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TWILLINGATE MAP-AREA, NEWFOUNDLAND
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H. Williams

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TWILLINGATE MAP-AREA, NEWFOUNDLAND (2E/10)

By

H. Williams

DEPARTMENT OF

MINES AND TECHNICAL SURVEYS

CANADA

CONTENTS

	Page
Introduction	1
Physical features	1
General geology	2
Table of formations	4
Ordovician	5
Northern belt (Snooks Arm and/or Lushs Bight Group) (Map-units 1-3)	6
Central belt (Map-units 4-7)	7
Southern belt (Map-units 4 and 7)	9
Silurian and possibly Ordovician (Map-unit 8)	11
Silurian	12
Central belt (Map-units 9 and 10)	13
Southern belt (Map-unit 9)	16
Port Albert Peninsula (Map-units 9, 11, and 12)	18
Ordovician-Silurian relationships	20
Intrusive rocks	22
Intermediate to basic intrusions (Map-unit 13)	22
Granodiorite (Map-unit 14)	22
Porphyritic granodiorite (Map-unit 15)	23
Dyke rocks	23
Age of intrusive rocks	23
Structural geology	24
Faults	24
Folds	26
Economic geology	27
References	28

Map 33-1963 Twillingate Map-area, Newfoundland .... in pocket

TWILLINGATE MAP-AREA, NEWFOUNDLAND

INTRODUCTION

Twillingate map-area of Notre Dame Bay, Newfoundland, has long been of geological interest as a principal locality for the Silurian rocks of northeastern Newfoundland and it presents many problems in stratigraphic and structural geology. Economic interest centres mainly around limestone deposits at Cobbs Arm, but several base-metal prospects and abandoned mines are known in the northwestern part of the area. The purpose of this work has been to integrate the results of earlier workers, to prepare a map of the area, and to study the stratigraphy, with particular attention to Ordovician-Silurian relationships.

The first published geological studies within the map-area were made almost 100 years ago by Murray and Howley of the Geological Survey of Newfoundland. Since that time the area has been visited intermittently by geologists, including those on the Princeton University expeditions during 1916 to 1918, Twenhofel and Shrock (1937)[1], Heyl (1936), Twenhofel (1947), Baird (1953), and Williams (1957). The eastern half of the map-area and parts of the western half were mapped by T.O.H. Patrick for the Geological Survey of Canada from 1953 to 1955. His field maps, notes, and collections were made available to the author.

Professor Marshall Kay of Columbia University visited the area in 1961 and again in 1962. During the latter year the author had several field trips with Professor Kay and is grateful for the fruitful conversations and correspondence that followed. The present field work was carried out during 6 weeks of the 1962 season. It involved reconnaissance mapping and fossil collecting wherever possible in the map-area. The author is indebted to B.A. Greene, D.W. Capstick, J.M. Purves, and W. Ryan for assistance in the field.

Physical Features

The map-area consists essentially of two large islands—New World and South Twillingate—and a multitude of smaller ones. The Port Albert Peninsula in the southeastern corner is part of the mainland of northeastern Newfoundland.

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[1] Dates or names and dates in parentheses refer to publications listed in the References.

The coastline of the larger islands is very irregular and deeply penetrated by embayments and arms of the sea, up to 5 miles long. Along the northern shores of the Twillingate Islands and the northwestern shore of New World Island, resistant volcanic and thick conglomerate formations and granite form prominent cliffs, which in places exceed 100 feet in elevation. Southeastward along Dildo Run and Port Albert Peninsula, the land surface is underlain by shale and sandstone with minor volcanic rocks, and the coastal slopes are gentle.

Inland the region is of moderate relief with an irregular hummocky topography. Tops of hills are generally 100 feet or less above the levels of nearby lakes, but in a few places relief is greater than 200 feet. Throughout the northwest peninsula of New World Island and Black Island, hills exceeding 300 feet lie within 1/4 mile of the shoreline. The highest point in the area, elevation 398 feet, is southeast of Bridgeport Harbour.

Most of New World Island, the larger islands of Dildo Run, and the Port Albert Peninsula are covered by spruce trees that are small and closely intergrown. Twillingate Islands and the northeastern extremities of New World Island are practically bare. Small lakes occur throughout New World Island and are in general aligned parallel to bedrock structural patterns.

The rugged interior of New World Island has resulted from glaciation and differential erosion of underlying rocks varying in resistance. Thick conglomerates form prominent ridges or headlands and volcanic terranes are characterized by alternating steep hills and narrow valleys. Slates and sandstones underlie the more gently rolling southeastern parts of the map-area. Longitudinal faults, which are prominent structural features, are marked by persistent valleys, lakes, and long arms of the sea. The entire area has been affected by glacial ice which moved generally northward.

GENERAL GEOLOGY

Ordovician and Silurian sedimentary and volcanic rocks of Twillingate map-area have been folded, faulted, and intruded by igneous rocks of varying compositions. Structures reflect the northeasterly trend that is common throughout most of Newfoundland, but an additional north-south trend is apparent in the volcanic rocks of Twillingate Islands and northwestern New World Island.

Regional faults dissect the area into four main northeast-trending belts, as follows:

(1) Northern belt — northwest of Luke's Arm fault;

(2) Central belt — bounded by Luke's Arm fault and Cobbs Arm fault;

(3) Southern belt — bounded by Cobbs Arm fault and an inferred fault (not shown on the accompanying map), passing between Dunnage Island and Port Albert Peninsula; and

(4) Port Albert Peninsula.

Rocks of the northern belt are altered green volcanic rocks (map-unit 1) with interbedded chert (map-unit 2) and clastic sedimentary rocks (map-unit 3), all intruded by granodiorite (map-unit 14). Their age is not definitely known and they cannot be correlated with rocks of the other belts. In the central and southern belts the rocks are dated by fossils and are of Ordovician and Silurian age. They consist of volcanic rocks (map-unit 4) and sedimentary sequences (map-units 5-9), which can be correlated generally from one belt to the other. All rocks on Port Albert Peninsula are tentatively assigned to the Silurian System. They include thick-set conglomerates (map-unit 9) with interbedded quartzite (map-unit 9b) overlain by a dominantly volcanic assemblage (map-unit 11) and grey quartzitic sandstone (map-unit 12).

Individual Ordovician and Silurian formations are unusually persistent along strike for this part of northeastern Newfoundland. Most can be recognized and mapped over the entire 20-mile length of New World Island. Top determinations, lithology, and map-patterns indicate that the overturned Ordovician-Silurian section exposed between Dildo Run and Cobbs Arm in the southern belt is repeated between Cobbs Arm and Herring Head in the central belt. Ordovician rocks at Little Byrne Cove are considered to be another faulted repetition of these strata.

The islands in Dildo Run and Dunnage Island are underlain by Ordovician sedimentary (map-unit 7) and volcanic rocks (map-unit 4), which are intruded by porphyritic granodiorite (map-unit 15). The granodiorite is lithologically different from that of South Twillingate Island, and its isotropic texture and fresh appearance suggest it is younger.

The history of stratigraphic nomenclature and correlation in the map-area is involved and shortcomings are apparent. The present study shows that in places the Ordovician sequence as interpreted by Heyl (1936) is in error and that Silurian rocks were commonly assigned to the Ordovician. Problems of correlation and age of each of the map-units are more fully discussed in the pages that follow.

