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BOTWOOD (WEST HALF) MAP-AREA NEWFOUNDLAND

(2E W½)

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H. Williams

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By

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CONTENTS

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INTRODUCTION

Botwood (west half) map-area includes most of the important copper-producing mineral belt of northeastern Newfoundland. The Tilt Cove and Little Bay copper mines are present producers, and several promising prospects are being explored. Apart from its economic aspects, the area is of geological interest for its many problems in correlation and stratigraphic nomenclature.

The purpose of this study is to integrate the results of earlier workers, to complete initial geological mapping, and to investigate the mineral deposits. Approximately 60 per cent of the area had previously been mapped geologically and the results published on a scale of 1 inch to 1 mile. During the 1961 field season the writer covered about 70 per cent of the area in reconnaissance fashion, including all previously unmapped parts. The investigation of mineral deposits remains to be done.

Physical Features

Botwood map-area is a region of moderately rugged topography. It is penetrated by long, narrow, deep arms of the sea that extend south to southwestward from Notre Dame Bay. The regional structure has had a marked control over the coastal physiography, as indicated by the alignment of many of the coastal indentations and headlands with structural trends. The coast is irregular, with many islands. An abundance of evidence indicates that it has been deeply submerged (Baird, 1951)[1].

Hills 400 to 500 feet high lie close to the coast; some of them rise almost vertically from the shoreline. The highest point (Hodges Hill, 1,870 feet above sea-level) is near the southwest corner of the map-area.

Coastal parts are more rugged than the interior, owing to differential erosion and glaciation of tightly folded heterogeneous strata. Roughly parallel ridges and steep narrow valleys are characteristic. Nearly all the high coastal areas are underlain by resistant lava flows. Valleys are underlain either by more easily eroded rocks, or zones of structural weakness. Farther inland the regions underlain by homogeneous igneous intrusive rocks have a fairly even, gently rolling surface, which in places is largely covered by muskeg.

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[1] Names and dates in parentheses refer to publications listed in the Selected Bibliography.

The entire region has been glaciated and the effects of this are reflected in the character of the landforms. Glacial striae, grooves, and roches moutonnées are common features. Drainage of the area is unsystematic and in a youthful stage of development. The largest rivers are those that empty into the uppermost reaches of the bays. Lakes and ponds are numerous and occur at practically all elevations. The larger lakes are elongate and aligned parallel to long arms of the sea.

GENERAL GEOLOGY

Consolidated rocks are chiefly and perhaps entirely of Palaeozoic age. The Mings Bight Group (map-unit 1), which outcrops near Pacquet Harbour, may be of Precambrian age for it is overlain by rocks that resemble Lower Ordovician rocks of the region. Rocks dated by fossils range in age from Early Ordovician to Middle Silurian. They are highly deformed, and the interpretation of their structure, even where outcrops are abundant, is most difficult.

Fossils are scarce in the Ordovician strata. Lower Ordovician graptolites have been reported by Snelgrove (1931) from the Snooks Arm area and a brachiopod of approximately the same age was collected by MacLean (1947) near Little Bay. Considerably more evidence supports the assignment of certain rocks to the Middle Ordovician. In the Bay of Exploits and New Bay areas, Heyl (1936, 1937) has mapped great thicknesses of sedimentary and volcanic rocks, which in places contain Chazy and Normanskill fauna. Espenshade (1937) has mapped lithologically similar rocks in the Pilleys Island area.

Rocks of Silurian age occur near the Exploits estuary. They are faulted against Ordovician rocks to the northwest, but conformably overlie Ordovician(?) rocks in the region southwest of Lewisporte. Questionable Silurian strata outcrop on Upper Black Island in Bay of Exploits, in the western part of New Bay, and on the northeastern end of the Burlington Peninsula.

Nowhere are continuous sections of Ordovician or Silurian rocks exposed. Tentative correlation is made between widely separated regions within the map-area from partial sections and limited fossil evidence.

