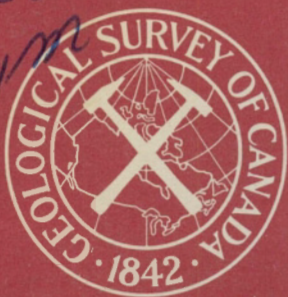


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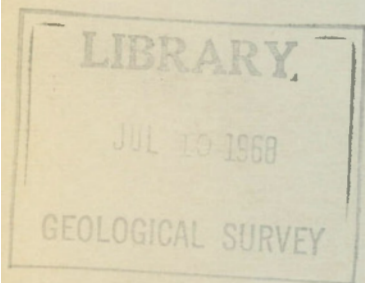
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MEMOIR 341

WHITBOURNE MAP-AREA,
NEWFOUNDLAND

W. D. McCartney



Price, \$3.50

1967

WHITBOURNE MAP-AREA, NEWFOUNDLAND

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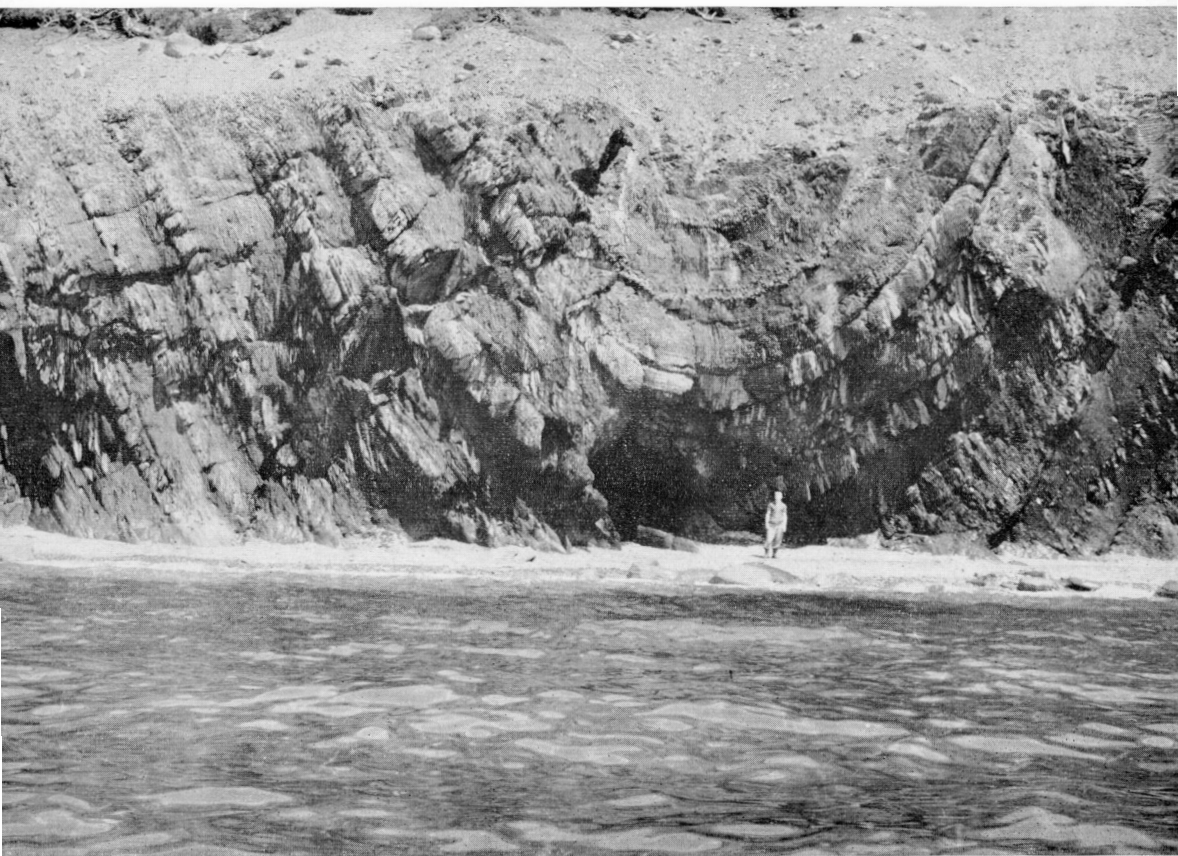
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PLATE I. *Uppermost Middle Cambrian slate and siltstone forming a syncline
1 mile south of Long Point, eastern Trinity Bay.*



GEOLOGICAL SURVEY
OF CANADA

MEMOIR 341

WHITBOURNE MAP-AREA, NEWFOUNDLAND

By
W. D. McCartney

DEPARTMENT OF
ENERGY, MINES AND RESOURCES

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Price subject to change without notice

ROGER DUHAMEL, F.R.S.C.
Queen's Printer and Controller of Stationery
Ottawa, Canada
1967

PREFACE

Many aspects of the geology of Avalon Peninsula, Newfoundland, have been studied since the pioneer work of Jukes in 1839. These studies have been largely motivated by economic interest in iron or base metals, or by palaeontological interest in the excellently preserved, fossiliferous Cambrian strata.

This report, which deals with the central and western sections of the peninsula, completes part of a systematic study of the Island of Newfoundland, pursued by the Geological Survey of Canada since 1949. It includes much new information on late Precambrian stratigraphy and correlations, on structural patterns, and on the many low-grade manganese deposits in Avalon Peninsula. The report is accompanied by a coloured geological map with diagrammatic cross-sections on a scale of 1 inch to 4 miles.

J. M. HARRISON,
Director, Geological Survey of Canada

OTTAWA, March 1, 1963

MEMOIR 341: Die Geologie des Kartenblatts Whitbourne (Neufundland).

Von W. R. McCartney

Eine Beschreibung der präkambrischen und frühpaläozoischen Gesteine im zentralen und westlichen Teil der Avalon-Halbinsel im östlichen Neufundland. Die meisten Gesteine sind offen gefaltete klastische Sedimentgesteine und so gut wie unmetamorphisiert. Das Gebiet enthält geringfügige Vorkommen an Mangankarbonat, unedlen Metallen und Baryt.

МЕМУАР 341: Геология листа геологической карты Уитбурн, остров Ньюфаундланд.

В. Д. Мэккартней

Описываются докембрийские и ранние палеозойские породы центральной и западной части полуострова Авалон, восточный Ньюфаундланд. В большинстве случаев они представлены кlastическими породами, смятыми в пологие складки и практически неметаморфизованными. Район содержит незначительные месторождения родохрозита, металлов и барита.

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WHITBOURNE MAP-AREA, NEWFOUNDLAND

Abstract

Late Precambrian and Palaeozoic sedimentary, volcanic, and plutonic rocks of Avalon Peninsula, Newfoundland, represent the most eastern exposed flank of the Appalachian folded belt. The oldest rocks, which form the Harbour Main Group, are subaerial andesitic to rhyolitic volcanics and intercalated sediments dated by H. W. Fairbairn as 568 ± 29 m.y. These volcanics, which are cut by Holyrood granitic rocks 574 ± 11 m.y. in age are overlain unconformably by about 7,000 feet of siltstones and greywackes of the Conception and equivalent Connecting Point Groups. In the west, Bull Arm volcanics overlying Connecting Point rocks are dated by Fairbairn as 494 ± 30 m.y. North-trending horsts were formed near the east and west boundaries of the area in later Precambrian time and contributed detritus to the intervening shallow basin. The arkosic Hodgewater Group, deposited in shallow water in the central basin, changes facies to the west across the regional north-northeasterly structural trend to become the more clastic sediments of the Musgravetown Group, deposited on Bull Arm volcanics in a dominantly deltaic environment. These arkosic rocks are overlain with minor discordance by thin beds of white quartzite of the Random Formation, overlain in turn by Lower Cambrian shales and limestone comprising pre-*Callavia*, *Callavia*, and *Protolenus* faunal zones. On the eastern horst, however, Lower Cambrian beds lie with angular unconformity on rocks of the Harbour Main and Conception Groups, and non-conformably on Holyrood granite. Middle and Upper Cambrian shales and slates and Lower Ordovician shales, sandstones, and oolitic iron ores are the youngest sediments exposed. Three granitic stocks were emplaced in the west in post-Cambrian, probably Devonian, time.

A major system of tear faults near the Isthmus of Avalon was formed in post-Lower Ordovician time. Large movements on north-trending faults occurred in Precambrian (post-Conception) time. Folds are upright and open over most of the map-area and the rocks are practically unmetamorphosed.

Low-grade Middle Cambrian manganiferous carbonate and slate beds discovered in southern Trinity Bay are less likely to be of future value than equivalent beds in Conception Bay. Lead, lead-zinc-silver, and barite veins in the map-area are of doubtful, though possible, economic value.

Résumé

Les roches sédimentaires, volcaniques et plutoniques du Précambrien supérieur et du Paléozoïque de la presqu'île Avalon, à Terre-Neuve, représentent le flanc exposé le plus oriental de la zone plissée des Appalaches. Les plus vieilles roches formant le groupe de Harbour Main comprennent des andésites subaériennes et des roches volcaniques rhyolitiques associées à des sédiments intercalés; selon Fairbairn, elles remontent à 568 ± 29 millions

d'années. Ces roches volcaniques, coupées par des roches granitiques Holyrood (574 ± 11 millions d'années), sont recouvertes en discordance par environ 7,000 pieds de siltstone et de grauwackes du groupe de Conception et des groupes équivalents de Connecting Point. À l'ouest, les roches volcaniques de Bull Arm qui recouvrent les roches de Connecting Point remontent, selon Fairbairn, à 494 ± 30 millions d'années. Les horsts à direction nord ont été formés près des limites est et ouest de la région au cours du Précambrien supérieur et ont donné des détritiques au bassin peu profond se trouvant à cet endroit. Les roches à arkose du groupe de Hodgewater, déposées en eau peu profonde dans le bassin central, changent de faciès à l'ouest à travers la direction structurale régionale nord-nord-est pour devenir les roches sédimentaires plus clastiques du groupe de Musgravetown, déposées sur les roches volcaniques de Bull Arm dans un milieu en prédominance deltaïque. Ces roches à arkose sont recouvertes, avec de faibles discordances, de minces couches de quartzite blanc de la formation de Random recouverte à son tour par des schistes et des calcaires du Cambrien inférieur qui comprennent les régions fauniques pré-*Callavia*, *Callavia*, et *Protolenus*. Sur le horst oriental, cependant, les couches du Cambrien inférieur reposent en discordance angulaire sur les roches des groupes de Harbour Main et de Conception et de façon non concordante sur le granite Holyrood. Les schistes et les ardoises du Cambrien moyen et supérieur de même que les schistes, les grès et les minerais de fer oolitiques de l'Ordovicien inférieur comptent parmi les plus jeunes sédiments qui affleurent. Trois massifs granitiques ont été mis en place à l'ouest après le Cambrien, probablement au cours du Dévonien.

Un réseau principal de failles de décrochement près de l'isthme d'Avalon s'est formé après l'Ordovicien inférieur, mais de grands mouvements de failles à direction nord se sont produits au cours du Précambrien (postérieurs au groupe de Conception). Les plis sont droits et ouverts sur toute l'étendue de la région et les roches, à peu près non métamorphisées.

Des carbonates à manganèse de qualité inférieure du Cambrien moyen et des couches d'ardoise découverts dans le sud de la baie Trinité ont vraisemblablement moins de valeur que les couches équivalentes de la baie Conception. Les filons de plomb, de plomb-zinc-argent et de barytine de la région seraient d'une valeur économique douteuse.

Chapter I

INTRODUCTION

Location and Access

Whitbourne map-area comprises about 2,700 square miles of land between north latitudes $47^{\circ}00'$ and $48^{\circ}00'$ and west longitudes $53^{\circ}00'$ and $54^{\circ}10'$ on Avalon Peninsula, southeastern Newfoundland (Fig. 1). This report deals mainly with the structure, stratigraphy, and petrology of the practically unmetamorphosed Precambrian and Cambrian rocks in this area.

The Trans-Canada highway from St. John's, 16 miles east of the map-area, constructed after completion of geological field work in the area, extends from the east border of the map-area near Round Pond to Grand Pond. An older paved road passes through most coastal villages in southern Conception Bay and extends north along the west shore of Conception Bay to Carbonear. Gravel roads provide access to much of the area, except along the west shore of St. Mary's Bay. In suitable weather all parts of the coast may be reached by small boats. The main Canadian National Railways line to St. John's passes through the map-area, with branch lines running north from Brigus Junction to Carbonear and southwest from Placentia Junction to Argentia. Air Canada operates scheduled flights to St. John's, about 25 miles northeast of Holyrood.

Previous Geological Work

Much has been learned about the general geology of the Avalon Peninsula from the first work of J. B. Jukes in 1839 and 1840 (1843), and from subsequent regional studies by A. Murray in 1868 and Murray and J. P. Howley between 1869 and 1883. Notable contributions were their reports of 1868, 1869, 1872, and 1881. These studies culminated in a map of Avalon Peninsula, published in 1881, which outlined the lithological subdivisions and structure of the region (Murray and Howley, 1881b).

Jukes subdivided the rocks into two formations equivalent to the Precambrian sedimentary rocks and the early Palaeozoic beds, with two subdivisions in each formation that correspond roughly to the Conception, Hodgewater, Cambrian, and

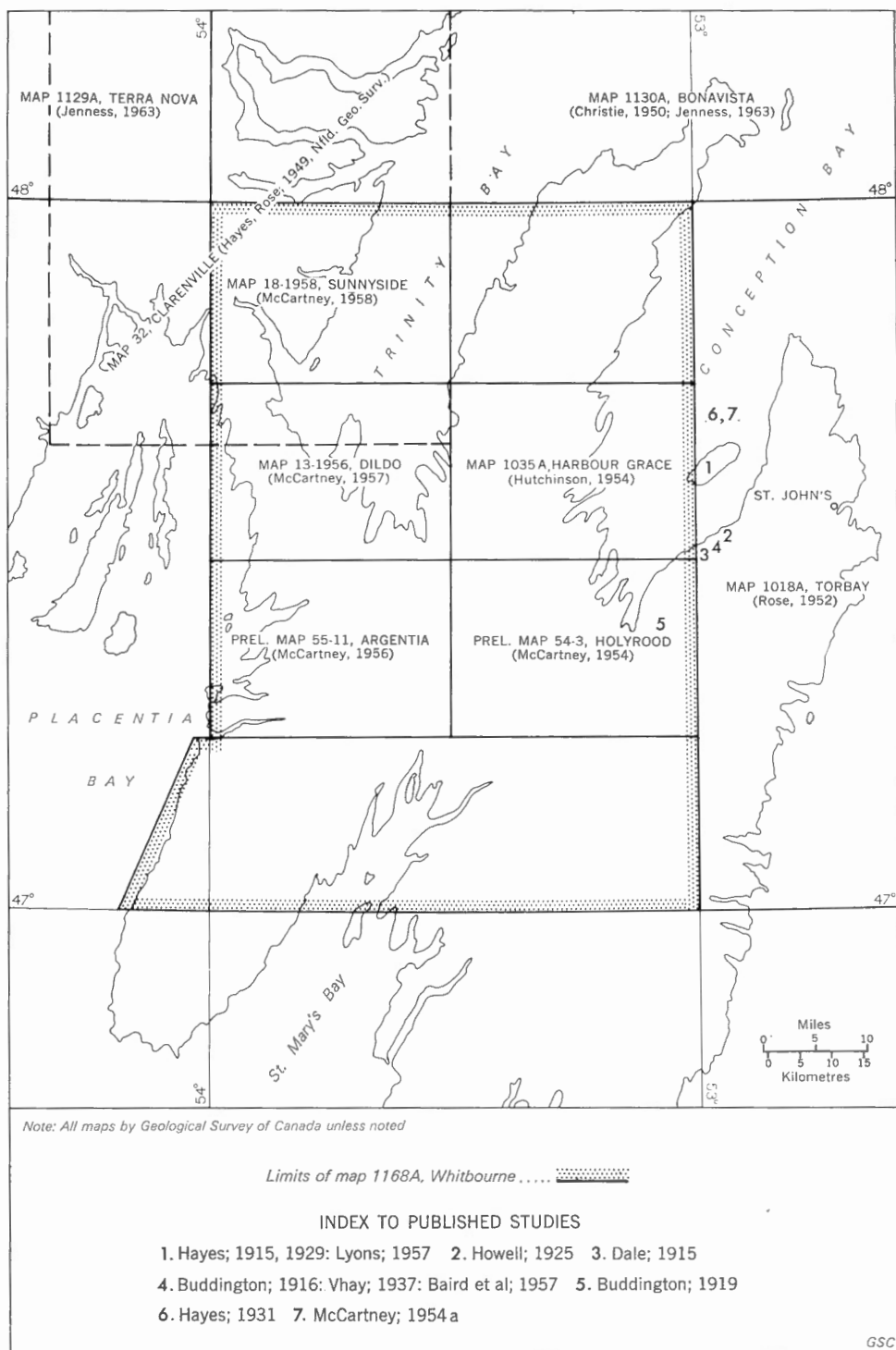


FIGURE 1. Index map showing locations of Whitbourne map-area and other published geological maps and studies, Avalon Peninsula.

Ordovician beds of the present report. The volcanic and granitic rocks were shown together on Jukes' geological map as areas of intrusive rocks.

Murray and Howley (1881b) recognized the major lithostratigraphic units of Jukes and subdivided his Lower Slate (Precambrian sediments) into four units that, in the east-central part of this map-area, correspond generally to the Conception Group and to the Carbonear, Halls Town, and Whiteway Formations of the Hodge-water Group. They did not recognize the position of rocks of the Snows Pond Formation, and error was introduced due to faulty lithological correlation with the older Carbonear Formation. They subdivided the igneous rocks of this area into a "Laurentian gneiss, etc." division, which crudely represents the main areas of granitic rocks; and a "metamorphic slates and sandstones, etc." division, which corresponds to the Harbour Main volcanic Group in this map-area.

Walcott (1899, pp. 218–220) proposed the term "Avalon Terrane" for the Precambrian sedimentary rocks lying above the "Archean gneisses" (Harbour Main Group), and introduced the names Conception and Torbay slates for the lower two formations of the 'series'.

Work on the Cambrian and Lower Ordovician rocks, as summarized in detail by Howell (1925, pp. 11–19, Table 1), includes notable contributions by Murray and Howley (1881a, pp. 156–157, p. 237), Matthew (1886, 1896, 1899), Walcott (1888; 1891, p. 548; 1900b, pp. 304, 316), and Van Ingen (1914). Howell's work in Newfoundland from 1912 to 1914, as a member of the Princeton expeditions, and a separate study in 1919 resulted in his detailed description of the Cambrian section at Manuels River (1925).

A. F. Buddington, also a member of the Princeton expeditions, clarified the relations and petrology of the Precambrian plutonic and volcanic rocks (1916, 1919).

Other Princeton workers included N. C. Dale, who described the mangani-ferous Cambrian beds at Kelligrews River and elsewhere (1915) and A. O. Hayes, who studied the iron ores of Wabana Island (1915, 1929) and later considered the structural geology of Conception Bay (1931).

This early work was generally of either a broad reconnaissance or a detailed nature, and nearly half a century passed after the publication of Howley's geological map of Newfoundland (1907) before a mapping program was designed to coordinate and augment this information. E. R. Rose (1952) began to meet this need in his study of Torbay map-area east of the present area (Fig. 1). He redefined the Precambrian rocks and, while generally following the subdivisions of earlier workers, presented a sound cornerstone for the mapping program now in progress. R. D. Hutchinson (1953) contributed much to the Precambrian stratigraphy, and, in conjunction with the writer's work, published a description of the newly named Hodge-water Group and its formations. These formations correspond to some of those shown by Murray and Howley (1881b), and are probably equivalent, in part at least, to those of Rose (1952).

Present Study

The writer was engaged in field work in this area during the summer months of 1951-55 and 1957 (Fig. 1). Holyrood map-area was examined in 1951 and 1952, Argentia map-area in 1953 and a few weeks of 1954, and Dildo map-area in 1954 and early 1955. The results were published as preliminary maps on a scale of 1 inch to 1 mile (McCartney, 1954b, 1956, 1957) and, together with the earlier map of Harbour Grace area (Hutchinson, 1953), provided geological coverage for the central half of the area covered by the present report. A map of the northwest one-eighth of Whitbourne map-area was subsequently published, also on a scale of 1 inch to 1 mile (McCartney, 1958), to show the unusually well-exposed features there. Other parts of Whitbourne map-area were mapped in 1955 and 1957 at the 1 inch to 4 mile scale required for the present publication.

Topographic maps recently published by the Surveys and Mapping Branch, of the Department of Mines and Technical Surveys, Ottawa, formed the base-maps for the writer's geological work. Air photographs were made available in 1952 through the National Air Photographic Library, Topographical Survey, Ottawa. A 4-wheel drive universal jeep, trailer, prospector canoe, and 22-foot freighter canoe with outboard motor were the principal modes of transportation. Shore-line traverses were conducted only during periods of ideal weather. Coastal work in each season was planned where possible for late June to mid-August.

Acknowledgments

The writer was ably assisted in the field by J. H. McKillop, K. A. Ewing, D. H. Magnusson, and K. J. Stewart in 1951; G. Grindley, C. Gourley, and C. R. McLeod in 1952; R. E. Seavoy, M. Pollard, A. C. Grant, J. Boyd, G. L. Sawyer, and C. R. McLeod in 1953; C. R. McLeod, A. C. Grant, W. McPherson, and J. Boyd in 1954; C. R. McLeod, H. E. Gebhardt, W. D. Smith, and T. H. Scantlebury in 1955; and V. G. Milne, W. W. Hutchison, R. I. McPherson, and F. Benoite in 1957. Pleasant and informative discussions in the field and office were enjoyed with L. J. Weeks, R. D. Hutchinson, E. P. Henderson, and S. E. Jenness of the Geological Survey, and with D. M. Baird, former Provincial Geologist. C. K. Howse, former Deputy Minister of the Newfoundland Department of Mines and Resources, was most cooperative. The writer is grateful to Professor M. P. Billings of Harvard University for helpful suggestions during the preparation of this report.

Courtesies were extended by many residents of the Avalon Peninsula, and the writer is particularly indebted to Mr. and Mrs. R. Chancey, Dr. and Mrs. D. M. Baird, and Mr. and Mrs. F. Didham for the hospitality shown on many occasions.

General Character of the Region

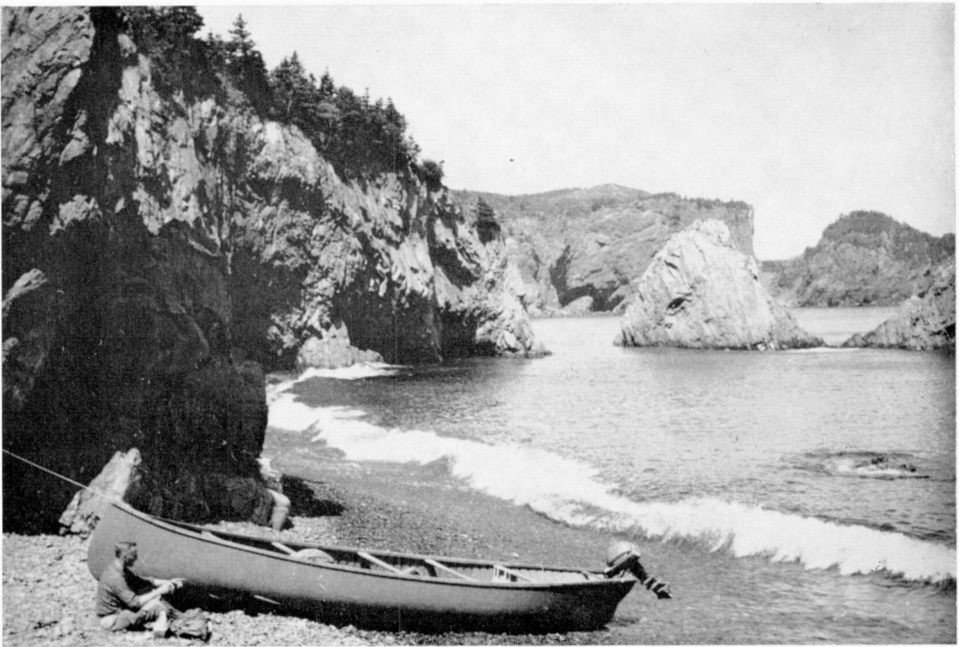
Topography

Bedrock geology in large part controls the topography of the area. The most irregular topographic features are underlain by volcanic rocks that form numerous

knobs, massive hills, and offshore rocks and reefs (Pls. II, III). These features are generally restricted in the western part of the map-area to the Bull Arm Formation, in the central part to the Chapel Cove Member of the Manuels River Formation, and in the eastern part to the volcanic rocks of the Harbour Main Group. Centre Hill (elevation 1,133), the highest point in the map-area, and several hills about 1,000 feet high are underlain by these rocks. The Holyrood granitic rocks underlie a boulder-strewn highland near the east border of the area, generally forming rounder hills than do the volcanic rocks within the granite and around its margins. The Holyrood Butter Pot (elevation about 1,020 feet), capped by a layer of quartz gabbro, is higher and has a steeper slope than most nearby granite hills. Cambrian shales and slates, commonly mantled by glacial deposits, underlie the low, gently rolling coastal areas near southeast Conception Bay and Bull Arm, Trinity Bay. Elongate strike ridges underlain by Precambrian sedimentary rocks are commonly smoothed due to glacial abrasion and in some areas are mantled by till. The wide valley connecting St. Mary's and Trinity Bays, including the valley of Rocky River, shows few outcrops other than those in stream beds, and is less than 200 feet above sea-level at the height of land near Whitbourne.

Glacial Features

Pleistocene and Recent deposits of this area were studied from 1957 to 1959 by E. P. Henderson (1960) and glacial features of a large part of southeastern Newfoundland were described by S. E. Jenness (1960).



WDM 6-3-54

PLATE II. Typical coast near Rantem Cove, southwestern Trinity Bay, composed of Bull Arm volcanic rocks.



WDM 7-5-54

PLATE III. *View southeast, showing bedrock control of topography at Long Harbour, eastern Placentia Bay. A major fault in the bay controls the distribution of Bull Arm volcanic rocks (far shore) and Musgravetown arkoses (foreground).*

The writer found no evidence of elevated marine features around Conception, St. Mary's, or southeastern Trinity Bays. Four stratified sand and gravel deposits were observed, however, on the east shore of Placentia Bay. These deposits lie off the mouth of Little Barachois River and the river flowing through Great Barasway; near Point Verde; and 2 miles north of Arnolds Cove. They are locally crossbedded, and are deeply scoured and filled with bouldery gravel. The steep crossbedding and local channelling suggest deposition of these sand and gravel deposits in a deltaic environment above the level of ocean wave action. They seem best developed in old or present river channels and are roughly 25 feet above present high-tide level. At several coastal localities between these four places, however, thick till rests on a low bedrock surface.

A similar stratified sand and gravel deposit at Long Beach, on the northern boundary of Whitbourne map-area, is 48 feet above high-tide level (E. P. Henderson, personal communication). Coarse gravel slightly above sea-level is poorly exposed around Broad Lake, southern Trinity Bay.

Till is widely but variably distributed. It mantles large areas underlain by the Hodgewater and Conception Groups in the central part of the map-area, and covers much of the Connecting Point Group in the northwestern area near Goobies. Much

of the material in the till was derived from a local source and is of considerable aid in extending bedrock contacts in some areas. No metamorphic or exotic fragments were found in the till by the writer, but E. P. Henderson collected several gneissic granite pebbles, on the east shore of Trinity Bay, that are not indigenous to the Avalon Peninsula.

Climate and Soil

Avalon Peninsula is encircled by the Labrador current, with attendant cold waters in spring and summer. Sea ice normally encircles the peninsula in March, although harbours are not frozen for long. Spring is delayed by the chill waters, and mean air temperatures in May are about 40 degrees, with common frosts. An easterly or northeasterly summer wind is cold and usually brings fog or drizzle, with temperatures below 55 degrees. Hot summer days are rare.

Precipitation is abundant and distributed throughout the year. St. John's averages 53.8 inches per year, with a low of 3.5 inches in June and July and a high of 5.9 inches in November. Measurable precipitation falls 13 to 18 days per month.

Soils on Avalon Peninsula are mainly formed from the till, the components of which are derived largely from the local bedrock. Hence, bedrock geology markedly affects the quality and distribution of the soils. Principal resulting divisions include the comparatively fertile lowlands overlying the Cambrian shales, the barren highland underlain by the Holyrood plutonic rocks, and the very rocky soil covering the volcanic rocks and, to a slightly lesser extent, the entire area. The overwhelming acidity of the soil is a direct reflection of the lack of widespread limestone in the bedrock. This acidity is locally relieved over those parts of the Cambrian limestone and shale beds where till is not excessively thick.

The geological and climatic factors have yielded a stony shallow acid soil with low fertility. The Dominion Experimental Farm, near St. John's, has much to offer in example and advice, but its influence has not yet reached the small settlements. General treatment for the improvement of most small garden plots and fields would include the addition of lime and organic matter in the form of peat, manure, and fish.

Peat bogs are widespread in areas of poor drainage. A study of bog reclamation by Federal and Provincial agencies is in progress near Colinet, northern St. Mary's Bay.

Culture

Avalon Peninsula supports about one-quarter of the population of Newfoundland with the provincial capital, St. John's, lying on the extreme east coast. Principal towns in Whitbourne map-area are Harbour Grace, Carbonear, Hearts Content, Hearts Delight, Whitbourne, Argentia, and Placentia. Numerous small settlements, originally established for fishing, dot the coast.

Whitbourne Map-area, Newfoundland

Fishing at most villages has diminished and the men seek employment elsewhere. Many were employed at the Wabana Iron Mines on Bell Island, and at, or in connection with, the United States Naval Air Base at Argentia.

Forest products are important in providing firewood and local building material, but are commercially exploited only on a small scale. Many areas of Avalon Peninsula have suffered from repeated fires, and the slowness of forest growth in the wind-swept environment restricts the potential of this source of revenue. Farming for domestic use is practised on a small scale by most families in the small villages.

Chapter II

GENERAL GEOLOGY

Avalon Peninsula, as shown in Table I, is underlain by unmetamorphosed Precambrian sedimentary rocks lacking limestone, by lesser amounts of Precambrian volcanic rocks, by an irregular stock of Precambrian granite in the east, and by small exposures of post-Cambrian granite along the western border. Cambrian shale, slate, and minor limestone beds are transitional upward into more clastic Lower Ordovician beds. In eastern Avalon Peninsula, Precambrian sediments succeeding the oldest volcanic rocks (Harbour Main Group) are greywacke-siltstone beds (Conception Group) that are overlain by arkosic rocks (Hodgewater Group). In the western third of the area, a greywacke-siltstone succession (Connecting Point Group) is overlain by a volcanic assemblage (Bull Arm Formation) and arkosic sediments. A thin quartzite (Random Formation) of uncertain age overlies the latter beds and disconformably underlies fossiliferous Lower Cambrian beds west of Conception Bay. Facies changes in late Precambrian arkoses are marked, but these changes are most pronounced in directions normal to the regional north-northeasterly structural trend.

Folds are generally open, moderate, upright, and gently plunging north-northeast or south-southwest, with local areas of steep to isoclinal folds. Northerly aligned faults had their principal movement in late Precambrian time, with less post-Cambrian movement. Tear faults in the northwestern part of the map-area were formed after post-Lower Ordovician folding. Angular unconformities are exposed or indicated at the upper contact of the oldest volcanic rocks (Harbour Main Group) with the Conception Group, below fossiliferous Cambrian beds on both the Harbour Main and Conception Groups in southern Conception Bay, and locally at the base of the Random quartzite. A disconformity, of unknown time significance, lies between the Random quartzite and overlying fossiliferous Cambrian beds.

The geology of the map-area as interpreted by the writer is summarized in the following Table of Formations.

Table I
Table of Formations
(thickness in feet)

Era, Period, or Epoch	Western Part of Map-Area		Eastern & Central Part of Map-Area	
	Group or Formation	Lithology	Group or Formation	Lithology
Post-Early Ordovician	Iona Islands, Powder Horn, and Northern Bight	Plutonic rocks in eastern Placentia Bay, ranging from older olivine gabbro to pale red biotite granite		
	Intrusive contact with Musgravetown Group			
Early Ordovician			Wabana Group 1,000 +	Shale and sandstone; oolitic hematite, black shale
			Minor disconformity	
			Bell Island Group 4,000 +	Sandstone and shale; oolitic hematite
			Base not exposed	
			(Clarenville Formation)	Presumed present, but hidden below waters of Conception Bay
Late Cambrian			Elliot Cove Formation 300 +	Shale, thin-bedded sandstone in upper part. <i>Agnostus pisiformis</i> , <i>Olenus</i> , and <i>Peltura</i> zones
Middle Cambrian	(Manuels River Formation)	Not known to be exposed but probably present north of Sunnyside	Manuels River Formation 430	Dark grey, black slate and shale, thin limestone bed, limestone nodules; andesite pillow lava (Chapel Arm Member) near southern Trinity Bay. Comprises <i>Paradoxides hicksi</i> , <i>P.davidis</i> , and <i>P.forchammeri</i> zones

Table I (cont'd)

Era, Period, or Epoch	Western Part of Map-Area		Eastern & Central Part of Map-Area	
	Group or Formation	Lithology	Group or Formation	Lithology
Middle Cambrian (cont'd)	Mafic dykes	Dykes striking near N60°W, in Placentia Bay and Bull Arm. Post-Lower Cambrian in age	Gabbro necks and sill	Diabase gabbro south of Chapel Arm; probably related to the Chapel Arm Member
	Intrusive contact with Lower Cambrian Formations		Intrusive contact with lower beds of Chamberlain's Brook Formation	
	Chamberlain's Brook Formation	Manganiferous beds exposed at Goobies(?)	Chamberlain's Brook Formation 350 +	Grey-green slate and shale, thin limestone, manganiferous beds at base. <i>Paradoxides bennetti</i> zone
	Minor disconformity (?)		Minor disconformity	
Early Cambrian	Brigus Formation 75 to 430+	Red and green slate commonly with limestone nodules. <i>Callavia</i> and <i>Protolenus</i> zones	Brigus Formation	As in western part of map-area
	Smith Point Formation	Pink algal limestone, red limy argillite laminae. Mainly pre- <i>Callavia</i> fauna	Smith Point Formation	As in western part of map-area
	Bonavista Formation 0 to 92+	Red and green slate, thin limestone and basal conglomerate. Hyolithids and <i>Coleoloides</i>	Bonavista Formation	As in western part of map-area
	Disconformity on Random Formation		Angular unconformity on Conception and Harbour Main Groups in south Conception Bay	
Early Cambrian or Late Precambrian	Random Formation 0 to 600	White quartzite, quartz-pebble conglomerate, arkose interbeds. Invariably present	Random Formation	As in western part of map-area. Lacking in Conception Bay
	Disconformity?		Angular unconformity locally, disconformity elsewhere	

Table I (*cont'd*)

Era, Period, or Epoch	Western Part of Map-Area		Eastern & Central Part of Map-Area	
	Group or Formation	Lithology	Group or Formation	Lithology
Precambrian	Musgravetown Group		Hodgewater Group	
	Crown Hill Formation 0 to 1,000	Red pebble conglomerate; minor green conglomerate and red siltstone	Snows Pond Formation (upper part) 2,000 to 6,000	Red arkose and siltstone 0 to 500 Grey-green, crossbedded arkose 0 to 2,000 Grey, wavy-bedded arkose and siltstone 2,000 to 4,000
	Undivided units (north of lat. 47°30') 1,200+	Red conglomerate and arkose, green siltstone, grey siltstone, slate, argillite		
	Trinny Cove Formation (south of lat. 47°30') 2,200	Green and red arkose, grit, siltstone; rare grey, wavy-bedded siltstone	(lower part) 1,100	Red arkose and siltstone. Grey-green, wavy-bedded siltstone, green arkose, apple-green slate
	Maturin Ponds Formation (south of lat. 47°35') 1,100 to 2,000	Massive and bedded red arkose and siltstone	Whiteway Formation 325	Red siltstone and arkose with minor green beds
	Big Head Formation (south of lat. 47°32') 1,500 to 7,000	Massive, pink, speckled arkose and subgrey-wacke 0 to 2,000 Green and grey siltstone and slate, white weathering 3,000 to 3,800 Red arkose, siltstone, conglomerate 100 to 1,200	Halls Town Formation 2,800 to 5,000	Massive, light grey arkose; siltstone
	Bull Arm Formation 8,000	Mafic volcanic flows, breccias, tuffs, tuffaceous arkose, minor felsite Rhyolitic tuffs, breccias and flows Mafic volcanic flows and breccias, red and green silt-	Carbonear Formation 3,200 to 4,000	Dark grey slate, siltstone

Table I (*conc.*)

Era, Period, or Epoch	Western Part of Map-Area		Eastern & Central Part of Map-Area	
	Group or Formation	Lithology	Group or Formation	Lithology
Precambrian (<i>cont'd</i>)	Bull Arm Formation (<i>cont'd</i>)	stone and arkose (494 \pm 30 m.y.)	Conception Group 6,000 to 8,000	Greyish green siltstone, slate, greywacke. Minor red siltstone and slate (Hibbs Hole Formation)
	Connecting Point Group 9,000+	Green and grey, well-bedded siltstone, slate, greywacke, black cherty argillite Minor red tuffaceous beds	60	Andesite lava flow near base of group at Holyrood Bay; dykes of di-basic gabbro
			500 +	Greyish green siltstone, slate, greywacke, subgreywacke; minor red siltstone, rare thin limestone bed, basal conglomerate
			Unconformity and local angular unconformity with Harbour Main Group	
			Holyrood plutonic series	Pink granite Quartz monzonite, quartz diorite, minor grey granite (574 \pm 11 m.y.) Gabbro, quartz hornblende gabbro
			Intrusive contact	
			Harbour Main Group 6,000 +	Andesite, basalt, rhyolite, and related ignimbrites, pyroclastic and minor intrusive rocks, red subgreywacke, conglomerate, siltstone, greyish green sediments similar to Conception beds (568 \pm 29 m.y.).

Nomenclature and Stratigraphic Relations

The problem of a satisfactory nomenclature for sandstones has resulted in several different classifications to choose from. Of these, the classification accepted by Pettijohn (1957, pp. 290–292) is widely known and has given rock names that are useful within the region. Modal analyses of selected sandstone specimens are given in this report, and are sufficiently complete to compare the sandstones of this area with those named in other classifications.

The limited number of modal analyses offered are not a representative sample of the sandstones of these thick groups and formations, yet they describe selected hand specimens as being megascopically typical of various formations.

The subdivisions selected for the rocks of this area vary in stratigraphic significance.

Within the Harbour Main Group, mafic, felsic, and sedimentary rocks can be represented by three generalized divisions (McCartney, 1954b), but each rock type occurs at various horizons in the sequence. Correlation between lithologically similar divisions is uncertain; hence, the divisions have limited use in a stratigraphic sense.

The Conception Group has been traced into rocks of the same name at the southeastern boundary of the map-area; hence, Rose's correlation of these rocks is now confirmed (1952). The Hodgewater Group occurs in the east half of the map-area, but passes beneath a cover of younger rocks in the central part of the map-area, to the west of which lie rocks of a more clastic facies that is typical of the Musgravetown Group. Rocks that are similar to the Hodgewater Group in lithology and stratigraphic position but which lie to the east of Whitbourne map-area, are named the Cabot Group (Rose, 1952).

The Precambrian Hodgewater, Musgravetown, and Cabot Groups and their formations are defined in a lithostratigraphic sense by their position in vertical sequence. Upper and lower boundaries are parallel or subparallel with bedding planes, and their lateral boundaries, except where members wedge out, are arbitrary implied hidden cut-offs that intersect the bedding planes vertically (Wheeler and Mallory, 1956, p. 2712). Absence of well-exposed transitions or fossil evidence prevents a more satisfactory subdivision and correlation within the facies concept (Moore, 1949, p. 32), and necessitates the arbitrary cut-off and use of several names for rock units of similar stratigraphic position, and possible equivalent age, in southeastern Newfoundland.

Cambrian map-units in the Avalon Peninsula are mainly defined by faunal zones. These zones are lithologically uniform, but vary in thickness over the peninsula. Thus Cambrian "lithostratigraphic units" can be shown to be fairly uniform in age.