Table of Formations

Era	Period or Epoch	Group	Formation	Lithology
PALAEOZOIC	Devonian (?)		Porphyritic granodiorite (map-unit 15)	Pink to grey granodiorite with phenocrysts of plagioclase and quartz
		Not in contact		
			Granodiorite (map-unit 14)	Medium- to coarse-grained granodiorite, quartz-rich, and foliated in places with patches of blue to grey quartz. May be of Ordovician age
		Intrusive contact		
			Diorite and gabbro (map-unit 13)	Medium-grained, massive, hornblende, pyroxene, plagioclase rocks. May be in part of Ordovician age
	Intrusive contact			
	Silurian	Botwood Group	Map-unit 12	Grey to green quartzitic sandstone
			Map-unit 11	Green to black amygdaloidal lava and pyroclastic rocks
			Map-unit 10 (Includes Pike Arm Formation at Pikes Arm)	Grey fossiliferous argillite, sandstone, and silty conglomerate
			Goldson Formation (map-unit 9)	Red to grey boulder-conglomerate with sandstone and fossiliferous argillite interbeds
	Silurian and Ordovician (?)		Map-unit 8	Interbedded greywacke, pebble-conglomerate, siltstone, and argillite in alternating successive layers. At least in part of Silurian age
	Middle to Late Ordovician		Map-unit 7	Black graptolite-bearing argillite and slate, grey slate, siltstone, minor sandstone, and limestone
			Map-unit 6	Crystalline limestone
			Map-unit 5	Grey sandstone, siltstone, and argillite
			Map-unit 4	Green pillow lava and pyroclastic rocks, minor sedimentary rocks
	Early Ordovician (?)	Equivalent to Snooks Arm Group and/or Lushs Bight Group	Map-unit 3	Quartzite, siliceous argillite, chert
			Map-unit 2	Chert, siliceous argillite, minor volcanic rocks
			Map-unit 1	Altered green lava, basaltic pillow lava, pyroclastic rocks, minor chert, argillite, and quartzite

Ordovician

Ordovician rocks of the map-area occur in each of the northern, central, and southern belts as previously defined. The dominantly volcanic assemblage of the northern belt contains no fossils. Lithologic similarities to Lower Ordovician rocks west of the map-area—i.e. Snooks Arm and Lushs Bight Groups (Williams, 1962)—suggest that the assemblage belongs to the Ordovician System. In the central belt the Ordovician rocks consist of hundreds of feet of lavas and fragmental volcanic rocks (map-unit 4) with minor associated sedimentary rocks (map-unit 5) overlain by approximately 100 feet each of limestones (map-unit 6) and black slates (map-unit 7) containing upper Caradocian-Trentonian graptolites (Kay and Williams, 1963). In the southern belt the Ordovician rocks are mainly sedimentary (map-unit 7) with seemingly interlayered lavas and pyroclastic rocks (map-unit 4), which are similar to those of the central belt. The sedimentary and volcanic rocks of the central and southern belts are probably stratigraphically equivalent, because in both belts the Ordovician rocks are structurally conformable below sedimentary rocks of map-unit 8.

Heyl (1936) reported the results of his studies in the Bay of Exploits area and defined the Exploits Series[1], of Ordovician age. His work included that part of Twillingate map-area lying west of a south-trending line drawn through the central part of Luke's Arm. All rocks west of this line were referred to the Exploits Series. Heyl (1936) divided the Exploits Series into nine formations, six of which are represented in Twillingate map-area and include rocks of the northern, central, and southern belts. The lowermost Luke Arm Formation of the Exploits Series included rocks of the present map-units 4 and 8 in the southern belt at Luke's Arm and Cottle's Bay. The Luke Arm Formation was interpreted as overlain by the Hornet (present map-unit 9) and Sansom Formations (present map-unit 8) at Intricate Harbour and on Farmer Head to the south. Rocks of the northern belt, exposed in the western part of New World Island, were interpreted by Heyl as three of the uppermost formations of the Exploits Series; namely, Mortons volcanics and Breakheart basalt (present map-unit 1), and Fortune tuffs and cherts (present map-units 2 and 3). From the foregoing it is obvious that Heyl's stratigraphic interpretation is not consistent with the present study and many deviations must be reconciled.

In Twillingate map-area the author feels that it is particularly incongruous to follow Heyl's nomenclature and stratigraphic interpretation. Several shortcomings are apparent. One is that the volcanic rocks of the northern belt do not form the uppermost formations of the Ordovician section, for they are not represented in the central and southern belts where continuous Ordovician-Silurian sections are exposed. The author regards the volcanic rocks of the

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[1] Now Exploits Group (Weeks, 1955; Williams, 1962).

northern belt as generally older than Ordovician rocks farther south[1]. A second shortcoming is that the conglomerates at Intricate Harbour (map-unit 9), which Heyl (1936) referred to the Ordovician Hornet Formation, are now considered to be of Silurian age and are interpreted as overlying, rather than underlying, rocks of map-unit 8 (Heyl's "Sansom Formation"). Because of these conflicting interpretations, Ordovician rocks of the central and southern belts are unclassified in this report pending further work and possible redefinition of the Exploits Series.

Northern Belt (Snooks Arm and/or Lushs Bight Group) (Map-units 1-3)

Ordovician rocks of the northern belt are separated into three lithologic map-units. The relative ages of the units are not known but between Chanceport Harbour and Carter's Cove, rocks typical of all three appear to be interbedded in alternating successive layers.

Volcanic rocks of map-unit 1 consist of altered green lava and associated pyroclastic rocks, which are in places sheared and altered to mineral assemblages typical of the greenschist facies of regional metamorphism. In places, well-preserved black or reddish brown pillow lavas are predominant. Bedded, thick green agglomerate and other fragmental volcanic rocks are widespread near Moreton's Harbour and more deformed varieties of these rocks are represented on North Trump Island and along the western shore of South Twillingate Island.

Throughout the northwestern peninsula of New World Island the volcanic rocks of map-unit 1 include large amounts of dark, medium-grained diorite and gabbro, which occur as small plugs, dykes, and sills and are generally inseparable from the volcanic rocks on this scale of mapping. It is probable that these intrusions were associated with the volcanism. The limited occurrence of similar rocks outside the volcanic terrane supports this suggestion. All of the volcanic rocks have been folded and broken by faults, but the thickness of the assemblage is probably in excess of 2,000 feet.

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[1]The westward continuation of the rocks of the northern belt (map-units 1-3) were first regarded by the author (Williams, 1962) as being at the top of the Exploits Group, because of relationships in the Pilleys Island area (Espenshade, 1937) and the then-apparent correlation between the Badger Bay Series (Espenshade, 1937) and the Exploits Series (Heyl, 1936). However, it now appears that a misinterpretation has been made, and that the Breakheart and Mortons Formations of Heyl in his Exploits Series are older than previously suspected. It is not known whether or not the Roberts Arm volcanics (Espenshade, 1937) of the Pilleys Island area, which have generally been correlated with the Breakheart and Mortons Formations, are also older.

Cherts (map-unit 2) and clastic sedimentary rocks (map-unit 3) of the northern belt are abundant between Luke's Arm and Chanceport Harbour, where they occur in association with volcanic rocks of map-unit 1. At Chanceport Harbour and to the south, grey-green to purple and red finely bedded chert occurs with individual beds ranging in thickness from less than 1/4 inch to several feet. The rocks are mostly aphanitic in texture, but locally silty varieties are present. Similar rocks are widespread throughout the Lower (?) Ordovician volcanic assemblages of Notre Dame Bay.

Sedimentary rocks of map-unit 3 are grey- to buff-weathered quartzite with interbeds of siliceous silty argillite. Beds rarely exceed 6 inches in thickness. On Cottle's Island and nearby islands, red siliceous beds are included in map-unit 3 that are not unlike the cherts of map-unit 2. In other places the rocks of map-unit 3 closely resemble those of map-unit 8. Their relative age is unknown and they cannot be correlated with nearby sedimentary rocks of similar appearance.

