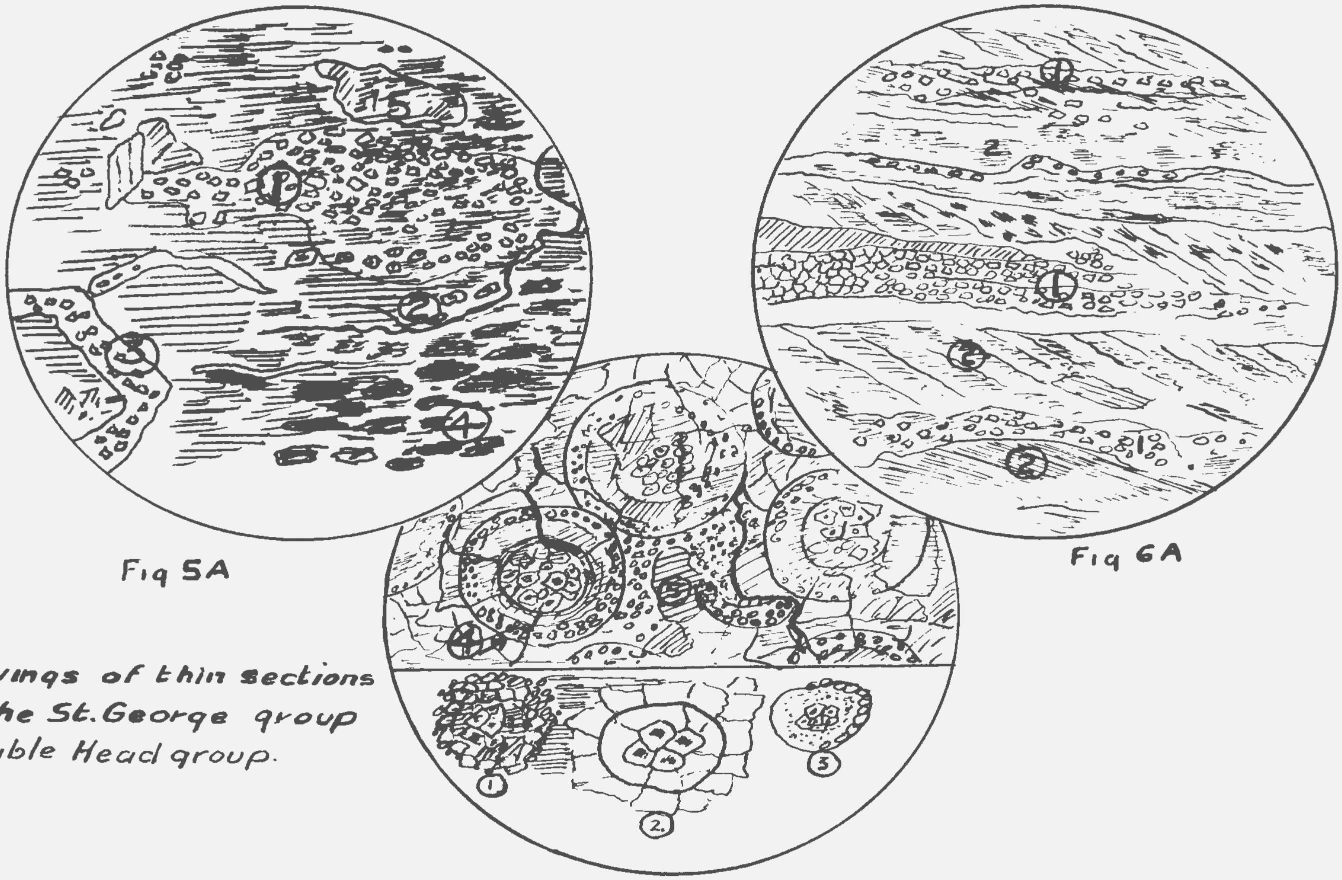


Fig 5A

Fig 6A

Drawings of thin sections from the St. George group and Table Head group.

Fig. 7A

Fig 5A. Raglan Head member.

① Dolomite crystals outlining fossil algae.
② Hematite stained solution cavity.
③ Dolomite crystals in shell remnant.
④ Finely crystalline clouds, possibly fecal pellets or pseudo-oolites.
⑤ Aggregate of calcite crystals.