Harbour Main Group

Definition

The Harbour Main Group comprises a succession of volcanic and sedimentary rocks more than 6,000 feet thick. Originally named the "Avondale volcanics" (Buddington, 1916) for their occurrence near Conception Bay, they were subsequently called "Harbour Main volcanics" (Howell, 1925) because the term Avondale had been used previously elsewhere, and finally "Harbour Main group" (Rose, 1952). The type locality remains the area near Avondale (lat. $47^{\circ}25'$, long. $53^{\circ}12'$), because Harbour Main (lat. $47^{\circ}27'$, long. $53^{\circ}10'$), cited as a type locality by Rose (1952), displays sedimentary rocks characteristic of the Conception Group.

Rocks in the group correspond to map-units "a and b" of Murray and Howley (1881b), and the writer's contacts between the Harbour Main and Conception Groups agree with the contacts of Murray and Howley between their units "a and b" and "c" along the coast of Conception Bay.

The foregoing definition of the group disagrees with the work of Hayes (1931), but rocks he considered to be the base of the Conception Group near the northern end of Bay de Verde Peninsula have since been interpreted as part of the Hodge-water Group (Jenness, 1963; and the writer).

Distribution and Thickness

Rocks of the Harbour Main Group are exposed in an anticline near Brigus Junction (lat. $47^{\circ}23'$, long. $53^{\circ}18'$), in a fault block near Brigus, southwest Conception Bay, and over much of the eastern quarter of Whitbourne map-area. They also extend along the western part of Torbay map-area east of longitude $53^{\circ}00'$ (Rose, 1952).

The base of the Harbour Main Group has not been observed, but a minimum thickness of 6,000 feet for the group seems established. A thickness of at least 7,000 feet occurs in some sections, but this may include repetition of some units, for the internal structure of the group is complex and is not yet well understood.

Lithology

Stratigraphic relations within the group are obscured by exceptionally intense faulting, apparent discontinuities of members, highly restricted areas of sedimentation and volcanism, and major and minor intrusions. Flows of basalt and andesite form an upper formation west and south of Colliers Bay and are commonly underlain by rhyolitic rocks. The gross sequence downward results in mixed rock types and becomes increasingly complicated by intrusive rocks. Lithological descriptions are here treated briefly, by rock type, and are intended to augment rather than repeat the descriptions of Buddington (1916, 1919), Rose (1952), and Hutchinson (1953). Ignimbrites are described in more detail because their mode of origin had

not formerly been recognized and they provide the most reliable structural information within the Harbour Main Group.

Ignimbrites (Welded Tuffs)

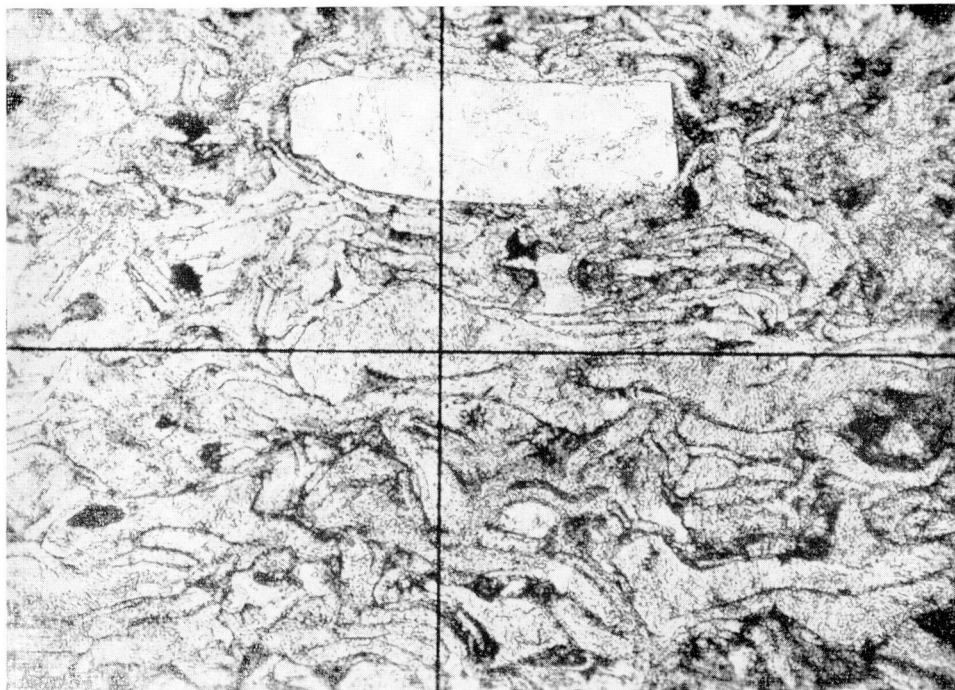
Ignimbrites (Marshall, 1935) tend to form more rugged or knobby outcrops than do most other rock types in the group. Pink, brick red, or pale grey ignimbrites are mainly hard massive rocks with abundant broken crystals of oligoclase and rounded embayed quartz. These crystals, commonly about 1 mm in diameter, resemble phenocrysts wherever the tuffaceous matrix has recrystallized. Subangular volcanic rock fragments, up to $\frac{3}{4}$ inch long, form as much as 20 per cent of some massive ignimbrites. The matrix, commonly brick red, has a lustre intermediate between the dull earthy lustre of similar crystal tuffs and the glassy lustre of dense porphyry or devitrified ignimbrites. Siliceous shards that comprise the matrix are as much as 0.8 mm long.

Most diagnostic of the ignimbrites are spherulitic welded tuffs (Iddings, 1899) and banded types that resemble flowbanded rhyolite. They are mainly deep red to pink where unaltered but, in common with other ignimbrites, pale to medium grey in exposures near granitic rocks, and uniformly pale pink adjacent to pink granite. The planar streaks are probably caused by the flattening and agglutination of hot siliceous shards under the weight of superincumbent tuff. These welded tuffs are found in close association with other ignimbrites of a more open texture that probably lay in the upper parts of individual tuff beds and were not compressed while hot.

Positive identification of typical ignimbrites is rare or lacking in rocks as old as these; yet the ignimbrites in the Harbour Main Group show crumpled, flattened, and welded shards clearly outlined by dusty hematite (Pl. IV). Excellent evidence of late Precambrian ignimbrites in central Sweden is presented by Hjelmquist (1955). In southeastern Newfoundland and elsewhere, published descriptions of 'flow' rhyolites strongly suggest that many are really welded tuffs.

The ignimbrites of the Harbour Main Group are widely distributed and are important in tracing some major structural features. Some discontinuities in ignimbrites are thought to be caused by their original deposition restriction to ancient valleys. Supporting evidence is their common association with red subgreywacke and siltstones that are probably fluvial deposits.

The most diagnostic welded tuffs are practically restricted to a south-trending zone between longitudes $53^{\circ}10'$ and $53^{\circ}14'$. Principal outcrop areas are the central peninsula between Gasters and Colliers Bays and localities near Avondale, including the excellent shore exposures at the head of Gasters Bay, the outcrop at the highway bridge over Salmon River, and the large exposure west and southwest of Lees Pond near Avondale railroad station. Rhyolitic tuffs are exposed south of Harbour Main Pond (lat. $47^{\circ}22'$, long. $53^{\circ}12'$), where they appear to occupy the crest of a poorly defined anticline. Exposures immediately southeast of Harbour Main Pond



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PLATE IV. *Photomicrograph showing texture in welded tuff (ignimbrite) from Harbour Main Group near Avondale, Conception Bay. Length of field is 2.3 mm.*

are andesite, and the ignimbrites zone is discontinuous either because of truncation by a hidden southward extension of the Brigus fault (Fig. 2), or because of a primary depositional termination.

The ignimbrites can then be traced from their junction with the Peaks Pond fault (lat. $47^{\circ}20'$, long. $53^{\circ}13'$) southward and eastward around the crest of a southerly plunging anticline. It is likely that they trend northeast from Southern Peak Pond to the southeastern side of prominent rhyolite porphyry hills $1\frac{1}{2}$ to 3 miles south of Holyrood, but outcrops were not found in the intervening 2 miles. Massive grey ignimbrite with partly recrystallized matrix forms large outcrop areas northeast of Big Island and Mobile Big Ponds near latitude $47^{\circ}17'$, and is abundant in the Harbour Main Group south of latitude $47^{\circ}15'$.

As seen in thin section, typical welded tuff (Pl. IV) has angular clear anhedral or broken phenocrysts of oligoclase and rare fragments of deep brown biotite. Flattened shards curve around the rims of these phenocrysts. Other welded tuffs contain about 3 per cent quartz as rounded highly resorbed phenocrysts, 6 per cent angular and broken orthoclase, and 3 per cent oligoclase phenocrysts. The groundmass is devitrified with transitions from pectinate structure, in which tiny needles

are developed perpendicular to the shard surfaces, to larger radiated and spherulitic aggregates that transgress shard boundaries. Microgranulitic textures are common.

Spherulites range from incipient crescentic grey forms outlined by chalcedonic quartz to fully developed spherulites with a core of grey tuff surrounded by a rim of granular quartz. In many cases, radially oriented sheafs of sericite comprise either the outer part or the entire spherulite.

Welded tuff is susceptible to conversion by modest thermal metamorphism to what appears to be rhyolite porphyry. Representative thin sections of transitional changes in welded tuff at decreasing distances from granite show a) rapid breakdown of shard outlines; b) coarsening of the microgranular groundmass, accompanied by increasing amounts of sericite; and c) coarser equigranular groundmass lacking sericite. Throughout these changes, the embayed quartz and broken or anhedral feldspar phenocrysts remain unaltered. Adjacent to granite, the light grey rhyolite porphyry becomes greyish pink or pink. These transitions, in order of increasing recrystallization, may be observed at Big Island Pond (lat. $47^{\circ}17'-18'$, long. $53^{\circ}7\frac{1}{2}'$), northwest of Mobile Big Pond, $3\frac{1}{2}$ miles east of Holyrood at Big Otter Pond, and west of Paradise Pond (lat. $47^{\circ}13'$, long. $53^{\circ}05'$).

Rhyolite Breccias

Rhyolite breccias are not widely distributed. Buddington (1916) described the rhyolite porphyry body and associated coarse rhyolite breccia 2 miles south of Holyrood, concluding that this seemed to be one of the main centres of volcanic activity in the region. This porphyry body is, in fact, a volcanic rock, now unroofed, which shed coarse avalanche and pyroclastic material onto its flanks. Volcanic debris included ignimbrites and coarse breccias associated with minor areally restricted red sandstones. These beds, occupying the southeast flank of an anticline, are now preserved along the southeast rim of the volcanic neck. Most breccia horizons and associated sandstone traced to the southwest appear to abut andesite. This termination is probably caused by the original restriction of these beds to a valley. The concentration of rhyolite breccia in this locality near Holyrood, as opposed to its paucity in most ignimbrite sections, suggests that these breccias were largely confined to the vicinity of this volcanic neck.

Buddington's analyses of the rhyolite porphyry neck (Table II, column 1), and a rhyolite flow east of Whitbourne map-area (column 2), are reproduced below (p. 20).

The sericitization and pyrophyllitization of these rhyolitic rocks have been described elsewhere (Buddington, 1916).

Mafic Volcanic Rocks

Mafic volcanic rocks, mainly andesite flows, breccias, and tuffs, ranging in colour from deep grey-purple to grey-green, constitute about two-thirds of the volcanic rocks distributed throughout the Harbour Main Group. The youngest known rocks in the group are andesite flows and breccias, slightly more than 1,000 feet

Table II

Analyses of Rhyolite Porphyry and Rhyolite

	Rhyolite Porphyry	Rhyolite
SiO ₂	75.85	76.24
Al ₂ O ₃	13.03	13.94
Fe ₂ O ₃	1.82	.89
FeO	.32	.13
MgO	.05	.27
CaO	.38	1.07
Na ₂ O	3.34	2.55
K ₂ O	4.47	4.95
H ₂ O ⁺	.35	.15
H ₂ O ⁻	.05	.03
MnO	.05	
Total	99.71	100.22

Analyses from Buddington (1919, pp. 458, 459).

thick, which are exposed on the west shore and south of Colliers Bay, Conception Bay. The stratigraphic significance of older mafic rocks is not known.

Representative flows are massive or amygdaloidal with some widely spaced red brecciated flow tops. Andesine or labradorite crystals, averaging 0.5 to 0.25 mm in length, form felted or oriented flow textures. Plagioclase is most commonly set in a chloritic matrix with carbonate. Some thin sections show tiny (0.02 mm) grains of epidote in patches of chlorite 0.2 mm in diameter. Oxyhornblende in some sections is moderately pleochroic, dark brown, and rimmed by opaque iron oxides. Epidote veinlets or patches result from alteration, and calcite, with or without epidote, is the most common amygdule filling.

Andesite porphyries commonly occur as small necks intrusive into rocks of the group. They show subhedral greenish cream andesine phenocrysts in a purple-grey uniform groundmass. The groundmass consists of microgranular felted andesine with less orthoclase. Minor constituents include dispersed patches of chlorite and small grains of magnetite and epidote.

Sedimentary Rocks

Sediments in the group are abundant from Holyrood Bay west to Gasters Bay, but decrease in amount to the south and southeast. The two types present are greenish grey siltstone, similar to the Conception rocks, and red subgreywacke, siltstone, and conglomerate.

Green, greenish grey, and grey slates and siltstones, commonly with regular, laminated bedding, are indistinguishable from rocks of the overlying Conception Group. Some of these rocks are clearly intercalated with Harbour Main volcanic rocks, but could not be traced for appreciable distances along strike. Other thicker

sections of Conception-like rocks are shown on the Whitbourne geological map as being questionable Conception Group. These sections lie in a strip east of Gasters Bay and north of Lees Pond; in a belt with minor volcanic rocks 1 mile west of Holyrood; in a belt south from Four Mile Pond (lat. $47^{\circ}20'$, long. $53^{\circ}06'$); and on the southeast border of the map-area in a block with poorly understood sheared, and probably faulted, contacts. Their assignment to either the Conception or the Harbour Main Groups is of critical importance in resolving the internal structure of the Harbour Main Group, and in evaluating the contact relations between the two. Most evidence, gathered by a detailed search along their contacts, suggests that these rocks are, in places, overlain by volcanic rocks and, for the most part, are probably present in the lower part of the Harbour Main Group. Shearing along their contacts is common, but the resulting displacement is judged to be minor except in the southeastern part of the map-area. Rose (1952) concluded that agglomerate, tuff, and tuffaceous beds among the lower members of the Conception Group show the waning effects of volcanic activity, which he considered is related to that of Harbour Main time. The writer, basing his work on apparently better exposures in southwestern Conception Bay, suggests that some of this evidence may have been observed in these grey and green sediments that belong within the Harbour Main Group. In this area, the principal upper contact of the Harbour Main Group is an unconformity, angular in places, that represents an appreciable interval of time.

These green and grey laminated siltstones may represent deposits formed in lakes or in marine embayments that extended into or around the volcanic land of Harbour Main time. Either interpretation accounts for what appear to be abrupt primary discontinuities in these beds. The band of slate immediately east of Avondale, for example, terminates abruptly at Lees Pond. Termination by faults may be possible, but was not supported by interruptions in the adjacent ignimbrite sequence lying to the west.

Red subgreywacke, fine to coarse conglomerate, siltstone, and rare slate are abundant locally in the group. They form about one-sixth of the section in southern Conception Bay, and are mainly associated with ignimbrites. South and east of a point 2 miles south of Holyrood, the red sediments are either less abundant or not exposed, and they are not known south of latitude $47^{\circ}15'$.

The conglomerates are coarse to pea-sized, composed almost exclusively of rocks typical of the Harbour Main Group. Mafic volcanic fragments are abundant. One cobble of diorite was found in a coarse conglomerate bed on the hillside south of the highway at Middle Arm, southern Gasters Bay. Rose (1952) reported a few pebbles of pink granite and syenite in conglomerates within the Harbour Main Group. Cobbles and pebbles are mainly subrounded.

Coarse subgreywackes, mostly red, consist of subrounded fragments of mafic and felsic volcanic rocks, with abundant quartz but lesser amounts of feldspar. They are unusually well sorted, with a unimodal size distribution and very minor intergranular argillaceous matrix. Some red subgreywacke and fine conglomerate beds

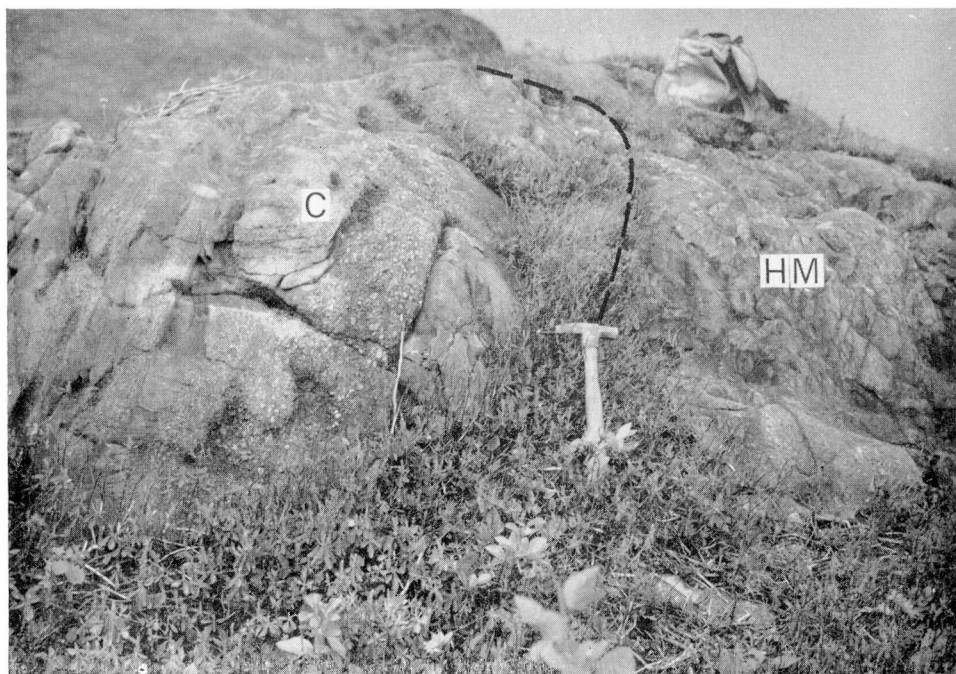
contain thin beds composed of subrounded magnetite grains. Such rocks 1 mile east of Avondale railway station have been drilled as an iron prospect, but there is no chance that these rare sedimentary laminae are of economic importance.

Red slates and siltstones are associated with the subgreywackes and conglomerates, and contacts are commonly very abrupt. Siltstones and subgreywackes are locally contorted by contemporaneous deformation.

These red beds are believed to be fluvial deposits. Their high content of mafic volcanic and similar unstable material points to rapid erosion and deposition; their fair degree of rounding in the coarser sizes indicates vigorous abrasion; thin lenses and beds of subrounded magnetite suggest a fluvial placer origin; and their common association with ignimbrites proves periodic subaerial exposure and strongly suggests a valley environment.

Contact Relations and Age

The base of the Harbour Main Group is not known to be exposed in south-eastern Newfoundland. Rare granitic subrounded pebbles were found in conglomerate 200 feet south of the highway at Middle Arm, Gasters Bay, and a



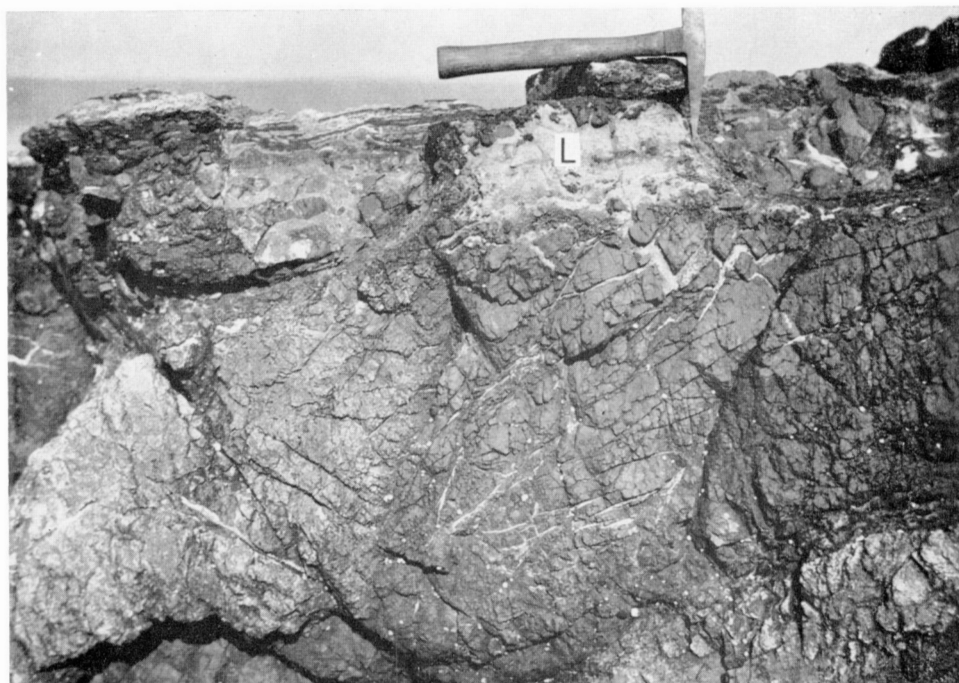
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PLATE V. Basal Conception beds (C) resting unconformably on Harbour Main volcanic rocks (HM). Hammer marks contact. Note large boulder of andesite to left of hammer. West shore of Colliers Bay in Conception Bay, looking north.

rounded inclusion of cataclastic granite is enclosed in basalt on the west peninsula of James Cove, eastern Colliers Bay. The source of these pebbles is not identified in present outcrops.

The upper contact with the Conception Group, which will be discussed on page 31, is an angular unconformity west of Hollyrood Bay (Fig. 4), and it appears to be an unconformity west of Colliers Bay (Pl. V).

Grey quartz monzonite intrudes Harbour Main volcanics and is overlain non-conformably by Lower Cambrian beds on the west and east shores of Hollyrood Bay at Chapel Cove Point and Duffs (Pl. VI).



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PLATE VI. Conglomeratic basal Cambrian limestone (L) nonconformably overlying quartz monzonite and an andesite dyke at Chapel Cove Point in Conception Bay.

Granite and quartz monzonite samples collected by H. Lilly of Memorial University, H. Williams, and the writer at various times between 1961 and 1964, and analyzed by R. K. Wanless and W. D. Loveridge, indicate a whole rock rubidium-strontium isochron age of 574 ± 11 m.y. (Wanless, personal communication, 1965). Based on a second analysis of the rubidium-strontium content of potash feldspar from a grey quartz monzonite collected by the writer from the east shore of Hollyrood Bay, a compatible age of 597 ± 42 m.y. is indicated (Fairbairn, per-

sonal communication, 1965).¹

An age of 568 ± 29 m.y. for the Harbour Main volcanics is indicated by Fairbairn.

Correlation

Volcanic rocks of the Bull Arm Formation near and north of Placentia in the western part of Avalon Peninsula, have been mistakenly correlated with the Harbour Main Group (Murray and Howley, 1881b; Howley, 1907; and Weeks, 1955). The younger Precambrian volcanic rocks of the Bull Arm Formation in western Avalon Peninsula overlie the Connecting Point Group, as indicated in recent publications (McCartney, 1956, 1957).

A tentative correlation of the Harbour Main Group with the widespread Precambrian volcanic rocks of Burin Peninsula, 70 miles west of Holyrood, is generally accepted by most workers in southeastern Newfoundland, but the marked variation in sedimentary facies and volcanic activity across the present regional strike weakens this lithological correlation. This problem is discussed in a subsequent description of the Bull Arm Formation.

Holyrood Plutonic Series

Three units of the Holyrood plutonic series are distinguished in this report: pink equigranular granite, darker quartz monzonite and quartz diorite, and quartz-hornblende gabbro and augite gabbro. The last two units are combined as map-unit B on the geological map accompanying this report (*in pocket*), but are separated on an earlier map (McCartney, 1954b). They are restricted in distribution to isolated stocks or to the margins of the granite. The name Holyrood granitic batholith (or rocks), as used by Rose (1952, pp. 20–21), includes the three rock types named above. The name Holyrood plutonic series is recommended for general reference to these rocks because (1) 'batholith' is a structural not a lithological term; (2) small bosses and stocks are isolated from the main body; and (3) part or all of the gabbro may have been derived in situ from older rocks of the Harbour Main Group. The term 'intrusive' is not used for the series because of the probable metamorphic origin of the gabbro, although the granite and quartz monzonite are, in fact, intrusive in origin.

Modal analyses of representative specimens of rocks from the Holyrood plutonic series are given in Table III.

Parts of the Holyrood plutonic series have been described by Buddington (1916) and Rose (1952). These rocks underlie much of the eastern one-sixth of the map area.

¹ Unpublished absolute age determinations by H. W. Fairbairn and R. K. Wanless used in this report were inserted by the author in October, 1965, as the manuscript went to press. Dr. Fairbairn's permission to publish is gratefully acknowledged (see Fairbairn, *et al.* (*in press*) and McCartney, *et al.* (*in press*). These preliminary age values remain subject to slight modifications.

Table III

Modal Analyses of Specimens from the Holyrood Plutonic Series

Rock Name	Specimen No.	Textures	Quartz (%)	Potash Feldspar (%)	Albite in Perthite (estimated %)	Plagioclase (%)	Plagioclase Variety	Hornblende (%)	Chlorite (%)	Magnetite (%)	Carbonate (%)
Granite	S4	Perthite	45	33.0	20	17.5	Ab ₈₀		4.5		
Granite	M1	Granophyric	37.2	34.0		6.5	Olig.				22.3
Granite	M126	Regular perthite	42.4	36.2	25	3.1	Olig.				
Granite	M141	Granophyric	20	42.3	15	16.3	Olig.		18.6	2.8	
		Ab rim on Pc									
Granite	M142	Perthite	49.7	37	15	9	Olig.		4.3		
		Ab rim on Pc									
Quartz monzonite	M144	Zoned Pc	23.2	32.6		20.2	Olig.		19.9	3.8	
Quartz monzonite	M151	Cataclastic	21.1	42.4		31.3	Ab ₈₀		4.5	0.9	
		Ab rim on Pc									
Quartz monzonite	J202	Regular perthite	18.3	45.4	5	34.9	Ab ₇₀		1.45	Neg.	
		Ab rim on Pc									
Quartz monzonite	M19	Perthite	21.5	37.9		35.3	Ab ₈₀		5.3		
		Granophyric									
Quartz monzonite	J183y		19.6	30.1		39.1	Ab ₇₀		10.7	0.5	
Quartz diorite	J183w		11.8	24.6		48.5	Ab ₇₀		12.7	2.4	
Quartz monzonite	J77	Zoned Pc	24.2	26.2		36.2	And.	11.5		1.9	
Quartz-hornblende gabbro	J98	Zoned Pc	16.2	0.9		56.8	Lab.	24.4		1.7	
Quartz-hornblende gabbro	M193	Zoned, poikilitic	8			57	Lab.	31		4.0	
Quartz-hornblende gabbro	J70	Zoned, poikilitic	12.1			64.7	Ab ₄₅	21.4		1.8	

Granite

A pale pink equigranular granite, with minor pink aplite, is the dominant rock in the Holyrood plutonic series. It is confined to a belt 33 miles long and 6 miles wide along the eastern border of Whitbourne map-area, and extends for an additional 2½ miles east of it (Rose, 1952).

The granite is coarse-grained, with grains nearly 6 mm in diameter on the average, and shows no linear or planar alignment of minerals. Inclusions are abundant only in marginal zones of the granite. Inland outcrops retain their pink colour on weathering, and the abundant white quartz grains stand out in relief. Detritus from weathering is coarse, angular arkosic sand.

The modal composition of the granite is 35 to 45 per cent quartz, 33 to 39 per cent orthoclase, 10 to 18 per cent plagioclase (mainly albite but approaching oligoclase in composition), and 4 to 8 per cent chlorite, which is pseudomorphic after biotite. Accessory minerals are zircon, apatite, and magnetite. Microperthite is commonly blotchy and irregular, and contains about 10 to 30 per cent albite. The granite is altered, with chlorite and lesser epidote derived from biotite, and markedly clouded feldspars flecked with abundant sericite.

Quartz Monzonite

The rocks in this unit are mainly quartz monzonite and quartz diorite of varying composition. A darker mottled pink and green colour, with lesser quartz but more abundant pale green saussuritized plagioclase and mafic minerals as compared with the pink granite, is diagnostic of these rocks. They form isolated stocks and small bosses near the western and southern borders of the granite, and comprise narrow zones marginal to granite along extensions of roof pendants and along parts of the main granite contact. Locally, the quartz monzonite or quartz gabbro merge with smaller bodies of gabbro and quartz gabbro. Some granite that is gradational with the quartz monzonite is darker in colour than the main body of granite, and has a higher proportion of pale green saussuritized plagioclase. Because it is a marginal facies, it is included with the quartz monzonite.

Pale grey cataclastic granite, some pinkish grey granite, and a unique pegmatite facies are associated with quartz monzonite on the east shore of Holyrood Bay. Because they are not identical to the main body of granite (Map-unit A), but, in part at least, strongly resemble grey cataclastic quartz monzonite 1 mile west at Chapel Cove Point near the entrance to Holyrood Bay, they are here classed with the quartz monzonite (Map-unit B) as an unusual marginal facies.

The rocks in Map-unit B are equigranular, with no obvious preferred orientation of mineral grains. Small dark schlieren occur locally in a fine-grained granite on the coast near Duffs, and a small outcrop of a peculiar white diorite with oriented hornblende crystals is surrounded by quartz monzonite south of Mount Carmel Pond, in the southeastern corner of the map-area.

Under the microscope, thin sections of the most typical rocks in Map-unit B are seen to contain 12 to 24 per cent quartz, 25 to 45 per cent orthoclase, 31 to 48 per cent plagioclase (andesine to oligoclase), and 4.5 to 13 per cent of either uralitic hornblende or chlorite. The common accessory minerals are magnetite and apatite. Some stocks of quartz monzonite approach the composition of the granite in Map-unit A. Plagioclase in many rocks of the group is zoned, with saussuritized cores and a clear thin albite rim. Myrmekite is conspicuous in minor grey granite and some quartz monzonite, and perthite is present in many thin sections. Alteration, mainly saussuritization and replacement of hornblende by chlorite, is common to all thin sections studied.

Sharp contacts with the main body of granite (Map-unit A) were seen at only two localities, where granite dykes cut quartz monzonite. Elsewhere, the contacts are gradational.

A pegmatitic facies, unique in the map-area, is associated with grey granite and adjacent quartz monzonite on the east shore of Holyrood Bay. It appears 125 feet southwest of a nonconformity overlain by Cambrian beds near Duffs; it extends 75 feet to the southwest as a pegmatite with giant quartz crystals up to 2 feet in diameter and a further 425 feet as a leucocratic granite with abundant patches of coarse-grained quartz and orthoclase. All giant crystals contain films and layers of orthoclase, which are parallel with crystal faces.

This pegmatite facies, the associated isolated knots of pegmatite in grey granite, and rare vugs are probably the result of a late local stage of magmatic differentiation exposed in a marginal zone. The more common and, presumably, equivalent stage in the main pink granite (Map-unit A) is represented by veins and irregular patches of pink sugary-textured aplite. This late stage was probably related to the widespread deuteric alteration characteristic of the Holyrood plutonic series and to the silicification, sericitization, and pyrophyllitization of adjacent intruded volcanic rocks.

Gabbro

Gabbro is closely associated with the granite (Map-unit A) and quartz monzonite (Map-unit B) as shown by its restriction to marginal parts of the plutonic series. It forms a capping, underlain by granite and cut by a few small granite apophyses, at the Butter Pot near Holyrood. It is included in this report as a minor part of Map-unit B but was shown as a separate map-unit on an earlier map (McCartney, 1954b).

The grain size and appearance of the gabbro in large outcrops varies erratically. At the Butter Pot near Holyrood, equigranular medium-grained gabbro contains fine-grained variations that grade to dense basaltic rocks. The fine-grained rocks contain stubby hornblende phenocrysts and specks of pyrite. On the west side of the Butter Pot, a fine-grained variety forms a band 50 feet wide that trends north for several hundred feet.

Specimens, as seen in thin section, are mainly labradorite and hornblende with interstitial quartz. Augite locally forms large subhedral to anhedral, rounded grains with lacy edges. These edges are mainly hornblende with an outer fringe of chlorite. Modal analyses show ranges of 8 to 16 per cent quartz, 52 to 65 per cent plagioclase (mainly labradorite), 11.5 to 31 per cent hornblende, and 1.7 to 4 per cent magnetite. One specimen contains 26 per cent augite, with labradorite and minor hornblende, chlorite, and biotite; another shows an abnormally high quartz content of 31.4 per cent and is presumed to be silicified. Plagioclase is commonly zoned and saussuritized, but is clear in some specimens; hornblende is poikilitic, enclosing small subhedral labradorite grains; and quartz is interstitial to the plagioclase.

Contact Relations within the Series

On the western edge of the Butter Pot, coarse pink granite (Map-unit A) is in sharp contact with a 6- to 12-inch wide band of fine-grained porphyritic pinkish grey granite. This band grades into a quartz monzonite, which lacks phenocrysts, near a sharp contact with a 10-inch wide band of dark greenish grey porphyritic quartz diorite. The quartz diorite in turn grades into medium-grained augite gabbro. Feldspars are saussuritized and augite has lacy edges rimmed with hornblende.

Contacts between the granite (Map-unit A) and the quartz monzonite (Map-unit B) are transitional, and are recognized where the pale pink colour and abun-

dant quartz, typical of the granite, are in evidence. The colour change is largely controlled by the greater plagioclase content of the monzonitic rocks.

Xenoliths are common in the outer margin of the quartz monzonite, but sparse in the granite. Xenoliths of light grey hornblende-quartz diorite, showing shadowy boundaries, are possibly representative of partly assimilated andesite fragments. Thin sections of this type of xenolith show a marked contrast in grain size, with abundant fine grains of hornblende and oligoclase up to 0.5 mm in diameter. These fine grains form a matrix around, and are in part enclosed in, large grains of orthoclase, oligoclase, and poikilitic quartz and hornblende, 1 to 2 mm in diameter. The large plagioclase grains show diffuse zonal boundaries. More felsic xenoliths are common, but are probably less significant in a genetic sense because their assimilation would have a minor influence on the composition of granite.

Contact Alteration and Metamorphism

The principal alteration effect near and in the Holyrood plutonic rocks is the development of abundant sericite visible in virtually all thin sections. This, and the characteristic alteration of mafic minerals to chlorite, hornblende, or epidote, complicates mineral identification and the interpretation of affected rocks. Silicification is locally the main type of alteration. Most of the alterations were probably related to a deuteric phase in the closing stages of crystallization of the granite and quartz monzonite.

Little mineralogical change has taken place along granite contacts in rhyolitic rocks of the Harbour Main Group. Epidote showed an increase in amount over chlorite, and the groundmass of ignimbrites became devitrified and turned pink near the contacts. Basaltic rocks of the same group have a dense siliceous appearance near the granite contacts, showing evidence of minor development of pyrite and secondary mica.

Adjacent to quartz monzonite contacts, thin beds of sandstone in argillite or siltstone contain porphyroblasts of oligoclase up to 7 mm in diameter. The preferential growth of these porphyroblasts in sandstone probably reflects the higher permeability of the sandstone and a chemical composition more similar to that of the quartz monzonite than of the enclosing argillite.

These contact effects have been recognized and used as an aid in geological mapping. They are developed over much of the elongate roof pendants in the main body of granite from Mount Carmel Pond northward to the cover of Cambrian rocks at Conception Bay, but extend only 50 to 200 feet from the contacts of the small stocks of quartz monzonite.

Mode of Origin

The writer suggests that the granite (Map-unit A) is an intrusive rock that was contaminated along parts of its margins and roof by the assimilation of mafic volcanic material. The resulting hybrid rocks formed the highly variable quartz

monzonite, dark granite, and quartz diorite. The gabbros may have been minor intrusions and basalts of the Harbour Main Group that were recrystallized adjacent to the molten granite under a relatively high water-vapour pressure.

The principal evidence to support this interpretation is the marginal distribution of the monzonitic and gabbroic rocks. Small stocks west of the principal granite area are invariably of monzonitic or dioritic composition and lack exposed granitic and gabbro facies. These stocks are probably slightly unroofed cupolas in which contaminated upper rocks of Map-unit B are underlain by granite (Map-unit A). Only the largest of these stocks, about 6 square miles in area, south of Mount Carmel Pond in the southeastern part of Whitbourne map-area, shows about 1 square mile of granite in association with the more intermediate facies. Adjacent to this granite are two outcrops of quartz-hornblende gabbro.

Other field relations suggesting the hybrid origin of the monzonitic and dioritic rocks (Map-unit B) include their transitional contact with granite, their variable composition, and the presence in them of partly assimilated mafic xenoliths.

The origin of the gabbro is problematic. Its distribution, most commonly as small bodies adjacent to roof pendants of mafic volcanic rocks in the granite, suggests that the gabbro formed only in local areas that attained temperatures approaching those of the adjacent granitic magma. A coarsening of grain size and the conversion of original augite and hypersthene to hornblende in original basalts and andesites, under the influence of this high temperature and a high water vapour pressure, would produce quartz-hornblende gabbro. No transfer of materials, other than water, would be required.

Age

Granitic rocks are intrusive into volcanic rocks of the Harbour Main Group. Intrusive relations with the Conception Group have not been proven in the present map-area, but Rose (1952) reported that the Holyrood "granite" (the Holyrood plutonic series of this report) intruded lower beds of the Conception Group in the adjoining Torbay map-area to the east. Small bodies of gabbro and diorite do intrude lower Conception rocks in the present map-area, but these are considered to be younger than the Holyrood plutonic series. Granite cuts sediments of the Harbour Main Group that resemble Conception beds. Relations of the plutonic rocks to Conception Group rocks in the southeastern corner of the map-area, and in Rose's adjoining Torbay map-area, are obscured by major faults adjacent to granite. Evidence of a pre-Conception age for the Holyrood plutonic series includes the presence of many large fragments of quartz monzonite in basal Conception conglomerate 3 miles north of Holyrood and the abundance of quartz and feldspar grains, without volcanic fragments, in some Conception beds.

From field relationships, therefore, the writer favours a pre-Conception Group age for the Holyrood plutonic rocks, perhaps related to a period of pre-Conception folding that is responsible for the local angular unconformity below Conception beds near the west shore of Holyrood Bay.

A rubidium-strontium isochron by R. K. Wanless and W. D. Loveridge indicates an age of 574 ± 11 m.y. (McCartney, *et al.* (*in press*)). A rubidium-strontium age of 597 ± 42 m.y.¹ was determined by H. W. Fairbairn (personal communication, 1965) for potash feldspar in a sample of grey granite collected by the writer. Several other samples collected contained excessive chlorite, and biotite age determinations were not attempted. This granite, which is nonconformably overlain by Lower Cambrian beds on the east shore of Holyrood Bay (Pl. VI), is part of the quartz monzonite suite (Map-unit B).

Conception Group

Definition

The Conception Group was defined by Rose (1952) as the thick assemblage of sedimentary rocks overlying the Harbour Main Group and underlying the St. John's slate member of his Cabot Group. Two units, originally named the "Conception slate" and the overlying "Torbay slate", were mapped separately where possible by Rose; they could not be separated in the same way in Whitbourne map-area, but the Torbay slate probably corresponds to the Hibbs Hole Formation of this report. The name Conception Group applies to the sedimentary rocks and the restricted and rare volcanic rocks that overlie the Harbour Main Group and underlie the Carbonear Formation of the Hodgewater Group in this report.

Distribution and Thickness

In the map-area, the Conception Group outcrops principally in a continuous belt that trends north-northeast from the east side of St. Mary's Bay across the central part of the Holyrood area to Conception Bay between longitudes $53^{\circ}13'$ and $53^{\circ}27'$. Some isolated blocks farther east are thought to belong to this group and are so mapped. The identification as Conception Group seems conclusive for some of these blocks, but has not been satisfactorily established for others. Structural as well as lithological factors are the basis of correlation with type Conception rocks to the west. Lithology alone is not a valid criterion for identifying these rocks, for some Conception-like rocks are intercalated within the Harbour Main Group.