Central Belt (Map-units 4-7)

Ordovician rocks are exposed along the southeastern boundary of the central belt from Duck Island on the northeast, southwestward to Luke's Arm. They include four mappable units. The lowermost, map-unit 4, comprises several hundred feet of basic volcanic rocks. These are mainly black, green, or dark red, altered basic flows, which are in places amygdaloidal and in others show pillow structure. Some pyroclastic rocks occur with the flows. These are mostly agglomerates, which appear similar to the lavas in composition.

The volcanic rocks were deposited in a lime-rich 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. The limestone is fossiliferous in a few places and serves to date the volcanism. Fossils were collected from limestone beds interlayered with flows on Duck Island and from irregular limestone patches on Boyds Island and the northwest shore of Cobbs Arm to the southwest. The following Ordovician forms were identified[1]:

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

On the northeast end of Duck Island, black slate is interlayered with the flows. The following graptolites, indicative of a

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[1] All fossil identifications are by L.M. Cumming, Geological Survey of Canada.

Middle Ordovician age, were collected:

Orthograptus whitfieldi (Hall)
Orthograptus sp.

Within the volcanic rocks between Cobbs Arm and Burnt Arm, and also at Tilt Cove, sedimentary rocks occur that consist of interbedded sandstone and siltstone or argillite (map-unit 5). These rocks are similar in appearance to types included with map-units 3 and 8. They have been distinguished as a separate unit because of their apparent interlayered relationships with the dated Ordovician volcanic rocks. It is possible that they are equivalent to map-unit 3, suggesting that the volcanic rocks of the northern belt (map-unit 1) are generally of the same age as those of the central belt (map-unit 4).

At Cobbs Arm and Squid Cove the volcanic rocks of map-unit 4 are overlain by limestones (map-unit 6) and black slates (map-unit 7). Limestones and black slates also occur near the top of the Ordovician section at Burnt Arm. In places the limestones and black slates are interlayered with the flows, but generally they form the uppermost beds of the dated Ordovician section in the central belt. Neither of these map-units (6 and 7) is thought to be continuous throughout the central belt. Discontinuity may be due to either disconnected depositional areas or erosional truncation.

The limestone (map-unit 6) is white to dark grey, medium-grained, and generally crystalline, with no apparent bedding. Fossils are rare, and those present are highly distorted. Crinoid stems are among the commonest organic remains, but distorted brachiopods and gastropods are present locally. This limestone is quarried commercially at Cobbs Arm.

Black slates (map-unit 7) conformably overlying the limestones are characteristically found at tide level along the shoreline because they are so readily eroded. The rocks are graphitic and pyrite-bearing. In some places they are argillaceous and soft, but in other places the argillaceous beds are separated by thin, hard, siliceous beds, which are essentially black cherts. Graptolites are abundant and can be collected in a number of localities where strong cleavage is not developed. Some of the localities and fauna are listed below:

Southwest head of first cove to the north of Cobbs Arm—

Orthoceras whitfieldi (Hall)
Climacograptus sp.

Southeast shore of Cobbs Arm—

Dicranograptus ramosus Hall
Orthograptus sp.

Northwest shore of Cobbs Arm opposite limestone quarry—

Dicellograptus pumilus Lapworth

One mile east of Squid Cove—

Dicranograptus ramosus Hall
Dicranograptus cyathiformis E & W

Eastern shore of Squid Cove—

Dicellograptus forchammeri Geinitz
Dicellograptus caduceus Lapworth

These forms are generally Middle or Middle to Late Ordovician.

Ordovician rocks at Little Byrne Cove are in every way identical with those of Cobbs Arm and Squid Cove. Dark green lavas predominate containing two beds of limestone, each about 3 feet thick, near the top of the section. These rocks are in turn overlain by black, graptolite-bearing argillite. The Little Byrne Cove exposures continue inland to the road that crosses New World Island, and their northeast continuation to the northwest shore of Burnt Arm is suggested by the presence of a small outcrop of green lava exposed at the shoreline in Burnt Arm. The stratigraphic relationships of the Little Byrne Cove Ordovician section with rocks of map-unit 8 to the south and Silurian conglomerates of map-unit 9a to the north, suggest that it is bounded by faults. Slickensides on the lavas at the southern contact, and tight folds in the black argillites to the north support this consideration. Orthograptus sp. collected from the black argillites at the top of the sequence suggests a Middle Ordovician age. The rocks at Little Byrne Cove are considered to be a faulted repetition of similar Ordovician rocks exposed between Cobbs Arm and Squid Cove.

Southern Belt (Map-units 4 and 7)

The stratigraphic relationships between the Ordovician rocks of the southern belt are less definite than those displayed by similar rocks of the central belt. Structures are more complex and the map-units are less continuous. In addition the rocks are intruded by porphyritic granodiorite (map-unit 15) throughout the islands of Dildo Run and locally small dioritic intrusions are known.

Sedimentary rocks (map-unit 7) occur at the top of the dated Ordovician section along the south shore of New World Island. They consist of black, pyritiferous slates, with interbedded grey slates, grey-green siltstones, and grey- to buff-weathered sandstones. A grey, crystalline limestone bed approximately 2 feet thick and similar to the Cobbs Arm limestone (map-unit 6), occurs interbedded with grey argillites on one small island of Dildo Run. Elsewhere basic to intermediate lavas and pyroclastic rocks (map-unit 4) are abundant

throughout the sedimentary rocks. The lavas contain closely spaced calcite amygdules in a few places. The pyroclastic rocks are mainly poorly bedded agglomerates.

Fossils are scarce in the Ordovician rocks of the southern belt to the east of Virgin Arm. Poorly preserved graptolites were found at only one locality, on the south shore of New World Island. They are probably equivalent to Middle or Middle to Upper Ordovician graptolites in similar rocks of the central belt.

Rocks similar to those of the central belt have been mapped southwest of Virgin Arm. Structural relationships in this area are complex and the stratigraphy has not been properly deciphered. Volcanic rocks (map-unit 4) are abundant and black slates (map-unit 7) and limestones (map-unit 6) are present locally. The following Ordovician fossils were collected:

One-half mile northwest along road from northeast head of Village Cove—

plates of *Cheirocrinus* sp.
Nicholella (?) sp.

One mile northwest along road from northeast head of Village Cove—

Orthograptus whitfieldi (Hall)
Orthograptus sp.
Orthoceras sp.
neotreme brachiopod

One-half mile east along road from southernmost head of Luke's Arm—

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

Central-south shore of Intricate Harbour—

Leptograptus sp.
Climacograptus or *Glyptograptus* sp.

Small cove on north shore of Summerford Arm, 1 mile west of Village Cove—

Orthograptus sp.

Silurian and Possibly Ordovician (Map-unit 8)

Rocks of map-unit 8 are extensive in both the central and southern belts. They are structurally conformable with overlying Silurian conglomerates and with underlying Ordovician black slates. The rocks are similar in both belts and consist of grey sandstone (greywacke) with interbedded siltstone, shale, and pebble-conglomerate. The conglomerate interbeds are similar to Silurian conglomerates and contain well-rounded pebbles of chert, quartz, and plutonic rocks, with angular pieces of grey to black slate in some places.

The contact between Ordovician black slates (map-unit 7) and rocks of map-unit 8 is abrupt in places and indicates a marked environmental change; in other places, e.g. opposite the limestone quarry in Cobbs Arm, at Squid Cove, and along the south shore of New World Island, black graptolite-bearing beds are interlayered with grey silty beds, which grade into the typical interbedded greywacke and siltstone of map-unit 8. Similar relationships are apparent between the Silurian conglomerates and beds of this map-unit. In most places, such as at Milliners Arm, the south shore of Intricate Harbour, and south of Herring Neck, greywackes of map-unit 8 change abruptly into coarse, thick-set, Silurian conglomerates, yet at Hillgrade the beds of map-unit 8 grade into coarse conglomerates (map-unit 9), which in places contain large fossiliferous coralline limestone boulders, considered to be of Silurian age.

