Geological Survey of Canada

STRATIGRAPHY OF BOTWOOD MAP-AREA, NORTHEASTERN NEWFOUNDLAND

Harold Williams

1969

CONTENTS

INTRODUCTION

The Botwood map-area described in this report lies between 49°00' and 50°00' north latitude and 54°00' and 56°00' west longitude. It is on the northeast coast of Newfoundland and represents part of the northeastern extremity of the Appalachian mountain chain. The map-area includes approximately 6,200 square miles of which about one third is occupied by the Atlantic Ocean in the northeastern part.

The present report and geologic map are based mainly on field investigations conducted by the writer but include the results of earlier work. About 60 per cent of the area was previously mapped and the object of recent work was to complete geological mapping and incorporate the results of earlier investigations in a consistent regional pattern. Toward this end, the entire area was mapped by reconnaissance methods during the summer months of 1961, 1962, and 1963. Geologic data was compiled on a scale of 1 inch to 2 miles for publication at a scale of 1 inch to 4 miles. The regional reconnaissance approach has permitted a re-evaluation of the geology of the frequently studied Botwood map-area and has served to bring out similarities rather than differences among the many previously mapped widely separated smaller areas.

No attempt is made to compile the available information on the orebodies and numerous mineral prospects in the map-area. Descriptions of these are available in reports of the Newfoundland Department of Mines and no additional detailed information was collected during the reconnaissance mapping. The author's views on the relationships between base metal mineralization and host rocks in the area have been published elsewhere (Williams, 1963).

Previous over use on Ordivician-Silurian stratigraphy and tectonic history of this part of Newfoundland have changed considerably because of recent work and continue to change as current research progresses. This report has been prepared hastily so that much of the accumulating data from which present views stem can be made available to current workers and those who contemplate studies in this area. It is not intended as a definitive final report but rather a compilation of information obtained during reconnaissance studies and subsequent field trips in the map-area.

The author was assisted in the field during the summer of 1961 by Ron Smith, Ingomar Ermanovics, Ron Trischuk, Mac Ryan, and Chesley Saunders; during 1962 by Bryan Green, Dave Capstick, John Purvis, and Mac Ryan; and during 1963 by Ted Bence, Pete Gummer, Harry Wood, Mac Ryan, and Carl Wheaton.

GENERAL GEOLOGY

The geologic setting of the Botwood map-area is the central Paleozoic mobile belt of the Appalachian mountain system. The map-area is underlain chiefly by rocks of Ordovician and Silurian age but many of the rocks are unfossiliferous and some of them, especially in the northwest extremity of the area are pre-Ordovician. The rocks have been complexly folded, faulted, and cut by a variety of intrusions. The major structural trend is northeasterly, but there are some significant deviations.

The Ordovician rocks consist of thick accumulations of basaltic pillow lavas, altered green lavas, pyroclastic rocks, greywackes, slates, cherts, and minor conglomerates and limestones. All of these rocks were apparently deposited in deep marine waters and contrast sharply with Silurian strata that have definite continental depositional aspects. The dominant volcanic assemblages of the Ordovician System are known as the Headlands and Wild Bight Groups, and the dominantly sedimentary assemblages comprise most of the Exploits Group and part of the Gander Lake Group. The stratigraphic sequences are not well known and the various groups are thought to be at least in part of the same age.

Silurian rocks consist of conglomerates and associated greywackes, mafic to silicic volcanic rocks, and red and grey quartzose sandstones, with minor coralline shale and siltstone, and corralline limestone. In the central part of the map-area the Silurian rocks referred to are the Botwood and Indian Islands Groups and their age has been confirmed in a number of localities by indigenous Silurian fossils. Elsewhere within the map-area the rocks are unfossiliferous and are considered to be Silurian for a number of indirect reasons. Red sandstones in the vicinity of Pilleys Island are an eastward continuation of the tentatively Silurian Springdale Group, and rocks of the Burlington Peninsula, tentatively assigned to the Silurian, are referred to the Cape St. John Group.

All of the layered rocks in the map-area have been affected by low grade regional metamorphism, and in addition thermal metamorphic aureoles are commonly developed around the margins of larger intrusions. Moderate to high grade metamorphic rocks are locally represented in the extreme northwest corner of the map-area and southeastward in the vicinity of Ocean Pond. In the northwest the metamorphic rocks are referred to the Fleur de Lys and Paquet Harbour Groups and consist of gneisses and schists that have been variously assigned to the Precambrian or Early Paleozoic. Metamorphic rocks of indefinite age are also represented in the southeast where they form part of the lower unit of the Gander Lake Group.

A wide variety of intrusive rocks is represented in the map-area. These range in composition from silicic to ultramafic and include such rock types as granite, granodiorite, quartz diorite, diorite, gabbro, pyroxenite, and serpentinite. Many of the granitic intrusions are of batholithic dimensions and are composed of rocks that are grey or pink and medium- to coarse-grained. Most of these rocks are massive and cut sharply across structures in the country rocks. A few are foliated or granulated and are concordant. The ultramafic intrusions and some mafic intrusions appear to be spatially related to Ordovician volcanic rocks and are thought to be of Ordovician age. The granitic intrusions are considered to be Devonian either on direct or indirect geological evidence, or radiometric age determinations.

PALEOZOIC OR PRECAMBRIAN ROCKS

These rocks of indefinite age are dominantly sedimentary or metasedimentary assemblages. They are assigned to the Fleur de

Lys and Pacquet Harbour Groups where they outcrop in the extreme northwestern part of the map-area and are known as the Gander Lake Group-lower unit where they outcrop southeast of Gander River. The Fleur de Lys and Pacquet Harbour Groups constitute a conformable succession and are of unknown relationship to nearby metamorphosed Paleozoic rocks. The lower unit of the Gander Lake Group appears to conformably underlie basic volcanic rocks and Middle Ordovician sedimentary rocks that together form the middle unit of the Gander Lake Group.

Fleur de Lys Group

Rocks in the map-area assigned to the Fleur de Lys Group (Fuller, 1941) either lie along strike or are included with rocks earlier described as the Mings Bight Formation (Watson, 1947) and the Mings Bight Group (Baird, 1951; Neale, 1958; 1959). Baird (1951) tentatively correlated the Mings Bight Group with the Fleur de Lys Group, which has its type area 10 miles to the northwest. Subsequently, Neale and Nash (1963) included gneisses and schists of the Mings Bight Group with the Fleur de Lys Group. The two groups have many lithological similarities and both bear similar relationships to nearby metamorphosed basic volcanic rocks (Neale and Kennedy, 1967; Church, in press). The term Mings Bight is therefore dropped and the rocks in the map-area earlier referred to as the Mings Bight Group are assigned to the Fleur de Lys Group. The rocks are bounded by granite along their southern boundary, except on the north side of Pacquet Harbour where they are presumably overlain by metamorphosed volcanic rocks. The thickness of the Fleur de Lys Group was estimated at 20,000 feet in the type area (Fuller, 1941) and at 1,500 to 2,000 feet (Watson, 1947) and 8,000 feet (Baird, 1951) in the vicinity of Mings Bight. The base of the group is not exposed and its true thickness is unknown.

The Fleur de Lys Group rocks in the map-area are grey medium-grained schists and gneisses that are composed essentially of quartz, sodic plagioclase, biotite, muscovite, and chlorite, with accessory amounts of apatite, calcite, magnetite, pyrite and epidote. Locally the rocks contain garnet, staurolite, kyanite, and green amphibole. The majority of the rocks are micaceous schists and gneisses but locally porphyroblastic augen gneisses, quartzites, and graphitic schists and slates have been reported (Baird, 1951).

One of the most obvious features of the rocks in this group is a distinct banding, which is most apparent in coastal exposures north of Pacquet Harbour. The bands differ in composition and texture but their mineralogy is the same and it is only the proportions of the constituent minerals that vary from one layer to the next. Some of the bands are less than one-half inch thick, whereas others exceed 10 feet and are continuous along strike for several hundred feet. Some of the thicker bands contain up to 70 per cent quartz and are granular or sugary textured; in contrast, thinner bands are richer in mica and are schistose. The thickness of the bands, their texture and mineralogy, and local occurrences of quartzite and graphitic schist all suggest that the schists and gneisses represent a metamorphosed sedimentary assemblage that consisted of interlayered sandstones and siltstones or shales in alternating layers.

The rocks of the Fleur de Lys Group are complexly folded. Two prominent phases of folding are evident in most exposures and recent work (Neale and Kennedy, 1967; Church, in press) indicated that these rocks have had a complex structural history of multi-phase deformation.

The common mineral assemblages of the Fleur de Lys Group rocks in the map-area indicate that most of the rocks were not metamorphosed beyond the greenschist facies of regional metamorphism. At Pacquet Harbour, however, the rocks contain well-formed red garnet, staurolite, kyanite, and green amphibole, and the plagioclase present is more calcic than is usual. These mineralogical changes indicate an increase in metamorphism and conditions typical of the amphibolite facies. Occurrences of garnet have been reported in the Fleur de Lys rocks near granite contacts (Baird, 1951), and possibly the higher grade metamorphism displayed in the rocks at

Pacquet Harbour can be correlated with the granite intrusion exposed to the west. In the Botwood map-area the Fleur de Lys rocks are considered to be slightly less metamorphosed in general than those in the type area to the northwest (Watson, 1947; Baird, 1951; Neale and Kennedy, 1967).

The Fleur de Lys rocks are in contact with meta-volcanic rocks of the Pacquet Harbour Group on the north shore at the entrance to Pacquet Harbour. The volcanic rocks are represented by medium-grained dark green to black amphibolites that apparently have had the same metamorphic history as underlying schists and gneisses of the Fleur de Lys Group. There is some interlayering or infolding of amphibolite and schist and gneiss over a distance of a few tens of feet in the contact zone. The Pacquet Harbour amphibolites and the Fleur de Lys rocks appear to be in normal stratigraphic contact and there is nothing to suggest an unconformity or tectonic boundary between the two contrasting assemblages. Similar relationships have been described between metamorphosed basic volcanic rocks and the Fleur de Lys Group northwest of Mings Bight near the type area (Neale, 1959a; Neale and Kennedy, 1967).

The Fleur de Lys Group rocks in the map-area are considered to be equivalent to lithologically similar rocks that are exposed 10 miles to the northwest in the type area. In both places the metamorphic rocks are thought to conformably underlie metamorphosed basic volcanic rocks. The Fleur de Lys rocks are much more deformed and metamorphosed than nearby tentatively Ordovician rocks and are therefore thought to be Cambrian or Late Precambrian in age. It is possible that the rocks are of Paleozoic age in the upper parts of the group and Late Precambrian in lower Parts (Williams, 1964; in press).

Pacquet Harbour Group

The term Pacquet Harbour Group is proposed by Church (in press) to designate a series of metamorphosed mafic volcanic rocks that extend southwestward from Pacquet Harbour. These rocks were earlier assigned to the Baie Verte Group (Baird, 1951) but they have an identical structural story to underlying rocks of the Fleur de Lys Group and are much more metamorphosed and deformed than the Baie Verte Group in its type area. The rocks are therefore thought to be older than the Baie Verte Group and more closely linked with the Fleur de Lys Group (Neale and Kennedy, 1967).

Within the map-area the Pacquet Harbour Group consists mainly of amphibolites except west of Woodstock and near the boundary of the map-area where pillows and fragmental textures are evident in rocks that have not been metamorphosed beyond the greenschist facies. These changes in metamorphism and in the appearance of the rocks make it most difficult to determine if certain exposures, i.e. especially northwest of Nippers Harbour, belong to the Pacquet Harbour Group or are part of younger volcanic sequences.

Amphibolites at Pacquet Harbour originated mainly through the metamorphism of basic lavas but locally near Woodstock and southwestward, banded and fragmental amphibolites are considered to represent originally layered tuffs and agglomerates as well as possible sedimentary rocks. The amphibolites are composed of green actinolite, plagioclase (albite to andesine), and quartz, with lesser amounts of biotite and accessory magnetite, chlorite, and epidote. Most of the rocks are medium- to coarse-grained and contain 45 per cent or more of actinolite, which occurs as slender prisms or elongated grains surrounded by finer grained matrix of granular plagioclase and quartz. The rocks commonly display a lineation produced by the alignment of actinolite crystals and in a few places attenuated amygdules are common. Some of the rocks contain plagioclase porphyroblasts or plagioclase porphyroblast aggregates that are also aligned.

Finely banded tuffs and agglomerates have been reported between Woodstock and Beaver Pond with original textural and structural features apparent on weathered rock surfaces (Baird, 1951). In places the tuffs have as many as 25 bands to one inch and in other places individual layers may be as much as 8 inches thick. The bands result from variations in the proportions of constituent minerals and are persistent, with even the thinnest bands extending for distances of 10 feet or more. The agglomerates contain fragments of altered lava up to one foot in diameter and are associated with metamorphosed basic flow rocks. Black slates that contain an 8-inch thick hematite-rich layer occur 3/4 mile southwest of Woodstock and crumpled and minutely folded slates occur 3 3/4 miles southwest of Woodstock (Baird, 1951).

The amphibolites at Pacquet Harbour display tight to isoclinal folds that plunge eastward and that have an earlier fabric preserved in the fold hinges. These folds are in turn refolded by open upright folds that probably represent a third phase of deformation.

The relationships between the Pacquet Harbour Group and nearby younger groups are in doubt and are currently being investigated. Neale and Kennedy (1967) have pointed out the possible correlation of the metavolcanic rocks at Pacquet Harbour and the Birchy Schist (Fuller, 1941) that outcrops in the eastern flank of the main Fleur de Lys outcrop belt to the west. Direct correlation remains premature pending the determination of the succession within the Fleur de Lys Group beneath each of the volcanic units.

Gander Lake Group - lower unit

The term Gander Lake Group (Jenness, 1958) is a modification of an earlier term Gander Lake Series (Twenhofel, 1947). The latter term was used to describe a great thickness of northeast-trending sedimentary rocks that are exposed along the northern shore of Gander Lake, 5 miles south of the Botwood map-area. Twenhofel (1947) assigned the rocks to the Silurian system but it has since been shown that they are no younger than Ordovician (Jenness, 1963).

The Gander Lake Series of Twenhofel was much more restricted than the present group of the same name. It was not considered to include volcanic rocks and excluded large areas of sedimentary and metamorphic rocks subsequently included by Jenness (1958; 1963) and Williams (1964; 1968). Jenness (1963) divided the Gander Lake Group into three broad lithologic units as follows: a lower unit composed chiefly of arenaceous rocks, a middle unit composed chiefly of mixed sedimentary and a well-defined belt of volcanic rocks, and an upper one composed chiefly of argillaceous rocks. These can be traced northeastward along strike in the Botwood map-area. The upper unit and sedimentary rocks of the middle unit have been dated by fossils and are Middle Ordovician. The age of the lower unit is as yet unknown.

The lower unit of the Gander Lake Group underlies approximately 400 square miles in the southeastern part of the Botwood map-area. It continues southwestward through central Newfoundland (Jenness, 1963) and probably merges with arenaceous rocks of the Bay d'Espoir Group (Jewell, 1939) on the south coast of the island. In the map-area, rocks of the lower unit underlie an area 22 miles wide and outcrop to the southeast for an additional 6 miles. The thickness of this extensive sedimentary assemblage has not yet been determined. The rocks are for the most part highly folded or metamorphosed and the base of the unit has not been found. In the type area the rocks are estimated to be 10,000 feet thick (Jenness, 1963).

The lower unit of the Gander Lake Group consists of a monotonous assemblage of micaceous quartzose sandstone, quartzite, siltstone, argillite, and slate. Most of the rocks are light to dark grey or greenish with a silvery sheen along parting planes. They are fine- to medium-grained and composed mainly of quartz with lesser amounts of plagioclase and rock fragments in a clayey or micaceous matrix. Almost all of the rocks have undergone low grade regional metamorphism and in the vicinity of Ocean Pond and northeastward they are intruded by granite and are metamorphosed to crystalline schists. Volcanic rocks are extremely rare and only a few rock outcrops of possible volcanic origin were observed in this clastic assemblage.

Primary features of the rocks are largely obliterated by the development of schistosity, which in most places parallels bedding. The schistose rocks commonly have a wafered appearance and break along micaceous parting planes not more than 1/10 inch apart. The partings represent original then shaly laminations in the sandy rocks. Relatively undeformed rocks occur one mile north of Indian Bay Big Pond and display even bedding with the beds ranging from less than 1/4 inch to not more than a few feet in thickness. Some of these less deformed rocks are finely laminated siltstones with 40 or more thin laminae of contrasting shades of grey contained within a thickness of one inch. Other primary features are not apparent.

Three specimens of arenaceous rocks from the lower unit were examined in this section. These consist of 70 to 90 per cent quartz, up to 5 per cent plagioclase and rock fragments, and from 10 to 25 per cent muscovite, biotite, and chlorite. Accessory minerals are iron oxides, leucoxene, magnetite, apatite, and sphene. The larger grains are dominantly quartz and are of rather even size. They are angular to sub-rounded with highly undulose extinction. These are surrounded by a finer-grained recrystallized matrix of quartz, plagioclase, and secondary micaceous minerals. One thin section showed quartz grains that were broken or recrystallized and aligned parallel to schistosity.

Some of the sheared arenaceous rocks of the lower unit contain a multitude of samll quartz stringers and veinlets. These are aligned parallel to schistosity and successfully obliterate primary features of the rocks. A few outcrops were noted that consist of more than 60 per cent quartz veinlets.

A few isolated outcrops of mafic igneous rocks occur throughout this sedimentary unit, mainly north of Indian Bay Pond. The rocks are schistose to massive and of medium grain size and greenish colouration. They consist of green amphibole and plagioclase with much chlorite and alteration products. Most of them are considered to be altered diorites but some may represent mafic volcanic rocks. Their mineral composition appear compatible with the grade of metamorphism displayed in the enclosing sedimentary rocks.

Rocks of the lower unit of the Gander Lake Group have been tightly folded with most of the beds dipping steeply to the northwest. Almost all of the rocks are schistose and where bedding is still discernible the schistosity is seen to commonly follow the bedding planes. The beds show small scale crenulations and minor folds with wavelengths from less than 1/2 inch to several feet. These plunge from 20 to 40 degre s southwest in a few places in the vicinity of Indian Bay Big Pond and at the northern end of Wing Pond. Three northeast-striking faults occur northwest of Indian Bay Pond. These are continuous for many miles and are prominent topographic features. Their nature and movement are unknown.

Regional metamorphism has affected all of the rocks of the lower unit with few exceptions. This is evidenced by the presence of schistosity, and recrystallization in the matrix of the arenaceous rocks with the development of muscovite, chlorite, and biotite. North eastward along strike the rocks of the lower unit pass into moderate to high grade crystalline schists. South of the map-area, Jenness (1963) has outlined chlorite and biotite zones in the low grade regionally metamorphosed rocks and has indicated an increase in the grade of regional metamorphism from the northwest to southeast across the rocks of the lower unit. These changes are not obvious in the map-area although such may be the case. Of more prominence is the transition from low grade metamorphic rocks in the south to high grade rocks northeast of Ocean Pond. This change in metamorphic grade can be readily correlated with the presence of extensive granite intrusions in the northeast, and in particular with the occurrence of garnetiferous muscovite leucogranite that appears to metamorphose the country rocks much more extensively and thoroughly than does any other.

Metamorphic rocks of the lower unit northeast of Ocean Pond are mainly muscovite-biotite schists but also include such varieties as garnet-muscovite-biotite schist, sillimanite-garnet-muscovite-biotite schist, staurolite- and andalusite-bearing schist, and minor amphibolite. These rocks are completely recrystallized but neverthe less show small scale compositional banding or parting that is thought to represent relict bedding. Compositional bands are generally not more than 1/4-inch thick.

Similar metamorphic rocks to those northeast of Ocean Pond occur locally at the southern edge of the map-area on the shores of Wing Pond. The metamorphic rocks there contain andalusite, kyanite, staurolite, and garnet and have dykes and lenticular bodies of muscovite-garnet pegmatite and numerous quartz veinlets associated with them.

The relationship between granite intrusion and regional metamorphism is not clear. Jenness (1963) considered granite intrusion to post-date low grade regional metamorphism and suggested that higher grades of metamorphism accompanied granite intrusion. It is possible that granite intrusion and accompanying metamorphism were more or less contemporaneous with deformation and regional metamorphism. This is suggested by the textures of the high grade metamorphic rocks in the map-area that are typical of regionally metamorphosed schists rather than thermally metamorphosed hornfelsic rocks.

Rocks of the lower unit of the Gander Lake Group appear to conformably underlie Middle Ordovician sedimentary rocks of the middle unit of the same group. They are therefore Ordovician or pre-Ordovician in age. On regional tectonic grounds it has been suggested that the lower unit of the Gander Lake Group occupies a similar position in east-central Newfoundland as does the Fleur de Lys Group in the west (Williams, 1964).

PALEOZOIC ROCKS

ORDOVICIAN

A large proportion of the Ordovician rocks in the map-area are of volcanic parentage. Ordovician volcanic rocks predominate in the western part of the map-area whereas sedimentary rocks are more widespread in the east. Generally the dominantly sedimentary assemblages overlie the dominantly volcanic assemblages but locally Ordovician sedimentary and volcanic rocks are interlayered. Fossils have been collected from a number of widely separated localities and these are chiefly graptolites of Middle Ordovician age, with a few species characteristic of the Early Ordovician. Late Ordovician fossils are unknown except for occurrences at Intricate Harbour.

Gander Lake Group - Middle and Upper Units

The middle and upper units of the Gander Lake Group were defined outside the Botwood map-area along the northern shore of Gander Lake (Jenness, 1963). The upper unit was defined as being composed chiefly of argillaceous rocks and the middle unit was distinguished by the presence of volcanic rocks and certain sedimentary rocks that were not recognized in the upper or lower units of the group in the type area. The rocks of these two units lie to the northwest and apparently above the previously described lower unit of the Gander Lake Group. The middle and upper units trend northeasterly across the Botwood map-area and form a belt that varies from 9 to 15 miles in width.

The lithologies of the middle and upper units of the Gander Lake Group are sharply contrasted with regard to the lithology of the lower unit but the distinction between the upper and middle units themselves appears less obvious in the map-area than in the type area at Gander Lake. Volcanic rocks and greywacke beds like those that define the middle unit of the Gander Lake Group occur elsewhere in the map-area in association with slates and argillites typical of the upper unit of the group. However, rocks of the middle unit of the type area can be traced northeastward across the map-area in a belt that varies from 1 1/2 to 4 1/2 miles in width. The stratigraphy of the rocks in the middle and upper units of the group in the map-area is almost everywhere in doubt and consequently the relationships between the two units are vague. The boundary between the middle and upper units in the map-area has no stratigraphic significance and has been drawn arbitrarily near the northwest extremity of volcanic and sedimentary rocks which lie along strike of the middle unit in the type area to the south. The volcanic rocks of the middle unit are considered to be older than argillaceous rocks of the upper unit, but otherwise the relationships between volcanic and sedimentary rocks of the middle unit and volcanic and sedimentary rocks of the upper unit, as well as the relationships between volcanic rocks and some of the sedimentary rocks of the middle unit itself, are all imperfectly understood. The thickness of the middle unit was estimated at 2,500 feet in the type area but it is probably much more in the Botwood map-area, particularly near First and Second Ponds of Gander River where its outcrop width is at least four times that in the type area. The thickness of the upper unit was estimated to exceed 10,000 feet in the type area (Jenness, 1963).

Lithology

Middle Unit

The middle unit of the Gander Lake Group is recognized, above all, by elongate belts of volcanic rocks, which are accentuated by the presence of associated mafic and ultramafic intrusions. Volcanic rocks comprise about one half of the middle unit and are apparently in places interlayered with sedimentary members. The greatest concentration of volcanic rocks is near Island Pond Brook, and these appear to tongue-out among sedimentary rocks northeast of Wiers Pond and reappear northeast of Island Pond. Pyroclastic rocks are more abundant than lavas and all altered to typical greenstones. Primary features have been obliterated in most exposures and the rocks are commonly sheared and everywhere rich in chlorite. They are chiefly altered mafic varieties (basalts) but locally altered silicic rocks occur that probably represent latites or quartz latites.