The distribution of the group east of Whitbourne map-area was shown by Rose (1952). The Conception Group may be stratigraphically equivalent to the Connecting Point Group which has been mapped to the northwest (Hayes, 1948; Rose, 1948; Christie, 1950; and Jenness, 1963). South of the map-area, the distribution of the group is tentatively that outlined by 'division c' of Murray and Howley (1881b).

The thickness of the Conception Group is about 7,000 feet.

¹ Unpublished absolute age determinations used in this report were inserted by the author in October, 1965.

Lithology

Basal Beds

The basal beds of the Conception Group range from boulder conglomerate upward through alternations of grey-green subgreywacke and siltstone to red sandstone and siltstone with rare restricted thin beds of limestone. Conglomerate fragments of local derivation include granitic and felsitic rock types with alteration features typical of felsites now found adjacent to the granite (Map-unit A). Cross-bedding and ripple-marks are rare.

Basal beds of the Conception Group are best exposed on the cliffs west of Colliers Bay, southwestern Conception Bay, and 6 miles to the south, in the valley of Salmon River. The clastic sequence at these two localities is between 60 and 100 feet thick.

Near Colliers Bay, the basal coarse conglomerate is as much as 6 feet thick, but is commonly thin or lacking (Pl. V). It lies unconformably on mafic lavas, which are locally cut by small plugs of diabase. Virtually all of the conglomerate pebbles and boulders near Colliers Bay are andesite, basalt, and diabase, but diabase pebbles are restricted or most plentiful near the small intrusive diabase bodies in the underlying Harbour Main Group. The lack of felsic blocks or fragments and the limited distribution of diabase fragments strongly suggests a local origin for the coarse clastic material. Conglomerates vary from pea-sized to coarse boulder conglomerate with blocky subrounded boulders up to $3 \times 1\frac{1}{2}$ feet in exposed dimensions. The latter are restricted to parts of the lowest bed of the Conception Group.

Grey-green coarse- to fine-grained subgreywacke in the lower members is moderately well sorted, has little quartz but abundant rock fragments, and shows rare crossbedding and ripple-marks. It is quite different from greywacke elsewhere within the group. Greyish red subgreywacke, with average grain size of 0.7 mm, contains angular grains of mafic volcanic rocks, lacks a clay-like matrix, and may or may not contain calcite. Coarser sandstone, with grain sizes up to 2 mm, have closely packed subangular mafic volcanic fragments and a few feldspar grains. The fine-grained subgreywacke contains 10 per cent quartz, 30 per cent feldspar (mainly plagioclase), 35 per cent rock fragments (mafic volcanic), 5 per cent chlorite in discrete grains, 5 per cent opaque minerals, and up to 15 per cent calcite.

A distinctive dull purple-red siltstone containing glistening feldspar fragments, occurs in beds 2 to 12 inches thick associated with dull red sandstone and siltstone above the coarser clastic beds west of Colliers Bay. It is also associated with thin red beds that contain limestone nodules described below, but limestone is lacking at Colliers Bay.

South of Harbour Main, basal beds overlying Harbour Main rocks are similar in some respects to the section west and south of Colliers Bay. The basal conglomerate in the valley of Maloneys River (lat. $47^{\circ}25\frac{1}{3}'$, long. $53^{\circ}10'$) is a massive reddish brown conglomerate with rounded felsite and mafic volcanic pebbles up to $1\frac{1}{2}$ inches in diameter. On the hill 1,000 feet east of Maloneys River, immediately north of the contact, a single monzonite boulder 8×15 inches in

maximum diameter lies in conglomeratic slate. Fine- to coarse-grained dull red arkose overlain by red siltstone is commonly found above the basal conglomerate member.

Rare pink or grey limestone beds and nodules are associated with red arkose and conglomeratic red slate in parts of the basal Conception rocks south of Bacon Cove (lat. $47^{\circ}29'$, long. $53^{\circ}10'$) and on the shore, and south, of Harbour Main. In places, these thin beds resemble Lower Cambrian nodular red slate. The nodular beds form a hill southwest of the mouth of Maloneys River at Harbour Main, and are exposed on the southwest shore of Harbour Main. The same structurally important horizon is recognized a mile to the south and 600 feet north of the contact in Maloneys River, and can be traced to outcrops 500 to 800 feet farther east. Minor reddish siltstone, lacking exposed limestone, is found at intervals above the unconformity between Maloneys River and Holyrood Bay (Fig. 4). The persistence of this unique horizon near the contact, and its association with basal conglomerate, demonstrates that the Conception beds lie essentially parallel with the unconformity. Hence, observed shearing and local faulting are probably minor despite severe crumpling adjacent to the unconformity.

On the southeast shore of Holyrood Bay, basal conglomerate beds are in fault contact with silicified Harbour Main volcanic rocks. The conglomerate contains abundant angular to subrounded fragments of quartz monzonite, up to 2 feet in diameter, that resemble parts of the granite and quartz monzonite sequence exposed on the shore northeast of the contact. They are enclosed in a green sandy matrix in the basal part of the conglomerate, and in a silty matrix in the upper part. The conglomerate is displaced by faults and is probably about 120 feet thick; it is brownish red in some upper parts and is overlain by red finely laminated slate 4 feet thick.

In South River, south of Holyrood and 3,000 feet downstream from Four Mile Pond, conglomerate outcrops near a contact with granite. Pebbles are mainly subrounded, 1 inch or less in diameter, with maximum subangular sizes up to 3 inches. About half the pebbles are pink dense porphyritic felsite, and no granite pebbles could be found. About a mile farther downstream, a similar conglomerate is found adjacent to andesite. Fragments are subangular, with abundant pink fine-grained rhyolite, green andesite, and intermediate volcanic rocks. All fragments of granitic composition that were found are too fine grained to be the granite of Map-unit A. Similar coarse conglomerate, interpreted as basal Conception, is exposed on the west crest of the hill half a mile north of Four Mile Pond.

The abundant pink felsite noted in these three localities is probably recrystallized ignimbrite that is markedly restricted to the present granite contact. The evidence suggests that the main granite intruded and altered ignimbrite prior to the deposition of Conception rocks in this area. No fragments of the granite were found in basal Conception conglomerates at these three localities. It is possible that the granite was not sufficiently unroofed at that time, or that it had weathered then, as it has now, to an arkosic sand.

The foregoing characteristics of the basal beds suggest a nearshore, shallow-water sedimentary environment with sediment derived from nearby areas of older volcanic rocks and from partly unroofed granitic rocks. The beds are transitional into overlying greywackes, and are probably the products of the transition from a subaerial to a deep-water environment.

Siltstone, Slate, and Greywacke

Siltstones, slaty siltstones, cherty argillites, slates, and greywackes, with laminated, cyclic, or graded bedding, are characteristic of the Conception Group. Graded beds are commonly from $\frac{1}{2}$ inch to 2 feet thick, but in a few places are more massive. The colours of fresh rock surfaces are dominantly grey-green and green, less commonly grey and red. Purple-red argillites and slate form minor undivided beds near the base of the group and comprise the thin Hibbs Hole Formation in the upper part of the group. Fine-grained beds normally weather to a chalk white colour. Although cleavage is common, it is seldom sufficiently well developed in the fine-grained hard sediments for them to be called slate, because of the high silt content of most of the fine-grained sediments, as well as the low rank of regional metamorphism. The most striking petrographic feature of the characteristic Conception sandstones is their bimodal size distribution formed by the abundant matrix that separates larger grains and rock fragments. All fragments are of rock types similar to those now exposed in the Harbour Main Group and the Holyrood plutonic series. No metamorphic rock fragments were recognized. The proportion of rock fragments appears to increase with increasing grain size, so that a small range of grain size must be selected for any systematic study of sandstone composition. It is probable that local variations in the composition of the fragments in the sediments are related to variations in the proportion of granitic to volcanic material at the source area. Thus thin sections from near latitude $47^{\circ}15'$, longitude $53^{\circ}10'$, either lack or contain an unusually low percentage of volcanic rock fragments. Some representative sediments are described below.

Some greenish grey dense siltstone is rhythmically banded. Light to dark grey layers, about $\frac{1}{2}$ inch thick, display merged or transitional contacts. About 5 per cent of the bands, however, appear to be graded and show a sharp contact at the top of darker fine-grained beds. In thin section, beds are seen to be of the same composition, apart from a slight coarsening of grain size in the lighter beds. Feldspar, quartz, chlorite, and epidote form the largest grains, up to 0.034 mm in diameter, in an abundant matrix of white mica, chlorite, and very fine quartz, feldspar, and opaque minerals. Some siltstone shows a fair degree of sorting with more epidote, quartz, and feldspar grains and with a markedly lower percentage of matrix. This rock shows crossbedding at a gentle angle, and suggests sufficient current action during deposition to separate the silt-clay sizes.

Dark greyish green siltstone from the northwest shore of Peak Pond (lat. $47^{\circ}20'$, long. $53^{\circ}13\frac{1}{2}'$) is finely laminated. Argillite layers are 0.3 to 3 mm thick, with thin laminae of silt in the thicker argillite beds. These fine-grained beds are

crumpled slightly along planes of incipient cleavage, but no recrystallization or rotation of minerals is discernible in thin section. Sparsely scattered through the argillaceous material are large subrounded grains of quartz, feldspar, and chert, which average 0.4 mm in diameter.

Greywackes form roughly one-tenth of the Conception Group. Subgreywacke normally occupies a near basal position in the group. An unusual greyish green subgreywacke from the northwest shore of Peak Pond, associated with the siltstone just described, lies several hundred feet above Harbour Main volcanic rocks. It is moderately well sorted and contains layers and lenses, about $\frac{1}{4}$ inch thick, that are rich in calcite. The subangular to subrounded rock fragments (45 per cent), averaging 2 mm in diameter, are mainly cherty argillite with andesite and siltstone fragments. Quartz and plagioclase grains total 10 per cent. The matrix (45 per cent) includes abundant fine-grained quartz and feldspar, but less white mica, and consists of about one-half fine- to coarse-grained calcite.

Near Cupids Long Pond (lat. $47^{\circ}29'$, long. $53^{\circ}17'$), sediments representative of the middle part of the Conception Group are exposed as elongate ridges. Medium- to coarse-grained greywacke locally forms about 25 per cent of these sediments. Some greywacke members contain grey-green slate fragments up to 3 inches long. A subrounded felsite pebble and a monzonite pebble were found farther north in slate.

Dark green-grey medium-grained greywacke, typical of rocks in the upper part of the Conception Group, consists of subangular fragments of quartz (13 per cent), feldspar (both orthoclase and plagioclase, 31 per cent), and chert, mafic volcanic rocks, felsite, and siliceous argillite or rhyolite (26 per cent). These fragments are "floating" in a fine-grained matrix of chlorite (20 per cent) and other material (10 per cent). A megascopically representative specimen contains grains up to 0.7 mm in diameter but averaging 0.4 mm.

Grey siltstone occurs in an open syncline of Conception rocks 7 miles south of Holyrood. It is commonly massive and locally resembles massive andesite of the underlying Harbour Main Group. Thin sections show an abundance of quartz but fewer feldspar grains, ranging from 0.15 to 0.09 mm in diameter. These form about 45 per cent of the rock. About 25 per cent of the rock is in the intermediate sizes, mainly quartz and feldspar, and about 30 per cent is a very fine grained matrix of sericite and unidentified material. Grains are mainly angular to subangular.

A siltstone interbedded with fine-grained greywacke from the same synclinal basin near Old Sea (lat. $47^{\circ}15'$, long. $53^{\circ}11\frac{1}{2}'$) has cream white to pale buff weathered surfaces and is light to dark greenish grey on fresh surfaces. Bedding is graded in some exposures and is mainly regular. Rock fragments other than chert are lacking. The matrix is dominantly fine-grained quartz and feldspar. Grain size in greywacke interbedded with this siltstone ranges from 0.3 to 0.1 mm for grains, and about 0.02 mm for most of the matrix. Roundness varies from 0.1 to 0.5 with abundant grains having a value of 0.3. Sphericity is even more erratic, with values of 0.1 to 0.9 and an abundance near 0.5. The estimated mineral com-

position is 35 per cent quartz, 30 per cent feldspar, 2 per cent chert fragments, 5 per cent epidote, 3 per cent chlorite, 1 per cent opaque minerals, and 24 per cent matrix.

Hibbs Hole Formation

The Hibbs Hole Formation, first named by Hutchinson (1953), is found near the top of the Conception Group as far north as latitude $47^{\circ}50'$ on the west shore of Conception Bay and southward to the east shore of Harricott Bay, St. Mary's Bay (lat. $47^{\circ}09'$, long. $53^{\circ}33'$). It is too small a unit for reproduction on the geological map accompanying this report, but was delimited in earlier larger scale maps (Hutchinson, 1953; McCartney, 1954b).

Shore exposures in western Conception Bay and eastern St. Mary's Bay show transitional contacts with undivided Conception Group beds above and below. The formation is 449 feet thick at the type section (Hutchinson, 1953) and is roughly the same thickness where observed by the writer.

The purple-red colour and dominance of fine-grained beds is characteristic of the formation, although some green slate is included. Regular laminated bedding is common, and also some graded bedding. Similar red slate and siltstone beds lie about 1,000 feet above the base of the Conception Group in the area south of Conception Bay.

East of Whitbourne map-area, the Torbay slate division of the Conception Group described by Rose (1952) is about 3,000 feet thick, displays bedding features indicative of shallow-water deposition, and is separated by a disconformity from the underlying Conception slate division. Despite these differences, the Hibbs Hole and Torbay divisions are characterized by red slate and occupy roughly equivalent positions with reference to overlying and underlying sediments.

Conglomeratic Sandstone

Grey massive conglomeratic sandstone forms prominent ridges and coastal bluffs on Little Colinet and Great Colinet Islands in St. Mary's Bay, near the southern border of the present map-area. The beds are about 600 feet thick, and contain rounded pebbles of jasper, chert, felsite, and minor granite. A block on the east shore of Great Colinet Island contains a pebble of pink granite that strongly resembles the granite east of Holyrood (Map-unit A). The matrix is a grey-green sandstone with numerous small glistening feldspar crystals. The upper beds are about 20 feet thick, of similar texture but red in colour. They are overlain on Little Colinet Island by 30 feet of green cherty argillite and a succession of regularly bedded and laminated grey and grey-green slate and siltstone at least 2,000 feet thick.

As the structural setting of these islands is not known, the place of the conglomeratic beds in the Precambrian stratigraphic column is uncertain. The overlying sediments are much like the Conception beds a few miles to the east and northeast.

A few miles south of Whitbourne map-area, E. P. Henderson (personal communication) has observed similar conglomeratic beds in the following four places: the southwest end of Great Colinet Island; a quarter mile east of Frapeau Point; near St. Mary's Harbour at Double Road Point; and 2 miles south of Gaskiers. At some of these localities, there are boulders measuring several feet in diameter. Variations in composition and size of pebbles and in the proportion of matrix to pebbles and boulders in this conglomeratic rock are striking in view of the well-bedded fine-grained marine sediments in which they occur. They are probably tilloids, as defined by Pettijohn (1957, p. 265).

Andesite and Basic Dykes

The only known lava flow in the Conception Group is a pillowed andesite on the west shore of Holyrood Bay, 2 miles north of Holyrood. It is about 60 feet thick, including a brecciated upper part 10 feet thick, and lies conformably between grey-green slates. The base of the flow lies on slate along most of the exposed contact, but is locally separated from it by up to 3 inches of grey, crystalline limestone. A narrow chilled zone occurs within the lava at its basal contact. Pillow structure is defined by a system of radiating and concentric ellipsoidal joints rather than by marked mineralogical or textural variations. Grey crystalline limestone fills many pockets and joints.

The andesite is pale grey-green with a dull lustre. Scattered cleavage faces of calcite, 1 mm in diameter, and minute chlorite grains are visible on fresh surfaces. About 60 per cent of the rock consists of a network of subhedral laths of andesine (Ab_{65}), mostly 0.3 to 0.6 mm long, with a maximum length of 1.3 mm. Interstitial to the feldspar are equal amounts of calcite and a colourless to pale green chlorite. Minor orthoclase, in part replaced by calcite, and some calcite amygdules with irregular patchy rims of chlorite are present in the middle of the flow. Iddingsite has been recognized in thin sections of the andesite. Feldspar phenocrysts, largely replaced by calcite, are concentrated immediately above the narrow chilled zone at the base of the flow.

The lava does not continue northwest of Holyrood Bay and may be related to a sill or flow partly exposed in the mouth of South River at Holyrood.

Analysis of a whole individual specimen of this lava indicated a potassium-argon age of 457 ± 82 million years (Wanless, personal communication, 1965). From geological relations and the indicated age of the Bull Arm Formation, the age should lie near the older extremity of the inferred margin of error. More satisfactory samples might be supplied by the plug and dykes mentioned below.

A small plug-like diorite body on the east shore of Colliers Bay (Hutchinson, 1953) and a few small mafic dykes intrude the lower and eastern beds of the Conception Group, notably northeast and south of Holyrood, 1 mile south of Avondale, and north of Bacon Cove. The apparent stratigraphic and geographic restrictions of these small intrusive bodies suggest that they are related to the extrusive andesite pillow lava described above.

Mode of Origin

The gross lithology, primary structures, and textures of the Conception Group sediments suggest that they were probably deposited for the most part by turbidity currents in a deep marine environment. The basal beds of the group, however, contain some intraformational conglomerate and a thin limestone bed, are better sorted than overlying beds, and locally display crossbedding and ripple-marks. These features are believed to indicate a shallow water, perhaps nearshore environment, transitional between the subaerial erosion of the Harbour Main rocks and the deeper water environment typified by the bulk of the Conception sediments. Most of the group consists of laminated green and grey siltstones and greywackes that display graded bedding and have a bimodal grain size distribution, features commonly regarded as indicating deep-water marine sedimentation. Some features characteristic of turbidity current action are lacking or are poorly developed, e.g., convolute bedding is rare and drag marks and flow marks were not found.

Towards the close of Conception sedimentation, depositional conditions again changed; the environment became shallow, either from being filled with sediments or by epirogenic movement and this resulted in the deposition of the purplish red Hibbs Hole sediments with varicoloured beds and shallow-water structures.

Sedimentary features of the overlying Hodgewater Group and Palaeozoic beds indicate that shallow-water deposition remained characteristic of post-Conception time.

Hodgewater Group

The names used for this group and its four formations were selected from localities in the Harbour Grace area (Hutchinson, 1953) and the northwestern Holyrood area (McCartney, 1954b). The group and formations were defined, contact relations described, and several measured sections presented by Hutchinson (1953, pp. 12–18). The group is confined to a belt trending north-northeasterly through the central part of the present map-area, and to limited northeast and southwest extensions beyond the area. Facies changes within, and northeast of, Whitbourne map-area are described and lithostratigraphic correlations proposed.

Carbonear and Halls Town Formations

Definition

The base of the Carbonear Formation lies at a transitional colour change from grey-green and green beds of the Conception Group to the dark grey to black slates and minor siltstone of the lower Carbonear Formation. The formation underlies massive arkose and bedded siltstone of the Halls Town Formation. The contact between the Halls Town and Carbonear Formations is relatively clear in outcrops from Grand Pond (lat. $47^{\circ}28'$, long. $53^{\circ}21'$) north to latitude $53^{\circ}45'$, but is obscure in the northeastern part of the map-area and in the south towards Harricott

Bay, St. Mary's Bay. Because of the difficulty in defining the boundary in these two places, the two formations have been considered as a single unit (Map-unit 4) in this report.

The Halls Town Formation is overlain by beds of the Whiteway Formation which, except in the northeastern part of the map-area, are red.

Distribution and Thickness

Near Grand Pond, rocks now called Carbonear and Halls Town Formations were mapped by Murray and Howley (1881b) as the *Aspidella* slates (subsequently the St. John's Formation of Rose (1952)) and the Signal Hill grey sandstone, respectively, with type sections east of Whitbourne map-area. The distribution of these two formations differs elsewhere in Whitbourne map-area, however, from the distribution of the units shown by Murray and Howley.

The two formations, which are combined to form Map-unit 4 in this report, extend in a generally linear belt along the west shore of Conception Bay south-southeasterly to St. Mary's Bay. Southwest of Conception Bay, the Carbonear Formation is 3,200 to 4,000 feet thick, and the Halls Town Formation is 2,800 to 5,000 feet thick. A combined thickness of 9,500 feet is indicated in the northeastern part of the area, north of Carbonear. The two formations are seemingly much thinner on the shores of St. Mary's Bay, but are not well defined there. Some removal of strata by faulting at Harricott Bay was suspected, but could not be verified.

Lithology

The Carbonear Formation is grey to black laminated slate in the lower part and interbedded grey slate and siltstone in the upper. The slate has a better cleavage and is softer than that in most other Precambrian beds. Graded bedding has been found in a few places, but is not pronounced. The siltstones have a high proportion of matrix to clastic grains, as was found also in siltstones in the Conception Group. Bedding features indicative of shallow-water deposition are lacking.

The Halls Town Formation is characterized by thick sections of massive pale grey to greenish grey arkose beds, which commonly show oscillation ripple-marks. These beds are especially characteristic of the lower part of the formation as exposed in outcrops southwest of Conception Bay. Coastal exposures show significant proportions of greyish green or green siltstone, but less slate. Red beds occur only in the extreme northeastern part of the map-area, where a dull red arkose member near the base of the Halls Town Formation was traced for 5 miles south from the northern boundary of the map-area. This bed, roughly 200 feet thick, wedges out or changes colour farther south. Two unusual rock types in the Halls Town Formation are thin green siltstone with wavy bedding, and red silty slate in beds a few feet thick. These rock types are common in the younger Snows Pond and Whiteway Formations (Map-unit 5).

Pale grey-green arkoses typical of the Halls Town Formation are fairly well sorted and contain few rock fragments. The modal composition of a specimen

selected as megascopically typical of the arkose is 30 per cent quartz, 5 per cent sodic plagioclase, 26 per cent orthoclase, 8 per cent rock fragments other than chert, 11 per cent cherty argillite and chert fragments, 13 per cent matrix, 5 per cent epidote, and 2 per cent chlorite, sericite, and calcite with rare sphene. Rare myrmekite and perthite grains are included with the orthoclase. Most grains are subangular, and average 0.12 mm in diameter. Coarser grained arkose shows similar textures and composition. The rock fragments (20 per cent) are mostly fine-grained siliceous argillite but include some fragments of rhyolitic and mafic volcanic rocks.

Correlation

The following correlations, proposed by Murray and Howley (1881b), have been supported by recent work. The slates of the Carbonear Formation are similar to, but thicker than, the St. John's slates that overlie the Conception Group east of Whitbourne map-area (Rose, 1952). Both formations are overlain by grey-green or grey sandstones, commonly with ripple-marks, and contacts are completely transitional in both the northeastern part of this area and in the Torbay map-area. The Halls Town Formation is similar in lithology, thickness, and stratigraphic relations to the lowest of three divisions of the Signal Hill Formation (Rose, 1952).

The Carbonear and Halls Town Formations are probably equivalent to, but lithologically different from, some lower part of the Musgravetown Group in the western third of Whitbourne map-area. This correlation is based on the lithostratigraphic equivalence of the overlying Whiteway Formation and the Maturin Ponds Formation (in the Musgravetown Group), as discussed in the following section.

Whiteway Formation

Definition

The Whiteway Formation consists of purplish red arkoses, siltstones, and red conglomerate that overlie the Halls Town Formation and underlie the Snows Pond Formation with apparent conformity. The name Whiteway was first proposed by Hutchinson (1953).

Distribution and Thickness

The formation lies adjacent to and west of much of the outcrop belt of the Halls Town and Carbonear Formations. It is exposed at several localities near Colinet, St. Mary's Bay, and can be recognized in exposures of stratigraphic importance west of St. Mary's Bay in the bed of Little Barachois River. An arbitrary termination for the formation is drawn 11 miles north of Little Barachois River in an area of sparse outcrops, because the red beds farther to the northwest are more clastic and include red pebble conglomerate and some unusually massive red arkose members. This lithology is similar to beds in the Musgravetown Group, and the rocks north and west of the arbitrarily drawn contact have been mapped as the Maturin Ponds Formation of that group.

The red beds characteristic of the Whiteway Formation are not present in a part of the central Bay de Verde Peninsula near latitude $47^{\circ}50'$ and longitude $53^{\circ}10'$ to $53^{\circ}20'$. In this region, the stratigraphic control provided by the overlying and underlying formations permits the Whiteway Formation to be extended from the characteristic red bed facies northeastward across a grey and grey-green facies into wedges of red beds that rapidly thicken northwards.

In the central part of the map-area, red beds are restricted to this formation and to equally thin members in the lower part of the Snobs Pond Formation, so that the red beds are important stratigraphic and structural guides despite their thinness. A thickness of about 325 feet is maintained in most localities, but the thickness increases toward the northern border of the map-area.

A section measured on the northeast shore below the mouth of Rocky River, St. Mary's Bay, comprises 234 feet of Whiteway Formation with the upper part not exposed.

Lithology

Purple-red slate, siltstone, and sandstone are the rock types characteristic of this formation, although members are commonly laminated or interbedded with red and grey or green alternations. Red beds form about one-third of the formation. The conspicuous red colour ranges from pale red-purple in most arkoses to greyish red and greyish red-purple in many slate beds.

Pale purple-red arkose typical of the formation is exposed on the north bank of Colinet River, 4,500 feet northeast of the bridge. Pink feldspar grains and rhyolitic rock fragments are discernible in outcrop, and discontinuous dark purple-red streaks composed of hematite-rich layers transgress the bedding planes. As seen in thin section, this arkose contains about 37 per cent rock fragments, which consist of welded tuff (7 per cent), chert (5 per cent), fine-grained granite (1 per cent), siliceous and mafic volcanic rocks (14 per cent), and sediments (10 per cent). These fragments occur in a sandy matrix of quartz (17 per cent) and feldspar (33 per cent); orthoclase is about twice as abundant as plagioclase, and there is about 13 per cent iron oxide, chlorite, sericite, and epidote. The grains are mainly sub-angular and closely packed.

Current directions, as indicated by planar crossbedding, were southeasterly at several localities at the head of St. Mary's Bay, but many more systematic measurements are needed to properly evaluate the paleocurrents. Rock fragments of granitic rocks and welded tuffs may have been derived from the Holyrood plutonic series and the Harbour Main Group.

Correlation

Lithostratigraphic correlations are here proposed for the Whiteway Formation with the red beds comprising the Maturin Ponds Formation of the Musgravetown Group in the western one-third of the map-area, and with the unnamed intermediate member of the Signal Hill Formation east of the map-area (Rose, 1952).

The first correlation is shown by the apparent merging of the Whiteway and Maturin Ponds Formations, but because of a westward thickening and coarsening of the beds an arbitrary boundary is imposed on the Whiteway Formation south of the Argentinia-Colinet road (lat. $47^{\circ}12'$, long. $53^{\circ}44'$). The Whiteway Formation has been traced south from its type locality at Whiteway, eastern Trinity Bay, by means of outcrop and diagnostic till fragments, to the north end of St. Mary's Bay. It reappears to the west on the west limb of a syncline; its axis is at Cape Dog (lat. $47^{\circ}05'$, long. $53^{\circ}41'$), after passing below the normal sequence of Snows Pond, Random, and Cambrian beds. Evidence that this is the Whiteway Formation was found in the canyon of Little Barachois River, St. Mary's Bay (lat. $47^{\circ}12'$, long. $53^{\circ}49'$), where unusual mottled orange and green chert beds, about 5 feet thick, are lithologically identical to thin beds found in the Whiteway Formation west and east of Colinet (lat. $47^{\circ}13'$, long. $53^{\circ}32'$ and $53^{\circ}34'$). Similar cherts are not known elsewhere in central or eastern Avalon Peninsula. The Whiteway Formation extends north from the exposed section on Little Barachois River to a large boggy area just south of the Argentinia road at latitude $47^{\circ}12'$ and longitude $53^{\circ}45'$. There, locally abundant red drift trends across a gap of 4 miles to join red arkose, siltstone, and conglomerate beds that form the southern end of the Maturin Ponds Formation, Musgravetown Group. The Maturin Ponds beds in the south, like the Whiteway Formation, are overlain by late Precambrian wavy-bedded grey-green arkose, and by the Random and Brigus Formations.

There is evidence for the tentative correlation of the Whiteway Formation with red arkose and conglomerate of the middle and upper part of the Signal Hill Formation. The Whiteway Formation was traced northeastward from the type locality through the northeastern part of Whitbourne map-area to a wedge of red clastic sediments, including red arkoses, which lie at the north border of the map-area. In this wedge, the red beds in the Whiteway Formation become thicker northward, and occupy their normal position above ripple-marked arkose typical of the Halls Town Formation and below wavy-bedded siltstones characteristic of the Snows Pond Formation. Red arkose in lower members of the Snows Pond Formation also becomes more abundant. Farther north near Bay de Verde, 8 miles northeast of the present map-area, a thick, pale red conglomerate member contains subangular to rounded felsite pebbles up to 2 inches in diameter and overlies these thick red "Whiteway" arkoses and siltstones. This rapid northward appearance, at Bay de Verde and on Baccalieu Island, of the conglomerate that is missing in the central part of Avalon Peninsula, reproduces the full sequence of the three divisions of the Signal Hill Formation at their type locality at St. John's, 35 miles south of Baccalieu Island (Rose, 1952). Although the intervening area lies beneath Conception Bay, the great similarity in sequence of lithology and general thicknesses extending upward from the top of the Conception Group, and the similar thickness of overlying Precambrian sediments, support this lithostratigraphic correlation.

Factors in the evaluation of red conglomerate and arkose as a reliable lithostratigraphic unit include: (1) the lack of conglomerate and the paucity of red beds

in other parts of the Hodgewater Group; (2) the lack of other thick conglomerate beds in the Cabot Group to the east (Rose, 1952); and (3) the well-defined distribution in the western part of Whitbourne map-area of a lithologically similar, somewhat younger conglomerate (Crown Hill Formation, Map-unit 13, Musgravetown Group) along a strike length of at least 65 miles. These coarse-grained sediments are believed to have been controlled by movements on major faults in the eastern part of Avalon Peninsula in late Precambrian time (Fig. 2) and by later Precambrian faulting in the western part of Avalon Peninsula when the Crown Hill conglomerate was formed.

In contrast with the suggested reliability, as lithostratigraphic units, of these red beds in the eastern and central parts of Avalon Peninsula, similar looking beds in the western part, with the exception of the Crown Hill Formation, are unreliable marker beds unless they are traced in the field. This may be because the latter red beds were probably deposited in a deltaic subaerial environment adjacent to Bull Arm volcanic rocks, whereas the former, farther east, were probably deposited in a shallow marine environment with nearby volcanic hills formed only during a single period of maximum movement on Precambrian block faults (Fig. 2).

Snows Pond Formation

Definition

The Snows Pond Formation is that part of the Hodgewater Group overlying the Whiteway Formation and underlying the Random Formation. The name was chosen for the characteristic exposures at the north end of Snows Pond (lat. $47^{\circ}30'$, long. $53^{\circ}23'$) (Hutchinson, 1953). Although only the lower beds are preserved at Snows Pond, virtually complete exposures of the overlying beds form the coastline of southeastern Trinity Bay. Several members in the formation have been useful in studying intraformational facies changes and contact relations with the overlying Random Formation (McCartney, 1957).

Distribution and Thickness

The Snows Pond Formation occupies a broad synclinal basin in the northeastern part of the map-area, underlies Random quartzite along the east shore of Trinity Bay, and forms much of the synclinal area south of Trinity Bay.

Within much of the map-area, Murray and Howley (1881b) mapped what is now recognized as the Snows Pond Formation as "Aspidella slate". The Aspidella slate is equivalent to what is now known as the Carbonear Formation. This misconception accounts for most of the major structural discrepancies between their remarkable map of 1881 and the writer's geological map, which accompanies this report.

The preserved thickness thins northward from 7,000 to 3,000 feet within a distance of 15 miles near the southeastern shore of Trinity Bay. This northward thinning is probably related to gentle truncation by an angular unconformity below the Random Formation at this locality.

Lithology

The most diagnostic feature of the Snows Pond Formation is the wavy irregular bedding of dark grey to black argillaceous and silty layers in light grey arkose. These dark finely sized layers show wisps, waves, and discontinuous streaks mainly caused by pronounced lensing, pinching, and swelling of the sand-sized layers. Truncations of layers, resembling low-angle crossbedding, are fairly common. The arkoses are medium to thick bedded where the dark grey laminae are lacking and commonly crossbedded in the upper part of the formation.

Conglomerate beds are thin except for a massive member 30 feet thick that has been traced south from Tickle Harbour Point, Trinity Bay (McCartney, 1957). A 1-foot thick conglomerate bed was observed in the upper part of the Snows Pond Formation on the shores of New Harbour and on the west shore of St. Mary's Bay. Pebbles within the conglomerate are subrounded, less than 1 inch in diameter, and dominantly green or grey dense quartzose argillite. The pebbles resemble rock types found in the Connecting Point and Conception Groups. The westward thickening of conglomerate in the upper part of the formation in southern Trinity Bay and a limited number of crossbedding directions suggest a western source of clastic material.

Red arkose and siltstone form about 1,100 feet of beds with interbedded grey and green sediments in the lower part of the Snows Pond Formation. These beds are combined with the red beds of the Whiteway Formation as Map-unit 5 of this report, because distinction between red beds becomes tenuous in areas where the rocks are poorly exposed and in the extreme northeastern part of the map-area, and also because of the thinness of the Whiteway Formation. The Whiteway Formation had been shown as a separate map-unit on earlier larger scale maps (Hutchinson, 1953; McCartney, 1954b, 1957). Red beds in the Snows Pond Formation form a useful map-unit near the southeastern shore of Trinity Bay (McCartney, 1957). In this area, the red beds indicate that a pale green crossbedded arkose, up to 2,000 feet thick, forms the upper members of the formation, but that this arkose abruptly thins to the north, probably as a result of a low angle angular unconformity at the base of the Random Formation. The green arkose is locally overlain by red siltstone and arkose at and south of Collier Bay, Trinity Bay, but both these members are lacking on the west shore of St. Mary's Bay.

Specimens of the light grey thick-bedded arkose in the western part of Holyrood map-area (McCartney, 1954b) and in the west branch of the Rocky River were found to have an average grain size of about 0.2 mm and to be moderately well sorted. Roundness varies from 0.1 to 0.7, with an estimated average of 0.4. Sphericity is as low as 0.3, but averages about 0.7. The principal constituents in the arkose are listed in Table IV.

A shallow current-swept submerged to deltaic sedimentary environment is suggested for the Snows Pond Formation by the good sorting of sandstone, wavy bedding, and crossbedding of these grey, greenish grey, and minor red arkoses. Prominent crossbedding in the greenish grey arkose at the top of the formation

Table IV

Modal Analyses of Arkoses, Snows Pond Formation

	G. 113 (%)	G. 109 (%)	J21-23 (%)
Quartz	27	34	24
Potash feldspar	32	20	25
Plagioclase	9	7	11
Chert	5	7	5
Rock fragments	16	17	28
Chlorite	3	1	1
Sericite	4	2	1
Matrix	4	6	3
Calcite	—	6	2

G. 113 from lat. 47°22', long. 53°31'; G. 109 from lat. 47°19', long. 53°31'; J21-23 from lat. 47°20', long. 53°35'.

(Unit 13 on the Dildo map-sheet, McCartney, 1957) further suggests that a deltaic environment was dominant at a late stage in the deposition of the formation.

Correlation

The Snows Pond Formation bears little lithological resemblance to the Trinny Cove Formation 2½ miles to the west near Long Harbour, but is probably equivalent to it. The Trinny Cove beds are coarser, showing common channelling, conglomeratic beds, and rapid colour alternations, although a few beds are identical with the typical wavy-bedded Snows Pond Formation. Both formations underlie the Random Formation and overlie lithostratigraphically equivalent formations. Although they are roughly equivalent, lithological differences that have resulted from their different environments of deposition (a nearshore and subaerial deltaic environment for the western beds, and a current-swept but mainly submerged deltaic environment for the Snows Pond Formation) prevents the use of the same name for both units.

The Snows Pond Formation may also be equivalent to some part of the lithologically different Blackhead Formation in the Torbay map-area (Rose, 1952) to the east. The Blackhead is the youngest Precambrian formation exposed there and the underlying beds seem equivalent to the Whiteway Formation, but no Random or Cambrian beds are preserved above the Blackhead Formation to permit a more reliable lithostratigraphic correlation.

Connecting Point Group

Name, Distribution, and Thickness

The oldest sedimentary rocks in the western half of Whitbourne map-area were named the Connecting Point Group by Hayes (1948). They are restricted to

a structurally high belt, 2 to 5 miles wide, in the northwestern corner of the map-area, from whence they extend northward to latitude 49°, as shown by Christie (1950). About 9,000 feet of strata have been recognized near and northeast of Southern Harbour, Placentia Bay, but the base of the group is not exposed.

Lithology

Beds of this group closely resemble those of the Conception Group described in a preceding section. Features of the group that distinguish it from most younger rocks include the regular commonly laminated, and in part graded types of bedding; the dull earthy-white weathered coating normally developed on inland outcrops; the absence of major red beds; the predominance of fine-grained sediments; and the abundant basic dykes which are believed to be related to volcanic rocks in the succeeding Bull Arm Formation.

Several tentative mapping units within the group were used in the field study of the internal structure of the group near Little Southern Harbour and La Manche, but these units could not be extended across faults or to the northwest corner of the map-area. Hence formal lithostratigraphic subdivision of the group is not warranted by the present work.

Dark grey laminated siltstone, slate, and siliceous argillite, with minor greywacke and greyish green siltstone and slate, form the oldest known rocks in the group. These are about 3,300 feet thick in a section west of and near Southern Harbour Station. Two poorly exposed beds of red tuffaceous siltstone, about 50 feet thick, are present in this section.

The oldest beds are overlain by a thick succession of green, grey, or black rocks, about two-thirds of which are siltstone and argillite, the other one-third being grey-green or grey greywacke. A few cherty black argillite beds are also present. The beds in this succession are about 4,000 feet thick.

The youngest preserved beds in the group are 2,000 feet thick and form the shores of Little Southern Harbour; some members can be traced south to the coast west of La Manche. The two most distinctive members, each about 150 feet thick, are dull red massive tuffs, which are commonly cut by ramifying veinlets of epidote. These tuffs lie in grey-green, grey, and green siltstone and greywacke which is overlain by interbedded red and greyish green siltstone and greywacke. The uppermost red and greyish green laminated beds are exposed on the southwestern tip of the peninsula south of Little Southern Harbour.

Bedding planes throughout the group are mainly regular and laminated or closely spaced. Some siltstone-argillite beds are massive. Local exceptions to regular bedding include lenses of greywacke, 1 inch thick by 10 to 12 inches long (as seen in cross-section), in continuous siltstone beds associated with shallow channelled bedding. Rarely, fine crossbedding is found in siltstone beds $\frac{1}{2}$ to 1 inch thick. Ripple-marks and crossbedding have been observed in the greywacke by Christie (1950) but not by the writer.

The greywackes contain subangular to subrounded grains of feldspar (25 to 50 per cent), quartz (15 to 25 per cent), and rock fragments (5 to 10 per cent) in a matrix of chlorite and epidote.

Correlation

The Connecting Point rocks were formerly called the Conception slates (Buddington, 1919), and were correlated with the type locality of the Conception Group in the eastern part of Whitbourne map-area. Hayes (1948) introduced the present name because the earlier implied correlation was supported only by similarities in thickness and lithology. This separate name is justified and is retained. The Connecting Point and Conception Groups are probably equivalent in part although their upper contacts are not likely comparable. This approximate correlation, based on the similarity of thickness and lithology of the two groups as noted by earlier workers, is strengthened by the present study of later Precambrian rocks. The Musgravetown and Hodgewater Groups are overlain by fossiliferous Cambrian beds and are, in part, mutually equivalent and comparable in thickness, despite variations in facies. Hence the underlying Connecting Point and Conception Groups are believed to occupy a similar position in the lithostratigraphic succession.

Musgravetown Group

The Musgravetown Group, named by Hayes (1948), is an arkosic and volcanic assemblage of rocks overlying the Connecting Point Group and underlying the Random Formation. It is correlated lithostratigraphically with part of the Hodgewater Group of the central part of this map-area. The group is here divided into the Bull Arm, Big Head, Maturin Ponds, Trinny Cove, and Crown Hill Formations. Because of facies changes, some sedimentary formations are not everywhere present.