The Middle Ordovician rocks (map-units 6-10) of the Bay of Exploits, New Bay, and Badger Bay areas are here referred to as the 'Exploits Group'[1]. In the west-central part of the map-area a major fault separates this group from volcanic and sedimentary rocks to the north. Most evidence indicates that the rocks north of the fault are Ordovician in age; probably most of them belong to the lower part of that system. In the Pilleys Island area, rocks north of the Exploits Group were named the 'Pilleys Series' by Espenshade (1937) and divided into the 'Lushs Bight' and 'Cutwell' Groups. In the Little Bay area, northwest of Halls Bay, MacLean (1947) correlated the volcanic and sedimentary rocks with those of the Lushs Bight Group. Farther north on Burlington Peninsula, several group names have been introduced to describe similar volcanic and sedimentary rocks. These are the 'Nippers Harbour Group'[2] (Baird, 1951), the 'Baie Verte Group' (Watson, 1947), and the 'Snooks Arm Group' (Snelgrove, 1931). The Snooks Arm Group is of Early Ordovician age, and the lithology of the Baie Verte Group suggests that it also is of that age.

Red sandstones (map-unit 15), conformable with fossiliferous beds of Silurian age, outcrop along the Exploits estuary and in the upper reaches of Bay of Exploits. They have been termed the 'Botwood Formation' by Twenhofel and Schrock (1937). These clastic rocks are underlain by volcanic flows (map-unit 14) and the two map-units (14, 15) are collectively referred to here as the 'Botwood Group'. Baird (1951) introduced the term 'Cape St. John Group' for rocks on the Burlington Peninsula that are here considered to be of possible Silurian age.

A great variety of intrusive rocks occurs within the map-area. These are generally younger than the layered rocks and clearly intrude and truncate structures within them. An exception to this is the sill-like body of serpentinite (map-unit 11) exposed along the contact of the Cape St. John Group and the Ordovician Snooks Arm Group. Neale (1957) has shown that clastic members of the Cape St. John Group contain pebbles of both the serpentinite and the Snooks Arm Group rocks. The serpentinite body is, therefore, considered to be of Ordovician age and pre-Cape St. John Group.

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[1] The term 'Exploits Group' is a modification of the term 'Exploits Series' introduced by Heyl (1936) to describe an assemblage of sedimentary and volcanic rocks some 12,000 feet thick in the northern part of the Bay of Exploits. Espenshade (1937) described a similar assemblage of rocks in Pilleys Island map-area, which he called the 'Badger Bay Series'. The rocks of these two areas are here correlated and collectively referred to as the 'Exploits Group'. Lithologic similarity is marked, and poorly preserved graptolites with a 'Normanskill aspect' (Espenshade, 1937) from the Badger Bay area are considered equivalent to Normanskill fauna found in similar rocks of Bay of Exploits. As the name 'Exploits' was applied first, the law of priority invalidates the name 'Badger Bay'. The term 'group' is used instead of 'series' because the upper and lower age limits of the assemblage are not defined.

[2] The rocks in this group are included with the Lushs Bight Group in this report, and the group name dropped.

The larger intrusive complexes (map-units 16, 17) are considered to be of Devonian age. They have been divided into two groups. One includes the granitic rocks (map-unit 17) and related types, which show free quartz; the other includes intermediate to basic rocks (map-unit 16), which can be referred to as diorite and gabbro. Most observations indicate that the granitic rocks are younger than the more basic varieties, but in a few places porphyritic diorite sills cut the granite, which suggests that the intermediate to basic intrusive rocks are of several ages. Furthermore, in some places diorite sills are folded along with the Ordovician layered rocks of map-unit 8, whereas, in others the structural trends of the layered rocks are truncated by the intrusive rocks.

The Palaeozoic sedimentary and volcanic rocks of Botwood map-area are many thousands of feet thick and have been subdivided in various ways by different authors. The present subdivision is based largely on age, but in places where fossils are absent, tentative lithological correlations have been made. No attempt has been made to add any new stratigraphic names to the large number that already exists.

Ordovician or Pre-Ordovician

Mings Bight Group (Map-unit 1)

This name was first used by Watson (1947) to describe a group of metamorphic rocks that extend from Pacquet Harbour westward beyond the limits of Botwood map-area. Baird (1951) estimated the thickness of the group to be about 8, 000 feet. The group consists of gneisses and schists composed essentially of quartz, feldspar, biotite, muscovite, chlorite, and hornblende, with small amounts of garnet, epidote, and magnetite. The rocks have resulted through the metamorphism of a sequence of sandstones and shales. Varieties within this group include banded gneisses, porphyroblastic augen gneiss, quartz biotite gneiss, hornblende schist and gneiss, graphitic schist, quartzite, and garnet-quartz-muscovite gneiss (Baird, 1951).