Green agglomerate with poorly sorted volcanic fragments from 1/2 to 6 inches in length occurs on the northeast shore of Second Pond (Gander River) and green lavas occur on the southeast shore of First and Second Ponds. Locally the lavas at Second Pond contain calcite amydules whereas those at First Pond are highly sheared. Lapilli tuffs, fine-grained tuffs, and spilitic lava are also known in the map-area (Jenness, 1958). Among many of the deformed rocks it is difficult to distinguish between lavas and pyroclastic rocks, and in some places it is difficult to distinguish between mafic volcanic rocks and altered mafic intrusions.

Sedimentary rocks of the middle unit of the Gander Lake Group are dominated by slates and argillites that are lithologically similar to those of the upper unit, but in addition the middle unit includes large amounts of greywacke and conglomerate beds and some clastic limestone. The age of some of these sedimentary rocks in the map-area is well defined for locally the argillaceous rocks are clastic limestones containing indigeneous Ordovician fossils. However, the coarser clastic rocks are unfossiliferous and some of them, such as the conglomerates between Gander River and Wiers Pond, are possibly not part of the Ordovician assemblage.

Slates and argillites of the middle unit are greyish green to dark grey and black with some red varieties represented. The black slates are distinctive and occur in units from 10 to 100 feet thick. They are pyritiferous, graphitic, and locally contain Ordovician graptolites. Greywackes have been described interlayered with Ordovician slates of the middle unit in the type area (Jenness, 1963) and similar clastic beds occur interlayered with slates and argillites in the Botwood map-area, particularly at the northeastern end of Island Pond. The greywackes are grey-green and weather various shades of light brown to buff. The rocks are well bedded with beds varying in thickness from one inch to 10 feet or more. In places they show marked graded bedding with tops facing northwest. In the coarser lower parts of the greywacke beds there are slate chips and volcanic rock fragments.

Conglomerates with interbedded sandstones occur in a northeast-trending belt approximately 7 miles long southeast of First Pond on Gander River. The rocks are well exposed along the Gander Bay road and at Wiers Brook. The conglomerates contain pebbles of chert, slate, a variety of mafic to silicic volcanic rocks, quartz, several types of acid plutonic rocks, pebbles of altered mafic intrusive rocks, and limestone. The conglomerates are green and chloritic and appear to be as badly deformed as nearby lavas and slates. Pebbles in the rocks vary in size from less than 1/4 inch to more than 6 inches and in places are attenuated into lenticular shapes. Some varieties of the conglomerates have quartz pebbles predominating and set in a shaly matrix. The relationships of the conglomerates to nearby Ordovician rocks are unknown but the variety of pebbles in the rocks and the lithologic similarities of the rocks to Silurian conglomerates elsewhere in the map-area suggest that they are younger than the Gander Lake Group and are not part of the Ordovician assemblage. Some of the pebbles of the conglomerates seem to represent a fair sampling of nearby Ordovician rocks.

Plutonic pebble conglomerates are not common in the Ordovician rocks of the map-area and a Silurian age for these rocks cannot be overlooked.

Crystalline limestones and recrystallized clastic limestones occur in association with black slates of the middle unit of the Gander Lake Group on the northwest shore of Wiers Pond about two miles from its northeast end. The limestones are grey and medium-grained and locally contain pebbles of grey chert and black slate. The rocks are fossiliferous and in places contain a multitude of Ordovician coiled cephalapods and some brachiopod shells. The limestone does not exceed 100 feet in exposed thickness and is bounded to the northwest by black slate that contains Ordovician graptolites. The contact between the limestone and slate is a normal stratigraphic one with the beds dipping steeply toward the southeast. It appears that the limestone overlies the slate but the beds may be overturned.

Upper Unit

The rocks of the upper unit of the Gander Lake Group are chiefly slates and argillites, which locally contain greywacke and pebble beds. Volcanic rocks are not widely represented but they are prominent in places, particularly between Gander Bay and Rocky Bay. The top of the unit lies between Gander River and Salmon Pond where Ordovician greyish green and black slates are followed conformably westward by fossiliferous Silurian beds; the base of the unit has not been defined. Along most of the northwestern boundary of the upper unit the beds are faulted against Silurian strata.

Slates and argillites of the upper unit are silver grey to dark grey and green with some red, purple, and black varieties locally represented. These rocks constitute more than 70 per cent of the upper unit with not more than 15 to 20 per cent arenaceous beds, and from 5 to 10 per cent volcanic rocks. Bedding is apparent in many of the deformed argillaceous rocks but it more conspicuous in coarser horizons where cleavage is not as strongly developed. The argillaceous rocks are thinly bedded with beds varying from one inch to less than 1/8 inch in thickness. Interlayered arenaceous rocks are greywackes with beds up to 2 feet thick. The greywacke beds contain fragments of grey to black slate and locally display grain gradation and cross bedding. They are similar to greywackes of the middle unit of the group.

Conglomerate beds are represented locally in the upper unit of the Gander Lake Group. They are known near Clarks Head of Gander Bay and along the northwest shore of a pond 3 miles northwest of First Pond on Gander River. The conglomerates are made up mainly of quartz, chert, slate, and volcanic rock fragments, which are usually between 1/4 and 1 inch in diameter. These rocks are interlayered with slates and greywackes typical of the upper unit and are considered part of the Ordovician sequence. One small isolated outcrop of conglomerate occurs along Salmon Pond Brook near the south edge of the map-area among Ordovician slates of the upper unit. The conglomerate has a sandy matrix and contains angular fragments of black slate that is identical to nearby Ordovician slate. The rock probably represents an intraformational sharpstone conglomerate.

Volcanic rocks of the upper unit are most extensive and best exposed along the southwest shores of Rocky Bay and the east shore of Gander Bay. Locally volcanic rocks are known in the upper unit on Gander River near Salmon Pond. The volcanic rocks at Rocky Bay are mainly agglomerates containing fragments of mafic green lava from one inch to one foot diameter set in a green matrix. Some of the volcanic fragments are vesicular or amygdaloidal and all appear similar in composition to the matrix of the rock. Broken green lava with relict pillow structures is represented among the pyroclastic rocks near Carmanville and on the east shore of North West Arm. Also associated with the volcanic rocks are conformable intercalations of black slates and slaty conglomerates, commonly not more than a few tens of feet thick. The black slates are pyritiferous and rusty weathering and the conglomerates contain fragments of quartzose sandstone.

Agglomerates are dominant among the volcanic rocks along the east shore of Gander Bay and are associated with tuffaceous pyroclastic rocks and green to black pillow lavas. The agglomerates occur in beds commonly more than 20 feet thick and contain angular to rounded poorly sorted fragments of scoraceous green lava up to one foot in diameter. Finer grained agglomerates are made up of better sorted fragments from about 2 to 4 inches in beds less than 10 feet thick. Tuffaceous rocks occur locally in beds from one inch to several feet thick. The rocks here are cut by granitic dykes.

The volcanic and sedimentary rocks of the upper unit appear to be conformable but the relative ages of the rocks are unknown. The only exposed contact is north of Mann Point of Gander Bay. Volcanic rocks, slates, and minor limestone, are there interlayered over a distance of 200 feet in the contact zone. The top side of the beds is in doubt at the contact although farther south between Mann Point and Main Point graptolitic slates of the upper unit face southeastward, suggesting that the volcanic rocks to the northwest are the oldest. Volcanic rocks of the upper unit along Gander River appear to be interlayered with deformed argillaceous rocks.

Structure and Metamorphism

Rocks of the middle and upper units of the Gander Lake Group are tightly folded about northeast-trending axes with beds dipping steeply southeast and northwest. Commonly beds dip southeast but are overturned with tops facing northwest. Slaty cleavage and kink banding are developed in all of the argillaceous rocks and also in some of the arenaceous rocks. Volcanic rocks of the middle unit are highly sheared and conglomerates commonly show pebbles that are attenuated or flattened. Cleavage in the rocks trends northeasterly, parallel to fold axes with dips either vertical or steep toward the southeast or northwest. Minor folds are well developed locally.

The upper unit of the Gander Lake Group is followed northwestward by Silurian rocks of the Botwood Group. The contact between the Ordovician and Silurian rocks is faulted throughout most of its length but between Gander River and Salmon Pond the rocks are apparently in normal stratigraphic contact, although the exact contact is not exposed. Graptolitic slates of the Gander Lake Group occur within 1,500 feet of fossiliferous Silurian rocks along Salmon Pond Brook. Most of the intervening area is concealed except for a few small outcrops of dark grey to black graphitic sandstone. Bedding in the rocks strikes northeast and dips steeply southeast with the Silurian rocks facing northwest, thus indicating that the succession is overturned. These relationships contradict an earlier view that the rocks of the Gander Lake Group in the type area occupy a northeast-trending trough or synclinorium whose axis lies near Gander River (Twenhofel, 1947; Jenness, 1963).

All of the rocks of the middle and upper units of the Gander Lake Group have been affected in varying degrees by low grade regional metamorphism. Shales and siltstones have been transformed to argillites, slates, or phyllites; conglomerates of the middle unit as exposed between Gander River and Wiers Pond are highly sheared with extensive development of chlorite; and basic volcanic rocks have been altered to mineral assemblages in which chlorite appears to be a major constituent.

Northeast of Island Pond rocks of the upper and middle units have been transformed to schists where they approach leucogranite intrusions in the vicinity of Ragged Harbour, and thin aureoles of metamorphic rocks occur around granite intrusions at Island Pond and south of Fredericton. Andalusite-garnet-muscovite-biotite schists occur on the west shore of Ladle Cove and sillimanite-garnet schists are abundant south of Aspen Cove. Spotted slates with incipient andalusite porphyroblasts occur in the metamorphic aureoles around the intrusions at Island Pond and south of Fredericton.

Age and Correlation

Ordovician fossils have been collected from rocks of the upper and middle units of the Gander Lake Group at nine localities within the Botwood map-area, and at 4 additional localities in the northwest corner of the Terra Nova map-area to the southeast. Three of the localities in the map-area within the middle unit - two localities on the northwest shore of Wiers Pond and the third, one mile southeast of Island Pond. The remaining ten localities are all within slates of the upper unit, and within the map-area three are located near

Main Point of Gander Bay and three others along Gander River east of Salmon Pond. With the exception of one shelly fauna collected from limestones of the middle unit at Wiers Pond, all the fossils collected are graptolites contained in black pyritiferous argillites or slates.

Fossil localities and identifications are as follow:

a. Middle Unit:

#WF-B367-63 GSC loc. 58326 Northwest shore of Wiers Pond 2.5 miles from northwest end.

> Climacograptus cf. C. scharenbergi type
> Orthograptus sp. cf. O. quadrimucronatus type
> Orthograptus sp. cf. O. calcaratus var. grandis (Ross and Berry, 1963) type.
> Climacograptus sp.

$WF-584-63 & WF-B-368-63 GSC loc. 58325 Northwest shore of Wiers Pond 2.3 miles from northwest end.

> Phylloporina sp.
> Dolerorthid impression
> Maclurites sp. aff. M. speciosa (Billings) - abundant
> Endocerid (?) cephalopod structure

$WF-B-209-63 GSC loc. 58320 1.3 miles southeast of Island Pond

> Indeterminate graptolites, an orthograptid?

b. Upper Unit, central part

#WF-197-63 GSC loc. 58315 East shore of Gander Bay, 3/4 mile northeast of Main Point.

> Fragments of Orthograptus and probably Climacograptus

#WF-198-63 GSC loc. 58314 East shore of Gander Bay one mile northeast of Main Point

> Diplograptus cf. D. multidens or Orthograptus cf. O. Calcaratus
> Dicellograptus sp.

#WF-B-96-63 GSC loc. 58316 One half mile east of Davidsville on Carmanville Road.

> Orthograptus quadrimucronatus var. spinigerus Lapworth, 1876
> cf. Leptograptus flaccidus Hall, 1865
> Orthograptus cf. O. quadrimucronatus Hall, 1865

c. Upper Unit, upper part

%WF-G-474-62 GSC loc. 52282 Gander River, 1.5 miles north of south edge of map-area.

> Climacograptus bicornis (Hall)
> Orthograptus sp.

% identification by L.M. Cumming, Geological Survey of Canada
$ identification by T.M. Bolton, Geological Survey of Canada
\# identification by B-D. Erdtmann, Indiana University

%WF-X-88-62 GSC loc. 52260 Gander River, one mile north of south edge of map-area.

Dicranograptus ramosus (Hall)
Climacograptus bicornis (Hall)
Orthograptus sp.
Dicranograptus sp.

%WF-G-491-62 GSC loc. 55277 Gander River, 0.2 miles north of south edge of map-area.

Climacograptus sp.
Orthograptus sp.

%WF-315-62 GSC loc. 52261 Salmon Pond Brook, 0.8 miles west of Gander River.

Dicellograptus sextans var. *exilis* E & W
Climcaograptus bicornis (Hall)
Orbiculoides sp.

%WF-X-568-62 GSC loc. 52265 1.2 miles southwest of Glenwood on road.

Climacograptus sp.
Orthograptus sp.

%WF-X-538-62 GSC loc. 52268 1.6 miles northwest of Carless Cove, Gander Lake, along a small brook.

Leptograptus sp.
Orthograptus sp.

%WF-X-539-62 GSC loc. 52272 1.5 miles northwest of Carless Cove, Gander Lake, along small brook.

Climacograptus sp. cf. *bicornis* Hall or *diplacanthus* Bulman

The last four localities listed are all south of the Botwood map-area, all located northwest of Gander Lake and Gander River.

All fossils collected from the upper and middle units of the Gander Lake Group indicate or favour a Middle Ordovician age with the possibility of a slightly younger age for several localities thought to lie near the top of the unit. The upper and middle units of the Gander Lake Group are in part time equivalents of the Exploits Group (Heyl, 1936) and the middle unit is probably in part equivalent to the Headlands and Wild Bight Groups. Basic volcanic rocks, slates, and fossiliferous limestones, as displayed in the middle unit, form a lithologic assemblage that is remarkably similar to that of the Ordovician Exploits Group at Cobbs Arm of New World Island (Kay and Williams, 1963). The Gander Lake Group has been traced across east-central Newfoundland (Jenness, 1963; Anderson and Williams, in press) where it merges with rocks of the Baie d' Espoir Group (Jewell, 1939).

Headlands Group

The term Headlands Group is proposed by the writer to include all of the dominantly mafic volcanic assemblages that apparently form a continuous belt along the headlands and islands of Notre Dame Bay from Tilt Cove southwestward to Halls Bay and all the way eastward to Twillingate Islands. These rocks were previously assigned a variety of local group and formational names in different areas. However, regional mapping has tended to bring out similarities among the rocks in separated areas, and it now appears that regional lithologic correlation is tenable. Previous names applied to rocks of the Headlands Group from northwest to east across the map-area are as follows: Nippers Harbour Group (Baird, 1951), Snooks Arm Series (Snelgrove, 1931) - later Snooks Arm Group (Baird, 1951), Lushs Bight and Cutwell Groups of the Pilleys Series (Espenshade, 1937) Breakheart and Mortons Formations, and parts of the Fortune and Sansom Formations (Heyl, 1936; 1937). The distribution of Headlands Group rocks and the localities where previous names were applied, and by whom, are outlined in Figure 1.

The Headlands Group contains Ordovician fossils in a few places but the rocks are for the most part unfossiliferous. The group boundaries are mainly faulted or are concealed by younger overlying strata or the sea; consequently regional stratigraphic relationships are unknown, questionable unconformity, either within the group or at its base, has been reported in the Tilt Cove area (Douglas, Rove, and Williams, 1940; Baird, 1951), but this report has not been confirmed by subsequent work (Neale, 1959; Williams, 1962; 1964) and and no particular significance is placed in it. A complete section of the group is nowhere exposed, but its maximum thickness probably exceeds 10,000 feet.

The stratigraphy within the group is almost everywhere in doubt, although several attempts have been made at stratigraphic subdivision. Lithologic units recognized in separated areas cannot generally be correlated but this is not surprising when the nature of deposition and the structural complexity of the rocks is considered. Possibly the clearest stratigraphic succession is displayed in the Betts Cove-Tilt Cove area where five subdivisions are recognized; three dominantly volcanic units, each separated by two dominantly sedimentary units. Neale (1957, 1959) has shown that all five units face southeastward and form a continuous stratigraphic succession, approximately 12,000 feet thick. Nearby in the Little Bay area, MacLean (1947) recognized three separate stratigraphic sections in the group, namely the Halls Bay Head, Little Bay Head, and Western Arm sections. Both the Halls Bay Head and Little Bay Head sections are intricately faulted or tightly folded and are hardly amenable to stratigraphic subdivision. In contrast, the Western Arm section is less deformed and occupies a fault-bounded block of northwest facing strata in excess of 13,000 feet thick (MacLean, 1947). Four unnamed formations are recognized; a basal pillow lava formation, a sedimentary formation, an upper pillow lava formation, and an upper-most pyroclastic formation. The Halls Bay Head and Little Bay Head sections are in fault contact and their relative ages are unknown; the Western Arm section presumably overlies the Little Bay Head section and is younger (MacLean, 1947).

Espenshade (1937) separated the Headlands Group rocks into the Cutwell and Lushs Bight Groups in the Pilleys Island area, each 5,000 feet thick. The Cutwell Group, containing equal porportions of volcanic and sedimentary rocks, was interpreted to underlie the dominantly volcanic Lushs Bight Group (Espenshade, 1937). Recent work suggests, however, that the contact between the Cutwell and Lushs Bight Groups should be relocated, from Long Island farther southward to Pilleys Island, and at the new location the contact is interpreted to be a fault (Williams, 1962). Farther eastward in the Bay of Exploits area, Heyl (1936) referred rocks of the present Headlands Group to the Breakheart, Mortons, and Fortune Formations, in order of decreasing age, and all were interpreted as a dominantly volcanic assemblage at the top of the Exploits Series. The formations have a total estimated thickness from 900 to 4,500 feet (Heyl, 1936).

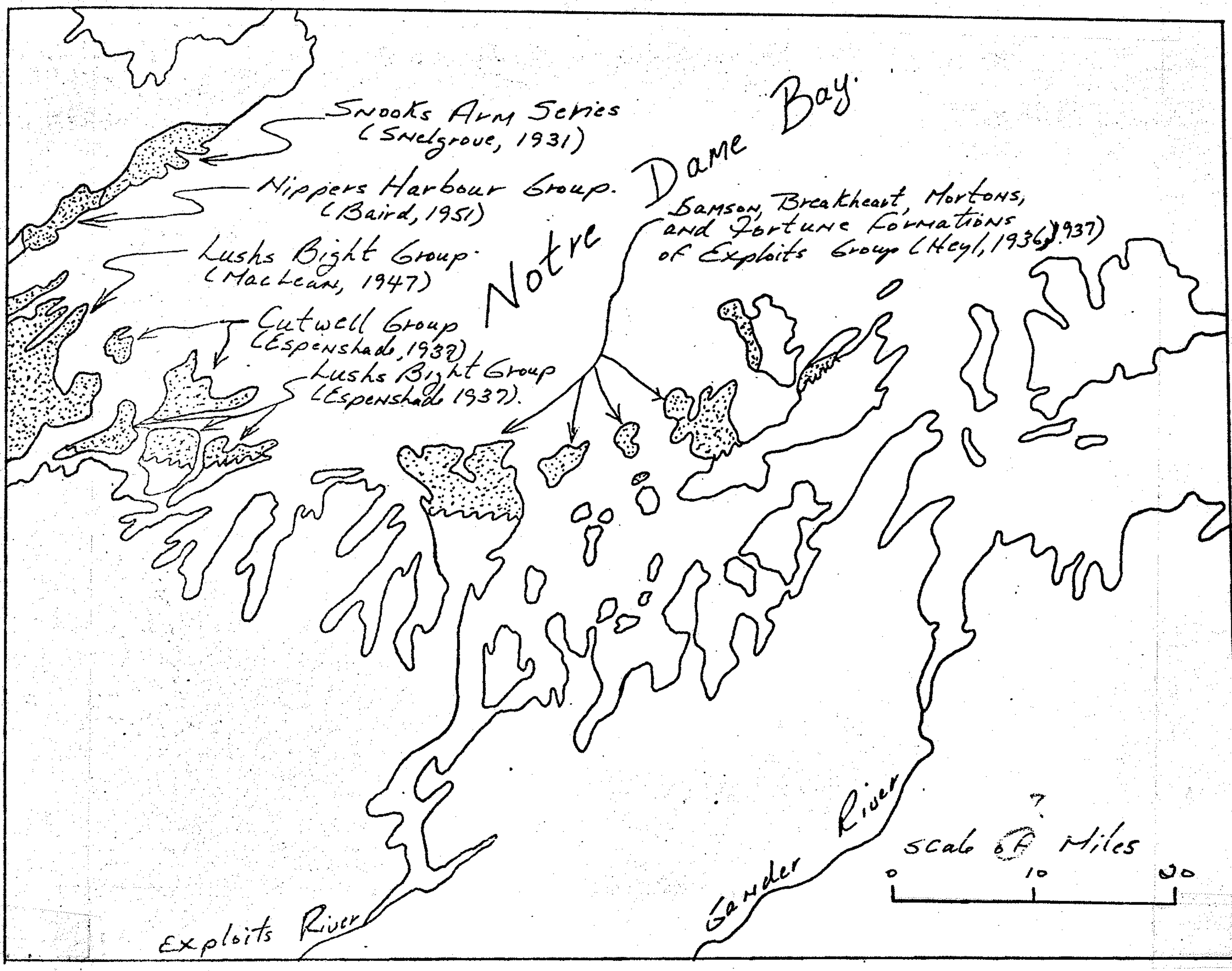

Figure 1. Distribution of the Headlands Group (speckled) in the Botwood map-area and previous nomenclature of the rocks throughout Notre Dame Bay.

Rocks typical of the Breakheart and Mortons Formations were mapped on western New World Island and there they appear to be interlayered in alternating layers (Williams, 1963).

Lithology

The following are the main lithological rock types recognized in the Headlands Group in order of decreasing abundance: sheared and broken green lavas and mafic pillowed lavas, a variety of pyroclastic rocks, greywacke-siltstone-slate assemblage, intermediate to silicic flows, cherts, and minor limestones. All of these rock types are locally interlayered commonly with thin sedimentary units (50 to 100 feet) alternating with much thicker volcanic units. The greywacke-siltstone-slate assemblages are represented only in certain areas whereas cherts are almost everywhere associated with thick volcanic accumulations. The proportions of sedimentary and volcanic rocks vary from place to place but the entire group does not contain more than 20 percent sedimentary members.

Sheared and broken green lavas and mafic pillowed lavas include a variety of textural types and display various degrees of deformation and alteration. Transitions are represented between highly deformed and altered green lavas and relatively unaltered black pillowed lavas. Individual flows range in thickness from a few tens of feet to several hundred feet where visible, but in most places deformation has destroyed details in the volcanic successions. Classification of the rocks is difficult because of the extensive alteration to which many of them have been subjected but available mineralogical and chemical evidence indicate that most of these rocks are basalts, commonly with spilitic compositional tendencies (Heyl, 1936; Espenshade, 1937; MacLean, 1947; Meane, 1957; Papezik and Fleming, 1967).

Sheared and broken green lavas are composed dominantly of secondary minerals that include plagioclase, chlorite, carbonate, epidote, serpentine, and actinolite. Few original minerals or textural features remain and the rocks are typical greenstones. Examples are well-exposed along the coastline between Little Bay and Halls Bay, and on Sunday Cove and Pilleys Islands. Less deformed varieties of green lava commonly show relict pillows that are sheared and attenuated and in this section the rocks are seen to contain original crystals of augite, and less commonly olivine, and plagioclase laths, all surrounded in a secondary matrix of chlorite, serpentine, epidote, and carbonate. The undeformed basalts are usually darker coloured than the deformed varieties and almost everywhere display pillow structures, and locally columnar jointing. The pillows are bun-shaped and measure 1 foot to 3 feet in diameter, or less commonly they are elongate and reach lengths of 10 feet or more. These rocks consist dominantly of augite and labradorite, but although they are fresh appearing in the field, petrographic examination reveals the presence of chlorite, epidote, and carbonate as secondary alterations. Some of the pillowed basalts are porphyritic with augite or plagioclase phenocrysts, others are amygdaloidal with amygdules of quartz, epidote, and carbonate, and a few are vesicular. Possibly the freshest basalts of the Headlands Group in the map-area occur on the southeast side of Western Arm south of Harrys Harbour. The rocks are porphyritic with unaltered augite phenocrysts that are usually twinned and in a few places they are zoned. Quartz amygdules are abundant and the matrix of the rock consists of partially altered augite and plagioclase laths, with accessory magnetite, chlorite, epidote, carbonate, and sericite. Excellent exposures of pillowed basalts can be seen along the north shore of Black Island (Bay of Exploits), at the north end of North Twillingate Island, New Bay Head, and on north Triton Island. Columnar jointing is displayed at Middle Arm.