The distribution of the group in the present map-area is confined to the area west of St. Mary's and Trinity Bays. Upper beds extend 12 miles farther south to Cape St. Mary. Christie (1950) and Jenness (1963) showed the distribution of the group northwest of Trinity Bay.

On northern Bay de Verde Peninsula, formations of the Hodgewater Group meet similar lithological units which were placed in the Musgravetown Group by Christie (1950). In particular, the Whiteway Formation and adjacent red arkosic beds in this area thicken rapidly to the north and become coarser grained.

The total thickness of the group is uncertain because the base of the Bull Arm Formation is not well exposed, and the thicknesses of the overlying formations are extremely variable in the northwest and southwest. The exposed thickness of the group in the east-dipping sequence north from Brine Islands, Placentia Bay (lat. $53^{\circ}27'$ to $53^{\circ}37'$) is about 13,000 feet.

Bull Arm Formation

Definition

The term Bull Arm Formation is used in a lithostratigraphic sense to designate the dominantly volcanic assemblage of rocks, in the lower part of the Musgrave-town Group, resting on rocks of the Connecting Point Group in the present map-area and underlying conformably the sedimentary formations of the Musgravetown Group. The original type area of southwest Bull Arm is recognized. A representative, structurally simple, and complete cross-section of the formation is exposed on the shore of Placentia Bay northwest from Fair Haven (lat. $47^{\circ}32'$, long. $53^{\circ}54'$). The formation there is about 8,000 feet thick.

The name 'Bull Arm felsite member' was given by Hayes (1948) to the volcanic rocks on the southwest shore of Bull Arm in the northwestern corner of the present map-area. These volcanic rocks, which had been mapped to the north as a lithological unit by Christie (1950), were tentatively mapped to the south as the Bull Arm 'group' (McCartney, 1956, 1957). This elevation to group status, adopted for preliminary publications while working towards the type area, now does not seem justified.

The formation includes mafic and felsic flows, breccias, pyroclastic rocks, tuffaceous arkose, red and green arkose, siltstone, and conglomerate. Green slate and siltstone that resemble some Connecting Point sediments are found intercalated with the flows, breccias, tuffs, and minor intrusive rocks, especially in the lower part of the formation.

Lithology

Mafic rocks form about one-half the total formation, tuffaceous and normal sediments about one-quarter, and felsic rocks about one-quarter. These proportions vary from a large (60 per cent) number of felsic rocks in southwest Trinity Bay, to negligible amounts in the southern half of the map-area. These variations are accentuated by the restriction of exposures in the south to upper more mafic members, but are also caused by a southward decrease in rhyolitic members.

Mafic volcanic rocks are the most abundant rock type in the formation. They include andesite and basalt in massive pale to dark green, grey, or deep purplish red flows and minor intrusions. These mafic volcanics commonly contain conspicuous thin winding veinlets of epidote. Amygdules, where present, are dominantly calcite with lesser epidote, prehnite, and chlorite.

Second in abundance are grey-green mafic breccias and lapilli tuffs of various types. One variety that comprises much of the upper third of the formation in Dildo map-area (McCartney, 1957) is a distinctive green and purple-red breccia. This rock type is an alteration product in which either breccia fragments or the matrix have been selectively changed from dull green or grey-green to a deep purple-red. The matrix is commonly a fine-grained mafic crystal tuff. Closely allied and about equally abundant is massive mafic breccia and lapilli tuff that locally has a crude stratification. This rock suite exhibits all gradations from a crystal tuff

matrix containing abundant fresh feldspar crystals and subangular exotic rock fragments, to a tuffaceous dull arkosic matrix holding better rounded and less abundant rock fragments. Some varieties resemble tillite. Fragments of granite and granitic rocks up to 3 inches in diameter occur in some agglomeratic and conglomeratic tuffs, notably in Placentia Bay on the outermost island off Fair Haven, in the eastern part of the United States Naval Air Base 2½ miles east of Argentia railway station, and on Crawley Island in Long Harbour. Dominant rock fragments are mafic volcanic rocks, but pink felsite forms up to one-third of the fragments. Mafic tuffs lacking coarse fragments are the least common of the mafic volcanic rocks.

Intrusive basalt breccia is probably common in the mafic breccias, but its intrusive origin can not always be proved. It is best exposed on the outer tip of Isaac Point, 3 miles northeast of Argentia. An intrusive core of basalt is flanked by breccia that clearly truncates bedding in greyish green siltstone. Similarly, a knob of basalt and basalt breccia is probably intrusive into the transitional contact with the Big Head Formation 4½ miles east of the Argentia railway station.

Abundant massive rhyolite breccia, lava, ignimbrite, and minor intrusive porphyry (Map-unit 9) lie on the west shore of Trinity Bay north and south of Rantem Cove, at Stock Cove, and north from Bull Arm to Centre Hill and beyond. This northerly distribution suggests that these areas were the most active sites of rhyolitic volcanism. Thin distinctive rhyolitic members were traced several miles in the regular eastward-dipping beds between Trinity and Placentia Bays. These less massive units comprise the core of a south-plunging anticline at Little Chance and Big Chance Coves, southwestern Trinity Bay. Although these thin members and some of the mafic members are of stratigraphic significance and outline structures in the formation, they were traced only in areas of abundant outcrop, notably in Dildo map-area (McCartney, 1957), and are too limited in areal exposure to warrant formal subdivision.

Intrusive bodies of purplish maroon to grey or grey-brown porphyritic trachyte are abundant along and near the shore of southwestern Trinity Bay. They contain pale orange oligoclase phenocrysts. Among the more important bodies is an elliptical neck, 3,000 by 2,000 feet in plan dimensions, that lies 1 mile south of Rantem Cove. Partly exposed apophyses of identical rock, probably sills, can be traced 2 miles north to coastal exposures of a sill-like body about 400 feet thick. The rock is offset to the northwest in the bay west of Rantem Cove. From the north shore the rock was traced north for 1 mile, and sporadic outcrops of identical lithology suggest that it is continuous with porphyritic rocks near Stock Cove. Southeast of Rantem, a multiple sill about 400 feet thick is well exposed along 2 miles of coast southeast from Big Chance Cove, and similar rock types are abundant 1¼ miles south of Big Chance Cove. The porphyritic rocks near Rantem Cove are thought to be near-surface feeders for the felsitic breccias, ignimbrites, and flows that are so conspicuous for 12 miles north of Rantem.

A pale pink spherulitic ignimbrite mottled with pale green lies amongst the massive pink felsite breccias that dominate the shore exposures. It contains coarse

crystals of quartz, microcline, and oligoclase in a microgranular quartz-feldspar groundmass. No outlines of shards are preserved. Although thin, this ignimbrite provides a useful stratigraphic marker below the massive breccias and associated rhyolite crystal tuffs. The rhyolitic breccia-ignimbrite-tuff beds are about 1,500 feet thick in southwestern Trinity Bay. They comprise a large outcrop width because they are involved in open folds and commonly strike parallel with coastal exposures. These structural features are not obvious in the massive section, hence the impressive coastal outcrops suggest an exaggerated thickness.

South from Rantem Cove in Trinity Bay to Fair Haven in Placentia Bay, the rhyolitic members are about one-sixth breccia, one-sixth to one-third intrusive and flow rocks, and about two-thirds rhyolitic tuffs. The tuffs include coarse crystal tuffs that contain abundant crystals, 2 to 3 mm in diameter, of angular micropertite and oligoclase, and fewer rounded partly resorbed quartz grains. Some tuffs that resemble trachyte porphyry contain up to 40 per cent phenocrysts. Similar trachyte crystal tuffs contain scattered 3 mm crystals of pinkish orange oligoclase in a dark siliceous greyish green matrix. Numerous small felsite fragments are present and the matrix weathers a chalky pinkish white. Many fine-grained green to pink rhyolitic lapilli tuffs have scattered and varied crystals in a dense greenish grey matrix.

A structurally important, fine-grained rhyolite breccia member, which grades laterally into fine-grained lapilli crystal tuff, lies near the top of the Bull Arm Formation, midway between Tickle Harbour in Trinity Bay and Fair Haven in Placentia Bay. It is between 200 and 300 feet thick, and is overlain by roughly 500 feet of mauve massive fine-grained tuff that is, at this locality, the uppermost member of the Bull Arm Formation. Because the rhyolite breccia and mauve tuff are present as the top members of the Bull Arm Formation for a distance of 15 miles, they prove that there is no angular truncation of the Bull Arm by the overlying Big Head Formation.

Two thin rhyolite members near Fair Haven in Placentia Bay display unusual features. One, a massive to flow-banded pink rhyolite, contains dark pinkish red clusters of piedmontite (a manganese epidote). The other member, a dark purplish red ignimbrite, shows marked sinuous pseudo-flow lines and contains abundant crudely spherical knots of coarse-grained quartz, averaging $\frac{1}{2}$ inch in diameter. Some transitional rocks within the second member contain large aggregates of fine-grained quartz. These transitions suggest that this member developed from spherulitic ignimbrite by recrystallization of the quartz in original spherulites.

Sedimentary rocks within the Bull Arm Formation are common, although not plentiful, and are especially important in studying the lower contact. Tuffaceous arkoses, red arkose, grey to grey-green dense laminated argillite and siltstone, and red siltstone are the common rock types, in order of decreasing abundance. These sediments form roughly one-fifth of the formation, but are rare on the shore of Placentia Bay from Long Harbour south to Placentia. In the large domal structure in the southwestern corner of the map-area, green and grey-green arkoses, tuffaceous arkoses, and siltstone become more abundant in proportion to the volcanic

rocks. The lower part of the formation is best exposed on the west shore of Great Pinchgut (lat. $47^{\circ}36'$, long. $53^{\circ}54'$), where red arkose, siltstone, bedded tuffaceous arkose, minor red conglomerate, and grey well-bedded siltstone form much of the lower part of the Bull Arm Formation. These red beds are underlain by grey-green siltstones that are interbedded with minor mafic flows and breccias on the north shore of Great Pinchgut.

Contact Relations and Age

The lower contact of the Bull Arm Formation is mainly hidden by major faults and, where exposed, difficult to define by lithology. Green-grey or grey fine-grained laminated beds low in the Bull Arm Formation are indistinguishable from rocks of the underlying Connecting Point Group. The lower contact is placed at the lowest recognized effusive rocks, as distinguished from the abundant underlying andesitic and basaltic sills and dykes. A contact within a syncline 2 miles west of Rantem Cove may be a conformable or disconformable lower contact of the Bull Arm Formation. Only two bands of poorly exposed basalt breccia are exposed in the syncline, and these breccias are identified as part of the Bull Arm Formation on the assumption that they are of pyroclastic or flow origin and not intrusive brecciated sills, which would indicate they were part of the Connecting Point Group. The synclinal structure above and below this assumed contact is identical; hence an angular unconformity is not present. Major faults define the contact at all or most other localities in the map-area.

The upper contact is transitional into overlying undivided Musgravetown sediments.

Rubidium-strontium ratios of ten samples collected and analyzed by H. W. Fairbairn indicate an age of 494 ± 30 m.y. (Fairbairn, personal communication, 1965).

Correlation

Field relations suggest that early Bull Arm volcanism accompanied some late stages of Connecting Point and Conception sedimentation, and volcanism may have continued while the Carbonear beds (Hodgewater Group) were being deposited in the central part of the map-area. The Bull Arm Formation, however, is not represented in the central or eastern parts of the map-area.

Tentative correlation of the Bull Arm Formation with some of the volcanic rocks of Burin Peninsula is suggested, but must await further field studies for verification.

Big Head Formation

Name, Distribution, and Thickness

The name Big Head Formation is here proposed for the predominantly fine-grained sedimentary rocks within the Musgravetown Group that overlie the Bull Arm Formation and underlie the red beds of the Maturin Ponds Formation. These

rocks are well exposed on the north shore of Long Harbour in Placentia Bay, where they form Big Head and extend west to the Point of the Gut. From Big Head, the formation extends north to latitude $47^{\circ}32'$, south of Tickle Harbour, and south to the southern border of the map-area. It is confined to the western quarter of the map-area. Thickness of the formation varies abruptly across a major tear fault along Long Harbour from about 1,500 feet north of Long Harbour to roughly 7,000 feet south.

Lithology

Red Beds. Red conglomerate and arkose beds about 100 feet thick lie near the base of the formation at the type section at Big Head. To the south, red beds form a basal subdivision, up to 1,200 feet thick, beginning 2 miles east of Ship Harbour (lat. $47^{\circ}23'$, long. $53^{\circ}50'$) and extending south to 1 mile beyond Placentia Sound, where they are terminated by a knob of basalt breccia. Farther south, at Northeast Arm, the red unit seems to be represented by red siltstones intercalated with basalt flows and breccias. Thus, the red basal subdivision appears to transgress the contact between the Big Head Formation and the underlying Bull Arm volcanic Formation.

Grey-green Siltstones. The dominant rock types in the Big Head Formation are grey-green and grey siltstone, slate, green cherty argillite, and arkose. These resemble, but are thought to be younger than, beds of the Conception Group and are regularly bedded and commonly laminated. Locally they show convolute bedding. They are from 1,500 to 3,800 feet thick except near Ship Cove in Placentia Bay, where they are thin and poorly defined. The grey-green siltstones form a prominent but variable proportion of the formation in all localities. South of Long Harbour, these beds form a middle subdivision, overlying the red beds discussed above, but at most localities north of Long Harbour and also in the stream near Ship Cove, in the southwestern corner of the map-area, they comprise almost the entire formation. In the stream near Ship Cove, minor volcanic breccia is intercalated with similar looking underlying beds and is assumed to belong to the Bull Arm Formation.

Arkose. South, and to a minor extent north, of Long Harbour, a lens of arkose overlies the grey-green siltstone and slate member of the Big Head Formation. The arkose is commonly massive and buff, greenish grey, or pink in colour. An unusual speckled appearance is characteristic. Locally, pink arkose resembles fine-grained granite, but laminated grey siltstone beds were eventually found in all questionable outcrops. Outcrops 1 mile south of Long Harbour Station (lat. $47^{\circ}28'$, long. $53^{\circ}44'$) are exceptionally massive.

As seen in thin section, the sandstones are well sorted, with subangular grains in a matrix consisting of sericite films and minor grains of epidote and chlorite. The matrix forms about 5 per cent of the rock. Fragments of felsic and mafic volcanic rocks are abundant, but generally less so than feldspar grains. In the darker varieties of sandstone, however, the proportion of rock fragments locally exceeds that of feldspar, and the rock is properly called a subgreywacke.

The arkose wedges out to the south at Northeast Arm, but thickens northward until it is 1½ miles northeast of Villa Maria (lat. 47°17' 30", long. 53°52'), from whence it maintains a uniform thickness of 2,000 feet northward to the east limb of a syncline, 2 miles southwest of Long Harbour Station. The arkose then extends to, but is truncated by, the Long Harbour fault (Fig. 3). Isolated outcrops are found farther north in fault segments, as close as 1½ miles from Broad Lake in southern Trinity Bay. Thin light grey to pinkish grey arkose beds, about 200 feet thick, outcrop in inland exposures on both sides of St. Croix Bay. This grey arkose is not present north of Long Harbour or northeast of Fair Haven.

The distribution of the arkose facies suggests a right-hand displacement on the Long Harbour tear fault, as discussed in Chapter III.

Contact Relations

The lower contact of the Big Head Formation is transitional and is arbitrarily drawn at the top of the uppermost known volcanic member of the Bull Arm Formation. At the type locality on the west shore of the point north of Crawley Island, in Long Harbour, a conglomerate, with angular to subrounded pebbles of basalt, minor slate, and diabase up to 1 inch in diameter, is interbedded with red arkose and conglomeratic arkose. It is underlain by green conglomerate with siliceous green siltstone and slate. These beds overlie basalt of the Bull Arm Formation, but the contact is not exposed. Minor tuffaceous beds occur within the formation at the type locality and a rhyolite dyke was observed in the lower beds. As previously described, red beds that form the base of the formation from near Ship Harbour south for 10 to 12 miles are overlain by basalt near Placentia Sound. Bull Arm volcanism is thus assumed to have continued longer near Placentia Sound than at Long Harbour, and the contact is considered transitional and time transgressive.

The upper contact with the Maturin Ponds Formation is exposed near the crest of Big Head. It is locally disconformable, with channels in greyish green siliceous siltstone filled with red pebble conglomerate. Near the road just north of Big Head, the contact is transitional for about 40 feet, with grey-green arkose in beds about 1 foot thick alternating abruptly with laminated siltstone, and grading upwards into a 10-foot thickness of dull pale purplish red siltstone and fine- to coarse-grained arkose. The arkose, in turn, is overlain by dark purplish red wavy bedded arkose and siltstone of the Maturin Ponds Formation. One mile north of Big Head, the contact is gradational upward from green siliceous siltstone into green gritty sandstone overlain by conglomeratic red arkose.

Correlation

The unusual persistence, equivalent thickness, and local massive appearance of the arkose and subgreywacke at the top of the Big Head Formation suggest a relation to the Halls Town Formation (Hodgewater Group) in the central part of the map-area. This crude lithological similarity is supported by the probable lithostratigraphic equivalence of the corresponding overlying beds (Whiteway and

Maturin Ponds Formations). However, the sandstones are separated by 14 miles of cover rocks, and facies differences prevent a definite lithostratigraphic correlation.

Maturin Ponds Formation

Name, Distribution, and Thickness

The name Maturin Ponds Formation is here proposed for red arkoses and siltstones that lie northwest of and adjacent to Maturin Ponds (north of Long Harbour near Placentia Bay). At this accessible type section, exposures are adequate and basal relations are well exposed. The name applies to beds conformably above the Big Head and below the Trinny Cove Formations. The red beds are confined to the western one-third of the present map-area south from latitude $47^{\circ}35'$ to the southwestern corner of the map-area, and southeasterly to their probable junction with similar beds of the Whiteway Formation and the lower part of the Snows Pond Formation at latitude $47^{\circ}12'$, longitude $53^{\circ}44'$. The thinnest section, which occurs in the southwestern corner of the map-area, is about 1,100 feet thick, but elsewhere the formation ranges from 1,500 to 2,200 feet thick.

Lithology

The lithology of the Maturin Ponds Formation is moderately uniform, but a distinctive massive red arkose is characteristic of the middle part of the formation north of Long Harbour, Placentia Bay, whereas a thick massive red conglomerate is prominent south of latitude $47^{\circ}15'$. At the type locality, the lower 500 feet of beds are purplish red arkose and siltstone with minor conglomeratic arkose. Bedding is clearly defined by thin dark red layers of siltstone in the pale red arkose and is mainly regular with less crossbedding and wavy bedding. From Long Harbour south to Northeast Arm, Placentia Bay, about 2,000 feet of beds of this type comprise the entire formation.

Massive red arkose forms a prominent and persistent bed at all localities north and northwest of Long Harbour. It lies in the middle part of the Maturin Ponds Formation and is consistently about 1,000 feet thick. Bedding in this member can seldom be discerned, even in well-exposed coastal outcrops. Vague streaks and swirls ("zebra-stripe bedding" is used as a field term) are defined by gradational deepening of the purplish red colour in elongate patches subparallel with the inferred bedding (Pl. VII). This colour change may be controlled by slight migration or more complete oxidation of the iron of the matrix following deposition of the sandstone; it is not related to change in grain size nor to discernible compositional variations.

South of Northeast Arm, Placentia Bay, purplish red, locally conglomeratic arkose in the lower part of the formation grades upward into a massive red conglomerate that is about 400 feet thick. Subangular to rounded pebbles average about 1 inch in diameter, but coarse parts of the conglomerate contain pebbles up to 4 inches in diameter. Red felsite pebbles are dominant; less common are pebbles of mafic volcanic rocks, siliceous green argillites, and white quartz.



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PLATE VII. *Purple-red siltstone and greyish red conglomeratic arkose and arkose from the Trinny Cove Formation, Musgravetown Group, showing typical bedding features. Lens of arkose in upper third; vague colour deepening, independent of grain size, within conglomeratic arkose ('zebra-stripe' streaking) in centre of photo; rapid fluctuations of grain size in lower part of photo. One-half natural size.*

The upper part of the Maturin Ponds Formation is bedded red arkose with darker red siltstone laminae. Bedding is regular, although it is wavy and irregular in some beds south of Northeast Arm. Crossbedding is common.

Feldspar slightly exceeds in abundance both rock fragments and quartz, as seen in most thin sections, but the arkose approaches a subgreywacke in composition.

Rock fragments are mainly volcanic fragments and fine-grained siliceous sedimentary rocks.

Source of Material

Paleocurrent directions were determined, with varying degrees of accuracy, at about 30 localities by planar crossbedding observations in the Maturin Ponds Formation south of latitude $47^{\circ}30'$. These directions show that currents flowed from $N35^{\circ}-70^{\circ}W$ of the observation points, with an average of $N60^{\circ}W$. Additional measurements made over a larger area would be useful, but were considered beyond the scope of the present study. A source area a few miles west of the east shore of Placentia Bay is inferred from current directions and the coarseness and common subangular shape of some conglomerate fragments. Bull Arm and Connecting Point rocks probably provided this detritus. A possible relation of such a source area to the Isthmus horst is discussed in Chapter III.

Correlation

Correlation, in a lithostratigraphic sense, of the Maturin Ponds Formation (Musgravetown Group) with beds including the Whiteway Formation (Hodgewater Group) is shown at their hidden junction at latitude $47^{\circ}12'$, longitude $53^{\circ}44'$, and has been discussed in a preceding section (pp. 40–42). A possible correlation with massive red arkose (Map-unit 11?) in the generally undivided Musgravetown sediments northwest of Bull Island, Trinity Bay, is based on marked similarities in lithology and thickness and on a roughly equivalent stratigraphic position.

Trinny Cove Formation

Name, Distribution, and Thickness

The name Trinny Cove Formation is here applied to beds conformably overlying the Maturin Ponds Formation and underlying the Crown Hill Formation or, where the Crown Hill cannot be recognized, the Random Formation. The name is chosen for the cove 19 miles northwest of Long Harbour, Placentia Bay, where the formation is exposed all along the east shore of the cove southward to its upper contact with distinctive red conglomerate (Crown Hill Formation) 2,000 feet north of Moany Cove, near Brine Islands.

The type section for this formation was selected, despite its distance from the type sections of the two underlying formations, because rocks in Trinny Cove are well exposed and dip uniformly to the southeast. Other sections are incomplete or are folded to give only partly understood repetitions of various beds. The principal disadvantage of the type section is that the beds there are offset by at least five faults. Movement on these faults is either known or is inferred to be minor within the type section selected.

The formation is present in three synclinal structures a few miles northeast, northwest, and southwest of Long Harbour, and is correlated with beds in the south-

western corner of the map-area. Beds overlying the Maturin Ponds Formation southeast of Long Harbour belong to the upper part of the Snows Pond Formation.

The thickness of the Trinny Cove Formation is roughly 2,200 feet at its type section. Variations in thickness elsewhere are not known because the top of the formation is not preserved in most other sections.

Lithology

Conglomerate, coarse arkose, and conglomeratic arkose are abundant in the type section. Irregularity and lensing of beds, abrupt changes in grain sizes, and channelling are characteristic (Pl. VII). Channels which form broad scours or sharp deep grooves are filled with coarse sandstone or conglomerate. Coarse beds are rare, however, 15 miles to the east of Trinny Cove. Red and grey-green variations are common, and a gradational colour change within beds is displayed along the coast 1 mile south of Trinny Cove.

Red beds dominate the middle part of the formation, and form about one-third of the lower and upper beds. Grey-green siltstone and arkose and minor grey conglomerate constitute almost one-half the Trinny Cove Formation, mostly in the lower and upper parts. Siltstone and slate are commonly finely laminated, but are locally contorted by contemporaneous deformation or by wavy bedding typical of the Snows Pond Formation.

The Trinny Cove Formation near Ship Cove, in the southwestern corner of the map-area, is dominantly grey-green finely bedded siltstone, slate, and less arkose with minor purple-red siltstone and one bed of grey conglomerate. The pebbles in the conglomerate are mostly green cherty argillite up to 3 inches in diameter, and are rounded to subangular. The formation at this locality is about 2,000 feet thick, and is overlain by up to 1,000 feet of red arkose and fine red conglomerate, which lie below the Random Formation.

Source of Material

The increasing westward abundance of conglomerate in the Trinny Cove Formation is interpreted as good evidence of a western source of material. The few crossbeds examined indicate current direction from the west or northwest.

Correlation

The position of the formation a few hundred to a thousand feet below the Random and above the Maturin Ponds (Whiteway?) Formations, as well as some similarities in bedding features, suggest a reliable correlation with most of the Snows Pond Formation. Lithofacies are different, however. These differences seem to represent a closer proximity to the source of detritus and a change from a mainly subaerial fluvial environment in the west to a submerged but shallow deltaic current-swept environment for the Snows Pond Formation in the central part of the map-area.

Crown Hill Formation

Name, Distribution, and Thickness

The name Crown Hill conglomerate member was originally proposed for the red conglomerate that lies at the top of the Musgravetown Group and is overlain by the white quartzite of the Random Formation (McCartney, 1958). This conglomerate has been elevated to formational stature. It underlies prominent ridges adjacent to the Deer Harbour syncline, including Crown Hill, and is well exposed opposite Sunnyside in Bull Arm and on the shores of Deer Harbour, southwest Trinity Bay. It comprises the upper beds in a syncline on Brine Islands, Placentia Bay. The formation ranges in thickness from 900 to 1,800 feet.

Lithology and Correlation

Bright red siltstone and dull red arkose are included in the lower 200 to 500 feet of the formation. The rest of the formation consists of distinctive red conglomerate containing pea- to walnut-sized pebbles, with subrounded pebbles up to 4 inches in diameter at some localities. Pebbles are red rhyolite, argillite, basic lava, and quartz.

The lithology is much the same throughout the northwestern part of the map-area, except that the conglomerate is sheared and green near Come By Chance River (lat. $47^{\circ}50'$, long. 54°). Red arkose and pea-sized conglomerate that underlie the Random quartzite in the southwestern corner of the map-area are not sufficiently similar to those of the Crown Hill Formation to warrant the use of the same name, although the beds are probably equivalent. They are exposed south from Gooseberry Cove.

To the north, the Crown Hill Formation has been recognized beneath the Random Formation in Random Sound, Smith Sound, and at Keels in Bonavista Bay (Jenness, 1963). Thus the formation maintains its lithostratigraphic identity for at least 40 miles north-northeast of Deer Harbour. It is also represented 25 miles south of Deer Harbour at Brine Islands, but is not present below the Random quartzite 19 miles south-southeast of Sunnyside, nor on the east shore of Trinity Bay 12 miles east of the Deer Harbour outcrops. This distribution is typical of the Precambrian sedimentary and volcanic facies of Avalon Peninsula, where lithostratigraphic units tend to maintain their identity for long distances along the regional north-northeasterly trend, but locally vary abruptly across this trend. This distribution reflects the trends of the original basins of deposition, of the Bull Arm and Middle Cambrian zones of volcanism, and of some major faults.

Undivided Musgravetown Sediments

Except for the Bull Arm and Crown Hill Formations, no formal lithostratigraphic subdivisions of the Musgravetown Group are proposed in the northwestern part of the present map-area. The informal units mapped previously there (McCartney, 1958) show structural trends and facies variations, but are of variable

lithology and thickness, and are here mapped as undivided Musgravetown sediments. Brief descriptions of these sediments that lie above the Bull Arm Formation but below the Crown Hill Formation follow.

Red Conglomerate, Red Arkose, and Green Siltstone

Conglomerate, arkose, and siltstone occur just above the Bull Arm Formation in the following three places: west of the Deer Harbour syncline; 2 miles south of Long Beach (lat. $47^{\circ}58'$, long. $53^{\circ}48'$); and 1,000 feet north of Great Mosquito Cove. Map-unit 4 on Map 18-1958 (McCartney, 1958) was shown to include the rocks in the first two localities, and Map-unit 8b those in the third.

Red conglomerate and coarse- to medium-grained red arkose, up to 350 feet thick, normally overlie the Bull Arm Formation. These rocks are overlain by about 500 feet of grey-green and grey slate, argillite, siltstone, arkose, and pea- to walnut-sized conglomerate in which siltstone is the dominant member. Conspicuous features include abrupt changes in grain size, rather irregular bedding, and rusty weathering calcareous lenses and nodules in some beds. The matrix of some of the conglomerate beds is a calcareous arkose. Rounded to subrounded pebbles are dominantly grey-green siliceous argillite and chert, which are probably derived from the Connecting Point Group.

Grey Siltstone, Slate, and Arkose

Dark grey siltstone, slate, and arkose in regular beds are well exposed on the eastern shores of Deer Harbour. They were shown as Map-unit 6 on Map 18-1958 (McCartney, 1958). Their development on the west limb of the Deer Harbour syncline is insignificant. Similar beds were seen near Gooseberry Cove at the south-east end of Random Sound just north of this map-area, but these rocks have not been recognized farther north. No equivalent lithological member is recognized south of Bull Arm. The basal and upper contacts of these grey sediments are transitional with red beds. Their thickness is at least 300 feet.

Miscellaneous Beds

Arkosic sediments enclosed in the northwestern part of the map-area are similar in lithology to parts of the Musgravetown sediments already described. Locally these sediments have been roughly subdivided in a map of the Sunnyside area (McCartney, 1958) into dominantly red or dominantly green types. The ratio of red to grey to green beds and their thicknesses vary so markedly, however, that this subdivision cannot always be made.

Contact Relations and Age

The lower contact of Musgravetown sedimentary rocks is transitional with the underlying volcanic rocks of the Bull Arm Formation at the base of the Big Head Formation near and south of Long Harbour, Placentia Bay. Exceptionally good exposures of the conformable contact between the undivided Musgravetown sedi-

ments and the Bull Arm volcanic rocks are visible on the west shore of Bull Arm near Great Mosquito Cove. A simplified stratigraphic section at the latter locality (see Table V) illustrates (1) the increase in the ratio of sediments to volcanic rocks near the top of the Bull Arm Formation; (2) the late minor lava flows that represent the uppermost members of the Bull Arm Formation; and (3) the thinnest known section of the rest of the Musgravetown Group, which is mainly undivided at this locality.

Table V

Simplified Stratigraphic Section of the Upper Part of the Musgravetown Group near Great Mosquito Cove, Bull Arm

Formation	Lithology (top)	Thickness (feet)
Crown Hill (> 1,250')	Red, pea- to walnut-sized conglomerate with some red arkose. On shore opposite Sunnyside	+ 1,000
	Bright red siltstone and red arkose with minor red conglomerate. 4,000 feet north of Great Mosquito Cove	200
	Not exposed. Conformity or possible disconformity	50
Undivided Musgravetown sediments (1,155')	Grey and green slate and siltstone with minor conglomerate	300
	Red laminated siltstone, arkose, and red conglomerate with pebbles up to 4 inches in diameter	25
	Greyish green and grey slate, siltstone, arkose, grit, and pea- to walnut-sized conglomerate	500
	Red conglomerate and red coarse- to medium-grained arkose	330
Bull Arm (> 1,270')	Andesite flow with brecciated upper part. 1,000 feet north of Great Mosquito Cove	60
	Red arkose with unusual lenticular, discontinuous buff interbeds	600
	Andesite flow	60
	Bright red conglomerate with volcanic pebbles loosely locked in an arkose matrix, associated with dull red subangular conglomerate and red pea conglomerate. North shore of Great Mosquito Cove	70
	Buff weathering, green, subangular conglomerate and overlying coarse, green arkose	40
	Coarse, red, angular conglomerate or agglomerate with fragments up to 4 inches in diameter	200
	Light pink, dense rhyolite crystal tuff or welded tuff	15
	Dull red, bedded agglomerate	20
	Grey, coarse arkose	150
	Massive, fine-grained rhyolite	15
	Maroon andesitic breccia and agglomerate	40
	Rhyolitic and andesitic crystal tuffs, fragmental crystal tuffs, and lapilli tuffs. South shore of Great Mosquito Cove	?
		<hr/>
		> 3,735

The upper contact of the Musgravetown Group is structurally concordant and appears to be conformable with the overlying Random Formation.

As outlined in a preceding section (p. 50), Bull Arm volcanic rocks indicate an age of 494 ± 30 m.y. (H. W. Fairbairn, personal communication, 1965).

Random Formation

Name and Definition

The name Random was selected by Walcott and Howley (Walcott, 1900) to describe "sandstones, quartzitic sandstone, and sandy shales" resting conformably on "Signal Hill conglomerate" (Crown Hill Formation in this report) and extending up to the base of the Cambrian system. The measured type section is 8 miles north of Whitbourne map-area, just east of Hickman's Harbour, Random Island.

The Random Formation was redefined by Christie (1950) to limit it to the beds below the Lower Cambrian green and red slates and limestone of the *Olenellus* (now *Callavia*) zone and above greywacke, conglomerate, or lava of the Musgravetown Group. As was defined by Christie, the formation contains white quartzite beds with interbedded arkose and siltstone. It underlies fossiliferous shale and limestones of Early Cambrian age, and overlies Precambrian rocks that are mainly arkosic or conglomeratic sediments and lack white quartzite. The beds thus defined agree with those of Walcott's (1900) original locality on Random Island. They have been recognized on the Avalon Peninsula (Hutchinson, 1953) and north of Whitbourne map-area (Christie, 1950; Jenness, 1963).

The base of the Random Formation is here defined as the base of the lowest quartzite member within the formation, irrespective of the type of late Precambrian sediments it rests upon. Such a definition is deemed necessary to eliminate the confusion caused by the inclusion of thick sections of underlying strata within the Random Formation. For example, Walcott, who had observed conglomerate (Crown Hill of this report) below quartzite at his type section, expected to find similar conglomerate beneath the Random, 24 miles to the south at Heart's Delight on the east side of Trinity Bay. Because conglomerate is negligible in the formation there, he incorrectly included 925 feet of Snows Pond Formation (as used in this report) with his Random, to give the commonly quoted thickness of Random Formation as 1,000 feet. The writer considers the Random Formation at Heart's Delight to be 45 feet thick. Similarly, Hayes (1948) incorrectly included part of the Musgravetown Group with his Random Formation in Random and Smith Sounds, as was pointed out by Christie (1950).

Distribution and Thickness

Quartzite typical of the Random Formation underlies all presently exposed isolated remnants of fossiliferous Cambrian beds in southeastern Newfoundland, including Avalon Peninsula, with the lone exception of southern Conception Bay.

The fossiliferous Cambrian beds in the latter area rest with angular unconformity on Harbour Main and Conception rocks.

The thickness of the Random Formation ranges from 18 to about 500 feet. The thickness is indeterminate in many localities because the lower contact is commonly hidden, and the formation is, in many places, tightly folded and contorted adjacent to the underlying competent arkoses or massive conglomerate. This contortion is discussed in Chapter III.

The maximum thickness of about 500 feet seems restricted to the west shore of Trinity Bay and to the axial region and west flank of the Trinity Bay synclorium. The thickness ranges from 45 to 90 feet on the southeast shore of Trinity Bay and west of St. Mary's Bay. On the southeast shore of Placentia Bay, the thickness ranges from 18 to 40 feet. The apparent thickness south of the mouth of Come By Chance River on the west edge of Whitbourne map-area is 60 feet.

Lithology

White quartzite and quartz-pebble conglomerate are characteristic of the Random Formation. At least one white quartzite bed is present with a fairly common pale purplish red quartzite which is found only in this formation. Most beds intercalated with white quartzite are similar to beds of the Snobs Pond Formation or parts of the Musgravetown Group below the Crown Hill Formation, but a few beds strongly resemble Lower Cambrian rocks. Thus a bright red slate underlies quartzite south of Gooseberry Cove in the southwestern corner of the map-area, and a grey silty slate with calcareous concretions is interbedded with quartzite on the north shore of Bull Arm, southwest Trinity Bay. At other localities, as on the west shore of Collier Bay in Trinity Bay, beds between the quartzite members of the Random Formation include a laminated siltstone that has alternating dark grey siltstone and quartzose white laminae about $\frac{1}{4}$ inch thick.

In contrast to all older sediments, the white and pale purplish red quartzites of the formation display a high degree of sorting and roundness and have an essentially monomineralic composition. As seen in thin section, the grain diameter of a megascopically typical pale red quartzite ranges from 0.1 to 0.5 mm, with an abundance of grains of about 0.3 mm diameter and a probable unimodal size distribution. Grains are coated with a thin hematite layer and are cemented by quartz. Shreds of white mica are dispersed throughout the intergranular areas. About 2 per cent of the grains are fine-grained siliceous fragments of cherty argillite and chert. The white conglomerates contain rounded quartz pebbles with a scattering of black cherty pebbles. These black pebbles may be the same as some small black cherty fragments observed in the quartzites, which can only have been derived, so far as the writer can ascertain, from black cherty members in the Connecting Point Group like those now exposed on and south of the Isthmus of Avalon.

Locally, the quartzite is markedly recrystallized, with individual grains showing strong strain shadows when examined under the microscope. This effect is most pronounced in specimens from the core of the narrow isoclinal syncline of Random

and Cambrian beds in the west-central part of the map-area (near lat. $47^{\circ}25'$, long. $53^{\circ}45'$).

Pyrite cubes with edges up to $\frac{3}{8}$ inch long are sparsely scattered through the white quartzite in some localities, as on the southeast shore of Trinity Bay.

Two quartzite members are present in a section of the Random Formation about 1 mile south of the mouth of Come By Chance River, Placentia Bay, whereas elsewhere one to four members occur. This section (*see* Table VI) is unusual because it lacks the thin calcareous conglomerate that usually overlies disconformably the uppermost bed of Random quartzite, and no evidence of a disconformity was discerned by the writer. Beds at this locality are overturned with a dip of 85 degrees east.

Table VI

Stratigraphic Section of Random Formation near Come By Chance River

Formation	Lithology (descending)	Thickness
Bonavista	Bright purple-red slate	Not measured
Bonavista?	Siliceous red siltstone	2'
	Sheared arkose	3"
Random	Crossbedded white quartzite	6'
	Grey, slaty siltstone	38'
	Crossbedded white quartzite	11' 6"
	Grey slaty siltstone interbedded with 1- to 2-inch quartzite beds	4'
Crown Hill	Sheared, dark grey, slaty siltstone	4'
(Musgravetown Group)	Greyish green, sheared conglomerate, base not exposed	+ 50'

The following section was measured 2 miles northwest of New Harbour; it lacks non-quartzose interbeds and is therefore typical of the formation in southeastern Trinity Bay.

Contact Relations and Age

The Random Formation in Whitbourne map-area is either of late Precambrian or Early Cambrian age. Some workers believe it can be either (Hayes, 1948; Christie, 1950); others believe it is Precambrian (Walcott, 1900; Hutchinson, 1953); there are still others who place similar white quartzite west of this area in the Lower Cambrian (Van Alstine, 1948; Rose, 1948; Widmer, 1950). The writer believes that white quartzite in southeastern Newfoundland varies in age, is more significant in a lithostratigraphic than in a time sense, and is related to the initiation of the Cambrian depositional sequence rather than to a final stage of Precambrian sedimentation.

Table VII

*Stratigraphic Section of Random Formation near New Harbour,
Southeast Trinity Bay*

Formation	Lithology (descending)	Thickness
Bonavista	Red, pebble-conglomerate with a calcareous matrix and well-rounded quartzite pebbles	1' 6"
Random (87' 7")	Pebble-conglomerate with dominantly red felsite pebbles and about 20 per cent quartz pebbles in a white quartzite matrix. Pebbles are fairly well rounded with an average diameter between $\frac{1}{4}$ and $\frac{1}{2}$ inch and a maximum diameter of $1\frac{1}{2}$ inches. Bedding shown by size variation	5' 10"
	Massive, light grey quartzite. Bedding discernible but not conspicuous	6'
	Similar light grey quartzite with well-defined purple-red bedding laminae at irregular, but generally about 1-inch, intervals. Laminae thickness $\frac{1}{16}$ to $\frac{1}{4}$ inch	11' 9"
	White to purple-red quartzite with some beds of pea conglomerate. Purple-red bedding laminae are caused by films of hematite on individual grains. Crossbedding is abundant and shows a normal tangential relationship with underlying beds	64'
	Covered area	5'
Snows Pond	Dark purplish grey, fine-grained arkose. Bedding formed by dull purple siltstone beds about $\frac{1}{4}$ inch thick at intervals of 1 inch to 6 inches	9' 9"

Fault strikes 120° , dips 85° south. Shows no visible displacement, but contains about 1 foot of gouge. No white quartzite lies southeast of the fault.

