# GEOLOGY OF THE HUMBER ARM AREA
# WEST NEWFOUNDLAND



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# GEOLOGY OF THE HUMBER ARM AREA,
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by

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## ABSTRACT

The area investigated includes the type section of the Humber Arm series along Humber Arm, as well as an area east of Blow Me Down Brook on the south shore of the Bay of Islands, the south shore of Middle Arm, and Woods and Eagle Islands. Five newly named formations can be recognized in the sedimentary part of the sequence. Graptolites found in the third youngest formation indicate a Tremadocian age and the series as a whole probably ranges in age from Middle Ordovician to Lower Cambrian. The youngest rocks are volcanic flows and associated basic and ultrabasic intrusions, which form the Bay of Islands Igneous Complex. They were not investigated. The Humber Arm series has been much deformed. The main folded structure is the Humber Arm synclinorium. Associated with this fold are dislocations ranging in magnitude from major reverse faults or thrusts, to strain-slip cleavage. High angle faults cut these structures. The stratigraphy is locally disrupted by zones of chaotic deformation which also mark the junction between the Humber Arm series and the main carbonate sequence to the east of the area. This sequence is a contemporaneous facies of the Humber Arm series but underlies it. The best explanation of the geological setting of the Humber Arm series is that it is allochthonous, being emplaced as a klippe during Taconic times, thus accounting for the superposition of older Humber Arm rocks on the youngest rocks of the main carbonate sequence, the facies contrast between the Ordovician parts

of the two sections, and the geology of the Rattler Block. This block is interpreted as an anticlinal window through which a lower tectonic slice of the Humber Arm series is seen. The chaotic zones are interpreted as rubble zones produced during the gravitational gliding of the klippe. Three structural units within the klippe are recognized; a lower slice seen through the Rattler window, the main Humber Arm slice and a slice containing the Bay of Islands Igneous Complex with some associated sediment. Differential movements within the klippe are thought to have produced these units.

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Dr. L.M.Cumming and Dr. W.H.Fritz of the Geological Survey of Canada identified the Graptolites and Trilobites respectively. In addition, Dr. L.M.Cumming suggested, in the field, potential fossiliferous horizons.

Dr. J. Rodgers of Yale University visited the writer in the field and made many valuable suggestions.

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Mrs.Claire Moorhead is thanked for the typing of the thesis and my wife for her invaluable help.

The perimeters of figure 2 are substantially based on Walthier(I949), Lilly(I963) and McKillop(I963).

# CHAPTER I

# INTRODUCTION

## Location and Size of Area

The area studied is situated in the central part of west Newfoundland, to the west of the town of Corner Brook (fig. I). It includes both shores of the Humber Arm, the south shore of the Bay of Islands up to the mouth of Blow Me Down Brook, the south shore of Middle Arm east to Long Point, as well as Woods Island and Eagle Island. Inland the area includes, on the north shore of Humber Arm, an area bounded to the east by a curved line running from Long Point to the mouth of Hughes Brook. On the south shore of Humber Arm only a coastal strip about one mile wide was investigated. The map area is about 200 square miles, while the coastal sections have a total length of about 70 miles, but these were more thoroughly investigated than was the inland area.

The field work was carried out between June and October, 1964.

## Geographic Setting

The general geography of the area has been adequately described by the authors referred to in Table I. Only the more important features will be described here.

## Topography

The area is a dissected plateau dominated by the fiord-like complex of the Bay of Islands and its associated arms, the Humber and Middle Arms; this latter arm bifurcates into the Penguin and Goose Arms. The shores of these arms are often cliffed. The land rises rather steeply from the coastline and may reach elevations of a thousand feet within a few miles of the shore. In general, however, the area of this thesis is underlain by shaly sediments which support a lower elevation than do the carbonates to the east, and the igneous rocks to the west.

## Drainage

Drainage is via a complex system of small streams linking numerous small ponds to the arms. The mouths of several larger streams are marked by raised deltas of Pleistocene age (Richards 1937; 1940). The higher parts of the area, especially to the north of Humber Arm, are poorly drained and largely covered by bog, through which scattered outcrops of bedrock protrude. The better drained areas support a dense cover of conifers.

## Climate

The region around the Humber Arm, in common with the rest of western Newfoundland, has a moderate climate. The average summer temperature varies little from 60°F. Rainfall is not heavy, but frequent. The predominant wind direction is from the south-west.

## Access

The main access routes generally follow the north and south shores of Humber Arm, but in some areas they extend several miles inland. A network of rough tracks in the wooded areas, usually privately owned, supplements the main road system. Access to areas south of the Humber Arm is provided by the Canadian National Railway's main line from St.John's to Port aux Basques and the Trans Canada Highway system.

Nearly all of the coastal section is passable at low tide but, since the high water mark is usually at or above cliff base, many headlands are negotiable for only a few minutes each day. The whole section between McIver's and Cox's Cove as well as that at Long Point are best seen with the aid of a boat but landing at these sections may be difficult except in the calmest weather. Boats are, however, readily available from any of the fishing villages.

## Population

Population is restricted to settlements on the shores of the arms, by far the largest of which is Corner Brook. Middle Arm east of Cox's Cove and the islands of the Bay are only inhabited during the summer.

## Survey Control

Good base maps on a scale of 1 : 50,000 and aerial photographic coverage are available for the area. The maps, though representing the topography adequately, do not always agree with the local nomenclature. Furthermore, many prominent geographic features do not seem to be named at all. Location names used in this thesis are in accord with those shown on the Department of Mines and Technical Survey's maps for the area.

## Geological Setting

Newfoundland encompasses the most north-easterly part of the Appalachian system. Here a two-sided symmetry may be recognized which is not so evident in the southern part of the system (Williams 1964). The axis of [redacted] symmetry is the central Newfoundland terrain which consists predominantly of metamorphosed eugeosynclinal strata invaded by granitic and ultrabasic rocks. To the east and west, the central terrain is faulted against sequences of relatively undeformed lower Paleozoic rocks underlain by a Precambrian and early Paleozoic basement. These rocks constitute the flanking terrains of Avalon and western Newfoundland. The western Newfoundland terrain is geologically defined as that part of Newfoundland which lies to the west of the Baie Verte-Grand Lake lineament. At the base of this terrain is a crystalline core of Precambrian age, physiographically expressed by the Long Range Mountains. West of the exposed core is a thick sequence of Cambrian clastic rocks, locally metamorphosed at its base, which grades up into a thick series of Lower to Middle Ordovician carbonate rocks referred to the St. George and Table Head groups (Schuchert and Dunbar 1934). This whole sequence, the Cambrian clastic rocks and the Ordovician carbonate rocks, will, for convenience, be called "the main carbonate sequence" in the remainder of the thesis.

Westwards, the main carbonate sequence is apparently overlain by a thick sequence of shales, sandstones, platy limestones and volcanic rocks, intruded by large masses of basic and ultrabasic rock. Schuchert and Dunbar (1934, p. 89) named these rocks "the Humber Arm series," defining the type section as the Humber Arm. It is this section that is the main subject of the present investigation.

## Previous Work

Murray and Howley (1874) make the first reference to the geology of the Humber Arm area on a small-scale map, but no description of the area is given in the accompanying paper.

Schuchert and Dunbar (1934) provided the basis for all later work in the area with their classic description of the stratigraphy of western Newfoundland. The Humber Arm section was made the type section for the Humber Arm series, which was regarded as the youngest part of the continuous sequence of Lower Paleozoic rocks lying to the west of the Long Range. Although the Humber Arm series was poorly fossiliferous at the type section, elsewhere a plentiful Mid-Ordovician fauna was found near its base. The youngest part of the series was assumed to be Upper Ordovician in age. The Humber Arm series was thought to consist of 5000+ feet of predominantly clastic sediments of deltaic origin with a sequence of volcanic rocks intercalated in the upper part. Several sections were measured in detail, but the "Humber Arm series" remained as the least understood stratigraphic series in west Newfoundland. They attributed this lack of understanding to the structural complexity of the series. "Every known exposure shows the effects of strong deformation" (ibid., p.86). Some of this deformation was attributed to the intrusion of large ultrabasic masses into the volcanic rocks. These igneous rocks, however, were described only briefly.

Cooper (1936) completed the classic description of the Humber Arm series with a study of the volcanic and associated intrusive rocks, naming them the "Bay of Islands Igneous Complex".

Later workers in the Humber Arm area deviated little from these classic descriptions.

<u>Previous work on Humber Arm type rocks elsewhere in western Newfoundland</u>

Weitz (1954) and Rodgers and Neale (1963) have provided adequate summaries of previous investigations of Humber Arm type rocks away from the type section. The distribution of these rocks is shown in Rodgers and Neale (ibid., fig. I) and Smith (1958, map I).

Schuchert and Dunbar noted several stratigraphic sequences near the coast 8 miles north of Bonne Bay which bore a lowest Ordovician fauna, yet, even though they could not be adequately separated from the Humber Arm strata, they were referred to a new sequence, the Green Point series. This series was then interpreted as a facies of the main carbonate sequence.

Johnson (1941), however, found that the Green Point series was only the lowest member of a whole sequence, some 6000 feet thick, that yielded fossils ranging in age from lowest to Middle Ordovician. These rocks could not be conveniently fitted into the geological framework of western Newfoundland, so Johnson (1941) suggested that they had been thrust from the east, over the main carbonate sequence, into their present position.

Kay (1945) restated this view. These authors, however, still regarded the bulk of the Humber Arm series as autochthonous (Kay 1951).

At the base of the Humber Arm series, Schuchert and Dunbar (1936) had described the Cow Head Breccia. This is a sequence of very coarse lime-breccias with interbedded shale. At Cow Head, the relationship of these breccias to other sequences is not clear, but on the Port au Port peninsula to the south, a thinner and less coarse series of lime-breccias is conformable upon the Table Head limestones of Mid-Ordovician age. The two breccia series were correlated and thought to have been derived from submarine fault scarps formed during Mid-Ordovician thrusting. Kindle and Whittington (1958; 1959), however, found that the breccias around Cow Head range in age from Mid-Cambrian to Mid-Ordovician and consequently cannot be part of the Humber Arm series. They are yet another anomalous clastic sequence, not younger than, but contemporaneous with, the main carbonate sequence.

This reinterpretation of the Cow Head breccias, previously thought to be an integral part of the Humber Arm series, reopened the whole question of the age and origin of the clastic rocks to the west of the main carbonate sequence.

Rodgers and Neale (1963) recognized that the geological setting of western Newfoundland was essentially similar to that of the Taconic region of the Appalachians in north-eastern U.S.A.

Many authors interpret the geology of that region as a klippe of Cambro-Ordovician clastic rocks, superimposed on a carbonate rich sequence of essentially the same age. Using this parallel, Rodgers and Neale (1963) suggested that the Humber Arm series is also a klippe superimposed on the main carbonate sequence. Hence the only part of Schuchert and Dunbar's original Humber Arm series not included in the klippe, are those rocks known to be conformable upon the Table Head limestones. Since the klippe was thought to have been emplaced as a submarine gravity slide during the deposition of these Mid-Ordovician clastic rocks, it was suggested that, at the base of the klippe, the two sequences would be intimately mixed. The boundary of the klippe was, however, drawn at the junction between the carbonate and clastic rocks. A similar view has been illustrated by Kay (1965).

Lilly has urged caution in accepting this view. He noted that the necessary information regarding the age of the Humber Arm series was lacking and, as the situation then was, several other hypotheses were as plausible as that incorporating all of the Humber Arm in a klippe. He suggested that two possible explanations existed for the geological setting of the Humber Arm type rocks. Firstly, the eastern Humber Arm rocks could be regarded as in place, overlying the main carbonate sequence in normal stratigraphic sequence. The Bay of Islands Igneous Complex, however, with some associated sediments, could be part of a klippe, emplaced over the eastern Humber Arm series. Secondly, in view of the similarity between the Cambrian part of the main carbonate sequence and the presumably older part of the Humber Arm series, the two may be considered of equivalent age. The younger Humber Arm rocks could then be considered as facies equivalents of the upper part of the main carbonate sequence, and the whole sequence thrown into a large mushroom-shaped fold and faulted to give the relationships seen in the field. According to this view, the structure of the Humber Arm series is broadly anticlinal and the main carbonate sequence does not completely underlie the Humber Arm series.

In the summer of 1964 then, the following different concepts of the Humber Arm series were current:

1. It is Middle Ordovician to ?Upper Ordovician in age and overlies the main carbonate sequence with a normal sedimentary contact.
2. It is Cambrian to Middle Ordovician in age and a facies of the main carbonate sequence which has been involved in a mushroom shaped fold, and faulted.
3. The series has a mixed origin; part is Middle Ordovician in age and part is a klippe of unknown age.
4. Virtually all the Humber Arm series is part of a klippe, its age being Cambrian to Mid-Ordovician.

It was part of the author's purpose to evaluate these concepts by a study of the type section of the Humber Arm series.

# CHAPTER II

## STRATIGRAPHY

### Introduction

The Humber Arm area is underlain by a series of shales, sandstones and platy limestones. To the west lies the Bay of Islands Igneous Complex and to the east, the main carbonate sequence. Adjacent to the main carbonate sequence, the Humber Arm series is somewhat metamorphosed. This metamorphism decreases rapidly westwards but structural complications do not, so that no single section shows the complete stratigraphic sequence. Indeed, no section can be found that embraces even a single formation. The coastal sections are well exposed, however, and the broad lithological divisions persist enough to allow a general stratigraphic synthesis. Only rarely are rock types encountered that cannot be referred to a formation but the rarity of fossils and shortage of good marker beds limits the detailed correlation of sections.

The Humber Arm rocks fall into four main divisions; an older arenaceous and shaly sequmnce, a carbonate-shale sequence, a younger arenaceous and shaly sequence overlain by the Bay of Islands Igneous Complex. The sediments can be further differentiated into a series of units of similar lithologies that can be grouped into five formations. Table I shows these units and how previous authors subdivided them.

Previous stratigraphic interpretations

When Murray (1874) first subdivided the rocks on his map of the Humber Arm area, he used the nomenclature developed by Logan (1864) for rocks in the Eastern Townships of Quebec. All of the shaly rocks were correlated with the Levis Shales, the anenaceous with the Sillery Sandstones and the igneous rocks were assigned to the "Serpentines etc". These sequences constituted the Quebec group of Lower Silurian age. Justification for these correlations was provided by Logan himself, who, on seeing the sandstones exposed in the Bonne Bay area, to the north of the Humber Arm, remarked that there could be little doubt that they were equivalent to the Sillery sandstones of Quebec (ibid., p.293). It is significant to note that Schuchert and Dunbar (1936, p.95) rejected this correlation since the Sillery sandstones were proved to be Lower Ordovician in age. They included the sandstones at Bonne Bay in their Mid-Ordovician Humber Arm series.

It is quite clear, however, that Logan and Richardson (in Logan 1864) recognized the essential unity of the older clastic rocks occurring on the western flank of the Appalachians, later to be emphasised by Rodgers and Neale (1963).

Schuchert and Dunbar (1934) proposed the name "Humber Arm series" and designated the Humber Arm as the type section (ibid., p.86). Although they outlined the rock types occurring there and measured several sections in detail, the series was left undivided. In general the rocks were thought to be youngest to the west. The age of the series was not determined at the type section but, elsewhere, Mid—Ordovician fossils were abundant and Schuchert and Dunbar determined the age of the series as Middle to ?Upper Ordovician. The rocks were thought of as the youngest series of an essentially continuous column of sediments which included the main carbonate sequence. Schuchert and Dunbar's basic tenets were accepted with little reservation by later workers in the area, who concentrated their efforts on refining the internal stratigraphy of the Humber Arm series.

Twenhofel (1940) briefly studied the south eastern shore of the Humber Arm. He notes (ibid.,p. 6) that F. Dykstra was working in the area at the same time, but this work, if recorded, was not available to the present author.

Riley (1962), who mapped the small part of the area included on the Stephenville map sheet, did not subdivide the Humber Arm series.

A significant advance towards unravelling the internal stratigraphy of the Humber Arm series was made by Walthier (1949), who recognized and named the Cooks limestone tongue which he considered divided the series into an upper and lower clastic sequence. This tongue was thought to pinch out to the south. McKillop (1963) mapped additional outcrops of limestone and lime breccias.

Weitz (1953) subdivided the Humber Arm series into 5 formations, none of which were regarded as valid by Lilly (1963) or by the present writer.

Lilly (1963), working in the Penguin Arm – Hughes Brook area, subdivided the competent horizons of the Humber Arm series into 3 groups, two of which were given the status of formation. These divisions, though separated by undivided shales, provided a basis for the present writer's stratigraphic interpretation of the area.

<u>Stratigraphy</u>

For the purposes of this thesis, the Humber Arm series has been divided into 5 new formations. Transition zones link ~~relate~~ all but two of the formations. The following new formational names are proposed; but because they will be referred to frequently in the text the transition zones between the formations are also named and given a letter prefix.

TOP
- H. The Woods Island formation.
- G. The Middle Arm Point-Woods Island formation transition zone.
- F. The Middle Arm Point formation.
- E. The Cooks formation.
- D. The Meadows-Cooks formation transition zone.
- C. The Meadows formation.
- B. The Summerside-Meadows transition zone.
- A. The Summerside formation.

The structure of the area is such that no continuous section of any formation is preserved, so that no type sections can be defined completely. For the following descriptions of these formations and zones, their geographic distribution is indicated on Figure 2. The sequence is described starting with the oldest formation.

## A. The Summerside formation

The formation is named after the village of Summerside on the north shore of Humber Arm. The name has previously been used by Weitz (1953) for all of the lower arenaceous sequence of the Humber Arm. In the present usage, it is restricted to the green sandstones and roofing slates which Weitz regarded as the middle member of his Summerside formation. The lower and upper member of Weitz's Summerside formation are equivalent and are called the Meadows formation in this thesis. The Summerside quartzites of Lilly (1963) and the sandstones described from Quarry Hill (Crow Hill) by McKillop (1963) are similarly re-interpreted and assigned to the Summerside formation. The rocks referable to the formation are found between Crow Head and Pettipas Point on the north shore of Humber Arm. They underlie the country to the north of Summerside, throughout the headwaters of Gillams Brook and they flank Frenchman's Pond. They also crop out in the Middle Arm just west of Long Point but are much reduced in variety and thickness. The section between Crow Hill and Church Cove, on the south shore of Humber Arm, has exposures of Summerside rocks but to the south they are thought to plunge under the Meadows formation. To the east it is suspected, but not proved, that the Summerside formation occurs in the low grade metamorphic zone. Nowhere is the true base of the formation seen.

No detailed stratigraphic subdivision of the formation can be given. Two broad subdivisions are, however, recognized:

A2. An upper red and green slate sequence.
A1. A lower arenaceous sequence.

A 1. The oldest member of the Summerside formation is tentatively regarded as the massive yellowish weathering sandstone which crops out to the west of the wharf at Summerside. The bedding in this rock type is quite obscure and its lithology is a uniform medium to coarse grained argillaceous sandstone. A similar rock type occurs on the south shore of the Arm, 400 yds. east of Church Cove. The sandstone may be as much as 20 feet thick.

Apparently overlying this member is a sequence of rusty-white weathering argillaceous sandstones. They are predominantly light green on the fresh surface but may be locally mottled red. Bedding is well marked ranging from 6 inches to 3 feet in thickness. This member is characterized by a sub-arkosic composition and is locally conglomeratic, containing rounded pebbles up to ¼ inch in diameter of white quartz and feldspar. This coarser facies may prove to be a separate mappable unit. More rarely the rock contains greenish brown shale fragments up to one foot long or small pebbles of red shale. Under the microscope the rocks are seen to consist of medium to fine grains of subrounded quartz with about 5% feldspar grains. The feldspars are often partially replaced by calcite or sericite. One or two percent of the rock consists of rounded grains and patches less than 4 mm. in diameter of a ?chlorite and ?sericite intergrowth (fig.3) which are typical of rocks of the Summerside formation and of the lower part of the Meadows formation. The matrix consists of fine quartz grains, chlorite and sericite with a very fine grained unidentified mineral, which together make up as much as 40% of the rock. The most common accessory mineral is zircon but garnet is occasionally found. Flecks of pyrite, often as distorted cubes, are sometimes present.

Large fallen blocks of this member, which have slipped to the shore under Crow Hill, sometimes show cross-sections of ripple marks. These have a wave-length of about 9 inches and an amplitude of about 4 inches.

Some of the more argillaceous beds, such as those found at Pettipas Point, show small scale convolute or slumped bedding. Large folds, which may have a non-diastrophic origin, occur under the northern scarp of Crow Hill. The proximity of this outcrop to a major reverse fault, however, suggests that these folds may have a tectonic origin. At this same locality, smaller, highly asymmetric recumbent folds and small thrusts within a single bed almost certainly represent primary structures. (fig. 4). The movement associated with these folds and thrusts has been from east to west. Further evidence for a westerly primary movement may be seen in the Curling road section at the crest of a hill leaving Corner Brook where primary interbedding-plane slip repeats a thin sandstone bed. The movement is opposite to that required by the local folding.

A most distinctive feature of these rocks is the development of a coarse fracture cleavage comparable with that described by Crook (1964) and called reticulate cleavage. Crook describes reticulate cleavage developed in weakly deformed mudstone from New South Wales. When seen on a weathered surface, this cleavage simulates ripple marks with a wave-length of a few inches, but with a small amplitude. No other arenaceous rocks in the area show this feature.

The total thickness of these beds is estimated to be in the order of 100 feet.

Overlying and perhaps locally interbedded with the green sandstones, is a series of dark red, medium to thickly bedded sandstones. These sandstones owe their colour to haematite which is present as a matrix, consisting of up to 35% of the rock, or, more rarely as irregular, included fragments. It is probable that the red colour locally gives way to green along the strike. Under the microscope the rock is seen to be poorly sorted. The sand grains are of two types; they may be rounded and spherical up to 3 mm. in diameter, or smaller, less than 1 mm. long, angular and non-rounded. Some of these smaller grains are single quartz crystals, whilst others consist of a fine mosaic of quartz crystals with or without calcite crystals. The calcite crystals often include small euhedral dolomite crystals. Feldspar occurs as larger detrital grains, partially replaced by calcite, with a composition in the andesine range and as smaller fresh grains which are probably authigenic. Small fragments up to 2 mm. in diameter of chloritized material containing very small lath#s of what may be feldspar, or pseudomorphs after feldspar, are found as well. The matrix of the rock is predominantly silt-sized quartz, chlorite and haematite.