Dark red pillowed lavas are in places common among the predominantly dark green to black pillowed varieties. The reddish lavas do not appear to form individual planar flows but are rather commingled with the green types. Texturally and mineralogically there is very little difference between the red and green varieties, other than the red lavas contain iron stain responsible for the colouration.

Intermediate to silicic flow rocks occur locally within the Headlands Group. Andesites, dacites, and trachytes have been reported from Bay of Exploits (Heyl, 1936) and chemically analysed soda dacite or quartz trachyte and acidic felsitic lavas and andesites have been reported from the Pilleys Island area (Espenshade, 1937).

Pyroclastic rocks of the Headlands Group are dominantly agglomerates but include large amounts of tuff and some fine-grained felsitic pyroclastic deposits. The agglomerates are composed of angular to sub-rounded volcanic rock fragments in a volcanic matrix. Fragments are poorly sorted as to size and range from less than 1 inch to 3 feet or more. Commonly the thicknesses of agglomerate beds vary directly with fragment size and range from a few feet in the finer grained varieties to several tens of feet, or more than 100 feet, in coarse, chaotic types. Agglomerates vary in colour from light grey to pink, green, black, and locally red, but green varieties are predominant. Some of the fragmental rocks appear to be compositionally similar to basaltic pillowed lavas but many are more siliceous and probably closely approach andesite and trachyte. Agglomerates are ubiquitous throughout the volcanic successions and are particularly abundant in the vicinity of Little Bay Island and Mortons Harbour.

Tuffaceous rocks accompany agglomerates in most exposures and are lithologically similar. Throughout the northern part of Long Island well-bedded siliceous tuffs are prominent and similar rocks occur associated with basic flows and siliceous sedimentary rocks south of Chanceport Harbour on New World Island. Some of the rocks are clearly pyroclastic, as evidenced by the presence of numerous volcanic rock fragments on weathered surfaces; others are felsitic textured and resemble flows in hand specimen, although they are clearly fragmental in thin section.

Medium- to fine-grained diorites and gabbros occur throughout the volcanic rocks of the Headlands Group as small plugs, dykes, and sills, and are generally inseparable on this scale of mapping. These intrusions are interpreted to be associated with the basic volcanism (Snelgrove, 1931; Heyl, 1936; Espenshade, 1937; Douglas, Rove and Williams, 1940; Neale, 1959; Williams, 1963). At Kings Cove porphyritic basalt dykes cut volcanic rocks, and nearby, lithologically similar basalt forms the matrix of agglomerates.

Clastic sedimentary rocks that are clearly interlayered with volcanic members of the group are best exposed between Betts Cove and Tilt Cove, at the north end of Long Island, and on Stag Island. The rocks are greyish green greywackes and conglomerates, dark grey to red and black slates, grey to dark green and purple siltstones, and greyish green to red argillites. Limestone beds occur locally associated with black slates. The greywacke and conglomerate beds vary from less than 1 inch to several feet in thickness and are composed of chert and slate chips and dark rock and mineral fragments. The siltstones, slates, and argillites are finely bedded with beds commonly less than 1 inch and usually not more than 1/4 inch. At Beaver Cove near Tilt Cove, siltstones display graded beds about 1/4 inch thick with coarser grey bottoms that grade upwards into finer purple tops. Fine scale cross-bedding was observed in thinly bedded grey siltstones at Snooks Arm and Neale (1957) reported convolute bedding in nearby argillites where overlain by greywacke beds. Hard dark grey to black slates on northern Long Island contain thin greywacke beds and cherty pyritiferous limestone lenses, and at Snooks Arm, black slates are locally graphitic and contain graptolites.

Buff-weathering grey sandstones and siltstones are common in the Headlands Group along the north shore of Luke Arm and greywacke-slate assemblages are exposed at Western Arm near Little Bay Head. Buff quartzitic sandstones and red and grey argillites, are included with the group north of Great Muddy Hole and red argillites, greywackes, and slates are included at Cottles Cove. The relationships of the Great Muddy Hole-Cottles Cove rocks to other rocks of the group are in doubt.

Cherts are common throughout the group but are minor in abundance compared to volcanic rocks and clastic sedimentary rocks. They are fine-grained to aphanitic with concoidal or splintery fracture and vary in colour from light grey to green, maroon, purple, yellow, and red. The cherts occur in the following ways: (1) as interstitial fillings among pillows in basalts, (2) as discontinuous beds several feet or tens of feet thick between flows, and (3) as finely bedded successions interlayered with siliceous tuffs, clastic sedimentary rocks, or flows; beds are generally less than 1/2 inch and rarely more than a foot. Some of the cherts are rich in manganese and iron and contain radiolaria and display globular and spheroidal textures (Sampson, 1923). These rocks have been interpreted as chemical precipitates genetically related with submarine volcanic activity (Sampson, 1923; Heyl, 1936). Other hard siliceous rocks, commonly referred to as chert, are composed of very fine-grained quartz and feldspar with some chlorite, carbonate, and magnetite. These rocks are not true cherts but siliceous siltstones and slates that were probably baked soon after deposition by ensuing volcanic eruptions.

Limestones are very minor in the Headlands Group but are widely distributed as intercalations among the volcanic and clastic sedimentary rocks. They are important for their contained organic remains that locally serve to date the volcanism and sedimentary deposition. Fossiliferous limestone beds with an overall thickness of about 10 feet occur intercalated with green agglomerates on a small island along the west side of Little Bay Island. The limestones are grey to pink, sugary textured, and contorted. Other examples of fossiliferous limestones are known at Lushs Bight, on the southern shore of Long Island, and on the northern shore of Southeast Arm. The Lushs Bight occurrence is approximately 200 feet thick (Espenshade, 1937) with the limestones associated with black slate and volcanic rocks; the limestones along the south shore of Long Island are interlayered with greyish green greywacke and conglomerate beds and occur in bands up to 20 feet thick, and the limestones at Southeast Arm occur as small lenses associated with tuffaceous lava (Heyl, 1937). The limestones at the former two localities are sheared and contain rock fragments suggesting that they were deposited as calcarenites. Additional limestone occurrences are known on Stag Island, where limestone lenses are associated with black slates, and on Seal Island, where irregular limestone lenses partially surround pillows in pillowed lavas.

Structure and Metamorphism

Rocks of the Headlands Group are generally steeply dipping and are extensively faulted and locally tightly folded. Structural trends vary across Notre Dame Bay from southwest in the Betts Cove-Tilt Cove area to mainly south and southeast in the Little Bay-Pilleys Island area to east and northeast in the Bay of Exploits, thus outlining an arcuate belt convex toward the southwest. Major faults and fold axes parallel this arcuate pattern across the headlands and islands of Notre Dame Bay, except in the Little Bay area, where sharply contrasted northeast and southeast structural trends characterize adjoining fault bounded belts. The significance of the arcuate structural pattern is difficult to access. The rocks form a structural belt bounded by faults and characterized by complicated internal structures, but the regional arcuate outcrop pattern may be the result of late regional flexuring (Williams, 1967; Donaghue, pers. comm., 196). Possibly the arcuate belt surrounds a large intrusion located beneath the surface of Notre Dame Bay (Espenshade, 1937).

In the Betts Cove-Tilt Cove area the structure is relatively clear. There, five distinct stratigraphic units form a continuous southeast-facing succession that occupies the slightly overturned northern limb of an easterly plunging syncline (Neale, 1957; 1959). Limited observations made by the writer's field party during the summer of 1962 support this interpretation, which is contrasted with earlier analyses whereby the five units were interpreted to be repeated and to form a northeast-trending anticline whose axis coincided with the middle unit (Snelgrove, 1931; Baird, 1951). Northwest and northeast striking high angle faults disrupt the fold pattern at Tilt Cove and similar faults are common in the vicinity of Betts Cove (Neale, 1957; Baird, 1951). Elsewhere, faults are the most prominent structural feature and an example of their local abundance is furnished by a compilation of faults and linears in the Little Bay area (Baird, 1956). Conceivably, the southeast-facing section of the Betts Cove-Tilt Cove area is equivalent to the northwest-facing Western Arm section of the Little Bay area (MacLean, 1947), the two separated by a northeast-trending, right-lateral fault that passes through Green Bay.

Structural trends are locally toward the north on the northwest part of New World Island, and in the vicinity of South Twillingate

Island and Headlands Group rocks display bedding and secondary foliation that paralled the contacts of the South Twillingate Island granite intrusion.

Almost all of the basic volcanic and sedimentary rocks of the Headlands Group have been affected by low grade regional metamorphism. This is most evident in the basaltic lavas which almost everywhere contain secondary minerals such as albite, epidote, chlorite, actinolite, serpentine, clinozoisite, carbonate, and sericite; all typical of the greenschist metamorphic facies. Green chloritic schists mark zones of intense shearing in the basic volcanic rocks and these are commonest in the Little Bay area. Locally, metamorphic mineral assemblages of amphibole and plagioclase in the basic volcanic rocks indicate more intense metamorphic conditions typical of the amphibolite facies of regional metamorphism. Amphibolites, composed essentially of actinolite, plagioclase (andesine), and quartz are common in the Nippers Harbour area, and amphibolitic rocks are distributed in a thin aureole around the South Twillingate Island granodiorite intrusion.

Age and Correlation

Identifiable Ordovician fossils are known at three localities in the Headlands Group rocks of the map-area and at two localities nearby in the western adjoining Sandy Lake map-area. Unidentifiable organic remains are known in the group at several additional localities in the map-area.

Identifiable fossils were first discovered in the Headlands Group by Snelgrove (1931) on the southwest shore of Snooks Arm, a third of a mile southeast of the settlement of Snooks Arm. The fossils are graptolites, contained in thin pyritic and graphitic black slate beds a few feet thick, which are interlayered with siliceous siltstones and grey slates. The graptolites were identified by R. Ruedemann as Loganograptus logani and Didymograptus gracilis and the host rocks correlated with the second and third Deep Kill zones of North America, or the Middle Arenig of Great Britain, i.e. late Early Ordovician. The Snooks Arm fossil locality was briefly visited by the author and Professor Marshall Kay during the field season of 1962. At that time two poorly preserved forms were uncovered, one of which was tentatively identified by Professor Kay as Didymograptus; thus supporting the earlier report.

The next report of organic remains in the Headlands Group was made by Espenshade (1937) in the Pilleys Island area. Crinoid stems and gastropod and brachiopod fragments were reported in the limestones at Lushs Bight and on the west shore of Little Bay Island. Those collected at that time were so poorly preserved, however, that they could not be identified. Subsequently, identifiable fossils were collected from the Little Bay Island locality by L.M. Cumming in 1961, and again by the author in 1962 although no additional forms were uncovered. The fossils are a definite Ordovician assemblage that Cumming interpreted to possibly represent the lower part of the Middle Ordovician (Chazy-Black River). The following forms were identified;

Scolopodus sp. Pander
Acontiodus sp. Pander
Maclurites sp. cf. M. logani (Salter)
Strophamena (Horderleyella) sp.
? Oxoplecia sp.
? Tritoechia sp.

The author also visited the Lushs Bight locality as well as a newly discovered fossiliferous limestone locality 3 miles to the southeast on the south shore of Long Island. Organic remains were collected but identifications could not be made owing to a poor state of preservation.

Heyl (1937) reported fossils on the north shore of Southeast Arm in the New Bay area contained in a small limestone lense associated with tuffaceous lava. The following forms were identified by C.H. Kindle and interpreted as of Middle Ordovician (Chazy) age;

Eoharpes sp.
Glaphurus cf. pustulatus
Ptychoglyptus sp.

MacLean (1947) reported a single brachiopod shell in Headlands Group rocks (previously Lushs Bight Group) in the western-adjoining Sandy Lake map-area. The shell was collected from a shale bed in a local lens of cherty sedimentary rocks located 4,900 feet north 29 degrees west from the west end of Clam Pond. The brachiopod was identified by B.F. Howell as belonging to the subfamily Acrothelinae and the genus Discotreta; its age was interpreted as fairly definitely Canadian (Early Ordovician), probably late Canadian (MacLean, 1947).

In addition, unidentifiable brachiopod shells were reported within a bed of red sandy argillite at Tilt Cove (Neale, 1959), and radiolaria, of no correlative value, were reported in chert beds of the Headlands Group (Sampson, 1923).

Re-examination of the forms from the Catchers Pond area (Neale and Nash, 1963; Williams, 1967) to the west of the map-area indicate a Lower Ordovician rather than a Silurian age for the limestone and surrounding volcanic rocks (Boucot, pers. comm., 196). The Catcher Pond rocks lie along strike with the Headlands Group rocks of the map-area and are now thought to belong to that group rather than nearby Silurian groups (Williams, 1967).

The above paleontological data clearly indicate that the Headlands Group is of Ordovician age and suggest that the rocks are mainly Lower Ordovician and lower Middle Ordovician. The graptolites from Snooks Arm occur near the middle of the exposed stratigraphic section and near the base of the uppermost sedimentary unit. These fossils are generally of the same age as the brachiopod shell collected near Clam Pond, in the upper part of the basal basalt pillow lava formation of the Western Arm section, thus suggesting general correlation. The fossiliferous limestones at Little Bay Island are apparently younger. They date rocks that were assigned to the Cutwell Group and interpreted to underlie rocks to the south that were assigned to the Lushs Bight Group (Espenshade, 1937). However, in the Little Bay area the Western Arm section, presumably lying toward the top of the Lushs Bight Group (MacLean, 1947), is dated paleontologically as older than the limestones of the Cutwell Group on Little Bay Island. This evidence, though tenuous, suggests that the relationships as interpreted by Espenshade (1937) may be reversed, with the rocks of Little Bay Island and nearby Long Island lying above Headlands Group volcanic rocks to the west and south.

The rocks at Snooks Arm (previous Snooks Arm Series) are separated from the Headlands Group rocks south of Green Bay (previous Lushs Bight Group) by metamorphosed volcanic rocks at Nippers Harbour that were assigned to the Nippers Harbour Group (Baird, 1951). Where mapped by Snelgrove (1931), the Nippers Harbour Group rocks were included with the Snooks Arm Series, and where mapped by MacLean (1947) the Nippers Harbour Group rocks were included with the Lushs Bight Group. Furthermore, the Western Arm section of the Lushs Bight Group in the Little Bay area was correlated lithologically with the Halls Bay Head section of the same group (MacLean, 1947), which in turn lies along strike with Headlands Group rocks of Sunday Cove, Pilleys, and Triton Islands. These relationships tend to justify the present regional grouping of all these dominantly volcanic, lithologically similar rocks in the western part of Notre Dame Bay.

In the Bay of Exploits area of eastern Notre Dame Bay the rocks of the Headlands Group were earlier assigned to the Exploits Series (Heyl, 1936), later Exploits Group (Weeks, 1955; Williams, 1962), and they were interpreted to form three of the uppermost formations of the Ordovician stratigraphic section, namely the Breakheart, Mortons, and Fortune Formations (Heyl, 1936). However, in continuous Ordovician-Silurian stratigraphic sections exposed on New World Island (Williams, 1963) and in the New Bay area (Heyl, 1937), sedimentary rocks of the Exploits Group grade upwards into Silurian conglomerates and the Breakheart, Mortons, and Fortune Formations are conspicuously absent. The dominantly volcanic rocks of the Breakheart, Mortons, and Fortune Formations are therefore thought to be older than previously expected and are reassigned from the Exploits Group to the Headlands Group rocks of western and eastern Notre Dame Bay is suggested by similar structural trends where the rocks are separated by the sea between Triton Island and New Bay Head, and by the presence of two small islands in the intervening area, League Rock and Sculpin Island, that are composed of volcanic rocks typical of the Headlands Group.

Fossiliferous rocks included in the Headlands Group on the north shore of Southeast Arm in New Bay were earlier correlated with the Sansom Formation (Heyl, 1937) of the Exploits Series. The structural relationships in this area are complex but the lithologic types represented appear more typical of the Headlands Group than

Heyl's Sansom Formation. Furthermore, the Sansom Formation in the type area has been reinterpreted to conformably overlie Middle Ordovician slates and to conformably underlie Silurian conglomerates (Williams, 1963), thus suggesting that the rocks of Chazy age in Southeast Arm are older than Heyl's Samson Formation in the type locality.

Other dominantly volcanic assemblages, probably wholely or in part equivalent to the Headlands Group are the Wild Bight Group (Espenshade, 1937; Williams, 1964), parts of the Roberts Arm Group (Espenshade, 1937; Williams, 1964), volcanic rocks of the Exploits Group such as those at Dildo Pond, Strong Island, and New World Island, and the middle unit of the Gander Lake Group (Jenness, 1963; Williams, 1964). Lithologic similarities are apparent between certain slightly altered rocks of the Pacquet Harbour Group and rocks of the Headlands Group. These groups are not far separated northwest of Nippers Harbour.

Wild Bight Group

The term 'Wild Bight' was introduced by Espenshade (1937) to denote a predominantly volcanic rock assemblage at Wild Bight of Badger Bay in the Pilleys Island area. The assemblage was referred to as the Wild Bight volcanics and it was interpreted to form the lowest formation in the Badger Bay Series (Espenshade, 1937). The predominantly volcanic rocks were mapped northeastward from the type area of Seal Bay Head by Heyl (1937) and southwestward from the type area to Marks Lake and North Twin Lake by Hayes (1951). Both of these authors referred to the rocks as the Wild Bight Formation. Similar rocks are widespread east of Seal Bay and in the vicinity of New Bay Pond and the assemblage is much more extensive than previously recognized (Williams, 1962). The author prefers the term Wild Bight Group as the rocks show signs of being divisible into several formations (Williams, 1964).

The Wild Bight Group occupies the central portion of a complex anticlinorium that plunges northeastward between Seal Bay and New Bay and is truncated to the south and southwest by faults and large granitic intrusions. The rocks are considered to be of

Ordovician age for they are overlain conformably by Middle Ordovician sedimentary rocks at Badger Bay and Leading Tickles, and they include a sedimentary assemblage north of New Bay Pond that locally contains Middle Ordovician graptolites. The thickness of the Wild Bight Group has been estimated at 1,500 feet in the type area (Espenshade, 1937), 2,000 feet in the western part of the New Bay area (Heyl, 1937), and 3,000 feet in the Marks Lake area (Hayes, 1951a). The base of the group is not exposed.

Lithology

The Wild Bight Group includes a variety of rock types that are mainly volcanic and predominantly pyroclastic. Altered green lavas, basic pillowed lavas, cherty siltstones, greywackes, and slates are all widely represented throughout the group and are locally more abundant than the pyroclastic rocks. All of the rocks are well-layered, except for the lava flows and certain coarse agglomerates, and in most areas a variety of volcanic and sedimentary rocks occur in alternating successive units. The units vary from a few tens to a few hundreds of feet in thickness, thus many rock types are observed in a short distance. Small gabbroic and dioritic intrusions, inseparable on this scale of mapping, are common throughout the group.

The pyroclastic rocks are dark green to grey, red, and pink agglomerates and tuffs that range from basic to silicic in composition. Among these, basic to intermediate green varieties are most abundant and are well displayed along the coastline of Notre Dame Bay and can be recognized throughout most of the inland exposures. Red agglomerates are exposed locally along the west shore of Seal Bay and northeast of Lockport, and pink silicic pyroclastic rocks are abundant south of New Bay Pond near the headwaters of Northern Arm Brook. The green pyroclastic rocks consist essentially of a variety of green to grey lava fragments in a dark fine-grained matrix. Some of the fragments are vesicular or amygdaloidal and a few are porphyritic. They are angular to subrounded in outline and rarely exceed one foot in diameter, even in the coarsest beds. Most of the fragments are from 1/4 inch to 4 inches in diameter. In places, the fragments include a few pink felsitic rock types and grey to green hard cherts or cherty siltstones, but these are relatively uncommon. Beds vary in thickness from less than one foot in tuffaceous horizons to more than 200 feet in the coarsest agglomerates. Red pyroclastic horizons that occur locally among the dominantly grey and green rocks contain all red fragments but are otherwise not appreciably different from the green types. Silicic pyroclastic rocks are of minor importance but they are fairly extensive south of New Bay Pond. They are made up of angular pink to grey felsitic fragments that are rarely more than 1/2 inch in diameter. These are set in a hard grey to pink or purple matrix.

A sample of green tuff collected 5 miles northeast of Northern Arm consists mainly of altered basic lava fragments that are composed of fine-grained plagioclase laths and clinopyroxene crystals set in a dark altered matrix. Some of the fragments are porphyritic with plagioclase and clinopyroxene phenocrysts and all of them contain much secondary chlorite and epidote. A few fragments in the rock appear to be of sedimentary origin and may represent recrystallized sandstone and shale, and possibly a few others that are coarser-grained than usual represent basic intrusive rocks. The tuff has very little matrix material and among that which can be seen chlorite and epidote are the most common minerals, with the remainder overshadowed by leucoxene. Only a few quartz grains occur in the rock, apart from those in possible sedimentary fragments.

Lavas are more abundant than pyroclastic rocks east and northeast of New Bay Pond and are widely represented in smaller amounts throughout the Wild Bight Group. Most of the lavas are altered basic varieties that are commonly pillowed and in places contain vesicules or amygdules. A few red varieties occur locally and most of the lavas are similar to those previously described in the Headlands Group. Sheared green and red to purple varieties occur in thin units among dominantly pyroclastic rocks along the west shore of Seal Bay and northeast of Lockport, and basaltic lavas that contain disseminated epidote and pyrite segregations are common near Lewis Lake. Silicic lavas, possibly related with silicic pyroclastic rocks, are common south of New Bay Pond. These are fine-grained to aphanitic purplish to green rocks that commonly contain pink or white feldspar phenocrysts.

A sample of green altered lava collected near Muddy Hole Brook has a glomero-porphyritic texture portrayed by segregations of altered clinopyroxene and plagioclase surrounded by a matrix of much finer grained plagioclase laths and epidote crystals that are masked by leucoxene. Most of the pyroxene crystals are completely altered to pseudomorphous aggregates of chlorite, actinolite, and epidote, and the plagioclase crystals are coated with alteration products. This rock is similar to altered green lava fragments found in nearby tuffs.

Sedimentary rocks of the group are greywackes, slates, and hard siliceous siltstones and argillites, and cherts. They occur in thin units among the volcanic rocks generally not more than 100 feet thick, except at the northern end of New Bay Pond where greywackes and slates are more abundant than volcanic rocks and may be as much as a thousand feet thick. The siliceous siltstones and argillites, slates, and cherts are readily recognized primarily because of their grey to black and purple to red colours that are contrasted with nearby drab green volcanic rocks, and they are also distinguished by fine layering with beds commonly less than 1/4 inch. Some of the greywackes are distinctive light grey to greyish pink but many are greenish and chloritic and are difficult to distinguish from fine-grained tuffs with which they are interlayered. Gradations between the tuffs and greywackes are also represented. An example of greywacke collected near the north end of New Bay Pond contains abundant plagioclase fragments and basic rocks fragments and basic rock fragments that together are more abundant than quartz fragments. Nearby on the north shore of New Bay Pond red to purplish slates, siliceous siltstones, and cherts are common, and locally iron stained black graphitic slates that contain graptolites are interlayered with thin beds of hard black cherty argillites or cherts.