The thickness of the rocks in map-unit 8 probably exceeds 2,000 feet, but in places it may be less and in general it is variable. The thickness apparently decreases in the southern belt from east to west with a maximum outcrop width of 9,000 feet at Milliners Arm, decreasing to 2,700 feet south of Virgin Arm. The beds dip approximately vertically, but structural complications exaggerate the true thicknesses. The attitude of bedding is generally parallel to the belts of outcrop, and dips are nearly vertical. Locally, gentle dips occur and northwestward strikes, at right angles to the belts of outcrop, have been recorded, particularly in the central belt.

It is not definitely known whether most of the rocks of map-unit 8 are of Silurian or Ordovician age. Rocks containing Silurian fossils have been mapped as representative of this map-unit, near its top, along the northwestern shore of Burnt Arm and also 1 mile northwest of Cobbs Arm on the trail to Herring Neck. The following fossils, indicating a Silurian age, have been identified:

One mile northwest of Cobbs Arm on trail to Herring Neck—

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

Northwest shore of Burnt Arm—

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

However, these relationships are confused by the occurrence of black, graptolite-bearing slates of Middle to Late Ordovician age, which are interbedded with greywackes and siltstones similar to those of map-unit 8 along the central southern shore of Intricate Harbour and also on a small peninsula 1 mile west of Village Cove in Summerford Arm. At both localities the graptolite-bearing beds are stratigraphically close to Ordovician volcanic rocks. This would suggest that the lowermost beds of map-unit 8 are of Ordovician age whereas the upper ones are Silurian, and that the Ordovician-Silurian boundary is contained within the conformable sequence of beds comprising this unit. It is equally possible that the rocks of map-unit 8 constitute a time-transgressing rock unit and that the basal part is of Ordovician age in some places and possibly Silurian in others.

Silurian

Silurian rocks are widespread throughout Twillingate map-area and are represented in the central and southern belts and on Port Albert Peninsula. Silurian beds of the central belt are dated by indigenous fossils and have been known since the early explorations of Murray and Howley (1881) of the Geological Survey of Newfoundland. They were later studied by Twenhofel and Shrock (1937). Rocks considered to be of Silurian age in the southern belt, and on Port Albert Peninsula, have not been dated by indigenous fossils, but considerable evidence favours a Silurian age.

All of the Silurian rocks are assigned to the Botwood Group (Williams, 1962), which is divided into four map-units (9-12). The Goldson Formation, defined by Twenhofel and Shrock (1937) in the central belt, comprises the lowermost map-unit (9), which also outcrops in the southern belt and on Port Albert Peninsula. Twenhofel and Shrock (1937) also defined the Pike Arm Formation at Pikes Arm in the central belt, and interpreted it to overlie the Goldson Formation. The present mapping has shown that this formation is much less continuous than the Goldson, and in places rocks of Pike Arm lithology are interlayered with Goldson conglomerates. The Pike Arm is therefore no longer considered to be of formational status and rocks originally referred to it at Fossil Point are included with map-unit 10. This is a lithologic unit with no stratigraphic significance and represents rocks of Pike Arm lithology that occur at different stratigraphic horizons throughout the Goldson Formation.

Map-units 11 and 12 exposed on Port Albert Peninsula were assigned to the Farewell Group by Patrick (1956) and Baird (1958). They are considered by the writer to be equivalent to lithologically similar map-units of the Botwood Group (Williams, 1962) in the Bay of Exploits to the southwest, and the name "Farewell Group" is therefore dropped.

Central Belt (Map-units 9 and 10)

Silurian strata of the central belt are mainly coarse, red and grey conglomerates (Goldson Formation), but include large amounts of interbedded red and grey sandstones and fossiliferous grey argillites. A thin layer of purple-green volcanic rocks, less than 100 feet thick and continuous for several hundred feet, is interlayered with the Silurian conglomerates northeastward from the northeast corner of Toogood Arm (Greens Cove). Pieces of the volcanic rocks are common in overlying conglomerate beds.

Coarse, red conglomerates of the Goldson Formation are exposed along the shoreline between Little Byrne Cove and Indian Cove and extend northeastward to Goshens Arm[1]. Similar rocks occur in the hills southeast of Toogood Arm, and along the peninsula that terminates in Herring Head. The conglomerates are probably more than 1,000 feet thick at Herring Head and contain very little sandstones or other sedimentary beds. In places they vary from dark red, to brownish, pink, or grey, and some varieties that weather red are actually grey or greenish on fresh fractured surfaces. The pebbles and boulders that make up the rocks are poorly sorted, subangular to well rounded, and surrounded by a red or grey-green matrix. A wide variety of pebbles and boulders was recognized, but the dominant types may vary considerably from place to place. They consist of numerous pink or green volcanic rocks, red and green quartzites, reddish sandstone, grey to green cherts, red chert or jasper, red shale, buff-weathered grey quartzite, and plutonic rocks such as granite and diorite. South of the canal at Herring Neck, a coarse conglomerate consists almost entirely of large, well-rounded pebbles and boulders of red hematitized gabbro, fresh pink-weathered diorite, red porphyry, and red quartzite. Elsewhere, green volcanic fragments predominate. Many of the fragments in the conglomerates are not known to outcrop within the map-area. Boulders locally exceed 1 foot in diameter but are generally less than 6 inches. Beds up to 20 feet thick near Herring Head display a crude grain gradation, indicating that they face northwest.

Grey conglomerates are as widespread as the red varieties in the central belt. The rocks contain individual beds ranging from 1 foot to a maximum of more than 20 feet. In places sandstone beds are abundant between the coarser layers and commonly

[1]Shown as Goldson Arm on older maps.

display crossbedding. Scouring and channelling are common at the base of the conglomerate beds and grain gradation is a prominent feature. A continuous section of grey conglomerate with interbedded sandstone is exposed between Pikes Arm and the first small cove to the southeast. The beds strike between north and northeasterly and dip steeply toward the southeast. Top determinations by the writer indicated that they face consistently northwestward and are overturned. Unless the succession is repeated by undetected longitudinal faults, the thickness of the coarse, clastic assemblage is more than 3,000 feet. Fragments within the grey conglomerates are rounded and generally smaller than in the red varieties; a few coarse varieties, however, contain rounded boulders up to 1 foot in diameter and angular slabs of shale, some of which exceed 2 feet in length. Fragments recognized within the grey conglomerates are as follows; grey-green chert, granite, quartz, several types of volcanic rocks, jasper, grey- to buff-weathered grey quartzite, grey to black argillites, grey sandstone, coralline limestone, and red shale or argillite. Chert pebbles are generally predominant, but are rarely the largest fragments present. Although the abundance of types of fragments varies and several may be absent in any one locality, the grey conglomerate is typically polymictic.

At the southeastern entrance of Pikes Arm, several of the conglomerate beds contain conspicuous, fossiliferous, coralline limestone fragments and an abundance of angular grey argillite fragments. Both the limestone and argillite are similar to coralline limestone growths and grey argillites occurring in nearby Silurian interbeds. The angularity of the argillite fragments and the presence of the easily destructible limestone fragments confirm a nearby source. Other examples of sedimentary cannibalism are common throughout the Silurian rocks in the region.