Rocks of the Mings Bight Group are overlain by volcanic rocks of the Ordovician(?) Baie Verte Group (map-unit 4). Baird (1951) suggested that an unconformity separated these two groups and the possibility that the Mings Bight Group is Precambrian. Neale (1958), however, suggested that the contact between the two groups is structurally conformable. The Mings Bight Group rocks may therefore be Ordovician—pre-Baie Verte in age—or pre-Ordovician.

Ordovician

Lushs Bight Group (Map-unit 2)

Espenshade (1937) proposed this name for volcanic flow rocks and pyroclastic rocks with minor interbedded sedimentary rocks exposed on Pilleys and Sunday Cove Islands. MacLean (1947) used the name for similar rocks farther northeast in the Little Bay area. Farther north, similar volcanic rocks that occur near Nippers Harbour were termed the 'Nippers Harbour Group' by Baird (1951), although exposures mapped along the northwest shore of Green Bay coincide with outcrops originally mapped (MacLean, 1947) as Lushs Bight Group. The term 'Nippers Harbour Group' has been dropped and rocks near Rogues and Nippers Harbours are here included in the Lushs Bight Group.

Apart from the abundant exposures of sedimentary rocks near Western Arm, most of the rocks of the Lushs Bight Group are of volcanic origin. They consist of sheared green lava, basaltic pillow lava, agglomerate, and tuff, with local interbeds of chert. Sedimentary types exposed at Western Arm are greywackes and shales, with chert, tuff, and some interbedded flows. The group is interpreted as of Early Ordovician age on the basis of the occurrence of one brachiopod shell collected by MacLean from a shale bed 4, 900 feet northwest of Clam Pond. MacLean (1947, p. 4) stated that the age of the shell "... is fairly definitely Canadian, probably Late Canadian."

Snooks Arm Group (Map-unit 3)

The Snooks Arm Group is exposed along the southeast coast of Burlington Peninsula from Beaver Cove to near Nippers Harbour. These rocks, first systematically mapped by Snelgrove (1931), form the northern limb of an easterly plunging syncline with a total thickness of approximately 12, 000 feet (Neale, 1957). The group consists of thick volcanic-flow members interlayered with sedimentary and pyroclastic units (Neale, 1957, 1958). The flows are black to green pillowed andesites and spilites, and the sedimentary rocks are green to maroon chert, black slate, green to greyish red argillite and greyish green greywacke. The pyroclastic rocks of the group are intermediate-compositioned agglomerate and tuff, which consist of andesite fragments and lesser amounts of sedimentary rock fragments. Also included in this group are diabasic leucodiorite and leucogabbro, and pyroxene porphyry. The porphyry is probably genetically related to the volcanic rocks of the group (Neale, 1958).

Graptolites found by Snelgrove (1931) establish the age of the Snooks Arm Group as Early Ordovician.

Baie Verte Group (Map-unit 4)

This term was proposed by Watson (1947) for a group of volcanic and sedimentary rocks on the Burlington Peninsula. The group consists largely of altered andesitic lavas to which the general term 'greenstone' may be applied. Interbedded with these rocks are fine-grained greywacke, tuff, agglomerate, chert, slate, and thin beds of marble. These rocks have been folded into a series of northeasterly trending anticlines and synclines.

No fossils have been found in the rocks of this group, but thick lavas and pyroclastic rocks of intermediate to basic composition, with thin interbedded marine strata, similar to rocks of the Baie Verte Group, are characteristic of the Ordovician System in Notre Dame Bay.

Cutwell Group (Map-unit 5)

Volcanic and sedimentary rocks in about equal proportions are characteristic of this group. The volcanic rocks are sheared green lava and pillow lava with coarse agglomerate and tuff horizons. Along the northeast shore of Long Island, sedimentary rocks predominate. These consist of greywacke and conglomerate with interbedded, pyrite-bearing, dark slate and cherty slate. Locally, thin limestone horizons occur within the sedimentary and volcanic rocks.