Structure and Metamorphism

The rocks of the Wild Bight Group are steeply dipping, tightly folded, and cut by faults. Northeasterly trends characterize the rocks in the northwestern part of the group and this trend is well displayed by northeasterly plunging folds in the type area and southwestward that have large amplitudes and short wavelengths. Structural trends are less consistent toward the southeast part of the group, but in the vicinity of southeast Seal Bay and at the north end of New Bay Pond the general trend is northwesterly. The rocks are folded into two distinct anticlines that are separated by an intervening syncline between Wild Bight and Beaver Bight. Dips are steep to vertical and the trends of the folded rocks are clearly evident on areal photographs. A similar tight anticline occurs northwest of Marks Lake and it exposes a long narrow belt of Wild Bight Group rocks that are flanked by sedimentary rocks of the Exploits Group on both sides. At the north end of North Twin Lake the group is exposed in two doubly-plunging northeast-trending anticlines that are connected by southeastward trending strata. The pattern probably resulted from two periods of deformation. Major faults parallel the fold axes and locally the strata are offset by minor traverse faults, which in the type area are interpreted as older than the longitudinal faults (Hayes, 1951a). All of the fault planes are steeply dipping but there is little direct evidence of their movement in most places.

A folded gabbroic sill separates strata of the Wild Bight Group from conformably overlying Ordovician beds along most of the exposed contact southwest of Badger Bay. The sill ranges in thickness from less than 300 feet to 600 feet and its great lateral extent and constant stratigraphic position has aided in the delineation of structure in its area of outcrop (Hayes, 1951). Red slates that are conspicuous among the volcanic rocks could also possibly serve as marker horizons for detailed structural mapping. Two distinct zones of red slate, each several tens of feet thick, outcrop in the southeast corner of Seal Bay and can be traced inland toward the southeast for several miles. Similar red slates occur two miles north of Lewis Lake and possibly represent a continuation of one of the Seal Bay red slate horizons.

A regional anticlinorium structure in the Badger Bay-Seal Bay area was first suggested by Espenshade (1937). It was later recognized by Heyl (1937) and named the Badger Bay Anticlinorium by Hayes

(1951a). The axis of the structure was described as lying between Beaver Bight and Wild Bight in the type area (Hayes, 1951a) and trending northeast along the peninsula between Badger Bay and Seal Bay (Hayes, 1951a; Heyl, 1937). The regional distribution of the Wild Bight Group, however, and the younger sedimentary rocks of the Exploits Group to the northwest and southeast, suggests that the axis lies farther eastward and passes slightly southeast of Leading Tickles and near Seal Bay Brook, from whence it may be either truncated by large granitic intrusions or it may change direction and trend southeast.

Low grade regional metamorphism has affected all of the rocks of the Wild Bight Group and its effects are most pronounced in the basic volcanic rocks, which commonly contain epidote, chlorite, carbonate, and sericite. A thin metamorphic aureole surrounds the large granitic intrusion in the southwest corner of the map-area. The thermal metamorphic aureole varies from 500 to 2,000 feet in width and is marked by the progressive appearance of chlorite, biotite, and locally garnet in sedimentary rocks.

Age and Correlation

The Wild Bight Group clearly underlies Middle Ordovician sedimentary rocks in the vicinity of Badger Bay and includes Middle Ordovician sedimentary members at the north end of New Bay Pond that contain the following Caradocian-Trentonian graptolites:

Leptograptus flaccidus Hall
Climacograptus sp. either *bicornis* Hall or *diplacanthus* Bulman
Orthograptus sp.

The relationships between the sedimentary members at New Bay Pond and surrounding volcanic rocks are vague. The sedimentary rocks have consistent attitudes and dip steeply southwest and appear to form an intercalation among the volcanic rocks. However, some of the sedimentary rocks are lithologically similar and of the same general age as strata that elsewhere overlie the Wild Bight Group. Possibly the sedimentary rocks occur in an overturned isoclinal syncline that overlies Wild Bight volcanic rocks at New Bay Pond in much the same was as Middle Ordovician strata overlie the Wild Bight volcanic rocks in the vicinity of Badger Bay and Leading Tickles. Depending upon the interpretation of these structural relationships the age of the Wild Bight Group is Middle Ordovician or slightly older.

The rocks of the Wild Bight Group in the vicinity of Seal Bay and eastward to Northwest Arm and Little Northwest Arm of New Bay were previously assigned to the Sansom Formation of the Exploits Series (Heyl, 1937), and only the rocks along the east shore of Badger Bay and local occurrences in Seal Bay were at that time considered typical of the Wild Bight Formation. The Wild Bight Formation was thus much more restricted than the present Wild Bight Group and this limited extent influenced thinking in early attempts toward regional correlation. Thus, Heyl (1937) correlated the Wild Bight Formation with volcanic rocks interpreted as interlayers in the Sansom Formation, and in sympathy with this view, mapped most of the Wild Bight Group in the New Bay area as the Sansom Formation. There are no distinctive lithologic similarities between the dominantly volcanic rocks assigned by Heyl (1937) to the Sansom Formation in the New Bay area and the dominantly sedimentary arenaceous rocks mapped as the Sansom Formation in the Bay of Exploits (Heyl, 1936), and as the Sansom Formation (i.e. present Ninepin Arm Formation) in the Bay of Exploits grades upward into Silurian conglomerates (Williams, 1963), then Heyl's early correlation of the Wild Bight Group and volcanic members of the Sansom Formation is considered erroneous. Heyes (1951a) questioned this correlation on evidence from the Marks Lake area where sedimentary beds typical of the Sansom Formation of Exploits Bay overlie the Wild Bight Group. Hayes (1951a) further considered it more likely that the Wild Bight rocks were equivalent to the Luke Arm Formation which was defined as lying at the base of the Exploits Series (Heyl, 1936).

The widespread occurrence of agglomerates and basaltic pillowed lavas throughout the Wild Bight Group as well as local occurrences of chert, slate, and greywacke suggests a lithologic correlation of the Wild Bight Group with parts of the Middle and Early Ordovician Headlands Group, middle unit of the Gander Lake Group, and certain volcanic members of the Exploits Group, i.e. those exposed at Dildo Pond, New Bay, and on New World Island.

EXPLOITS GROUP

The Exploits 'Series' (Heyl, 1936), later Exploits Group (Hayes, 1951; Weeks, 1954; Williams, 1962) was defined in the Bay of Exploits area and the term 'Exploits' has been used consistently to denote Middle Ordovician sedimentary and volcanic rocks throughout northeastern Newfoundland that are lithologically similar to, but commonly widely separated from, rocks in the type area. The name has taken deep root in Newfoundland stratigraphic nomenclature and has been used within the map-area in the New Bay area (Heyl, 1937), the Marks Lake and Hodges Hill areas (Hayes, 1951; 1951a), and the Comfort Cove area (Patrick, 1954). Outside the map-area the name has been applied to rocks in the Rattling Brook area (Hriskevitch, 1950), Stoney Lake area (Peters, 1952), Sandy Lake area (Neale and Nash, 1963), and as far southwestward as Buchans (Swanson and Brown, 1962). Similar rocks of approximately the same age were referred to the Badger Bay Series where maped by Espenshade (1937) in the Pilleys Island area. Subsequently, these rocks were also included in the Exploits Group (Williams, 1962).

The term Exploits Group as here used lumps all those Ordovician sedimentary and volcanic rocks in the central and southwestern parts of the map-area that do not find a natural place in any other of the Ordovician groups. The Exploits Group thus includes a wide variety of Ordovician strata extending from New World Island in the northeast across the type area of Bay of Exploits and westward into New Bay. Rocks of the Exploits Group at Badger Bay and in the southwest corner of the map-area at Middleton Lake extend southwestward beyond the map-area for an additional 50 miles.

Geological investigations over the last six years in the Bay of Exploits and nearby areas have shown that the stratigraphic succession of the Exploits 'Series' as interpreted by Heyl (1936), 1937) and later workers is in error. Previous stratigraphic interpretations were questioned when Marshall Kay collected an Upper Ordovician (Ashgillian) brachiopod fauna at Intricate Harbour (Hornet Formation) in rocks assigned to the Middle Ordovician (Heyl, 1936), and when Williams (1963) and Kay and Williams (1963), mapping in the Twillingate area, recognized several local inversions in the sequence. Some formations, previously interpreted to lie near the base of the Middle Ordovician Exploits 'Series' (Hornet and Sansom) were discovered to occur at the top of the sequence and were either Late Ordovician or Silurian. Other formations (Mortons, Breakheart, Fortune), earlier interpreted to form the upper parts of the Exploits 'Series', are absent in continuous Ordovician-Silurian sections. It was thus implied that the original sequence within the Exploits 'Series' was inverted, at least locally. Most of the volcanic rocks and cherts (Mortons, Breakheart, and Fortune Formations) have been removed from the Exploits Group and assigned to the Headlands Group. Other rocks (Hornet and Sansom Formations) are reassigned to the Late Ordovician and/or Silurian Ninepin Arm and Goldson Formations. The present Exploits Group throughout the type area is thus restricted compared to the original Exploits 'Series'.

The Exploits 'Series' as originally defined has an overall thickness of 12,000 feet in the type area (Heyl, 1936). Of that thickness only 4,600 feet of strata are included in the present Exploits Group. Elsewhere within the map-area, thicknesses of strata included in the group reach values of 9,000 feet at Badger Bay (Espenshade, 1937) and feet in the New Bay area (Helwig, 1967). Table I summarizes the sequence and subdivisions of the Exploits Group and equivalents as interpreted by earlier workers. Formations marked with an asterisk are now, for the most part, excluded from the Exploits Group.

Locally the succession is relatively clear and the progress being made indicates that ultimately several successions will be distinguished. Most of the rocks are of Middle Ordovician age but accumulating evidence indicates that some, particularly parts of the volcanic succession of New World Island, are Early Ordovician. In a broad way, central parts of the group are dominated by slates, siltstones, and greywackes with coarser clastic beds appearing at the top of the section and the main volcanic formations occurring toward the base. The top of the succession is drawn where slates and siltstones, commonly graptolite-bearing, give way to the greywackes and pebble conglomerates of the Ninepin Arm Formation. In a few areas of structural complexity or indefinite stratigraphy, no attempt was made to separate the beds of the Ninepin Arm Formation and they are also included within the Exploits Group. The base of the group is unexposed, except in the Badger Bay area and near Leading Tickles. There the conformably underlying rocks, previously included in the Badger Bay Series as the Wild Bight Formation (Espenshade, 1937), have been mapped separately as the Wild Bight Group (Williams, 1964). Most evidence suggests that the Wild Bight Group at Badger Bay and Leading Tickles is equivalent to basal parts of the Exploits Group farther east.

Based upon the present reconnaissance study, it is neither practical nor desirable to devise a single set of formational names that can be used regionally to subdivide the rocks of the Exploits Group. The structure and stratigraphy are still unknown throughout large parts of the map-area and further studies are required. The rocks have been reclassified in the Bay of Exploits and New Bay areas (Kay, in press; Helwig, 1967; Horne, in prep.) and new names introduced. Only a few of these have regional importance. For purposes of description in this report a review of the stratigraphy and history of stratigraphic nomenclature is presented according to individual areas.

Bay of Exploits Area

The Exploits ('Series' was defined in this area, and the sequence subdivided into nine formations. These, in order of decreasing age, are as follow: Luke Arm, Hornet, Sansom, Sivier, Foulke Cove, Mortons, Breakheart, Lawrence Harbour, and Fortune Formations (Heyl, 1936). All of the rocks were considered to be Middle Ordovician (Normanskill and Chazy) age, suggested by graptolites and shelly fauna collected in a few separated localities. No complete section exists so that the stratigraphy was built up from partial sections and extension and correlation of the rocks across the islands and headlands that make up Bay of Exploits. The succession was considered to be composed of three lithologic subdivisions; conglomerates and greywackes toward the base (Hornet and Sansom), dominantly argillaceous rocks throughout the central parts of the section (Foulke Cove and Sivier), and mainly volcanic rocks toward the top (Mortons,

Heyl (1936) Bay of Exploits	Heyl (1937) New Bay	Espenshade (1937) Pilleys Island	Hayes (1951) Marks Lake	Patrick (1954) Comfort Cove	Williams (1962 Botwood
EXPLOITS SERIES	EXPLOITS SERIES	BADGER BAY SERIES	EXPLOITS GROUP	EXPLOITS GROUP	EXPLOITS GROUP
Fortune Fm*	Fortune Fm*				Chert, tuff* map-unit 10
Lawrence Har. Fm.				Volcanic unit*	
Breakheart Fm*	Breakheast Fm.*	Roberts Arm Fm*			Dominantly Volcanic rocks map-unit 9
Mortons Rm*	Mortons Fm*				
Sivier Fm	Sivier Fm (in-cl. Law. Har.)	Crescent Lake Fm* Burtons Head Fm	Cresent Lake Fm*	Black shale division	Argill. sed with volcanics map-unit 8
Foulke Cove Fm.	Foulke Cove Fm	Julies Har. Fm	Sivier Fm		
Sansom*	Sansom Fm*	Gull Island Fm Shoal Arm Fm Beaver Bight Fm Wild Bight Fm*	Sansom Fm	Greywake* division	Psamitic sedi-mentary rocks map-unit 7
Hornet Fm*	Wild Bight Fm*		Wild Bight Fm*		Dominantly* volcanic roc rocks map-unit 6
Luke Arm Fm					

Table I. Sequence and subdivisions of the Exploits Group and equivalents, northeastern Newfoundland. (*formations excluded from newly defined Exploits Group)

Breakheart, and Fortune). Sedimentary and volcanic rocks occur in roughly equal proportions and almost all of the sedimentary formations defined by Heyl (1936) contain volcanic interlayers. Patrick (1954) and Williams (1962) made no attempt to outline the formations recognized by Heyl (1936) but influenced by Heyl's views grouped the rocks into three comparable lithologic units.

Subsequent work showed that the stratigraphic succession of the Exploits 'Series' is erroneous and major revision is necessary. This was indicated, first by the discovery of an Upper Ordovician (Ashgillian) brachiopod fauna in the Hornet Formation (Kay and Williams, 1963) and secondly by the incongruities apparent between the succession interpreted by Heyl (1936) in the Bay of Exploits and that of Williams (1963) in the eastward adjoining Twillingate area.

In some places rocks assigned to the Exploits 'Series' do not actually form part of the succession and in other places the succession within the 'series' is inverted. For example, volcanic rocks of Heyl's Mortons, Breakheart, and Fortune Formations north of the Luke Arm Fault do not form part of the Exploits succession but rather form a natural part of the Headlands Group.

An example of an inverted sequence is found at Farmers Head of Intricate Harbour where conglomerates of the Hornet Formation, dipping south, appear to underlie greywackes of the Sansom Formation, which lie farther south. But the beds are overturned and face north, making the greywackes the older strata rather than the younger as interpreted by Heyl (1936). The conglomerates and greywackes of the Hornet and Sansom Formations are for the most part reassigned to the Ninepin Arm Formation and the rocks can be traced across Sansom, Hornet, and Swan Islands all the way to Baptist Cove of Fortune Peninsula (Helwig, 1967). At Baptist Cove, the greywackes and conglomerates were assigned to the Fortune Formation (Heyl, 1936) but the stratigraphic position of the beds with respect to conformably underlying Middle Ordovician (Caradocian) graptolitic slates at Lawrence Harbour leaves little doubt but that the sequence at Baptist Cove is similar to that at Farmers Head and eastern New World Island. In the latter localities, conglomerates of Hornet-type conformably overlie greywackes of Late Ordovician-Silurian age that in turn rest above Middle Ordovician argillaceous rocks. Heyl (1936) placed the Sansom and Hornet Formations toward the base of the Exploits 'Series', except in the New Bay area where the Hornet-type conglomerates are dated by contained Silurian limestone clasts. It is now clear that the greywackes and conglomerates are of Late Ordovician and Silurian age and conformably overlie Middle Ordovician (Caradocian) slates (previous Foulke Cove, Sivier, and Lawrence Harbour Formations). This depositional pattern of Caradocian slates followed conformably by Late Ordovician-Silurian greywackes and then conglomerates is apparent wherever the section is defined and sedimentation was continuous from Middle Ordovician into Silurian. Of all the formations then, originally assigned to the Exploits 'Series', only the Luke Arm, Foulke Cove, Sivier, and Lawrence Harbour remain as part of the present Exploits Group.

Badger Bay Area

Rocks presently assigned to the Exploits Group in the Badger Bay area are dominantly clastic sedimentary rocks with local basic volcanic interlayers and a few thin limestone beds. These were formerly assigned to the Badger Bay Series and more specifically to the Beaver Bight, Shoal Arm, and Gull Island Formations, and the Julies Harbour and Burtons Head Groups, in that order of decreasing age, as interpreted by Espenshade (1937). All of these units can be distinguished in the coastal section at Badger Bay but no attempt was made to separate them inland, except by Hayes (1951) who mapped the preceding five units of Espenshade (1937) as two broader units (Sansom and Sivier Formations). Continuity of the stratigraphic section is clearly displayed by the Beaver Bight, Shoal Arm, and Gull Island Formations but the relationships of the Julies Harbour and Burtons Head Group to one another and to the rest of the section is less certain. Middle Ordovician graptolites have been collected at four localities; two within the Burtons Head Group, one within the Julies Harbour Group, and another at the top of the Shoal Arm Formation.

The Badger Bay Series as defined by Espenshade (1937) included beds of the present Wild Bight Group at its base and was interpreted to include a thick volcanic unit (present Roberts Arm Group) at its top. The upper volcanic sequence was correlated with the Mortons and Breakheart Formations in the Bay of Exploits area and lower parts of the Badger Bay Series were equated with the Hornet or Samson Formations (Espenshade, 1937; Heyl, 1937). Reinterpretations made in the stratigraphic succession at Bay of Exploits, combined with relationships elsewhere, suggest that Espenshade's interpretation of the stratigraphy at Badger Bay needs revision.

Greywackes and pebble conglomerates of the Gull Island Formation are similar to the Late Ordovician-Silurian Sansom and Hornet Formations of Bay of Exploits, and this analogy has been drawn by most previous workers. This implies that other dated Middle Ordovician rocks, interpreted to overlie the Gull Island Formation (Espenshade, 1937) are actually not in sequence. Recent investigations in the type area during 1968 suggest that the Julies Harbour Group includes both Ordovician and Silurian rocks with typical Goldson-type conglomerates overlying Ordovician black slates.

Greywackes and pebble conglomerates at Middleton Lake also resemble Late Ordovician-Silurian rocks (Sansom and Hornet Formations) in Bay of Exploits and correlation between the Middleton Lake greywackes and the Gull Island Formation was implied by Hayes (1951) who mapped both as part of this Sansom Formation. Like the Exploits Bay greywackes, the Middleton Lake beds appear to overlie Middle Ordovician graptolite-bearing slates where the rocks have been traced 10 miles southwestward along the Exploits River (Williams, 1966). This suggests that upper parts of the Exploits Group section are everywhere similar in the map-area.

Revision of the Badger Bay sequence as suggested above is also consistent with the stratigraphic relationships at Leading Tickles and New Bay. There Middle Ordovician graptolitic slates (approximately equivalent to dated beds of the Shoal Arm Formation at Gull Island of Badger Bay) overlie the Wild Bight Group and are overlain, first by greywackes like those of the Gull Island Formation, and then locally by Silurian conglomerates. Reconsideration of the stratigraphic sequence at Badger Bay deserves special attention for if the original sequence as interpreted by Espenshade (1937) is erroneous, then these errors have been compounded by extension of the succession into nearby areas (Hayes, 1951; 1951a; Kalliokoski, 1953; 1955; Neale and Nash, 1963; and Williams, 1962). The stratigraphic sequence as interpreted by Espenshade (1937) is summarized in Table II and is compared with the broad nomenclature used in this report and possible reinterpretation of the succession.

New Bay Area

Rocks similar to those of the Bay of Exploits area were mapped in the New Bay area (Heyl, 1937), thus providing a connection between the former and the Badger Bay area to the west (Espenshade, 1937). As in the case of the Bay of Exploits Area, Heyl (1937) emphasized the dominantly psammitic nature of sedimentary rocks in presumed lower parts of the succession, the argillaceous nature of upper sedimentary members, and a great thickness of volcanic rocks at the top. The Ordovician rocks were assigned formational names of the Exploits 'Series', except for lower volcanic members and cherts that were assigned to the Wild Bight Formation as defined by Espenshade (1937). Thus the section was subdivided into the Wild Bight, Sansom, Foulke Dove, Sivier, Mortons, Breakheart, and Fortune Formations (Table II). Few changes were made compared with the stratigraphic interpretation in the type area, more than that the Lawrence Harbour Formation, previously interpreted to overlie the Breakheart Formation (Heyl, 1936) was reinterpreted as a member of the Sivier Formation and thus was considered to occupy a stratigraphic position below the dominantly volcanic Mortons and Breakheart Formations. The Wild Bight Formation was mapped only in a narrow band trending southwest from Seal Bay Head and the remainder of the Wild Bight Group, as presently outlined, was mapped as the Sansom Formation. The restricted Wild Bight Formation was considered equivalent to volcanic interlayers in the Sansom Formation of the type area and following this reasoning it was assumed that the basal measures of the Exploits 'Series' (Luke Arm and Hornet Formations), recognized in the east, were not exposed in New Bay.

		Espenshade (1937) Nomenclature	Thickness (feet)	Williams (this report		
Ordovician	Badger Bay Series	Roberts Arm Fm	1,500		Roberts Arm Group (locally includes Silurian rocks)	
		Crescent Lake Fm.	500			
		Burtons Head Gp.	2,000		~ fault ~	
		Julies Harbour Gp.	2,000	Exploits Group	Gull Island Fm.	(?) Burtons Head Gp.
		Gull Island Fm.	2,000	Exploits Group	Shoal Arm Fm.	
		Shoal Arm Fm.	1,500			(?) Julies Harbour Gp.
		Beaver Bight Fm.	1,000	Exploits Group	Beaver Bight Fm.	~ fault ~
					Conformity	
		Wild Bight Fm.	1,500		Wild Bight Gp.	

Table II Subdivisions of the Exploits Group in the Badger Bay area.

Heyl (1937) collected Middle Ordovician fossils in a few localities and these were used to substantiate the sequence as proposed.

Inconsistencies apparent in the definition and delineation of the formations of the Exploits 'Series' in the type area were extended into the New Bay area, with few exceptions. Most of the rocks assigned to the Mortons, Breakheart, and Fortune Formations (Heyl, 1937) are not in sequence and have been reassigned to the Headlands Group (Williams, 1964). Continuous Ordovician-Silurian sections exposed at several localities, display Silurian conglomerates resting conformably, or at most disconformably, upon Middle to Late Ordovician sedimentary rocks of Heyl's Sivier Formation. The conglomerates and underlying greywackes correlate generally with Late Ordovician-Silurian rocks that were assigned to the Hornet Formation in the Bay of Exploits, and all are lithologically similar and contain fossiliferous limestone clasts of approximately the same Late Ordovician-Silurian age. Heyl (1937) correlated the New Bay conglomerates with the Silurian Goldson Formation (Twenhofel and Shrock, 1937) of New World Island, but in addition outlined a group of silstones, slates and greywackes at Besom Cove, which he regarded equivalent to the Silurian Pike Arm Formation (Twenhofel and Shrock, 1937), also of New World Island. The Besom Cove shales (Heyl, 1937) have been shown to underlie the Silurian conglomerates (Williams, 1964) rather than overlie the conglomerates (Heyl, 1937), and the discovery of Middle Ordovician graptolites at four localities within the Besom Cove rocks indicates that they are part of the Exploits Group and roughly equivalent to Heyl's Sivier Formation.