It is suggested that the rock is at least partially derived from a volcanic terrain. The small angular grains cannot have been originally quartz, calcite or dolomite, since they are replaced by a mosaic containing all of these minerals. No recrystallization process is likely to result in a reduction of average grain size. The shape of the grains greatly resembles that of volcanic glass shards, which suggests that the grains were originally shards but have been replaced by quartz as single crystals or by quartz, calcite and dolomite, as a fine mosaic. The chloritized fragments and andesine feldspar could also have been derived from volcanic rocks.

The member varies in thickness; in the Humber Arm area it is not more than 15 feet thick, whereas at Frenchman's Pond it is at least 60 feet thick.

The thickness of the whole lower arenaceous part of the Summerside formation is estimated to be 250 feet.

A 2. Above the arenaceous sequence, and perhaps locally interbedded with it, occurs a sequence of red and green slates, the roofing slates of previous authors. In general, the red slates underlie the green slates, though locally they can be seen to pass into each other along their strike. Bedding in the slates is revealed only by a few horizons of reddish or greenish, buff weathering, current bedded siltstones, usually less than 6 inches thick. The siltstones consist of fine silt grains set in a calcareous or argillaceous matrix but locally the hand samples have a cherty aspect. Fine bedding features within the siltstones are revealed by haematite rich layers.

The slates themselves are very fine grained and have a well developed slaty cleavage, so perfect that they were formerly quarried for use as roofing slates. Since no other rock type in the area has such a well developed cleavage, and they grade upwards into rocks without such a cleavage, it is possible that they have a mineralogy which is different to that of other Humber Arm argillaceous rocks. In view of the suspected volcanic origin of some of the components of the red sandstone beneath the slates, it is suggested that the slates themselves contain a significant proportion of finer-grained volcanic material.

The slates are in the order of 50 feet thick; the total thickness of the Summerside formation is not less than 300 feet. No upper limit can be placed on the green slates, however, since they pass, by gradation, into the basal rocks of the Meadows formation.

## B. The Summerside-Meadows formation transition zone.

The transition between the Summerside and Meadows formations is marked by a gradual change from green slates to bluish shales.

The transition is exposed about 300 yards west of Long Point in Middle Arm, 50 yards west of Pettipas Point and twice along the sections under Crow Hill. Typically, ascending the section, the green slates of the Summerside formation lose their competent silty beds and change colour to bluish green. Higher in the section, the beds are blue or silvery blue and alternate with darker beds. With the colour change, the good slaty cleavage is lost. The transition takes place over an estimated 30 stratigraphic feet, but the zone is invariably complicated by folding and faulting.

At Pettipas Point the transition zone can be seen in both the coastal and road sections; although disrupted by faults it can be followed easily. The transition zone is repeated by an anticline along the southern shore of Humber Arm. The eastern occurrence, west of Crow Hill, is well exposed in the railway section but poorly exposed in the road section above. At these localities the transition zone is disrupted by high angle faults but the general character of the transition is preserved. The western occurrence of the zone, along the shore east of Church Cove, includes a sequence of lustrous red shales not seen elsewhere. The transition is further complicated by a block of brown shale belonging to the Meadows formation, which has been faulted into the zone. A covered section, near the wharf at Church Cove, separates the blue banded slate of the transition zone from the brown shales of the Meadows formation. The transition zone is thickest and best exposed in the Long Point area where it can be seen to grade into the Meadows formation.

## C. The Meadows formation

The name Meadows formation is proposed for a sequence of sandy and shaly rocks, typical members of which are exposed in the general area of Meadows, situated between Summerside and Gillams on the north shore of Humber Arm. At this locality, not all the characteristic horizons are developed, but no other section, with the possible exception of the Curling shore section, is as well exposed and characteristic of the formation as a whole.

The Meadows formation incorporates all of Weitz's original Summerside formation with the exception of its middle member (now the writer's redefined Summerside formation). It also includes the McIver's quartzites of his McIver's formation, also Lilly's (1963) Irishtown quartzites, while its upper part is considered to be equivalent of his Penguin Arm quartzites.

Rocks referable to the Meadows formation outcrop extensively in the map area. In Middle Arm, the formation occupies the shore section from just north of Barachois Brook to west of Parkes Cove. The whole of the north shore of Humber Arm from the mouth of Hughes Brook to McIver's, shows outcrops of the formation, except for the part underlain by the Summerside formation and the Rattler Block (see Fig. 2). Most of the country between Middle Arm and Humber Arm, east of a line between McIver's and Cox's Cove, is also underlain by the formation.

On the southern shore the formation is seen between Benoit's Cove and Halfway Point; between Sopers and Davis Cove; and also between De Grouchy Point and Brakes Cove.

Unfortunately the internal relationships of the formation are not well understood but the writer tentatively proposes to subdivide the Meadows formation as below:

| | | |
|---|---|---|
| TOP | D. | Transition zone into the Cooks formation. |
| | C.6 | Dark shales with medium bedded white quartzites at the top grading down into massively bedded quartzites, often coarsely conglomeratic. |
| | C.5 | Dark shales with well bedded quartzites. |
| | C.4 | Dark violet micaceous shales with massive dolomite, greywackes and thin yelow weathering siltstones. |
| | C.3 | Dark brown-black shales with scattered white quartzites and common, thin, rusty weathering greywackes. |
| | C.2 | Dark brown shale with ribbon-like siltstones. |
| | C.1 | Dark brown shales with medium bedded brown weathering quartzites and perhaps a few massive white quartzites towards the base. |
| | B. | Transition zone into the Summerside formation. |

It seems probable, however, that these "members" interfinger to a varying degree and only represent local facies developments. Some could even be the same horizons tectonically repeated.

## Description of the chief units of the Meadows formation

<u>C. 1</u> The oldest member of the Meadows formation is believed to be a sequence of dark brown shales with 6 to 18 inch thick beds of dark brown weathering quartzites. These beds crop out behind the fish-plant at Davis Cove west of Summerside and along

the Ball Diversion, just before the Curling road junction on the south side of Humber Arm. They seem to be missing at other localities.

Several thick beds of white weathering quartzite occur above the transition zone west of Davis Cove and at several other localities. These beds are assumed to be part of the lowest sequence of the Meadows formation but it is possible that they are faulted into the sections. The total thickness of this lower series is estimated to be 50 feet.

C. 2 A series of dark brown shales is found on the north west shore of Davis Cove, interbedded with thin white siltstones which range in thickness from 1 mm. to 2 inches. Each siltstone bed shows current bedding and has a "wavy bedded" appearance (fig.5). The siltstones consist of angular silt sized quartz grains set in a chloritic matrix. Composite ?chlorite-?sericite grains, similar to those described from the Summerside formation are common (fig.3). The thickness of these beds is estimated to be 50 feet.

C. 3 Overlying the lower beds at Davis Cove, is a series of massive white weathering quartzites, interbedded with black to brownish shales. Locally the shales contain medium bedded, rusty weathering argillaceous sandstones, thin wavy siltstone laminae and, more rarely, grey current bedded limestones. The white weathering quartzites consist of quartz grains of various sizes but averaging about 2 mm. in diameter which tend to be rounded but are often tectonically stretched or recrystallized.

The matrix is often calcite, sometimes containing euhedral dolomite crystals, but may, however, be chloritic or sericitic. The weathered colour depends on the nature of the matrix. Those with a calcite matrix weather pure white; those with much dolomite or chlorite weather browner. If much chlorite is present the fresh rock has a greenish tinge. Feldspar grains are small and uncommon. The main accessory minerals are normal and metamict zircon, with rarer garnet, epidote and possibly kyanite.

The quartzite beds range in thickness from between 2 and 6 feet. The thinner beds tend to be more impure than the thicker ones. They are usually quite homogeneous and show no internal structure. Two examples of coarse current bedding were, however, seen, one a ½ mile north of Benoit's Cove and the other at Curling (fig. 6). Sometimes the quartzites are crudely graded. These beds are conglomeratic at the base, with pebbles up to ¼ inch in diameter, but this coarse zone is separated by an ill-defined shaly parting from the upper massive, but finer grained, part of the bed. Asymmetric load casting, at the base of the quartzites, is sometimes encountered. The asymmetry of the load casts indicates movement which is always from the west.

The thinner sandstones or quartzites which are interbedded with the shales, weather a deep rusty brown. These beds are up to 9 inches thick and often show ripple-drift current bedding. They are characteristically fine grained and have an argillaceous and calcareous matrix.

The limestone, though uncommon, are comparable to the platy limestones of the Cooks formation. The interbedded shales are black or brown weathering and locally contain buff weathering siltstone laminae. Bedding plane fissility is well developed in the shales and at the mouth of the Rattler Brook these planes of parting are lined with blade-like gypsum twins. Pyritiferous horizons are not common.

In contrast to the fissile shaly rocks, another argillaceous rock type is characterized by its massive black aspect. These rocks occur as well-defined beds up to 10 feet thick which show no lamination or grading. Over half of the rock consists of an argillaceous and micaceous matrix which contains unsorted quartz grains varying in size from silt to grains ¼ inch in diameter. The larger grains are conspicuous but not common. Rarer constituents are feldspar and grains of ?chlorite-?sericite-type intergrowth.

A clue to the origin of this rock is provided by occasional inclusions of plastically deformed blocks of yellow weathering siltstone (fig. 7). These blocks, up to one foot in length and several inches wide, may be oriented in any direction within the bed. There is every gradation between blocks with well defined internal lamination to those with no internal lamination which resemble concretions.

It is likely that these beds are deposits of the mudflows or fluxoturbidites such as those described by Dzulynski et al. (1959). Essentially, a series of unconsolidated beds, probably well sorted, creeps or flows down a slope. The violence of the movement is enough to destroy any original bedding and mix the sequence, but not enough to form a suspension, from which a graded bed could deposit. The siltstones, with their dolomite cement, were at least partially lithified and competent enough to retain some cohesion.

Although the "fluxoturbidites" are most common in the C.3 zone, they do occur in other zones of the Meadows formation. The possible significance of similar "fluxoturbidites" exposed outside the thesis area near the base of the Humber Arm series along the south-east shore of Humber Arm will be briefly considered in the discussion.

A much more uncommon resedimented argillite may be described as a shale breccia. Flat fragments of shale between 1/8 and 1/4 of an inch in diameter are set in shaly matrix, the proportion of fragments to matrix being about equal. The fragments are distinguished from the matrix by slight textural and colour differences. This type of breccia could have been formed by the down slope creep of a shaly sequence, some beds of which were more competent than others and yielded by fracture rather than by flow.

Beds referable to the C.3 division are the most widely distributed in the area. They make up the whole of the section from Apsey Cove to Davis Cove. In Middle Arm they occur between Parkes Cove and the mouth of the Barachois Brook, while at Curling they make up the section east of the fish plant.

Since the beds are repeated by folding and complicated by faulting, the thickness is difficult to estimate. It must, however, be at least 600 feet.

C. 4 The zone of violet shales and massive dolomite-rich sandstones, is believed to overlie the C.3 sediments. It was not recognized between Apsey Cove and Davis Cove, but is seen under the C.5 zone at McIver's. It can also be found on the foreshore near the fish plant at Curling. Similar rocks occur on the point north-east of Parkes Cove and just north of Benoit's Cove.

The rocks of this unit are best exposed north of the mouth of Rattler Brook, south of McIver's. Here about 200 feet of brownish shales assigned to the C.3 zone contain, near the top, several small lenses of dolomitic breccia. These beds grade up into a sequence of brownish weathering quartzites interbedded with brown-black shale which also includes a few current bedded pyrite beds up to 4 inches thick. A massive greywacke forms the first point to the north of Rattler Brook. It yielded the following analysis:

| | |
|---|---|
| Carbonate material | 20% |
| Clay | 35% |
| Quartz | 45% |

Staining, using Evamy's (1963) method, shows that, with the exception of a few calcite grains, the carbonate component is iron-rich dolomite.

To the north of the point the greywacke is succeeded by 200 feet of dark violet shales containing abundant white mica flakes with interbedded yellow weathering siltstone. These siltstones greatly resemble those found as inclusions in the "fluxoturbidite" horizons described above. The violet shales grade upwards into the brownish shales and quartzites of the C.5 zone. The total thickness of the violet shales and lower greywacke is about 200 feet. Elsewhere the zone is thinner.

Below the greywacke which forms the point north of the Rattler River, the beds show resedimentation features (fig. 8). Greywacke blocks of various shapes and sizes are distributed throughout a shaly matrix. The largest of these are rounded slumped masses, whose asymmetry indicates slumping from the east. Smaller masses are mushroom-shaped, up to 4 inches in diameter or small trace fossils. These masses probably represent load casts and the filling of worm burrows associated with a greywacke bed later removed by slumping. Other masses are ellipsoidal in shape with diameters up to 5 inches, and are marked by striations parallel to their equator. They can be compared with sandstone whirl balls described by Dzulyński et al. (1956, cf. pl.X., fig. 2 ). The formation of these whirl balls is attributed to the action of vortices developed in mudflows. The direction of the dip of the striations on the whirl balls indicates direction of movement of the mudflow. The striations in the examples found, dip steeply westwards, indicating a movement of the mudflow from the east.

Sedimentary dykes and sills are well developed below the slumped horizons (fig. 8). Small offshoots from the sills are ptygmatically folded and deflection of the bedding in the shales adjacent to the dykes is common. The folds and deflections are probably effects associated with compaction of the sediments. Some of the dykes show a set of calcite-filled fractures, apparently the refracted equivalent of the bedding plane cleavage of the shales. Dzulynski and Radomski (1956) attribute similar dykes in Poland to the injection of quicksand following rapid loading by slumps or turbidity currents.

C. 5 A sequence of brown-black shales and interbedded massive whitish quartzite, about 200 feet thick, overlies the C.4 sediments. This sequence is very similar to the C.3 rocks.

C. 6 The youngest rocks of the Meadows formation are a sequence of whitish quartzite with lenses of coarse conglomerate. Rocks of this horizon form the hill behind West Street, Corner Brook and are also found at Irishtown, Petries, Benoit's Cove, McIver's, to the west of Parkes Cove, and outside the thesis area at Penguin Cove. The coarse conglomeratic facies has been observed at the Corner Brook, McIver's, Benoit's Cove and Penguin Cove localities. At the other localities the quartzites are coarser than usual and locally contain white quartz pebbles up to ¼ inch in diameter.

The conglomeratic horizons are lenticular developments of the finer grained quartzites. The individual conglomerate horizons are usually less than 6 feet thick and are interbedded with finer grained quartzite (grains up to 2 mm. in diameter), which also forms the "matrix" of the conglomerates. These finer grained quartzites are comparable with the white weathering quartzites found elsewhere in the Meadows formation. The phenoclasts in the conglomeratic horizons vary greatly in size, shape and lithology. They are not imbricated and tend to be scattered; it is uncommon to find two phenoclasts in contact. Walthier (1949, p. 24) found boulders up to 5 feet in diameter. Lilly (1963, p. 68) records diameters up to one foot at Penguin Arm. McKillop (1963, p. 63) described boulders slightly larger than this at the Corner Brook locality. In general the conglomerates tend to become coarser eastwards. The phenoclasts are of the following lithological types:

Rounded, subspherical, white quartz pebbles up to 2 inches in diameter.
Deeply weathered boulders of an acidic plutonic rock.
Sandstone and conglomerate pebbles.
Yellow weathering, grey, very fine grained, dolomitic siltstone pebbles.
Uncommon pebbles of white limestone with black oolites.
Platy grey limestone fragments.
Cobbles of grey fossiliferous limestone.
Shaly fragments.

In addition a single boulder of black limestone containing trilobite fragments was found.

Walthier (1949) recorded a biotite schist boulder while McKillop (1963) reported small fragments of fine grained igneous rock. In general, the igneous rocks are deeply weathered, the quartz well rounded, while the sediments can be either sub-angular or rounded.

The authors cited above, record the presence of St. George and Table Head carbonate fragments in the conglomerates. A careful search by the writer, however, failed to discover any carbonate fragments that could be referred to these formations.

All the fossiliferous limestones are of Lower Cambrian age. At Corner Brook the conglomerates and associated quartzites are about 400 feet thick.

The conglomerate and quartzites grade into the Meadows-Cooks transition. At McIver's the upward sense of the transition zone is clearly indicated by load casting on the base of some of the quartzites.

D. Transition zone into the Cooks formation.

A sequence of sediments, transitional between the Meadows and the Cooks formations, is exposed at several localities. The zone is best seen along the shore section beneath Sopers to the west of Curling, but can also be seen west of Halfway Point, and, outside the thesis area, between Penguin Cove quartzites and Penguin Cove limestones along the north-west shore of Penguin Cove. At these localities both the Meadows and the Cooks formations are exposed in the same section as the transition zone. In McIver's river, at Skeleton Cove south of the Rattler Brook and between Cox's Cove and the first headland east, the transition zone is exposed but its field relationships are not clear.

Since the zone everywhere consists mainly of incompetent rocks, it is much folded and faulted as well as being primarily deformed.

The most common rock types of the transition zone are beds, usually less than 9 inches thick, of brown weathering quartzite and grey current bedded limestone with interbedded black shale.

The shale is more abundant than the quartzite and limestone. Near the top of the transition zone several horizons are characterized by yellow weathering siltstone laminae which show both contorted and current bedding. Oolite horizons are exposed at Sopers (just east of Giles Point), Skeleton Cove, McIver's River, and Penguin Cove. These horizons, usually less than 6 inches thick, are not found in any other zone of the Humber Arm series.

The oolite beds are composed of well-formed, unabraded calcite oolites, or more rarely pseudo-oolites up to 3 mm. in diameter. Under the microscope the oolites commonly show radial and concentric structure and sometimes have a coarser patch of calcite, often resembling shell fragments, as a nucleus. Commonly, several concentric rings have been pyritized. The matrix, medium sized calcite crystals, also contains scattered grains of quartz ranging between angular silt-sized grains and well-rounded subspherical grains, up to 4 mm. in diameter. Usually these quartz grains make up less than 3% of the rock but at Sopers a calcareous sandstone crops out which contains 15% of abraded and crushed oolites. The oolites are concentrated near the top of the sandstone bed and this part of the bed shows current bedding. Although none of the other oolite beds shows grading in size or concentration of oolites, the shales immediately above may contain oolites flattened by compaction.

The assemblage of oolite with non calcareous shale is anomalous since most authorities consider oolite formation to be restricted to shallow, calcium carbonate saturated environments. The unabraded condition of most of the oolites and grading of the oolite-bearing calcareous sandstone, suggest transportation by turbidity currents from the environment of formation to the predominantly muddy environment in which the shaly rocks of the transition zone were deposited. Flute marks on the base of an argillaceous sandstone which crops out just east of Cox's Cove, provides further evidence for the action of turbidity currents (fig. 9). The currents forming these marks flowed from the north. The slumped nature of many beds towards the top of the zone suggests that the beds were deposited with an initial dip steep enough to facilitate density flows; indeed, the oolites themselves occur as rounded slumped blocks at the Penguin Cove and McIver's River localities.

Larger scale slumping may account for the absence of the transition zone in the McIver's shore section. Above the conglomerates of the Meadows formation at McIver's is a chaotic zone consisting of platy limestone fragments embedded in black shale. These are well displayed on the small tide-island to the south of McIver's Cove (not to be confused with McIver's Island which is underlain by the rocks of the Meadows formation). To the north of the mouth of McIver's Brook the platy limestones are less chaotic but are much deformed by slumping. Since the beds of the transition zone are found in McIver's Brook on strike with the slumped zone, this slumped zone must die out along its strike.

The thickness of the transition zone is difficult to estimate. It is not known how much it is thickened by folding. Since, however, the oolite zones do not seem to be repeated by folding, the thickening may not be great. 300 feet is the estimated thickness.

## E. The Cooks Formation.

The Cooks formation is essentially the equivalent of Walthier's (1949, p. 25-26) Cooks limestone tongue. It is reinterpreted, however, not as a tongue, but as a formation that does not appreciably change thickness throughout the map area. Furthermore, it is restricted to those rocks which have limestone as the carbonate component and black shale as the shaly component. The lack of arenaceous material sharply differentiates the Cooks formation from the underlying Meadows and Summerside formations.

On the south shore of Humber Arm, at least, the formation can be subdivided as follows:

- E. 2. Platy grey limestone with black shale and only rare limestone breccia.
- E. 1. Predominantly lime-breccia.

These divisions incorporate the Mt. Moriah limestone conglomerates described by Schuchert and Dunbar (1934, p. 89) and Twenhofel (1940). They are thought to be equivalent to Lilly's 1963, p. 69) Penguin Arm limestones and to McKillop's (1963, p. 70) calci-rudites.

The type section of the Cooks formation is defined as the shore section between Giles Point and Halfway Point, on the south shore of Humber Arm. Although this is the best section of the Cooks formation exposed in the area, it is strongly deformed since it coincides with the core of a synclinorium; furthermore the top of the formation is not exposed at this locality.

Rocks referable to this formation, away from the type section, can be seen capping Mt. Moriah where they have been carried eastwards by a thrust (Walthier 1949). Others also occur just south-east of Frenchman's Head but here their stratigraphic relationships are not clear. On the north shore of Humber Arm they are found at Bound Head and for about ½ mile north of McIver's Cove. In Middle Arm, the Cooks formation occupies all of the coastal section from Cox's Cove west to Black Head with the exception of the section south of Parkes Beach.

E. 1 In the type section, the lowest part of the formation is characterized by an abundance of lime-breccias. At Giles Point the contact between the breccias and the transition zone is sharp but overturned, while at Halfway Point, high angle faulting complicates the contact. These lower lime-breccias have been called "intraformational limestone conglomerates" by Schuchert and Dunbar (1934, p.89) who considered that the conglomerates were formed by subaerial desiccation and redeposition. Some, however, were thought to be formed as a result of submarine sliding.

The rock types represented in the E.1 sequence may be classified as follows:

1. Platy light grey to dark grey weathering limestones, averaging about 4 inches in thickness, interbedded with black shale. The rocks of type 1 occur interbedded with the other types.
2. Platy limestone fragments chaotically set in a dark shaly matrix.
3. Platy limestone fragments set in a calcareous matrix.
4. Limestone boulders and platy limestone fragments set in a shaly matrix.
5. Limestone boulders and platy limestone fragments set in a calcareous matrix.

These rock types are thought to form a genetic series resulting from primary deformation.