Fossils are known within the sandy matrix of the grey conglomerates, particularly at the southeastern head of Goshens Arm, but are not as well preserved as similar forms in nearby argillites. The general Silurian age for the conglomerates is best established by interbedded fossiliferous argillites.

Argillites and sandstones are exposed at Fossil Point of Pikes Arm, southwest of Toogood Arm, on Burnt Island, and in the southwest head of Goshens Arm. At Fossil Point, dark grey argillites alternate with grey siltstone and sandstone interbeds. The argillites contain abundant fossils and coralline limestone nodules. Fossil collections from these and similar rocks throughout the central belt include the following forms, which indicate a Silurian, and in places, a Middle Silurian age.

Fossil Point of Pikes Arm—

Pentamerus oblongus Sowerby
Encrinurus anticostiensis Twenhofel
Halysites catenularia (Linnaeus)
Zaphrentis stokesi Edwards and Haime

Calymene sp.
Hyolithes sp.

Southern headland at entrance to Pikes Arm—

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

Southwest end of Herring Head Peninsula—

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

Burnt Island to north of headland separating Burnt and Goshens Arms—

Goldsonia burntensis S & T
Orthoceras sp.
Zaphrentis sp.
Encrinurus sp.
Favosites
Halysites
Coelospira hemispherica (Sowerby)
Rhynocospira (?) sp.

Southeast shore of Toogood Arm—

Encrinurus sp.
Heliolites sp.
Paleofavosites sp.

Northeast end of Burnt Arm—

Coelospira sp.
Favosites sp.
Heliolites sp.

Southwest head of Goshens Arm—

Encrinurus anticostiensis Twenhofel
Leptaena sp.
Halysites sp.
?Delthyris sp.
Zaphrentis stokesi E & H

Southeast shore of Goshens Arm, 1 mile west of Toogood Arm—

Encrinurus anticostiensis Twenhofel
Zaphrentis stokesi E & H
Bumastus sp.
Fenestella sp.
Lingula sp.

Additional faunal lists and measured stratigraphic sections are reported in Twenhofel and Shrock (1937).

On Burnt Island of Goshens Arm, several hundred feet of medium to coarse red sandstones outcrop along the northwestern and southern shores. The rocks consist of quartz grains in a red hematitized matrix and in outward appearance they look almost exactly like certain varieties of red sandstones from the Botwood Group of Exploits Bay and the Springdale Group of the Pilleys Island area (Williams, 1962). Bedding is pronounced, but cross-lamination, so apparent in the Botwood and Springdale beds, is not developed. Twenhofel and Shrock (1937) reported the occurrence of numerous echinoderm columnals and a few brachiopods and corals in these red sandstones.

The relationships between the red and grey conglomerates, the fossiliferous argillites, and the red sandstones, are in doubt. The grey conglomerates are generally older, as they occur in several places structurally conformable above underlying beds of map-unit 8. However, at least partial contemporaneity is indicated between some of the rock types, because coarse red conglomerates exposed between Little Byrne and Indian Coves seem to pass laterally into the grey varieties exposed at the southwest head of Goshens Arm. Elsewhere, fossiliferous argillites, similar to those of the Pike Arm Formation (Twenhofel and Shrock, 1937), occur interlayered with grey conglomerates, and locally, argillite fragments occur within the conglomerate.

Brownish and reddish weathered conglomerates and sandstones, outcropping at Carter's Cove, and on the headland forming the western entrance to Virgin Arm, are lithologically similar to Silurian beds of the central belt to the east. Locally the conglomerates contain pebbles of grey limestone. These rocks are considered to be the southwestern continuation of Silurian rocks of the central belt.

Southern Belt (Map-unit 9)

Grey conglomerates of the southern belt outcrop continuously from Jack's Island to Intricate Harbour. They are lithologically similar to grey conglomerates of the central belt and at Intricate Harbour they contain coralline limestone boulders, which may be of Silurian age. Unlike the Goldson conglomerates of the central belt, with which they are correlated, these conglomerates do not

contain fossiliferous argillite interbeds, and both red conglomerates and red sandstones are absent.

On Jack's Island and along the shoreline to the southwest, the conglomerate sequence is more than 2,000 feet thick. The beds have an orange to reddish or buff colour on the weathered surface, but the matrix of the rock is grey. Abundant well-rounded fragments of pink granite up to 1 foot in diameter are prominent near Milliners Arm, and locally coarse beds contain angular argillite or siltstone fragments measuring 2 feet in length. Coralline limestone boulders in conglomerates exposed on the south shore of Intricate Harbour in places exceed 5 feet in diameter, although few are more than 1 foot. The limestone fragments are restricted to the coarser beds and are invariably accompanied by large angular fragments of grey argillite and siltstone.

Typical polymictic conglomerates of the southern belt were stated by Heyl (1936) to be of Chazy (Middle Ordovician) age on rather tenuous fossil evidence where they outcrop at the mouth of Intricate Harbour. From a limestone boulder within the conglomerate he collected the brachiopod Dalmanella and a pygidium of the trilobite Encrinurus. Neither of these genera is restricted to the Ordovician; in fact both occur in Silurian beds elsewhere in Notre Dame Bay (Twenhofel and Shrock, 1937; Williams, 1962). Also, the fossils at Intricate Harbour are in boulders and only serve to give a lower limit for the age of the enclosing rock.

Most evidence indicates that the fossiliferous limestone boulders in polymictic conglomerates of the southern belt are Silurian and that the boulders were not derived from Ordovician limestones (map-unit 6) that outcrop in the map-area. The Ordovician limestone is medium to coarse grained, crystalline, and generally unfossiliferous, whereas the limestone boulders in the conglomerate are fine grained, sugary textured, and typically fossiliferous. In places they are composed entirely of coral growths, which indicate an organic reef origin. This possibly represents a different environment of deposition from the Ordovician limestones, which are associated with pillow lava and are overlain by black graptolite-bearing slates. Fossils collected from limestone boulders in polymictic conglomerates on the south shore of Intricate Harbour include:

Favosites sp.
Paleofavosites sp.
Fossopora Etheridge or Billingsaria
Heliolites (?) sp.
fragments of a large rugose coral

The following forms were collected from similar conglomerates near Hillgrade:

Catenipora sp.
Diplophyllum (?) sp.

Although these forms do not definitely indicate a Silurian age, most are typical of the Silurian and are unknown in Ordovician limestones of the map-area.

During the field season of 1962 the author observed coralline limestone of Silurian age along Salmon Pond Brook, a tributary of Gander River, south of Twillingate map-area. This limestone is lithologically similar to the limestone boulders of the polymictic conglomerates of the southern belt of New World Island and contains one of the same fossil forms, i.e. Favosites sp. Therefore the fossiliferous limestone boulders in the conglomerates on New World Island are most likely Silurian in age.

The lithological similarities between the conglomerates of the southern belt and known Silurian conglomerates of the central belt, together with their similar stratigraphic positions in the different belts, favours a Silurian age for the former and supports the correlation proposed.

Silty conglomerate is closely associated with polymictic conglomerate at the north entrance to Intricate Harbour. Heyl (1936, p. 6) considered the silty conglomerate to be Chazy and stratigraphically below the polymictic type. The Chazy age was based solely upon the presence of the brachiopod Cristiania. Brachiopods from the same rocks were recently studied by Professor Alwyn Williams, The Queen's University, Belfast (Marshall Kay, pers. comm.) and interpreted as Late Ordovician (Ashgillian). Fossils collected by the author from the same locality include the following:

Encrinurus sp.
Calopoecia sp.
Zaphrentis sp.

According to L.M. Cumming they are rather indeterminate and represent either Late Ordovician or Silurian.

The detailed structural and stratigraphic relationships at this locality are in doubt and definite conclusions must await further work. The silty conglomerate is of local extent and has not been shown separately on the map accompanying this report.