New World Island and Remaining Areas

Rocks of the Exploits Group in the New World Island area form a northeast-trending belt across New World Island and occupy the area of Dildo Run from whence they can be traced across the islands and headlands of Bay of Exploits all the way southwestward to Lewisporte and Thward Island. The Ordovician succession of New World Island consists of several hundred feet of mafic volcanic rocks, locally with fossiliferous Middle Ordovician limestone lenses, overlain by about 100 feet each of crystalline limestone and Caradocian black siliceous argillite and slate (Kay and Williams, 1963). This succession is for the most part overturned toward the north and the Ordovician rocks are overlain by greywackes of the Ninepin Arm Formation that contains Silurian fossils in its upper parts. Similar volcanic rocks with limestone lenses and in turn overlain by graptolitic argillite occur in a faulted slice at Little Burne Cove and northwest of Pike Arm at Greens Cove. West of Virgin Arm, Ordovician volcanic rocks are abundant although most are probably faulted repetitions of those exposed between Cobbs Arm and Virgin Arm. Locally near Village Cove limestone lenses within the volcanic rocks contain Ellesmerocerids of earliest Ordovician (Gascanadian) age (M. Kay, pers. comm. 196), and northwest of Village Cove, tuff beds among the volcanic rocks contain Arenig-Llandeilo brachiopods (Neuman, 1969).

At Dildo Run and southwestward the rocks are mainly argillites and siltstones are interlayered mafic volcanic rocks. Locally conspicuous are zones of coarse chaotic rocks containing siliceous greywacke boulders to 5 feet in diameter surrounded by a shaly matrix. It has not year been succinctly determined whether or not these chaotic rocks are depositional or of tectonic origin. The sediments and volcanic rocks at Dildo Run are intimately related and interlayered and on south New World Island the argillites, locally containing Caradocian graptolites, are overlain by greywackes of the Ninepin Arm Formation.

Green agglomerates at Dildo Pond are overlain by sedimentary rocks in Loon Bay and the Ordovician sedimentary rocks, locally graptolite-bearing, are followed by greywackes and sharpstone conglomerates of the Ninepin Arm Formation at Campbellton.

Recently, early Middle Cambrian trilobites were discovered in a limestone lense within mafic volcanic rocks that lie in or near the chaotic rocks of Dunnage Island (Kay and Eldridge, 1968). The volcanic rocks containing the fossiliferous limestone lense appear to form a large block surrounded by argillite within the chaotic zone.

Lithology

Rocks of the Exploits Group, as presently outlined, are dominantly sedimentary, though including thick basal volcanic units and volcanic interlayers throughout most of the remainder of the section. Predominant among the sedimentary rocks are argillites, siliceous argillites, slates, siltstones, and greywackes; with some conglomerate, chert, and tuffaceous sedimentary rocks; locally significant chaotic rocks; and minor limestone. Volcanic rocks are for the most part mafic lavas but locally include large quantities of agglomerate and tuff of similar composition. Collectively the rocks are a typical marine eugeosynclinal suite. All have been affected by folding and/or faulting so that the pelitic sedimentary rocks display a well-formed cleavage in most places and the mafic volcanic rocks show evidence of shearing and partial adjustment to the greenschist facies of regional metamorphism. In the following generalized description no attempt is made to arrange the rocks of the Exploits Group in chronologic order, though in a broad way volcanic rocks are more abundant toward the base of the sequence, argillaceous sedimentary rocks in its central parts, and greywackes toward the top.

Volcanic rocks of the Exploits Group are well-represented at Loon Bay, on New World Island, and at various places in New Bay and eastward to Comfort Cove and Dildo Run. Most are of mafic composition and are mainly green to reddish brown pillowed flows with associated pyroclastic rocks. Locally, as at Loon Bay, pyroclastic rocks predominate. The volcanic rocks include fossiliferous limestone lenses, in some places and graptolitic black graphitic slates in some others. It is from these sedimentary interbeds that the rocks are dated as Ordovician. Most of the fossils are Middle Ordovician but in a few localities on New World Island limestone lenses within the volcanic rocks contain early Middle and Early Ordovician forms (Kay, in press; Neuman, 1969). The volcanic rocks are at least 1,000 feet thick in some places and possibly reach maximum thicknesses of several thousand feet.

Well-formed pillow structures are common and in places the flows contain numerous closely-spaced amygdules. Pillows usually measure from one to three feet in diameter with local oblate forms reaching 10 feet in length. Agglomerates, such as those exposed at Loon Bay consist of green angular fragments from 1/4 inch to one foot diameter set in a greenish matrix. The coarser pyroclastic rocks are unsorted and are apparently devoid of bedding. There is little distinction between the matrix and fragments within the pyroclastic rocks on a fresh surface but fragments are quite apparent on weathered surfaces. Many of the rocks are fresh appearing but almost all are internally altered to some degree. Common alteration products are chlorite, epidote, actinolite, ozisite, carbonate, and serpentine.

Some of the basic volcanic rocks, particularly those of New World Island, were deposited in a lime-rich marine environment. Calcite is the commonest amygdule material and in places limestone is present either as irregular patches surrounding pillows or as small lenses among the flows. Limestone beds from three to 10 feet or more thick occur interlayered with basic volcanic rocks on Duck Island and at Little Byrne Cove, and locally the Duck Island volcanic succession and volcanic rocks at Comfort Cove include black slate beds, in places graptolite-bearing.

A thick white to grey crystalline limestone unit overlies the volcanic succession of the Exploits Group of central New World Island, and although most prominent at Cobbs Arm, the same horizon can be seen at Burnt Arm, Squid Cove, and as far southwest as Cottles Island. The limestone reaches maximum thicknesses of 100 feet or more at Cobbs Arm where for decades it was quarried commercially for use in the Newfoundland paper-making industry.

Central parts of the Exploits Group succession are dominated by shales and siltstones with alternating thin sandstone, greywacke, and conglomerate interbeds, and finely-bedded cherts and siliceous clastic rocks. In most places the pelitic rocks have a distinct cleavage and are more appropriately termed argillites or slates; and where deformation has been intense, the rocks are phyllites. The pelitic rocks are mainly grey to dark grey and black but commonly green, purple, or pale red. They are evenly bedded with beds ranging from less than one inch to six inches or more and continuing along strike for several tens of feet. Common in some localities, e.g. Besom Cove and Badger Bay, are limy siltstone and limestone lenses from one inch to six inches in length and an inch or so wide. In a few places large oval-shaped arenaceous limestone concretions from 6 inches to 3 feet in largest dimension are prominent and in a few others the rocks contain buff to grey and bluish grey tube-like fillings or cherty concretions.

Cherts and siliceous shales and siltstones that occur among the pelitic rocks are usually grey or green and weather white or grey. Locally the rocks are red and purple and the alternating thin highly coloured laminae portray a distinctive appearance. Many of the rocks are finely-laminated with 30 layers or so to the foot. There appears to be all gradations between chert, siliceous shale, siliceous siltstone, and typical shale or slate. Some of the rocks, casually referred to as chert in Notre Dame Bay, are in fact siliceous siltstone, and show fine-scale cross-lamination or grain gradation. The latter is evidenced by colour variations that reflect grain size across a single laminae.

Black pyritic and graphitic shales, slates, and siliceous argillites are very distinctive among the pelitic parts of the Exploits Group. Where not highly cleaved these rocks almost everywhere yield abundant graptolites. The black shales are the least competent among the finer grained clastic rocks and are invariably more deformed than nearby beds. These rocks are easily eroded and commonly outcrop along the coast in flat wave cut benches that are submerged during high tide.

Chaotic rocks are included in the Exploits Group and outcrop in the vicinity of Chapel Island and Dunnage Island, and extend southwestward to St. Johns Bay. The chaotic rocks are of special interest although as yet their mode of occurrence and significance are unknown. They are essentially coarse pelitic conglomerate or breccia containing a varied assemblage of sedimentary and volcanic rocks. Largest clasts are boulders of greywacke, commonly 10 feet in diameter, and blocks of lava, locally to be measured in hundreds of feet, that are suspended in a black pyritic argillaceous matrix. Smaller clasts are chert, argillite, slate, granite, diorite, limestone, and chert pebble conglomerate. The matrix of the rock is in most places sheared and scaly and without primary structures. In a few places the matrix displays contorted bedding or else areas of bedded argillite that alternate with chaotic paste.

Early Middle Cambrian trilobites occur in a limestone lens within volcanic rocks of the chaotic zone on the southeast shore of

Dunnage Island (Kay and Eldridge, 1968). Horne (1968) has interpreted the fossils to date the depositional age of the nearby chaotic rocks and Kay (1967) suggests that the rocks form a stratigraphic unit, in sequence, which underlies Caradocian argillites of the Exploits Group to the northwest. Although appearing to occupy a consistent stratigraphic position, it is possible that the chaotic rock unit represents a hugh melange zone that is essentially of tectonic origin and as much is a structural, rather than a stratigraphic, unit. This interpretation is suggested by penetrative textures exhibited between boulders and argillaceous matrix of the rocks and the recognition of various boulders within the unit, e.g. chert pebble conglomerate and plutonic rocks, that are probably of Caradocian or younger age. According to this interpretation, fossiliferous Middle Cambrian rocks within the chaotic zone represent large transported blocks that are not in sequence. Similar chaotic rocks or melange zones are associated with major klippen movements in western Newfoundland and the Taconic region of Vermont and New York. The presence of melange rocks in the Bay of Exploits may warrant profound reinterpretations of the paleogeography.

Greywackes of the Exploits Group are well represented in the Gull Island Formation and upper parts of the Shoal Arm Formation (Espenshade, 1937) at Badger Bay, throughout much of the section in New Bay, and in upper parts of the section in Bay of Exploits. The rocks weather from grey to green to greyish brown and brown, with most beds from one foot to 6 feet thick, and less commonly from five feet to 25 feet, reaching a maximum of 50 feet. Greywacke beds are separated in most places by comparatively thin siltstone or argillite interbeds that accentuate stratification within the rocks. The finer-grained interbeds, about 3 inches to 2 feet thick, are grey to black and everywhere darker than the adjacent greywacke beds.

Graded-bedding is apparent in various stages of development in most greywacke exposures and sole markings and cut-and-fill structures are prevalent in some places. Slump folds are evident locally in the New Bay area (Helwig, 1967). Cross-bedding and marks are rare. At Badger Bay, greywackes of the Gull Island Formation contain limy lenses about 3 feet by 6 inches that parallel bedding. Elsewhere dark shale chips are common, particularly in basal parts of greywacke beds. Presumably, these were derived from underlying pelitic rocks that were fragmented by currents responsible for greywacke deposition.

Angular to subangular quartz grains and feldspar fragments are the most abundant constituents of the rocks with lesser chert fragments and/or shale, volcanic rock, and plutonic rock fragments, all set in a fine-grained siliceous matrix. The quartz grains are clear and unaltered with sharp grain boundaries. Most display undulose extinction. The feldspar grains are mainly plagioclase with polysynthetic twinning and these are also clear. Rock fragments composed of two or three large quartz and plagioclase grains are common in some specimens whereas silicic volcanic rocks or shale chips are prevalent in others.

Conglomerates of the Exploits Group occur in widely separated localities and most are associated with greywackes within the section. The rocks are of restricted areal extent and consist of a variety of pebbles, generally from one inch to 4 inches in diameter set in a greywacke matrix. Commonest among the contained detritus are well-rounded chert pebbles that lie side by side with angular argillite fragments. Locally common are pebbles of granitic rock, quartz-feldspar porphyry, a variety of volcanic rocks, sandstone, and limestone. The conglomerate beds generally range from one foot to 10 feet thick but are not persistent along strike for more than a few hundred feet. Examples are found at Chennyville of southern New World Island, at East Hare Island and nearby parts of Fortune Peninsula, within the Burtons Head and Julies Harbour Groups of Badger Bay (Espenshade, 1937), and at Middleton Lake. Many of these rocks, particularly within the Burtons Head and Julies Harbour Groups of Badger Bay (Espenshade, 1937) are probably of Silurian age.

Structure and Metamorphism

Rocks of the Exploits Group are everywhere folded, faulted, and steeply dipping. Structures trend northeasterly in the Badger Bay and Dildo Run areas but in the western parts of Exploits Bay and New Bay they trend northerly and slightly west or north. Northeasterly-trending folds that plunge steeply northeast are well-displayed in Badger Bay whereas northwesterly-trending folds are prominent throughout the Fortune Peninsula. Most folds are tight and a few are isoclinal. Faults commonly parallel fold axes and are ubiquitous. Commonly the rocks are overturned toward the northwest, especially in the New World Island area where northwest facing, steeply southeast-dipping sections are repeated in fault bounded belts.

Regionally the rocks of the Exploits Group at Badger Bay and New Bay occur on opposite sides of the Badger Bay anticlinorium (Hayes, 1951), which is occupied in its central parts by strata of the Wild Bight Group. The Badger Bay section is interpreted to be faulted against the Roberts Arm Group to the northwest and the New Bay section, which includes Silurian strata in its upper parts, is faulted against the Headlands Group to the north. East of Exploits Bay the Ordovician strata are separated from Silurian rocks to the southeast by faults and in the New World Island area Ordovician-Silurian sections, locally repeated in fault bounded belts, are terminated northward by the Luke Arm fault.

Age and Correlation

Ordovician fossils have been collected widely from rocks assigned to the Exploits Group in the Botwood map-area. Most are graptolites from the black graphitic and pyritic shales and argillites generally within the middle and upper parts of the group. These are well represented at New World Island, New Bay, and locally present in the Bay of Exploits and Badger Bay areas. Shelly faunas occur locally in volcanic rocks of the group (contained in limestone lenses) at New World Island, and Middle Cambrian trilobites have been collected in a large block within chaotic rocks in the Dildo Run area (Kay and Eldridge, 1968).

Fossil localities and identifications are as follow:

G.S.C. loc. 55272 and 47253

Northwest shore of Lawrence Harbour, 1000 feet east of northwest corner of harbour.

Diplograptus (*Orthograptus*) cf. *quadrimucronatus* (Hall)
?*Pleurograptus* species
Orthograptus truncatus (Lapworth)

% WF-290-62 G.S.C. Locality 52280

Shore of Burnt Bay opposite Imperial Oil wharf at Lewisporte

Dicranograptus ramosus var. *longicaulis* (Lapw.)
Climacograptus sp.

% WF-527-62 G.S.C. locality 52310

One mile northwest along highroad from northeast bottom of Village Cove, New World Island.

Orthograptus sp.
neotreme brachiopod

% WF-718-62 G.S.C. locality 52252

South shore of Boyds Island, New World Island

Orthoceras sp.
an endoceras cf. *Walcottoceras*
Tropidodiscus sp.

% WF-716-62 G.S.C. locality 52253

First cove north of Cobbs Arm, New World Island

Orthoceras whitfieldi
Climacograptus sp.

% WF-740b-62 G.S.C. locality 55276

South shore of Cobbs Arm 3,000 feet east of bottom of Rogers Cove, New World Island.

?*Orthograptus* sp.

% WF-741a-62 G.S.C. locality 52269

Southeast shore of Cobbs Arm, 3,000 feet northeast of bottom of Rogers Cove, New World Island.

Dicranograptus ramosus (Hall)
Orthograptus sp.

% WF-744-62 G.S.C. locality 52271

Northwest shore of Cobbs Arm opposite limestone quarry, New World Island.

Dicellograptus pumilus (Lapworth)

% WF-444-62 G.S.C. locality 52248

On coast one mile east of Squid Cove, New World Island.

% identification by L.M. Cumming, Geological Survey of Canada
# identification by B-D. Erdtmann, University of Indiana

Dicranograptus ramosus (Hall
Dicranograptus cyathiformis (E & W)

% WF-528-62 G.S.C. locality 52249

One-half mile east along road from southern bottom of Lukes Arm, New World Island.

Dicellograptus sp. cf. D. divaricatus var. salopiensis (E & W)
Orthograptus sp.

% WF-550-62 G.S.C. locality 52307

On southeast shore near northeast end of Duck Island, New World Island.

Orthograptus whitfieldi (Hall)
Orthograptus sp.

% WF-526-62 G.S.C. locality 52247

One-half mile northwest on road from northeast bottom of Village Cove, New World Island.

Plates of Cheirocrinus sp.
Nicolella? sp.

% WF-549-62 G.S.C. locality 52308

Southeast shore of Duck Island near centre of Island, New World Island.

Maclurites sp.

%WF-G-723-62 G.S.C. locality 52309

One mile northwest of bottom of Village Cove on road, New World Island.

Orthograptus whitfieldi (Hall)
Orthoceras sp.

% WF-559-62 G.S.C. locality 52302

Small Cove on north shore of Summerford Arm, one mile west of entrance to Village Cove.

Orthograptus sp.

% WF-573-62 G.S.C. locality 52303

Northeast bottom of Little Byrne Cove, 100 feet northeast of mouth of stream running into cove, New World Island.

Orthograptus sp.

% WF-593-62 G.S.C. locality 52294

East shore of Squid Cove, New World Island.

Dicellograptus forchammeri (Geinitz)
Dicellograptus caduceus (Lapworth)

% WF-271-62 G.S.C. locality 52287

East shore of St. John's Bay, one mile north of Stanhope.

Dictyonema sp.

% WF-500-62 G.S.C. locality (none)

South shore of New World Island, 5 miles northeast of Virgin Arm Tramway.

Poorly preserved graptolites

% WF-135-62 G.S.C. locality 49986

Northwest shore of Sops Arm, Badger Bay, one-half mile from bottom of Sops Arm.

No identifiable material (in limestone)

% WF-132-62 G.S.C. locality 49989

Centre of western shore of Duck Island, Badger Bay.

Orthograptus sp.

% WF-133-62 G.S.C. locality 49990

Southeast end of northern Arm in Burtons Harbour, Badger Bay.

Climacograptus bicornis (Hall)
Orthograptus sp.

% WF-17-62 G.S.C. locality 49392

North end of Beach Island, Northwest Arm, New Bay.

Leptograptus flaccidus var. *macer* (Hall)
Climacograptus bicornis var. *peltifer* (Lapworth)
Mesograptus sp.

% WF-57-62 G.S.C. locality 49393

Northeast end of large island at southwest bottom of Little Northwest Arm, New Bay.

Orthograptus sp.
?*Glyptograptus* sp.

% WF-32-62 G.S.C. locality 49394

Northwest shore of Shoal Cove, Northwest Arm, New Bay.

Orthograptus sp. cf. *O. quadrimucronatus* (Hall)
Orthograptus sp.

% WF-100-62 G.S.C. locality 49398

East shore of Southwest Arm, New Bay. On a line joining Brimstone Head and Paradise Cove.

Orthograptus sp.
Diplograptus sp.

% WF-102-62 G.S.C. locality 49399

Northwest shore of Strong Island Sound, New Bay.

Diplograptus sp.
?*Pleurograptus* sp.

% WF-95-62 G.S.C. locality 49401

On head of first peninsula west of Passage Rocks, Southwest Arm, New Bay.

?*Glyptograptus* sp.

% WF-103-62 G.S.C. locality 49403

North shore of West Arm Brook, 3,000 feet above its mouth, New Bay.

Orthograptus sp.

% WF-PW-9-62 G.S.C. locality 49243

Southeast shore of Rogers Cove, New World Island.

Dicellograptus sp. cf. D. pumilius (Lapworth)
Orthograptus sp. cf. O. calcaratus (Lapworth)

#WF-108-63 G.S.C. locality 58327

Northwest end of Farmers Island, Bay of Exploits.

Orthograptus cf. O. truncatus (Lapworth, 1877)
branch fragments of Dicellograptus?

WF-574-63 G.S.C. locality 58329

Road cut on Leading Tickles Road, northwest of Mill Cove, New Bay.

Climacograptus of C. diplacanthus (Bulman, 1932):- probably a synonym for Climacograptus spiniferus (Ruedemann, 1912)
Climacograptus cf. C. Tubuliferus (Lapworth, 1876)
Climacograptus cf. C. bicornis (Hall, 1865)
Orthograptus sp.
Climacograptus diplacanthus (Bulman, 1932)

WF-616-63 G.S.C. locality 58313

Joe Whites Cove, southeast shore of New World Island

Orthograptus cf. O. quadrimucronatus (Hall, 1865)
Climacograptus aff. C. raricaudatus (Ross and Berry, 1963)
Dicellograptus sp.
Climacograptus aff. C. bicornis (Hall, 1848)
Orthograptus aff. O. calcaratus (Lapworth, 1876)
Climacograptus aff. C. caudatus (Lapworth, 1876)
Dicellograptus cf. D. forchammeri var. flexuosus (Lapworth, 1876)
Orthograptus cf. O. truncatus (var. recurrens, Ruedemann, 1925)
Orthograptus cf. O. truncatus (Lapworth, 1876)

WF-2-68 G.S.C. locality (none)

South shore of Gull Island, Badger Bay.

Climacograptus bicornis (Hall, 1847)
Orthograptus cf. O. calcaratus var. acutus (Elles and Wood, 1907)
Glossograptus fimbriatus (Hopkinson, 1872)
Orthograptus cf. O. truncatus (Lapworth, 1877)
Dicellograptus cf. D. sextans (Hall, 1843) or D. divaricatus (Hall, 1859)

WF-30-68 G.S.C. locality (none)

One mile south of Ward Head on the northwest shore of Western Arm, New Bay.

Nemagraptus gracilis (Hall, 1847)
Dicellograptus cf. D. divaricatus (Hall, 1859)
Pseudoclimacograptus cf. P. stenostoma (Bulman, 1947)
Glyptograptus teretiusculus (Hisinger, 1840)

WF-23-68 G.S.C. locality (none)

South shore of Gull Island opposite community stage of Leading Tickles.

Glyptograptus cf. G. euglyphus (Lapworth, 1880)
Climacograptus cf. C. antiquus (Lapworth, 1873)
Dicellograptus cf. D. sextans var. exilis (Elles and Wood, 1903)

% WF-671-62 G.S.C. locality 52264

East shore of Virgin Arm 8,700 feet from south bottom of Arm, New World Island

No identifiable material (Gastropod?)

% WF-717-62 G.S.C. locality 52254

Southeast shore of Boyds Island northeast of Cobbs Arm, New World Island.

No identifiable material (Brachiopod?)

% WF-672-62 G.S.C. locality 52251

East shore of Virgin Arm, 9,500 feet from south bottom of Arm, New World Island.

No identifiable material (Gastropod?, crinoid debris?)

% WF-G-775-62 G.S.C. locality 52246

One-half mile east of Squid Cove, northwest of road, New World Island.

An unidentified trilobite hypostome

% WF-X-506-62 G.S.C. locality 52291

Southwest shore of Burnt Arm 700 feet east of bottom, New World Island.

No identifiable material

% WF-135-62 G.S.C. locality 49986

Northwest shore of Sops Ar., Badger Bay, one-half mile from bottom of Sops Arm.

No identifiable material

% WF-PW-3-62 G.S.C. locality 49244

Northwest head of Intricate Harbour.

No identifiable material

% WF-PW-8-62 G.S.C. locality 49242

At brook running into Little Byrne Cove, New World Island.

Unidentifiable graptolites.

All of the graptolite faunas of the Exploits Group fall within the Middle and Upper Ordovician or graptolite zones 10 to 14 as defined by Berry (1960) in North America. Some of the forms from localities near the top of the Exploits Group and contained in beds that lie conformably beneath greywackes of the Ninepin Arm Formation, clearly indicate a younger zonation than forms interpreted to be lower in the succession. However, subdivision and detailed correlation of the Exploits Group from one area to another must await further work.

The Exploits Group is equivalent for the most part to the middle and upper units of the Gander Lake Group and many of the faunas are similar in age to those of the sedimentary rocks of the Wild Bight Group at New Bay Pond. Volcanic rocks of New World Island locally contain Lower Ordovician forms (Kay, 1967) in which case they are equivalent to parts of the Headlands Group.