The simplest type of deformation seen in these rocks is sliding along bedding planes similar to that described by Cloos (1964) from the southern Appalachians. At several places between Giles Point and Cooks Point a limestone bed may be seen showing such deformation. The direction of movement in this sliding is opposite to that arising from bedding plane slippage caused by folding, and furthermore only a single bed is affected. The movement was from east to west, indicating that the paleoslope at that time was as depicted in fig. 10.

A stronger primary deformation resulted in a knotting or balling-up of the sediment. These knots are enclosed by undeformed sediments. In this case the limestones were not competent enough to fracture but the sediment did not lose cohesion during the movement. The movement indicated by the asymmetry of the folds is from east to west in the examples seen just east of Cooks Cove.

More severe slump movement resulted in the limestones yielding by fracture during the flowage of the argillaceous material. The resultant rock contains platy limestone fragments chaotically dispersed in a shaly, friable matrix; the type 2. breccia.

Where the sequence that gave rise to a mudflow contained thicker beds of limestone these ruptured and formed limestone blocks. Blocks which were not fully lithified became rounded during transportation. The type 4 breccia formed in this way.

In some cases the mudflow gained sufficient momentum to give rise to a density current which washed the limestone fragments free of mud and redeposited them as a platy limestone breccia of type 3.; the calcareous matrix was derived from the same current. The absence of imbricate structure in the breccias suggests deposition from a spent density current rather than from one with enough residual energy to provide a final tractional movement along the bottom. Breccias of this type are often, but not always, graded, with the largest plates at the base of the beds. The lack of grading of some breccia beds is attributable to the peculiar hydrodynamic properties of platy fragments which deviate considerably from Stokes Law.

The exotic blocks found in these breccias are of several different types, the most common being a light grey limestone of somewhat coarser grain than the normal Cooks type, which sometimes contains Lower Cambrian fossils. Blocks of two sorts of oolite rock are represented. One is a grey limestone with black oolites; the other, a grey limestone with widely scattered grey oolites. Other blocks of grey saccharoidal limestones contain diffuse dark red patches. At Bound Head, large masses of thin platy limestone interbedded with a highly calcareous shale are found in the breccia (fig. 11). This rock type is apparently in place to the north as part of the Penguin Arm limestones (Lilly 1963, p. 121, fig. 14). At Halfway Point a massive block of breccia, some 8 feet by 5 feet by an unknown dimension, contains blocks of breccia and is itself part of a breccia. At this same locality a large block of buff weathering sandstone is found in the breccia (fig. 12). This block measures 9 feet by 4 feet and could not have been transported by normal marine currents. Much smaller blocks of a similar sandstone occur as occasional components in other localities. The sandstone is comparable with some of those from the Meadows formation, consisting of medium sized, rounded to subrounded quartz set in a calcareous matrix which makes up about 25% of the rock. It also contains about 5% fresh feldspar, some of which is microcline.

It is suggested that the breccias of type 5 which contain very large blocks, represent the residue of density currents, too coarse to be put in suspension but transported along the bottom by sliding and saltation. The blocks in these breccias show signs of having ploughed through their matrix before finally coming to rest, but their bottom contact is always conformable with the limestones and shales below. The matrix of the blocks probably represents beds disrupted by the impact of the blocks during the last stage of their movement when the blocks had only enough kinetic energy left to throw the argillaceous components of the disturbed beds into suspension.

Exotic blocks are most common in this type of breccia suggesting that the flows had their origin in a facies not represented in the area.

A different type of slumping can be seen at the base of the Cooks formation at McIver's where the Meadows formation passes directly into a platy limestone breccia with a shaly matrix typical of the Cooks formation. This breccia contains arenaceous blocks as well as limestone fragments immediately to the south of McIver's Brook. To the north of the brook a much distorted sequence of platy limestones and shales crop out (fig. 13).

A sequence, about 30 feet thick, of rock types not exactly equivalent to any others exposed in the area crops out above the distorted platy limestones. The sequence includes black shales, siltstones, carbonates and carbonate breccias. An unusual rock type, 2½ feet thick, is found in this section consisting of a dark grey limestone with a coarse brownish yellow weathering network of dolomite replacing about 50% of it. It is crowded with small, less than 1 mm. long, euhedral quartz crystals.

Another chaotic zone separates this sequence from a series of massive hard green shales containing a thin band of fine dolomite breccia, forming the small headland west of McIver's Cove. The green shale is separated by a covered zone from the Cooks formation which crops out on the north shore of the next cove north. None of these slumped horizons can be seen in McIver's Brook; therefore it is assumed that the disturbed zone pinches out to the east. The zone is not found on strike at Cox's Cove but may be hidden under the superficial deposits that occur there.

It is suggested that this disturbed zone has a mixed origin. The lowest coherent carbonate-shale sequence with lithologies not seen elsewhere in the area is interpreted as a large slipped block which rode over and disturbed the limestone-shale sequence below. The geometry of the folds in the limestone-shale sequence suggests that the slipped blocks travelled from the east. The green shale horizon, however, is correlated with similar rocks in the G.1 zone of the Middle Arm Point-Woods Island formation transition zone, and is therefore a tectonic slice.

The erratic distribution of the breccia zones near, or at, the base of the Cooks formation indicates that the breccias were not deposited as continuous sheets. In the type section they are developed at the base of the formation, and only thinner and less coarse breccias are found above. In other localities, however, the breccias are found higher in the section; hence the presence of breccias does not uniquely define the base of the formation. Moreover, the direction of coarsening of the breccias is not clear. The breccias on the north-western limb of the main synclinorium along the southern shore of the Humber Arm are much coarser than those on the south-eastern limb. Furthermore, the breccias are very coarse at Bound Head and this outcrop is believed to originally represent a more western facies than elsewhere. Breccias are less coarse and less frequent between Cox's Cove and Black Head. To the north-east, in Penguin Arm, however, the breccias contain fragments up to 2 feet in diameter, and a massive grey limestone facies is developed. This limestone also occurs at McIver's.

Although no firm conclusions regarding the geography of the paleobasin or the source of the breccias have been drawn, the necessary information could probably be obtained from a more careful and statistical study of the breccias. The thickness of the E.1 zone, breccias and interbedded shales and limestones, is estimated to be 100 feet.

E. 2 The upper part of the formation consists of black shales with interbedded limestones and uncommon laminae of buff weathering siltstone. Green shale and dolomitic beds are typically absent, a feature which distinguishes the Cooks formation from the Middle Arm Point formation.

The limestone beds of the Cooks formation are very fine grained, weather light or dark grey, and have a bluish cast on the fresh surface. The limestones range in thickness from fine laminae to beds 18 inches thick; the beds being generally more abundant and thicker towards the top of the formation. Frequently the limestone beds contain fine current bedded dolomitic laminae emphasised by different weathering. Normally the upper and lower bedding planes are sharp and planar but certain horizons show a nodular development of uncertain origin.

The nodular horizons resemble ripple marks, however, in cross-section they show a regular thickening and thinning which may cut out part of the limestone, leaving isolated elliptical masses strung out along the bedding. The pinch-cuts are not recrystallized as one would expect if the nodules were formed by boudinage. Moreover, the nodules cannot be concretions since they are often current bedded. Brueckner (pers. comm. 1964) has suggested that the nodular development resulted from a partial solution of an originally continuous limestone horizon soon after the deposition.

Other beds referable to the upper part of the Cooks formation are in fault contact with zones of chaotic deformation under the beacon south-east of Frenchman's Head. Near the fault the beds have been dolomitized and are brown and greenish in colour. Thin, fine lime-breccia beds, typical of breccias in this zone, are exposed at this same locality.

The top of the formation is difficult to define. It is the author's opinion, however, that it grades up into the overlying Middle Arm Point formation. Evidence for this is described below (Section F.).

Since the top and base of the E.2 zone are never present in the same section an accurate estimate of its thickness cannot be made. In the type section at least 500 feet of sediment are present and this can be taken as a minimum thickness.

## F. The Middle Arm Point formation

The name Middle Arm Point formation is proposed for a sequence of black and green shales with more competent dolomitic strata exposed to the south of Black Brook, to the south of Middle Arm Point and elsewhere in the thesis area. The strata on Middle Arm Point, however, are referred to the G. transition zone.

Parts of this new formation include units of Weitz's (1953) North Arm and McIver's formations as well as the western outcrop of the Cooks limestone tongue proposed by Walthier (1949). The formation is lithologically similar to the Green Point series described by Schuchert and Dunbar (1934, p.38) who found lowest Ordovician graptolites in the series but were unable to establish its stratigraphic relationships with the rest of the western clastic sequences.

Schuchert and Dunbar (1934, p. 87) say: "It is probable that the Green Point beds are also thrust into the Humber Arm series on the north side of Middle Arm of Bay of Islands, for in Seal Cove, near Pigeon Head, we observed interbedded shales, thin limestones and sandstones with intraformational breccia like those of the Green Point beds". The writer concluded, after a visit to this locality, that these shales belonged to the Middle Arm Point formation.

According to the present interpretation, the formation is a normal part of the Humber Arm series. It overlies the Cooks formation and grades up into the Woods Island formation. The formation can be divided into two units:

F. 2. Black and green shales with rare competent beds.
F. 1. Black and green shales with competent beds.

The whole formation is characterised by black and green shales and dolomite as the main carbonate mineral.

F. 1 The base of the formation can be seen along the northern shore of the cove, south of Middle Arm Point where platy limestone of the Cooks type pass, by gradation, into a series of massive yellow weathering dolomitic beds, up to 2½ feet thick, interbedded with black shale. This sequence is approximately 150 feet thick.

A different transition takes place at Skeleton Cove, immediately south of Big Head where about 10 feet of grey platy limestones, with contorted and disrupted bedding, grade up into a sequence 10 feet thick, of rusty weathering black and green shales. The shales contain interbedded, thin, yellow weathering dolomitic laminae.

The base of the formation is defined as the lowest horizon with bedded dolomite rich layers and usually corresponds with the first green shale horizons.

Above the basal shaly sequence at Skeleton Cove, a sequence of yellowish brown weathering siltstones crops out and forms the scarp running east from Big Head. The siltstone beds average about 6 inches in thickness and are frequently current bedded with worm-marked bottoms. These beds are intensely folded about 50 stratigraphic feet above the base of the section and pass into a zone of chaotic deformation.

Lithologically similar beds occur south of Whites Brook, north of McIver's (fig. 14) where they are faulted against the Cooks formation. Here several other types of competent beds are interbedded with the green and black shale. The most conspicuous type is dolomite breccia, up to 3 feet in thickness, consisting of light yellowish dolomite pebbles up to one foot long, set in a darker yellowish-green fine grained dolomitic groundmass. Small sandstone pebbles consisting of millet-seed sand grains in a carbonate matrix are occasionally found in these breccias.

Another type of breccia consisting of sub-circular plates of dolomite, about 2 inches in diameter, occur as lenses up to one yard long. The origin of these breccias is probably similar to that of Cooks type breccias. A few greenish-grey weathering carbonate beds, about 3 feet thick, also occur in this section. These also contain abundant millet-seed sand grains.

A similar sequence of rocks is in thrust contact with the Meadows formation about 450 yards north of John's Beach, north of Benoit's Cove. Near the thrust the rocks are disturbed, but above it, the sequence starts with about 3 feet of thin carbonate beds interbedded with black, and lesser amounts of green, shale. Thin beds of violet micaceous shale with worm markings are also found in this sequence, the whole of which is referred to the lower part of the Middle Arm Point formation.

As well as the green and black shales with platy yellow-brown weathering dolomites typical of the F.1 zone, an unusual breccia crops out in the cliffs to the south of the house at Lower Beach, about 1½ miles north of John's Beach. The breccia zone is approximately 7 feet thick and consists of a black friable shaly matrix wrapped around scattered fragments. Each fragment is itself a breccia, consisting of several small, less than one inch in diameter, flattened plates of yellowish-green dolomite cemented together. The margins of the breccia zone show some calcite cementation. The breccia probably represents the deposition from a mudflow rather poor in fragments.

Massive, 5 feet thick blocks of limestone, apparently derived from the cliff behind, are strewn on the beach about 100 yards south of Lower Beach. The limestone is coarser grained than any other seen in the Middle Arm Point formation and, under the microscope consists of coarse calcite crystals which contain widely scattered recrystallized oolites.

It is difficult to estimate the thickness of the F.1 zone because of the incomplete sections. The writer suggests, however, that it is over 500 feet thick.

F. 2 The upper part of the Middle Arm Point formation is a thick pyritiferous sequence of green and black shales with only scattered dolomitic competent beds. Most outcrops of these rocks are highly deformed and they are frequently involved in zones of chaotic deformation (fig. 15). A relatively undeformed section through these shales can, however, be seen for about 400 yards along the coast to the south of the nameless brook which falls into the sea south of Middle Arm Point. The northern part of the section is faulted against rocks belonging to a younger formation, while in the south the rocks grade up into the G. transition zone. The thickness of these shales is about 400 feet. The top of the formation is conveniently placed at the last black shale horizon.

## G. The Middle Arm Point-Woods Island formation transition zone.

A series of sediments grading upwards into the Woods Island formation and downwards into the Middle Arm Point formation, can be recognized at several localities within the mapped area.

The transition zone can be divided into several lithological divisions which are listed below:

| | | | estimated thickness |
|---|---|---|---|
| TOP | H. 1 | Woods Island formation. | |
| | G. 6 | Laminated brown shale and siltstone | 10 feet |
| | G. 5 | Hard green shale with red-brown weathering siltstone and bedded white weathering chert. | 80 feet (G. 5 and G. 4) |
| | G. 4 | Hard green shale with massive beds and blocks of yellow weathering sandstone. | |
| | G. 3 | Soft brownish-green fissile shale with regular bedded green micaceous greywacke | 300 feet (max) |
| | G. 2 | Hard green shale with medium bedded yellow dolomitic beds | 30 feet (G. 2 and G. 1) |
| | G. 1 | Hard green shale with thin bedded white limestones: limited downwards by the presence of black shale. | |
| | F. 2 | Black and green shale of the Middle Arm Point formation. | |

Nowhere is this complete sequence exposed. Parts of it are exposed on Middle Arm Point as well as to the north of the prominent headland north of Black Brook, and on the north end of Eagle Island. Very similar beds are exposed on Balance Point (north-west of Gillams), at Jennings Cove, McIver's and in the bed of a small stream between Voy's Beach and John's Beach. This zone is almost certainly present in the eastern half of Woods Island but was not investigated there.

The transition zone is best developed to the north of the prominent headland north of Black Brook where the green and black banded shales of the F.2 division of the Middle Arm Point formation, grade into the hard green shale of the G.1 division of the transition zone. Over about 20 feet the green and black banded shales lose their black shale component but a small fault disturbs the gradation. Unidentified calcareous fossils are present in the upper part of the green and black shales and are also abundant in the G.1 division. Thin white limestone beds less than one inch thick, provide the only indications of bedding in the green shales and are thought to be of organic origin, representing a mature stage of the fossil.

This zone grades up into the G.2 zone, characterized by the same hard green shale but containing yellow weathering dolomitic siltstones and rare vitreous black quartzite beds less than 6 inches thick. This sequence is about 10 feet thick and passes, by gradation, into the G.3 zone which consists of a regular alternation of laminated, soft brownish-green shales with fine grained, micaceous greenish greywacke. The greywackes occur in beds, as thin as 6 inches or as thick as 6 feet but are most commonly between 2 and 3 feet thick and make up somewhat more than 50% of the section. They are not megascopically graded but may be finely current bedded and their bottom surfaces sometimes show flute casts and worm markings (fig. 16). The currents producing the flute casts appear to have come from the east. The total thickness of this zone is in the order of 300 feet.

The G.3 zone is in fault contact with the G.4 zone which consists of another hard green shale sequence. The lower part of the shale contains interbedded yellow dolomites and thin black quartzites with rare white limestone; the upper part of the shale has interbedded yellow weathering sandstone up to 5 feet thick and contains irregular lumps of the same sandstone. The whole G.4 zone is about 50 feet thick. The rest of the transition zone is faulted out at this locality but is found under Middle Arm Point.

The G.4 zone is faulted towards its base against a zone of chaotic deformation immediately to the north of Middle Arm Point.

The G.4 zone consists of shale, usually green but locally red, yellow weathering sandstone beds ranging in thickness from 9 inches to 8 feet, and a few black quartzite beds. The top of the G.4 zone is marked by a few dolomite beds up to 2 feet in thickness, which pass into the rocks of the G.5 zone.

The G.5 zone is a sequence of hard green shale which contains brownish-red weathering siltstones up to 5 inches in thickness, thin bedded yellow dolomitic rocks, and a few greenish-grey, white weathering thin chert beds.

The contact with the G.6 zone is complicated by primary deformation, but the base of this zone is a medium bed of micaceous calcareous sandstone which grades up into a laminated brown shale and white siltstone sequence which occasionally shows load casts. Towards the top of this sequence a thin bed of limestone breccia is found. The massive microconglomerate of the Woods Island formation occurs at the top of this section.

The transition sequence at Middle Arm Point has suffered much from primary sedimentary deformation. The sandstone members, in places, thicken and thin considerably along their strike; one bed was seen to thin from 9 feet to 9 inches in about 60 feet. The black quartzite beds are most susceptible and often become transgressive, showing many features which may be compared to those shown by intrusive igneous rocks. Sedimentary dykes and sills are commonly found and sometimes contain fragments of the host rock, forming sedimentary intrusion breccias. A body of black, hard quartzite, some 20 feet long is intruded into the sequence and is best described as a sedimentary laccolith.

The sedimentary deformation is probably connected with the loading effect of the massive microconglomerate which lies immediately above the deformed zone.

The transition zone crops out along the northern shore of Eagle Island, but is somewhat different in character. The whole section dips steeply eastwards or is vertical, but the beds face to the west. At the extreme north-eastern corner of the island, beds referable to the Middle Arm Point formation are directly overlain by a coarse, 10 feet thick microconglomerate. Within the Middle Arm Point formation, ptygmatically folded black quartzite dykes occur as well as an isolated block of sandstone about 3 feet across. The microconglomerate itself has a basal microconglomerate consisting of platy fragments, up to 4 inches across, of yellow weathering dolomites and dolomitic siltstones of the Middle Arm Point formation. These are set in a coarse groundmass of microconglomerate with fragments of rounded quartz up to 1/8 inch in diameter. The lower bedding planes show deep, bulbous flute casts. The main body of the microbreccia is similar to that of the H.1 division of the Woods Island formation. To the west and overlying this bed is a sequence comparable to the G.3 division of the transition zone but the greywackes are less in number and are thinner to the west. Flute marks are well developed on the lower surface of some of these greywackes (fig. 16), of the type described by Radomski (1958, cf. fig. 10, p. 363) as "hoof-like casts". They are thought to be formed by high velocity currents. Moreover they are often composite, another feature thought to indicate high velocity currents.

The current direction, as indicated by the flute marks, is from the east. This is confirmed by the current bedding in the greywackes.

Above this zone, on the north-west corner of the island, is a sequence of fissile green shales with patchy red zones. They grade up into a sequence of browner shales comparable with the G. 6 transition zone. Towards the top of the shales is a four foot thick sequence of platy grey limestones, some of which consist of a network of limestone tubes, a half inch or more in diameter. The core of these tubes consists of a rod of white, coarsely crystalline calcite, up to ¼ of an inch in diameter. These tubes may have an organic origin but in thin section no internal structure could be seen; they consist of very fine grained calcite surrounding the coarse calcite core. This horizon occurs a few feet below the base of the Woods Island formation, in the same stratigraphic position as the limestone breccia at Middle Arm Point.

A small part of the transition zone crops out at Balance Point where it is faulted at its base, against the Cooks formation, and overlain by a zone of chaotic deformation. The lowest part of the sequence consists of several tens of feet of massive-looking hard green shale with a bluish cast. Its fracture is more splintery than the hard green shale found at other occurrences of the transition zone. The only sedimentary feature seen in the shale was a block, about 3 inches across, consisting of small black shaly pellets set in a dolomite-calcite matrix. Quartz pseudomorphs after euhedral dolomite crystals are common within the black shaly pellets, which may indicate the hard green shale as a whole has been silicified, resulting in its more splintery fracture.

Higher in the section, yellow weathering sandstones up to 3 feet thick are irregularly interbedded with the shale. The irregular interbedding is a result of movement along several small faults that cut the beds at right angles to the bedding. Thin cherty beds and reddish weathering siltstones are also found in this part of the section. The whole sequence is about 50 feet thick and equivalent to the G.4 and G.5 parts of the transition zone.

Hard green shale, probably equivalent to the G.1 part of the transition zone, occurs at Jennings Cove and at McIver's. At McIver's, the hard green shales contain thin white limestone bands and pass, apparently upwards, into green and black shales, much disturbed by slumping. It must be assumed that the section is inverted since the green shale normally overlies the green and black shale.

Isolated outcrops of hard green shale similar to that of the transition zone, can be seen at several localities. Amongst these are outcrops in the eastern half of Woods Island; about ½ mile up Clarks River and in the river between Voy's Beach and John's Beach, as well as the road above.

### H. The Woods Island formation.

The name Woods Island formation is proposed for a sequence of shaly and sandy rocks with a few volcanic flows, typical members of which are exposed on Woods Island in the Bay of Islands. The arenaceous members are equivalent to Lilly's (1963,p. 71) "Western sandstone" formation and are correlative with parts of Weitz's North Arm and McIver's formations. The formation was subdivided as follows:

| | | |
|---|---|---|
| TOP | I. | Shales with interbedded volcanic flows and breccias: base of the Bay of Islands Igneous Complex. |
| | H. 5 | Thick bedded arkosic sandstones. |
| | H. 4 | Volcanics. |
| | H. 3 | Shales, siltstones and sandstones |
| | H. 2 | Shales with rare microconglomerate and green argillaceous siltstones. |
| | H. 1 | Massive microconglomerate. |
| | G. | Transition zone. |

<u>H. 1</u> The oldest member of the formation, a massive microconglomerate, occurs at several localities. It is exposed at Middle Arm Point and on the prominent headland to the north of Black Brook. It also forms the prominent headland on the north-eastern coast of Woods Island and forms the north-western corner of Eagle Island. Outside the thesis area it caps the western part of the peninsula between Middle Arm and North Arm (Lilly 1963,pl. 1) The blocks of sandstone visible in the cliff to the west of Black Head are probably referable to this member but were not investigated.

The massive microconglomerate is variable from locality to locality but its diagnostic characteristics remain constant. It is typically buff coloured and when washed by the sea weathers spheroidally, reflecting its homogenous nature and lack of fracturing or joints.