Port Albert Peninsula (Map-units 9, 11, 12)

Three lithologically distinct map-units are recognized in rocks of Port Albert Peninsula. The lowest unit (9) consists of grey conglomerate with much interbedded sandstone and quartzite (9b); it is overlain by sheared green amygdaloidal lavas and pyroclastic rocks (11),

which are in turn overlain by buff-weathered, green or grey, cross-bedded sandstones (12). The lowest unit (9) is probably equivalent to Silurian rocks of New World Island, but because the volcanic rocks (11) and the upper sedimentary unit (12) are not represented in the Silurian of New World Island, they are tentatively regarded as younger.

Coarse conglomerates of map-unit 9 are exposed along Beaver Cove and the northwestern shore of Little Beaver Cove at the settlement of Port Albert. The rocks are badly sheared, and originally-round pebbles are represented by discoidal forms which are cigar-shaped in plan with a length-to-width ratio in places exceeding 10 to 1. Fragments in the rocks include grey chert, sheared and greasy siltstone, red jasper, quartz, granite, and a variety of acid to intermediate volcanic rocks. At Beaver Cove the rocks contain elongated, fossiliferous limestone slabs, whereas at Port Albert the conglomerate contains locally abundant fragments of buff-weathered limestone and buff quartzite or conglomerate. The dominantly conglomeratic rocks are not more than a few hundred feet thick and are separated by interbedded sandstones or sequences of sandstones and siltstones. The lithological similarities between the Port Albert conglomerates and the Silurian conglomerates of New World Island are not striking, but the apparent dissimilarity is largely caused by the much higher degree of deformation displayed by the Port Albert rocks.

Rocks of map-unit 11 are mainly green to black, amygdaloidal lava, with lesser amounts of green tuff, and minor agglomerate. They are restricted chiefly to a distinct belt that extends southwestward from Little Beaver Cove, but similar volcanic rocks occur locally interbedded with sedimentary rocks of map-units 9 and 12. Grey- to buff-weathered green sandstone of map-unit 12 apparently overlies the volcanic rocks of map-unit 11. Bedding in the sandstones is gently dipping and the axis of a small syncline bearing northeastward along Farewell Harbour is indicated. The rocks are similar in appearance to some grey and green sandstones or quartzites of the Botwood Group (Williams, 1962).

In the past, lower Palaeozoic rocks of northeastern Newfoundland were generally assigned to the Ordovician System, particularly where volcanic rocks were present. The presence of Silurian rocks was admitted only where contained fossils demanded it. Accordingly, Twenhofel (1947) described a measured section of sedimentary and volcanic rocks (map-units 9 and 11) at Port Albert on the northwest shore of the peninsula as representative of Ordovician strata. As they are here considered to be Silurian (for reasons stated below), it is rather ironic that they were primarily described "in order that the striking differences in the rocks of the two systems (Ordovician and Silurian) may be shown" (Twenhofel, 1947, p. 66). Baird (1958) mapped the northeastward continuation of the Port Albert rocks as the Farewell Group and tentatively assigned them to the Ordovician. A Silurian age is mainly based on the presence of fossiliferous limestone fragments in conglomerates at Beaver Cove.

The age of the limestone is not known, but it is similar to Silurian limestone elsewhere in northeastern Newfoundland, and the poorly preserved fossil forms (corals and crinoidal debris) are not unlike those found in Silurian rocks. The fact that similar limestone fragments occur in known Silurian conglomerates throughout northeastern Newfoundland supports this conclusion.

Recent mapping suggests that the rocks of Port Albert Peninsula are continuous with the Silurian Botwood Group to the southwest, and that the succession of conglomerates (map-unit 9), volcanic rocks (map-unit 11) and sandstones (map-unit 12) correlates approximately with the same rock units of the Botwood Group south of Lewisporte.

Ordovician-Silurian Relationships

The relationship between the Ordovician and Silurian rocks of northeastern Newfoundland is a major, unsolved, stratigraphical problem. Two factors combine to obscure the relations. First, the rocks of both systems are highly deformed, and the interpretation of structure, even where outcrops are abundant, is most difficult. Secondly, most of the Ordovician and Silurian rocks are unfossiliferous. In many places where fossils do occur, deformation has destroyed much of the detail; in other places, the fossil-bearing strata are bounded by faults and thus the fossils only serve to date the beds that contain them.

Bearing upon the Ordovician-Silurian relationships is the interpretation of orogenic history and, specifically, the reality and extent of Taconic (Ordovician) orogeny, which was apparently widespread throughout the Canadian Appalachians (Neale, et al., 1961). Two opposing views have been expressed, which bear directly upon the problem. Heyl (1936, 1937) and Twenhofel and Shrock (1937) considered the Ordovician and Silurian rocks of northeastern Newfoundland to form an apparently continuous and conformable succession with no intervening orogenic break. Espenshade (1937), Patrick (1956), Neale (1957)and Neale and Nash (1963) thought it more likely that the deposition of the Ordovician and Silurian rocks was interrupted by Taconic orogeny in Ordovician time. However, it should be pointed out that these views were not based upon comparisons between well-dated Ordovician and Silurian rocks, and, at least in some cases, the ages assigned to these rocks have been subsequently changed.

Neither of the above views furnishes a unique solution to the Ordovician-Silurian relationships displayed in Twillingate map-area, but both have certain merits. Whether a combination of the theories is logical or tenable remains to be determined. The major difficulty in setting up an attractive hypothesis is encountered when one tries to relate the apparent structural conformity between the rocks of the two systems with abundant evidence that implies uplift and erosion of Ordovician rocks before or during deposition of the Silurian beds.

The well-dated Ordovician rocks consist of basic pillow lava with lenses of Maclurites-bearing limestones and overlying beds of graptolite-bearing, black, pyritiferous slate. These rocks are typical of a deep-water marine environment. In contrast, the Silurian rocks are characterized by great thicknesses of coarse red to grey conglomerate with associated fossiliferous argillite and red sandstones. These represent a very different environment. In the map-area the rocks typical of the two systems are separated by structurally conformable greywacke, pebble-conglomerate, and silty beds of map-unit 8.

Locally, on the southeast shore of Cobbs Arm, black slate containing Ordovician graptolites (map-unit 7) is overlain by beds of greywacke, argillite, and silty conglomerate, which contain the following Silurian fossils:

Heliolites sp.
Halysites sp.
Favosites sp.
Catenipora sp.
Zaphrentis stokesi E & H
Pentamerus sp.

This is the only locality in the map-area where well-dated Ordovician and Silurian rocks occur in other than fault contact. The Silurian conglomerate has angular fragments of black graptolitic Ordovician slate. The slate fragments were apparently indurated at the time the conglomerate was formed and derived from a nearby source, yet in the area of exposure there is a general parallelism between the Ordovician and Silurian beds. This relationship is displayed in a local area bounded by faults. The position of the Silurian beds relative to those of map-unit 8, which overlies the Ordovician rocks elsewhere, is not known.

The general impression of the author is that the Ordovician rocks must have been locally thrown up into welts, which lay outside the present belts of outcrop. The earliest movements affecting the Ordovician rocks and responsible for changing the environment of deposition are probably to be correlated with the Taconic orogeny of the Canadian Appalachians. However, crustal instability continued throughout much of Silurian time. This is indicated by the orogenic nature of Silurian conglomerates, and by evidence of both sedimentary cannibalism and contemporaneous volcanism.