ORDOVICIAN AND SILURIAN

The map-units within the map-area, previously assigned to the Ordovician (Heyl, 1936; Espenshade, 1937) are now interpreted to be at least in part of Silurian age. These are the Roberts Arm Group in the west and the Ninepin Arm Formation in the central part of the map-area. The Roberts Arm Group is unfossiliferous and consists mainly of volcanic rocks. The Ninepin Arm Formation is composed mainly of greywackes that are dated locally as either Middle to Late Ordovician or Lower Silurian. In most places these greywackes conformably overlie Middle or Late Ordovician rocks of the Exploits Group and grade upward into Silurian Goldson conglomerates

Roberts Arm Group

The term 'Roberts Arm; was introduced by Espenshade (1937) to denote a predominantly volcanic rock assemblage exposed between Halls Bay and Badger Bay and occurring on the southern shores of Sunday Cove, Pilleys, and Triton Islands to the south of the Lobster Cove Fault. The assemblage was referred to as the 'Roberts Arm volcanics' and it was regarded to form the uppermost formation of the Badger Bay Series (Espenshade, 1937). Southwest of the type area the volcanic rocks were mapped by Hayes (1951) and farther extensions of the rocks outside the Botwood map-area were mapped by Kalliokoski (1953, 1955) and Neale and Nash (1963). Hayes (1951) subdivided the rocks into two units; intermediate to silicic volcanic rocks with some sedimentary rocks, that he referred to as the 'Mortons volcanics', and mainly basaltic pillow lavas and minor sedimentary rocks, referred to the 'Breakheart Basalt'. Kalliokoski (1953, 1955) and Neale and Nash (1963) referred to the rocks as the Roberts Arm Formation and Kalliokoski, like Hayes (1951), divided the rocks into two informal units; one consisting of predominantly basaltic pillow lava, and the other predominantly rhyolite, pyroclastic rocks, and minor sedimentary rocks. The rocks can, therefore, probably be divided into several formations and for this reason the term Roberts Arm Group is preferred. In addition the Roberts Arm Group as presently outlined contains rocks earlier assigned to the Crescent Lake Formation of the previous Badger Bay Series (Espenshade, 1937; Hayes, 1951).

The Roberts Arm Group as presently outlined is bounded by a major fault to the southeast so that its relationships to dated sedimentary rocks in Badger Bay is unknown. Toward the north the group is either faulted against rocks of the Headlands Group or else overlain by red sandstones and conglomerates of the Silurian (?) Springdale Formation (Espenshade, 1937). The thickness of the Roberts Arm volcanics was estimated at 1,500 feet in the type area (Espenshade, 1937) and the Crescent Lake Formation (Espenshade, 1937), presently included in the Roberts Arm Group, at 500 feet. As the base of the group is unexposed the combined figure of 2000 feet is a minimum thickness.

Lithology

The Roberts Arm Group consists of a variety of volcanic rocks, and includes rocks such as slate, siltstone, and chert that were earlier assigned to the Crescent Lake Formation. The volcanic rocks are mainly dark green to black and purple to reddish brown basaltic flows. These may be pillowed or massive and alternate with basic tuffs and agglomerates. Many of the flows are vesicular or amygdaloidal with the commonest vesicule fillings being calcite, quartz, chlorite, or epidote. A few of the individual flows show columnar jointing. Most of the volcanic rocks are fresh appearing though altered internally. Red and green ferruginous cherts commonly fill interstices in pillowed flows or else occur as thin beds intercalated with the flows.

Silicic volcanic rocks are less abundant within the group but are locally extensive, e.g. Pilleys Island. These are pink to green and purple rhyolite flows and tuffs and are thought to occur mainly toward the top of the succession (Espenshade, 1937).

Sedimentary rocks, formerly assigned to the Crescent Lake Formation (Espenshade, 1937) and here included within the Roberts Arm Group, are red and green slate and argillite with some chert and sandstone beds. These were interpreted to occur in exceedingly tight isoclinal folds southeast of Crescent Lake (Espenshade, 1937) but they may be interlayers among the volcanic rocks. Sedimentary interlayers among the volcanic rocks occur locally at Pilleys Island and southwest of Badger Bay. Northeast of Kippens Pond, sedimentary rocks of the group in places include volcanic fragmental interlayers and all are faulted against greywackes of the Exploits Group to the south.

Structure and Metamorphism

Rocks of the Roberts Arm Group are mainly steeply dipping and folded about axes that trend northeast, except at Pilleys Island where structures trend easterly. This change in regional structural trend probably results from late open flexuring about northward trending axes. Rocks of the Group are probably truncated northeastward by the submarine eastward extension of the Lobster Cove Fault.

The fault boundary between the Roberts Arm Group and the Exploits Group, trending southwestward from Tommys Arm, does not exactly coincide with the boundary of the Crescent Lake Formation (included in the present Roberts Arm Group) and sedimentary rocks of the Exploits Group to the southeast as mapped by Hayes (1951). Hayes (1951) locally showed the same type of rock, or rocks of the same map-unit, on both sides of this lineament, thus implying stratigraphic continuity from the Exploits Group into the Roberts Arm Group. All previous workers have held this view of a continuous and conformable succession from the lowermost beds at Badger Bay (Wild Bight Group) upward through a thick sedimentary succession (Exploits Group) and finally into volcanic rocks (Roberts Arm Group). Recent work by the author (1968) in Badger Bay suggests that the sequence is disrupted above the Full Island Formation (Espenshade, 1937) of the Exploits Group and that the Burtons Head and Julies Harbour Groups include both Ordovician rocks of these groups are equivalent to fossiliferous beds of the Shoal Arm Formation, which are earlier interpreted to lie near the base of the succession. All of this indicates that the Roberts Arm Group is not in stratigraphic continuity with rocks assigned to the Exploits Group to the south.

Toward the north, the Roberts Arm Group is in contact with red sandstones of the Springdale Formation (Espenshade, 1937) or else faulted against the Headlands Group. Where overlain by red sandstones the contact between the sandstones and volcanic rocks is steeply dipping or overturned toward the north and the sandstones have been interpreted to unconformably overlie the volcanic rocks (Espenshade, 1937). Locally where exposed at Bumblebee Bight and Shoal Arm of Triton Island, the contact appears conformable and the volcanic rocks are no more deformed or metamorphosed than the underlying Springdale sandstones.

Age and Correlation

No fossils have been found within the Roberts Arm Group. It has been traditionally assigned to the Ordovician on lithology for its rocks are similar to those of Ordovician Groups nearby. Most workers have correlated the Roberts Arm volcanic rocks with the Breakheart and Mortons volcanics (Heyl, 1936) to the east and interpreted by Heyl to occupy a stratigraphic position at the top of the Ordovician succession. Recent revision of the general stratigraphy in both the Badger Bay and Exploits Bay area indicates that this correlation is no longer tenable. Within the map-area the top of the Ordovician succession is generally shale followed by greywackes of the Ninepin Arm Formation and then Silurian Goldson conglomerates. Red sandstones, such as those that overlie the Roberts Arm volcanic rocks occur still higher within the succession.

These relationships, combined with the fact that the Roberts Arm volcanics are overlain by Silurian (?) Springdale sandstones, suggests that the Roberts Arm Group may be at least in part of Silurian age. If the contact between the volcanic rocks and Springdale sandstones of Pilleys and Triton Islands is indeed conformable, then this suggests that the Roberts Arm Volcanics are in part equivalent to Springdale Group volcanic rocks that underlie the red sandstones to the west. The lithology of the Roberts Arm Group does not compare well with volcanic rocks of the Springdale Group but it may be that the volcanism was of different nature in adjoining areas and that the Roberts Arm volcanic rocks represent the mafic submarine equivalent of the largely silicic terrestrial Springdale volcanic rocks. This reasoning, though tenuous, suggests that the Roberts Arm Group is Silurian in age.

Ninepin Arm Formation

The Ninepin Arm Formation is a new formational name that is proposed for the mainly greywacke beds that conformably overlie late Middle to Upper Ordovician shales of the Exploits Group and pass gradationally upward into Silurian Goldson conglomerates. The rocks are well represented on New World Island and can be traced westward across Samson and Hornet Islands to the eastern shore of the Fortune Peninsula. In a few areas where mapping has not been sufficiently detailed to outline the Ninepin Arm Formation e.g. New Bay and southwest of Badger Bay, the rocks have been included with the Exploits Group. The type area of the formation is at Ninepin Arm of eastern New World Island where the thickest section is exposed (about 5,000 feet) and where the greywackes, conglomerates, and siltstones, of the Ninepin Arm Formation conformably overlie Caradocian slates at Joe Whites Cove and are overlain conformably by Silurian Goldson conglomerates on the north side of Milliners Arm. Rocks assigned to the formation occur locally on the west coast of South Change Island and at Campbellton in Bay of Exploits.

The Ninepin Arm Formation can be recognized wherever continuous Ordovician-Silurian sections are exposed and the contact between the rocks of these two systems in interpreted to be within this formation. The thickness of the formation varies from a maximum of 5,000 feet in its type area to 1,000 feet or less in the western parts of New World Island. The thickness is variable in the New Bay area and the rocks are about 2,000 feet thick at Badger Bay. At Change Islands the formation is estimated to be 3,000 feet thick (Eastler, 1968).

Where mapped by Heyl (1936) the greywackes of the Ninepin Arm Formation were interpreted to occur near the base of the Exploits 'Series' and were referred to the Samson and Hornet Formations of presumed Middle Ordovician age. The same rocks were referred to the Fortune Formation north of Lawrence Harbour (Heyl, 1936) and interpreted to occur at the top of the Exploits 'Series'. The same rocks were referred to the Siview Formation in New Bay and at Leading Tickles (Heyl, 1936). Patrick (1956) followed Heyl (1936) in assigning the rocks to the lowermost greywacke division of the Ordovician Exploits Group at southwestern New World Island and nearby Islands. In the Badger Bay area, rocks presently considered equivalent to the Ninepin Arm Formation were assigned to the Gull Island Formation and upper parts of the Shoal Srm Formation (Espenshade, 1937), or the Samson Formation (Hayes, 1951), and interpreted to occupy the central part of the Ordovician Badger Bay Series (Espenshade, 1937) or Exploits Group (Hayes, 1951; Williams, 1962). Locally at Change Islands, the greywackes of the Ninepin Arm Formation were assigned to the Ordovician (?) South End Formation (Baird, 1957) and were grouped with cross bedded sandstones that are presently considered Silurian (Williams, 1964).

The stratigraphic interpretations arising from all of this previous work are erroneous, in varying degrees, and major revisions in the stratigraphy have been necessary in most places. The Ninepin Arm Formation was mapped in the Twillingate area and its stratigraphic relationships were delineated by Williams (1963) and Kay (1967). Similar rocks have been recognized in the same general stratigraphic position in the New Bay area (Point Leamington greywacke, Helwig, 1967), southwest New World Island (Horne, 1968), and at Change Islands (Easterler, 1968).

Lithology

The Ninepin Arm Formation consists of alternating beds of greywacke, siltstone or slate, and pebble conglomerate. Greywackes are in most places predominant occurring in beds a few inches to a few feet in thickness and consisting mainly of poorly sorted quartz and feldspar grains, shale chips, and chert and volcanic rock fragments. The rocks are grey where freshly fractured but weather buff or greyish brown. Coarser beds are generally thickest and locally contain well-rounded granite pebbles or other well-rounded clasts that occur side by side with angular siltstone or shale clasts. The shale clasts resemble shales and siltstones within the succession and are interpreted to be locally derived. In a few places the greywackes contain limy lenses or ellipsoidal concretions that weather out more readily than the surrounding rock.

The greywackes display a multitude of sedimentary features all indicative or consistent with turbidity current transportation and deposition in an unstable marine environment. Most evident are linguloid sole markings and graded bedding, but also conspicuous are convolute bedding, small scale cross-bedding (never large scale), load casts, scour channels, and intraformational sedimentary breccias. Linguloid sole markings and convolute bedding are best displayed on the west coast of Change Islands, large scour channels are evident at Baptist Cove of Fortune Peninsula, and graded bedding and small scale cross-bedding are evident in almost all exposures. In the New Bay area, the rocks contain slump folds, and at Campbellton intraformational sharpstone breccias are well-displayed.

Structure

Rocks of the Ninepin Arm Formation are folded and in most places steeply dipping but the deformation in this rather competent unit appears less intense than that exhibited by the incompetent, conformably underlying Ordovician slates and argillites. Throughout New World Island and westward through Samson and Hornet Islands to Fortune Peninsula, the beds are vertical or steeply east-dipping and generally north-facing. In New Bay the dips are steep to moderate and the rocks are folded about north to northwest-trending axes. In Badger Bay and southwestward the rocks are involved in a series of tight anticlines and synclines that trend northeasterly. Siltstones or slates that alternate with the greywackes or pebble beds have a well-developed slaty cleavage that is much less apparent or absent in the coarse, more competent, beds.

The contact between Caradocian Exploits Group black slates and the overlying Ninepin Arm Formation is generally gradational but in places it may be abrupt, e.g. Cobbs Arm and Squid Cove of New World Island. The same can be said of the upper contact of the formation where in most places the greywackes and pebble conglomerates grade upward into coarse Goldson conglomerate, but in a few other places the contact is abrupt. The contacts are everywhere structurally conformable.

Age and Correlation

In its type area the Ninepin Arm Formation conformably overlies Middle Ordovician (Caradocian) slates and argillites and is conformably overlain by Lower Silurian (Llandovery) conglomerates. Both upper and lower contacts are gradational with the inference being that the Ordovician-Silurian boundary falls somewhere within the formation and that its age limits are late Middle Ordovician to Early Lower Silurian. The formation is equally well exposed in sequence north of the type area in another fault bounded belt of northern New World Island. There, rocks mapped with the upper part of the formation contain Silurian fossils, both along the northwestern shore of Burnt Arm and one mile northwest of Cobbs Arm on the road to Pike Arm. The following forms have been identified by L.M. Cumming, Geological Survey of Canada:

G.S.C. localities 52297 and 49240

Northwest of Cobbs Arm on road to Pike Arm.

Strictlandia sp.
Heliolites sp.
Zaphrentis sp.
Parmorthis elgantula (Dalman)
?*Clorinda* sp. cf. *C. becsiensis* (Twenhofel)
Paleofavosites sp.
Dalmanella sp.

WF-X-505-62, WF-X-507-62, WF-X-508-62, and WF-G-826-62 G.S.C. localities 52301, 52290, 52258, and 52259

Northwest shore of Burnt Arm

Zaphrentis sp.
Coelospira sp.
Halysites sp.
Heliolites sp.
Camarotoechia sp.
a proetid trilobite
crinoidal fragments.

Toward the west on the south shore of Intricate Harbour, black graptolite-bearing slates of Middle to Late Ordovician age are interlayered with greywackes and siltstones at the base of the Ninepin Arm Formation. The following graptolites were identified by L.M. Cumming:

WF-609-62 G.S.C. locality 52298

Central south shore of Intricate Harbour at west entrance to a southeast-trending irregular shaped cove, New World Island.

Leptograptus sp.
Climacograptus or Glyptograptus sp.

These relationships and fossil identifications support the evidence from the type area that the formation ranges from late Middle Ordovician to Silurian in age.

In the New Bay area the formation has not been mapped separately but a recent subdivision of the rocks in that area (Helwig, 1967) indicates that fossiliferous-limestone-boulder conglomerates occur at the top of a thick, dominantly greywacke succession (Point Leamington greywacke) lithologically correlative with the Ninepin Arm Formation. As mapped by Helwig (1967) the Point Leamington greywacke includes graptolite bearing Middle Ordovician argillites in the central parts of the succession. Nearby on the east shore of Fortune Peninsula at Baptist Cove, conglomerates included in the upper part of the Point Leamington greywacke contain Late Ordovician-Silurian coralline limestone boulders indicating that upper measures of the formation are of Silurian age. This data agrees well with the relationships in the type area of the Ninepin Arm Gromation, and suggests correlation between the two areas.

Probable correlatives of the Ninepin Arm Formation are also represented at Badger Bay where the rocks have been referred to the Gull Island Formation and Shoal Arm Formation (upper part) (Espenshade, 1937), or else mapped as part of the Samson Formation (Hayes, 1951). The succession in Badger Bay as interpreted by previous workers implied that the Gull Island Formation was overlain by Middle Ordovician rocks of the Julies Harbour and Burtons Head Groups. However recent field work suggests that the latter groups contain both Ordovician and Silurian rocks indicating that they are not in sequence, thus removing a major obstacle in correlating the Shoal Arm Formation (upper part) and Gull Island Formation with the Ninepin Arm Formation. The relationships at Badger Bay are therefore interpreted as similar to those at Leading Tickles where Helwig (1967) has mapped Point Leamington greywacke in close stratigraphic proximity to Ordovician rocks of the Wild Bight Group.

It is quite possible that the Ninepin Arm Formation, a lithologic map-unit, is time transgressive. Present data, though tenuous, suggest that it is generally younger in the east than toward the west. Biostratigraphic studies, fully utilizing the graptolite faunas present, could clarify this possibility.

Mafic and Ultramafic Rocks

A discontinuous northeast-trending belt of mafic and ultramafic intrusions extends across the eastern part of the map-area near Gander River and local occurrences of ultramafic rocks are found in the northwest part of the area at Tilt Cove and toward the west. The Gander River belt (Jenness, 1958) of intrusions extends for 40 miles from the southern boundary of the map-area to within a few miles of the coast of Ragged Harbour where it is apparently truncated by a granite batholith. Southwest of the map-area this belt can be traced for an additional 30 miles. Its maximum width is approximately 4 miles. The Gander River belt of intrusions coincides with a belt of Ordovician mafic volcanic rocks which form most of the middle unit of the Gander Lake Group. In a general way the mafic intrusions and volcanic rocks geographically separate the lower and upper units of the Gander Lake Group.

An arcuate serpentinite belt, approximately 12 miles long and from a mile to a few hundred yards in width, extends from Betts Cove to Tilt Cove of the Burlington Peninsula. The belt is bounded on the southeast by Lower Ordovician rocks of the Headlands Group (previously Snooks Arm Group) and for more than one half of its length it separates the Headlands Group from the younger Cape St. John Group on the northwest. Elsewhere along its northwest boundary the belt is bounded by quartz-feldspar porphyry. Local ultramafic intrusions northwest of Betts Cove are surrounded by quartz-feldspar porphyry. These are either large exotic blocks in an extruded porphyry, inclusions in intrusive porphyry, or else represent the exposed parts of an underlying surface that is exposed by the erosion of a porphyry sheet.

The mafic and ultramafic rocks of the Gander River belt have been assigned to the Ordovician because of their close spatial association with Ordovician mafic volcanic rocks and because they been intruded and altered by Devonian granite (Jenness, 1963). Ultramafic rocks of the Tilt Cove Belt appear to cut Silurian (?) rocks of the Cape St. John Group, but Neale (1957) has shown that conglomerates of the Cape St. John Group contain pebbles of the ultramafic rocks, and the intrusive relationships are interpreted as the result of later remobilization of Serpentine.

Also of probable Ordovician age is a folded gabbroic sill that occurs along the boundary of the Wild Bight and Exploits Groups in the Badger Bay area. The sill is approximately 600 feet thick and its lithology has been described by Espenshade (1937) and Hayes (1951).

Lithology

All intrusions of the Gander River Belt cut Ordovician volcanic and sedimentary rocks but nowhere has a sequence of intrusions been well documented. Gabbros of the belt are fine- to medium-grained and massive rocks that are dark green to black and weather greyish green or grey. In most exposures the original pyroxene and plagioclase crystals have been partially altered to aggregates of actinolite, chlorite, ozisite, and carbonate. Coarse-grained varieties with individual crystals up to 5 inches in length have been reported by Jenness (1958) near Chrome Hill and on the east side of Gander River between First and Second Ponds. Smaller areas of pyroxenite occur within or nearby the gabbroic rocks. About 30 such occurrences have been noted, most of which are too small to show on the accompanying geologic map. Where unaltered the pyroxenites are greenish black and weather greyish green or brown. Where altered they are lighter coloured but still brownish weathering. The rocks are generally medium grained and massive and in hand specimen appear to be monomineralic. Petrographic descriptions by Jenness (1958) indicated that the rocks contain two pyroxenes, diopside and bronzite, with small amounts of magnetite. The clinopyroxene is predominant. Commonest alteration minerals are actinolite and serpentine with lesser amounts of talc, carbonate, chlorite, and zoisite.

Serpentinites within the belt appear to be mainly alterations of pyroxenite and locally they can be traced into less altered rocks. Serpentine is common in fractured or brecciated zones or as irregular shaped patches within pyroxenite. The rocks are dark green and weather brownish. In places they contain relict pyroxene crystals and Jenness (1958) reported the local occurrence of equigranular relict dunite textures. Talc and carbonate are common as later alterations and magnesite has been reported (Jenness, 1958). Most of the serpentinite bodies contain disseminated -hromite and locally they contain asbestos fibre in widths up to 1/4 inch.

The Tilt Cove Belt consists mainly of brownish weathered serpentinized peridotite and pyroxenite in its wider parts and serpentinite or talc carbonate rock in its more narrow parts. Less altered rocks locally exhibit layering with alternate bands of peridotite and pyroxenite varying from an inch to several feet thick. The serpentinites are massive, dark green, and composed mainly of flaky antigorite (Neale, 1957). Pyroxene relicts are rare but mesh structure, suggesting derivation from original olivine, is relatively common. In thinner parts of the belt, serpentinites are gradational with rusty brown weathered talc-carbonate rock that in turn grades into talc schist in places along the northwest margin of the belt. Mappable inclusions of pillow lava and banded tuff have been distinguished within the belt near Betts Big Pond and in the vicinity of Tilt Cove (Neale, 1957).

SILURIAN

Silurian rocks are widespread throughout the map-area and occur in separated troughs or fault-bounded belts that in most places trend northeasterly. The rocks are of distinctive facies and include thick conglomerates with fossiliferous shale interbeds, and thick volcanic accumulations that are mainly terrestrial and are succeeded conformably by red and grey fluviatile sandstones. These rocks are sharply contrasted with nearby Ordovician rocks and indicate entirely different depositional conditions from those that prevailed during the Ordovician Period.

Many of the Silurian rocks are unfossiliferous but those that have been dated by fossils are of Llandovery or Early Wenlock age with few exceptions. The faunas are entirely of the shelly variety, except for the local occurrence of Silurian graptolites (Ludlow) near Glenwood (A.J. Boucot, pers. comm. 1968).

Almost all of the rocks presently assigned to the Silurian system were at one time or another regarded as Ordovician or Devonian. Williams (1967) has summarized the reasons underlying erroneous age assignment as follow: (a) few of the rocks were dated by indigenous fossils and where mapped by different geologists were assigned to different systems, (b) Silurian limestone boulders, discovered locally in conglomerates, suggested to early workers a Devonian rather than Silurian age for the enclosing rocks and correlative beds. Subsequently the same rocks were found to contain indigenous Silurian fossils, (c) extensive volcanic activity was not recognized in the Silurian until relatively recently, although it was long known that Ordovician volcanism was widespread in central Newfoundland; accordingly, all volcanic rocks (many of them Silurian in age) were assigned to the Ordovician.

Dated Silurian rocks in the central part of the map-area are referred to the Botwood Group and the Indian Islands Group. The Botwood Group is further subdivided into the Goldson, Lawrenceton, and Wigwam Formations. Undated rocks assigned to the Silurian occur in the northwestern part of the map-area. These are referred to the Cape St. John Group.

Botwood Group

The Botwood Group from the most extensive belt of Silurian rocks in Newfoundland. In the map-area the group extends from Bishops Falls in the south, northeastward along the Exploits River and across Exploits Bay, then eastward toward Indian Arm Pond and northeastward to the coast at Farewell Harbour. The rocks can be traced across Change Islands and Fogo Island farther toward the northeast and are also well-exposed on Bishops Islands and Little Fogo Islands north of Fogo Island. The Botwood Group is intruded by the large Mount Peyton Batholith in the south and by the Fogo Batholith in the north. The boundaries of this major Silurian outcrop, which is continuous for almost 100 miles across the map-area, are mainly faulted, except locally at Salmon Pond Brook where the Botwood Group appears to overlie Ordovician argillites of the Gander Lake Group with structural conformity.

Rocks assigned to the Botwood Group, i.e. Goldson Formation, also occur outside of this main outcrop area. The Goldson Formation occurs in fault bounded belts at New World Island and at several places in New Bay. In both areas the Goldson Formation overlies greywackes of the Ninepin Arm Formation or similar rocks included in the Exploits Group. Locally at New World Island, Goldson conglomerates unconformably overlie Ordovician rocks.

Red sandstones and conglomerates exposed at Sunday Cove, Pilleys, and Triton Islands (Springdale Formation) are described with similar beds of the Botwood Group with which they are correlated.