A shallow angular unconformity is thought to underlie the Random Formation in southeast Trinity Bay. Although it is not apparent in the outcrops preserved, Hutchinson (1953) inferred an "angular discordance" below the Random Formation because fold axes in Random and Cambrian beds diverge by 30 degrees from the trend of fold axes in the adjacent older Hodgewater Group. He believed a prolonged period of weathering and erosion was represented during the accumulation of the Random sediments. The writer confirmed this divergence of fold directions and indicated a low-angle truncation of 4,000 feet of upper Snows Pond beds by the Random Formation (McCartney, 1957). Elsewhere in the present map-area, the Random Formation appears concordant but rests on several rock types (Crown Hill conglomerate, green arkose, red arkose, and red pea-conglomerate).

Walcott (1900), basing his opinion on a disconformity observed at the base of overlying fossiliferous Lower Cambrian beds, considered the Random Formation the upper member of the Precambrian sedimentary rocks. Although the conglomer-

ate and disconformity were not significant looking features, Walcott concluded that it was not safe to assume they marked only a slight erosion interval. Hutchinson agreed with Walcott's interpretation, and placed both the Random and Blue Pinion Formations of Fortune Bay in the Precambrian, although he believed that the disconformity did not represent a major time interval (Hutchinson, 1953, 1956).

The interpretation of the Random and similar quartzites in southeastern Newfoundland most acceptable to the writer is that they represent shoreline deposits formed in late Precambrian and/or Early Cambrian time by a Cambrian sea transgressing a regolith developed on poorly consolidated late Precambrian sediments of low relief. This interpretation explains the variation in Cambrian age of fossiliferous beds overlying the Random and similar quartzite and the remarkable persistence of a thin quartzite blanket, where Cambrian beds are preserved, over an area of 7,500 miles in southeastern Newfoundland. Some further data on contact relations of the Random Formation are given in Chapter III.

Cambrian Rocks

The Cambrian beds within the map-area form a sequence of shale, slate, and limestone up to about 1,500 feet thick and, in southern Conception Bay, are overlain by Lower Ordovician shale and sandstone beds estimated to be more than 8,000 feet thick (Rose, 1952).

The fossiliferous Cambrian rocks of southeastern Newfoundland have been studied by Walcott (1888, 1900b), Howell (1925), and Hutchinson (1956). Formation names used here follow those redefined by Hutchinson (1956, 1962), and the present discussion is restricted to avoid duplication.

The writer's Cambrian fossil collections are listed in summary fashion in the appendix.

Lower Cambrian Series

Definition and Contact Relations

The Lower Cambrian beds lie disconformably on the Random Formation or, in Conception Bay, rest with angular unconformity on rocks of the Harbour Main and Conception Groups and nonconformably on quartz monzonite. They are overlain with probable disconformity by manganese beds of the Middle Cambrian *Paradoxides bennetti* zone (Chamberlain's Brook Formation).

The Lower Cambrian Series is subdivided into three conformable formations related to lithological variations and controlled by faunal zones. Hutchinson (1956) recognized three faunal zones extending upward from a pre-*Callavia* fauna of brachiopods and hyolithids through a *Callavia* zone to a *Protolenus* fauna lacking *Callavia*.

The relation of faunal zones to the formations in which the distinctive Smith Point Limestone forms the key division was shown by Hutchinson (1956, 1962).

Distribution and Thickness

The distribution of the Lower Cambrian beds within the map-area is restricted to isolated, downfolded and/or downfaulted blocks in southern Conception Bay; to a zone, the Chapel Arm Synclorium, extending through eastern Trinity Bay and for 25 miles to the south; to parts of the west shore of St. Mary's Bay; and to the southwest and northwest corners of the present area. This distribution, and the continuity of distinctive lithological units, suggests that the sea, in late Early Cambrian time, covered the entire map-area with the possible exception of the present highland area south and southeast of Holyrood Bay.

The principal feature of the series within the map-area, as discussed by Hutchinson (1962) is the rapid thickening westward from Manuels River (12 miles northeast of Holyrood), where the Bonavista and Smith Point Formations are absent, to maximum thickness in a northerly trending zone in eastern Trinity Bay. The writer suspects that overlap occurred southeast of Conception Bay, which allowed Middle Cambrian beds as well as the Lower Cambrian Brigus Formation to lie directly on Precambrian rocks. This suspicion is based upon the occurrence of two large blocks of probable Middle Cambrian¹ grey shale in a gravel pit south of the Cambrian contact at the highway near Seal Cove, and the apparent absence of Lower Cambrian detritus in the gravel. Precambrian rocks are exposed in a nearby stream. As such detritus near basal Cambrian rocks commonly contains Lower Cambrian (and Precambrian) fragments, it seems likely that a patch of Middle Cambrian shale, which provided the observed blocks, rests on or has been removed from granite south of the Seal Cove pit. The scarcity of outcrops in this area has so far prevented verification of this overlap interpretation.

The total thickness of the Lower Cambrian Series increases from about 75 feet at Manuels River (Rose, 1952) to about 450 feet west of Colliers Bay, Conception Bay, and to 579 feet near New Harbour in southeast Trinity Bay (Table VIII). A maximum thickness of 1,000 feet has been reported in western Trinity Bay (Hutchinson, 1956).

Lithology

Bright red and apple-green shales and slates, commonly with limestone nodules, and pink algal limestone are distinctive and fairly reliable criteria for recognizing Lower Cambrian beds. The following measured section 2 miles northwest of New Harbour, southeast Trinity Bay, best illustrates the stratigraphy of the Bonavista, Smith Point, and Brigus Formations (Table VIII).

Conglomerate. The conglomerate at the base of the fossiliferous Cambrian section rests disconformably on the Random quartzite west of Conception Bay. Around Conception Bay, the conglomerate rests with angular unconformity on the Harbour Main and Conception Groups, and with nonconformity on quartz monzonite in Holyrood Bay. In southern Conception Bay, rock fragments locally derived from below the unconformity predominate in the pockets and layers of conglomerate. The

¹No grey shale has been recognized within the Lower Cambrian of southeastern Newfoundland.

Table VIII

*Stratigraphic Section of the Lower Cambrian Series near
New Harbour, Trinity Bay*

Formation	Bed	Lithology (descending)	Thickness	Total Thickness
		Manganiferous carbonate beds 7½ feet thick with <i>Paradoxides bennetti</i> at the top (Basal Middle Cambrian)		
		Disconformity ?		
Brigus	37	Grey-green slate with no visible manganese	7'6"	7'6"
	36	Layer containing manganiferous, black- weathering nodules	1"	7'7"
	35	Grey-green slate	52'	59'7"
	34	Red and, in smaller amounts, purple-red slate, with an interfingered transitional contact with overlying slate	33'	92'7"
	33	Green slate	9'	101'7"
	32	Fissile, bright red slate lacking nodules	44'	145'7"
	31	Green slate	4'	149'7"
	30	Dark grey, massive limestone with pink lime- stone blebs and rare fossils	6"	150'1"
	29	Green slate	4"	150'5"
	28	Pink and greenish limestone, fossiliferous	4"	150'9"
	27	Grey-green silty slate. Bedding shown only by discontinuous dark grey streaks visible on wave-smoothed surfaces. Sparse black nodules	55'	205'9"
	26	Medium grey limestone with <i>Protolenus</i>	3"	206'
	25	Green silty slate with poor cleavage	14'	220'
	24	Red slate with sparse calcareous nodules	35'	255'
	23	Well-laminated limestone	2"	255'2"
	22	Red slate with sparse calcareous nodules	9'	264'2"
	21	Red slate with abundant pink limestone nodules aligned along particular bedding planes	9'6"	273'8"
	20	Bright red slate with a purple-red band 1½ feet thick	5'	278'8"
	19	Green slate mottled with a purplish tinge, especially toward the top	5'6"	284'2"
	18	Red slate with two limestone nodule beds near the top	4'10"	289'
	17	Green slate lacking nodules	14'	303'
	16	Red slate with fairly abundant nodules and vague streaks along bedding	112'	415'
	15	Pink limestone	6"	415'6"
	14	Red silty slate and slate. Limestone nodules sparsely scattered along some bedding planes	10'	425'6"
	13	Pink limestone	3"	425'9"
	12	Red slate with limestone nodules	5'	430'9"

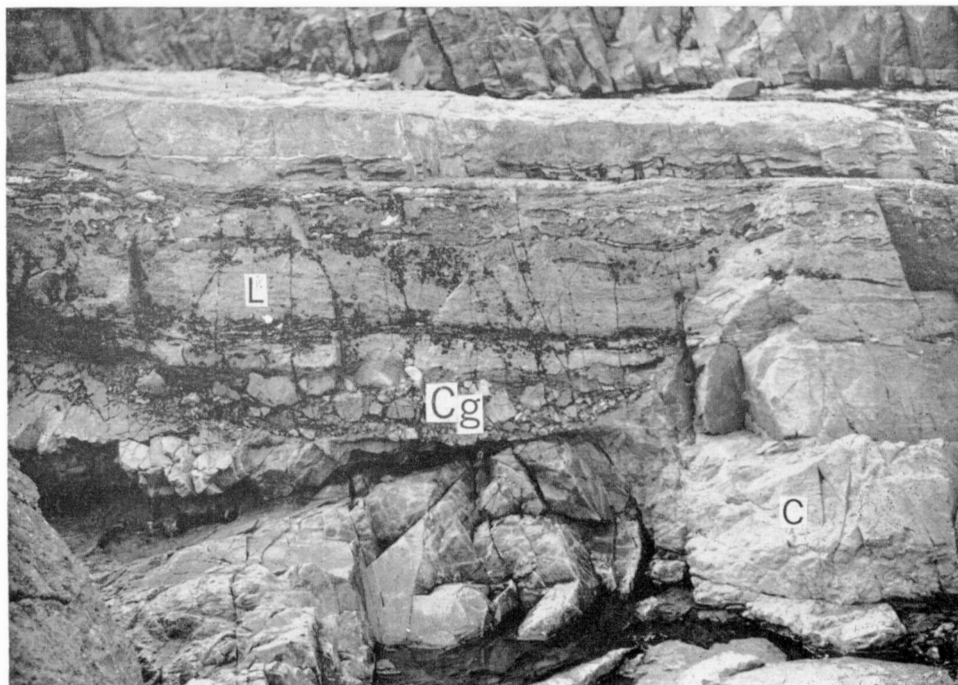
Table VIII (*conc.*)

Formation	Bed	Lithology (descending)	Thickness	Total Thickness
Smith Point	11	Pink algal limestone	1'6"	432'3"
	10	Red slate	4'3"	436'6"
	9	Pink limestone	4"	436'10"
	8	Red slate	9"	437'7"
	7	Pink limestone with abundant algal beds	5'	442'7"
	6	Pink algal limestone with dark red algal layers at 6- to 24-inch intervals	36'	478'7"
	5	Pink limestone with irregular interbeds of green calcareous argillite	6'	484'7"
Bonavista	4	Bright brick-red slate with nodules generally restricted to a thin bed 10 feet from top	42'	526'7"
	3	Light green, silty slate with bedding faintly discernible in a few places by gradational colour variation	49'	575'7"
	2	Moderately clean limestone in upper 3 inches grading downward to pebbly limestone. Mainly pockets of conglomerate enclosed by irregular pink limestone blebs	8"	576'3"
	1	Pebble-conglomerate with red felsite pebbles and fewer white quartz pebbles. Sub- rounded with average diameter of ¼ to ½ inch, maximum diameter 1¼ inches. Matrix calcareous, with pebbles weathered out in relief	9"	577'
		Disconformity		
Random		Siliceous conglomerate and quartzite		

conglomerate is a basal part of both the Bonavista Formation (in Trinity Bay) and the Brigus Formation (in southeastern Conception Bay).

At Bacon Cove, Conception Bay, the basal clastic section varies rapidly in thickness from 0 to 3 feet, and is thickest in depressions on the steeply dipping Conception siltstone and slate (Pl. VIII). The basal conglomerate contains angular to subrounded pebbles and blocks of Conception slate up to 1 foot long, in a matrix of calcareous arkose. Most observed arkose grains are subangular to subrounded quartz, with less feldspar, felsic lava, and tuff fragments, and no mafic volcanic fragments. The upper part of the clastic beds is overlain by massive pink limestone which, in adjacent outcrops, rests directly on the Conception Group.

West of Colliers Bay, Conception Bay, the basal clastic beds are similar, but rest on andesite of the Harbour Main Group. Basal conglomerate is generally pea-sized and composed almost entirely of dull red andesitic fragments in a calcareous silty matrix.



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PLATE VIII. Limestone (L) and a lens of basal Cambrian conglomerate (Cg) above contorted Conception siltstone (C), marking angular unconformity at Bacon Cove in Conception Bay. Conglomerate lens is up to 10 inches thick.

At Duffs, Holyrood Bay, black arkosic calcareous siltstone contains abundant angular fragments of grains identical to those in the nonconformable underlying granite.

Around and south of Trinity Bay, the Cambrian conglomerate is invariably underlain by the Random Formation, and the pebble content is dominantly felsite and quartz with minor amounts of slate and siltstone. Quartz and felsite fragments are mainly subrounded. Angular or flat fragments, present in small amounts, strongly resemble nearby late Precambrian arkose and siltstone, which is present below or within the Random Formation.

Basal contact relations are further discussed in Chapter III.

Shale and Slate. The slate, shale, and thin limestone beds of the Lower Cambrian Series are much the same in both Bonavista and Brigus Formations. They are assigned to their respective formations by their positions below or above the Smith Point Limestone and by their fossil content. Red is the dominant colour; there is less bright green and grey-green, and colour changes within members are locally visible. Changes from red to green are especially common adjacent to faults, fractures, and even along some joints. Locally, the colour changes within a member show no

apparent relation to mechanical breaks. Bedding throughout the shale-slate sequence is lacking or vague in many exposures and, where discernible, is defined by layers containing scattered limestone nodules, by rare limestone beds, or by streaky or gradational colour boundaries. Variation in grain size, if present, is too gradational to form clear bedding planes, and siltstones are lacking.

Limestone. The Smith Point Formation comprises the only limestone bed of significant thickness on Avalon Peninsula. Massive pink algal limestone in the lower part and pink limestone alternating with crenulated laminae and thin beds of deep red argillite in the upper are typical of the formation. The formation is present in all areas of Lower Cambrian rocks within the map-area west of Holyrood, Conception Bay. Because it commonly forms scarps or elongate shoreline points, limestone is often the best exposed of the Cambrian sediments. Regular scarps are well developed high on the west shore of Colliers Bay, Conception Bay, and south of Thornlea, Trinity Bay.

Some unpublished geological and chemical data pertinent to cement production were prepared by J. C. Bogert (1939) following his investigation of the formation in southeastern Trinity Bay. The increased local demand for agricultural lime warrants the following summary.

Table IX
Analyses of the Smith Point Formation
(Summarized from Bogert, 1939)

Number	1a	1b	1c	1d	2a	2b	2c	3a	3b	4a	4b	4c
Thickness Relations	7'2" Top	8'2" Middle beds 2' below 1a	11'6" Below 1b to bottom	26'10" Weighted average	3'6" Begins 4' from top, continues downward	7'6" Begins 3' below 2a	4'3" Begins a short distance below 2b	18'3" Upper beds	9' Below 3b	Within limestone	Within limestone	Selected specimens
Description	Red limestone	Light red limestone	Pink limestone		Abundant crypto-zoons	Red limestone	Pink limestone	Red limestone	Pink limestone	Crypto-zoon	Shale	Limestone
SiO ₂	18.90	21.89	18.00	19.61	18.24	16.30	13.23	30.44	21.22	35.11	50 to 70	14 to 22
Al ₂ O ₃	6.47	0.74	2.04	2.85	4.62	3.38	2.54	2.08	2.07	4.83	13 to 23	3.5 to 6
FeO	0.54	0.57	1.36	0.91	0.36	0.57	1.00	0.93	1.36			
Fe ₂ O ₃	1.71	1.65	0.06	0.99	2.96	1.94	0.68	1.55	0.28	10.90	6 to 10	2 to 2.5
CaCO ₃	70.21	72.33	75.92	74.23	69.78	73.28	78.53	63.55	72.11	44.05	2 to 25	65-78
MgCO ₃	1.92	1.32	2.07	1.82	2.66	2.15	2.55	2.05	2.24	3.20		

Locality description: 1a-1d; Donalds Cove, Heart's Delight (upper 10 feet not sampled). 2a-2d; Western Point, Heart's Delight (lower 13 feet brecciated and not sampled, top 4 feet not sampled). 3a-3b; hilltop outcrops south of Cavendish (weathered outcrops tend to reduce CaCO₃ content and do not expose full width). 4a-4c; selected specimens from trenches north of Heart's Desire.

The proportion of interbedded shale in the limestone evidently increases to the south and west from Heart's Delight, Eastern Trinity Bay. Thus the analyses presented in Table IX may represent the highest calcium carbonate content that could be expected in the formation.

Age and Correlation

The fauna of the Lower Cambrian rocks are readily assigned to the standard zones of the North Atlantic faunal realm. As shown by Hutchinson (1956, Table 5), the fossiliferous Lower Cambrian beds of Trinity Bay are equivalent to and older than those of New Brunswick (Hanford Brook Formation) and Cape Breton Island (MacCodrum Formation). The unfossiliferous quartzites and associated clastic beds that conformably underlie fossiliferous beds at St. John, New Brunswick (Ratcliffe Brook and Glen Falls Formations; Hayes and Howell, 1937), and on Cape Breton Island (Morrison River Formation; Weeks, 1954) may be as young as the lower part of the Brigus Formation (Hutchinson, 1956, Table 5) or may be older Cambrian or late Precambrian (Weeks, 1954).

Middle Cambrian Series

Definition and Contact Relations

Beds of this series, with the exception of a basal manganiferous member and an areally restricted volcanic member, lack distinctive lithological marker horizons, but fossil distribution allows a satisfactory subdivision into faunal zones. Howell (1925) recognized five divisions in what are now classed as Middle Cambrian beds. He considered the lowest of these, comprising manganiferous beds, to be of uncertain, but probably late Lower Cambrian, age. Hutchinson (1956) reported *Paradoxides bennetti* in these beds, and the writer has collected the same species from the upper part of the manganese zone in Trinity Bay. Hence Hutchinson (1956) added the manganese beds to the base of Howell's Chamberlain's Brook Formation of the *Paradoxides bennetti* zone.

Shales containing *Paradoxides hicksi* were named the Long Pond Formation, and those containing *Paradoxides davidis*, the Kelligrew River Formation by Howell (1925). He considered overlying unnamed beds to be of unknown age but to possibly contain a *Paradoxides forchhammeri* fauna. The shales of these three zones, *P. hicksi*, *P. davidis*, and *P. forchhammeri*, make up the Manuels River Formation as defined by Hutchinson (1956; definition modified by personal communication). This twofold formational subdivision of the Middle Cambrian Series is followed in this report.

Lithological variations within the Middle Cambrian Series are subtle and cannot always be relied upon in identifying the two formations under consideration. Particular rock types that are troublesome in attempting lithostratigraphic formational subdivisions are grey-green unfossiliferous massive slate and dull red slate. Grey-green slate comprises most of the Chamberlain's Brook Formation, but is also common in the underlying unfossiliferous upper part of the Brigus Formation. Red slate is restricted in most areas to the Lower Cambrian strata, but locally is conspicuous in the lower part of the Chamberlain's Brook Formation, as in the coastal cliffs north of Norman's Cove, southern Trinity Bay. Dark grey to black slates,

present in the Manuels River Formation, are lacking in Cambrian beds below the upper part of the Chamberlain's Brook Formation.

Fossils are sufficiently well distributed throughout the Middle Cambrian Series, especially in limestones and nodules, to enable the three lower *Paradoxides* zones to be identified in good coastal outcrops. The large *Paradoxides* can commonly be identified on bedding surfaces in slate in coastal outcrops, but cannot always be collected owing to the development of cleavage oblique to the bedding planes. As fossils can seldom be found in scattered inland exposures, the Middle Cambrian beds are not subdivided on the geological map that accompanies this report.

Middle Cambrian beds at Manuels River, southeastern Conception Bay, are fully described by Howell (1925) and mentioned only briefly here. Throughout the area they are similar in faunal content and lithology, with the exception of the Chapel Arm volcanic member.

Contact relations within the Middle Cambrian Series appear conformable and transitional with no significant lithological variation. Hutchinson (1956) favoured a disconformity at the base of the Middle Cambrian Series because of a faunal break below the manganese zone and because he found two localities where shale-pebble conglomerate formed the base of the manganiferous member. The writer has collected large specimens of the manganese bed from all localities on the shores of southern Trinity Bay. Although surface oxidation normally masks the internal texture, many of these specimens, after being sawn and polished, show a marked chaotic breccia-like distribution of angular calcareous fragments up to an inch in diameter. A diastem or disconformity is thus indicated and, although underlying beds are sparsely fossiliferous, the apparent coincidence of this lithological break with the base of the *Paradoxides bennetti* zone suggests a disconformity.

Distribution and Thickness

The two principal areas of exposed Middle Cambrian beds are the coastal fringe of southeast Conception Bay, and part of the Chapel Arm synclinorium extending from latitude 47°45' to latitude 47°23' in southeast and south Trinity Bay. Lower beds of the Chamberlain's Brook Formation are also preserved in southern Conception Bay at Red Rock Cove; in Salmon Cove in Gasters Bay; west of Colliers Bay; and south of Brigus Bay. In the northwestern corner of the map-area, one outcrop at Goobies is probably Middle Cambrian in age; other remnants of these rocks may be present north of Sunnyside, below a cover of till.

The Middle Cambrian beds at Manuels River are about 300 feet thick (Rose, 1952) and on the south shore of Trinity Bay, about 780 feet thick. Approximate thicknesses of the Chamberlain's Brook and Manuels River Formations in southern Trinity Bay are 350 and up to 430 feet, respectively.

Lithology

Chamberlain's Brook Formation. This formation is mainly dull grey-green slate, with dark grey slate in the upper third of the section. Limestone beds less than 2 feet thick are restricted to the upper half of the formation.

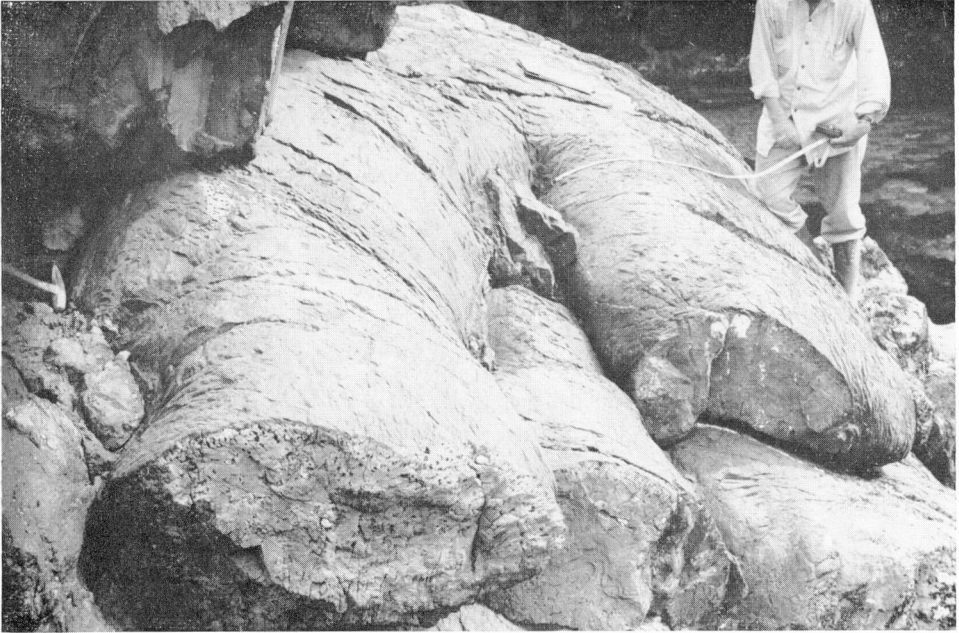
The basal manganese member forms a distinctive horizon and has been described in detail by Dale (1915). Manganese localities in southern Trinity Bay not formerly described show the same characteristics as, but are thinner than, those in southern Conception Bay. These new localities were shown on a previous map (McCartney, 1957) and are discussed in Chapter IV. The manganese member is readily recognized around Conception and Trinity Bays, but was not found to the south on the west shore of St. Mary's Bay. A manganese locality near Ship Cove, Placentia Bay was incorrectly reported by Dale (1915, Pl. XIV, pp. 376, 433), who stated that a bed of manganese carbonate from Placentia Bay, said to have been analyzed by Hunt in 1857, was described by A. Murray. Murray, however, did not work in Newfoundland until 1861. Jukes is the only geologist known to the writer who visited Placentia Bay prior to 1857, and if he had collected the specimens, it would probably have been from near Mortier Bay, southwestern Placentia Bay where he described bands of indurated white "marl" and concretionary limestone (Jukes, 1843, vol. 2, pp. 280-283, section 7). Jukes was not near Ship Cove in this map-area and no Middle Cambrian beds lie on the east shore of Placentia Bay. A diligent search by the writer failed to find the source of the quotation given by Dale (1915, p. 433).

Grey and white volcanic breccia and bedded tuff, 16 feet thick, were found in the formation only near Hopeall Head, eastern Trinity Bay.

Manuels River Formation. The overlying Manuels River Formation is mainly a sequence of dark slates, with minor limestone beds and black and grey limestone nodules. Dark grey to black slate and shale with fine regular distinct bedding is typical of the formation. Lavas are absent from the formation adjacent to Conception Bay and northern Trinity Bay.

Pillow lava and breccias, here called the Chapel Arm Member, are restricted to a belt from Hopeall Head south to Cape Dog, St. Mary's Bay, and are well exposed on the shores of Chapel Arm (Pl. IX). The base of the andesite pillow lavas is normally a regular plane resting on dark grey to black slate or, in southern Chapel Arm, on light grey bedded tuffaceous limestone. Two flows, separated by about 20 feet of slate, comprise the member at most localities in Chapel Arm. The andesite is pale to dark grey and commonly contains calcite amygdules. In many pillows, the amygdules are more abundant and the andesite matrix is finer grained in the outer zone. Grain size and textures vary considerably. The fine-grained lava shows a felted texture with andesine laths up to 0.2 mm long, irregular smooth blebs of chlorite 0.3 to 0.5 mm long, and calcite patches up to 1 mm in diameter. The ratio of andesine to chlorite is about three to one, and the rock has a highly variable and irregularly distributed calcite content up to 30 per cent. In the coarse-grained parts of the pillows, minor orthoclase is interstitial to andesine and is mainly concentrated in irregular patches.

Coarse andesite breccias are associated with the pillow lava at Hopeall Head, eastern Trinity Bay, and at Cape Dog, St. Mary's Bay. Structural relations at the former locality are obscured by faults adjacent to the thick mass of breccia, but



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PLATE IX. Bifurcation pillow in the Chapel Arm lava flow, Manuels River Formation, on east shore of Chapel Arm, Trinity Bay.

parts of the breccia containing smaller fragments are crudely stratified and suggest a submarine environment of deposition. At Cape Dog, vesicular pillow lavas appear to grade into andesite breccia from west to east. These volcanic rocks are at least 400 feet stratigraphically above a fossil locality containing *Paradoxides bennetti* on the west shore of Cape Dog, and they are probably above the *P. bennetti* zone in the Manuels River Formation. The upper limit of the *P. bennetti* zone was not accurately defined at this locality, however, and the lavas could be slightly lower in the section than their lithological equivalents in Trinity Bay.

Crudely bedded tuff, lacking pillow lava, lies within the *Paradoxides davidis* zone at scattered points for 1½ miles along the southwestern shoreline in Chapel Arm, Trinity Bay. These tuffs are separated by a fault from the thick pillow lava that occupies the coast south from Norman's Cove. At one locality south of this fault, however, the tuff horizon is occupied by amygdaloidal lava, only 3 feet thick, that is underlain by dark grey tuffaceous bedded limestone. Thus the pyroclastic beds of southwest Chapel Arm overlie the same limestone as the pillow lava in southern Chapel Arm and are a tuffaceous facies of the Chapel Arm Member within the *Paradoxides davidis* zone.

Spread Eagle Gabbro Bodies. Diabasic gabbro (Map-unit 18) forms at least eleven isolated small necks, in the central part of the map-area, which show a marked southerly trend, extending at least 19 miles south from Trinity Bay in a

zone no more than 3 miles wide. They commonly form isolated steep hills, such as Spread Eagle Peak, but small bodies form subdued knobs with outcrops restricted to the crest. Most bodies are subcircular in outline and are believed to be volcanic necks. An exception is the large sill west of Chapel Arm that occupies the contact between Random and Cambrian beds along part of its length, then transgresses bedding to the northeast and stratigraphically upward. At Norman's Cove, this sill probably joins a gabbro neck that is intrusive into the lower part of the Chamberlain's Brook Formation (lower Middle Cambrian), the youngest beds known to have been intruded by the gabbro in Whitbourne map-area.

The gabbro is crudely diabasic and dark green. Fresh specimens are difficult to obtain from the rounded outcrops. Outcrops weather an orange-brown colour. In thin section, the rock is seen to be mainly saussuritized labradorite laths with coarse intergranular crystals of partly chloritized augite.

The distribution of these small necks or plugs is confined to areas in which the Chapel Arm Member was deposited in upper Middle Cambrian beds. The gabbro necks were probably feeders for the Chapel Arm lava, in which case one or more necks should lie close to the thick breccia zones at Hopeall Head in Trinity Bay and at Cape Dog in western St. Mary's Bay. Although such necks have not been found as yet, it is possible that future magnetic anomalies around the two localities may reveal their presence.

Age and Correlation

The Middle Cambrian beds are more commonly represented in Whitbourne map-area than elsewhere in Eastern Canada, with the four *Paradoxides* zones of the standard North Atlantic faunal realm being present. Faunal correlations have been presented by Hutchinson (1952, p. 54; 1956, Table 5, 1962).

Upper Cambrian Series

Definition and Contact Relations

Van Ingen (1914) applied the name Elliot Cove Formation to all Upper Cambrian rocks near Elliott's Cove, Random Island, 10 miles north of the present map-area. Only the lower part of this formation is exposed in and east of Whitbourne map-area. The *Agnostus pisiformis*, *Olenus*, and *Peltura* zones have been recognized by Hutchinson (1956).

The lower contact with the Manuels River Formation is apparently conformable and occurs in an unfossiliferous sequence of finely bedded dark grey to black slates. The upper contact is not known to be exposed in southeastern Newfoundland; the Cambrian beds are believed to be overlain, but not with angular discordance, by Lower Ordovician beds (Hutchinson, 1956). Palaeozoic sandstones, which, in this area, first appear in the upper parts of the Elliot Cove Formation, become more abundant in the Ordovician beds. Thus the upward increase in sandstone: shale ratio is thought to be a transitional rather than an abrupt feature. The uppermost Cambrian beds and about 800 feet of the lowermost Ordovician beds are

concealed in Whitbourne map-area beneath the waters of Conception Bay south of Kellys Island.

Distribution and Thickness

Exposures of the Upper Cambrian beds in the map-area are extremely rare and sparsely fossiliferous, and only the lower zone (*Agnostus pisiformis*) has been questionably identified in the writer's collections (see Appendix). This zone is exposed near the southeast coast of Conception Bay in a bluff of black fissile pyritiferous shale 0.1 mile north of Lawrence Pond and in dark slate one mile south of McLeod Point near the east shore of Chapel Arm, Trinity Bay. In addition, the zone is probably present in dark grey slate and grey siltstone in a syncline on the east shore of Trinity Bay at latitude 47°44', longitude 53°30' (see *Frontispiece*).

A pale green-grey slate, containing *Orusia*, forms a low, partly submerged outcrop on the west bank of Lower Gullies River about 500 feet south of the highway near southeastern Conception Bay.

Lithology

The few exposures observed within the area do not allow a valid description of the formation. Good exposures described by Howell (1925) near the mouth of Manuels River, 2 miles east of this area, are mainly dark grey, green, and black shales with minor lenses of limestone and siltstone. Some dark shales are pyritiferous and thinly bedded. The youngest Cambrian sandstones in the present map-area, commonly with ripple-marks, appear in the upper part of the Elliot Cove Formation. At Manuels River, the formation is more than 300 feet thick, but the upper part is not preserved.

Age and Correlation

Beds of the Elliot Cove Formation contain *Agnostus pisiformis* and *Peltura*. A similar range is represented in beds at St. John, New Brunswick (Hayes and Howell, 1937) and in the Salmonier Cove Formation in Fortune Bay, southern Newfoundland (Hutchinson, 1956).

Lower Ordovician Rocks

The fossiliferous Lower Ordovician beds are divided by Van Ingen (1914) into three disconformable series, each containing four to eight formations (Rose, 1952). The Clarendville Group is exposed at and near Random Island, north of Whitbourne map-area, and probably lies beneath Conception Bay south and east of Kellys Island. It is overlain by the Bell Island Group, which forms Kellys and Little Bell Islands, and much of Bell Island. Total thickness has been estimated at 4,000 feet (Rose, 1952), although only 2,600 feet are actually exposed. The overlying Wabana Group is more than 1,000 feet thick and outcrops only on north-western Bell Island.

These areas were studied in detail by Van Ingen (1914) and Hayes (1915), and their results are summarized and augmented by Rose (1952). Map 1018A has been extended from the east by Rose to include these islands, and this part of the map is reproduced by Hutchinson (1953) and the writer.

The Ordovician rocks differ from the underlying Cambrian beds because they include a much greater proportion of sandstone to shale, abundant thin lenticular strata, and important beds of oolitic hematite ore near the contact of the Bell Island and Wabana Groups. The Bell Island Group consists chiefly of grey, brownish, and greenish sandstones, grey, brown, and black shales, and micaceous sandy shales. It also includes some beds of whitish sandstone, red oolitic hematite, and ferruginous sandstone and shale (Rose, 1952). The overlying Wabana Group is similar in composition but graptolitic pyritiferous black shales are more abundant.

Palaeozoic (?) Plutonic Rocks

Two granitic bodies intrude beds of the Musgravetown Group on the western fringe of the map-area. They are probably related to large volumes of similar rocks reported farther to the west and northwest (Hogg, 1954; Van Alstine, 1948; Jenness, 1957).

Iona Islands Intrusions

These rocks were named in an earlier report (McCartney, 1956) to define a suite of intrusive rocks ranging, in order of decreasing age, from olivine gabbro to granite. They underlie Fox Island and the Iona Islands in eastern Placentia Bay, with the exception of the eastern half of Burke Island.

Shore exposures are virtually continuous. Age relations of rocks of the suite are displayed by sharp intrusive contacts of felsic dykes cutting more mafic rocks and by xenoliths of mafic rocks in more felsic rocks. In contrast to the older much altered plutonic rocks of the Holyrood plutonic series, the constituent minerals are clear, with only minor amounts of chlorite and no sericite.

Lithology

The oldest gabbro is a dark grey equigranular rock with an average grain size of 4 mm. It contains 60 to 70 per cent labradorite, 15 to 20 per cent augite and bronzite, 7 per cent bright brown biotite, and 1 to 5 per cent olivine. Laths of plagioclase are euhedral and control the grain boundaries of most of the interstitial mafic minerals. The next youngest gabbro is almost identical to the first but lacks olivine. A faint colour variation in some dykes establishes the age relations. The next youngest rock is a medium grey diorite, which forms much of the Iona Islands. It is moderately homogeneous in composition, but ranges up to 5 mm in grain size. The composition is about 66 per cent zoned andesine-oligoclase, 21 per cent

orthoclase, 6 per cent augite, 4 per cent biotite, and 3 per cent quartz. Reddish pink massive granite has intruded diorite to form all of Fox Island and narrow sill-like bodies on the Iona Islands. Approximate modal composition is 30 per cent quartz, 55 to 61 per cent orthoclase, 6 to 12 per cent oligoclase, and 3 per cent dull green biotite. Some of the dykes contain vugs lined with small euhedral quartz crystals, and a thin fluorite vein on Harbour Island is thought to be genetically related to the granite. Westward-dipping granite sills are locally crowded with diorite, gabbro, and hornfels inclusions to form an intrusive breccia.

Mode of Origin

The Iona Islands intrusive suite was probably injected in successive related stages as essentially liquid magma of increasingly felsic composition. Evidence includes the numerous dykes, the lack of variation in rock types other than at sharply defined boundaries, the intrusive breccia in some granite dykes and sills, and the lack of pronounced flow features other than in aligned breccia fragments. The age sequence is established by intrusive relations and xenoliths that show little evidence of cross-assimilation. In the gabbro, augite is speckled with biotite, and andesine is converted to oligoclase as an outer shadowy zone within 1 cm of some chilled granite dykes. The increasing felsic composition of the successive rocks suggests a nearby source in which differentiation during crystallization of an original basaltic magma yielded the liquid melts of the Iona Island intrusions.

Age

On Burke Island, the intrusion of the Iona Island rocks produced a dense dark grey cordierite hornfels in what is probably part of the Trinny Cove Formation of the Musgravetown Group. No diagnostic beds could be identified, however, and the hornfels may be in Middle Cambrian rocks.

Similar gabbro and granite intrude Middle Cambrian beds on Red Island, 8 miles west of Iona Islands (Hogg, 1954). The thin fluorite vein on Harbour Island is probably related to the intrusive rocks. This suggests a possible relation of the Iona Island rocks with the fluorite-bearing St. Lawrence granite 75 miles to the southwest, which is assumed to be Devonian in age (Van Alstine, 1948).

Northern Bight Granite

The granite in the northwestern corner of this map-area was named the Northern Bight granite by Rose (1948) and extends 8 miles west and about 4 miles north of the present map-area (Jenness, 1957). It is a pink equigranular medium-grained granite with minor biotite. It resembles and may be related to the Iona Islands granite. Exposed contacts in the area are not known, but the granite is thought to intrude rocks of the Musgravetown Group and is probably post-Cambrian in age. It lacks the large phenocrysts that are common in granite 36 miles northwest of this area (Jenness, 1957).

Powder Horn Diorite Complex

This complex, named by Rose (1948), is restricted to a small area along the northwest border of Whitbourne map-area and is not well exposed. Most outcrops are fine-grained gabbro and porphyritic gabbro intimately associated with medium-grained granodiorite and hornfels. Minor rock types include rhyolite porphyry dykes and some dark grey well-bedded siltstone. The complex seems to comprise rocks equivalent to the rocks of the Bull Arm Formation, particularly to its hypabyssal intrusions, and intrusive granodiorite and hybrid granite that may be related to the Northern Bight granite.

Chapter III

STRUCTURAL GEOLOGY

Structural Divisions and Ages of Deformation

The map-area may be divided into five structural divisions that appear to be largely dependent on the structural competence of the rocks comprising or adjacent to the divisions.

The first division is the mixed assemblage of volcanic, sedimentary, and granitic rocks south of Conception Bay. Structure in this area is dominated by major faults (Fig. 2), such as the Topsail fault immediately east of this area (Rose, 1952), the South River fault extending south-southeast from Holyrood, and the Brigus and Peak Pond faults extending south from Colliers Bay.

Faults also dominate the structure of the second division in the northwestern corner of the map-area, on the north of the isthmus of Avalon Peninsula (Fig. 3). Again, a thick assemblage of volcanic rocks are involved, along with the eastern fringe of Palaeozoic granitic rocks and well-indurated beds of the Connecting Point Group. Dominant faults include the Come By Chance and Long Beach faults, which bound the horst of Connecting Point rocks. Other faults in this northwestern sector comprise an important tear-fault system.

A third major structural unit lies in a north-trending central belt of this map-area between the southeast and northwest competent blocks described above. This region is characterized by open large-scale gently plunging folds in late Precambrian arkosic sediments of the Hodgewater and Musgravetown Groups. A similar broad dome in the southwest corner of the map-area is occupied by the Bull Arm Formation, but the formation there shows a marked decrease in the proportion of volcanic to arkosic members.