The following sequence of events may have some bearing on the situation. Ordovician time ended with uplifts in certain areas, probably accompanied by granite intrusion, and shoaling of the seas in others. Clastic beds of map-unit 8 were deposited in the still submerged parts of the basin and Silurian(?) limestone reefs grew at the margins of the shoals and near the uplifted Ordovician areas. Further, more pronounced uplift exposed the limestones and underlying Ordovician rocks and rapid erosion caused the deposition of the thick Silurian clastic assemblages in the still shoal or submerged parts of the basin. Thrust faulting, climactic folding (Acadian?), and granite

intrusion were later events.

Intrusive Rocks

A wide variety of intrusive rocks occurs within the map-area, but only the larger bodies are shown on the accompanying geological map. Granitic rocks are the most widespread, but locally, as on the northwestern peninsula of New World Island, diorite and gabbro are common. An assortment of acidic to basic dykes occurs in widely separated localities.

Intermediate to Basic Intrusions (Map-unit 13)

Intermediate to basic dykes and irregular small intrusive bodies are known in widely separated localities throughout most of the region, but are much more common in the northwestern part of the map-area where they occur in association with volcanic rocks of map-unit 1. Most of those bodies are small and irregular, and have not been outlined on the accompanying geological map. The rocks are dark grey to greenish black, medium to fine grained, and massive. The coarser varieties appear to be composed essentially of amphibole and plagioclase, and the finer-grained types closely resemble some of the coarse flow rocks with which they are associated.

Granodiorite (Map-unit 14)

An acidic intrusive body of batholithic dimensions underlies most of South Twillingate Island, the adjacent northwestern shoreline of New World Island, and smaller offshore islands in the vicinity. It is rich in grey to bluish quartz (30-50%) and soda plagioclase (40-60%), and notably deficient in potash feldspar (0-10%). It is best referred to as granodiorite. The rock is massive to foliated, of medium to coarse grain, and weathered to various shades of grey or pink. Mafic constituents are not abundant.

As seen in thin section the rock is deformed and altered. Quartz occurs as highly strained aggregates of anhedral crystals with crenulated boundaries. Commonly, several crystals within an aggregate are large and surrounded by smaller seriate grains, which have apparently originated through crushing and recrystallization. The plagioclase (mainly oligoclase) is commonly much altered, but less deformed than quartz. Biotite and amphibole are altered to green or colourless chlorite and aggregates of chlorite and epidote. Magnetite is a minor accessory.

Foliated, fine-grained rocks, mineralogically similar to the granodiorite on South Twillingate Island, occur at the southeastern tip of South Trump Island. The rocks are near the projection of the Luke Arm fault across Friday Bay and are thought to be a cataclastic phase of the granodiorite. Elsewhere to the north on South Trump Island the granodiorite is well foliated.

The granodiorite of South Twillingate Island is in places contaminated with inclusions or screens of dark plagioclase-amphibole rock, particularly near its contacts. Most of these may represent inclusions of Ordovician basic volcanic rocks of map-unit 1, some others may be derived from basic dykes. The granodiorite is restricted to the northern belt and is bounded by and gradational with volcanic rocks over most of its exposed contacts. The volcanic rocks are metamorphosed at the contacts and represented by mineral assemblages in which amphibole and plagioclase predominate.

Porphyritic Granodiorite (Map-unit 15)

Small plugs and stocks of porphyritic granodiorite occur throughout the islands of Dildo Run cutting Ordovician rocks of map-units 4 and 7. The rocks weather buff to grey and pink, and are grey on fresh surfaces. Phenocrysts of grey plagioclase feldspar up to 1/4 inch in diameter are prominent, along with deeply embayed phenocrysts of quartz which are generally smaller, less abundant than plagioclase, and about 1/8 inch in diameter. The phenocrysts are surrounded by a grey, fine-grained to aphanitic groundmass consisting of granular quartz and feldspar. Mafic minerals are subordinate. Amphibole phenocrysts, partly altered to chlorite and carbonate, are prominent. Laths of chlorite, pseudomorphous after amphibole or biotite, are aligned parallel to the boundaries of the larger quartz and feldspar phenocrysts, suggesting flowage. Accessory minerals are magnetite and apatite.

Dyke Rocks

Most of the dyke rocks are not shown on the accompanying geological map because of scale limitations. Compositionally, they range from acidic to basic or ultrabasic, and include such rock types as granite, micropegmatite, diorite, gabbro, and lamprophyres. All of these are minor in areal extent. Their chronological sequence is not known. Dykes of felsite, gabbro, and lamprophyre cut the granodiorite on South Twillingate Island and Silurian sedimentary rocks. The lamprophyre dykes are post-orogenic and are probably the youngest intrusive rocks within the map-area. Heyl (1936) has given detailed petrographic descriptions and chemical compositions of some of the dyke rocks.

Age of Intrusive Rocks

Granitic rocks of the map-area are of several ages. The granodiorite on South Twillingate Island cuts basic volcanic rocks (map-unit 1) that are thought to be Early Ordovician, but apparently does not cut Ordovician or Silurian rocks southeast of the Lukes Arm fault. The granodiorite (map-unit 14) is highly deformed and its contacts are parallel to structures in the country rocks. These features suggest that it is pre-tectonic and older than other granitic rocks (e.g. map-unit 15), which are fresh, massive, and crosscutting.

Granite boulders are common throughout the Silurian Goldson Formation and indicate that granitic rocks were under erosion at the time the conglomerates were accumulating. No Precambrian rocks are known in the immediate vicinity, which suggests that granitic boulders within the Silurian conglomerates are probably of Ordovician age. It is possible that some of these boulders were derived from varieties of the granodiorite on South Twillingate Island or similar bodies.

The porphyritic granodiorite in Dildo Run (map-unit 15) cuts Ordovician volcanic rocks (map-unit 4) and black slates (map-unit 7), and acidic dykes correlated with it cut the tentative Silurian rocks of Port Albert Peninsula. This granodiorite has not been physically deformed and is considered post-orogenic and probably Devonian.

Basic intrusive rocks of map-unit 13 are spatially associated with volcanic rocks of map-unit 1 and are probably in part contemporaneous with the Ordovician volcanism. However, similar rocks occur as dykes cutting the Twillingate granodiorite and are known elsewhere throughout Notre Dame Bay to cut Silurian rocks. It would appear then that the basic intrusions are of several ages.

Most of the dyke rocks within the map-area are known to cut Silurian rocks and are therefore of post-Silurian age. Many of them, in particular the basic lamprophyres, are remarkably fresh and undeformed, indicating that they are among the youngest of the intrusive rocks.

STRUCTURAL GEOLOGY

Faults and folds are numerous in Twillingate map-area and are developed extensively on both large and small scales. Longitudinal faults that dissect the area into northeast-trending belts are the most prominent structural features. At least two periods of faulting and one of folding can be distinguished.

Faults

Regional faults are reflected in topography, especially by long arms of the sea, lakes, and depressions. They have a dominantly northeasterly trend and are either parallel to the stratigraphic units or cut them at acute angles. There is little direct evidence on the attitudes of the fault planes and the absolute movements along them. Most of the faults are straight, suggesting steep dips, and those that cross the stratigraphic units display a consistent left-hand strike separation.

The most prominent fault in the area is the Lukes Arm fault, which strikes northeasterly from Luke's Arm to Carter's Cove

and across Friday Bay to Indian Cove and Goshens Arm. Its overland course is marked by topographic depressions, which are connected by submarine chasms. Structural and stratigraphic discontinuity is pronounced across the break, and shearing and brecciation are apparent in most places. The fault is continuous for more than 20 miles across the map-area and, according to Heyl (1936), persists for at least another 20 miles to the southwest.