The rock consists of rock and mineral fragments which can be as coarse as 1/8 inch in diameter. Since these fragments tend to be rounded, the name "microconglomerate" is applicable. Rarely, lenses of limestone and yellow dolomitic pebbles, up to 4 inches across, are found in the rock but usually the grain size is uniform. These fragments are set in a matrix of silt sized quartz grains with a calcite cement. The rock fragments include the following types:

Abundant fine grained volcanic material of various kinds. The fragments are usually fresh but may have been chloritized. They are of basic or intermediate composition.
Medium grained calcite marble.
Fine grained carbonate rock, some of which may be arenaceous.
Composite, coarsely crystalline quartz grains.
Sandstones of various grain sizes.
Composite grains of quartz and feldspar.
Shaly fragments.

The mineral grains include:

Strained and unstrained quartz.
Feldspar-microcline-orthoclase-albite. They are usually fresh but may be partially replaced by calcite.

The fragments in these lists fall into three groups:

1. Those derived from basic or intermediate volcanic rocks.
2. Those derived from granite rocks.
3. Those derived from sedimentary rocks, probably of the Humber Arm type.

The thickness of the member is extremely variable. It is 250 feet thick at the first headland north of Black Brook and has a similar magnitude at the Woods Island locality; at Middle Arm Point it is represented by two beds each about 40 feet thick separated by about 10 feet of shale, whereas on Eagle Island it is much thinner, only some 30 feet thick. The sea, however, covers any westward extension of this member that may be present.

The rock is remarkably homogeneous throughout its thickness. The only indications of bedding are very rare strings of limestone pebbles. Sometimes these limestone pebbles have been completely weathered out so that bedding is revealed by a string of cavities in the rock. The basal bedding surface shows no non-diastrophic structures. ~~which are sedimentary in origin~~. It may, however, show coarse grooving, attributed to interbedding plane slip.

<u>H. 2</u> The top of the microconglomerate passes, by gradation, into a micaceous argillaceous sandstone at Middle Arm Point, and this rock grades up into green and locally red shale. The sequence is faulted against rocks of the Cooks formation. A similar gradation is exposed on the first headland north of Black Brook but again the section is tectonically terminated.

Beds which are thought to represent the continuation of the section are exposed between Black Brook and Whites Brook. The oldest part of the section, exposed just south of the mouth of Black Brook, consists of green, locally red shale, interbedded with thin dolomitic siltstones and white platy limestones. Some of the green shales contain shallow, ill-defined calcite cones about ¼ inch in diameter. Above these beds is a sequence of regularly bedded olive green shales and greenish siltstones. The relationship of this sequence with the H.1 microconglomerate is indicated by a massive, 8 feet thick bed and a thin lens, less than one inch thick, of microconglomerate which are interbedded with shale.

The top of this zone is taken to be a massive bed of dolomitic sandstone which crops out just north of the mouth of

Whites River. The thickness of the H.2 zone is estimated at 300 feet.

H. 3 Above the dolomitic sandstone is a sequence of white weathering siltstone and dark shale. Bitumen is sometimes found lining the joints of the siltstones in this sequence. The sequence is terminated by a fault at the mouth of Whites River but a very similar sequence of beds crops out just west of Frenchman's Cove where it grades up into the arkosic sandstones of the H.5 zone.

A sequence of dark shales and medium bedded sandstones, often showing current bedding and load casting (fig. 17), occurs beneath the arkosic sandstones of the H.5 zone on Woods Island. These beds have also been assigned to the H.3 zone.

In view of the discontinuous exposures of this zone, no accurate estimate of its thickness was made. The minimum thickness, however, is 400 feet.

H. 4 About 200 feet of altered basic volcanic flows crop out on the headland to the west of Tiheay Cove on the south shore of Woods Island. The flows rest upon about 6 feet of sheared red shale which contains quartz nodules, elongated in the plane of shearing, and small fragments of sandstone and haematite-stained limestone. The flow contact dips westwards.

The volcanic flows weather rusty red or dark green. The lower flows are massive and vesicular but higher flows consist of well formed pillows up to 2 feet across (fig. 18). The pillows are commonly set in a white calcite, sometimes bituminous, matrix which, in some places, grades into grey limestone xenoliths.

Locally the flows are crowded with xenoliths which include apple green shale, red shale which is often silicified into a hard jaspery substance, and sandstone. The xenoliths are up to 2 feet across but often their margins are ill-defined and are streaked out into the lava.

The volcanic horizon can be traced northwards across Woods Island as a low discontinuous ridge along which deeply weathered red outcrops of volcanic rock are found. The horizon thins to less than 10 feet on the northern shore of Woods Island and has, in addition to fine grained volcanic rock with red shale xenoliths, a coarser gabbroic component. The coarser facies occurs both as thin, devious tongues within the finer grained rock and as zones up to 4 feet across. Under the microscope the coarser facies consists of feldspar laths up to ¼ inch long, altered to fine grained calcite with small, euhedral dolomite crystals. The ferromagnesian minerals are altered to a mixture of chlorite, antigorite and ilmenite. Pseudomorphs, apparently after pyroxene, can be recognized.

The Woods Island volcanic horizon is probably an extension of the volcanic horizon found on the prominent rounded ridge about 3 miles south of Shoal Point shown by Cooper (1936). Other volcanic flows in the same stratigraphic position are included in Lilly's (1963) map, unit 13, on the peninsula between Middle Arm and North Arm. Furthermore, similar volcanic rocks, which crop out below the Summerside formation just west of Long Point (Lilly 1963 p. 64-65), could represent the H.4 volcanic horizon tectonically included in the section.

The top of the flows, to the west of Tiheay Cove, is marked by a 6 or 7 inch thick bed of red shale which was partially eroded before being overlain by a sandstone bed one foot thick. Overlying the sandstone is a sandstone with red shale fragments, separated by a small fault from the beds of the H.5 zone.

H. 5 The youngest beds of the Humber Arm series studied by the writer are a sequence of massive arkosic sandstones exposed on the western half of Woods Island and along the coastal section west of Shoal Point to the mouth of Blow Me Down Brook.

The lithology of the upper arkosic sequence varies but generally the sequence consists of light to yellowish brown weathering massive beds of arkosic to subarkosic sandstone with less common thinly bedded micaceous and argillaceous horizons. The rock is commonly coarse grained to conglomeratic with pebbles up to ½ inch in diameter. The more abundant pebbles are composed of quartz, feldspar, limestone or red chert. Volcanic material is uncommon though chlorite is sufficiently abundant in the matrix of some of the beds to give a greenish weathering colour. Haematite in the matrix colours the rock red in a few localities.

Typically, the rock consists of coarse to medium, rounded to subrounded grains, mainly quartz but between 20% and 25% microcline, orthoclase and albite, set in a matrix of finer quartz grains, chlorite and sericite, cemented by calcite. Well rounded zircon is the main accessory mineral.

The beds may be as much as 6 feet thick but are not graded. No current bedding was seen by the writer but Lilly (pers. comm. 1964) reports large scale current bedding can be seen on Seal Island to the west of Woods Island. The beds are often load casted, this feature is developed when a coarser facies has settled into a finer facies. Channelling is also common.

An unusual feature is the occurrence of well developed ridges on some of the bedding surfaces (fig. 19). These ridges are spaced about three inches apart but bifurcate to form a loosely knit network. The whole system is traceable for several yards along the strike. A cross-section of the network shows that it extends downwards into the bed at right angles to the bedding. The veins, as they appear in the cross-section, anastomose downwards, becoming thinner and finally dying out before reaching the lower bedding plane of the bed that contained them. The ridges are produced by differential weathering. The ridges themselves are well cemented with a calcareous matrix, whilst the interstices have only a poor argillaceous matrix. No explanation is offered for the differential cementation.

Although the top of the sequence is not exposed within the thesis area, the H. 5 member is estimated to be 400 feet thick.

## I. The Bay of Islands Igneous Complex.

Although the author did not study the Bay of Islands Igneous Complex a brief account of it is given here since it forms an integral part of the Humber Arm series. This account is taken from Smith (1958), Lilly (1963, p. 73-75) and Cooper (1936).

Essentially the complex consists of a series of volcanic flows about 1,000 feet thick, intruded by large masses of ultra-basic, basic rock and minor acidic rock. The basal volcanic flows are interbedded with red and black shale and with often well graded impure sandstones. The present author noted a sedimentary sequence just north of Number Four Mine Brook consisting of greenish shale, greenish glauconitic sandstone and grey, rusty weathering limestone which is locally oil-bearing. The sediments probably intertongue with the lavas and represent younger sequences than the Woods Island formation.

The volcanic flows are basic andesitic in composition and are often interbedded with tuffs and breccias. The contact with the intrusive rocks is usually marked by a metamorphic aureole of the granulite amphibolite type. Locally the aureole is garnetiferous. Less competent rocks near the aureole are often much deformed.

The intrusive rocks, according to Smith (1958,p.1) "combine the features of typically gravity stratified sheets (e.g. the Bushveld complex) with those of the massive ultrabasic plutons characteristic of orogenic belts (e.g. the serpentine masses of the Appalachian belt )". He considers the plutons to be wedge-like, thickening at depth. Cooper, however, considers the plutons to be lopolithic. Lilly (pers. comm. 1964) has suggested that the intrusions were deformed about a north-south axis during intrusion and that the layering of the masses indicates a basin-like shape.

## J. Sequences not assigned to formations.

Several sedimentary sequences are found in the map area that cannot be satisfactorily assigned to a recognized formation.

J. 1 The most important of the unassigned sequences is exposed immediately north and south of Lower Beach and consists of brownish yellow dolomitic siltstones up to 8 inches thick, interbedded with dark violet shales. The siltstones have worm markings and load casted bottoms while their upper surfaces can be ripple marked (fig. 21). The sequence is structurally complex.

A similar, though less deformed sequence of sediments crops out $\frac{1}{4}$ mile south of Frenchman's Head.

The sequences are somewhat like the dolomitic zones of the Meadows formation but they differ in type of bedding and thickness of the competent beds. The dolomitic beds are only slightly similar to those of the Middle Arm Point formation.

It is possible that the sequence represent a western facies of the Summerside since both show evidence of being deposited in shallow water and rocks typical of the Summerside formation do not crop out west of Pettipas Point.

J. 2 A massive bed of dense grey limestone crops out within the clastic sequence a few hundred yards west of the main carbonate sequence, both at Long Point (Lilly 1963) and south of Corner Brook (McKillop 1963). These authors have interpreted the limestone as either a facies recurrence of the Table Head limestone or as a tectonic slice of the Table Head limestone incorporated in the Humber Arm series.

<u>J. 3</u> A sequence of well bedded, fine grained carbonate rock with interbedded calcareous black shale, crops out immediately north-west of Apsey Cove. The carbonate rock is white or buff weathering and occurs in beds up to 2 feet thick. The lower bedding plane of the carbonate rock is usually irregular and convolute bedding is well developed within the bed (fig. 22). The sequence grades to the north-west into a zone of chaotic deformation.

# CHAPTER III

## PALEONTOLOGY

The rocks of the Humber Arm series exposed within the thesis area are poorly fossiliferous but previous authors have described fossils in phenoclasts from conglomerates and breccias. Schuchert and Dunbar (1934) reported fossils from a locality "west of Curling" but did not identify them or say if they were in situ or not.

The present author found fossils of the following types:

A. In situ:-

i) Graptolites
ii) Brachiopods
iii) Unidentified calcareous fossils
iv) Trace fossils.

B. Derived:-

i) Trilobites
ii) Molluscs
iii) Unidentified calcareous fossils.

A. In situ.

i) Graptolites.

Graptolites have been found in the black shales of the Cooks formation almost exactly half way between Black Head and Cutwater Head, east of Middle Arm Point. The fossils were found in an angular block, measuring 8 x 6 x 4 feet, perched on an unstable scree slope, about 12 feet above sea level. The lithology of the block which consists of platy limestone, black indurated shale, and calcareous laminae, is exactly comparable with the lithology of the rocks forming the cliff, as are all of the other blocks forming the scree slope. At the time of investigation, occasional fragments were falling from the cliff and adding to the scree slope. No organic growth was seen on the surface of the block. There can be little doubt, therefore, that the block was very recently derived from the cliff behind.

The graptolites were plentiful and well preserved as a carbonaceous film, in a zone about 9 inches thick in the block. None were found in other parts of the block or in the cliff behind. Dr. L. M. Cumming of the Geological Survey of Canada, kindly identified the graptolites. They are now a part of the Survey's collection.

Dr. Cumming provisionally identified the following forms:

| | |
|---|---|
| Dictyonema sp. cf. D. cyathiforme. | Bulman (1950) |
| Dictyonema sp. cf. D. rusticum. | Bulman (1950) |
| Dictyonema sp. cf. D. lapworthi. | Bulman (1950) |
| Anisograptus matanensis. | Ruedemann. |

Their age is Tremadocian.

ii) Brachiopods.

Several beds yielding brachiopods were found in the same boulder that yielded the graptolites though graptolites and brachiopods occurred in separate beds. The author tentatively identifies them as:

?Lingulella sp.
?Siphonotreta sp.

They are poorly preserved and crushed.

iii) Unidentified calcareous fossils.

These forms are found at the top of the F.2 zone and in the G.1 zone. Limestones which may be formed by them occur in the H.2 zone.

Several different types of structures are found in these rocks. They appear to be part of a growth series. Figures 23 to 28 show the stages of development.

The youngest form consists of two cones joined at their apices, to give an "X" shaped cross-section. They are set in a shaly matrix. In the more mature forms, the "X" is highly asymmetric with one cone much larger than the other. The cones grow laterally, the original central depression is filled and becomes thickened. The amount of shaly matrix is much reduced until, finally, the forms coalesce and a thin, nodular, limestone bed results.

It is possible that the forms represent different organisms but the gradational nature of the forms suggests that they are growth stages of a single organism. Their identification awaits further work.

iv) Trace fossils.

Brief attention is drawn to the occurrence of trace fossils in rocks of the Humber Arm series. They are not widespread but may be locally abundant. The most common types occur as bottom markings on beds, particularly common in the D.4, F.1, and J.1 zones where they are useful top and bottom criteria. They are usually simple in form (fig. 29). Another type occurs as zones of more calcite-rich sandstone in the H.5 zone of the Woods Island formation (fig. 30). They may be lobate or vermiform.

B. Derived fossils.

Fossiliferous blocks were found in:

a) The conglomeratic horizons of the Meadows formation.
b) The lime-breccias of the Cooks formation.
c) The chaotic zones of deformation.

The fossils include:

i) Trilobites.

Trilobites were found in a cobble of dark limestone which was a component of the conglomeratic zone of the Meadows formation at McIver's.

Dr. W.H. Fritz of the Geological Survey of Canada kindly identified the forms as:

| | |
|---|---|
| <u>Austinvillia</u>? sp. | (abundant) |
| <u>Pagetides</u> sp. | (rare) |

The cobble is catalogued as G.S.C. loc. 66026. Their age is Lower Cambrian.

ii) Mollusca.

Walthier (1949) reports that in the conglomerates at Benoit's Cove he found limestone boulders containing <u>Volborthella</u> sp. indet. and <u>Salterella</u> <u>rugosa</u>. McKillop (1963) reports Volborthella sp. cf. <u>V. concavi</u> from the conglomerates at Corner Brook.

The author found these forms in the conglomerate at McIver's as well as the two previous localities. These forms are also tentatively identified in boulders in the lime-breccias. They are both Lower Cambrian in age.

iii) The unidentified calcareous fossils.

The unidentified fossils occur in abundance in certain chaotic zones. Notably that west of Apsey Cove and Frenchman's Head.

<u>C. Recommendations for future collecting</u>.

Any further paleontological investigations should be concentrated to the west of the synclinorium axis where structural deformation is less marked. In particular the McIver's section is recommended for collecting in the Meadows formation; the Cox's Cove - Middle Arm Point - McIver's section for formations stratigraphically above. Fossils are most likely to be found in the Summerside formation at Long Point.

# CHAPTER IV

## STRUCTURAL GEOLOGY OF THE HUMBER ARM AREA.

### Introduction.

All previous investigators have agreed that the Humber Arm area is structurally complex. Not only have the rocks been much folded, they have also been disrupted by faults of several different types and ages. There has, however, been little agreement on even the basic structural pattern of the area. The age of folding has usually been regarded as Taconic.

Howley (1874) thought that the area was underlain by two formations which were repeated by folding. Schuchert and Dunbar (1934) considered that the dip was predominantly to the west. Walthier (1949), however, described a large syncline on the south shore of Humber Arm with associated parasitic folds. Weitz (1953) denied the existence of this fold and reverted to the ideas of Schuchert and Dunbar. Riley (1962) agreed with Walthier's concept of a syncline, but Lilly (1964,fig. 1) suggested that a mushroom shaped fold may exist in the area.

Whilst much of the detailed structure remains imperfectly understood the writer was able to recognize four structural zones, each with its own mode of deformation. These zones are shown in fig. 31. They are:

1. The zone of faults and folds.
2. The zone of block faulting.
3. The zone of chaotic deformation.
4. The zone of mixed structure.

A fifth structural zone, though strictly referable to zone four, may be conveniently described separately, as it is a distinct geological unit:

5. The Rattler Block.

## 1. The zone of faults and folds.

Within this zone, by far the most extensive in the area, the rocks are deformed by faults and folds, into a great variety of different structures. The folded structures, although essentially of one age, reflect the different lithologies of the formation. Furthermore, the folding stresses were not uniformly distributed throughout the zone so that some parts are more deformed than others. The dislocations are of two main types, one associated with the folding and the other much later.

The structures can be arranged according to their apparent relative age of formation. The oldest is listed first:

A. Early bedding plane thrusts.
B. The main folds.
C. Dislocations associated with the folds.
D. Later high angle faults.

**A.** Early bedding plane thrusts.

The differentiation between primary and secondary structures developed within the area, is often difficult. Bedding plane thrusts attributed to primary deformation have been described in an earlier chapter. They are considered to be primary because of their limited effect, their movement, often contrary to that required by the local folding, and the lack of associated re-crystallization. There are, however, rare bedding plane thrusts which are lined with calcite. The slickensides on the thrust surfaces indicate a direction of movement which is not that expected if they were produced by interbedding plane slip during folding. Furthermore, the thrust planes themselves are folded in an exactly similar way as are the beds below and above. They are clearly pre-folding.

The thrusts may be associated with an earlier, hitherto unrecognized, period of folding, but could, however, have been produced by interbedding plane slip under the influence of gravity. Recrystallization along the slippage plane could be induced if the slipping layer were thick enough. No brecciation seems to be associated with the movement. This latter view is given some credence by the virtual restriction of these thrusts to the transition zone between Cooks and Meadows formations, where slumping and sliding are known to have taken place. The best example of these thrusts can be seen a few yards south-east of Giles Point.

B.1. The main folds in the Humber Arm area.

The most conspicuous structures in the Humber Arm area are folds produced during the main period of folding. The major structure so produced is a fold, named by Walthier (1949, p.33), the Humber Arm syncline. The writer, however, prefers to call it the Humber Arm synclinorium.

The synclinorium, with its parasitic folds, occupies all of the northern shore of Humber Arm as far north-west as Apsey Cove and all of the southern shore as far north-west as Benoit's Cove. The axial zone of the synclinorium trends north-south and passes under the arm about half way between Cooks Cove and Halfway Point but is recognized again on the northern shore at Gillams. To the north it is believed that the trace of the axial zone swings to the north-east and the synclinorium breaks down into a series of discreet anticlines and synclines.

The synclinorium is strongly asymmetric about its axis. The eastern limb is approximately three times thicker than the western limb and is more strongly deformed; indeed, the eastern part of the eastern limb has been affected by low grade metamorphism. The axial planes of the folds that make up the synclinorium, however, tend to form a fan about the axial zone (Walthier 1949, pl. 1, fig. 20).

Minor structures in the Humber Arm shore section plunge southwards, at between 5° and 25°. It is assumed that the major structures likewise plunge in a southerly direction, accounting for the offset of rock types across the arm formerly attributed to a dislocation. This interpretation is supported by lack of offset in the main carbonate sequence, across the head of the arm (Lilly 1963, pl. 1; McKillop 1963, pl. 1).

To the south of the mapped area, it is believed that the plunge reverses in direction (Lilly pers. comm. 1964), causing a closure of the synclinorium in that direction. This closure probably accounts for the disappearance of the Cooks formation to the south, interpreted by Walthier as a sedimentary lensing out.

In the following ~~sections~~ areas various, more detailed, aspects of the folding will be described.

The eastern limb of the synclinorium is separated from the main carbonate sequence by a zone of chaotic deformation. To the west of this zone, and insensibly grading into it, is a thick sequence of low grade metamorphic rocks, best exposed on the southern shore between Brake Cove at Humbermouth and Seal Head in the C.N.R. yards, Corner Brook. The zone is less well exposed on the northern shore between the mouth of Hughes Brook and Irishtown. Since the rocks are much deformed, it is not at present feasible to assign them to any particular formation, but as they grade up into the Meadows formation, they were regarded during mapping as the lower part of that formation. It is, however, possible that the Summerside formation and even some shale belonging to the Table Head group are represented.

Essentially, these easternmost rocks consist of a series of dark greenish to silver grey phyllitic shales. The most obvious structure shown by them is a sub-slaty cleavage which dips steeply westwards. Occasionally contorted bands of slightly different colour can be seen intersecting the cleavage planes. Only rarely, however, is true bedding visible. Harder, platy fragments aligned in the cleavage direction are usually either quartz or calcite segregations. Some indication that the beds do not dip uniformly to the west, can be seen just east of the coach cleaning sheds, east of Seal Head. On the shore a mass of medium bedded quartzites are folded into a tight and composite anticline. The corresponding syncline can be seen in the railroad cut just above, and is broad and open, the axial plane dipping steeply westwards.

Seal Head (McKillop's Railway Syncline) may be used as a model for the structure of this whole eastern sequence. The artificial outcrop along the railway yard, about 100 feet high, consists of rocks assigned to the C.6 conglomeratic zone of the Meadows formation, folded into a large open syncline. The core of the syncline is occupied by massive quartzites, while the flanks consist of thinner quartzites with interbedded shales. These thinner quartzites are often stretched into boudins on the eastern limb and repeated by drag folding on the western limb. The eastern limb dips westwards at about 40°, whilst the western limb dips steeply eastwards near the core of the syncline, but on the flank is vertical or overturned, dipping steeply westwards. The axial plane of the structure, estimated by eye, dips westwards at about 65°. The cleavage in the shaly beds dips westwards at about 60° and can be regarded as being parallel to the axial plane. The cleavage is also axial to the minor folds.