The Cutwell Group was defined by Espenshade (1937) in the Pilleys Island map-area as part of the Pilleys Series. This 'Series' consisted of the Cutwell and Lushs Bight Groups, and was correlated generally with Lower Ordovician rocks (Snooks Arm Group) of the Tilt Cove - Betts Cove area. Limited fossil evidence (MacLean, 1947) indicates an Early Ordovician age for the Lushs Bight Group. Fossils from Limestone Island, collected and identified in 1960 by L.M. Cumming of the Geological Survey, prove an Ordovician age for the Cutwell Group and strongly suggest that it may represent the lower part of the Middle Ordovician. The following fossils were identified:

Scolopodus sp. Pander
Acontiodus sp. Pander
Maclurites sp. cf. *M. logani* (Salter)
Strophomena (*Horderley ella*) sp.
(?) *Oxoplecia* sp.
(?) *Tritoechia* sp.

The Cutwell Group, therefore, is probably younger than the Lushs Bight Group and hence cannot underlie it as inferred by Espenshade (1937). The contact between the two groups on Pilleys Island is marked by a fault. The assignment of an early Middle Ordovician age to the Cutwell Group suggests that it is probably the equivalent of the volcanic rocks (map-unit 6) at the base of the Exploits Group.

Exploits Group (Map-units 6-10)

The rocks of this group underlie most of the central part of the map-area. Formations within it were originally assigned by earlier workers to two geographically separated groups, but the present reconnaissance study has indicated that the rocks form a single continuous group. Individual formations show considerable variation, but the major lithologic types are persistent across Notre Dame Bay.

The Exploits Group consists of clastic sedimentary rocks, lavas, and pyroclastic rocks. The dominant volcanic assemblages are restricted to the top and bottom of the group but numerous thin flows and pyroclastic horizons occur throughout the other parts.

A volcanic assemblage (map-unit 6) forms the base of the group in the New Bay and Badger Bay areas. It is not represented farther east in the Bay of Exploits. Espenshade (1937) referred to these rocks as the 'Wild Bight volcanics'. Green agglomerate and tuff are the most common members, followed by green lava, greyish green tuff, and chert. Thin red chert and slate beds occur at different horizons and can in places be traced over several thousand feet. Some black shale and greywacke are also known within the assemblage. North of New Bay Pond, a thick sequence of sandstone, shale, and chert (map-unit 6a) is bordered conformably by lava and pyroclastic rocks of the 'Wild Bight volcanics' (map-unit 6). It is not known whether these sedimentary rocks represent a conformable intercalation among the volcanic rocks of map-unit 6 or a synclinal remnant of younger overlying sedimentary rocks (map-unit 7). East of New Bay Pond the 'Wild Bight volcanics' contain large quantities of diorite commingled with the flow rocks. The exact age of the 'Wild Bight volcanics' is unknown as no fossils have been found in them. However, they conformably underlie rocks of Middle Ordovician age in the New Bay area.

A sequence of predominantly sedimentary rocks (map-units 7, 8) several thousand feet thick, ranging from conglomerate to shale, overlies the 'Wild Bight volcanics'. This sedimentary sequence was divided into the Hornet, Sansom, Foulke Cove, and Sivier Formations by Heyl (1936) in the Bay of Exploits area; and into the Beaver Bight, Shoal Arm, Gull Island, Julies Harbour, Burtons Head, and Crescent Lake Formations by Espenshade (1937) in the Badger Bay area. Because of the scale of mapping no attempt was made to delineate and describe these formations on the accompanying geological map.

Lithologic similarities between the Gull Island Formation of Badger Bay and the Sansom Formation of Bay of Exploits suggest that the two are stratigraphically equivalent. The Sansom Formation is of Chazy age and is overlain by beds of Normanskill age (Heyl, 1936). On the strength of this the writer has tentatively divided the sedimentary rocks of the Exploits Group into two lithologic units, namely, an older, more arenaceous group (map-unit 7) of Chazy age, and a younger, more argillaceous group (map-unit 8) of Normanskill age. Complex structures and widely separated fossil localities make the distinction between these two groups in places very approximate, particularly in the New Bay area. Appreciable thicknesses of pillow lava (map-unit 8a) occur interlayered with the sedimentary rocks of the younger argillaceous group (map-unit 8).

Volcanic rocks (map-unit 9) occurring at or near the top of the Exploits Group are predominantly basaltic and consist chiefly of massive or pillowed flows and coarse-grained basic tuffs. Espenshade (1937) termed these rocks the 'Roberts Arm volcanics' in the Pilleys Island area, and Heyl (1936) referred to similar rocks of the Bay of Exploits area as 'Breakheart basalt' and 'Mortons volcanics'. These volcanic assemblages are probably stratigraphically equivalent. Green pillowed basalt predominates, and in places is remarkably undeformed and characterized by abundant bun-shaped pillows. In some places pyroclastic rocks occur interlayered with the flows and, in other places, flows are separated by thin red chert or marble beds. Acid-flow and pyroclastic rocks are included with this assemblage on and near Pilleys Island.