The term Botwood Group was used by Williams (1962) to designate the Silurian sedimentary and volcanic rocks at Exploits Bay and is a modification of the earlier term Botwood Formation, introduced by Twenhofel and Shrock (1937) to describe the red sandstones in the vicinity of Botwood. The latter were subsequently referred to the Springdale Formation (Twenhofel, 1947; and later workers) as that term was used first to describe correlative red beds west of the map-area in Halls Bay. The term Botwood Formation was therefore dropped. As presently outlined the Botwood Group can be devided into three mappable units each of formational status as follow; (a) a basal conglomerate unit referred to the Goldson Formation (Twenhofel and Shrock, 1937), (b) a middle volcanic unit referred to the Lawrenceton Formation, and (c) an upper sandstone unit named the Wigwam Formation. At Fogo of Fogo Island, the Wigwam Formation has volcanic interlayers (Brimstone Head Member) and at Little Fogo Islands the sandstones are overlain by agglomerates referred to the Seal Nest Member. Volcanic rocks surrounded by sandstones southwest of Exploits Bay are assigned to the Lawrenceton Formation as they are locally overlain by sandstones of the Wigwam Formation and are interpreted to be exposed in anticlinal structures. Other volcanic rocks, i.e. east of Indian Arm Pond and central Port Albert Peninsula, may be similarly exposed upper parts of the Lawrenceton Formation but the structure in these areas is in doubt.

The thickness of the Botwood Group is estimated at 15,000 feet. No continuous sections are exposed but several thousands of feet of each of the three formations recognized within the group occur in separated areas.

Silurian rocks of the Botwood Group were in many places referred to the Ordovician or Devonian by earlier workers and the general succession locally misinterpreted. The details of previous work are involved and have been summarized elsewhere (Williams, 1967). Some of the more common and previously used formational and group names assigned to the rocks by early workers are as follow: Fogo Group, Farewell Group, Indian Islands Group (Baird, 1958) in the Fogo map-area, Farewell Group, Indian Islands Group, Springdale Group (Patrick, 1956) in the Comfort Cove map-area, Botwood Formation, Pike Arm Formation (Twenhofel and Shrock, 1937) in the Bay of Exploits area, Springdale Formation (Twenhofel, 1947), and Hornet Formation of Exploits 'Series' (Heyl, 1936) at Intricate Harbour of western New World Island. More recently, rocks of the Botwood Group have been referred to the North End and South End Formations (Eastler, 1968) at Change Islands. All of these rocks are not thought to belong to the Botwood Group and its composing formations and most of the names have been dropped.

The three formations recognized in the Botwood Group viz: Goldson, Lawrenceton, and Wigwam Formations are displayed in sequence on the west side of the main outcrop belt in the vicinity of Lewisporte and eastward, and also on the west side of Port Albert Peninsula. The Lawrenceton and Goldson Formations are not represented along the east side of the main Silurian outcrop belt southwest of Port Albert

Peninsula, except for a single occurrence of fossiliferous Goldson conglomerate east of Ten Mile Pond. The Lawrenceton and Wigwam Formations are exposed northeastward along strike at Change Islands and Fogo Island, and the Goldson Formation is represented toward the west as New World Island and New Bay, and occurs locally at the northeast end of Upper Black Island.

Goldson Formation

The Goldson Formation was defined by Twenhofel and Shrock (1937) at Goldson Arm of New World Island but these workers neither extended or recognized the formation outside of the type area. Where they studied the thick section of conglomerates south of Cobbs Arm the rocks were referred to the Ordovician, because the north-facing beds seemed to underlie dated Ordovician beds toward the north at Cobbs Arm (Twenhofel and Shrock, 1937). Where mapped by Heyl (1936) at Intricate Harbour of New World Island, the rocks were assigned to the Ordovician Hornet Formation of the Exploits 'Series' and where mapped by Patrick (1956) and Williams (1962) in the Bay of Exploits, the rocks were also assigned to the Ordovician Exploits Group, in accordance with the views of earlier workers. Similarly, at Port Albert Peninsula the rocks were erroneously assigned to the Ordovician (Twenhofel, 1947).

The Goldson Formation is composed mainly of conglomerate but locally it has interbeds of sandstone, limy argillite, and coralline shale. These finer grained fossiliferous rocks were given formational status, i.e. Pike Arm Formation, where mapped by Twenhofel and Shrock (1937) at Fossil Point of New World Island, but they do not form a continuous mappable unit as does the conglomerate. The Pike Arm is now tentatively regarded as a member of the Goldson Formation and similar occurrences of argillite are included in the Goldson Formation as presently outlined.

In the type area at Goldson Arm of New World Island, the Goldson Formation is approximately 2,000 feet thick with neither top or base exposed. Probably 5,000 feet of dated beds conformably overlie the Ninepin Arm Formation south of Cobbs Arm. Elsewhere, exposed thicknesses are in the order of 1,000 feet or less.

Conglomerates of the Goldson Formation are grey to buff, brown, or red and are composed of sub-angular to well-rounded pebbles and boulders of a variety of rock types. The rocks are of variable coarseness, texture, and fragment composition and include well bedded to coarse and thick-set types. Commonest among the contained fragments are volcanic rocks, cherts, sandstones, and plutonic rocks, but locally some varieties have large shale clasts and limestone boulders. Characteristically the conglomerates are polymictic but examples or oligomictic types made up almost entirely of diorite boulders occur near Pikes Arm and a conglomerate that contains chiefly metamorphic rock fragments occurs nearby to the southwest. The conglomerates show graded bedding, scouring and channeling of underlying beds, and locally cross bedding. Some are completely unsorted and include well-rounded plutonic boulders side by side with angular slabs of argillite, all surrounded by smaller fragments and included in a silty matrix. Silurian fossils occur locally both within boulders and the matrix of the conglomerates but their Silurian age is best determined from fossils contained in limy argillite and coralline shale interbeds.

The conglomerate beds generally vary in thickness from a few feet to 10 feet or more and alternate with pebble beds or greywackes that have graded bedding, sole markings, and are in most respects similar to the underlying Ninepin Arm Formation. Greywackes are common with the formation southeast of Lewisporte and locally in New Bay.

Red varieties of Goldson conglomerate are restricted to northern New World Island where they are exposed along the shoreline between Little Byrne Cove and Indian Cove and extend northeastward to Golden Arm. Similar rocks occur in the hills southeast of Toogood Arm and along the peninsula that terminates in Herring Head. These rocks have few sandstone interbeds. Locally they vary from dark red to brownish, pink, or grey and some varieties that weather red are grey or greenish on fresh fractured surfaces. Commonest fragments are pink or green volcanic rocks, red and green quartzite, reddish sandstone, grey to green chert, red chert or jasper, buff weathered grey quartzite, and plutonic rocks. Near the ( ) at Herring Neck one variety of conglomerate consists mainly of well-rounded pebbles and boulders of red hematitized gabbro, fresh pink-weathered diorite, red porphyry, and red quartzite.

Fossiliferous limestone boulders, though sparce, occur in the conglomerates in all major outcrop areas. They are commonest at Pike Arm and Intricate Harbour of New World Island, and at Northwest Arm of New Bay, but occur locally near Lewisporte and at Beaver Cove of Port Albert Peninsula. One large limestone boulder in the base of the conglomerate west of Besom Cove, New Bay, has exposed dimensions of 10 feet by 6 feet by 3 feet and is composed almost entirely of Silurian coralline limestone with minor shale lenses. The shales within the limestone boulder are lithologically similar to shale interbeds within sandstones below the conglomerate, suggesting that all of these lithologies are roughly of the same Silurian age and that the boulder did not travel far. Similarly at the southeast entrance to Pikes Arm, several of the conglomerate beds contain conspicuous fossiliferous, coralline limestone fragments and abundant angular argillite fragments. The limestone and argillite fragments are similar to coralline limestone and grey argillite in nearby Silurian interbeds. Other examples of sedimentary cannibalism are also common among the Silurian clastic rocks.

On Burnt Island of Goldson Arm, several hundred feet of medium to coarse red sandstone outcrops along the northwestern and southern shores. The rocks consist of quartz grains in a red hematitized matrix, and although included with the Goldson Formation, they more closely resemble red sandstones of the Wigwam Formation. In this particular area the Goldson Formation includes clastic rocks of varying lithology and the stratigraphic relationships between red sandstones must still be deciphered.

Sheared conglomerates of the Goldson Formation with stretched pebbles and boulders occur on the west shore of Port Albert Peninsula at Beaver Cove and at Little Beaver Cove. Fragments in the rocks include grey chert, sheared and greasy siltstone, red jasper, quartz, granite, a variety of acid to intermediate volcanic rocks, and a few highly elongated fossil limestone boulders. Conglomerate units are not more than a few hundred feet thick and are separated by interbedded sandstones or sequences of sandstone and siltstone. These conglomerates are not strikingly similar to those of the type area but the dissimilarities are mainly the result of the much more intense deformation evident in the Port Albert Peninsula occurrences.

The thick conglomerates of the Goldson Formation are a relatively competent structural unit and consequently the formation is much less deformed than underlying incompetent units. Most of the rocks are steeply dipping or overturned, except locally in the New Bay area where more gentle dips are apparent. At New World Island, steeply dipping to slightly overturned conglomerate successions face northwest and occur in northeast-trending, fault bounded belts. Locally at Pike Arm the Goldson Formation is involved in a northeast plunging synclinally folded structure.

The base of the Goldson Formation is well-exposed in the New World Island and New Bay areas. Elsewhere it is faulted against older rocks. In most localities the conglomerates conformably overlie beds of the Ninepin Arm Formation but locally at northern New World Island, the Goldson Formation lies directly on Ordovician volcanic rocks or black slate of the Exploits Group. Conformable contacts at the base of the Goldson Formation are well-exposed at Northwest Arm and Western Arm of New Bay where the conglomerates overlie greywackes and siltstones of either Silurian or Late Ordovician age. The underlying beds are included in the Exploits Group but have been mapped separately as the Point Leamington greywacke where more detailed work was done by Helwig (1967). Similarly at New World Island, the Goldson Formation overlies greywackes of the Ninepin Arm Formation at Milliners Arm, south of Pike Arm, at Hillgrade, and at Farmers Head of Intricate Harbour. This same relationship is also apparent south of Summerford on Farners Island.

Local unconformity at the base of the Goldson Formation is apparent on the west side of Greens Cove and northward to Pike Arm. There, the conglomerates directly overlie volcanic rocks or black slates that contain Ordovician graptolites (Kay, 1968). A similar relationship is evident on the south side of Cobbs Arm at Rogers

Cove where coarse conglomerates containing Silurian fossils overlie Middle Ordovician graptolitic black siliceous argillite and slate. Little structural significance is placed in these unconformable relationships and they are interpreted as simple stratigraphic overstepping rather than indicating a major tectonic event separating the Ordovician and Silurian rocks.

Large shale clasts of the Exploits Group and Ninepin Arm Formation occur within coarse, thick-set Goldson conglomerate beds and generally have a cleavage that is everywhere parallel, indicating that the clasts were deformed after incorporation into the conglomerate and that they were not involved in a deformative event prior to detachment from their source rocks.

Idigneous Silurian fossils have been collected from the Goldson Formation at several localities in the New World Island area and east of the Ten Mile Pond, and fossils of either Silurian or Late Ordovician-Silurian age have been collected from limestone boulders in the conglomerates in almost all major outcrop localities. The limestone boulders are thought to be generally of the same age as the enclosing conglomerates and the authors interpretation is that most are of Silurian, rather than of Ordovician, age. Where specific age assignment can be made within the Silurian, all fossils collected belong to the Llandovery or Wenlock, except at Intricate Harbour where indigenous fossils of Late Ordovician (Ashgillian) age are present in rocks mapped as typical Goldson conglomerate (Williams, 1963). The Intricate Harbour faunas have recently been studied by Neuman (1969) and the relationships suggest that the lithologic map-unit (Goldson Formation) is diachronous and although generally of Early Silurian age it is locally Late Ordovician. The fossiliferous section at the north shore of Intricate Harbour is also thought to be much condensed and rather atypical of the general regional stratigraphy.

The following is a list of the fossil localities, and forms collected at each, throughout the Goldson Formation (identifications by L.M. Cumming).

A. Indigenous fossils from matrix of conglomerate or interbedded argillites.

Northeast end of Upper Black Island, Exploits Bay. Limy siliceous beds interbedded with chaotic conglomerate.

Stricklandia exploitensis (Shrock and Twenhofel)
Zaphrentis sp.
a dalmanellid
bryozoans

G.S.C. locality 52274

South shore of Cobbs Arm, 3,000 feet east of bottom of Rogers Cove, New World Island.

Catenipora sp. Zaphrentis cf. stokesi
brachiopod species A.

WF-709-62 G.S.C. locality 52266

Southeast headland at entrance to Pikes Arm, New World Island.

Calymene blumenbachii (Brongniart)
Strictlandia sp.
Zaphrentis sp.
Dolerorthis sp.
Halysites sp.
Favosites sp.

WF-X-510-62 G.S.C. locality 52305

One-half mile southwest of Toogood Arm on northwest shore of Burnt Arm.

Coelospira sp.
Favosites sp.
Heliolites sp.
a large indeterminate polecypod

WF-618-62 G.S.C. locality 52306

Northwest shore of Intricate Harbour, 1,000 feet southeast of western-most head at entrance to Harbour, New World Island.

Encrinurus sp.
Calopoecia sp.
Zaphrentis sp.

WF-G-852-62 G.S.C. locality 52300

Southeast shore of Toogood Arm, one-half mile northeast of bottom of Arm, New World Island.

Encrinurus sp.
Heliolites sp.
Paleofavosites sp.

WF-G-794-62 G.S.C. locality 52296

Northeast shore of Burnt Island, Goldson Arm, New World Island.

Favosites sp.
Aphrentis sp.
Halysites sp.

WF-G-793-62 G.S.C. locality 52299

Northwest shore of Burnt Island, Goldson Arm, New World Island

Goldsonia burntensis (Shrock and Twenhofel)
Orthoceras sp.
Zaphrentis sp.
Encrinurus sp.

WF-G-795-62 G.S.C. locality 52292

Southeast shore of Burnt Island, Goldson Arm, New World Island.

Coelospira hemispherica
Rhyncospira ? sp.

WF-X-509-62 G.S.C. locality 52293

Southeast shore of Goldson Arm, one and one-half miles southwest of Toogood Arm, New World Island.

Encrinurus anticostiensis (Twenhofel)
Zaphrentis stokesi (E and H)
Bumastus sp.
Fenestella sp.
Lingula sp.

WF-X-501-62 G.S.C. locality 52257

Southwest end of Goldson Arm at Government wharf, New World Island.

Encrinurus anticostiensis (Twenhofel)
Leptaena sp.

WF-X-502-62 G.S.C. locality 52256

Southwest end of Goldson Arm near Government wharf, New World Island.

Halysites sp.
?Delthyris sp.
Zaphrentis stokesi

WF-PW-1-62 and WF-PW-1a-62 G.S.C. localities 49236 and 49233

Southeast side of Cobbs Arm in small cove 4,000 feet northeast of bottom of Rogers Cove.

Heliolites sp.
Paleofavosites sp.
Favosites sp.
Halysites sp.
Zaphrentis stokesi (Edwards and Haimes)
Pentamerus sp.

WF-PW-2-62 G.S.C. locality 49237

Fossil Point, Pike Arm, New World Island

Pentamerus oblongus (Sowerby)
Encrinurus anticostiensis (Twenhofel)
Halysites catenularia (Linnaeus)
Zaphrentis stokesi (Edwards and Haimes)
Calymene sp.
Hyolithes sp.

WF-PW-5-62 G.S.C. locality 49246

Small Island on southeast side of Pike Arm, 2,000 feet northeast of Fossil Point, New World Island.

Heliolites interstinctus (Linnaeus)

WF-PW-7-62 G.S.C. locality 49241

Small cove at southwest end of Herring Head Peninsula, New World Island.

Brachyprion leda (Billings)
Dolerorthis Flabellites (Foerste)
Favosites sp.
Zaphrentis sp.
Leptaena sp.

WF-PW-11-62 G.S.C. locality 49235

Southeast side of Rogers Cove at bottom of Cove, New World Island.

Halysites sp.
Heliophrentis sp.
Dalmanella sp.
Delthyris sp.

WF-PW-12-62 G.S.C. locality 49234

On peninsula between Burnt Arm and Goldson Arm, New World Island.

Pentamerus oblongus (Sowerby)

WF-566-63 G.S.C. locality 58317 (ident. by T.E. Bolton, G.S.C.)

East shore of eastern emblayment of Rocky Pond, east of Campbellton.

Clathrodictyon sp.
Halysites sp.
Favosites sp.
Heliolites sp.
Strophochonetes sp.
Howellella sp.
Atrypa sp.
cup coral, bryozoa, pentamerid brachiopod cross-section.

WF-615-63 G.S.C. locality 58323 (ident. by T.E. Bolton)

East shore of New World Island between Cobbs Arm and Milliners Arm, north-northwest of Brandies rock.

Zaphrentis sp. like Z. stokesi of Shrock and Twenhofel
Haylsites sp.
Tiny brachiopod - Plectatrypa-like
Large gastropod - Hormotoma ? sp.
sponge

WF-113-63 G.S.C. locality 58324 (ident. by T.E. Bolton)

Northern entrance to Intricate Harbour, New World Island.

Lophospira sp.
cup coral - indeterminate
Dolerorthid impression
Catenipora sp.

B. Fossils from limestone boulders in Goldson conglomerates

WF-E-61 G.S.C. locality 47256

Southeast shore of Osmonton (Northwest) Arm directly east of north top of Long Island, New Bay.

Favosites sp.
?Delthyris sp.
crinoidal debris

WF-B-61 and WF-14-62 G.S.C. localities 47254 and 49397

Southeast shore of Osmonton Arm opposite north end of West Hare Island, New Bay.

Favosites cf. gothlandicus
Zaphrentis cf. stokesi
Halysites sp.
indeterminate massive coral

WF-680-62 G.S.C. locality 52250

Northwest shore of New World Island, 3,000 feet northeast of Hillgrade.

Catenipora sp.
Diplophyllum? sp.

WF-604-62 G.S.C. locality 52255

Northeast extremity of Farmer Head, New World Island.

Favosites sp.
?Paleofavosites sp.
Fossopora (Etheridge) or Billingsaria
Heliolites? sp.

WF-105-62 G.S.C. locality 52289

South shore of Intricate Harbour, one-half mile east of south entrance to harbour.

Paleofavosites sp.
fragments of large rugose coral

WF-25-62 G.S.C. locality 49983

Small cove on west shore of Besom Cove Peninsula. Small cove is directly east of northeast tip of Long Island, Osmonton (Northwest) Arm.

Halysites sp.
Stauria sp.
a trilobite fragment, crinoid columnals, bryozoa

WF-116-62 G.S.C. locality 49987

At bottom of Cove on south side of the largest island in Western Arm, New Bay.

Favosites sp

WF-84-62 G.S.C. locality 49400

Northwest shore of Western Arm, New Bay, 4,000 feet from mouth of West Arm Brook.

Favosites sp.
Zaphrentis ?

WF-426-63 G.S.C. locality 58321 (ident. by T.E. Bolton)

Northwest shore of northwesternmost Farewell Duck Islands.

Zaphrentid ?

C. Indigenous fossil localities where no forms identified

WF-PW-4-62 G.S.C. locality 49239

Small cove at southern head at entrance to Pikes Arm, New World Island.

WF-535-63 G.S.C. locality 58328

East shore at southwest end of Ten Mile Lake.

D. Fossiliferous limestone boulders in which no forms identified, from Goldson Formation.

WF-260-62 G.S.C. locality 52263 and 52281

Canadian National railway to Lewisporte at point 300 feet south of intersection of railway and Lewisporte highway, i.e. approximately 3 miles south of Lewisporte.

WF-339-62 G.S.C. locality 52270

Northwest end of Upper Black Island, Exploits Bay.

WF-265-62 G.S.C. localities 52262 and 52285

East shore of Burnt Bay, opposite Lewisporte, three-quarters of a mile north of bottom of bay.

WF-331-62 G.S.C. locality 52286

Northeast end of Upper Black Island - limestone boulder in chaotic rocks.

Possible equivalents of the Goldson Formation occur at several localities within the map-area. Conglomerate exposed on the west side of Horwood Bay and on the north shore of Western Indian Island are lithologically similar to the Goldson Formation. These conglomerates assigned to the Indian Islands Group, are highly sheared and are underlain by fossiliferous Silurian argillites that are rather unlike the Ninepin Arm greywackes that conformably lie beneath the Goldson Formation in the type area. In the Badger Bay area, conglomerate of the Exploits Group locally overlie Middle Ordovician black slates and lithologically are similar to the Goldson Formation. Other conglomerates on the Gander Bay highway and tentatively included in the Gander Lake Group-middle unit could conceivably be Lower Silurian and Goldson equivalents.

Lawrenceton Formation

The name Lawrenceton Formation is proposed for the volcanic unit of the Botwood Group which overlies the Goldson Formation and is conformably overlain by sandstones of the Wigwam Formation. The volcanic rocks are represented in almost continuous exposure along the western side of the main Exploits Bay Silurain outcrop belt and they are well-exposed at Change Islands. Volcanic rocks at Cann Island, south of Seldom on Fogo Island, may be correlatives. Southwest of the map-area, the volcanic rocks can be traced for an additional 60 miles to Rogerson Lake (Williams, in press).

The type area is chosen at Lawrenceton of Exploits Bay where a thick section of volcanic rocks are exposed in the Burnt Arm anticline and where the volcanics are clearly overlain by red conglomerates and sandstones of the Wigwam Formation. A similar conformable relationship between the Lawrenceton and Wigwam Formations is evident at Farewell Head and Farewell Duck Islands, and on the small islands north of North Change Island. The base of the Lawrenceton Formation is exposed on the west side of Change Islands where the volcanic rocks and interbedded red conglomerates overlie greywackes and siltstones of the Ninepin Arm Formation. Volcanic rocks, resembling those of the Lawrenceton Formation also overlie greywackes (Ninepin Arm Formation ?) at Cann Island. At Farewell Duck Islands and Port Albert the volcanics overlie Goldson conglomerates.

The Lawrenceton Formation is probably 5,000 feet thick in its type area but appears to thin toward the east and northeast and is less than 1,000 feet at Port Albert Peninsula. Farther northeastward at Change Islands the formation is estimated at 3,000 feet thick.

All early workers, either assigned the volcanic rocks of the Lawrenceton Formation to the Ordovician or else reasoned indirectly that it was more probable that the rocks were Ordovician rather than Silurian (Hriskevitch, 1950; Twenhofel, 1947; Baird, 1958). Williams (1962) was the first to recognize that certain volcanic rocks at Exploits Bay conformably underlay Silurian red beds and were Silurian in age. All future work has supported this conslusion both in the map-area and in adjoining areas (Anderson and Williams, in press;

Williams, in press). Recent mapping at Change Islands has unveiled the presence of fossiliferous Silurian pebbles in red conglomerates interlayered with the Lawrenceton volcanics (Eastler, 1968). The following forms were identified;

Favosites
Heliolites
Thecia
unspecified stromatoporids, crinoids, gastropods, and cephalopods.

The Lawrenceton Formation consists mainly of volcanic rocks but also includes interbeds of red conglomerate and sandstone. The volcanic rocks are purplish green to purple, red, and green and flows and pyroclastics are represented in roughly equal proportions. The flows are thick and massive and are commonly amygdaloidal or vesicular with calcite and quartz the commonest vesicule fillings. Locally they are porphyritic, and rarely are they pillowed. Baird (1968) has referred to the flow rocks of this formation at Change Islands as rhyodacites, dacites, and andesites. Elsewhere basalts and rhyolites are also thought to be represented. Common among the flows are red to brownish andesites that are both amygdaloidal (calcite) and porphyritic with euhedral feldspar phenocrysts up to 1/2 inch in length. Flows are predominant at the type locality but elsewhere are secondary to coarse agglomerates and tuffs.