The last two structural divisions involve structurally incompetent Cambro-Ordovician rocks. The gently inclined monoclinical Cambrian shales and Ordovician beds in and southeast of Conception Bay may have been shielded from orogenic forces by old faults (Topsail, Brigus, South River) and by the underlying and adjacent bulwark of granite (Fig. 2; also McCartney, 1954a). Axial-plane cleavage is lacking in these beds northeast of Holyrood Bay, although it is present in Cambrian beds in the areas to the west.

The fifth structural division comprises Cambrian and Random beds in the Chapel Arm synclinorium in and south of Trinity Bay. There the underlying Precambrian arkoses, forced into characteristic open folds, appear to have entrapped the overlying incompetent Cambrian beds to produce upright isoclinal folds in the central core of the synclinorium, more open upright folds on the fringes (*see Frontispiece*), and a west-dipping thrust fault system on the east flank of the synclinorium. The intensity of folding may be in part related to compensations for the adjacent tear-fault system (Fig. 3).

Three ages of deformation are recognized in the map-area, although the effects of the two older disturbances are restricted to small areas. A period of deformation that includes post-Harbour Main and pre-Conception Groups is evidenced by a local angular unconformity below Conception beds at Holyrood Bay (Fig. 4). The Holyrood granitic rocks were probably emplaced at a late stage of this deformation. Another period of deformation that is younger than Conception rocks but older than Cambrian rocks is shown by an angular unconformity below fossiliferous Cambrian beds and above Conception beds at Bacon Cove, Conception Bay (Pl. VIII). Evidence of this disturbance, which may have been expressed mainly as high-angle faults of large displacement (Fig. 2), is best seen in Conception Bay. If it is assumed that massive conglomerate beds in the late Precambrian arkosic rocks are related only to high-angle faults or volcanism, then north-trending faults in the Isthmus of Avalon were active after, and also possibly before, similar faults near Conception Bay. Post-Lower Ordovician (probably Devonian) folding and faulting deformed both Cambrian and Ordovician beds in and north of this map-area (Christie, 1950; Jenness, 1963). The Iona Island and Northern Bight intrusive rocks are probably related to this major orogeny. Evidence of these events is presented in the following sections.

Folds

Open Large-Scale Folds or Flexures

Two large sections lack the relatively close spacing of fold axes common elsewhere in the area. These are the central part of Bay de Verde Peninsula in the northeast and a broad doubly plunging anticline in the southwest between Placentia and St. Mary's Bays.

In the northeastern corner of the area, the basin-like structure outlined by the Whiteway Formation and lower part of the Snobs Pond Formation is well defined on air photographs, and traverses at average 2-mile intervals on the Bay de Verde Peninsula showed no structural complications. Dips in the area of east-trending beds and on the east limb of the basin are uniformly low, commonly less than 20 degrees to the north or west. The northwestern boundary is poorly exposed, but is thought to be an anticline with an axis about 3 miles east of Trinity Bay.

The open doubly plunging anticline west of St. Mary's Bay is poorly exposed,

but dips are unusually low (10 degrees and less are common) within the broad crestal area.

Common Folds

Precambrian sediments in the map-area commonly occur as symmetrical folds with essentially vertical axial planes that strike, for the most part, north-northeast. This strike varies locally from north to northeast. The limbs dip on an average of 30 to 40 degrees. Except in southern Conception Bay, the plunge of these folds is almost always less than 15 degrees with numerous reversals of plunge direction. Such reversals yield several canoe-shaped synclines, including the Deer Harbour syncline north of Bull Arm, Trinity Bay, the Cambrian syncline southeast of Long Harbour, Placentia Bay, and the more open Snows Pond syncline (lat. $47^{\circ}30'$, long. $53^{\circ}23'$).

Exceptions to the gentle regional plunge are the steep plunges of beds in the lower part of the Conception Group in the eastern part of the map-area. Irregular folds plunge about 50 degrees north-northeast near Holyrood Bay, and 45 to 60 degrees south-southwest on the shores of Peak Pond, 5 miles southwest of Holyrood. These local variations from the regional fold pattern are thought to be directly related to the position of the sediment adjacent to the massive volcanic rocks of the Harbour Main Group. The plunge at Peak Pond may be a drag effect adjacent to the Peak Pond fault. West of Holyrood Bay, faults within the Harbour Main Group were observed to pass into contorted folds on crossing the angular unconformity at the base of the Conception beds. This unconformity is described later in this chapter.

Conventional small-scale drag folds are extremely rare in the map-area and were observed only in areas of unusually intense folding and contortion. Examples were seen in some siltstone beds underlying the Random Formation in the displaced segments of the tight syncline west of the Chapel Arm synclinorium (lat. $47^{\circ}19'$, long. $53^{\circ}47'$). Differential movement between beds during the moderate regional folding was in part taken up by open folds, commonly with an interval of several hundred feet from the crest to the adjacent trough. Many of these are indicated on the accompanying geological map by the configuration of formational boundaries, but most could not be shown.

Cleavage relations, lack of drag folds, observations on a large scale in coastal cliffs, and a great many top-determinations by crossbedding, graded bedding, ripple-marks, and channelling verify the open upright fold pattern typical of the thick Precambrian sediments.

Tight Locally Isoclinal Folds

Tight folds are mainly restricted to the incompetent beds of the Random and Cambrian rocks in the western half of the map-area, but locally are developed in Conception rocks and Carbonear slates in a zone along the west shore of Concep-

tion Bay. In only a few places are the limbs overturned, as in the east boundary of the Random-Cambrian syncline south of Long Harbour railway station, in several isoclinal folds in southernmost Chapel Arm, Trinity Bay, and in Conception and lower Hodgewater beds in the stream flowing from Bad Pond to Colinet River (lat. $47^{\circ}16'$, long. $53^{\circ}29'$). Hutchinson (1953) shows unusually steep to vertical dips northwest of the Snows Pond syncline (lat. $47^{\circ}31'-33'$, long. $53^{\circ}24'-25'$).

The Random quartzite, although it would seem a more competent rock type than the overlying Cambrian slate and limestone, has clearly acted as an incompetent structural unit along with the overlying beds. Evidence of this is seen in the isoclinal folds of the Deer Harbour syncline (lat. $47^{\circ}53'$, long. $53^{\circ}47'$) where the quartzite is repeated by isoclinal folds above massive conglomerate of the Crown Hill Formation. An early stage of this modified décollement slippage is displayed on the west shore of St. Mary's Bay at and south of Bear Head (lat. $47^{\circ}03'$), where open undulating folds and crumples in Random quartzite and adjacent underlying siltstone die out within a stratigraphic thickness of 3 feet, and pass downward into grey wavy-bedded arkose of the upper part of the uniformly dipping Snows Pond Formation. In some cases, however, the minor folds in these tight synclinoria continue stratigraphically downward, becoming more open. An example of this is seen southwest of the thin syncline south of Long Harbour Station, where minor folds are discernible within the upper part of the Snows Pond Formation and in the Maturin Ponds Formation east of Placentia (lat. $47^{\circ}15'$, long. $53^{\circ}58'$). These minor folds are not thought to persist farther to the south within the Bull Arm volcanic rocks.

The persistence downward of these folds eliminates the possibility that they originated as true décollement structures involving slippage at the base of the Random Formation prior to or at an early stage of post-Ordovician folding. Rather, the tight folds in some Random and Cambrian beds are thought to have originated when fairly open synclines in massive arkose underlying the Random Formation caught up and crumpled the overlying incompetent beds.

Wabana 'Monocline'

The Cambrian and Lower Ordovician beds in and adjacent to southeast Conception Bay, where exposed, are unique in having a shallow and remarkably uniform dip to the northwest. This fact has greatly facilitated the submarine mining of bedded iron ores northwest from Bell Island. It has a direct bearing on the probable extension of these beds to the west and north, and on the safe cover between the ore horizons and the bottom of Conception Bay.

The writer believes that only the Palaeozoic beds in southeast Conception Bay have enjoyed an unusual protection from post-Ordovician deforming forces. The lack of cleavage in this monocline, and its presence in all Cambrian beds west of Holyrood Bay, is probably significant. One of two, probably related, sheltering factors was the massive basement of granitic and engulfed volcanic rocks below

these Cambro-Ordovician beds, as interpreted by extrapolation of the geology from the south and from aeromagnetic data compiled for Conception Bay by the Geophysical Section of the Geological Survey of Canada (reported with notes by McCartney, 1954a). The second factor is the protection supplied by Precambrian faults, which offered pre-existing surfaces of movement for post-Ordovician adjustment east (Topsail fault) and west (South River and Brigus faults) of the uniformly dipping Palaeozoic beds (Fig. 2). This "pressure shadow" concept may be supported by the unusual orientation of a high-angle fault system in the Wabana mines which is described in the following section.

Faults

Many of the faults within the area are unusually well exposed in coastal cliffs; others are recognized by a combination of discontinuous structural and stratigraphic units and by shearing with or without alteration. Many are extended along assumed surface traces by physiographic observations and airphoto interpretation. The true relative movement on most faults is not satisfactorily proven; yet the faults are classified by the apparent movement with varying degrees of assurance. Many faults, especially in the eastern half of the map-area, were most active in Precambrian time, with post-Cambrian renewal of movement. Tear and thrust faults in the northwestern quarter of the map-area are post-Cambrian in age.

Tear Faults

Northwest Avalon System

The recognition of a major system of complementary tear faults in the northwestern half of the map-area (Fig. 3) is aided by the observed displacement of fold axes and of Cambrian and Precambrian beds, and by the near-juxtaposition of Precambrian formations which are believed to be equivalent but are of contrasting sedimentary facies or markedly different thicknesses. Because tear faults offset fold axes in Cambrian beds, they are probably one of the youngest structural features of the map-area.

Fault planes of the tear faults were not observed. A near-vertical dip is probable from the evidence of shear planes that are closely spaced west of Tickle Bay in southern Trinity Bay, drag effects on cleavage and bedding, and the linear or gently curved surface trace of the faults. As shown in Figure 3, the tear faults with left-hand displacement vary in strike from $N10^{\circ}W$ to $N50^{\circ}W$, whereas those with right-hand displacement vary from $N35^{\circ}E$ to $N65^{\circ}E$. In most cases, the faults intersect with the obtuse angle facing the direction of crustal shortening.

The set of faults striking northwest extends as far east as latitude $47^{\circ}20'$, longitude $53^{\circ}32'$, 4 miles southeast of Placentia Junction, but does not appear to offset structures and formations in Rocky River farther to the east. One principal

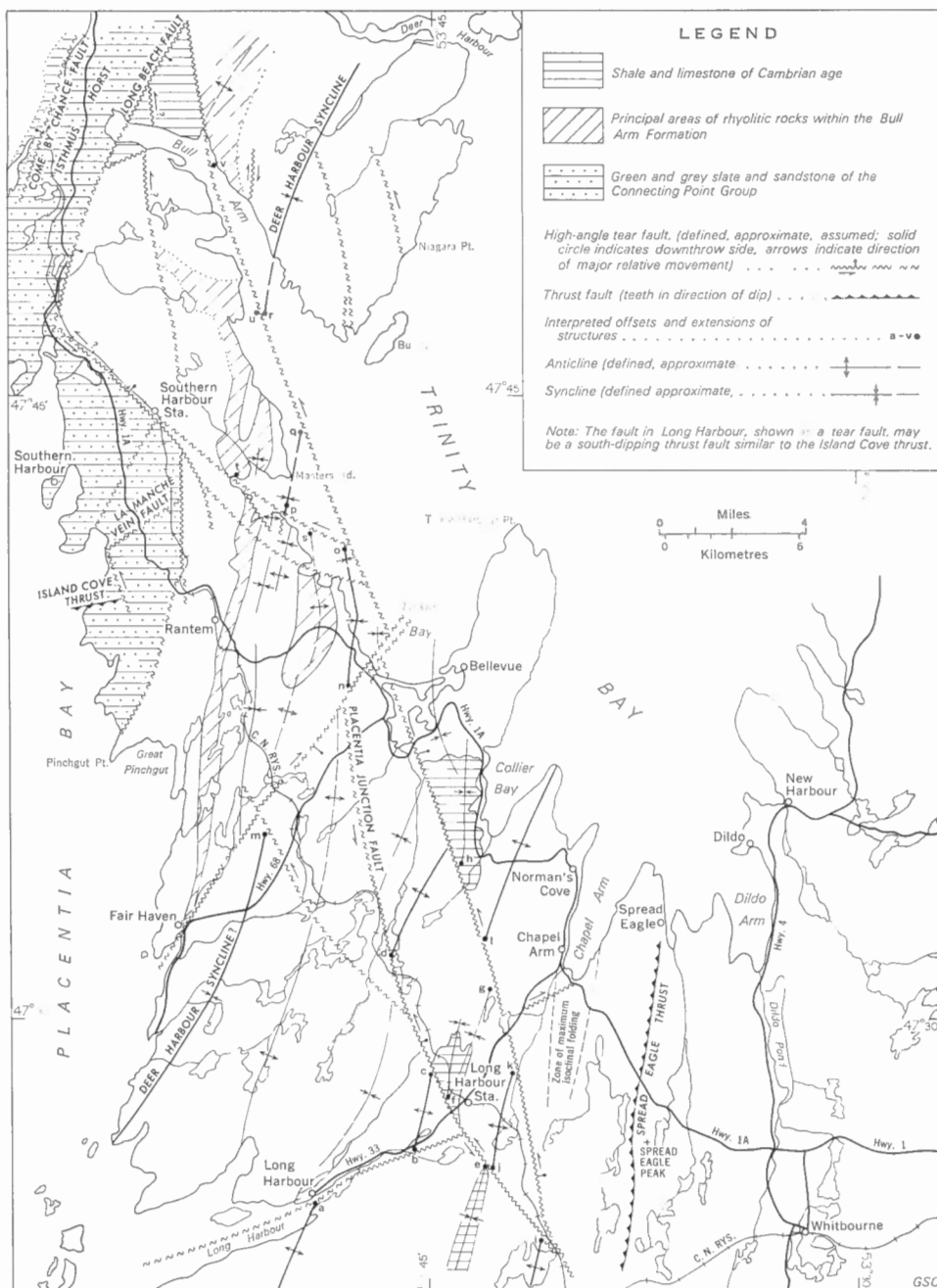


FIGURE 3. Tear fault system, northwest Avalon Peninsula.

northwest trending fault bifurcates northwest of Placentia Junction, with the western branch displacing the axis of an anticline in red arkosic sediments by about $2\frac{1}{4}$ miles (offset i-j, Fig. 3). One outcrop 2 miles south-southeast of Long Harbour Station on the northeast side of the fault appears to be dragged to the southeast. Nearby, on the southwest side of the fault, massive Random quartzite is strongly silicified or recrystallized and most individual grains show marked strain shadows. The Cambrian syncline overlying this truncated quartzite is thought to be displaced about $2\frac{1}{4}$ miles to the northwest and lowered about 500 feet to preserve the southerly plunging Cambrian synclinalorium west of Long Harbour railway station (offset e-f, Fig. 3). The Cambrian beds at 'f' on Figure 3, seem to be dragged to the southeast, and must be in fault contact with an anticline 'c' exposing moderately old Precambrian beds of the Big Head Formation. At latitude $47^{\circ}30'$, the principal fault plane swings to a more northerly strike with a minor splay extending to the northwest. This fault is not recognized to the north of its intersection near Tickle Bay with the fault extending northeast from Fair Haven, Placentia Bay.

A major bifurcation to a more northerly direction begins in the northwest fault about 1 mile north of Placentia Junction and emerges on the shore at Broad Lake, Tickle Bay. The Cambrian beds west of Long Harbour railway station are again offset to the northwest by 2 to 3 miles (offset g-h, Fig. 3) and are lowered several hundred feet in the northeast block. The correlation of these three synclinal segments (e-f, f-g, g-h) of Random and Cambrian beds is justified by the similar facies in each segment of the strata below the Random Formation, particularly a thin sequence of red arkose (McCartney, 1957) that underlies Random quartzite in each of the three blocks. Also, the grey to dark grey wavy-bedded facies characteristic of the upper part of the Snows Pond Formation, which is virtually lacking in the presumed equivalent Trinny Cove Formation, seems to be displaced to form an abrupt (faulted) facies change $2\frac{1}{2}$ miles north-northwest of Long Harbour railway station, and to be further displaced to the peninsula east of Tickle Bay. This Snows Pond grey facies in its present position seems well within the Trinny Cove sedimentary environment and would seem more in place if it were 'returned' several miles to the southeast.

The question remains as to whether the above faults can be extrapolated farther to the north-northwest. An intensely sheared zone striking southwest is exposed in the southwestern part of Tickle Bay (Fig. 3). This zone is believed to be a complementary tear fault with right-hand net slip. Detailed mapping within the well-exposed Bull Arm volcanic rocks west of Tickle Bay has discouraged the possibility that the northwest fault from Placentia Junction can continue along strike to join the major southeast-trending fault at Southern Harbour station (lat. $37^{\circ}25'$, long. $53^{\circ}55'$). It is more likely, however, that a northwesterly trending fault, which must lie beneath the waters of the outer part of Bull Arm, is an offset extension of the set extending from Placentia Junction. This fault intersects the north shore of Bull Arm at Centre Bay and continues 3 miles northward, but does not offset the Long Beach fault. Minor splays of this extrapolated fault system (from Placentia

Junction to north of Centre Bay) would be represented by the two faults north of Bull Island.

If this submarine extrapolation were correct, the net effect would be a relative northwestward and slightly downward shift of the northeast blocks. Such a shift of about 4, but no more than 6, miles would allow a crude alignment of formations on opposite shores of Bull Arm, notably the unusually wide outcrop width of rhyolite rocks (u-v, Fig. 3), and a greater transitional distance for the observed drastic thinning of the Musgravetown sediments from northeast of to north of Great Mosquito Cove; it would provide a similar more reasonable distance for the westward thickening of the Crown Hill conglomerate as observed south of Sunnyside, and might provide a general alignment of the Deer Harbour syncline (lat. $47^{\circ}50'$, long. $53^{\circ}50'$) with the south-plunging syncline topped by Crown Hill conglomerate at Brine Islands (m-r, Fig. 3). It should be possible to consider this interpretation further if aeromagnetic data become available. Until such time, it seems the most likely hypothesis to account for most structural and stratigraphic problems at Bull Arm.

A minor but well-exposed tear fault 3 miles south of Placentia Junction strikes $N50^{\circ}W$ and exhibits the left-hand displacement expected in this system. It offsets an anticline in late Precambrian beds by 2,000 feet and has a negligible vertical component of relative movement. A similar minor tear fault striking northwest with a left-hand displacement of about 1,000 feet offsets the Crown Hill Formation at the north end of the Deer Harbour syncline (lat. $47^{\circ}59'$, long. $53^{\circ}43'$).

Two faults that strike northeast and have a probable right-hand displacement extend northeasterly from Long Harbour and Fair Haven (Fig. 3). The Long Harbour tear, or possible thrust, fault here separates a major anticline on the south coast from a roughly aligned major syncline to the northeast. A horizontal movement of 3 miles is thus apparent on the fault. The only evidence that this displacement is right-handed is that the Big Head Formation is thought to be about 7,000 feet thick southeast of Long Harbour, and is known to be about 1,500 feet thick north of Crawley Island, Long Harbour. These two sections, of varied thickness, would be forced into juxtaposition across Long Harbour if the fault movement were left-handed—an 'uncomfortable' but not satisfactorily disproved interpretation. The decrease in outcrop width of the Bull Arm Formation to the north of the Long Harbour fault shows that the southeast block has been raised roughly 2,000 feet or more relative to the northwest block.

An alternate interpretation is provided if the Long Harbour fault is assumed to be a low-angle thrust dipping south-southeast, parallel with the exposed Island Cove thrust. If the block south of Long Harbour had been thrust 3 miles to the northwest, the present distribution of folds and beds could have been produced. The tear fault interpretation is preferred by the writer and is used in Figure 3.

Relative movement on the tear fault extending northeast from Fair Haven is not proved, but the most satisfactory solution is that the northwest block moved about 3 miles to the northeast with little vertical displacement.

Conception Bay System

The dominant set of tear faults in Conception Bay strikes northeast and shows a left-hand displacement. This is directly opposed to the relative movement of faults of this orientation in northwest Avalon Peninsula, but agrees with the movements on a system of faults exposed in Ordovician rocks in the Wabana mines (Norris, 1957).

The best evidence for the dominance of the horizontal component of relative movement is shown by the fault that intersects the west shore of Conception Bay at Carbonear. This has an inferred strike of $N75^{\circ}E$, and a left-hand displacement of from 3,500 to 4,000 feet (Hutchinson, 1953). Any appreciable vertical component of movement would have altered the outcrop width of the broad undulating dome of Conception Group rocks.

At Shearstown 11 miles south of Carbonear, a fault striking northeast is reported to have a relative movement about 4,000 feet down, on the southeast side (Hutchinson, 1953). This postulated movement explains some features but not others. The writer believes that a large component of left-hand displacement would better align some structural features, particularly the anticlinal structure of Conception rocks north and south of Spaniards Bay and the west-dipping sections of Carbonear slates northwest and south of the fault at Shearstown. The Snows Pond syncline (lat. $47^{\circ}30'$, long. $53^{\circ}23'$) appears to intersect the fault at Shearstown, but has not been recognized north of the fault. The zone of steep dips that occurs in Shearstown Brook is similarly not found northwest of the fault, nor is its role as a drag or fold feature understood by the writer. The Shearstown fault is suspected by the writer, according to relations across Spaniards Bay, of being a tear fault with a left-hand displacement of about 2 miles. Hutchinson interpreted it (1953) as having a major vertical component of relative movement, on the basis of relations in Shearstown Brook; and it displays some apparent contradictory evidence to both interpretations.

Better evidence of a left-handed movement on a fault striking about $N45^{\circ}E$ is found at Gasters Bay, southern Conception Bay. Here major post-Cambrian differential vertical movement seems precluded by the preservation of two small gently dipping basins of Lower Cambrian sediments north (Bacon Cove) and south (Salmon Cove) of Gasters Bay (Fig. 2).

The east-dipping Conception beds at Harbour Main are equivalent to those south of Bacon Cove because a thin limestone bed is restricted to these two localities. The beds are probably bounded on the west by the same north-striking vertical fault. This fault and the Conception beds are offset $1\frac{1}{4}$ miles, in a left-handed sense, on opposite sides of Gasters Bay. Ignimbrites that extend north from Avondale are offset a similar distance to the southwest. The major unconformity at the base of the Conception Group near the Blue Hills shows an apparent left-handed displacement of the fault of $2\frac{1}{4}$ miles.

The principal movement on the northeast-striking set of tear faults is later than that on the north-striking high-angle faults in Conception Bay, as is indicated

by the offset of the Salmon Cove fault across the outer part of Gasters Bay (Fig. 2). This does not preclude later movement and adjustment (including post-Cambrian) on the north-striking faults, however, and later movement was seldom in the same relative direction as the earlier major movement.

The apparent left-handed direction of movement on the northeasterly trending faults in west and southwest Conception Bay is seemingly incompatible with the direction of crustal shortening as shown by the regional north-northeasterly trend of the fold axes in rocks of all ages. A post-Ordovician fault system exposed in the Wabana iron mines shows similar "anomalous" movement with a major component of strike-slip. As reported by Norris (1957), faults striking $N70^{\circ}W$ have a dominant right-handed (dextral) movement, whereas faults striking $N30^{\circ}E$ show a general left-handed (sinistral) displacement. Stratigraphic throws of 6 to 65 feet are shown (Norris, 1957, Fig. 1). Although cleavage is lacking, a well-developed joint set is parallel with the fault system. Two interpretations of the Wabana fault system are here offered.

The first hypothesis assumes that the left-handed Gasters Bay fault (*see* Fig. 2) extends for 16 miles below Conception Bay and lies parallel with and close to the southeast shore of Bell Island. The left-handed tear faults striking $N30^{\circ}E$ at Bell Island could be second-order faults related to the Gasters Bay fault, while the right-handed faults striking $N70^{\circ}W$ would be interpreted as the probable complement of the second-order faults (McKinstry, 1953).

The second interpretation of the Wabana fault system assumes that the faults comprise a non-ideal¹ conjugate set and does not, at first glance, seem compatible with the regional north-northeast trend of fold axes. Such a conjugate set would be expected if simple compressive horizontally directed pressures were aligned at about $N20^{\circ}W$. A theoretical fold axis resulting from these forces would strike at $N70^{\circ}E$. A major, but unusual, fold direction of this orientation is exposed in late Precambrian sediments at the tip of the Bay de Verde Peninsula northeast of this map-area and 33 miles north of Bell Island (Christie, 1950). If this interpretation were correct, the Wabana basin northwest of Bell Island might have a synclinal axis that strikes considerably more east of north than the regional trend would suggest. Submarine contours at 5-fathom intervals (drawn by the writer from plotted field data kindly supplied by the Hydrographic Service of the Department of Mines and Technical Surveys) suggest that the Ordovician beds maintain their observed strike to the northeast of Bell Island until truncated by the offshore Topsail fault. The submarine contours, however, do not show decipherable Ordovician structure west and northwest of Wabana Island because of a deep trough (probably resulting from glacial scour), which attains its maximum depth of 960 feet roughly 4 miles west of Bell Island.

A submarine seismic reflection survey would help to resolve the regional structure and the dependent distribution of the ore horizons and to evaluate, in terms

¹ Non-ideal because the faults form an obtuse angle facing the proposed direction of maximum compression.

of mine safety, the nature and thickness of the cover of younger beds and unconsolidated bottom sediments.

Tear faults of small displacement near Conception Bay show movement in a direction opposite to that of the major tear faults in Conception Bay, but similar to those of the Northwest Avalon fault system. Examples are the complementary set of faults offsetting the Harbour Main-Conception contact at Burnt Point, Bay de Grave, which show a left-handed displacement of 700 feet on the northwest-striking fault and a right-handed displacement of 750 feet on the fault which strikes N75°E (Hutchinson, 1953). East of Conception Bay, Rose (1952) reported a system of northwest-striking tear faults with evidence of left-handed displacement. At both these localities, these tear faults, with movements compatible with the regional fold pattern, are younger than the high-angle north-striking fault system.

Normal and Reverse Faults

North-trending high-angle faults are a major, locally dominant, structural feature in the map-area, with large assumed components of vertical movement. They are most abundant south and east of Conception Bay (Fig. 2) and control the distribution of the Connecting Point rocks in the northwestern corner of the map-area (Fig. 3). Fault planes dip at angles in excess of 75 degrees. They strike parallel or subparallel with fold axes and with much of the bedding; hence the horizontal component of movement, if significant, is not recognized by offsets of stratigraphic or structural units. Slickensides, where exposed, are steeply aligned within 30 degrees of the dip direction as measured on the fault plane, but large Precambrian fault movements were followed by minor post-Cambrian adjustments which, in many cases, are opposite in their stratigraphic effects. Hence slickensides are probably of limited value in understanding the early dominant stage or stages of fault movement.

Conception Bay Faults

In southern and eastern Conception Bay, these north-trending faults control the east boundary of the Holyrood granitic rocks (Topsail fault, Rose, 1952) and form a complex set in southwest Conception Bay (Fig. 2) and south therefrom. The generalized structure of the basement rocks of this area is a southerly plunging anticline, passing on the flanks and to the south under an unconformable cover of Conception Group rocks and to the north beneath a north-plunging partly faulted anticline of Conception rocks at Colliers Bay; it passes beneath Cambro-Ordovician sediments with marked angular unconformity and beneath the waters of Conception Bay. The areas of dominantly Harbour Main volcanic rocks were sliced into many high-angle fault wedges with a cover in some down-dropped blocks of Conception rocks. The abundance of faults mapped in the area of numerous outcrops between Holyrood and Colliers Bay is probably a representative sample of the structure adjacent to the Holyrood plutonic rocks, but, to the south, limited exposures and less detailed mapping south of latitude 47°15' have undoubtedly allowed many

faults to remain unrecognized. Precambrian fault movement in and adjacent to the volcanic rocks may have been taken up in the upper part of the Conception Group rocks and the Carboniferous sediments by folding. Thus an unusually tight series of folds that trend along, and are restricted to, the west coast of Conception Bay north of latitude $47^{\circ}45'$ may overlie a northward continuation of this fault zone. Alternatively, the zone may swing to a more easterly direction off the northwest shore of Conception Bay.

The effect of these high-angle faults on the submarine extension of the Wabana iron ore is not known, but they are not likely the controlling factor in the westward termination of the ore. The minor post-Cambrian adjustments, as shown by scattered basins of Lower Cambrian beds on many fault blocks, would not likely be of sufficient magnitude to remove the ore horizons. Furthermore, considering the thick incompetent Cambro-Ordovician beds below the ore, the faults would probably be modified or die out below the ore. A major fault, the "Colliers Bay Fault Zone" was proposed by Hayes (1931) as the westward termination of the Wabana ore, but the present work disproves this fault and, as outlined above, discourages the theory of a north-trending fault termination. In particular, Hayes indicated that this fault occurred along the steep northwest shore of Colliers Bay parallel with the minor Marysvale fault described below. In fact, the basal Conception beds continue southward without displacement across the extension of Hayes' proposed fault to the Blue Hills (Fig. 2). The principal known faults in Conception Bay are described below from west to east.

The Marysvale fault strikes from 15 to 30 degrees east of north and is vertical where exposed in a prospect pit 800 feet north of Colliers River (Fig. 2). At this pit, the east side of the fault has moved about 300 feet downward relative to the west side, as shown by the stratigraphic displacement of basal Conception conglomerate from its exposure in the bottom of the pit to its repetition about 150 feet east of the fault. A minimum displacement of the same order of magnitude and in the same direction has been proven north of Highway 2, where the Smith Point limestone and overlying beds are faulted against lower Conception slate. At Marysvale Harbour (lat. $47^{\circ}30'$, long. $53^{\circ}12'$), the fault has a very small displacement (probably less than 50 feet) in an opposite direction. This direction of displacement is demonstrated by the basal boulder conglomerate of the Conception Group (Hutchinson, 1953, Pl. II) that lies east of the fault, and which must be in fault contact with near-basal red siltstone exposed about 400 feet to the south-southwest in a small stream. Three faults trending northwest near Marysvale Harbour down-drop the basal Conception unconformity to the southeast where it is exposed (un-faulted) on the west shore of Colliers Bay and above English Cove. The Marysvale fault was not offset, however, because it truncates the west limb of a Cambrian syncline 1 mile south-southwest of its intersection with these cross-faults. The writer considers the Marysvale fault a minor post-Cambrian feature, because the stratigraphic throw on both Precambrian and Cambrian beds is of the same order of magnitude and in the same direction.

The Brigus fault, near Brigus (Hutchinson, 1953), shows a minimum stratigraphic throw of 4,500 feet measured in the lower part of the Conception Group, with the west side moving down relative to the east side. The presence of an east-dipping remnant of Cambrian beds on the east block and their absence from the west block, however, show that, had even a quarter of this movement occurred in post-Cambrian time, Cambrian beds would be present west of the Brigus fault. Post-Cambrian movement, if any, is indeterminate. Near Brigus, the fault strikes northerly and is normal, with vertical or steep dips up to 70 degrees to the west. In contrast to the Marysvale fault, it is offset by a set of younger minor tear faults striking northwest and northeast (Hutchinson, 1953). Although diagnostic outcrops are lacking, the Brigus fault probably continues south to and beyond Conception Harbour (as shown on Fig. 2). It probably was displaced by the Gasters Bay fault, and continues south as a fault in the lower part of Salmon River. Much of the stratigraphic throw at Salmon River seems to have displaced upper members of the Harbour Main Group. This displacement has probably downdropped and hidden a thick andesitic section that underlies the Conception Group for at least 7 miles north from the Blue Hills, and which is thought to reappear in its unfaulted position south from the railway tracks at Salmon River through Nord and Southwest Ponds. At Peak Pond (lat. $47^{\circ}20'$, long. $53^{\circ}13'$), the Peak Pond fault dominates the recognizable stratigraphic throw at the faulted Conception-Harbour Main contact extending south-southwest from Peak Pond. Apparent movement on the suggested Brigus-Peak Pond fault is consistent in order of magnitude and direction of relative movement along the minimum 25 miles of its strike length.

The near-vertical Salmon Cove fault has a variable but northerly strike and an apparent Precambrian stratigraphic throw of at least 1,000 feet on the northwest shore of Gasters Bay, with the east block of Conception rocks displaced relatively downward (Fig. 2). Intense crumpling and local silicification adjacent to the fault prevents a reliable estimate, but a displacement of thousands of feet seems precluded because the unconformity at the base of the Conception Group is preserved east of the fault near Bacon Cove and west of the fault that lies west and south from Harbour Main. The fault could not be traced in Harbour Main rocks to the south, and does not displace the basal Conception beds between Holyrood Bay and Harbour Main (Fig. 5). Post-Cambrian movement on this fault at Salmon Cove resulted in a stratigraphic throw of at least 150 feet in a sense opposite to the movement known to have occurred in Precambrian time. *Callavia bröggeri* collected 40 feet west of the fault (GSC collection 20226) shows that the upward relative movement of the beds east of the fault was sufficient to remove from view the Smith Point and Bonavista Formations.

The South River fault is exposed on the west shore of Holyrood Bay and 700 feet southeast of Harbour Main Point. It dips 75 to 85 degrees east and strikes approximately $N15^{\circ}W$. Reverse movement in Precambrian times was in excess of 5,000 feet, as shown by the relative uplift of the east block and the subsequent removal of the uniformly dipping section of Conception rocks preserved west of the

fault, on the northwest shore of Holyrood Bay. Movement in post-Cambrian times was in excess of 50 feet and in an opposite (normal) sense. *Strenuella strenua* was collected 15 feet east of the fault northwest of Red Rock Cove (GSC collection 20225); hence, the thin lowermost Cambrian Smith Point and Bonavista Formations were faulted from the section. A thin fault slice of cataclastic kaolinized quartz monzonite separates Cambrian rocks from Conception beds adjacent to this fossil locality. The fault is not exposed but is thought to extend S15°E up the western side of the valley of South River, because of the presence of a strong lineament extending for 12 miles south of Holyrood Bay. Reliable stratigraphic evidence of relative movement is lacking along this southern extension. It is likely that the South River and Topsail faults intersect in the southeastern corner of the map-area. Numerous outcrops to the southeast are sheared near the expected junction, but major and minor fault planes were not satisfactorily distinguished.

The Topsail fault system lies east of the writer's map-area and marks the eastern boundary of both the Holyrood granitic rocks and the Palaeozoic sediments. As described by Rose (1952), the fault strikes N13°E and dips 80 degrees to the east. Rose recognized both Precambrian and post-Ordovician movement on the plane of this fault and interpreted both movements as thrusts.

Isthmus Horst System

The fault planes (shown on the geological map accompanying this report) bounding the apparent horst of Connecting Point rocks in the northwestern corner of the map-area have not been directly observed. At Long Beach (lat. 48°00', long. 53°48') and on the northeast coast of Placentia Bay, prominent closely spaced shear planes associated with the Long Beach and Come By Chance faults are essentially vertical.

The relations on the Come By Chance fault are almost completely hidden beneath a thick cover of glacial drift along the assumed fault position. The Bull Arm Formation may be represented by scattered outcrops of a dull reddish crystal tuff west of the fault, but almost the entire Musgravetown Group is missing west of the fault on the east shore of Placentia Bay, where sheared conglomerate of the Crown Hill Formation is overlain by Random and Cambrian beds. The fault, though poorly exposed, is thus indicated by stratigraphic evidence.

Age Relations

The earliest major fault movements in the area appear to have taken place on the north-trending faults bounding the Isthmus horst in the northwestern part of the map-area. These movements probably occurred at the close of Bull Arm volcanism and resulted in initial uplift of the horst to shed coarse detritus of Connecting Point rocks to the east, followed by the eastward transport of volcanic material. The next major movements are thought to have occurred on north-trending faults in the eastern part of the map-area, and the resulting highland shed coarse material, represented by coarse conglomerates near Bay de Verde north of this area and by the Signal Hill Formation east of this area, to the north and east. The erosion of

the block-faulted highlands in later Precambrian time would account for the local angular unconformity between fossiliferous Cambrian beds and underlying Harbour Main, Conception, and granitic rocks in southern Conception Bay. Final Precambrian movement further uplifted the Isthmus horst and shed volcanic detritus eastward to form the Crown Hill conglomerate. This conglomerate, up to 1,300 feet thick, is restricted to a belt less than 12 miles wide but at least 65 miles long parallel with and adjacent to the eastern boundary of the Isthmus horst. Throughout these Precambrian fault movements in the west and east, the central part of the map-area remained depressed, receiving non-conglomeratic sediments from the west and possibly also from the east. Movement was renewed on these north-trending faults in post-Cambrian time but, in this area near Conception Bay, the amount of this movement was less than one-tenth that of Precambrian time and was mainly in an opposite sense.

Tear and thrust faults developed after the folding of Cambrian beds, possibly in Devonian time.

Thrust Faults

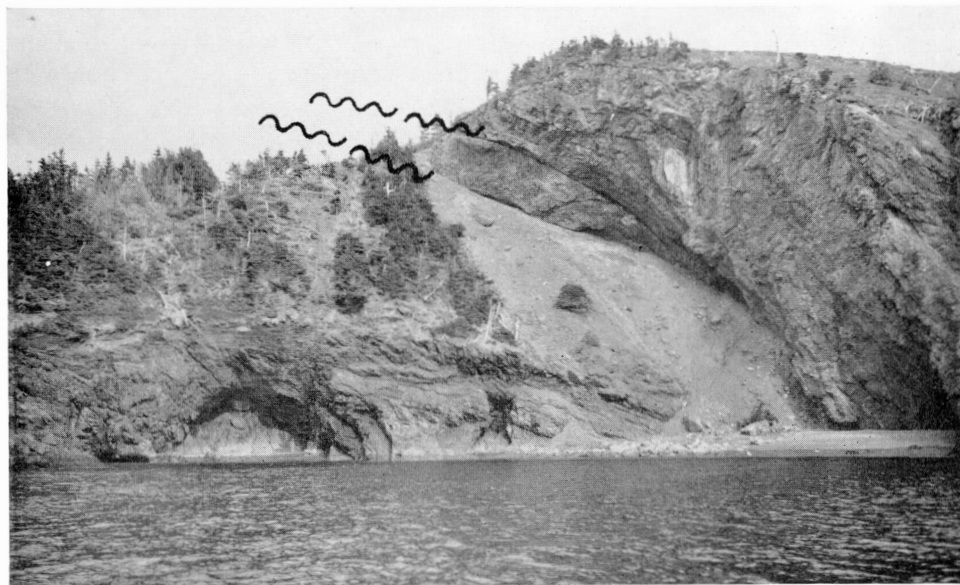
Two thrust faults and a minor fault system have been recognized in the map-area. The Spread Eagle thrust (Fig. 3) is a west-dipping imbricate thrust fault that affects Lower Cambrian and late Precambrian beds on the east margin of the Chapel Arm synclinorium. The fault extends south from Spread Eagle Bay and attains a maximum net slip of more than 1,200 feet near Spread Eagle Peak (Fig. 3). This net slip cannot be more closely measured because the fault northwest of Spread Eagle Peak is subparallel with the bedding of the hanging-wall in green arkose beds of the upper part of the Snows Pond Formation. A cross-section drawn nearby shows a minimum possible net slip of 1,200 feet (McCartney, 1956). The true net slip is probably larger but not likely to exceed 3,000 feet because, 5 miles to the north near Spread Eagle Bay, the thrust lies within the 500 feet of Lower Cambrian beds, although it is again subparallel with bedding in the hanging-wall.

This thrust is thought to have afforded release outward (eastward) from the axis of isoclinal folding in the core of the Chapel Arm synclinorium. The maximum indicated thrust displacement lies $4\frac{1}{2}$ miles east of the junction of the complementary Long Harbour and Placentia Junction faults, a junction that appears to involve a crustal shortening of about $2\frac{1}{2}$ miles and that would induce especially severe readjustments within some adjacent fault wedges. Thus, although the Spread Eagle thrust strikes parallel with and seems related to the regional folds, movements on the thrust seem in part related to the structural adjustments imposed by the Northwest Avalon tear fault system (Fig. 3).

The northward extension of the Spread Eagle fault may be represented by thrust faults near Cavendish, or the principal fault planes may remain submerged in eastern Trinity Bay. Where thrust faults are exposed on the shore north of Cavendish a minimum net slip of about 200 feet is suggested by stratigraphic displacement on the eastern thrust plane, but another unknown movement is indicated

along a steeper bedding thrust, 240 feet to the west, which is thought to lie at or near the base of the Middle Cambrian beds. The manganese zone is possibly represented by a dark red limestone bed at the bedding thrust, but is more probably faulted from the section along with the upper 100 to 300 feet of Lower Cambrian beds.