In the Bay of Exploits area the top of the Exploits Group is represented by red, green, and grey bedded chert, with tuff, shale, and sandstone. This assemblage (map-unit 10), termed the 'Fortune Formation' by Heyl (1936), is not represented in exposures around Badger Bay. The formation was originally separated on the basis of relative age and lithology, but its age distinction is not definitely established. Red cherts of map-unit 10 are everywhere underlain by basic flows of map-unit 9 but in places the cherts are also overlain by basic flows.

Black shale of map-unit 10, which is exposed along the northern shore of Lawrence Harbour, contains the following graptolites (as identified by L.M. Cumming of the Geological Survey):

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

These fossils indicate a Normanskill age for the enclosing shale. The position of this shale relative to volcanic flows of map-unit 9 is not known.

Silurian

Beds of definite Silurian age have been recognized in the Botwood Group (map-units 14, 15). Sedimentary rocks (map-unit 15) of the group consist of sandstone, shale, and conglomerate. The sandstone is reddish brown to greyish pink and grey, and almost everywhere shows cross-lamination. Locally it contains red to grey conglomerate and shale interbeds. South of Norris Arm, dark grey shale and argillite is predominant. Volcanic rocks (map-unit 14) of the group are purplish green flow and pyroclastic rocks, which conformably underlie the sedimentary rocks. The contact between the sedimentary and volcanic rocks is sharp with little intermingling of the two in the contact zone. Near Exploits River the contact is marked by a thin zone of sharpstone conglomerate which contains many fragments of the underlying purplish volcanic rocks. This zone grades upward abruptly into the more typical sandstone facies of map-unit 15.

Sedimentary rocks of the Botwood Group were mapped by Twenhofel and Schrock (1937) near the head of Bay of Exploits and assigned to the Silurian System. Later, Twenhofel (1947) stated that this assignment was incorrect and that the rocks were Devonian. He based his re-interpretation largely on the fact that Silurian fossils collected from the Botwood rocks at Martin Eddy Point were contained in limestone pebbles in conglomerate, and on the assumption that the pebbles were lithified before detachment from the parent rock, making a post-Silurian age for the conglomerate seem more reasonable.

However, the present investigation of the exposures at Martin Eddy Point showed that grey shale interbedded with the limestone-pebble conglomerate was also fossiliferous, and the fossils in both the limestone pebbles in the conglomerate and the interbedded grey shale are of Silurian age. The following forms were identified by L.M. Cumming of the Geological Survey:

Fossils from limestone pebbles in conglomerate—

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

Fossils from grey shale interbedded with conglomerate—

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

Fossiliferous Silurian beds also occur south of the Trans-Canada Highway between Rattling Brook and Jumpers Brook. These beds are brittle, grey to greyish blue shale. They were not previously mapped as part of the Botwood Group, but are regionally conformable with beds of the Botwood Group to the northwest and are structurally conformable and lie along the strike of beds classified as Botwood by Hriskevitch (1950) in the Rattling Brook map-area to the south. The following Middle Silurian fossils were collected from these beds (identification by L.M. Cumming, Geological Survey):

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

The fact that certain members of the Botwood Group contain Silurian fossils whereas others are conformable with Silurian strata, renders it very probable that the entire group (map-units 14, 15) belongs to that system.

Red sandstone and conglomerate exposed on Sunday Cove, Pilleys, and Triton Islands, and referred to the Springdale Group by Espenshade (1937), are here tentatively correlated, on the basis of lithological similarities, with sedimentary rocks (map-unit 15) of the Botwood Group.

The assignment of the Cape St. John Group to the Silurian System is also tentative. These rocks were considered to be Ordovician by Baird (1951) and earlier writers. Neale (1957) suggested that the Cape St. John Group unconformably overlies rocks of Ordovician age, i.e. Snooks Arm Group. Rocks of the Cape St. John Group might, therefore, be correlated with the Botwood strata but the lithologies of the two groups are not strikingly similar. The rocks of the Cape St. John Group are rhyolites, trachytes, andesite flows and pyroclastic rocks, and water-lain tuffaceous sedimentary rocks. This assemblage is quite different from that of the Botwood Group in the map-area.