The plunge on the structure is indicated by various minor structures (Wilson 1961 : this paper, a general paper on the use of minor structures in the field, was referred to continuously during the structural study of the area). The long axis of the boudins and the minor folds plunge southwards at about 20°. The intersection of bedding on the cleavage surfaces indicates a somewhat higher degree of plunge. In general, the minor structures show that the beds have been squeezed out of the synclinal core, but on the western limb movement parallel to the cleavage is indicated.

If this syncline can be taken as reflecting the structure of the eastern zone as a whole, the following generalizations can be made. The cleavage, which is orientated north-south and dips steeply westwards, is axial-plane cleavage about which the bedding is folded. Beds dipping westwards at a shallow angle are likely to be normal limbs; beds dipping westwards at a high angle are likely to be overturned. The folds plunge southwards. Beds similarly deformed, crop out south of Corner Brook in the beds of Corner Brook and Watsons Brook, while the bluffs behind West Street, Corner Brook, represent the southern extension of the Railway syncline. The eastern limb of the syncline is thickened, probably by reverse faulting, to the south of the Hospital at Corner Brook.

The eastern sequence may be regarded as ending just under Crow Hill on the southern shore and at Crow Head on the northern shore where the sequence is truncated by a reverse fault, described in a later section.

Above this fault, the nature of the folds is strongly dependent on the lithologies of the folded beds. The lowest competent members of the Summerside formation, all appear to dip westwards, some more steeply than others.

Where anticlinal fold hinges are exposed, such as in the cliff behind Pettipas Point, it is clear, however, that the shallow dipping beds are the normal western limbs of anticlines, whilst the more steeply dipping beds are the overturned eastern limbs. The axial planes of these folds strike north-south and dip westwards at between 50° and 60°, while boudinage is sometimes developed on the normal limb. No synclines were seen and they have probably been faulted out. No evidence for a plunge on the folds was noticed, but a study of aerial photographs of the area around Pynns Pond, north of Summerside, reveals large anticlines plunging southwards. Although no detailed study of the fold system was made, it would appear that between Crow Head and Pettipas Point there are at least six anticlinal axes, repeating the lower horizons of the Summerside formation along the road and shore sections.

The shales above the lower competent beds of the Summerside formation, have been deformed in a different manner. They have taken on an excellent slaty cleavage which dips between 50 and 60 degrees westwards. The folds in the slates are almost monoclinal in form. The normal limb, the eastern limb of the synclines and western limb of the anticlines, dips westwards at an angle less than the cleavage. The "inverted" limb dips nearly vertically either west or east and is much shorter than the normal limb. The shortening is at least partially caused by numerous small folds developed on this limb. The axial planes of these smaller folds are also parallel to the cleavage. The best exposures of this type of fold are found along the railway section to the east of Church Cove. Frequently, however, the "inverted" limbs are sheared off. Exposures showing plan sections of similar folds can be seen at the extreme western end of Frenchman's Pond (fig. 32). The beds affected by the folding here are the more shaly and thinner bedded members of the lower arenaceous series.

The rocks of the Meadows formation are folded in yet another manner. Major fold axes are only seen affecting the more massive quartzites and all of these are again anticlines. No detailed study was made of the fold distribution but there are at least fifteen such anticlines between Davis Cove and Gillams on the eastern limb of the synclinorium. Twenhofel (1940, p.41) reports between seven and fifteen anticlines between Curling and Cooks Brook on the south shore of the Humber Arm.

The axial planes of the anticlines dip westwards east of the synclinorium core. In general they dip at a moderate angle in the east but approach the vertical at Gillams. In many cases, however, the geometry of the folds is obscured by fracturing and quartz veining, since the quartzites have yielded by fracture as well as by folding. The western limbs are sometimes considerably thinned (fig. 33) and the eastern limbs overturned. The plunge of the folds, measured directly on the major fold axes, or deduced from the plunge of the minor folds, is between 10° and 20° to the south. The shales have been thrown into tight folds which plunge steeply southwards just west of Gillams, in the core of the synclinorium. The high angle of plunge may either be associated with local effects in the core of the synclinorium, or with the Gillams transverse fault described by Lilly (1963.;p.101).

In general, the argillaceous rocks of the Meadows formation do not develop a slaty cleavage but have a shaly parting parallel or subparallel with the bedding.

The rocks of the Meadows formation to the west of the axial zone of the synclinorium are less deformed than to the east. The beds dip uniformly eastwards, generally at an angle less than 40°, with only a few reversals due to folding.

The Meadows formation grades into the D. transition zone at Sopers. Since this sequence has no massive competent beds, the style of deformation is different to that of the Meadows formation. In general the rocks are strongly folded, their axial planes dipping westwards at angles up to 70°. The axial planes of the anticlines tend to dip less steeply than those of the synclines. The western limbs of the anticlines dip westwards at about 45° while the eastern limbs are overturned and dip westwards at about 80°. These anticlines have crenulated axial zones which tend to be flat giving the folds a box-like shape (fig. 34). Often the apices of the individual crenulations have been nipped off and isolated from the rest of the bed, causing small scale repetitions of beds in the axial zone of the folds. Frequently the axial zones have been cut out by faults that are not always calcite lined and have the appearance of small scale unconformities (fig. 35).

The amount of stratigraphic repetition caused by the folding is difficult to estimate. The oolite beds in this section do not seem to be repeated so the repetition may be quite small. The oolites themselves are not deformed. Specimens taken from the limbs and axial zones of the fold have a circular cross-section. The oolite beds on the limbs, however, are cut by small tension gashes.

The contact between breccias of the Cooks formation and the transition zone is overturned at Giles Point. There is no evidence for a fault, but the shales are somewhat crushed and lie above the breccia which dips steeply to the east. This same contact has been cut out by a thrust fault under Mt. Moriah, which is described by Walthier (1949, p.34). This thrust is probably only of minor importance, carrying the base of the Cooks formation eastwards to rest directly on the Meadows formation.

The folds in the Cooks formation are influenced by the lithology of the rocks involved and their position in and near the core of the synclinorium. On the flanks of the synclinorium, above the massive limestone breccia horizon, the proportion of shale to limestone beds is high. The style of deformation is similar to that found in the transition zone. Towards the core of the synclinorium, the limestone beds are thicker and more frequent and the folds tend to be tighter and more acute. The axial planes of the folds dip steeply to the west or east about the axial zone of the synclinorium. In the axial zone itself, the folds are very tight and almost isoclinal. The axial planes are vertical, and the folds may plunge in anomalous directions. Throughout the whole of the Cooks formation the platy limestones tend to develop calcite filled tension gashes.

**B. 2** The western limit of the synclinorium.

To the west, the synclinorium passes into the Rattler anticline on the north shore and a minor anticline near Benoit's Cove on the south shore. The former will be described in a separate section. The latter is a poorly exposed feature indicated by a change of direction of the dip, north of Benoit's Cove. The axial zone could not be located with any certainty.

B. 3 The fold system north of Humber Arm.

To the north of the Humber Arm, it is believed that the synclinorium breaks down into a series of discreet anticlines and synclines, trending north-east - south-west. This belief is based on several traverses across the area, observations along the south shore of Middle Arm, and on comparisons with Lilly (1963, fig. 1), who shows north-east - south-west trending folds in the north of the present area.

The section between Long Point and Middle Arm Point is of particular interest, since it is there that Lilly (1964) suggested a mushroom-shaped fold existed. The section, however, is apparently broadly synclinal in nature with a series of smaller anticlines superimposed on it. The folds trend north-east - south-west. A few yards south-west of Long Point, the beds of the Summerside formation can be seen dipping at a moderate angle to the west. By the first point north of Barachois Brook, the strike of the Meadows formation has swung to the north-west; the beds dip to the south-west. Crossing the brook the strike is to the north-east, nearly parallel to the coast. Probably a large north-east dipping fault has been crossed. The dip of the beds changes to the south-east at Parkes Cove, marking a synclinal axis. The corresponding anticlinal axis is found just west of Parkes Cove.

On it the beds strike north-west - south-east and dip to the south-west at 20° showing the plunge on the structure. To the west of this axis, the conglomeratic zone of the Meadows formation crops out, much faulted and folded. A small asymmetric syncline is exposed in these rocks (fig. 36), plunging to the south-east at 35°. The eastern limb is steeper than the western limb. Westwards, the quartzites give way to rocks of the transition zone into the Cooks formation. The structures in these rocks are similar to those developed in the same horizon east of Giles Point in Humber Arm. The axial planes of the folds dip to the east and locally the folds are recumbent. No criteria were available to tell which way the folds face, but the zone as a whole is assumed to become young to the west on stratigraphic grounds, even though the dip of the beds is predominantly to the east. A covered interval separates these rocks from the Cooks formation west of Cox's Cove.

The structure west of Cox's Cove is difficult to interpret, and was not studied in detail. In general the minor folds plunge to the south and the axial planes lean to the east. An anticlinal axis probably exists between Black Head and Cutwater Head.

C. Dislocations associated with the folding.

A series of dislocations cut the structures developed during the main folding. These dislocations result from the late movements ~~out~~ of the core of the synclinorium and may be regarded as the last effects of the forces responsible for the folding. The dislocations range in magnitude from large reverse faults or thrusts through smaller reverse faults or thrusts, to closely spaced shears, fracture cleavage, kink bands and strain-slip cleavage. These structures are best developed on the eastern limb of the synclinorium.

The largest structure of this type is the Crow Hill - Crow Head reverse fault or thrust. This structure, which brings up the Summerside formation and repeats the Meadows formation, is well exposed on Crow Hill and in the road and rail sections below. It is essentially a faulted anticline. Figure 37.4 shows a diagrammatic section through the eastern part of Crow Hill.

The summit of Crow Hill is a cap of sandstone belonging to the lower part of the Summerside formation. Only the highest escarpment is in place; the lower blocks down to the shore are fallen and slipped masses. The cap of sandstone as a whole dips gently westwards but is much folded. At the extreme eastern edge of the escarpment, the sandstone rests on black shale of the Meadows formation. The contact is a thrust (fig. 38). The black shale has poorly developed cleavage which dips westwards at about 30°, less steeply than the bedding. Near the thrust plane, this cleavage is obliterated but, in a zone 2 or 3 inches thick adjacent to the thrust, the shales are more resistant to weathering and have a poorly developed secondary cleavage dipping westwards less steeply than the original cleavage. The thrust surface itself dips westwards at about 30° and truncates the bedding of the sandstone. The rest of the sandstone cap rests on red and green slate and locally is stained red itself. It is tightly folded but it is difficult to determine if these folds are associated with the thrust or were produced during primary deformation.

The section along the road is not well exposed. Passing up the road westwards from the small quarry at the western limit of Corner Brook, scattered outcrops of weathered shales of the Meadows formation occur. Current bedding in rare occurrences of grey limestone indicates that the beds are inverted. Higher up the hill, the outcrops are in the green and red slate of the Summerside formation. The crest of the hill is occupied by sandstones of the Summerside formation which are above the thrust.

The railway section is well exposed. The first rock type seen west of Crow Gulch is dark shale of the Meadows formation which is followed by about 12 feet of platy limestone, locally conglomeratic with interbedded shale. This sequence is very similar to rocks of the Cooks formation and its presence in this part of the section is difficult to account for. It is probably faulted in, but may represent a limy facies of the Meadows formation not exposed elsewhere. More dark shales are exposed for about 280 feet to the west of this. The shales are darkest to the east and become greener to the west and are referable to the Meadows-Summerside transition zone. Faults cut the rocks which are faulted against a sequence of red slate which crops out for about 200 feet along the cutting. The red slates are in thrust contact with the tightly folded green conglomeratic sandstone of the same type forming the cap of Crow Hill. The stratigraphic section is generally ascended to the west of this sandstone.

The structure above the thrust is not well understood. Several smaller thrusts are exposed, an example ~~of which~~ may be seen in the slate quarries above the road. Here red slate is thrust over green conglomeratic quartzite and the thrust dips 10° westwards. The whole of this sequence has been disrupted by high angle faults that trend north-south and have rotated blocks about a horizontal axis. The slaty axial plane cleavage of the slates has been re-orientated and locally is gently folded about a north-south axis.

The thrust is not as well exposed along the north shore of Humber Arm, but the scarp formed by the lower competent member of the Summerside formation, immediately above the thrust, is clearly visible between Summerside and Irishtown. The Summerside formation is separated by a few feet of no exposure from the shales of the Meadows formation at Crow Head. The thrust passes through this zone. Higher up, under the scarp, the sandstones rest on red or green slate of the Summerside formation. Further to the north the thrust probably passes into an unfaulted anticline but this was not observed.

Several smaller thrusts, such as that of Mt. Moriah, have been recognized by Walthier (1949, p.34). They all form part of his "cleavage fan".

The smaller scale structures forming part of the fan are locally very well developed. Beds are often cut by a series of shears spaced from between 4 inches and one foot apart.

More rarely, they are spaced close enough to be called fracture cleavage. The amount of displacement on each shear is small and the beds may be crumpled into small folds with the shears as the axial plane. The movement and inclination of these shears is always in accord with the fan concept (figs. 39 - 40). Below the main Crow Hill - Crow Head thrust, these shears are not well developed but their place is taken by kink bands (Wilson 1961) or well developed strain-slip cleavage which is seen as small south-plunging wrinkles on the older cleavage surfaces. The movement indicated by these structures is always a net movement of the upper segment to the east. This is true both to the east and west of the railway syncline, showing that the dislocations are associated with the main synclinorium rather than with the local folding.

As Walthier noted (1949, p, 34), the axis of the "cleavage fan" does not quite coincide with the axis of the synclinorium. He suggested that this may be due to re-orientation of the forces responsible, or that the structures had different origins. In the Humber Arm area the non-coincidence is small and may be illusory since neither the axis of the synclinorium nor that of the "cleavage fan" can be defined with sufficient accuracy. Furthermore, this "cleavage fan" is a composite structure. One type of cleavage and shearing is closely associated with the folding and is parallel with the axial planes of the folds. ~~The other~~ Another type cuts the folds at varying angles. In the field, it is difficult to distinguish between the minor structures developed during the different stages of deformation, since there seems to be a transition between them.

**D.** The later high angle faults.

Later than the folding and the dislocations associated with them, are high angle faults of various types. They were not studied in detail by the present writer, but an account of some of them can be found in Lilly (1963), McKillop (1963), Weitz (1953) and Walthier (1949). They are of two main types. One set trends approximately east-west and has a horizontal component as well as a vertical one. Examples of this type are the Gillams transverse fault (Lilly 1963, p.101) and the Corner Brook fault (McKillop 1963, p.81). A second group of faults trends north-south, and includes both reverse and normal faults with a predominantly vertical movement. Very often these fault planes have been deeply excavated by the sea and are conspicuous. When examined more closely, however, they often prove to have a throw of only a few feet.

## 2. The zone of block faulting.

High angle faults are the only structures which deform the upper arkosic member of the Woods Island formation. These competent rocks outcrop on the western half of Woods Island and between Shoal Point and Blow Me Down Brook as blocks of approximately uniform dip, separated from blocks of differing dip by high angle faults. Near the faults the beds may be gently deformed by flexure. On Woods Island faults are most prominent trending in a north-west - south-east direction, but other faults, trending approximately east-west, are not uncommon. It is not known if these faults are associated with the folding of the rest of the area, or with the high angle faults later than the folding. Perhaps both types are represented.

### 3. The zones of chaotic deformation.

At several localities within the Humber Arm area, the rocks show intense deformation of a type different to that produced by folding and faulting in other parts of the area. In general these zones are characterised by ill-sorted blocks of competent rock chaotically set in a friable shaly matrix.

The zones of chaotic deformation are found in the following areas:

a) Between the main carbonate sequence and the Humber Arm series.
b) To the east of the upper arkosic member of the Woods Island formation.
c) Flanking the Rattler Block.
d) As a component of the mixed zones.

The two latter occurrences will be described in separate sections. In the following sections, the components and field relationships of the chaotically deformed zones will be described. Figures 41 to 51 illustrate various features of the zones.

#### i) The blocks.

The blocks found in the chaotic zones may be either fragments of disrupted beds or relatively cohesive groups of beds set in a shaly matrix. The fragments of disrupted beds are highly variable in size, shape and composition. Many different rock types have been recognized but, with only a few exceptions, they belong to the Humber Arm series. Sandstones and quartzites of the Meadows and Woods Island formations are common, as are limestones, lime-breccias and silty dolomites of the Cooks and Middle Arm Point formations. Commonly, slightly more competent shale blocks are set in the matrix but is is difficult to determine where the blocks end and the matrix begins. Red and green shale blocks are found in the chaotic zones in the east of Woods Island. Some of the red shale resembles that of the Summerside rather than that of the Woods Island formation. Locally, pyrite nodules are abundant and are of two sorts, well developed cubes or aggregates of cubes, and sub-spherical masses with a radial structure. Volcanic blocks are sometimes found, the largest of which can be seen at Peter Point on Woods Island. No plutonic blocks were found.

Petrographically, the blocks may be altered or unaltered. The very fine grained limestones of the Cooks formation often retain their fine grained texture; sandstones are often unrecrystallised; volcanic rocks may retain their spherical vesicles and the delicate internal structures and shape of calcareous fossils occurring within the shaly blocks are often preserved. Less frequently the blocks are altered. Limestones can be re-crystallised but never coarsely so, the calcite, however, is never streaked out into the shaly matrix. The volcanic blocks may be chloritized and have their vesicles deformed. Sandstone blocks may be converted to quartzites but are only rarely crushed or veined with quartz. It is interesting to note that the ridge and furrow structure developed in the Woods Island formation is represented in a recrystallized form (fig. 20). The size of the blocks ranges from less than 1 mm. to an undetermined upper limit. Blocks measuring 8 feet and more in all dimensions, are not uncommon in the zones on Woods Island and at Frenchman's Head. Blocks much larger than this have been seen but they are usually of the composite type, consisting of coherent groups of beds. When this type of block is large it is difficult to tell if it is a block or a normal sequence of sediments. The whole of the prominent headland on the north-eastern coast of Woods Island may conceivably be a block. In general, the large homogeneous blocks tend to be sandstone or calcareous shale, whilst carbonate blocks are smaller.

The shape of the blocks may be angular or rounded, platy or approaching spherical. The blocks never have striated surfaces but some of the sandstone blocks have kidney-shaped surfaces resembling those of slumped bodies, while others are crudely elliptical. Small elliptical masses, up to 1½ inches long, are locally abundant in the shale. If these blocks are etched with hydrofluoric acid, the adhering shaly matrix disintegrates, leaving an angular core of limestone, or more rarely, sandstone. The cores are often crushed and the fractures filled with coarse calcite crystals but are, themselves, never recrystallized. The matrix around these cores contains small chips of limestone, ranging in size from 1 mm. upwards. The original elliptical shape of the blocks is due to shale having been pressed into the concavities of the irregular cores.

There is almost every gradation between blocks having no relationship to surrounding blocks and coherent groups of beds enclosed within the matrix. An intermediate gradational stage has blocks isolated in the matrix but occurring in roughly linear zones as if a single horizon had been disrupted. Sometimes current bedding in such zones gives constant directions for tops over several yards and a ghost stratigraphy and structure can be recognized. Such zones are more common near the margins of the chaotic zones. Another type of block can be seen just east of Tiheay Cove where a sequence of well bedded quartzites and shales pinch out along the strike (fig. 47). The sequence is a composite block.

The concentration of blocks in the matrix is variable, but is usually low.

ii) The matrix of the chaotically deformed zones.

Two lithological types of matrix can be recognized. The zone between the main carbonate sequence and the Humber Arm series, has a black shaly matrix, whereas, in addition, the other zones locally have a green and black banded shaly matrix, similar to the shales in the upper part of the Middle Arm Point formation. This comparison is supported by the occurrence of the calcareous fossils in the shaly matrix. Both types of matrix may be very friable, crumbling into sub-lenticular masses. Later deformation has locally compacted the matrix and this compaction is accompanied by the development of a poorly defined plane of parting, or as in the case of the zone adjacent to the main carbonate sequence, a relatively good cleavage. This cleavage, however, bears no relationship to the intricately contorted beds seen in the matrix. The smaller blocks may be rotated so that their longest axis is in the plane of this parting or cleavage. The most noticeable feature of the matrix, is the absence of calcite or quartz stringers, indicating that the material constituting the blocks was not mobilised during deformation. Only when close to later faults does the shaly matrix show any slickensides. Adjacent to these faults, the shale may take on a perfect mirror-like polish. These faults are often calcite lines and tend to stand out from the shaly matrix because of their greater resistance to weathering. The faults are usually compound; one fault showed eight separate slickensided surfaces, indicating four different directions of movement. The faults often curve round larger blocks and the intensity of the deformation of the chaotic zones does not increase near them.

It is concluded that the faults were formed later than the chaotic deformation.

iii. Contacts of the zones.

The contact between the chaotic and non-chaotic zones is usually faulted but may locally be gradational. The gradation may take the form of a gradual disappearance of deformation or it may be represented by a zone of coherent but intricately folded sediments. These folds do not have any relationship with the regional folding and are plastically deformed in a manner more like that produced by primary than secondary deformation.

iv. Characteristics of the individual zones.

Each zone of the chaotic deformation has its own characteristics which are outlined below.

The zone between the main carbonate sequence and the Humber Arm series is poorly exposed in the area. The best section is in the bed of Corner Brook where the chaotic zone is separated from the main carbonate sequence by the Corner Brook fault. (McKillop 1963, p. 81). The first rock type exposed to the west of this fault, is a small isolated mass of brownish yellow limy shale. To the west of this shale, is a sequence of black shales with a north-south trending sub-slaty cleavage. Bedding is not seen in these shales but they contain rather scattered blocks, usually elliptical in shape, with their long axes coincident with the cleavage. The blocks consist of carbonate or quartzite. McKillop (1963, p.60) reported one block of carbonate, 4 feet by 1½ feet in size, but they are usually less than one foot long. About ¼ mile downstream from the contact, the zone grades into normally bedded members of the Meadows formation. This zone of chaotic deformation is characterized by only a few blocks and by having a matrix which is coherent and cleaved.