A second low-angle thrust fault, the Island Cove thrust, is exposed within undivided Connecting Point rocks at Island Cove Head, Placentia Bay (Fig. 3, Pl. X).



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PLATE X. *South-dipping thrust fault at Island Cove, eastern Placentia Bay. Movement was probably related to Northwest Avalon tear fault system.*

This fault plane undulates but has an average strike of $N70^{\circ}E$ and a dip of 30 to 45 degrees south. A markedly brecciated zone up to 30 feet thick is overlain and underlain by thrust planes. No estimate of the net slip is possible. The fault trace is discernible as a lineament on aerial photographs for 1 mile inland from the coast, where it appears to be truncated by a fault extending south-southeast from La Manche.

The direction of movement at first glance seems incompatible with the regional structural trends but the thrust is almost certainly a secondary fault that is well oriented to take up structural adjustments or drag effects within fault blocks of the tear fault system. This orientation also provides a mechanism for rapidly changing the net slip of tear faults or even terminating them, a circumstance that seems to apply to the Island Cove thrust. The northwest-striking tear fault at which the thrust is thought to terminate cannot be found, other than as a short weak lineament southeast of the junction with the thrust (Fig. 3). If the small triangle of rock

exposed northwest of the thrust is considered "stationary", it will be seen that all adjacent rocks can move as a unit to the northwest by this combination of tear faulting and northwest thrusting.

A third minor thrust and reverse fault system occurs northwest of Chapel Cove Point in Holyrood Bay, Conception Bay (Hayes, 1931). The faults in this system dip at varying generally steep angles to the east within the thin Lower Cambrian and lower Middle Cambrian beds, and movements are measurable in tens of feet. They lie immediately east of the major east-dipping South River fault (Fig. 2) and are thought to represent minor faults associated with moderate post-Cambrian movements on the South River fault. Precambrian movement on the latter fault was described in a preceding section and was probably in a reverse sense. Post-Cambrian displacement was normal and formed the west boundary of the Chapel Cove Cambrian basin.

Hayes (1931) concluded that this minor fault system demonstrated "in a restricted zone, the tectonics of Conception Bay as a whole". The writer disagrees with this extrapolation. Much or most of the deformation and plutonic intrusion near Conception Bay is clearly Precambrian in age, as shown by the angular unconformity and nonconformity at the base of gently folded fossiliferous Lower Cambrian beds. Furthermore, the six small Cambrian basins on each of the peninsulas in southern Conception Bay contain only Lower Cambrian and lowermost Middle Cambrian beds so that differential vertical movements involving these basins in post-Cambrian time were relatively minor. Had they been major, then some basins should have been either uplifted and removed by erosion, or down-dropped with a cover of Middle and Upper Cambrian and Lower Ordovician rocks.

Dilation Faults and Associated Dyke Sets

Fault planes, in which the net slip is negligible, are occupied by dykes and are best developed in the southwestern corner of the map-area, south of Placentia. Along the coast south-southwest of Ship Cove, five to ten dykes per mile are exposed. These dip steeply north or south, but are essentially vertical with remarkably uniform strikes of $N60^{\circ}W$. The same attitude holds for less abundant dykes between Fair Haven and Bald Head in Placentia Bay (Fig. 3). A few vertical dykes strike $N80^{\circ}W$ on and near Bull Island, Trinity Bay.

This orientation of dykes is considered to reflect the plane of minimum pressure during post-Lower Ordovician folding, because it is the preferred plane for dilation by dykes, is perpendicular to fold axes, and bisects the conjugate set of tear faults of the northwest Avalon system.

Unconformities

Harbour Main – Conception Contact

Previous workers (Howley and Murray, 1918; Buddington, 1919; Hayes, 1931; Rose, 1952; and Hutchinson, 1953) have presented varying interpretations

of the time interval represented by the contact at the base of the Conception Group. The writer's detailed mapping of this contact has indicated that it is a significant time interval.

The base of the Conception Group is hidden along most of the contact by till or by faults. A further complication near the east boundary of the map-area is the appreciable thickness of Conception-like beds now recognized in the lower part of the Harbour Main Group. Only beds that are well defined as basal Conception are considered in this discussion.

Evidence of a local angular unconformity is seen from the west shore of Holyrood Bay west to Maloneys River (Fig. 4), where the lithological trend and poorly defined bedding in older Harbour Main volcanic rocks strike north-northeast and appear to be truncated almost at right angles by contorted basal beds of the Conception Group. The contact zone is complicated by minor shearing and crumpling of relatively incompetent Conception siltstones against massive underlying volcanic rocks. Compensation of fault movements in volcanic rocks by folds in (and confined to) the lower part of the Conception sediments (Fig. 4) accounts for at least part of this localized folding. Despite this structural complexity, basal conglomerate or near-basal red arkose, siltstone, and a thin limestone bed of the Conception Group were found at intervals along the contact from the west shore of Harbour Main south to Maloneys River, then east toward Holyrood Bay. The basal beds are not exposed or are lacking between the highway and Holyrood Bay. The presence of these basal beds along most of the contact demonstrates the lack of major fault movements, and the structural features indicate a local angular unconformity.

Although the contact between Conception and Harbour Main rocks appears to be an angular unconformity between Harbour Main and Holyrood Bay (Fig. 4), no angular truncation was proven along the contact farther to the west. A boulder conglomerate at the base of the Conception Group is well exposed at Marysvalle in Colliers Bay (lat. $47^{\circ}30'$, long. $53^{\circ}12'30''$) and conglomeratic beds are exposed to the south on the ridge west of Colliers Bay (Pl. V and Fig. 5). Similar conglomerate and coarse sandstones are exposed adjacent to the concealed contact in Salmon River (lat. $27^{\circ}30'$, long. $53^{\circ}14'$). The rocks below unfaulted parts of the contact are a thick undivided sequence of massive mafic volcanic rocks of the Harbour Main Group. Reliable evidence of their attitude is rare, but they appear to trend and dip roughly parallel with the overlying Conception beds. The lithological change at the unconformable contact is abrupt, with only rare red siltstone found locally below the contact and no recognizable volcanic rocks above the basal Conception beds west of the shore of Holyrood Bay.

Evidence of the angular unconformity at the base of the Conception Group thus appears to be restricted to the Holyrood area. As discussed in Chapter II, basal Conception conglomerate northeast of Holyrood contains abundant quartz monzonite fragments. The writer concludes that Harbour Main rocks were deformed adjacent to the Holyrood plutonic series when the granite was intruded in pre-Conception time. A subsequent period of erosion was terminated by deposition of

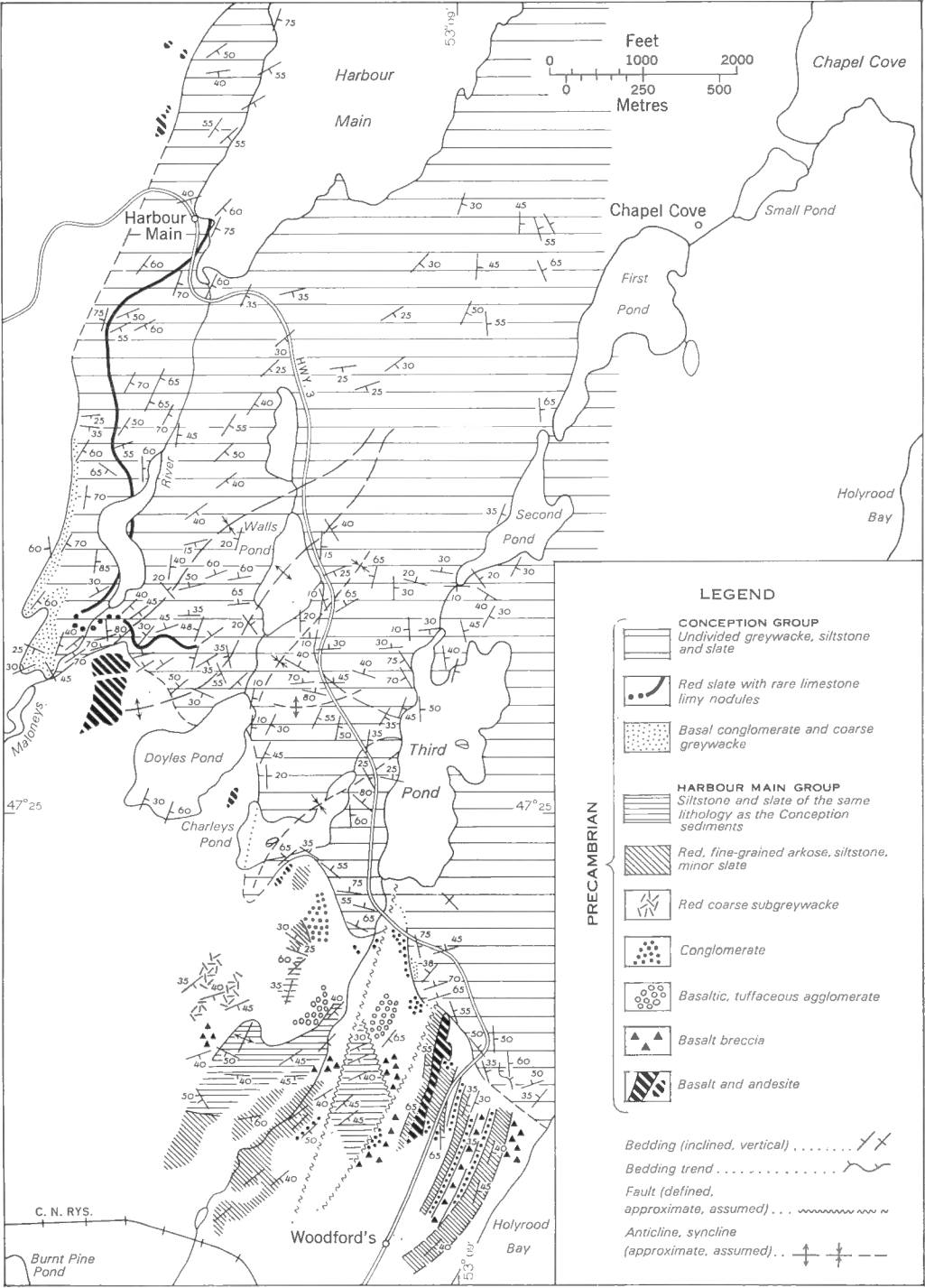
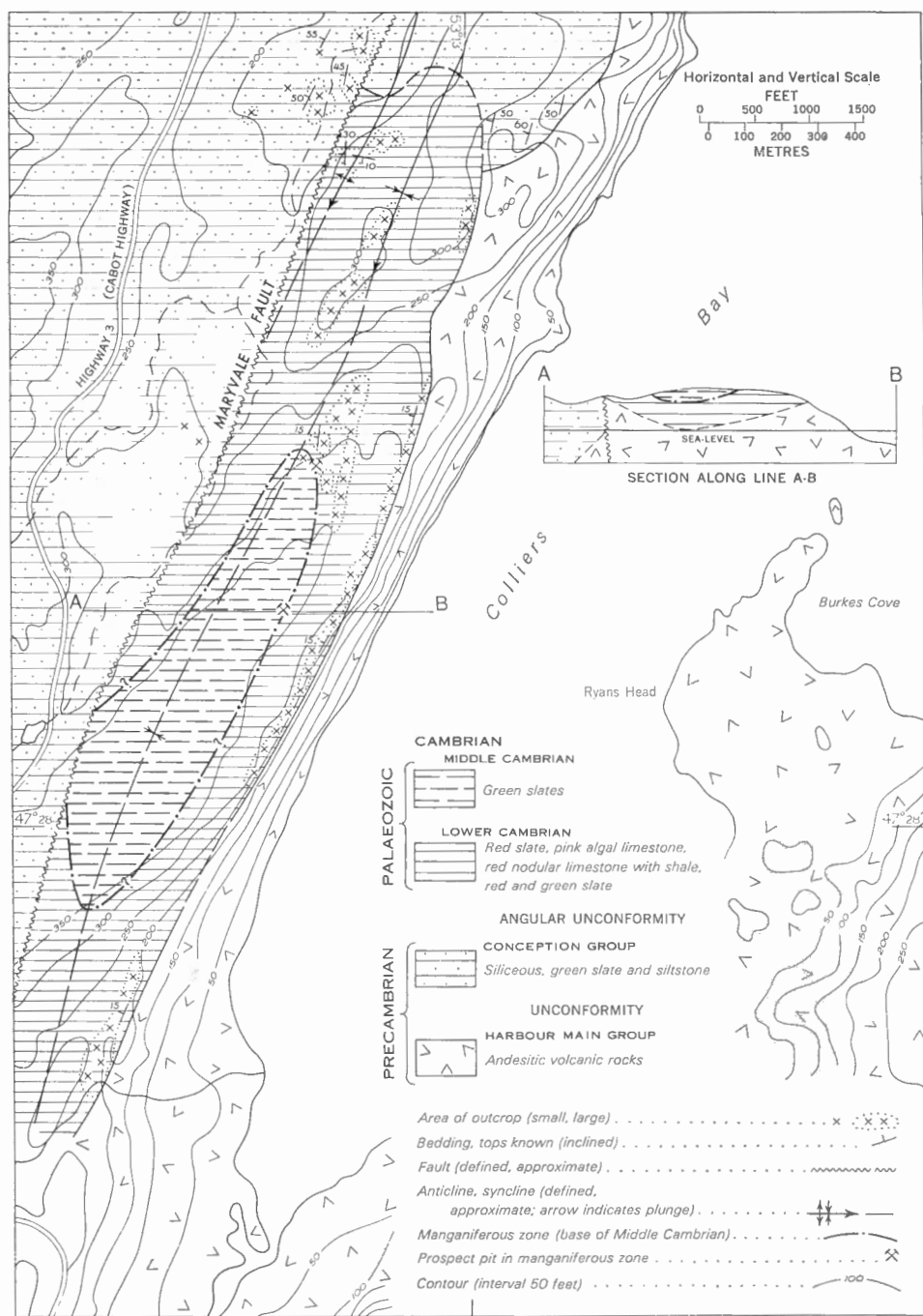


FIGURE 4. Folded angular unconformity between Harbour Main Group and Conception Group, north-west of Holyrood Bay.

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FIGURE 5. Probable distribution and structural setting of manganiferous zone northern end of Cambrian basin, Colliers Bay, Conception Bay.

the basal Conception beds. Farther west, however, the Harbour Main volcanic rocks were not seriously disturbed by the more distant granite intrusion, and no angular unconformity can be proven below basal Conception conglomeratic beds. A significant interval of time is probably represented by this contact.

Connecting Point–Musgravetown Contact

Structural relations in the northwestern part of the area between the Connecting Point Group and the overlying Bull Arm Formation of the Musgravetown Group suggest a transitional contact defined by the lowest Bull Arm volcanic rocks. Two factors that disguise these relations are the dominance of faults in controlling this contact along the east side of the Isthmus horst (Fig. 3), and the remarkable similarity of green siltstone beds, intercalated with the Bull Arm volcanic members, to the underlying Connecting Point sediments. The abundance of these sediments in the lower part of the Bull Arm Formation suggests an upward transition in sedimentary rock types from grey-green, laminated beds to irregularly bedded arkoses and subgreywackes during Bull Arm volcanism. Satisfactory direct evidence of the contact relations is not known to be exposed in this map-area. Christie (1950) and Jenness (1963) have reported an angular unconformity at the Connecting Point–Musgravetown contact 17 miles north of this map-area.

Basal Random Contact

The existence of an angular unconformity at the base of white quartzite of the Random Formation was proposed by Hutchinson (1953) to explain the truncation by the Random Formation of folds in the underlying Hodgewater Group on the southeast shore of Trinity Bay. The intersections of these fold axes and the Random Formation are not exposed, and beds above and immediately below the contact appear structurally conformable in each coastal outcrop. However, further evidence of the existence of this unconformity is provided by the abnormal thinning of two unnamed members of the Snows Pond Formation (Map-units 11 and 13 on Map 13-1956, McCartney, 1957) between Dildo Arm and Whiteway Bay. Of these, Map-unit 13 is 2,000 feet thick west of Dildo Arm but is absent 4 miles north of Hopeall Peninsula, and Map-unit 11 is reduced from about 5,000 to about 1,000 feet in an interval of 7 miles between Hopeall Peninsula and the north shore of Whiteway Bay. Such rapid thinning of these arkosic sediments cannot be reasonably explained as the result of normal sedimentary thinning, facies changes, or thinning by faulting. It is therefore interpreted as an erosional phenomenon, evidence of the existence of an unconformity.

The writer agrees with Hutchinson (1953) that this slightly angular unconformity indicates a prolonged time interval in southeast Trinity Bay, and would prefer that some part of this time interval be taken as the tenuous beginning of Cambrian time.

Elsewhere in the map-area contacts between Random and Hodgewater or Musgravetown sediments appear conformable, if not actually gradational.

Basal Cambrian Contact

The writer interprets the contact between basal Cambrian beds and the underlying Random Formation as a disconformity because of the presence of conglomerate at the contact. At Long Cove, in Trinity Bay, irregularities up to 4 inches deep in the upper surface of the Random quartzite are probably sharp-edged channels. They are filled with arkosic argillite of the overlying fossiliferous Cambrian beds. Such features are unusual, however, and elsewhere, as in Spread Eagle Bay 4½ miles southeast of Long Cove, the basal conglomerate is planar. The basal Cambrian beds overlie Random beds in Trinity, Placentia, and St. Mary's Bays, but not in Conception Bay.

On the shores of southern Conception Bay, fossiliferous Lower Cambrian beds rest with marked angular unconformity upon rocks of the Harbour Main and Conception Groups and lie nonconformably on granitic rocks. Younger Precambrian rocks appear to have been removed by erosion following block faulting in post-Conception time.

Basal Cambrian nonconformities have been seen at two localities on the east and west shores of Holyrood Bay: near Duffs and at Chapel Cove Point. In both exposures arkosic argillite and limestone rest on, and fill former fissures in, cataclastic grey granite and quartz monzonite. The basal Cambrian beds also overlie nonconformably an andesite dyke that intrudes the quartz monzonite (Pl. VI). Evidence of this nonconformity includes pebbles of quartz monzonite in the overlying limestone; grains of myrmekite, quartz, and feldspar in the Cambrian beds, identical to those in the quartz monzonite; the cataclastic texture and shattered appearance of the igneous rocks overlain by undeformed Cambrian beds; the lack of thermal metamorphic effects in the temperature-sensitive calcareous and argillaceous Cambrian beds; and the faunal and lithological evidence that these overlying beds form the base of the Cambrian rocks in southern Conception Bay.

Misleading features that are apt to cause misinterpretation of the nature of the basal Cambrian contact are best seen at Chapel Cove Point. There, lamellar extensions of limestone penetrate quartz monzonite, and irregular extensions of quartz monzonite rise above the lowest arkosic bed of the Cambrian into the overlying limestone. These peculiar relationships can be explained, however, by the deposition of basal Cambrian beds on an originally knobby Precambrian rock surface, cut by narrow fissures, similar to the present rough-surfaced exposures of quartz monzonite. Clastic quartz, mud, and lime could easily have been washed into the open fissures to form the dyke-like bodies visible today. The irregular projections of quartz monzonite into the overlying basal Cambrian beds were formerly knobs on the Precambrian surface. There is no reason to interpret either of these features as the products of granitic intrusion. A similar effect of minor topographic irregularities, formed from contorted siltstone below basal Cambrian beds, can be seen at Bacon Cove (Pl. VIII).

Secondary Foliation

Cleavage is developed in fine-grained sediments almost everywhere in the area, and is oriented parallel or subparallel with the axial planes of folds (*see Frontispiece*). The strikes of the cleavage planes range from north to N35°E and dips are mainly steep to the east or west, rarely as low as 70 degrees. This persistent cleavage has proven an aid in confirming determinations of tops of beds, in discriminating between small outcrops and slumped or glacially dislodged blocks, in verifying the assumed position of some fold axes by noting the cleavage-bedding relations in areas of locally derived blocky till fragments or slumped blocks, and in measuring the plunge of folds by the trace of bedding on cleavage surfaces.

Bedding-plane parting in the essentially monoclinical Cambrian beds of southeastern Conception Bay is generally well developed, with large slabs splitting fairly readily along bedding planes. This is a primary sedimentary feature that may have been intensified during lithification. The lack of secondary folia, which would dominate these primary features, is probably related to the structurally sheltered position of these beds.

Chapter IV

ECONOMIC GEOLOGY

The only current¹ mine production in the map-area is submarine mining on the east border of the area from the western extremity of the Wabana Iron Ore deposits on Bell Island. Shipments from the mine in 1961 totalled about 2,292,000 long tons of oolitic hematite ore. The ore is derived from beds of Lower Ordovician age.

Low-grade syngenetic manganiferous carbonate, shale, and slate beds lie at the base of the Middle Cambrian sediments. Many millions of tons of this material are available if an economic treatment or use can be devised. Large areas of the manganese zone have not been adequately investigated.

Deposits in Precambrian rocks include veins with galena, galena-sphalerite-silver, and goethite-hematite. Of these, the La Manche vein appears to be of most economic interest.

Barite fills variable thin veins formerly mined near southern Trinity Bay.

Iron

Wabana Iron Ore Deposits

The Wabana Iron Ore deposits comprise three syngenetic beds of oolitic hematite in Lower Ordovician sandstone and shale. From the surface exposures 1½ miles east of this map-area, on the northwest shore of Bell (Wabana) Island, submarine mine workings follow the regular and gentle northwest dip for 2 miles from the shore of Conception Bay, to a vertical depth of 1,850 feet. Total production from 1895 to the end of 1961 has been about 73,309,000 long tons of ore.

The mine workings east of this map-area were studied in detail by Hayes (1915, 1929, 1931) and have recently been described by Rose (1952) and Lyons (1957). Lyons' paper, as well as presenting much new data on the sedimentary variations within ore beds, summarized the problem of the western termination of the Cambro-Ordovician basin below Conception Bay and discussed the views of Hayes (1931) and the writer (McCartney, 1954a). Hayes proposed that a major fault extended north-northeast from Colliers Bay and terminated the Cambro-

¹ This mine was closed in mid-1966.

Ordovician beds below Conception Bay, whereas the writer found no evidence of a major fault in the position indicated by Hayes. The Marysvale fault with minor displacement is parallel with the fault proposed by Hayes (Fig. 2). Dominant faults trend northerly and principal movement was in Precambrian time, as discussed in Chapter III. The writer suggests that the Cambro-Ordovician beds occupy a synclinal structure with an axis northwest of Bell Island trending northeast or north-northeast. The western termination of these beds is more apt to have taken place by a reversal of the observed northwest dip combined with a northeasterly plunge. The Palaeozoic beds may also be truncated in part by faults in southwestern Conception Bay.

Iron Deposits in Precambrian Rocks

Thin lenticular veins and joint fillings of goethite and hematite lie in Precambrian beds west of Conception Bay at the north end of Snows Pond (lat. $47^{\circ}30'30''$, long. $53^{\circ}22'30''$) and in a zone extending north from Western Bay (lat. $47^{\circ}53'$, long. $53^{\circ}05'$). One such deposit, the Workington mine, adjacent to the north boundary of this map-area (long. $53^{\circ}02'$) underwent extensive preparations for production, including the building of a railway 7 miles long, a shipping pier at Old Perlican, and a surface plant. However, only a few tons of ore from an irregular vein up to 7 feet wide were shipped and the lack of ore closed the operation in 1903 (Howland, 1938). The early abortive attempt at mining this deposit was no doubt influenced by the proximity to the Wabana ore deposits, and many residents assumed that the prospects are a continuation of the Wabana ore. The oolitic hematite ore beds on Bell Island, however, were deposited on the bottom of the Lower Ordovician sea many millions of years after the deposition of the Precambrian rocks on the west shore of Conception Bay.

The vein prospects west of Conception Bay are confined to the lower and middle parts of the Hodgewater Group, mainly in the Halls Town and Whiteway Formations. Goethite and hematite form narrow veins or coat jointed or brecciated rock fragments. All areas of impressive red colour, which at the surface appeared a few tens of feet in width, were found to be only superficially mineralized along narrow openings in the rock. Some vein specimens display colloform and botryoidal structures with minor euhedral quartz crystals in vugs.

Manganese

Low-grade manganiferous beds are present at the base of the Middle Cambrian Series (Fig. 6). The beds east from Duffs to Topsail and those west of Colliers Bay, Conception Bay, comprise the most promising localities and warrant further investigation. Blocks of manganese carbonate lie above a syncline on the shore of Salmon Cove in Gasters Bay and thin manganiferous green shale outcrops near the west end of the Cambrian basin at Chapel Cove. The manganese zones in

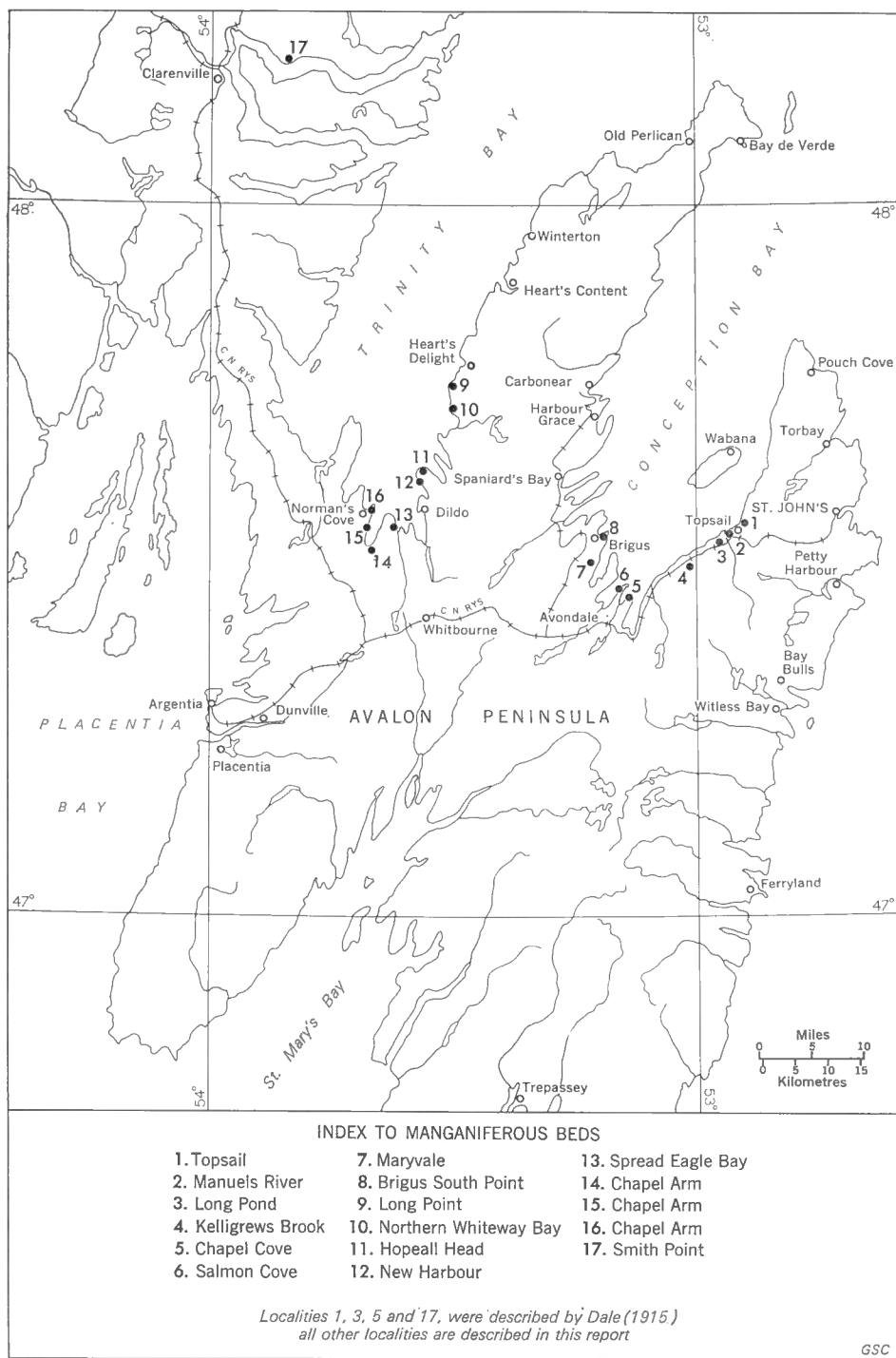


FIGURE 6. Exposed manganiferous beds, Conception Bay and Trinity Bay.

numerous localities in southwestern Trinity Bay are thinner than those of Conception Bay. Thickness, grade, and the results of beneficiation tests are described in the following sections.

History

In southeastern Conception Bay, the Dominion Iron and Steel Company employed several men in exploration of the manganese zone at Kelligrews River in 1900 and experimented with the ore in 1901 (Howley and Murray, 1918). An attempt at mining the ore was made in 1909 and, in 1910, a 1½ mile area was staked, an adit driven 80 feet, and extensive stripping done. Dale (1915) presented a detailed mineralogical and general stratigraphical description of most of the manganese deposits of Conception Bay and the locality north of this map-area at Smith Point, Trinity Bay. Wiseman (1942) sampled the manganese beds at Manuels and reported on the preliminary results of diamond drilling at Kelligrews. Four of his bulk samples from Kelligrews were submitted to the Ore Dressing and Metallurgical Laboratories, Department of Mines and Resources, Ottawa, but tests showed the ore was not amenable to flotation (Mines Branch, 1942). Macaulay (1944b) systematically sampled the manganese zone at Manuels River.

Drilling, trenching, and sampling on the manganese zone in southeast Conception Bay has been done only at widely separated surface exposures at Topsail, Manuels River, Long Pond, and Kelligrews River (Fig. 6).

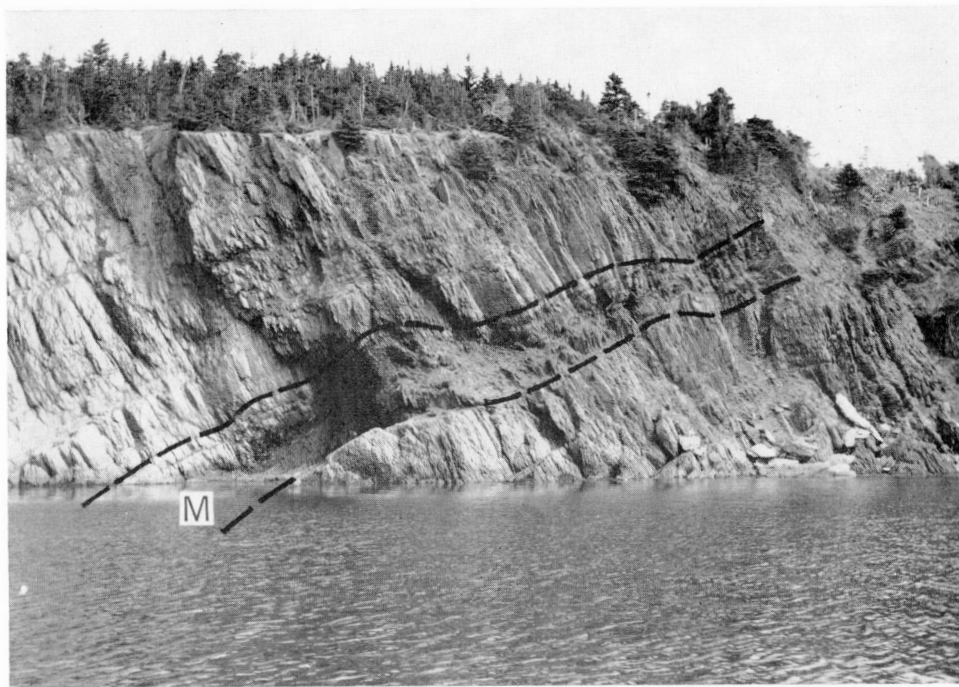
Manganiferous beds at Brigus South Point in southwest Conception Bay, were described by Dale (1915) and Hutchinson (1953). They have also been studied by Sudess (1940), Spearman (1941) and Scott (1952), and were systematically sampled by Macaulay (1944a).

New localities west of Colliers Bay and in southeastern and southern Trinity Bay have been briefly described (McCartney, 1954b, 1957) and are discussed in the following sections.

Stratigraphy and Lithology

The manganese beds lie at the base of the lower Middle Cambrian *Paradoxides bennetti* zone (Chamberlain's Brook Formation) at Brigus (Hutchinson, 1953). No fossils were found within the manganese beds at Manuels or Kelligrews River, although *P. bennetti* were found immediately above, and Lower Cambrian fauna below, the manganese beds in southern Conception Bay and in southern and southeastern Trinity Bay. The manganese beds, therefore, all lie within a limited stratigraphic range and are probably essentially contemporaneous in the localities in the map-area. The base of the manganese beds is taken as the contact between the Lower and Middle Cambrian sediments (Pl. XI).

Because of the stratigraphic restriction of manganiferous beds in this map-area, a knowledge of the stratigraphy and fossil content of the Cambrian sediments is a reliable guide to prospecting and drilling. As shown in Chapter II, red shales and slates are mainly, but not invariably, confined to beds below the manganese zone. Dark grey laminated slate or shale is confined to beds 200 or more feet



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PLATE XI. *Black-weathering manganese zone (M) in Middle Cambrian slate, northern Whiteway Bay, Trinity Bay. Beds dip gently to the west.*

above the manganese zone. Dull grey-green shale or slate overlies, but is also found below, the manganese zone. Large trilobites, 8 to 18 inches long, can be found above the manganese zone but are lacking below. A variety of small fauna is common in many beds of the overlying Middle Cambrian Formations (*see Appendix*).

The manganese beds are thought to be primary sediments and have not been metamorphosed. In surface exposures, black manganese oxides line fractures, and coat and penetrate exposed surfaces to a maximum observed depth of $\frac{1}{2}$ inch. Fresh material, with the manganese occurring as a carbonate, can be seen on newly broken faces of the surface material. Oxides are rare in drill core from a depth of 41 feet at Kelligrews River (Wiseman, 1942); hence the bulk of the material, if mined, would very likely be manganiferous carbonate rather than oxide. Sink-float tests on oxidized material suggest that subsurface carbonates should give a better sink product than surface oxides. Any evaluation or metallurgical tests of the manganese deposits should include careful studies of the variation of oxidation with depth.

The banded and nodular structure of the mineralized zone is developed at all localities, and is well illustrated by the photographs of Dale (1915, Figs. 15, 20, 21, 22, 25, and 29). Thin sections show recognizable carbonate areas, but the

extremely fine grain-size prevents identification. Chemical analyses by A. F. Budington (reported in Dale (1915)) and staining tests by J. D. Bateman (reported in Mines Branch report (1942)) showed that the manganese at Manuels River occurs as manganese-iron-calcium carbonates. These are disseminated in the shale, and are concentrated in carbonate nodules, pale green cherty lenticles, and in red iron-oxide laminae.

Thickness and Grade

The grade and thickness of the manganese deposits have been assumed by several workers to be fairly uniform in southeast Conception Bay from Duffs east to Topsail. This assumption has not been adequately tested, and some variation might be expected. The same zone in southeast Trinity Bay is better exposed, and varies drastically in thickness and grade, while maintaining similar textural and mineralogical features. Further testing between Kelligrews River and Duffs is required before the uniformity of deposits in this area can be established. In general, the Manuels and Kelligrews Rivers localities are similar, and the Brigus and Marysvale localities seem similar. Available data is summarized and compared below.

Manuels River

As Dale (1915) described the manganese occurrence at Manuels River in detail and as it is 2 miles east of the map-area, only its similarity in thickness and grade to the Kelligrews River manganese zone is mentioned in this report. Four bulk manganese samples collected by Wiseman (1942) were submitted to the Ore Dressing and Metallurgical Laboratories, Ottawa, and formed the basis for their report on flotation tests of the material (Mines Branch (1942)). Analyses of these surface samples are given in Table X.

Table X

Partial Analyses of Manganiferous Beds at Manuels River (Data from Mines Branch report, 1942, p. 2)

Bulk Sample No.	1	2	3	4
Weight	481 lb	1134 lb	1063 lb	226 lb
Position and thickness	Upper 1'11"	Middle 4'8"	Lower 5'	Same as 2 plus Upper 14" of 3
Manganese	5.68	10.69	9.27	10.35
Iron	9.26	5.67	5.21	5.37
CaO acid soluble }	3.09	2.96	2.50	2.81
MgO }	1.84	1.22	1.16	1.19
Phosphorus	0.09	0.07	0.10	0.06
Sulphur	0.36	0.13	0.12	0.10

The beds dip regularly to the northwest at about 13 degrees, and are overlain by Middle Cambrian shales and a few thin beds of limestone. This structural setting

is common to the manganese zone southeast of Conception Bay, and would allow open pit mining, if economically sound.

Kelligrews River

Between 1900 and 1910, an adit about 80 feet long was driven and extensive stripping done at the exposed manganese zone at Kelligrews River (Howley and Murray (1918)). Dale identified but did not describe the locality (1915, Pl. XIV, p. 373). Present exposures are slumped and screened with loose shale. Two drill holes and a test pit sampled by R. Wiseman gave the following results.

Table XI

Partial Analyses of Manganiferous Beds at Kelligrews River
(Data from Wiseman, 1942, unpublished)

	Test Pit		Drill Hole No. 2		Drill Hole No. 3	
	Width (inches)	% Mn	Width (feet)	% Mn	Width (feet)	% Mn
	14	7.93	0.7	3.10	1	1.21
	27	7.98	1	5.86	1	8.10
	13	12.41	1	7.07	1	5.35
	11	14.00	1	7.59	1	8.27
	14	21.90	1	11.90	1	12.58
	3	30.33	1	18.10	1	18.79
	8	9.31	1	11.04	1	8.62
	13	8.27	1	6.38	1	8.96
	7	8.36	1	7.07	1	5.47
			0.8	5.00	1	1.90
					1	2.24
Averages	110	11.6	9.5	8.6	11	7.41
Averages	49	16.1	3.0	13.7	3.0	13.33

The partly oxidized surface material is of higher grade than the unoxidized drill core from depths of 55 to 65 feet (Drill hole No. 2) and 41 to 52 feet (Drill hole No. 3). This lower grade is probably more representative of the zone as it might be mined.

Brigus South Point (Brigus South Head)

The manganese zone is more oxidized, of higher grade, and better exposed at Brigus South Point than it is in southeast Conception Bay, but the Brigus locality lacks the shallow dip and structural continuity of the manganese zone southeast of Conception Bay. The zone strikes N10°E and dips east into the sea at 47 degrees (Dale, 1915, Fig. 41; Hutchinson, 1953, Pl. VB). Contours drawn by the writer from data kindly supplied by the Hydrographic Service, Ottawa, suggest that the eastward submarine extension of the manganese zone is terminated within ¼ mile, possibly by the Salmon Cove fault (Fig. 2). Hence extensive submarine mining down the dip of the beds, analogous to Wabana iron mining, is not considered

feasible by the writer. Almost all the manganese beds above sea-level have been removed by coastal erosion.

The manganese zone, as measured by Van Ingen and Hayes, is reported by Dale (1915) to be 15 feet thick, with the best apparent values in middle beds 4½ feet thick. Sampling by Macaulay (1944a) was confined to a 3½-foot thickness of the best grade material. This 3½-foot average thickness was carefully sampled in 16 trenches at 30-foot intervals, separate samples being taken of a lower "high-grade" bed about 1½ feet thick, and an upper lower grade bed about 2 feet thick.

Two bulk samples of this lower "high-grade" zone were submitted by Mr. Fernand Roy, Brigus Manganese Limited, to the Ore Dressing and Metallurgical Laboratories, Mines Branch, Ottawa, and provided material for mechanical concentration tests (Mines Branch, 1943a, 1943b). Partial analyses of this material are given in Table XII.