Heyl (1937) mapped certain strata (map-unit 12) as Silurian on the peninsula between Southwest Arm and Northwest Arm of New Bay. The rocks consist of coarse to fine arenaceous conglomerate, grey shale, and much quartz-rich sandstone. They are light grey and weather to various shades of brown and buff. In places interlayers of coarse conglomerate are present that contain large shale fragments and less commonly lenticular to rounded fossiliferous limestone masses. The following fossils were collected from the limestone masses and indicate a Silurian age (identification by L.M. Cumming, Geological Survey):

Favosites cf. *gothlandicus*
Zaphrentis cf. *stokesi*
Favosites sp.
(?) *Delthyris* sp.
crinoidal debris

Heyl (1937) stated that the irregular lens-like masses of limestone carrying the Silurian fossils and within the conglomerate layers were deposited in place. A sample collected by the author shows erosional truncation of a *Favosites* specimen within such a limestone mass, indicating that it is a transported block. The fossils collected, therefore, only set a lower limit to the age of these rocks. The degree of deformation of the rocks of map-unit 12 and their apparent conformity with Ordovician rocks of map-unit 8 suggest that there was no intervening orogenic break between their deposition and that of the Ordovician rocks. The Silurian(?) sandstones of the New Bay area are so similar to some Ordovician varieties that, without the aid of fossils, their distinction is most difficult.

Twenhofel and Schrock (1937) reported the occurrence of a flow breccia (map-unit 12a) containing fossiliferous Silurian limestone fragments on Upper Black Island. This breccia is therefore Silurian or post-Silurian in age. It is in fault contact with Ordovician graptolite-bearing shales on the northeast end of the island, but its relationships to the rocks on the southwestern part of the island are unknown.

Intrusive Rocks

Much of the southwestern, southeastern, and northwestern parts of Botwood (west half) map-area is underlain by granite, granodiorite, and diorite. Near North Twin Lake, South Twin Lake, and Hodges Hill, granite and diorite bodies occur in intimate association.

The granite is pink to buff and grey with hypiodiomorphic texture. The typical phase is a coarse-grained mixture of quartz, potash feldspar, and plagioclase, with lesser amounts of biotite and amphibole. The mafic constituents rarely exceed 5 per cent. Associated diorite is in places gradational with the granite and in other places cut by it. This diorite is medium to coarse grained and composed of green amphibole and plagioclase with variable amounts of quartz and biotite.

Southeast of Norris Arm a large body of intermediate to basic rocks intrudes the Silurian strata of the Botwood Group. These rocks are medium to coarse grained and massive, and consist essentially of amphibole and plagioclase in roughly equal amounts. Varieties more basic than diorite are present and there is also some associated quartz diorite, pink syenite, and granite. The relationships of these various rock types are not well known.

Several varieties of intrusive rocks occur on Burlington Peninsula in the northwestern part of the map-area. Medium- to coarse-grained massive granite (map-unit 17) is found in the northwestern and southwestern parts of the peninsula. The west-central part is underlain by the Cape Brule granite (map-unit 17a) (Baird, 1951), which is a distinctive porphyritic rock. It consists of cloudy 'eyes' of quartz and phenocrysts of feldspar set in a fine-grained greyish groundmass.

Serpentinized ultrabasic rocks (map-unit 11) form a thin arcuate belt in the Betts Cove - Tilt Cove area. Alteration to talc and carbonate is locally prominent, and primary banding is displayed in some outcrops.

The intrusive rocks of Botwood map-area are of several ages. The ultrabasic rocks and some basic dykes (included with map-unit 16) are older than the regional folding and are considered to be of Ordovician age. The larger intrusions of granite (map-unit 17) and diorite (map-unit 16) cut Silurian strata and are therefore post-Silurian in age. By analogy with radiometrically dated bodies in nearby areas, they are probably of Devonian age.

STRUCTURAL GEOLOGY

Ordovician and Silurian strata of the map-area are folded, faulted, and intruded by several kinds of plutonic rocks. The folds trend in a northeast direction and axial-plane cleavage and drag-folding are well developed in many places. The map pattern of the Middle Ordovician Exploits Group suggests the presence of a northeastward-plunging anticlinorium whose axis crosses Badger Bay, Seal Bay, and passes between Leading Tickles and Northwest Arm. Rocks of the Exploits Group are exposed on the northwestern and southeastern flanks of this structure.