Fig 6A. Raglan Head member.

① Dolomitic laminae in finely sheared, very finely crystalline limestone.

Fig 7A Oolitic dolomite from base of St. George group

① Poorly defined oolite with zoned dolomite crystals at centre and smaller crystals at rim. ② Oolite from same slide showing zoned dolomite at centre and overgrowth of dolomite at well defined rim. ③ Partial replacement at rim. ④ Dolomite overgrowth, but well defined concentric structure retained. ⑤ Large recrystallized calcite grain.

Fig 1. Dragfolding in thinly bedded shaly limestone of the Reluctant Head formation, East of the Bend in Hughes Brook.

Fig 2. Shaly limestone of the Reluctant Head formation on the west limb of the Shellbird Island Syncline, the axis of the syncline is to the left. Humber Gorge locality.

Fig 3. Limestone cobble-conglomerate of the area near Dam Pond, stratigraphically near the base of the Reluctant Head formation.

Fig 4. Outcrop of shaly limestone of the Reluctant Head formation overlain by dolomite of the St. George group. East of the Bend in Hughes Brook.

Fig 5. Thrust in upper St. George dolomite near Port au Port. The folded bed(1) is thrusted over the flatter lying beds in the foreground (2) The beds in the background(3) are in turn thrusted over the rounded nose of the fold.

Fig 6. Cryptozoan reefs near the top of the St. George group. In the distance is a Pleistocene terrace on which part of the town of Port au Port is built.

Fig 7. Limestone breccia of the Cow Head type near Port au Port. The crudely bedded breccias overlie younger Tetragraptus bearing shales.

Fig 8. Mud roll in limestone breccia of the Cow Head type, Port au Port.

Fig 9. Interbedded limestones and dolomites of the Raglan Head member. Raglan Head, Goose Arm. To the left are dip slopes of dolomites of the St. George group.

Fig 10. Southwest face of Raglan Head. To the left of the dark shadow are beds of the Raglan Head member.

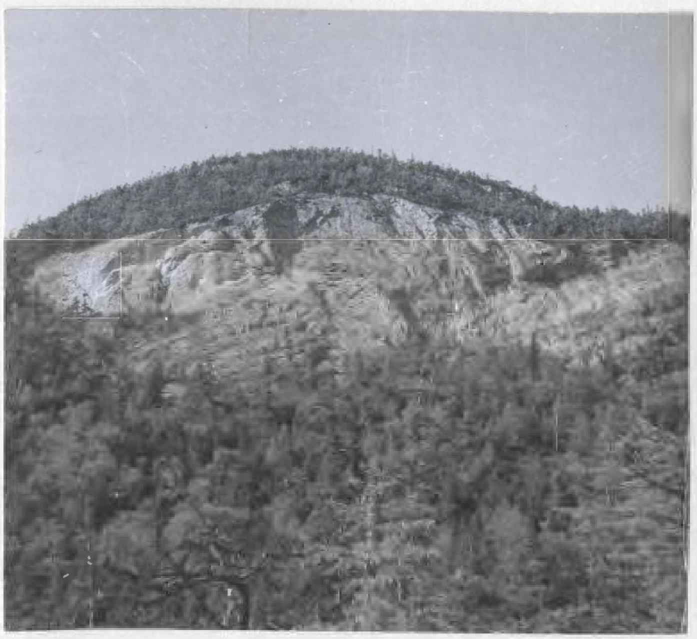


Fig 11. To the upper left are brecciated and contorted beds of the Table Head group. Below these are beds of the upper dolomite members of the Corner Brook formation. East of Hughes Brook and north of the Gillams fault.

Fig 12. Upper center, beds of the Corner Brook formation of the St. George group. Far right, are dolomites of the Hughes Brook formation. North side of Wild Cove valley.

Fig 13. Calcareous sandstone of the lower part of the Humber Arm group. South shore of Penguin Arm.

Fig 14. Thinly interbedded limestone and calcareous shale of the Penguin Arm Limestone formation of the middle part of the Humber Arm group. North shore of Penguin Arm.

Fig.15. Crudely bedded limestone breccia of the Penguin Arm limestone formation. West of Penguin Arm Village.

Fig 16. Detail of beds shown in Fig 15 on opposite side of page.

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