The best display of pyroclastic rocks of the formation occurs at Change Islands where shoreline occurrences have been laid bare by wave erosion. Most of the rocks are red or brownish and less commonly green or pink. Thick bedded agglomerates predominate with finer tuffaceous beds in places. The agglomerates consist of a variety of angular to well rounded volcanic fragments that vary from less than 6 inches to 3 feet or more in diameter. Most are amygdaloidal or vesicular reddish brown or dark grey to black andesite and basalt, others are pink silicic lava or tuff. Red appearance of many of the rocks results from either hematitic red volcanic fragments, or a hematitized tuffaceous matrix surrounding the fragments. Some of the fragmental volcanic rocks contain fragments that appear to be water worn and the detail of bedding in other examples also suggests that the volcanic debris was in places transported by water.

Sedimentary members of the Lawrence Formation are also best displayed at Change Islands, where in places there appear to be all gradations between sedimentary and volcanic fragmental rocks. About 100 feet of red conglomerate with interlayered purple amygdaloidal lava occurs on the west side of North Change Island at Fox Cove and 50 to 100 feet of red micaceous sandstone occurs among the volcanics on the east side of South Change Island about 1/2 mile north of Crow Head. The sandstone at Crow Head is thin bedded and displays mud cracks, ripple marks and rain prints. The sandstone beds are in places disrupted by intermingled large fragments of purplish red porphyritic lava, and poorly sorted red agglomerates bounding the sedimentary beds contain wisps and shreds of sandstone around the larger volcanic fragments. This suggests contemporaneous volcanism and sandstone deposition.

Wigwam Formation

The name Wigwam Formation is proposed for the dominantly sandstone unit of the Botwood Group which conformably overlies the Lawrenceton Formation. The Wigwam sandstones are the most extensive rock type of the Botwood Group and occur in a broad belt up to 10 miles wide that can be traced from the Exploits River in the south of the map-area to Port Albert Peninsula in the northeast. The sandstones are also well-exposed on Change Islands and Fogo Island and occur still farther northeastward at Little Fogo Islands. Southwest of the map-area the Wigwam sandstones can be traced an additional 70 miles to Rodeross Lake (Williams, in press).

The Wigwam sandstones were earlier referred to the Botwood Formation where mapped by Twenhofel and Shrock (1937) at Exploits estuary, and to the Farewell Group and South End and Fogo Formations where mapped by Patrick (1956) and Baird (1958) respectively in the Comfort Cove and Fogo map-areas. Mapping in the intervening areas has shown that these rocks form a continuous belt (Williams, 1962; 1964) and occur in the same relative stratigraphic position. The type area of this formation is chosen at Exploits Bay, which was also the type area of the Botwood Formation to which the rocks were earlier referred. As the term 'Botwood' has been dropped as a formational name (Twenhofel, 1947), and revised as a group name (Williams, 1962), and as the type area remains the same, i.e. north of Wigwam Point, then the rocks are referred to the Wigwam Formation. The names Farewell, South End, and Fogo have been dropped.

Following Twenhofel's work in 1947, the Wigwam sandstones were referred to the Springdale Formation in the type area of Exploits Bay and this name was used southwestward in the Rattling Brook area (Hriskevitch, 1952) and locally in the Comfort Cove area (Patrick, 1956). Use of the term Springdale implies correlation with red beds 40 miles across strike and to the west of the Exploits Bay area. Most agree that this correlation is highly probable but the Springdale Formation is undated and the term 'Springdale' has been used as both a formation and group name without redefinition. For these reasons the new name Wigwam Formation is preferred to designate the sandstone unit of the Botwood Group.

The Wigwam Formation conformably overlies volcanic rocks of the Lawrenceton Formation. This relationship is clearly displayed at Exploits River, Lawrenceton, Port Albert Peninsula, and at the small islands north of North Change Island. Conglomerates generally occur at the base of the formation and these contain fragments of the underlying volcanic rocks. The eastern boundary of the Wigwam Formation is mainly faulted but near Salmon Pond, west-facing grey sandstones are structurally conformable with west-facing Ordovician slates and argillites of the upper unit of the Gander Lake Group. Here, the Lawrenceton, Goldson, and Ninepin Arm Formations are all apparently missing.

On Fogo Island typical Wigwam sandstones are overlain and in part interlayered with silicic volcanic rocks, and farther north at Little Fogo Island (presumably at higher stratigraphic levels), the sandstones are overlain by coarse red and pink agglomerates. These volcanic rocks are included within the Wigwam Formation and referred to respectively as the Brimstone Head and Seal Nest members of the formation.

The Wigwam Formation was estimated at 5,800 feet thick in a stratigraphic section reasonably well exposed between Wigwam Point and

Peters Arm (Twenhofel and Shrock, 1937). Southwest of Wigwam Point, conglomerates at higher stratigraphic levels provide an additional 1000 feet of beds. This is considered to be a maximum thickness of the formation and presumes that the beds are not repeated by faults. Elsewhere the formation is more complex structurally and appears to be somewhat thinner. At Change Islands the formation was estimated at 4,000 feet by Baird (1958) and 2,500 feet by Eastler (1968).

The Wigwam Formation consists of micaceous sandstone, siltstone, conglomerate, volcanic rocks, and locally slate and argillite or hornfelsed equivalents. The sandstones are typically red or grey but also pink, buff, or brown and associated conglomerates or finer clastic rocks show corresponding colour variations. The rocks are well-sorted and composed mainly of quartz grains and detrital muscovite, commonly with a hematitic matrix around the quartz grains that causes the red colouration. Some of the rocks are evenly bedded or finely laminated but the majority show cross-bedding, current and oscillatory ripple marks of various sizes and patterns and ripple drift lamination. Less commonly the rocks display mud cracks, rain prints, and scour channeling. At the south end of Change Islands the sandstones are grey and tuffaceous and nearby at Fogo Island, well-sorted beds contain angular silicic volcanic fragments up to several inches in diameter, suggesting derivation from nearby active volcanic centres.

Conglomerate beds occur among the sandstones locally and are best displayed along the Exploits River and at Norris Arm. The conglomerates are red or grey and composed of chert and volcanic rock fragments, and at Martin Eddy Point and High Point they contain fossiliferous Silurian limestone boulders.

Grey fossiliferous argillites and siltstones are included in the formation south of the Exploits River, and dark grey to black, hard hornfelsic rocks, exposed on the south side of the Trans-Canada Highway at Norris Arm are interpreted as hornfelsed equivalents of nearby beds by action of the Mount Peyton Batholith to the south.

The Brimstone Head volcanic member of Northwest Fogo Island consists mainly of poorly bedded hard and compact silicic volcanic rocks, most of which are fragmental. The fragmental nature of the rocks is evident only on a weathered surface. The rocks are dark grey but weather light grey to white and break with a concoidal fracture. The Brimstone Head member also includes green lava and bedded pyroclastic rocks at Fogo Harbour and vesicular facies are common on the islands east of the mouth of Fogo Harbour (Baird, 1958).

The Seals Nest member, probably near the top of the Wigwam Formation, consists of agglomerates and volcanic breccias, flows, and tuffs. Most spectacular are coarse reddish brown agglomerates composed of angular to rounded lava fragments up to 5 feet in diameter. These are well-exposed at Seals Nest Islands where they conformably overly north-dipping red sandstones. Purplish or grey lavas with feldspar phenocrysts are common at Bishops Islands, and bright red silicic volcanic rocks occur north of Seals nest Islands. At one locality, Eastler (1968) has reported intermediate to acidic plutonic cobbles and pebbles with a volcanic conglomerate of this member.

Red sandstones and conglomerates lithologically similar to the Wigwam Formation occur at Sunday Cove, Pilleys, and Triton Islands. These rocks are undated and were assigned to the Springdale Formation where first mapped by Espenshade (1937). As these beds are now considered to be correlative with the Wigwam Formation, they have not been designated as a separate map-unit on the accompanying map. These beds are vertical to steeply south-dipping, but face north and are bounded northward by the Lobster Cove Fault. The red beds were interpreted to unconformably overlie volcanic rocks of the Roberts Arm Group (Espenshade, 1937) but where not faulted at Triton and Pilleys Islands, the contact appears conformably, or at most disconformable.

The Wigwam Formation contains indigenous Silurian fossils at Martin Eddy Point, southeast of Exploits River near Jumpers Brook, and at Salmon Pond Brook and the Trans-Canada Highway a few hundred feet southeast of the southern border of the map-area near Salmon Pond. The forms identified at these localities are as follow (identified by L.M. Cumming, Geological Survey of Canada).

WF-596-61 G.S.C. locality 47251

Martin Eddy Point, north shore of Exploits River.

Octobronteus sp.
Atrypa reticularis
?*Idiorthis* sp.
Zaphrentis sp.

WF-E-27761, WF-J-F-1&2-61 G.S.C. localities 47725 and 47252

Southeast of Exploits River near Jumpers Brook and between Canadian National railway and Trans-Canada highway.

Pentamerus oblongus (Sowerby)
Eophacops cf. *marklandensis* (McLearn)
Goniophora or *Pterinea* sp.
Pleurotomaria sp.
Parmorthis sp. (Schuchert and Cooper 1931)
Leptaena rhomboidalis
Rhabdocyclus sp.
Hormotoma sp.

WF-320-62 G.S.C. locality 52284

One and one-half mile west along Salmon Pond Brook from its mouth at Gander River.

Chonetes sp.

From this same horizon where exposed southward along strike on the Trans-Canada highway the following forms were identified by A.J. Boucot (pers. comm., 196).

Howellella sp.
Protochonetes sp.
Isorthis aff. *orbicularis*
Atrypa reticularis
sphaerirhyncid
leptostrophid
syringoporoid
snails
orthotetacid

These collections are indicative of a Silurian age. The first two collections suggest a Late Llandovery-Early Wenlock age. The Salmon Pond Brook forms are consistent with a Wenlock age but a single monographid, identified by A.J. Boucot (pers. comm. 1968) suggests a Upper Silurian Ludlow age.

In addition to the above, the following Silurian fossils identified by A.J. Boucot have been collected from boulders in the conglomerate at Martin Eddy Point;

Atrypa reticularis
Zaphrentis sp.
Nuculites sp.
Dalmanella cf. *elegantula* (Dalman)
?*Dalmanella*
Favosites sp. cf. *gothlandicus*

These are of the same general age as the indigenous fossils from limy shale interbeds. Additional forms contained in boulders at

Martin Eddy Point are given by Twenhofel and Shrock (1937) and Twenhofel (1947).

Fossils were collected at two other localities in the Wigwam Formation within the map-area, i.e. northeast of Island Pond and on the northwest shore of Port Albert Peninsula. The forms from these localities are either indeterminate or of little correlative value.

<u>WF-X-106-62 G.S.C. locality 52283</u>

One mile northeast of northern end of Island Pond.

<u>Favosites</u> sp.
<u>crinoidal</u> fragments
undeterminate brachiopod

<u>WF-95-63 G.S.C. locality 58318</u>

Northwest shore of Port Albert Peninsula opposite south end of Dunnage Island.

indeterminate.

Silurian fossils also occur locally in the Wigwam Formation south of the map-area near Glenwood (Anderson and Williams, in press).

Correlatives of the Botwood Group are represented west of the map-area where a thick volcanic unit and overlying red bed unit of the Springdale Group are lithologically similar to the Lawrenceton and Wigwam Formations. The Springdale beds are undated but correlation with the Botwood Group has been proposed or implied by all previous workers. Lithologic correlation of the Botwood Group with other Silurian occurrences throughout Newfoundland has been summarized by Williams (1967).

The relative ages and age spans of the formations within the Botwood Group are not well defined. For example the Goldson Formation, although generally Llandovery in age, locally contains Wenlock or even Late Ordovician (Ashgillian) fossils. Similarly the Wigwam Formation has indigenous fossils that are Llandovery in places but Ludlow forms are present locally. This suggests that the formations are time transgressive. Biostratigraphic correlation awaits future work.

Indian Islands Group

The term Indian Islands Group was first used by Patrick (1956) to designate the Silurian strata on both sides of Horwood Bay, and by Baird (1958) who mapped the northeast continuation of these beds across the southern Bog Bay Islands and Indian Islands. Prior to this phase of mapping the rocks were described and dated by Twenhofel and Shrock (1937) and Twenhofel (1947). All of these workers interpreted the Silurian Indian Islands Group to occupy a northeast-trending syncline at Horwood Bay bordered to the east and west by older strata. Also, at Indian Islands and Yellow Fox Island, Twenhofel and Shrock (1937), Twenhofel (1947), and Baird (1958) all interpreted the section to be southward facing. The present study indicates that the structural relationships at Horwood Bay are more complex than previously considered and the section at Indian Islands, though probably continuous, faces north and not south.

In the Comfort Cove area, Patrick (1956) assigned the strata bounding the Indian Islands Group both west and east of Horwood Bay to the undated Farewell Group. Baird (1958) similarly assigned the strata west of Horwood Bay at Port Albert Peninsula to the Farewell Group. Subsequent work (Williams, 1963, 1964) indicates that the strata west of Horwood Bay can be correlated lithologically with the Silurian Botwood Group and that these rocks are probably faulted against the Indian Islands Group at Horwood Bay. East of Horwood Bay, the beds earlier assigned to the Farewell Group (Patrick, 1956) have been found to contain Silurian fossils and as they appear to conform with strata of the Indian Islands Group and are lithologically unlike any rocks of the Botwood Group, then the beds east of Horwood Bay are included in the Indian Islands Group. The name Farewell Group has been dropped. The present Indian Islands Group then includes all those rocks assigned to that group by Patrick (1956) and Baird (1958) and also includes the rocks between Horwood Bay and Gander Bay earlier assigned to the Farewell Group (Patrick, 1956). Southwest of Horwood Bay the rocks can be traced southwestward to near Duder Lake where they are interpreted to be faulted against Wigwam sandstones of the Botwood Group to the south.

The Indian Islands Group has been divided into three lithologic subdivisions none of which has formational status. These are as follow: cherty siltstone and sandstone (Map-unit 17) confined to the peninsula between Horwood and Gander Bays; phyllite and sheared sandstone and siltstone, minor limestone and volcanic rocks (Map-unit 18) that occurs at Horwood Bay and extends northeastward to Dog Bay Islands and composes most of the Indian Islands; and sheared grey conglomerate (map-unit 19) that outcrops on the west side of Horwood Bay and on the north side of Western Indian Island. The distribution of these map-units within the group, combined with facing directions where obtainable, do not generally support previous structural interpretations suggesting a synclinal axis at Horwood Bay and a south-facing section and Indian Islands and Yellow Fox Island (Twenhofel and Shrock, 1937; Twenhofel, 1947; Patrick, 1956; Baird, 1958). The conglomerate unit on the west shore of Horwood Bay, though highly sheared with stretched fragments, has graded beds that locally face northwest. Similarly at Western Indian Islands and nearby islands to the west, graded bedding in the conglomerates indicate tops toward the north. These relationships suggest that the conglomerate is the youngest of the Indian Islands Group and is underlain by map-units 18 and 17 respectively. The conglomerates of map-unit 19 resemble those of the Goldson Formation and if the two are equivalent then the rocks of map-units 17 and 18 represent lower units of the Silurian succession not represented in the nearby Botwood Group.

Neither the base or top of the Indian Islands Group is accurately defined. The contact between the Indian Islands Group and Botwood Group to the west is interpreted as a fault but it may be a conformable contact with the conglomerates on the west side of Horwood Bay equivalent to those of the Botwood Group at Port Albert, both exposed on opposite sides of a syncline with northeast-trending axis through Farewell Harbour. The boundary of the Indian Islands Group with the Gander Lake Group to the east is interpreted as a fault. The thickness of the rocks exposed at Indian Islands and Yellow Fox Island was estimated at 10,600 (Twenhofel, 1947) but undetected faults may occur between the islands making thickness estimates hazardous.

The rocks of the Indian Islands Group are the most deformed of all dated Silurian rocks in the map-area. Original shales and siltstones are now well-cleaved and kink-banded slate and phyllite and pebbles in conglomerate beds have been elongated to many times their original maximum dimension. Fossils have been collected locally in limestone beds but these too have been stretched or flattened. Silurian faunas have been identified by Twenhofel and Shrock (1937), Twenhofel (1947), and reported by Baird (1958). Additional Silurian collections were made by Patrick (1956) and identifications are on file in Geological Survey of Canada paleontological reports. More recently fossil determinations have been made by McKerrow and Boucot (pers. comm., 196). Fossils collected in 1963 from rocks earlier assigned to the Farewell Group (Patrick, 1956) have been identified as follows (identification by T.E. Bolton):

WF-175-63 G.S.C. locality 58322

West shore of Gander Bay, three-quarters of a mile southwest of Seal Island.

Favosites sp.
Favosites cf. F. favosus
strictlandid?

Recent collections from Goose Island have been tentatively interpreted as Upper Llandovery (A.J. Boucot, pers. comm., 196) and a sample submitted to T.T. Uyeno, Geological Survey of Canada, for conodont analysis yielded the following distorted and long ranging forms:

Hindeodella sp.
Plectospathodus ? sp.
Spathognathodus sp.

Twenhofel (1947) suggested correlation of parts of the Indian Island Group with the Goldson Formation of New World Island. This is also suggested by subsequent work although the lithologies are generally dissimilar.

Cape St. John Group

Rocks of the Cape St. John Group make up most of the northeast end of the Burlington Peninsula in the northwest part of the map-area. The rocks were first studied in the vicinity of Tilt Cove where they were assigned to the Ordovician and referred to as the 'Gross Pond and Red Cliff volcanics' (Snelgrove, 1931; Douglas, Williams, and Rove, 1940). The rocks at Tilt Cove and northward were later studied by Baird (1951) who introduced the name Cape St. John Group but followed earlier workers in assigning the rocks to the Ordovician. These workers interpreted the Cape St. John Group to conformably overlie the Lower Ordovician Headlands (previous Snooks Arm) Group and both groups were thought to pre-date the intrusion of ultramafic rocks that lie near their contact. Subsequently, Neale (1957) produced evidence to indicate that the Cape St. John Group were actually older. The recognition of these relationships removed a major obstacle to the correlation of the Cape St. John Group with lithologically similar post-Ordovician rocks of the nearby Springdale Group (Espenshade, 1937; MacLean, 1947). The Cape St. John Group was thus assigned to the Devonian, in accordance with the presumed age of the Springdale Group at that time. In later regional studies the rocks have been assigned to the Silurian (Neale and Nash, 1963; Neale, in prep.) because of reassignment of the Springdale Group following recognition of indigenous Silurian fossils in the correlative Botwood Group.

The Cape St. John Group is made up chiefly of silicic volcanic rocks with lesser mafic volcanic rocks and not more than 5 per cent sedimentary members. Also included are quartz-feldspar porphyries that in places cut the volcanic rocks or else are intricately commingled with the volcanic rocks. The stratigraphic succession of the rocks is unknown except that locally conglomerates and sandstones form the base of the succession. The thickness of the Cape St. John Group is estimated at 6,500 feet to the west of the map-area at Mic Mac Lake (Neale, in prep.).

Lithology

Sedimentary rocks of the Cape St. John Group occur near Tilt Cove and Betts Cove and consist of pale brown, greyish red, and pale grey conglomerates, sandstones, and siltstones. Primary features are well preserved locally and include cross bedding, ripple marks, grain gradation, and scour and fill structures. Mudcracks have been reported at one locality north of the Betts Cove-Tilt Cove area and another occurrence at Seal Island Bight (Neale, 1957). Clastic fragments in most of the sedimentary rocks are derived from associated volcanic rocks but also include red chert, argillite, and mafic volcanic rocks from the Headlands Group. Well-rounded granite boulders are present locally and also ultramafic rock fragments and detrital chromite (Neale, 1957). Baird (1951) has reported conglomerates of the Cape St. John Group with boulders up to 4 feet long that consist of a variety of volcanic rocks.

Silicic volcanic rocks of the Cape St. John Group include buff, pale red, brown, grey and black aphanitic and porphyritic rhyolite, trachyte, and latite flow rocks and pale red crystal lithic tuff, lapilli tuff, and agglomerate. Flow structures and spherulitic structures are common in the flow rocks and the pyroclastic rocks are made up of volcanic fragments with minor intrusive or sedimentary rock fragments. Basic volcanic rocks are comparatively rare and are mostly massive or sheared purplish grey, brownish red, and black amygdular basalts and minor andesites. Amygdules are common and the vesicule fillings are chiefly calcite and chlorite. Pillows are absent, except for local development within a few thin andesite flows.

Quartz-feldspar porphyry, commonly associated with silicic volcanic rocks, is abundant in the western part of the Cape St. John Group. The rock is pale reddish grey or pale brown to pink and consists of phenocrysts of quartz and feldspar, approximately 1/4 inch in diameter, set in a fine-grained to aphanitic felsitic groundmass. Quartz phenocrysts are commonly round with embayed boundaries and feldspar phenocrysts are euhedral. These rocks are included in the Cape St. John Group because of their close association with silicic volcanic rocks of the group.

Highly deformed and moderately metamorphosed silicic and basic meta-volcanic rocks and porphyry are included in the Cape St. John Group along the coastal area from Pacquet Harbour to La Scie. These rocksrange from banded amphibolite, to quartz-feldspar-biotite schist, meta-porphyry, coarse fragmental volcanic rocks, and minor marble. Some of the less metamorphosed rocks resemble quartz-feldspar porphyry and silicic volcanic rocks of the group in the south, others have been completely recrystalized with original features obliterated.

Structure and Metamorphism

Rocks included within the Cape St. John Group are of varied structural aspect. The style of deformation varying from isoclinally folded strata with penetrative cleavage and minor folds in the north to beds that have gentle dips and no internal fabric toward the south. These contrasting structural styles may mean that rocks of different age and different structural and metamorphic histories have been erroneously included in the same group. The lack of well-defined boundaries, however, between the rocks of different structural aspect may also be interpreted to mean that the degree of deformation increases gradually from south to north. The style of folding and degree of deformation may also reflect the competency of the rocks involved. Solutions to these problems require further work.

Recent work by Neale and Kennedy (1967) indicates that siliceous to basic tuff sequences between Grand Cove and La Scie show evidence of two phases of deformation. The first of these produced tight to isoclinal folds which trend easterly and have a related poorly developed axial plane schistosity, evidenced by preferred orientation of sericite in siliceous rocks and hornblende in basic rocks. The second deformation produced east-trending upright folds with associated non-penetrative strain slip cleavage. Toward the south the rocks are everywhere much less deformed and these structures cannot be recognized. North of Tilt Cove, a general curved outline of the group that is concave northward suggests later regional flexuring about north-trending axes.

Age and Correlation

Rocks of the Cape St. John Group are undated but they are assigned to the Silurian because of lithologic similarity to rocks of both the Springdale Group and Silurian Botwood Group. Several lines of indirect geologic evidence support this assignment. Basal members of the Cape St. John Group that are interpreted to unconformably overlie the fossiliferous Lower Ordovician Headlands (Snooks Arm) Group contain pebbles of Ordovician (?) ultramafic rocks that intrude the Headlands Group, in addition to numerous pebbles of the underlying volcanic and sedimentary rocks (Neale, 1957). West of the map-area at Flatwater Pond, other basal conglomerate members of the Cape St. John Group nonconformably overlie an altered granitic pluton that cuts the Fleur de Lys Group but is as yet of unknown relationship to nearby Ordovician (?) rocks of the Baie Verte Group (Baird, 1951). Also west of the map-area, quartz-feldspar porphyries that in places cut the Cape St. John Group volcanic rocks or are intricately commingled with the volcanic rocks are also found as fragments in basal conglomerate members of the group (Neale, in prep.). The relationship suggests conglomerate deposition, volcanism, and shallow intrusion of porphyry that were all contemporaneous in part. Similar porphyryies occur among volcanic rocks of the Silurian (?) Springdale Group that is in turn correlated lithologically with dated Silurian rocks of the Botwood Group.

Metamorphic rocks at Grand Cove were originally mapped as equivalents of the Cape St. John Group (Neale, 1958). Other workers, e.g. Church, (pers. comm., 196) questioned this interpretation and regarded the metamorphic rocks to be older and equivalent to the Fleur de Lys Group to the west. In a more recent communication, Neale and Kennedy (1957) have regarded some of the rocks west of Grand Cove as equivalent to the Fleur de Lys Group, but still maintain that others at Grand Cove and eastward to La Scie are part of the Cape St. John Group as originally assigned. The northern limit of the Cape St. John Group and structural relationships in the north remain in doubt, pending future detailed studies.