North-northeasterly-trending faults, best displayed at Burnt and Virgin Arms, are probably related to the Lukes Arm fault. Displacement of the Ordovician volcanic rocks of map-unit 4 in the central belt is consistently toward the southwest as the rocks are followed southwesterly across the faults. The fault passing through Burnt Arm has a strike separation of more than 1 mile in the north, but this vanishes southwestward. There is no indication that the Lukes Arm fault or the north-northeasterly-striking faults displace one another, thus contemporaneity is suggested. The faults displace steeply dipping beds and therefore postdate the folding. Abnormal shearing in the Twillingate granodiorite, exposed on the southeastern tip of South Trump Island, is most likely related to movement along the Lukes Arm fault, which is therefore indicated to be younger than the granodiorite intrusion.

A major southwest-northeast regional fault has been inferred between Cobbs Arm and Luke's Arm along the contact of Ordovician volcanic rocks (map-unit 4) and Silurian conglomerates (map-unit 9) in the central belt. This fault is not reflected in the topography, but stratigraphic evidence for it is strong. The overturned Ordovician-Silurian stratigraphic section, exposed between Dildo Run and Cobbs Arm, is repeated between Cobbs Arm and Herring Neck, and at Cobbs Arm northwest-facing Silurian conglomerates are in contact with Ordovician volcanic rocks to the north. The boundary between the Ordovician and Silurian rocks must therefore be faulted. The significance of this fault in the structural development of the area, the attitude of the fault plane, and absolute movement along it, are completely open to conjecture. Another structural break of similar nature must separate the Ordovician rocks at Little Byrne Cove from rocks of map-unit 8 to the south because of similar stratigraphic discontinuity; and, as the Ordovician rocks are followed northward by Silurian conglomerates, and rocks of map-unit 8 are missing, then the Ordovician rocks must also be faulted along their northern boundary.

The fault that marks the Ordovician-Silurian boundary through Cobbs Arm is considered to be older than the Lukes Arm and associated faults and probably predates or is contemporaneous with climactic folding. It is offset by faults that pass through Burnt and Virgin Arms, and its undulating trace at the surface indicates a different tectonic style, in contrast to the sharp, linear, later faults. The continuity of the Ordovician and Silurian map-units on both sides of the break further suggests that it originated before the rocks were folded. The author prefers to consider this as a thrust fault, whereon the Ordovician and Silurian rocks exposed between Cobbs Arm and

Herring Neck were moved northwestward from their place of deposition. The repeated section was subsequently tilted and overturned to the northwest. In accord with this interpretation, the Ordovician rocks at Little Byrne Cove can be viewed as another, smaller thrust sheet, which overrode the main thrust sheet.

A regionally significant fault may strike northeasterly between Dunnage Island and the northwest shore of Port Albert Peninsula. It is not exposed and its nature is unknown. Its presence is inferred on stratigraphic discontinuity and topography.

Folds

Folding was apparently of less importance than faulting in the structural evolution of the map-area. A regional northeast-plunging anticline, probably modified by faulting, occupies the southeastern part of the area, with its axis near Dildo Run. Small synclines occur to the southeast of Toogood Arm and near Farewell Harbour on Port Albert Peninsula. Southeast of the Lukes Arm fault, fold axes trend northeasterly and generally plunge toward the northeast; on the northwest side of the fault the dominant structural trend is between north and north-northeasterly, with fold structures less well defined. Different structural trends on the northwest side of the Lukes Arm fault are probably connected with the presence of the Twillingate granodiorite. That the structural trends are related to the batholith is supported by the observation that bedding and foliation in the volcanic rocks of map-unit 1 are usually parallel to the contacts.

The distribution of Ordovician and Silurian rocks and the attitudes of bedding indicate a northeasterly plunging anticlinal structure in the southeastern part of the map-area. Ordovician rocks of Dildo Run are followed to the northwest by rocks of map-unit 8 and then by Silurian conglomerates. To the southeast, the Ordovician rocks are followed by Silurian beds of the Port Albert Peninsula. Northwest of Dildo Run the beds dip steeply southeasterly and are overturned; to the southeast, the Silurian rocks generally dip southeastward and are upright. These features are in harmony with an anticlinal structure plunging northeastward and overturned to the northwest. Correlation of the map-units along the separated limbs of the fold is not obvious. Facies changes or faulting may explain this circumstance.

The local fold southeast of Toogood Arm is indicated by arcuate ridges of conglomerate. The structure is topographically distinct, but local attitudes in the crestal areas of the fold are variable and both northeast and southwest plunges are indicated. Regional relationships indicate that the fold is an overturned syncline and its plunge must therefore be northeastward. The axis of the fold is offset along a fault that trends southerly from the southernmost cove in Pikes Arm. The structure is also truncated to the northwest by a possible continuation of the Burnt Arm fault passing between Toogood and Pikes Arms.

The syncline at Farewell Harbour is an upright asymmetrical one. This is a local fold within the Silurian rocks which regionally constitute the southeast limb of a northeasterly plunging anticline. Bedding at Farewell Harbour is gently dipping to horizontal, indicating a gentle plunge for the local structure. The direction of plunge is unknown.

ECONOMIC GEOLOGY

A few abandoned mines, operated shortly before the turn of the century, and several base-metal prospects are known within the map-area. These are all located northwest of the Lukes Arm fault in volcanic rocks of map-unit 1. Southeast of the fault the rocks appear less favourable for base-metal mineralization, and limestone is the chief material of economic interest. At Cobbs Arm an irregular bed of limestone supports a quarrying operation. Several abandoned quarries are located in the general vicinity. One gold prospect, Taylors Room (Heyl, 1936), is known at Moreton's Harbour.

Most of the prospects have been described in detail by Heyl (1936) and Douglas, Rove and Williams (1940), and a summary of the data is provided by Snelgrove and Baird (1953). For the history of development, production, and detailed geology of the mineralized areas the reader is referred to these authors. The following are the names of the prospects and the minerals associated with each:

Moreton's Harbour Antimony Deposit—
Stibnite, arsenopyrite, pyrite, sphalerite, galena, minor chalcopyrite.

Little Harbour Arsenic Mine –
Arsenopyrite, minor pyrite, sphalerite, chalcopyrite, stibnite.

Bridgeport Chalcopyrite Deposit –
Chalcopyrite, pyrite, magnetite.

Taylors Room Gold Prospect –
Arsenopyrite, sphalerite, galena, chalcopyrite, pyrite, pyrrhotite, minor gold (not visible).

Wild Cove Copper Prospect –
Pyrite, chalcopyrite, sphalerite, galena.

Sleepy Cove Prospect –
Chalcopyrite, pyrite.

Cobbs Arm Pyrite Prospect –
Pyrite.

Economic limestone deposits of the area are localized within the thin belt of Ordovician rocks that strikes southwestward from Cobbs Arm to Luke's Arm and Cottle's Bay. The stratigraphic position of the major limestone lenses is well defined, for the lenses occur above the Ordovician volcanic rocks of map-unit 4 and below black slates of map-unit 7. Smaller bodies are known within the volcanic rocks.

Limestone lenses occur above the volcanic rocks at Cobbs Arm and similar occurrences are known at Burnt Arm, Squid Cove, and on the south shore of Cottle's Bay. Most of them are small, of low relief, and found at tide level, thus making quarrying impracticable. The largest known bodies are at Cobbs Arm, where one steeply dipping lens (about 100 feet thick) extends approximately 100 feet above sea-level and 2,000 feet along strike. It is presently being quarried. Probably 500,000 tons of quarryable limestone remains in this deposit. Quarryable limestone above sea-level throughout this general area is in the order of 2 million tons.

The present quarrying operation is small, with an annual production generally less than 15,000 tons. The limestone is transported to Botwood by water, then by rail to the paper mills at Grand Falls.

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