Small local folds are well displayed in the sedimentary and volcanic rocks of the Exploits Group between Wild Bight and Shoal Arm of Badger Bay. There the general structure consists of two anticlines separated by a syncline whose axis lies near Beaver Bight. Dips are steep and the fold axes plunge to the northeast.

Silurian strata of the Botwood Group are folded into asymmetrical anticlines and synclines that plunge to the southwest. An anticlinal axis lies near Burnt Arm of Bay of Exploits and a corresponding synclinal axis is located to the southeast. Several minor folds were observed in well-bedded sandstones along Exploits River. The axes of these folds plunge gently toward the southwest at approximately 10 to 15 degrees. The structure of the Botwood Group is far more complicated than has been indicated by earlier workers.

Faults are a prominent structural feature of the map-area. The major faults trend in a northeast direction parallel to fold axes and topographic grain of the countryside. Transverse faults are of less importance. Little direct evidence regarding actual movements along the faults was observed.

METAMORPHISM

Most of the rocks of the area have been affected by low-grade regional metamorphism. Its effects are most pronounced in volcanic rocks of Ordovician age. The intermediate to basic lavas and pyroclastic rocks are altered to epidote, chlorite, and other minerals typical of the greenschist facies of regional metamorphism. Mineral assemblages typical of the amphibolite facies are present within volcanic rocks of the Baie Verte Group and Nippers Harbour (i.e. Lushs Bight) Group on Burlington Peninsula (Baird, 1951).

Evidence of low- to medium-grade thermal metamorphism appears in the sedimentary rocks of the Exploits and Botwood Groups near the margins of dioritic and granitic intrusions. Biotite is abundant in argillaceous rocks of the Botwood Group south of Norris Arm where they are intruded by diorite. Elsewhere biotite, and in places garnet, can be seen in rocks of the Exploits Group at their contact with large intrusive masses. Contact-metamorphic aureoles rarely exceed a few thousand feet in thickness, and high-temperature metamorphic mineral assemblages are not found.

OROGENY

The orogenic history of the map-area is obscure. Discussions bearing on the orogenic history of the Notre Dame Bay region have been presented by Heyl (1936, 1937), Espenshade (1937), MacLean (1947), Hayes (1951c), Neale (1957), and others. However, conclusive evidence for dating the various deformations is lacking. Many lines of indirect evidence have been used to demonstrate the reality of the Taconic, Caledonian, and Acadian revolutions. Angular unconformities, which furnish the most conclusive proof of earlier folding, are rare, and although such structures have been described by some authors, their reality is not accepted by others. Furthermore, no angular unconformities separating well-dated fossiliferous rocks are known.

The two major orogenic events recognized over most of the Canadian Appalachian region are the Taconic orogeny in Ordovician time and the Acadian orogeny in Devonian time (Neale et al., 1961).

Most authors state that the Notre Dame Bay region of Newfoundland was affected by two major orogenies. The youngest of these can be correlated with the Acadian, but there is some question as to whether or not the earliest deformation was Taconic (Ordovician) or Caledonian (Silurian).

The marked truncation of structure in steeply dipping Ordovician layered rocks north of North Twin and South Twin Lakes by diorite and granite intrusions, suggests that igneous intrusion post-dated the deformation of these rocks, but there is no conclusive evidence indicating that this deformation took place in either Ordovician or Silurian time. In fact it may have been pene-contemporaneous with the (Acadian?) igneous intrusions.

No evidence of an angular unconformity between Ordovician and Silurian rocks has been found in the map-area. Consequently some authors, e.g. Heyl (1936, 1937), Twenhofel and Schrock (1937), and Hayes (1951c), have suggested that the first Palaeozoic orogeny occurred at the end of the Silurian period, i.e. Caledonian. Thus, in the New Bay region, Heyl (1937) interpreted the Ordovician and Silurian strata as being structurally conformable and having identical metamorphic histories. However, there is some doubt concerning the exact location of the Ordovician - Silurian contact in this region and further work is required. In addition, there are no known post-Silurian rocks in the area whereby an upper time-limit of deformation can be established. Hence it is possible that rocks of the New Bay region have been subjected to only one (Devonian?) period of deformation.