Table XII

*Partial Analyses of Best Grade Manganese Beds from
Brigus South Point*

(Data from reports by Mines Branch, 1943a, 1943b)

Sample weight	2,590 lb	About 200 lb
Thickness of bed	1½–2 ft	1½–2 ft
Mn (%)	33.35	27.76
Fe (%)	3.80	
SiO ₂ (%)	18.69	24.97
P (%)	0.06	
CO ₂ (%)	6.69	
S (%)	0.13	
CaO (%)	Trace	

Marysvale

Manganese beds were found in the upper part of an elongate syncline south of Marysvale and west of Colliers Bay, Conception Bay (Fig. 5). The thickness of the manganese deposit in this basin has not yet been determined. Two pits at the north end of the manganese zone are partly filled with water, and a third pit on the east limb of the basin is slumped and was not fully excavated. The history of this locality is not known to the writer. From the north pit (Fig. 5), a 15-pound block of material at the water line was taken as a sample. After sawing and trimming all but a thin layer of manganese oxide from this grab sample, it contained 41.72 per cent manganese, 1.94 per cent iron, 9.37 per cent silica, 0.41 per cent sulphur, and 0.05 per cent phosphorus.¹ This sample represents a massive brown carbonate bed 4 inches thick and cannot be considered as representative of the entire manganese zone. It is significant, however, that the surface material at Brigus South Point, 2 miles north of these pits, is of higher grade than surface material

¹Analyst: J. A. Fournier, Mines Branch.

at Manuels River, and the Marysvale deposit may prove to be similar in grade and thickness to the Brigus manganese zone. Grab samples of manganiferous green slate from a slumped test pit on the east limb of the syncline contained 9.53 per cent manganese, 7.9 per cent iron, 40.7 per cent silica, and 0.08 per cent phosphorus.¹

The manganese zone in the Marysvale basin, though relatively small, is far more amenable to shallow mining than the zone at Brigus and warrants further sampling and thickness determinations. The northern part of the zone can probably be readily explored by shallow pits and trenches, but the southern half is covered by glacial drift of unknown thickness. The probable distribution is shown on Figure 5.

Salmon Cove and Chapel Cove, Conception Bay

Loose blocks of massive manganiferous carbonate lie on the shore of Salmon Cove, Conception Bay (loc. 6, Fig. 6). No Middle Cambrian beds are exposed, but the blocks are probably within a few tens of feet of the manganese beds and lie above the axis of a small north-plunging syncline that is flanked by Lower Cambrian beds. A minimum width of 2 feet of massive carbonate has been seen in some blocks.

Inconspicuous manganiferous nodular shale beds of unusually low grade occur near the northwestern side of the Cambrian beds north of Chapel Cove, Conception Bay. Films of manganese oxide coat fractures in a band about 3 feet thick. Dale (1915) described some nodules that had hematite cores associated with pyrite. The beds are fractured and sheared near the South River fault, and their stratigraphic position is not certain.

Long Point, Trinity Bay

The two northern localities on the southeastern shore of Trinity Bay are not typical of the manganese zone. They may represent a facies on the fringe of the principal area of manganese deposition. The northern locality 0.4 mile south of Long Point comprises a bed of dark red manganiferous limestone 2 feet thick. It is overlain by two beds of purple-red slate 3 feet thick, separated by 14 feet of green slate. A specimen of the limestone contained 7.78 per cent manganese, 8.1 per cent iron, 33.2 per cent silica, 0.34 per cent phosphorus, and 0.25 per cent sulphur.¹

Northern Whiteway Bay, Trinity Bay

A similar uncommon red limestone bed, 1½ feet thick, comprises the manganese zone ½ mile southwest of Cavendish, 2.4 miles south of the Long Point locality. This bed is overlain by 3½ feet of manganiferous green slate containing bulbous manganese nodules up to ½ inch in diameter. The nodules commonly contain a core of hematite. Other beds in the slate contain discontinuous lenses of hematite ¼ inch thick and about 3 inches long. A massive green manganiferous carbonate bed near the top of the green slate varies in thickness from 3 to 5 inches. A specimen from the red limestone bed contained 10.21 per cent manganese, 4.5

¹Analyst: R. A. Rogers, Mines Branch.

per cent iron, 26.0 per cent silica, 0.20 per cent phosphorus, and 0.46 per cent sulphur.¹ There is no red slate overlying the manganiferous zone at this locality.

One thousand feet to the south-southeast, on the southeast limb of a syncline, the zone is exposed as black-weathering manganiferous slate with two massive manganiferous carbonate beds 4 and 8 inches thick, respectively, separated by 1 foot of manganiferous green slate. The manganese zone in this locality is about 5 feet thick (Pl. XI). A specimen of the manganiferous green slate contained 4.92 per cent manganese, 12.3 per cent iron, 36.7 per cent silica, 0.47 per cent phosphorus, and 0.176 per cent sulphur.¹ A specimen from the upper of two manganiferous carbonate beds, 4 inches thick, contained 7.17 per cent manganese, 8.9 per cent iron, 24.4 per cent silica, and 0.59 per cent phosphorus.¹

Hopeall Head, Trinity Bay

The manganese zone in southeastern Trinity Bay is thickest at Hopeall Head. The beds form the northwest tip of the Hopeall Peninsula and are well exposed southward up the cliff to the navigation marker. They strike N25°E, dip 35 degrees east, and are probably truncated to the east at a shallow depth by a fault adjacent to massive volcanic breccias of the Chapel Arm Member of the Manuels River Formation. The zone is 10 feet thick and is almost entirely manganiferous black-weathering green slate. The section is summarized in Table XIII, and partial analyses of some beds are listed in Table XV.

Table XIII

Stratigraphic Section of the Manganese Beds, Hopeall Head, Trinity Bay

Sample No.	Lithology (top)	Thickness
M4	Green slate	
	Dull green slate with black manganese stain	1'2"
	Dull green slate	1'3"
	Green slate with manganese stain	3'1"
	Green slate with less distinct cleavage and with streaks and thin lenses of manganese oxide. Average lens size is $\frac{1}{2}$ by $\frac{1}{32}$ inch	2'1"
	Green slate with abundant manganese nodules. A lenticular bed of massive manganiferous carbonate, 3 inches thick, overlies this nodular bed in places	0'1"
M2	Green silty slate	0'2"
M1	Green slate with abundant manganese oxide on cleavage planes	1'9"
	Pale pink angular fragments of manganiferous carbonate in a grey-green carbonate matrix. Base of manganese zone	9"
	Disconformity ?	
	Green slate, probably Lower Cambrian	8'
	Red slate	12'
	Green slate	30'

¹Analyst: R. A. Rogers, Mines Branch.

New Harbour, Trinity Bay

This locality is 1.15 miles south of the navigation marker at Hopeall Head. The manganese zone, 7 feet 7 inches thick, overlies the measured Lower Cambrian section shown in Table VIII. The beds strike N22°E and dip 55 degrees west. The zone probably continues northward along strike, but is faulted from the continuously exposed section on the northeast shore of Hopeall Peninsula.

The section is summarized in Table XIV, and partial analyses of some beds are listed in Table XV.

Table XIV
*Stratigraphic Section Including the Manganese Beds,
Northwest of New Harbour, Trinity Bay*

Sample No.	Lithology (top)	Thickness
M9	Grey, blocky slate containing <i>Paradoxides bennetti</i>	2"
	Greenish grey slate with manganese nodules	5"
	Green slate	3"
M8	Green slate with abundant manganese oxide nodules	3"
	Greenish grey, blocky slate stained with manganese oxide and with sparse nodules	3'10"
M7b	Green slate and nodular manganiferous carbonate	2½"
M7a	Massive manganiferous carbonate	3½"
	Blocky green slate	9"
M6	Nodular, manganiferous green slate	3½"
	Massive green argillite	10"
M5	Green slate with manganese oxide nodules	4"

Partial analyses of the selected samples in the two thickest manganiferous sections in southeast Trinity Bay show that the manganese zone is of lower grade here than in southern Conception Bay. These analyses are tabulated in Table XV.

Table XV
*Partial Analyses of Selected Beds from the Manganese Zone
at Hopeall Head and Northwest of New Harbour, Trinity Bay*

Sample No.	Mn (%)	Fe (%)	SiO ₂ (%)	P (%)	S (%)
M1	15.92	9.0	26.1	0.37	0.077
M2	6.66	4.7	33.2	0.37	0.021
M4	4.7	5.2	43.9	0.12	0.040
M5	3.50	5.8	43.5	0.04	0.22
M6	5.28	6.3	43.2	0.06	0.072
M7a	8.04	5.1	17.0	0.31	0.73
M7b	15.00	10.2	25.3	0.23	0.125
M8	1.30	11.0	45.5	0.45	0.034
M9	2.00	13.5	26.1	1.32	0.26

Analyst: R. A. Rogers, Mines Branch. Sample locations are noted in the measured sections of Tables XIII and XIV.

Spread Eagle Bay

The thickest manganese beds in southern Trinity Bay are 1.3 miles south-southeast of McLeod Point, on the west shore of Spread Eagle Bay. The beds strike N10°E and dip 35 degrees to the west. The upper green slate, stained with manganese oxide, contains *Paradoxides bennetti*. Immediately north of the exposure at the shoreline, a reverse fault, with a displacement of about 100 feet, strikes N70°W and dips 60 degrees to the north. This fault caused a repetition of the manganese zone on the shore about 400 feet north of the fault. The entire zone is 12½ feet thick, but is almost entirely green manganiferous slate and probably contains little manganese, although exposed faces are commonly stained or coated with black manganese oxide. A massive nodular manganese carbonate bed, 6 inches thick, was selected as the bed with the highest manganese content, and a specimen from this thin bed contained 19.86 per cent manganese, 4.8 per cent iron, 19.7 per cent silica, 0.23 per cent phosphorus, and 0.082 per cent sulphur.¹

Chapel Arm, Trinity Bay

Three localities near Chapel Arm are similar to the Spread Eagle Bay manganese zone, with a manganiferous carbonate bed 2½ to 4 inches thick lying within slightly manganiferous green slate.

On the point northeast of Long Cove, the carbonate bed is 2½ inches thick. A specimen from this bed contained 8.33 per cent manganese, 9.6 per cent iron, and 28.9 per cent silica.¹ Specimens of *Paradoxides bennetti* were observed in two beds 6 and 16 feet, respectively, above this carbonate bed.

At Norman's Cove on the northern edge of a minor intrusive body of gabbro, a specimen from a massive nodular manganiferous carbonate bed, 4 inches thick, contained 11.53 per cent manganese, 10.2 per cent iron, and 23.7 per cent silica.¹

Part of the manganese zone forms a small outcrop in the north-flowing brook that enters the west arm of Chapel Arm. A massive nodular carbonate bed exposed in manganiferous green slate is only 2 inches thick.

Beneficiation

The low grade of the manganese zone prevents economic exploitation unless the protore can be either mechanically beneficiated at low cost or used in a metallurgical process yielding a product such as electrolytic manganese, ferromanganese, or silicomanganese.

Three sets of concentration tests were conducted by the Ore Dressing and Metallurgical Laboratories, Bureau of Mines (now Mines Branch), Ottawa. The first were unsuccessful flotation tests on bulk samples from Manuels River that contained 10.35 per cent manganese (Mines Branch, 1942). These tests showed that the concentrates contained only about 30 per cent of the manganese that was in the original samples, and their manganese content was only 24 to 26 per cent.

¹ Analyst: R. A. Rogers, Mines Branch.

Calcining the material prior to flotation neither improved the grade of concentrate nor increased recovery. No separation tests based on specific gravity differences were attempted; yet, because of the extremely fine grain-size and disseminated distribution of the manganiferous carbonate in this locality, it was concluded that "this manganese deposit cannot be exploited by any known means of concentration short of chemical treatment" (Mines Branch, 1942, p. 20). The writer emphasizes that these flotation tests and conclusions were based on partly oxidized surface material from one locality. No tests have yet been made on similar material from Kelligrews River, and no concentration tests based on specific gravity differences have been conducted on any material from the manganese zone southeast of Conception Bay.

Concentration tests by jigging, tabling, flotation, and sink-and-float were made on a 2,590-pound sample from the highest grade material (33.35% Mn) from Brigus South Point (Mines Branch, 1943a). In these tests only the sink-float method showed encouraging results. Sink-float tests produced a roasted sink product containing 57.06 per cent manganese and 8.10 per cent silica. The recoverable manganese particles of the Brigus ore were carbonate centres with oxide coatings. This fact is significant because the material at depths of 40 feet or less is believed by the writer to be mainly manganiferous carbonate; hence, the sink-float method using mined material rather than surface samples should give better results. The recovery by sink-float was low because of untreatable fines, and the float product assayed 27.92 per cent manganese compared to 42.67 per cent in the sink product.

A second sample of Brigus material, tested by the sink-float method, yielded a product containing 42.03 per cent manganese and 6.88 per cent silica from protore containing 27.76 per cent manganese and 24.97 per cent silica. Fifty-nine per cent of the manganese was recovered. Subsequent roasting raised the grade of the sink product to 55.71 per cent manganese and 9.12 per cent silica (Mines Branch, 1943b). High-grade products were obtained in the coarsest sizes treated ($1\frac{1}{4}$ to $1\frac{1}{2}$ inch screen sizes). Roasting, although raising the grade, broke down the lumps.

Unbeneficiated Brigus material produced commercially acceptable silico-manganese in a single stage electric smelting test (Campbell, *et al.* 1956).

Conclusions

The following conclusions seem justified from the available data:

1. The manganese zone is a low-grade syngenetic body that was deposited in earliest Middle Cambrian time as manganiferous carbonates with variable proportions of mud. The beds are preserved below a large area in southern Conception and Trinity Bays.

2. The grade probably varies by changes in the proportions of manganese, iron, and calcium in the carbonate, and by the proportions of shale to carbonate.

3. The zone in southern Conception Bay is more promising than that in Trinity Bay, but is still inadequately known. Only three localities have been adequately sampled; the high-grade thin bed at Brigus South Point; the lower grade

surface exposures at Manuels River; and the unoxidized low-grade beds from drill holes at Kelligrews River.

4. The manganese zone is present, but has not been observed, along 5 miles of the contact between Lower and Middle Cambrian beds west from Kelligrews River to the shore near Duffs. Along this 5-mile interval the manganese zone probably varies in grade and thickness, and a reconnaissance investigation might provide considerable valuable information. This area is selected because the gentle northwest dip, should ore be found, would facilitate early mining by open-pit methods, and a large tonnage is probable. Initial work might be done about 500 feet southeast of the northeastern corner of Lawrence Pond, and about 1,500 feet east of Indian Pond and 1,000 feet south of the mapped fossil locality. Shallow pits should expose the manganese zone near these points, or drill holes collared 100 feet north of these points should intersect the zone at a shallow depth. Drill core, rather than shallow pits, would provide a more representative sample of the zone as it might be mined. Further drilling if warranted, would be influenced by initial results and guided by the assumed position of the contact between Lower and Middle Cambrian beds.

5. The shallow basin west of Colliers Bay in Conception Bay, merits sampling and thickness determinations of its manganese beds (Fig. 5). The area underlain by this zone is less than one-fifth of a square mile.

6. Zones that contain blocky manganiferous carbonate beds may have more economic potential than wide zones of sparsely manganiferous slate, for the carbonate nodules and beds should respond to sink-float treatment in coarse sizes, whereas the sparsely manganiferous green slate is not amenable to mechanical concentration.

Lead

La Manche Mine

The La Manche mine follows a galena-calcite vein that is exposed on the east shore of Placentia Bay at La Manche (lat. $47^{\circ}41'30''$, long. $53^{\circ}57'$) and which underlies at least part of a well-defined linear valley extending to the north-northeast.

The vein is well exposed on the shore of La Manche Cove, and was probably known to fishermen prior to its acquisition as part of a land grant used for the first trans-Atlantic cable. Messrs. Ripley and Company, a subsidiary of the cable company, began mining in 1857. Mining continued under the Placentia Bay Lead Company and, from 1863 to 1873, under the La Manche Mining Company. The mine was closed in 1873. The Newfoundland and Canadian Trust Company assumed control of the property in 1889, but no production was recorded after they reopened the mine in 1890 and the mine was soon closed. In 1924, the La

Manche Mining Syndicate gained control, but a shaft sunk in 1927 was flooded and the mine was closed. In 1928, the property was optioned to the Newfoundland Mining Corporation, which renewed development work, but all work was discontinued in 1929. The property was examined by the Buchans Mining Company in 1935, and by F. W. Foote for Dana and Company and the La Manche Company Ltd. in 1936. N. E. Chute examined the area for the Newfoundland Geological Survey in 1937. A final report is in the files of the Geological Survey of Canada (Chute, 1939) and a summary report was published (*in* Snelgrove and Baird, 1953, pp. 80–81).

Buchans Mining Company dewatered and examined the property when they renewed underground work from 1946 to 1948 but production was nil. The writer undertook some detailed structural studies in 1955 in an attempt to locate a possible faulted northeastern continuation of the vein.

Recorded production from 1857 to 1868 is 2,375 tons of galena. Ore mined to 1893 is given as 18,762 tons (Howley and Murray, 1918).

Geology

The vein lies in a thick succession of slightly metamorphosed grey and green siltstone and slate of the Connecting Point Group. The vein strikes northeast and transects an undulating broad anticline in the eastern part of the Isthmus horst (Fig. 3). Mafic dykes exposed near the mine and in other areas of the Connecting Point rocks are older than the vein, probably related to Precambrian volcanic rocks of the Bull Arm Formation and not likely related to the La Manche mineralization. No similar veins were observed in the northwestern part of this map-area.

Vein Distribution

The vein is now poorly exposed on the surface. From the shore of La Manche Cove, it occupies a pronounced linear valley trending northeasterly. It has been traced along the adit, which extends about 1,800 feet northeast from the portal on the shoreline (Chute, 1939), and vein material on the dump of a shaft lies on the presumed extension of the vein, 3,000 feet from the shore. Road construction about 1956 is said to have uncovered vein material in a shallow pit adjacent to the La Manche road, about 3,700 feet from the portal of the adit. Specimens of coarse galena in calcite, collected from the northwest side of the road, were sent to the writer in 1957 by F. Benoite of Southern Harbour. About 3,500 feet from the shore, the linear valley along which the vein lies is offset 500 feet to the north, then continues for 6,500 feet to the northeast and dies out at the southeast end of a pond about 1,000 feet west of the railway tracks. Vein fragments are included in the dump of a prospect pit 5,000 feet northeast of the offset. This dump and the recently exposed vein material on the La Manche road suggest that the linear valley, offset from the known vein, is in part underlain by an extension of the La Manche mineralized zone. Bedrock is well exposed on both sides of this linear valley, and no significant parallel faults or lineaments are known to the writer. The lineament

offers a promising exploration target and is well defined on aerial photograph number A-13259-68 available from the National Photographic Library, Topographical Survey, Ottawa.

The seaward extension of the vein is not known, but Foote reported (*in* Chute, 1939, p. 32) that the vein was followed by a drift for 200 to 250 feet beyond the shore. The drift intersected the bottom of the cove and was flooded. An appreciable seaward extension is suggested in a report by Foote (*idem*) recording the observation of a vein roughly 2,000 feet from shore at a depth of 16 fathoms. This observation was made in 1926 while the bottom was being scanned through a water glass in an effort to recover a sunken boiler.

Mineralogy

The vein is of the epithermal type, with coarse galena aggregates in a calcite gangue and with minor sphalerite, chalcopyrite, pyrite, barite, and quartz.

The vein structure is banded, with a well-developed comb structure and numerous vugs. Banding is defined by variations in colour and texture of the calcite and by a local concentration of galena near the middle of the vein.

Calcite ranges in colour from white to pale grey and pale purple. Crystals range in length at least up to 3 inches and are oriented perpendicular to the vein walls to form a comb structure. Chute (1939, pp. 39–40) recognized an early white calcite stage, a second stage of purple calcite enclosing much of the galena of the vein, and a third calcite stage, which lines vugs and seems contemporaneous with pale pink barite plates, tiny chalcopyrite crystals, and rare quartz in some vugs.

Galena aggregates are formed by individual galena crystals, up to $\frac{1}{4}$ inch along the edges, which are subparallel with each other. The general appearance of the aggregates simulates a single crystal of galena up to 5 inches long, but the slight variation in orientation produces sheaf-like radiating aggregates that increase in diameter toward the centre of the vein. In most cases these aggregates are separated by calcite but locally merge to form bands of galena.

Dark brown sphalerite is not abundant and commonly is separate from galena, but has a similar radiate structure. Polished sections show that much of the sphalerite contains small patches of galena and some contains chalcopyrite (Chute, 1939). The sphalerite is scattered in the vein as discontinuous layers up to 2 inches thick.

Chalcopyrite is in minor amount, occurring as tiny grains on calcite in vugs and scattered through the calcite. Some vein fragments with abundant sphalerite found by Chute on the old dumps contain colloform laminae of chalcopyrite up to $\frac{1}{4}$ inch thick. No such mineralization is known at or above the present adit level, and the specimens were probably from the flooded vein below the adit level (Chute, 1939, p. 43). This ore includes microscopic pyrite grains that are extremely rare in the vein.

Minor barite occurs as tabular pink or white crystals on vug linings. Pink or white barite forms veins near Trinity and eastern Placentia Bay, and is a minor

gangue mineral at Silver Cliff mine; hence, the barite may have some genetic significance.

Grade and Thickness

The following data are summarized from the work of Foote as quoted in Chute (1939, pp. 48–50). The adit that extends from the shore near high tide level is 1,685 feet long and the vein was sampled along 803 feet of it. Chip samples, taken across the vein from the roof or floor, show that the vein width varies from a few inches to at least 5 feet 3 inches, and lead content varies from 1.73 to 11.65 per cent. Average values of lead for 687 feet of the vein as exposed in the adit were 5.04 per cent in an average width of 2.20 feet. The Hunt shaft, which lies 1,485 feet from the portal of the adit, was sampled at about 10-foot intervals above the adit level. The vein in the lower 335 feet of the 410-foot shaft contained 7.25 per cent lead and averaged 3.80 feet in width. Three levels accessible from the Hunt shaft were sampled at 5-foot intervals along a total length of 325 feet. The vein contained 9.10 per cent lead and averaged 3.58 feet in width. Foote concluded that the proved ore in the old workings above the adit level comprises 12,500 tons containing 8.2 per cent lead, and the probable ore indicated by the adit exposures is 48,500 tons containing somewhat more than 6 per cent lead.

A 300-pound sample of dump material from a shaft 2,600 feet northeast of the portal of the adit was collected by Foote in 1927. This sample contained 15.2 per cent lead, 1.5 per cent zinc, 0.05 per cent copper, 0.6 per cent iron, 4.6 per cent insoluble material, 0.8 ounce of silver per ton, and a trace of gold (Chute, 1939).

Conclusions

The preceding data suggest that the vein, of epithermal type, was formed in open spaces produced by repeated small movements along the northeast-trending fault. The source of the mineralization is not known, but in western Avalon Peninsula barite is common in almost all veins, and is the only mineral in some. Wall-rock alteration, a feature shared by most other small veins in the map-area, is not discernible.

The proved and possible ore of 61,000 tons estimated by Foote was based on accessible mine workings above the adit level along the adit extending 1,685 feet from the shore. It does not include ore below sea-level or in the possible direct or *en échelon* extension of the vein to the northeast, nor along the offset linear valley extending farther to the northeast. An investigation by skin divers of the seaward extension should be possible.

Lead-Zinc-Silver

There are numerous small veins containing galena and sphalerite in the area near Placentia. Many of these lie in green or grey slate or siltstone of the Big Head Formation, Musgravetown Group; these rocks are similar to, but younger than, the

wall-rock of the La Manche vein. The only veins mined, however, lie in mixed volcanic and sedimentary rocks of the Bull Arm Formation. Wall-rock alteration is not discernible adjacent to most veins, but in a few veins a zone a few inches thick is silicified and contains disseminated pyrite.

Silver Cliff Mine

Location and History

The mine is located on part of the United States Naval Air Base at Argentia, eastern Placentia Bay, and lies adjacent to a stream 1,700 feet south-southeast of Broad Cove, Placentia Sound.

A vein was discovered about 1881 by John Burke and was mined for a short time by two English companies. The vein in the Silver Cliff mine was probably discovered about 1891 (Howley and Murray, 1918). J. W. Foran then operated the mine for a few years until his death in 1898. In 1897 this work was being conducted under the Tharsis Company (*idem*). Mining was resumed from 1922 to 1925 by the Silver Cliff Mining Company, Limited, and a small mill with a capacity of 50 tons per day was installed. The operation was closed due to lack of ore (Chute, 1939).

Records of production are not complete, but about 2,000 tons of ore were mined and several hundred tons of concentrates shipped.

Geology

The mine, lying in late Precambrian beds of the Bull Arm Formation, contains mainly amygdaloidal to massive basaltic lavas, mafic breccias, and red conglomerate, with minor red arkose and a few rhyolite members. The principal fault underlies the brook flowing north-northwesterly into Broad Cove, and has a displacement of at least several hundred feet, but the relative movements were not proved by Chute (1939) nor by the writer.

The old workings, as described by Chute (1939), include a drift 250 feet long, a shaft, and exploratory workings on an essentially vertical vein system (Fowler vein) that strikes N55°–70°W. The more productive vein (MacKay vein) strikes northeast and dips steeply southeast. This vein was mined by two adits about 400 feet long and a deeper drift said to be 100 feet long. Only the outer part of the upper adit was accessible in 1955.

The vein is a brecciated fault zone, with galena and sphalerite forming lenses and a matrix around volcanic fragments. The ore in this fault zone probably ranged from less than 1 inch to 3 or 4 feet thick, and only one or two ore shoots were discovered (Chute, 1939). Widths and mineral distribution are thus erratic, but the following channel sample collected by the writer across 3 feet of this vein at the portal of the upper adit may indicate approximate ratios of the principal metals. This sample contained 5.08 per cent lead, 4.90 per cent zinc, 0.15 per cent copper, 3.19 ounces silver per ton, and 0.02 ounce gold per ton.¹

¹ Analyst: J. A. Fournier, Mines Branch.

Pyrite, galena, sphalerite, chalcopyrite, quartz, manganiferous carbonate, and barite are the vein minerals. Pyrite forms part of the vein-filling and is disseminated in a bleached altered zone a few inches thick alongside the vein. The minor gold content of the vein is probably associated with pyrite, as Chute (1939) reported that values of 6 to 8 dollars for gold per ton of pyrite were determined by F. W. Foote. Galena crystals range up to $\frac{1}{4}$ inch in diameter. Silver is probably associated with the galena for no minerals containing silver have been recognized. Howley and Murray (1918) reported that an exceptional specimen contained 336 ounces of silver per ton, and 30 ounces of silver per ton of lead concentrate was used in calculating ore reserves (Chute, 1939).

Sphalerite seen by the writer is dark brown, contains exsolved inclusions of chalcopyrite, and is fine grained. Chute (1939) reported that a little of the sphalerite is light brown, and that some of it comprises coarse aggregates with individual crystals up to 1 inch across. Chalcopyrite is present only in minor amounts, and in part occurs as small crystals on quartz in vugs. Barite forms minor small plates. Manganiferous carbonate is a minor vein material and is coated in places with a black oxidized film.

The same group of minerals forms a narrow vein at Broad Cove Point and is exposed in several prospect pits scattered for at least $\frac{1}{4}$ mile southeast of Silver Cliff mine. Chute (1939) reported that an adit 75 to 100 feet long lies 1,500 feet southeast of the Silver Cliff mine.

Conclusions

The veins near the Silver Cliff mine, and similarly mineralized veinlets near Placentia, were probably formed principally by deposition in open fissures. Wall-rock alteration is either lacking or was restricted to silicification and pyrite formation within a few inches of the vein walls. Breccia fragments in the vein are not replaced. No veins more than 1 foot wide are displayed along the many tens of miles of well-exposed coastline in the Placentia district, although bedrock is mainly concealed on the shores of Northeast and Southeast Arms. Faults are common near the Silver Cliff mine, but their ages in relation to mineralization are not known.

It is likely that some veins in the Placentia district contain hidden ore shoots of commercial value, but these targets are small and, although they are contained in faults, the search cannot be localized by our present geological knowledge. Most exposed faults are not mineralized, and only exceptionally wide parts of mineralized faults would be of economic interest. The fact that the MacKay vein strikes northeast, as does the La Manche vein, may favour exploration of faults and lineaments of similar orientation, but too few veins are known to establish a preferred orientation. Mineralized veins are scattered along the southwestern side of the large fault underlying the stream flowing west-northwesterly into Broad Cove, but none are known northeast of the fault. Investigation of this fault by modest trenching or shallow drilling might be rewarding, although the Fowler vein is adjacent to and parallel with the fault and is thin and sparsely mineralized. Most surface exposures

near the mine were probably examined and many test pits dug prior to 1927. The potential ore shoots might be responsive to modern geophysical exploration, but would presumably be small. Hence there seems little justification for major exploratory effort in the Placentia-Silver Cliff district.

Veinlets, Placentia District

Narrow veinlets near Placentia, 4 miles south of the Silver Cliff mine, are mainly quartz and galena in dense white-weathering green slate and siltstone near the contact of the Bull Arm and Big Head Formations. In Southeast Arm, veinlets were observed opposite Placentia (Strouter Adit) and one mile to the southeast on a small island. Galena is disseminated in veinlets in similar rocks 1.2 miles northeast of Placentia in Northeast Arm on the shore southeast of Seven Islands. At Black Point, 5 miles southwest of Placentia, two veinlets containing galena range up to 4 inches in width. Narrow veinlets similar to the Silver Cliff veins are reported in a shaft in amygdaloidal basalt about 500 yards west of the railway station at Jersey side, one-third mile north of Placentia (Chute, 1939).

Barite

The barite vein on the southeast shore of Collier Bay, 1 mile southwest of Collier Point, is the largest of several veins in southwestern Trinity Bay (McCartney, 1957). Production from 1902 to 1904 totalled 6,615 tons before work was discontinued in 1905 (Howley and Murray, 1918). A shaft and adit at the open pit on the shore are inaccessible, and a pit or shaft about 300 feet south of the shore is filled.

Toronto mining interests examined the vein in 1951 and, after successful bleaching tests, expressed considerable interest, but had done no further exploration up to December, 1955 (Carr, 1958). The vein was examined by the writer in 1954 and by C. W. Carr, Mines Branch in 1956 (1958).

The wall-rock is grey-green arkose of the uppermost part of the Snows Pond Formation and is of late Precambrian age. Ripple-marks are common, and in this district a purplish red cast is characteristic of beds less than 700 feet below the Random Formation. The beds strike $N35^{\circ}-70^{\circ}E$ and dip to the northwest at 25 degrees.

The vein strikes $N15^{\circ}W$ and is approximately vertical (Pl. XII). It is filled with an aggregate of coarse-bladed barite with crystal faces up to 2 inches long. Colour is white, red, or salmon-pink. The length of the vein is not known, but coarse blocks of barite are piled near a filled shaft about 300 feet from the open pit along the strike of the vein. No trace of barite was found along the south trend of the vein, 1,000 feet or more from the shore in an area of plentiful outcrops. Carr (1958) received reports that the barite vein is exposed 1 mile south at Long Cove, but the chances are small that this is the same vein, for small veins of barite



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PLATE XII. *Barite vein with parting of arkose. Open cut of Collier Bay vein in Trinity Bay, looking south.*

are fairly common in the district (McCartney, 1957). Any postulated extension of such veins between widely separated points requires confirmation at intervals of a few hundred feet. In common with all barite veins in the western Avalon Peninsula, thickness varies rapidly with depth; it may likewise vary rapidly along strike. Present exposures show a thickness of at least 9 feet of barite in the open cut, and a massive width of 4 feet 7 inches flanked by arkose with subsidiary veins $\frac{1}{4}$ inch to 12 inches in thickness at a point 35 feet vertically below the open cut on the shore (Carr, 1958). Snelgrove and Baird (1953) reported that the vein “is said to have averaged 20 feet over a distance of 300 feet”. This width would likely include some discrete horses and layers of arkose, judging from present exposures. Partial analyses of two typical coarse specimens from the open pit are given in Table XVI.

Table XVI

Partial Analyses of Coarse Barite from Collier Bay, Trinity Bay

Specimen No.	BaO	SrO	SO ₃	Fe ₂ O ₃	FeO	Total
MB 54-1	61.53	4.14	35.44	0.10	0.09	101.29
MB 54-2	61.09	2.95	34.46	0.42	0.05	98.97

Analyst: S. Courville; strontium determinations, by X-ray fluorescence, by R. J. Traill, Geological Survey of Canada.

The coarse grain of the barite suggests a use as heavy aggregate for concrete in coating underwater pipes and for radiation shielding. The grab samples, with 93.63 and 92.97 per cent BaSO_4 , are slightly below the normal minimum grade of 94% BaSO_4 used in chemical industries. Carr (1958) reported that the barite can be bleached.

The barite veins are massive and in sharp contact with wall-rock; hence, a clean coarse product could be shipped. No modern exploratory work has been done although modest tonnage could probably be proved at low cost.

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APPENDIX

Cambrian Fossil Collections from Southern Conception Bay and South and East Trinity Bay

Fossils collected were especially useful in resolving the Middle Cambrian stratigraphic and structural problems of southern Trinity Bay. No collections were made from fissile slates in which diagnostic fossils could be recognized in the field. R. D. Hutchinson, who identified the following collections, recently completed a systematic study of Cambrian fossils from southeastern Newfoundland (Hutchinson, 1962); hence, the more diagnostic fossils in the writer's collections are listed only in summary fashion in order of decreasing age. Numbers refer to the permanent collections of the Geological Survey of Canada.

Lower Cambrian, Pre-*Callavia* zone

Collection No. 20230 is from 200 feet northeast of the basal Cambrian contact near Duffs, east shore of Holyrood Bay.

Hyolithes sp.

Coleoloides sp. cf. *C. typicalis* Walcott

Remarks: The Bonavista Formation and the lower part of the Smith Point Formation are characterized by these genera, which were readily recognized and seldom collected.

Lower Cambrian, *Callavia* zone

Brigus Formation

Collection No. 20229 is from 400 feet northeast of No. 20230, east shore of Holyrood Bay, Conception Bay.

Callavia broggeri Walcott

Strenuella strenua (Billings)

Remarks: Other collections from the Brigus Formation containing *Strenuella strenua* were made at Red Rock Cove 15 feet east of a fault near Harbour Main Point, Conception Bay (No. 20225); at Whalens Brook, 0.7 mile northwest of the mouth of Colliers River, Conception Bay (No. 20227); 0.7 mile west-southwest of English Cove, Colliers Bay (No. 20228); and on the point southwest of Whiteway Bay, Trinity Bay (No. 24625). *Callavia broggeri* was collected at the east end of Salmon Cove, Gasters Bay, Conception Bay (No. 20226).

Lower Cambrian, *Protolenus* zone

Brigus Formation, upper part

Collection No. 24622 is from 500 feet south, and 206 feet stratigraphically below, the manganese zone, northeast shore of New Harbour, Trinity Bay.

Protolenus (?) sp.

Middle Cambrian, *Paradoxides bennetti* zone

Chamberlain's Brook Formation

Remarks: Most collections were restricted to the zone fossil to confirm field identifications. These collections of *Paradoxides bennetti* were made from the following localities: in the upper part and above the manganese zone, west shore of Spread Eagle Bay, Trinity Bay (Nos. 24633, 24634); from the dip slope forming the east shore of a small cove 1,200 feet southeast of McLeod Point, southern Trinity Bay (No. 25026); from a limestone bed on the shore 1.2 miles south of Long Point, east shore Trinity Bay (No. 24626); from shale lying on the manganese zone 1.15 miles south of Hopeall Head light-house (No. 24623); from thin limestone beds that overlie a bedded volcanic breccia 1,000 feet southeast of Hopeall Head (Nos. 24620, 24621); and 0.8 mile south of the highway on the east side of a cart road east of Kelligrews River, Conception Bay, where the collection is from a pit 180 feet south of a prominent shale outcrop and also contains *Andrarina tenera* (Hartt) (No. 21943). A collection from 80 feet above the manganese zone on the west shore of Spread Eagle Bay lacks *P. bennetti* but includes *Ctenocephalus terranovicus* Resser and *Bailiella* sp. (No. 24635).

Middle Cambrian, *Paradoxides bennetti* zone

Paradoxides lamellatus sub-zone

Chamberlain's Brook Formation, upper part

Remarks: Two collections include the first reported occurrence of *P. lamellatus* in Avalon Peninsula, although the trilobite is common in the Cambrian of St. John, New Brunswick. Collection No. 24614 is from a green limestone bed, 6 inches thick, in grey slate on the shore of the west arm of Chapel Arm, Trinity Bay. It is 280 yards northeast of the junction of the Long Harbour road with the highway. The horizon lies 240 feet below pillow lavas and 73 feet below dark grey slate containing *Paradoxides hicksi*.

Fauna include:

Paradoxides lamellatus (Hartt in Dawson)

Bailiella sp.

Solenopleura (?) sp.

Palaeacmaea (?) sp.

Collection No. 24624 is from a grey limestone bed 4 inches thick in grey slate on the northeast shore of Cavendish Bay, Trinity Bay, 500 feet west of longitude 53°30'.

Fauna include:

P. lamellatus (Hartt in Dawson)

Ctenocephalus terranovicus Resser

Andrarina ouangondiana (Hartt in Dawson)

Middle Cambrian, *Paradoxides hicksi* zone

Manuels River Formation, lower part

Collection No. 24637 is from the west shore of a small cove, 1,200 feet south-east of McLeod Point, southern Trinity Bay, in well-bedded dark grey slate about 92 feet stratigraphically below pillow lava.

Fauna include:

Paradoxides hicksi Salter

Clarella venusta (Billings)

Solenopleura applanta (Salter)

Agraulos socialis Billings

Bailiella tenuicincta (Linnarsson)

Eodiscus scanicus (Linnarsson)

Peronopsis sp.

Condylonyge sp.

Less complete collections from the zone in southern Trinity Bay include Nos. 24902, 24636, and 24615.

Middle Cambrian, *Paradoxides davidis* zone

Manuels River Formation, upper part

Collection No. 24638 is from the southeast shore of Chapel Arm, Trinity Bay, 2,000 feet north of the principal stream, and 75 feet stratigraphically below a pillow lava flow.

Fauna include:

Paradoxides davidis (Salter)

Meneviella venulosa (Salter)

Ptychagnostus atavus (Tullberg)

Pleurestinium granulatum (Barrande)

Hypognostus sp.

Peronopsis sp.

Condylonyge sp.

Collections numbered 21941 and 21942 are from a shale outcrop in a road-cut 0.8 mile south of the highway on the east side of Kelligrews River, south-east Conception Bay (from a stratigraphic interval 5 feet thick).

Fauna include:

Paradoxides davidis (Salter)

Meneviella venulosa (Salter)

Solenopleura variolis Salter

Ptychagnostus punctuosus (Angelin)

Cotalagnostus altus (Gronwall)

Eodiscus punctatus (Salter)

Peronopsis cf. *fallax* (Linnarsson)

Hartshillia cf. *inflata* Illing

Corynexochus sp.

Phalacroma sp.

A very similar fauna is represented by collections 20222, 20223, and 20224 from a shallow pit on the east of the secondary road 0.2 mile east-southeast

of the northeast end of Indian Pond, southern Conception Bay. Other diagnostic but less complete collections from the zone in Trinity Bay include Nos. 24617, 24618, 24619, 24628, 24629, 24630, 24639, 24640.

Upper Cambrian ?, *Agnostus pisiformis* zone

Elliot Cove Formation, lower part

No reliable collection was made from this zone. Collection No. 21944 comprises poorly preserved cranidia from a very fissile pyritiferous black shale, 900 feet north of the northeast corner of Lawrence Pond, southeast Conception Bay. These were identified as *Agnostus* sp. by Hutchinson, with the following comment: "The only species of *Agnostus* known from eastern Newfoundland is the genotype *A. pisiformis* (Linnaeus), which occurs in, and gives its name to, the early Upper Cambrian *pisiformis* zone. Your lot is, therefore, probably referable to this zone. In Europe, however, *Agnostus* is also present in the latest Middle Cambrian beds, so the possibility that your lot is late Middle Cambrian cannot be excluded". (Hutchinson, personal communication, 1952.)

This collection involved several hours of search amongst difficult material and may represent late Middle Cambrian beds that have not formerly yielded fossils. The early Late Cambrian age seems more probable.

Upper Cambrian

Elliot Cove Formation

Remarks: Collection No. 21946 is from sparsely fossiliferous pale green-grey slate in the west bank of Upper Gullies River about 500 feet south of the highway, southeastern Conception Bay. It contains only poorly preserved *Orusia* sp., which establishes a Late Cambrian age.

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