The equivalent section on the north shore is found in the Hughes Brook area. It was not studied by the author but Lilly (1963 p.63) describes this zone. The lowermost shales of the Humber Arm series are "interbedded with quartzite lenses, many of which have been broken up into subrounded tabular blocks" (ibid., p.64

At the Long Point locality, the main carbonate sequence is overlain by a sequence of black calcareous shales, which contains widely scattered blocks that appear to be carbonate concretions rather than fragments of disrupted beds. No trace of bedding can be seen in the shales, which crop out for several hundred yards eastwards between Long Point and the main carbonate sequence. Just east of Long Point the shales contain a large mass of grey limestone (J.2, p.62). Long Point itself consists of a hard green shale and is overlain to the south-west by a thin chaotic zone containing blocks of yellowish brown weathering dolomitic siltstone, identical to rock types in the Middle Arm Point formation. Above this zone is a green shale containing small blocks elongated in the well developed cleavage. The green shale underlies the volcanic horizon previously described.

Outside the thesis area, the chaotic zone adjacent to the main carbonate sequence is better developed. At the head of Penguin Arm, large blocks of massive limestone as well as platy limestones, similar to those of the Cooks formation, occur as isolated blocks in black shale adjacent to the St. George's formation.

A rock type containing blocks of disrupted dolomitic beds similar to the "fluxoturbidite" horizons described from the Meadows formation, occurs further west on the south shore of Penguin Arm near the base of the Humber Arm series and is thought to represent the special type of chaotic deformation described in the discussion.

To the north, at Bonne Bay, this same contact is marked by a chaotic zone which is well exposed at Gadds Harbour and Neddies Harbour. The zone separates the Gadds Harbour slates, which overlie the main carbonate sequence, from a series of massive greenish sandstones. It is postulated that a zone of chaotic deformation is general between the main carbonate sequence and the Humber Arm series as redefined in Chapter V (pp. 102-103).

The best developed and exposed chaotic zone is found between the beacon south-east of Frenchman's Head and Shoal Point. The eastern contact is a fault of unknown magnitude, which separates it from the limestones of the Cooks formation. The fault seems to have thrust the limestones westwards over the chaotic zone, folding them into a recumbent syncline. Some of the limestones are dolomitized near the fault, which is probably of the high angle and reverse type. North-west of this contact is a chaotically deformed zone about 1.5 miles wide. Near the eastern contact, the blocks are usually of the composite type but blocks of the simple type occur further west towards the interior of the zone. The whole zone is crudely lineated in a north-south direction and blocks of similar lithologies tend to occur in zones aligned in this direction. The first exposure east of Frenchman's Cove is not blocky but is much folded and grades up into a blocky zone eastwards. West of Frenchman's Cove, the section is only locally blocky and the deformation decreases to the west. The rocks are not strongly deformed west of Shoal Point.

A similar chaotic zone is found to the north of Frenchman's Cove on the eastern half of Woods Island. This zone, however, contains more "inclusions" of coherent sediment, which are locally strongly folded. Some folds are completely overturned and appear to be synclines but according to current bedding have older rock in the core. (fig. 52). The axes of these folds vary from the regional north-south trend, and plunge in many directions at angles up to 90°(fig. 53).

A zone of chaotically folded yellow dolomitic siltstones with interbedded shales crops out south of Frenchman's Cove in the bed of Clarks Brook. The siltstones are plastically folded about randomly orientated axes and are not recrystallized or significantly fractured. Often fold noses occur as isolated blocks in the phacoidally cleaved but indurated shaly matrix. Rocks of the Meadows and Cooks formations crop out east of this zone and are normally deformed.

Since a similar zone of plastic folding on the flanks of the Rattler Block, grades upwards into a zone of chaotic deformation, it is assumed that the zone in Clarks Brook does the same. It is further assumed that a zone of chaotic deformation occurs beneath the upper part of the Woods Island formation and extends around the flanks of the Bay of Islands Igneous Complex.

## 4. The zones of mixed structure.

To the east of the western zone of chaotic deformation is a zone of deformation characterised by an alternation of thin chaotic zones with coherent sediments. This zone makes up most of the section between Black Head and the first point north of McIver's. Its continuation to the south crops out along the shore between Frenchman's Head and just north of John's Beach. Since this zone is folded and faulted as well as chaotically deformed, its structure is the most complex in the area. Fortunately the northern shore section is well exposed. Figure 37.2 shows a diagrammatic cross-section between Middle Arm Point and McIver's Point. In general, the beds in the mixed zone dip southwards but minor folds plunge southwards down the dip of the beds. The boundary between the chaotic zones and the coherent sediment is usually a fault (fig. 54). The displacement across these chaotic zones is considerable but no greater than that across the high angle faults that cut the sequence. There is no blocky development associated with these faults.

Little information concerning the mixed zone on the southern shore, ~~more~~ other than ~~is~~ that shown on the map, is available.

## 5. The Rattler Block.

The Rattler Block is the geological unit which outcrops between the mouth of Rattler Brook, south of McIver's and Apsey Cove. Its extension inland is not definitely known but it is probably limited to the north and west by the McIver's - Gillams road. The anticlinal structural interpretation of the block is shown in figure 37.3.

The rocks of the Meadows formation dip generally eastwards west of Gillams whereas they dip north-west at McIver's. The strike lines on the Meadows formation between these two points describe an arc concave to the south-west around the Rattler Block but are somewhat disrupted by faults.

At the mouth of the Rattler Brook, the intricately contorted shales of the Meadows formation are separated by a small fault from a zone of chaotic deformation. This zone is well exposed in the bed of the brook and consists of blocks, including one volcanic block, set in a shaly matrix. Up stream, the zone passes, by gradation, into a zone of contorted but coherent sediments. A similar transition is seen along the shore section. The contorted zone passes into a zone of normally folded rock which dips generally to the north-west, referable to the lower part of the Middle Arm Point formation. These beds form the scarp which runs eastwards from Big Head to the north of Skeleton Cove. Below the scarp is a zone of poor exposure which may cover a fault or another chaotic zone. Isolated patches of brownish shale with thin silty laminae below this zone may belong to the Meadows formation. On the south-eastern shore of the cove, rocks of the Meadows-Cooks transition zone are exposed, including a deformed oolite bed. The whole section is much folded and is essentially overturned. A fault zone separates these beds from the Cooks formation which outcrops on Bound Head and is represented by platy limestones with inter-bedded shale and lime-breccias containing large boulders of limestone. These beds strike east-west and dip southwards. The Cooks formation is separated by a zone of no exposure from the hard green shales of the Middle Arm Point - Woods Island transition zone that form Balance Point. They dip to the south-east. To the south-east of the point, these rocks are in fault contact with a zone of chaotic deformation which appears to overlie and truncate the rocks of the transition zone. The actual contact, however, is exposed in the intertidal zone and dips, conformably with the sediments, steeply to the south-east. It is marked by a thin calcite lined fault zone. A later thrust has faulted the chaotic zone over the truncated sediments. The thrust surface is nearly horizontal and is marked by small patches of calcite with east-west trending slickensides. The zone of chaotic deformation extends some 1,200 yards south-west to Apsey Point and contains plates of limestone in a black shaly matrix. Sometimes the beds are quite coherent and, to the south-west, large masses of sandstone, probably representing the lowest member of the Woods Island formation, are included in the shale. Some of the blocks are 50 feet long. Towards Apsey Point, shaly blocks contain the unidentified calcareous fossils. The shaly matrix is, here, the contorted and sheared green and black banded type. The zone grades into the J.3 sediments which are not represented elsewhere in the area. A zone of no exposure separates this outcrop from the Meadows formation on the western limb of the Humber Arm synclinorium.

Essentially the Rattler Block is interpreted as an anticlinal zone with a core of rocks belonging to the Cooks and Middle Arm Point formations and to the D. and G. transition zones. These are flanked by zones of chaotic deformation and overlain by rocks of the Meadows formation.

# CHAPTER V

# DISCUSSION

In this chapter the rival concepts of the Humber Arm series noted in the introduction will be discussed using as much of the available evidence as is possible. The first essential in discussing these concepts is a knowledge of the age of the Humber Arm series.

## 1. The age of the Humber Arm series.

Fossils were found in the Humber Arm series both in situ and derived as fossiliferous fragments in conglomerates and breccias. The fossils found in situ are graptolites of Tremadocian age and were found in rocks referred to the upper part of the Cooks formation. Since it is believed that there is virtually a continuous sequence between the Summerside and Woods Island formations, the Woods Island, Middle Arm Point and the top of the Cooks formation can be regarded as Ordovician in age, whilst the bulk of the Cooks formation, the Meadows and Summerside formations can be regarded as Cambrian in age. Confirmation of the age of D. transitional zone and indirectly of the beds above and below it, awaits identification of the fossils found there.

The fossils found in the conglomerates and breccia phenoclasts, fall into two main types; those found in the lime-breccias, and those found in the polygenetic conglomerates. The fossils found in the lime-breccias are Lower Cambrian in age and it has been suggested that they indicate the age of the breccias themselves (Rodgers and Neale, 1963, p. 722), as do the fossiliferous boulders in the Cow Head breccia. At Cow Head, some 70 miles north of the Humber Arm, Schuchert and Dunbar (1936) described a sequence of lime-breccias similar, but thicker and coarser than those found in the Humber Arm area. These breccias were originally thought to lie at the base of the Humber Arm series and to be Mid-Ordovician in age. Kindle and Whittington (1958, 1959), however, found that the sequence ranged in age from Mid-Cambrian to Mid-Ordovician. Furthermore, they found that the age of the fossils found in any particular boulder was very nearly the same as the age of those found in the matrix containing the Boulder. Evidently the boulders represent pieces of a carbonate bank or reef which were broken off and transported, soon after their deposition, into a more shaly facies. If the breccias in the lower part of the Cooks formation had a similar origin, as the writer suggests, then it would follow, that since the fragments contain Lower Cambrian fossils, this is the age of the lime-breccias. The Meadows and Summerside formations would then be at least as old as Lower Cambrian.

The fossiliferous limestone boulders in the Meadows conglomerates all indicate a Lower Cambrian age. If the conglomerate as a whole is to be regarded as Lower Cambrian, the fragments must be interpreted as having been derived from a contemporaneous limestone-rich facies, which was disrupted by the currents that swept the other components of the conglomerates into the basin of the deposition.

This interpretation of the ages of the various formations, depends upon a correct interpretation of the structure of the area. As hinted by Lilly (1964), the main Humber Arm fold could be an anticlinorium, not a synclinorium. According to this interpretation, the Cooks formation would be older than the Meadows formation and be a facies equivalent of the Middle Arm Point formation. The Woods Island formation could then be a facies of the Meadows and Summerside formations. All available evidence, however, indicates that the structure is a synclinorium, and the regional distribution of the formations is in accord with their proposed relative ages and with a synclinorium with a southerly plunge and associated flanking anticlines.

Nevertheless, the ages deduced for the Humber Arm series in the type section, are at variance with that proposed by Schuchert and Dunbar (1934, p. 98), for the Humber Arm series in general. They report finding fossils at three localities.... "one near Rope Cove south of the mouth of the Serpentine River, another west of Curling on the south shore of Humber Arm, and a third just north of Cormorant Head on the north-west shore of the St. George Peninsula." (ibid., p. 98). None of the fossils were said to indicate an age younger than the Middle Ordovician.

There can be little doubt that at the latter locality, the Table Head limestones pass, by gradation, into a shaly sequence which yields Mid-Ordovician fossils (Riley 1962). It is equally clear, that some of the clastic rocks to the west of the main carbonate sequence are older than Mid-Ordovician.

Johnson (1941), for example, recognized, north of Bonne Bay, a clastic sequence estimated to be between 6,000 and 7,000 feet thick, which ranged in age between basal Ordovician and lower Middle Ordovician. His lowest division was the Green Point sequence. Oxley (1953) recognized a similar sequence in the St. Barbe district. Kindle (1945) reported Tetragraptus, a Lower Ordovician form, in the Humber Arm slates which overlie the main carbonate sequence in the Pistolet Bay area, in northern Newfoundland. Furthermore, Kindle (pers. comm. to Lilly 1964) reports that the "Triarthrus" reported from Rope Cove (Schuchert and Dunbar 1934, p. 90) is in fact, Bienvillia, a latest Cambrian form. More recently Cumming, (1965, p.104) reports Lower Ordovician graptolites in deformed shales, lying above gently dipping rocks of the main carbonate sequence from two localities on the Port au Port Peninsula.

It is evident that there are two separate sequences of clastic rocks occurring on the western flank of the main carbonate sequence. One, only proved to exist on the Port au Port Peninsula, is later in age than the Table Head limestones, and has a normal sedimentary contact with them; the other is contemporaneous with the main carbonate sequence. Both are currently known as the "Humber Arm series".

To prevent further confusion, the writer suggests that a new name be proposed for the clastic sequence of Mid-Ordovician and perhaps later age, which has a sedimentary contact with the Table Head limestones. The name "Humber Arm series" could then be retained for those rocks which are of the same age as the main carbonate sequence but apparently overlie them, such as those rocks in the original type section. It is further suggested, that in contrast to previous practice, clastic rocks to the west of the main carbonate sequence, should be assumed to belong to the Humber Arm series in its redefined sense, rather than Mid-Ordovician or later in age, unless the contrary can be proved.

## 2. Stratigraphy and sedimentation.

The question now arises, if there are two contemporaneous sequences of a different facies to the west of the Long Range, what was the original relationship between the two? A partial answer to this question may be obtained by a consideration of the stratigraphy and sedimentation of the Humber Arm series in the area studied.

Within the series a crude cycle of sedimentation can be detected. The oldest rocks are arenaceous and include red and green shales, probably rapidly deposited. They are overlain by a slowly deposited shale-carbonate sequence, which at first, is sand-free and limy but later, is more sandy and dolomitic; green shale reappears. A thin series of green flysch-like rocks marks a transition into a rapidly deposited arenaceous sequence with green and red shales, completing the cycle.

The earliest part of this cycle is represented by the Summerside formation. The true base of this formation is nowhere exposed, but at Long Point a volcanic flow apparently underlies the clastic part of the sequence. If this is so, then a source for the suspected volcanic material in the Summerside rocks is at hand. A period of ?Lowest Cambrian volcanism must, however, be assumed. It is, on the other hand, possible that the contact is tectonic. A near-shore environment of deposition is indicated by the green and red colour of the rocks and their arkosic composition. There is slender evidence, in the shape of slump structures, and interbedding plane slip, that sediments were deposited on a slope dipping westwards.

The B. transition zone indicates a rapid change from oxidizing to reducing conditions. The sediments of the Meadows formation, however, are difficult to characterize. They are not flysch as defined by Bouma (1962, p.139) and show little evidence of being deposited from turbidity currents. They include clean orthoquartzites, sometimes conglomeratic, as well as greywackes. This association has been attributed to the action of fluxoturbidites (Kuenen et al. 1956; Unrug 1963; Dzulynski et al. 1959). The sequences described by these authors, however, show features, such as graded bedding and evidence of strong contemporaneous erosion, not seen in the Meadows formation.

Previous authors have considered the Humber Arm to be deltaic in origin. This is probably the best interpretation of the conditions of sedimentation of the Meadows formation. The slope of the delta was probably to the west and was the site of slumping and occasional mudflows. The coarsening of the conglomeratic zones to the east may indicate a source in that direction.

The top of the Meadows formation, the D. transition zone, and the base of the Cooks formation show indications of increased activity in the basin of deposition. After a brief period of coarser sedimentation marked by the Meadows conglomeratic zone, arenaceous sedimentation gradually halted. At the same time the sediments were much disturbed by slumping and sliding. The source and direction of transportation of lime-breccias is not clear. The direction of slump overturning suggests a paleoslope to the west but the coarsening of the breccias may be taken to indicate a source also in that direction. It is possible that two or more sources could have contributed the material to the breccias. In this context it is worth noting that Kindle and Whittington (1958, p. 339) say that Mid-Cambrian boulders in the lower part of Cow Head are not known in place in West Newfoundland. Their source is evidently not the main carbonate sequence. Blocks higher up in the Cow Head breccia, however, are derived from the St. George and Table Head formation.

The bulk of the Cooks formation represents a period of slow sedimentation, lasting from ?Lower Cambrian to lowest Ordovician. No arenaceous sediment was deposited. Although the limestones are not graded and have no bottom markings, it is possible that they were deposited from turbidity currents, accounting for their current bedding and the regular alternation of shale and limestone. The source of these currents must have been a distant site of shallow water carbonate sedimentation. The black pyritiferous shales indicate reducing bottom conditions. Sedimentation of the Middle Arm Point formation was dolomitic and more arenaceous. Since this arenaceous material is silt sized, or well rounded and frosted larger grains, some might have been windborne. The presence of green shale indicates periods of less reducing bottom conditions. The base of the G. transition zone marks the termination of strongly reducing bottom conditions and the beginning of a short period of flysch-like deposition. The rocks of the G.3 sequence show a regular alternation of greywacke and shale and are often flute marked. The turbidites flowed from the east. These rocks pre-date an arenaceous period of sedimentation. The presence of bedded chert may indicate a mingling of fresh and salt water (Bien et al. 1959) as at the mouth of the delta. The H.4 volcanic rocks indicate an earlier period of submarine volcanism than the main Bay of Islands Igneous Complex. They are overlain by molasse—like sediments of the H.5 zone, which were probably deposited in shallow water deltaic conditions. The red shale may even indicate local subaerial deposition.

The facies relationships within the original basin of deposition were probably not simple. The existence of two separate facies, one arenaceous and the other calcareous, in Lower Cambrian time is indicated by rare lenses of carbonate breccia in the Meadows formation, by the derived oolites in the D. transition zone and the sudden influx of lime-breccias with uncommon arenaceous blocks at the base of the Cooks formation. An interfingering between the Cooks formation and the Middle Arm Point formation, probably exists since the lithological equivalent of the Middle Arm Point formation to the north and south of the Humber Arm area contains the same fauna as the Cooks formation in the Humber Arm area.

The most important facies contrast, however, is between the Humber Arm series and the main carbonate sequence. While the lower clastic Cambrian of the Humber Arm series is comparable with the Mt. Musgrave formation (Lilly 1963, p. 15) of the main carbonate sequence, and the Cooks formation is comparable with the Reluctant Head formation (Lilly 1963, p. 21), the Ordovician parts of the sequences are of greatly contrasting facies.

The Ordovician rocks of the Humber Arm series are platy limestones and dolomitic siltstones with interbedded shales, coarse arkosic rocks and volcanics. At least the G.3 part of the sequence was derived from the east where, today, the pure massive limestones and dolomites of the main carbonate sequence are exposed. These carbonates contain no arenaceous, shaly or volcanic rich horizons, yet the two sequences crop out within two miles of each other in the Penguin Arm locality. Possible explanations of the contrast will be discussed in the next section.

## 3. The relationship between the Humber Arm series and the main carbonate sequence.

As previously noted, the Humber Arm series apparently overlies the main carbonate sequence. Not only, then, is there a facies contrast between the two sequences, but also, the older rocks of the Humber Arm series are superimposed upon the youngest rocks of the main carbonate sequence. Within the Humber Arm series itself, there are also local superimpositions of older over younger rock such as in the Rattler Block. Since the critical contacts are marked by zones of chaotic deformation, it is probable that the movements producing these zones are those that telescoped the facies and superimposed the Humber Arm series over the main carbonate sequence.

Processes that may produce such chaotically deformed zones may be classified under three headings:

a) Diastrophic processes.
b) Sedimentary processes.
c) Resedimentary processes.

a) Diastrophic processes.

By the term "diastrophic processes", the author means to imply those tectonic processes which are activated by forces originating deep within the crust and only modified by the effect of gravity. Several different processes fall into this category.

i) High angle reverse faulting is the most obvious process that could produce the chaotic zones and result in the proximity and observed tectonic relationships of the Humber Arm series and the main carbonate sequence. Several features of these zones, however, make it unlikely that the zones represent fault breccias of this type. No breeciation of the main carbonate sequence is seen next to these zones; the deformation is restricted to the Humber Arm series. Little recrystallization of the fine grained limestones,or of delicate fossils, has taken place within the zones. If the faulting forces were strong enough to effect the movement postulated, it is to be expected that within the zones considerable mobilization of calcite or even of quartz, would be evident. Crushing of the matrix and blocks is less than that to be expected along major reverse faults. Any slickensides seen in the zones are usually associated with the minor calcite-filled faults that have cut the zones. Furthermore major faults that do cut the Humber Arm series do not have blocky breccia zones.

ii.) It could be that faulting, cutting poorly consolidated rocks, produced the chaotic zones. This mechanism would involve the movement of a rigid basement on which a sequence of sediments was actively being deposited. The sediments near the base of the sequence may be quite lithified and yield by fracture or folding, but the youngest only partially consolidated sediments, could yield by flowage and disruption. Little friction or heat would be generated. The chaotic zones in the Humber Arm series are crudely concordant, however, and not transgressive as they would be if produced by faulting of this type. Furthermore, the chaotic zones are found at different, discreet horizons within the series.

iii) Breccia may be formed during folding of a series of sediments of differing competences. The chaotic zones could be interpreted as disrupted, less competent horizons, folded between competent beds. The geometry of small folds within the zones, however, bears no relationship to regional trends which are reflected only in the crude north-south cleavage, secondarily developed in the zones. Furthermore, where a sequence of competent and incompetent beds are known to be tightly folded, such as in the core of the synclinorium, no blocky development is seen.

It seems unlikely that these diastrophic processes have been responsible for the deformation in the chaotic zones.

b) Sedimentary processes.

It is possible that the chaotic zones were not produced by deformation but by chaotic deposition. Ordinary sedimentary processes though, are not likely to have been energetic or persistent enough to move blocks as large as those found in the zones over the required distances. The zones could be tillites which are ill-sorted with regard to shape, size and composition of the contained blocks alike. There is, however, no trace of grooved blocks or striated pavements nor any indication that the blocks were dropped from melting icebergs.

c) Resedimentary processes.

Several types of chaotic zones resulting from the disturbance and resedimentation of a series of poorly consolidated sediments have been described in the literature.

Deposits from mudflows bear a striking resemblance to the chaotic zones of the Humber Arm series. Dorreen (1951) described rubble bedding from the Talara formation of north-western Peru. "Blocks of sandstone and shale may be seen dipping in any direction; cobbles and rounded pebbles protrude from the shale while crumpled and compressed "flowage shale" enclosing the blocks contains an intricate variety of minor contortions." (ibid., p. 1834). He describes exotic blocks of sandstone up to a diameter of 40 feet and his figures 5,6,8,9 and 13, closely resemble outcrops along the Frenchman's Head section. He concludes (ibid., p. 1849) "Rubble bedding is a feature resulting from subaqueous mudflows following subaqueous tectonic movement".