Silurian strata of the Botwood Group appear to conformably overlie Ordovician rocks of map-unit 8 southwest of Lewisporte, but the contact has not been seen. Furthermore, it is not definitely established that the underlying rocks are of Ordovician age. An angular unconformity has been reported by Neale (1957) separating the Silurian(?) Cape St. John Group from Ordovician rocks, and another by Espenshade (1937) separating the Silurian(?) red beds of map-unit 15 on Pilleys Island from Ordovician rocks. These reports of structural differences between Ordovician and probable Silurian rocks are perhaps the best evidence for the Taconic orogeny in the map-area.

Sedimentary and volcanic rocks of the Botwood Group appear to be much less metamorphosed than Ordovician beds. In addition, the difference of the types of sedimentary rocks in the Botwood Group from those in the Ordovician formations suggests a major change in environment of deposition. Twenhofel (1947) has pointed out that the Silurian formations of northern Newfoundland contain large amounts of coarse clastic material indicating uplift and rapid erosion of the source areas in Late Ordovician or Early Silurian time. This uplift might readily be attributed to the Taconic orogeny. Also noteworthy is the apparent lack of Upper Ordovician strata in the Notre Dame Bay region, which suggests a major time-hiatus.

Most evidence suggests a period of uplift during Late Ordovician or Early Silurian time, but there is no proof that the uplift was accompanied by widespread folding, which could be related to the Taconic orogeny. Nor can the proponents of Caledonian orogeny set an upper limit to it that would eliminate the Acadian orogeny as a possibility for the first Palaeozoic deformation. R.R. Potter (personal communication) suggested that some Ordovician rocks within certain narrow belts in Notre Dame Bay were folded during the Taconic orogeny, but that others were unaffected. Localization of deformation may well explain some otherwise conflicting observations and inferences.

ECONOMIC GEOLOGY

The map-area lies within the Central Mineral Belt of Newfoundland (Snelgrove, 1928), a northeast-trending strip of mineralized country stretching from the southwest coast of the island to Notre Dame Bay. A great variety of mineral deposits is known within the map-area (Douglas, Rove and Williams, 1940). Chalcopyrite is the commonest economic mineral, but occurrences of gold, sphalerite, galena, chalcocite, pyrrhotite, arsenopyrite, bismuthinite, stibnite, manganese, hematite, and asbestos have also been reported. Most of the mineral deposits are of the pyrite-chalcopyrite type and are localized in sheared lava and related volcanic rocks of the region. Although the list of mineral occurrences within the area is impressive, the only presently producing mines are at Tilt Cove and Little Bay; both have recently resumed production after long periods of dormancy. Pilleys Island pyrite mine is the most important past producer. Most of the other mineral occurrences were not subjected to more than exploratory stages of development.

The Tilt Cove copper mine, Newfoundland's largest producer of copper, was discovered in 1857 and active mining began in 1864. The mine was closed in 1917 and lay dormant until 1954 when Maritime Mining Corp. Ltd. began development work (Donoghue, Adams and Harpur, 1959). Several new orebodies were established by diamond-drilling, and mine development and shaft sinking started in early 1956. Construction was completed in August 1957 and production started at a rate of 1,500 tons per day. Chalcopyrite, the chief ore mineral, occurs with pyrite, usually replacing it to some extent. The host rocks for the orebody are highly chloritized, sheared, and brecciated andesitic pillow lavas and pyroclastic rocks of the Snooks Arm Group. The ore occurs as either massive sulphide deposits or as disseminated stockworks of pyrite and chalcopyrite.

The Little Bay deposit was discovered in 1878 and was worked until 1892. During its long period of dormancy, diamond-drilling was conducted by several companies in anticipation of reopening the mine. The property was acquired by Atlantic Coast Copper Corp. Ltd. in 1957 and production started in May 1961. The initial production rate of 600 tons per day is to be increased to 1,000 tons per day. The ore occurs as lenses and pods of chalcopyrite in chlorite schist and as veins of quartz carrying pyrite and chalcopyrite. The region is underlain by highly altered, sheared pillow lava of the Lushs

Bight Group. The mine occurs in one of several shear zones that lie in an en échelon arrangement about 3,000 feet from a through-going fault.

The two presently producing mines in the map-area and most of the mineral occurrences and prospects are located along the coast. This distribution probably results from more detailed prospecting in these readily accessible areas. Recently, several interesting prospects have been discovered inland, notably southwest of Crescent Lake, where New Jersey Zinc and British Newfoundland Exploration Co. began drilling operations in the summer of 1961.

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