CANADA
DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA
MEMOIR 265

TORBAY MAP-AREA, NEWFOUNDLAND

BY

E. R. Rose

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
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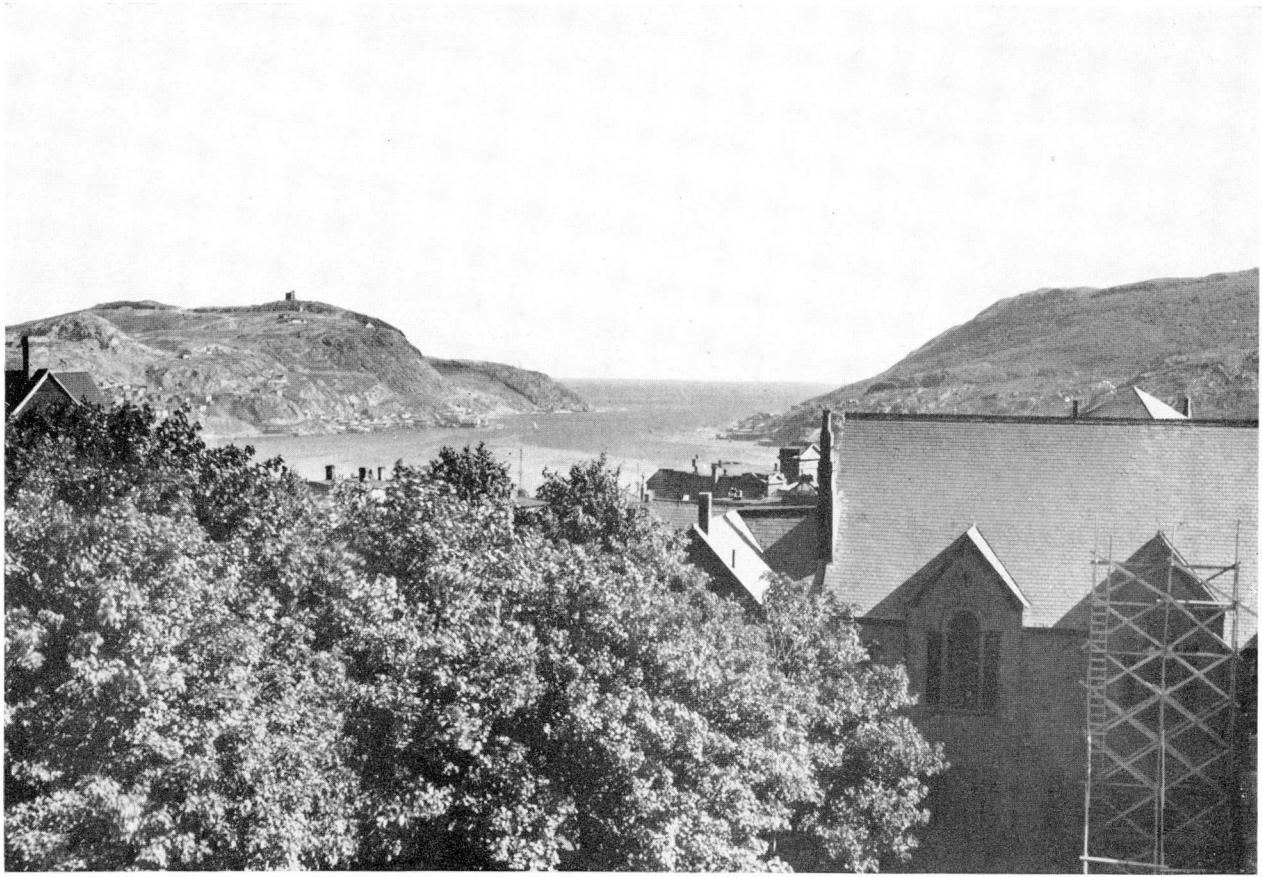

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The "Narrows", St. John's harbour, engraved across steeply dipping resistant beds of Signal Hill sandstone and conglomerate, with Signal Hill and Cabot tower on the left, and the South Side Hills on the right (view easterly from the city. (Pages 6, 22.)

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PREFACE

Avalon Peninsula, a highly irregular and almost disconnected land area of some 3,800 square miles at the southeastern tip of the island of Newfoundland, includes the capital city of St. John's and about one-quarter of the population of the province. Since the first reconnaissance survey by Jukes, in 1839, many eminent geologists have contributed to our knowledge of its rock formations and mineral resources.