Renz et al. (1955) describe, from western Venezuela, boulders and slabs up to 1 km. long embedded in strongly deformed shale. These blocks and slabs are at least 30 km. from any possible source and are thought to have been transported by gravity sliding from a submarine escarpment.

Hawley (1957) describes Ordovician slide breccias from Vermont. Boulders, up to 50 feet long, are chaotically set in a friable matrix of green and black shales which are blurred and streaked. The matrix has what Jones (1937) described as a phacoidal cleavage (that is a tendency to break up into biconvex lenticular fragments). Hawley (ibid., p. 68) says that the zones "... appear to have been deformed by flowage without the development of a good cleavage, commonly with the disintegration of less mobile beds into blocks and boulders". Furthermore, within the zones some of the beds are folded isoclinally, perpendicular to the cleavage of the zones. This cleavage, however, agrees with regional trends and is secondarily superimposed on the chaotic zones.

Several authors (e.g. Dott 1961, and Schemerhorn and Stanton 1963) have reinterpreted certain tillite-like horizons as the deposits of mudflows.

Kugler (1953) compares chaotic zones in Trinidad with the Alpine wildflysch. These zones contain blocks 200 m. x 100 m. x 20 m. "swimming" in rubbly shale.

Wildflysch, however, not only occurs as lenses in otherwise normal sedimentary sequence, but also as "cushions" to various nappes (Collet 1927, p. 85). This second type has been regarded as the deposit from mudflows derived from the fronts of advancing nappes and later overrun by them (e.g. Hills 1963, p. 61).

The chaotic zones derived from mudflows, when their upper surfaces are exposed, are usually overlain by a normal sedimentary sequence, usually of a turbidite facies. The mudflows took place on the water-sediment interface and the whole mass of the material transported was involved in the chaotic deformation. The Humber Arm chaotic zones grade up into undeformed sediment; the contact is not sedimentary. Neither are the zones derived as mudflows from advancing nappes and later overrun by them, since they contain blocks derived from both above and below the zones. (This latter mode of origin, however, may be tenable for the mudflow-like rocks exposed at the base of the Humber Arm series on the south-east shore of Penguin Cove).

The Humber Arm chaotic zones bear some resemblance to the chaotic deformation seen in certain orogenic regions. In the Apennines, for example (Maxwell 1964; 1959a; 1959b; Merla 1957; Wise and Bird 1964), an autochthone is overlain by the allochthonous "argille scagliose" (scaly shale). The argille scagliose are a chaotic mass of friable shale which includes exotic blocks of all sizes up to one with an area of 200 sq. km. These blocks include types of the same age as the autochthone but different facies. Igneous blocks, including ultrabasic types, also occur as components of the argille scagliose; some ophiolitic blocks are as much as 1.5 km. thick. The allochthone is believed to have been emplaced by orogenic landslips. The sediments of the allochthonous sequence were originally deposited to the west of the autochthone. They were uplifted on a series of fault blocks, and being mainly incompetent in nature, flowed eastwards under the influence of gravity, over the autochthone. During this process, the more competent rocks yielded by fracture and were transported as blocks. The movement was submarine since some of the blocks were the site of sedimentation during transport. The process can be compared with gigantic mudflows carrying massive blocks. It is only a difference in scale that separates deformation of the argille scagliose type from mudflows. Similar chaotic zones are known from the Himalayas (Heim and Gansser 1939, p. 154) and from the Moroccan Pre-Rif nappe (Choubert and Marcais 1952).

These terrains are predominantly chaotic in nature. The Humber Arm series, however, only contains a few limited zones of chaotic deformation and is predominantly coherent.

Structure described by Barrington Brown (1938) and Baldry (1938) from Equador and Peru resemble more closely those found in the Humber Arm area. These authors described great thicknesses of lithified rock which slipped many kilometers oceanwards. The slippage surfaces have shallow dips and are marked by a zone of chaotic deformation which may be as thin as several inches or as thick as several hundred feet. The chaotic zones were described as "clay pebble-beds" and superficially resemble boulder clay. The authors claim that the zones contain material from sequences both below and above them and may be locally transgressive. This theory, although accepted by de Sitter (1956, p. 272) and Hills (1945), has been rejected by geologists working in the area (Knights 1956, p. 1029). The chaotic zones have been reinterpreted as deposits from superficial mudflows (Marchant and Black 1959) and large scale movement of coherent sediment denied. The basis of the reinterpretation is the sedimentary contact between the chaotic zone and the overlying sediments, which are of a turbidite facies. Barrington Brown (1959), in a discussion of these results, makes reference to a Newfoundland occurrence, presumably the Cow Head breccias, which he interprets as "chaotic zone produced during intraformational sliding". This interpretation is not tenable in view of the results obtained by Kindle and Whittington (1958).

Even though this mechanism has been rejected in its "type localities", it would seem to offer the best explanation of the mode of origin of the Humber Arm chaotic zones. After the whole Humber Arm sequence had been deposited it became unstable with respect to gravity and certain incompetent horizons yielded by flowage. These "mudflows" carried with them, also under the influence of gravity, the main mass of the Humber Arm sequence. This type of movement can be considered as a special type of argille scagliose, during which the "cover" remains essentially coherent and does not break up into discreet masses.

The main zone of movement would be between the main carbonate sequence and the Humber Arm series. Since the upper part of the series, containing the Bay of Islands Igneous Complex, would have considerable momentum, the western zones of chaotic deformation could represent the last differential movements within the pile of sediments before it finally came to rest. Because of this differential movement, some lower parts of the pile may have overrun higher parts, repeating stratigraphic units. The Rattler Block may now be interpreted as an erosional and tectonic window, through which a higher part of the sequence, overrun by a lower part, may be seen. It is possible that the volcanic rock at Long Point and the associated chaotic zone beneath, represent a lower tectonic level overrun by the slice containing the Summerside formation in that locality.

Essentially, then, the Humber Arm series in the Humber Arm area can be interpreted as a klippe lying on top of the main carbonate sequence. Within the klippe differential movement, at least at three levels has produced internal chaotic zones. The bulk of the series has been overrun itself by the Bay of Islands Igneous Complex and some associated sediments. This later zone of movement is marked by the Woods Island - Frenchman's Head chaotic zone and the zone of mixed structure. It is not known how extensive the lower slice, exposed in the core of the Rattler anticline, is.

The actual mechanism of movement can only be surmised. Hubbert and Rubey (1959) have shown that, theoretically at least, hydrostatic pore-water pressure can reduce the shearing strength of sediments to a value approaching zero, and used this concept in explaining large overthrusts. Compaction was considered to be a main cause of increasing pore pressure. Laubscher (1961) suggests that pore pressure may be increased by gaseous material produced by bacterial action on hydrocarbons.

Hydrocarbons are found in the Humber Arm rocks. Dott (1963, p. 115) and Kamon-Kaye (1956), note that failure in sediments and subsequent flowage may be induced by rapid loading by extrusive igneous rocks. Pore pressure could be increased by any forces uplifting a pile of sediment as well as by the emergence of the top of the pile above water level. If such a zone of high pore pressure developed within a rock sequence and was of regional extent, flowage could be envisaged if the sequence were unstable with respect to gravity. Since friction is low in such zones, little heat could be developed during movement. Recrystallization would be minimized. Less porous and more competent beds would yield by fracture. Rounding of blocks could be produced by the liquefaction of poorly cemented porous arenaceous beds; or in the case of carbonates by solution induced by the high hydrostatic pressure. Figure 55 shows the breakup and rounding of a silty dolomitic bed just south of Black Brook. Any crushing of fragments and recrystallization could be attributed to the effect of the latter part of the movement when pore pressure was decreasing and friction increasing.

A major difficulty in accepting this theory of deformation is the presence of very tightly folded competent beds, usually of whole or partial carbonate composition, within the chaotic zones, It is, however, well known that under conditions of high water pressure, the elastic limit of rocks is lowered and the plasticity is increased. Furthermore, under high ambient pressures, rocks can withstand greater loads without rupturing and plasticity is increased (Beloussov 1962, ch. 18). Since the tightly folded rocks occur near the margins of chaotic zones or as isolated masses within the zones, it is possible that the high hydrostatic pressure induced plastic behaviour in the normally brittle rocks and that the rate of deformation at the margin of the zones was not great enough to cause failure. The isolated masses of deformed rock would represent blocks of the confining zones, detached and incorporated within the movement zone.

A further difficulty is the poor development of the chaotic zone between the Humber Arm series and the main carbonate sequence. Much of the zone could have been lost during transport. This would presumably consist of a shaly sequence below the Summerside formation. Later deformation has "annealed" the matrix of this zone into a uniform coherent mass. It is, however, still blocky. Some of the material at the base of the Humber Arm may represent the shales at the top of the Table Head sequence into which the klippe slid (Rodgers and Neale 1963, p.727).

Smith (1958) has suggested that the Bay of Island Igneous Complex is wedge-shaped, widening at depth and hence could not have moved laterally. Cooper (1936), on the other hand, regards it as a rootless body as does Lilly (1963). These two authors have proposed differential lateral movement within the complex itself. A gravity survey, carried out recently by the Dominion Observatory of Canada, may resolve the shape of the complex.

## 4. The root zone of the klippe.

Some difficulty is encountered in locating the original site of deposition of the Humber Arm series. Since the main carbonate sequence extends around the northern end of the Long Range and is found as small patches to the east of the Long Range, it can be assumed to have originally covered the present site of the Long Range. The Humber Arm rocks could not have been deposited there and then have slid off during its uplift (Rodgers and Neale 1963). A source to the west is not likely since locally, in the Appalachians to the south and in Labrador, rocks equivalent to the main carbonate sequence rest directly on the shield. Also, according to paleomagnetic investigations (Black 1964) the Gulf of St. Lawrence was not significantly opened during Cambrian and Ordovician times. Subsidence which may have accompanied the initial opening of the Gulf, could have provided a trough in which the klippe finally came to rest.

A source to the north or south is possible but not likely, since the "grain" of West Newfoundland is predominantly north-south.

Any speculation concerning an eastern source of the klippe is complicated by the possibility that considerable transcurrent movement has taken place along the Cabot fault (Wilson 1962), or an equivalent of it. An eastern source must, however, be considered most probable even though no rocks of the same facies or of undoubted Cambrian age are known from the Central Newfoundland terrain.

The facies of the Humber Arm series suggests that it represents a sequence of rocks transitional between the miogeosynclinal main carbonate sequence and the eugeosynclinal rocks of central Newfoundland. It can be further speculated that the Humber Arm series was deposited to the east of the Long Range on the flank of a gently oscillating basement block that completed one oscillation between Lower Cambrian and Mid-Ordovician times. The initial subsidence of the block was possibly accompanied by volcanism and followed by the rapid deposition of deltaic rocks on a paleoslope which dipped to the west. Towards the end of Lower Cambrian times the supply of arenaceous material to the basin was halted, possibly because of the drowning of the crustal block. The slow carbonate-shale deposition probably lasted until Lower Ordovician times when the crustal block was re-activated and a new delta built out westwards into the basin of the deposition. The uplift of the block was accompanied by volcanic and intrusive activity which resulted in the formation of the Bay of Islands Igneous Complex. It is probable that the final uplift of the block was accompanied by a subsidence of the Long Range block on which the main carbonate sequence was being deposited and that these movements, together with the load of igneous rocks, provided much of the gravity potential necessary for the emplacement of the klippe.

## 5. Age of emplacement and deformation of the klippe.

Rodgers and Neale (1963, p. 727) ~~speculate~~ suggest that the Long Point formation on the Port au Port Peninsula, which is late Mid-

Ordovician in age at its base, is a neoautochthonous sequence, deposited on the klippe after it was emplaced. Brueckner and Utting (per. comm. 1964) and Rodgers (m.s.) confirmed this speculation.

The emplacement of the klippe, therefore, took place during Taconic times though the actual movement could have started earlier. The deformation of the klippe and the main carbonate sequence probably took place together, after the emplacement of the klippe, but not later than the Carboniferous. It was during this deformation that the main Humber Arm folds were formed and the chaotic zones cleaved. The main movement of the Humber Arm folding seems to have been eastwards and was perhaps modified by crustal readjustments following the emplacement of the klippe. The high angle faults are probably Post Carboniferous in age since similar faults cut Carboniferous rocks to the south.

## Conclusions.

Despite the incomplete nature of the present investigation, there is some justification for the recognition of six formations within the Humber Arm series. Much information concerning the stratigraphy and structure is still lacking, but it appears likely that Rodgers and Neale's (1963) speculations are to a large extent valid. The age of the rocks is probably Pre-Middle Ordovician to Cambrian and they represent a contemporaneous facies of the main carbonate sequence, but the pre-Taconic relationships of these facies are not understood. The proximity of the two facies and the origin of the chaotically deformed zones are related and best explained by the emplacement of the Humber Arm series as a klippe during Taconic times. After emplacement, the klippe was deformed about a north-south axis and cut by later high-angle faults.

# APPENDIX A

Pleistocene fossils from a raised delta at Lark Harbour.

At the crest of the hill on the road connecting Bottle Cove to Little Port, just west of Lark Harbour, a raised gravel and sand delta has recently been excavated for road metal. The delta surface is at an elevation of approximately 100 feet. It contains abundant fossils. All indicate environmental conditions comparable with those existing today in Western Newfoundland waters. Miss E. Brown kindly identified the following forms.

1. Mollusca.

A. Pelecypoda

i) *Hiatella arctica* Linné*
ii) *Mya arenaria* Linné
iii) *Mya truncata* Linné
iv) *Mya edulis* Linné
v) *Pecten islandicus* Müller

B. Gastropoda.

i) *Busycon* Sp.*
ii) *Littorina saxtile* Olivi
iii) *Buccinum undatum* Linné
iv) Skenea planorbis Fabricius*

2. Arthropoda.

A. Crustacea.

i) Balanus crenatus Bruguiere

3. Echinodermata.

A. Echinoidea.

i) Strongylocentrotus ?drobachiensus Müller*

* Not previously recorded in Richardson (1939/1940).

# APPENDIX B

Hydrocarbon occurrences in the Humber Arm Area.

Barrington Brown (1938.b) briefly reviews the hydrocarbon occurrences in Western Newfoundland. The Green Point series is regarded as the main petroliferous horizon in the area. Cumming (1965) enumerates six types of occurrences of petroleum on the Port au Port Peninsula. He regards the occurrences as being related to the capping and associated effects of the base of the klippe. Carbonate rocks beneath the klippe are thought to be the source beds.

In the Humber Arm area bitumen is found filling fractures in the rocks but is confined to rocks stratigraphically above, and including, the Middle Arm Point formation which is the equivalent of the Green Point series. The occurrence of bitumen is further restricted to the western part of the area. A unique occurrence outside the area has been referred to in section I.

Any prospect of economic quantities of hydrocarbon existing in the area depends on what sequence contains the source rock. If the main carbonate sequence contains the source beds, a structural closure is provided by the Rattler anticline. The whole Bay of Islands is a broadly anticlinal structure and may also form a trap. If the source rocks are the Green Point series or their equivalents, it is unlikely that they are presently buried deeply enough to have retained their hydrocarbons.

# APPENDIX C

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APPENDIX.D.

FIGURES.

Figs. 1. and 2. in back pocket.

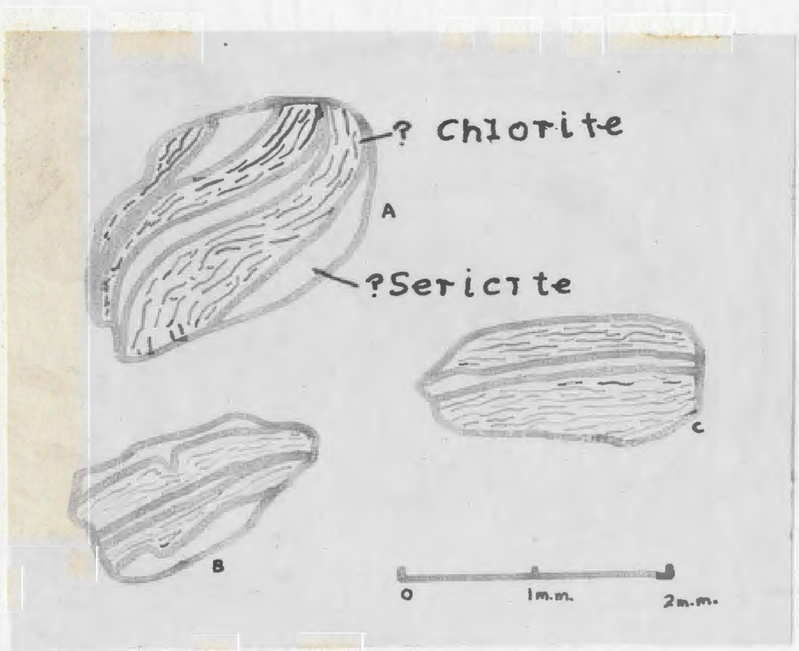



Fig.3. ?Chlorite-?Sericite intergrowths.

a. and b. from the Summerside formation.

c. from the base of the Meadows formation.

( plane polarized light.)

Fig.4. Primary deformation in argillaceous sandstone of the Summerside formation. Crow Hill, north face.

Fig.5. Wavy and current bedded siltstones with interbedded shale from the C.2. zone of the Meadows formation. West shore of Davis Cove. The prominent bed to the right of the photograph is about 2 inches thick.

Fig. 6. Coarse current bedding in the C.6. zone of the Meadows formation. Benoit's Cove.

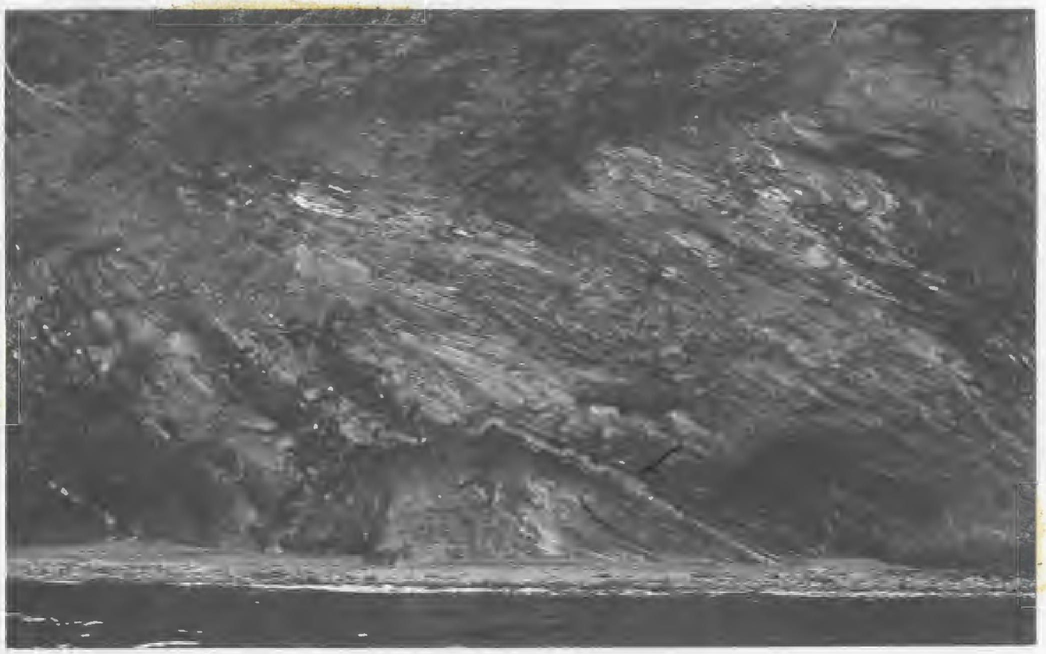

Fig. 7. Block of dolomitic siltstone and violet shale in a fluxoturbidite horizon of the Meadows formation. Large quartz grains are conspicuous. South-east of Long Point.

W E

Fig.8. Sandstone dykes and sills in the Meadows formation. A sandstone whirl-ball can be seen in the top left hand corner. The first point north of the Rattler Brook mouth.

N S

Fig.9. Flute casts and worm marks on base of a siltstone bed of the D. transition zone. East of Cox's Cove. The length of the long flute cast just below the centre of the photograph is about 6 inches.



E W

Fig.10. Platy limestones and shales of the Cooks formation showing primary repetition of a limestone bed on the western flank of the small anticline(arrow). Between Giles Point and Cooks Cove. The height of the arrow [illegible] is about 10 feet.

Fig.11. Large limestone boulder in the lime-breccias of the Cooks formation. Bound Head.

Fig.12. Large sandstone boulder in the lime breccias of the Cooks formation. Halfway Point.

Fig.13. Primary deformation of Cooks platy limestones. Just north of McIver's Brook mouth.

N S

Fig.14. Bedding plane thrust repeating a thin dolomitic siltstone of the Middle Arm Point formation and folded shales near the head of the hammer. About 1 mile north of Middle Arm Point.

Fig.15. Primary? contortions in black and green shales of the Middle Arm Point formation. Just north of Black Brook.


Fig.16. Flute casts on base of green argillaceous siltstone of the G. transition zone. North shore of Eagle Island.

Fig.17. Slump rolls and load casts in current bedded sandstone interbedded with shale. Woods Island formation just north-west of Peter Point.

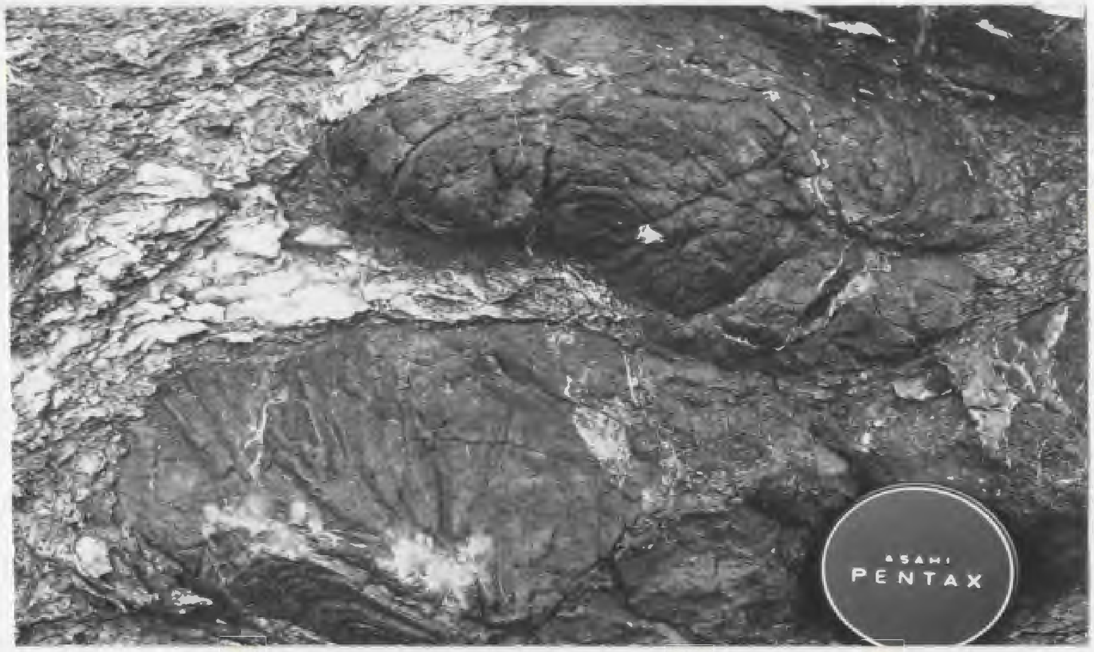



Fig.18. Pillowed volcanic flow with a calcite matrix from the volcanic horizon of the Woods Island formation just west of Tiheay Cove, Woods Island.


Fig.19. Erosional ribs producing a ridge and furrow structure in the upper arkosic part of the Woods Island formation on the west end of Woods Island. The white, prominent ridges are rich in calcite matrix.

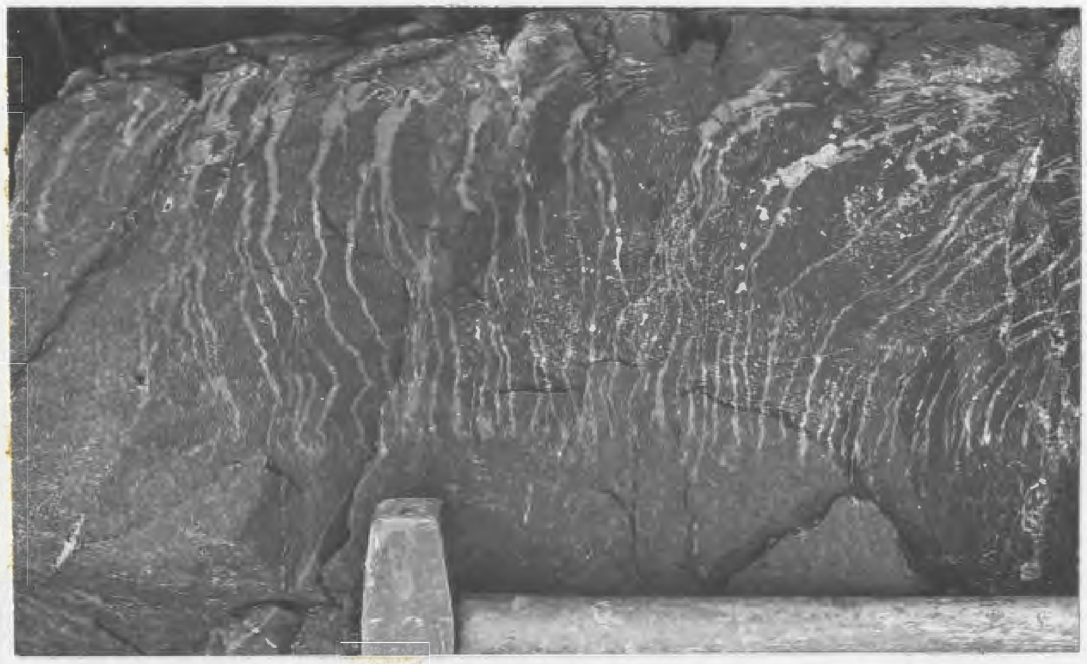


Fig.20. A recrystallized quartzite block from the zone of chaotic deformation at Frenchman's Cove. The white streaks are calcite cemented, while the darker parts are vitreous and hard with a silica cement. The pattern is interpreted as a recrystallized ridge and furrow structure seen in fig.19.

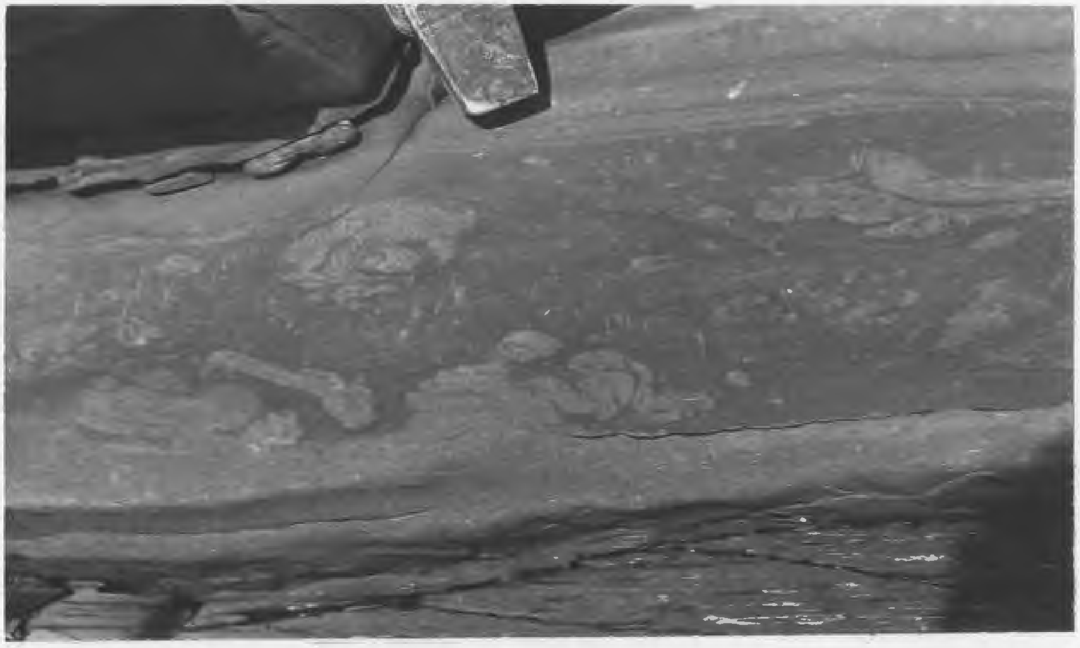


Fig.21. Ripple marks on the top surface of a dolomitic siltstone bed of the J.1. sequence just north of Lower Beach.

Fig.22. Convolute bedding in a fine grained carbonate-rich rock of the J.2. sequence. Apsey Point.

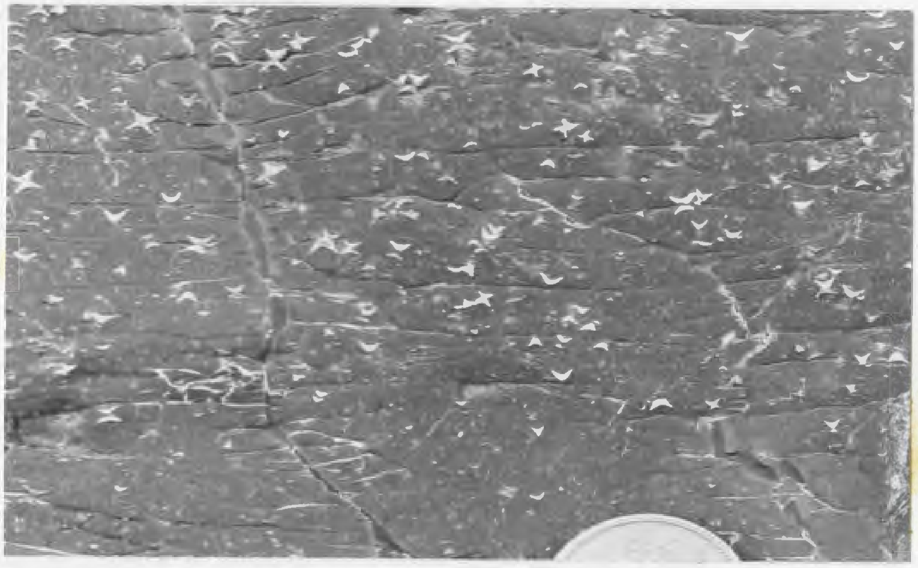


Fig.23.

Figs.23-28. Calcareous bodies interpreted as "unidentified calcareous fossils". Figures are arranged in a sequence that is thought to represent the growth stages of a single organism. Fig.23. youngest. Localities for collecting these forms are given in the text.

Fig. 24.

Fig.25.

Fig.26.

Fig.27.

Fig.28.

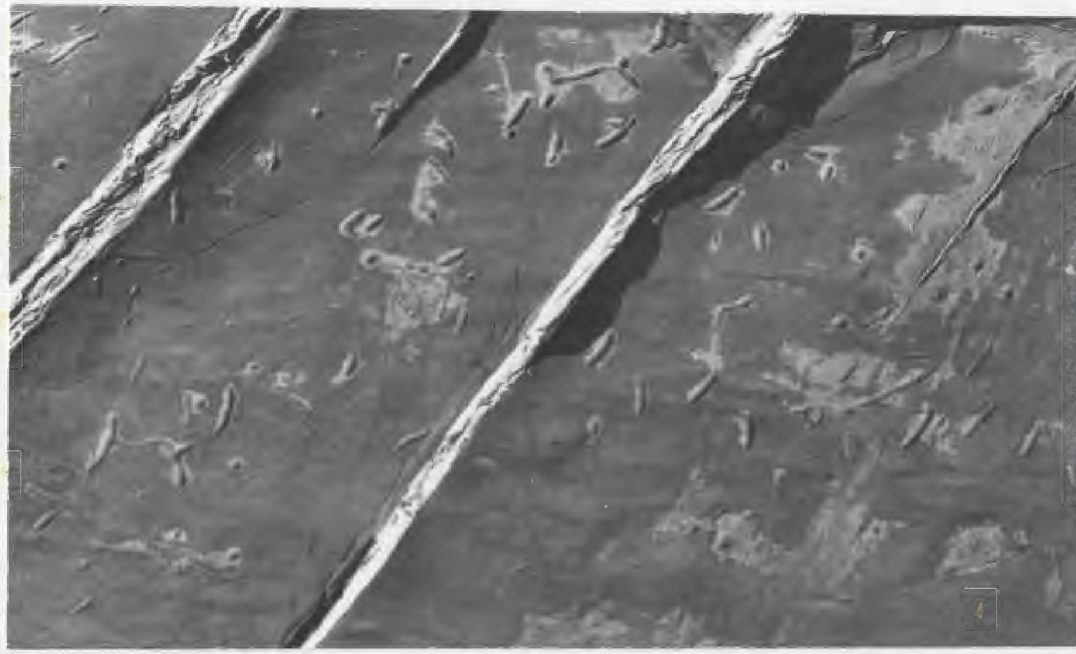


Fig.29. Simple trace fossils on the bottom of a dolomitic siltstone horizon. South-western shore of Eagle Island.

Fig.30. Lobate trace fossil in the upper arkosic part of the Woods Island formation on the west end of Woods Island. The trace fossil is richer in calcite matrix than the surrounding rock.

Fig.32. An anticline, plunging north-east, with the eastern limb partially sheared off and an axial plane fracture cleavage developed in the argillaceous sandstones of the Summerside formation. South-western end of Frenchmans Pond.

Fig.33. An anticline in massive quartzite of the Meadows formation, with the western limb thinned as compared with the eastern limb. Just west of Davis Cove to the east of the Humber Arm synclinorium axis.


Fig.34. Box shaped fold in platy limestones, sandstones and interbedded shale of the D. transition zone east of Cox's Cove.

Fig.35. Small thrust, probably resulting from the faulting of a box shaped fold(fig.34.). Locality and horizon as in fig.34.


Fig.36. Asymmetric syncline plunging south-west in quartzites, shales and thin bedded siltstones of the Meadows formation west of Parkes Cove.

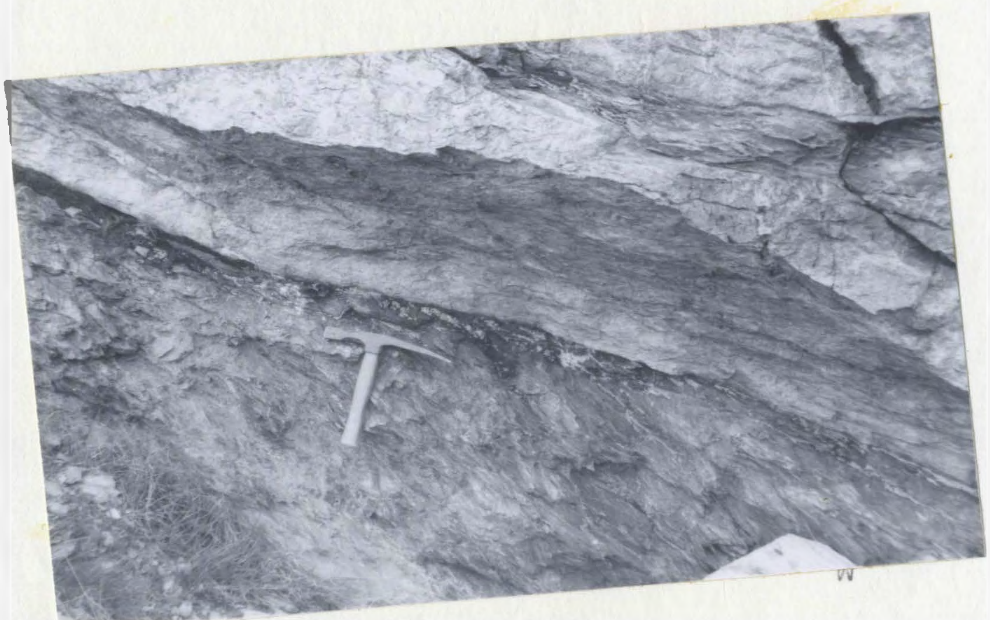



Fig.38. The Crow Head-Crow Hill thrust at Crow Hill. Just above the hammer head. Rocks above the thrust are the lower quartzites of the Summerside formation, those below the thrust the shales of the Meadows formation.

W E

Fig.39. Late shearing and associated folding in the shales of the Meadows formation at Leahy Cove on the eastern limb of the Humber Arm synclinorium.

Fig.40. Late shearing and associated folding in the shales of the Meadows formation just west of Gillams in the core of the Humber Arm synclinorium.

N.W. S.E.

Fig.41. Chaotic deformation just south of Whites River mouth. Rounded white limestone blocks and angular dark sandstone blocks in a friable shaly matrix.

Fig. 42. Chaotic deformation on south coast of Woods Island. Massive blocks of sandstone embedded in a friable shaly matrix.

Fig.43. Chaotic deformation at Frenchman's Cove. Blocks of limestone in friable shaly matrix.

Fig.44. Massive block of argillaceous limestone set in a **shaly** matrix. Note fracturing in the block which is parallel with the plane of parting in the shale. The scale is given by hammer(arrow).

Fig.45. Rounded block of quartzite embedded in black shale with a relatively good cleavage. The bed of Corner Brook near the contact between the Humber Arm series and the main carbonate sequence.

Fig.46. Chaotic deformation at Frenchman's Head. Most of the blocks are limestone and a crude stratification dipping towards the bottom right of the photograph can be detected.

Fig.47. Massive composite block of sandstone embedded in shale just west of Tiheay Cove, Woods Island. The block, when seen from the other side, consists of interbedded sandstones and relatively undeformed shales.

Fig.48. Chaotic deformation at Frenchman's Head. A large composite block can be seen at the left of the photograph.

Fig.49. Composite fault cutting the zone of chaotic deformation at Frenchman's Head. There is no increase of deformation near the fault.

Fig.50. Quartzite block in the zone of chaotic deformation at Frenchman's Head.

Fig.51. Plastically folded, isolated block of interbedded dolomitic siltstone and shale in the zone of chaotic deformation at Apsey Point.

Fig.52. Overturned synclines in rocks of the ?Middle Arm Point formation on the south-eastern coast of Woods Island.

Fig.53. Small completely closed antiform in current bedded dolomitic siltstone of the Middle Arm Point formation on the south-eastern shore of Woods Island. The plunge is 90 degrees.

Fig.54. Zone of chaotic deformation(left) intersecting rocks of the Middle Arm Point formation in the zone of mixed structure just north of Black Brook.

Fig.55. Dolomitic siltstone bed, fragmented and rounded in a zone of chaotic deformation, just north of Black Brook. Blocks derived from this bed can be recognized scattered in the shale, for 30 yards along the coast. Rounding probably caused by pressure solution of the dolomitic component.

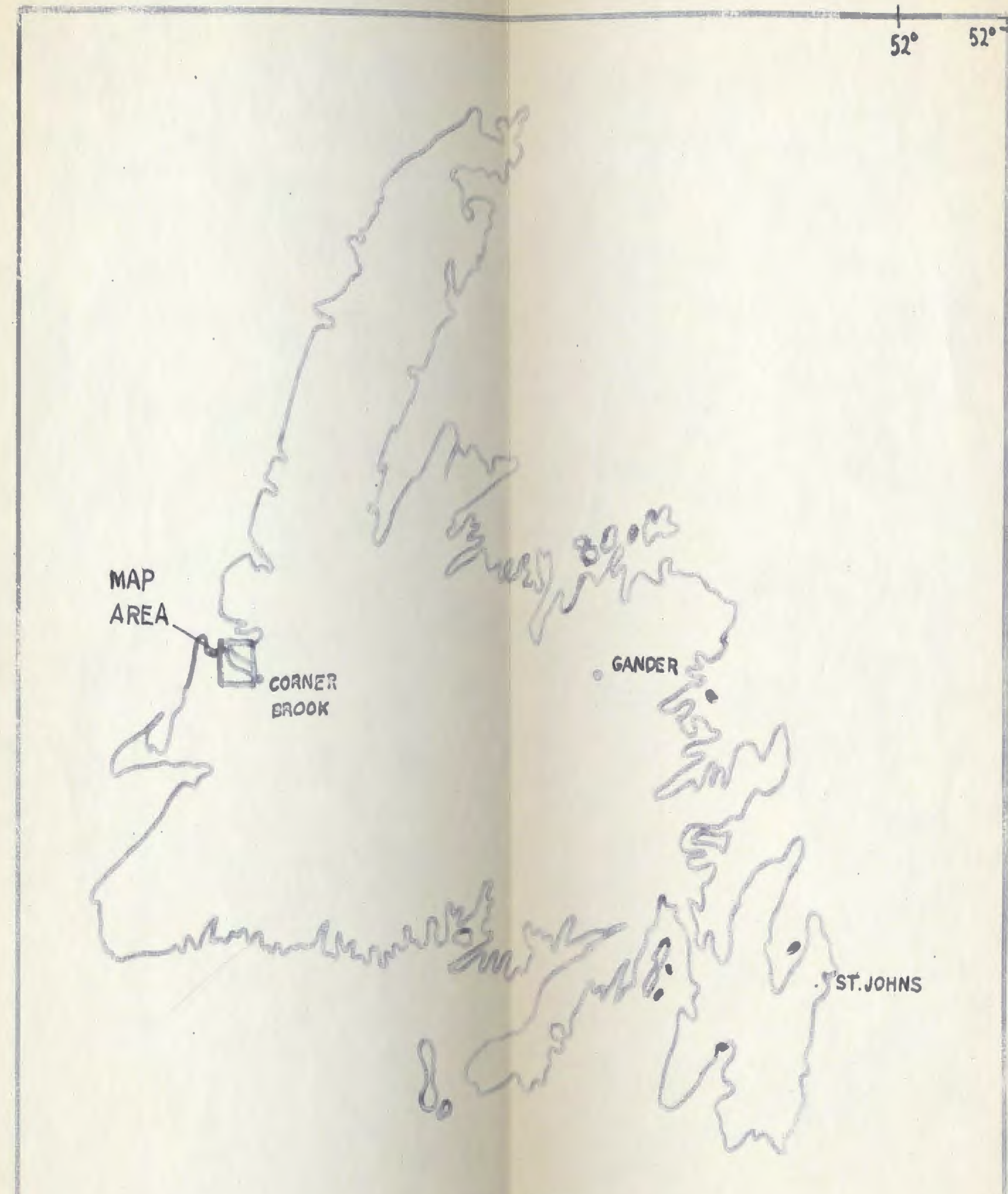

Fig. 31. STRUCTURAL DIVISIONS OF THE HUMBER ARM AREA.

1. Zone of folds and faults
2. Zone of block faulting.
3. Zone of chaotic deformation.
4. Zone of mixed deformation.
5. The Rattler Block.

(6. The main carbonate sequence.)

## TABLE ONE

| Present Divisions | Estimated thickness in feet | Present Formations (1965) | Lilly (1963) | McKillop (1963) | Weitz (1954) | Walthier (1949) | Schuchert and Dunbar (1934) |
|---|---|---|---|---|---|---|---|
| H5 | 400 | Woods Island Fm. | Western Sandstone Fm. | not studied. | North Arm Fm. | not studied. | Humber Arm Series |
| H4 | 200 | | | | | | |
| H3 | 400 | | | | | | |
| H2 | 400 | | | | | | |
| H1 | 250 | | | | McIver's Fm. | | |
| G6 | 10 | Transition. | | | | | |
| G5 | 80 | | | | | | Undivided |
| G4 | | | | | | | |
| G3 | 300 | | | | | | |
| G2 | 30 | | | | | | |
| G1 | | | | | | | |
| F2 | 400 | Middle Arm Point Fm. | | | | Upper Clastics | Green Point series |
| F1 | 500 | | | | | | |
| E2 | 500 | Cooks Fm. | | | | Cooks limestone tongue | |
| E1 | 100 | | Penguin Arm Limestone Fm. | calci-rudites | | | |
| D | 300 | Transition | | | | | |
| C6 | 400 | Meadows Fm. | Penguin Arm, Irishtown and Summerside Quartzites | Upper and lower shales and Quartzites | upper and lower Members; Summerside Fm. | Lower Clastics | |
| C5 | 200 | | | | | | |
| C4 | 200 | | | | | | |
| C3 | 600 | | | | | | |
| C2 | 50 | | | | | | |
| C1 | 50 | | | | | | |
| B | 50 | Transition | | | | | |
| A2 | 50 | Summerside Fm. | | | Top of the Lower Member | | |
| A1 | 250 | | | | | | Cowhead Breccias |
| Σ | 5500-ft. | | 6,000+ ft. | | 12,000+ ft | 4000 - 8,500 ft. | 5,000+ ft. |




INDEX MAP

FIG. 1