The present report deals in some detail with an area of about 500 square miles at the northeastern tip of the peninsula centred about St. John's and Torbay airport and including Bell Island, famous for its Wabana iron ores. The formations described are partly of Precambrian and partly of early Palæozoic age, the latter including the classic Cambrian section of Manuels River and the iron-bearing Ordovician strata of Bell Island. The report deals with their stratigraphic and structural dispositions, and with their relations to various batholithic and minor intrusions and to a variety of mineral deposits. It is illustrated by several figures and plates, and is accompanied by a coloured geological map of the Torbay area on a scale of 1 inch to 4 miles.

GEORGE HANSON,

Chief Geologist, Geological Survey of Canada

OTTAWA, November 15, 1951

Torbay Map-area, Newfoundland

CHAPTER I

INTRODUCTION

GENERAL STATEMENT

Torbay map-area lies within north latitudes 47°00′ and 47°50′ and west longitudes 52°30′ and 53°00′, in the Avalon Peninsula of eastern Newfoundland. It has an area of 1,345 square miles, of which about 805 square miles are ocean covered.

This easternmost tip of North America jutting into the North Atlantic Ocean contains the city of St. John's, which is linked to the mainland by modern rail, air, and sea services. Trans-Atlantic air and sea travel facilities are also available.

A network of paved and gravel roads provides for motor travel through much of the area, and outlying parts of the coast may be reached by small boats. Away from the roads, travel across country is difficult in most places because of thick bush, wet bogs, and generally rough terrain.

About one-quarter of the population of the province of Newfoundland is concentrated in this area, in and around St. John's, Wabana, and the small fishing villages that dot the coast, and the few producing mines and quarries in the area have aided materially in maintaining employment there. In particular, the iron mining industry on Bell Island in Conception Bay has been a bulwark in Newfoundland's economy since the discovery and early development of the ore around the turn of the century.

St. John's, the provincial capital, with a population of about 45,000[1], is situated on a magnificent, natural, land-locked harbour (*See* Frontispiece), which is capable of accommodating all but the largest of modern ocean liners. It is a seaport, the eastern terminus of the Newfoundland Division of the Canadian National Railways, a distributing centre, and an important centre of the Newfoundland fishing and sealing industries. Wabana, with a population of 8,171 (1945 census), an important iron mining settlement, is served by small, private steamship ferries, which operate between Portugal Cove and The Beach. Other settlements in the area include the fishing villages of Pouch Cove, Bauline, Flat Rock, Torbay, Portugal Cove, St. Phillips, Quidi Vidi, Topsail, Manuels, Foxtrap, Long Pond, Petty Harbour, Bay Bulls, Witless Bay, Mobile, Tors Cove, Cape Broyle, Calvert, Ferryland, and Aquaforte, most of which have a population of less than a thousand.

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[1] 1945 census.

PREVIOUS GEOLOGICAL WORK

Prominent among the many geologists who have worked within the map-area are: J. B. Jukes, Alexander Murray, J. P. Howley, T. C. Weston, G. F. Matthew, C. D. Walcott, G. van Ingen, A. O. Hayes, N. C. Dale, A. F. Buddington, B. F. Howell, H. A. Baker, and J. S. Vhay.

The first geological report and map of Newfoundland by Jukes (27)[1] was published in London, England, in 1843, as a result of his field work for the Newfoundland Government in 1839-40. In that report, the rocks of Avalon Peninsula were named and classified as follows:

"Upper Slate Formation	a. Belle Isle shale and gritstone b. Variegated slates
Lower Slate Formation	a. Signal Hill sandstones b. St. John's slate"

with intrusive areas of granite, "sienite", porphyry, and basalt, etc., shown on the map.

Sir William E. Logan, founder and first Director of the Geological Survey of Canada, 1842-1869, was next invited by the Governments of Great Britain and Newfoundland to carry on official geological surveying in Newfoundland. To this end, Alexander Murray and an assistant, H. H. Beckett, were sent to Newfoundland in 1864.

Murray, who later became Director of the Geological Survey of Newfoundland, and who was knighted for his services, continued official geological mapping in Newfoundland from 1864 to 1883. In 1869, J. P. Howley was appointed Assistant Geologist; he succeeded Murray in 1883, and continued his services until 1909. The results of their work were assembled and published in collected form in two volumes: the first (35), published in 1881 in London, England, comprises their reports from 1864 to 1880, and the second (25), issued in St. John's, Newfoundland, in 1918, includes those from 1881 to 1909. These volumes contain much information on the geology of the area under present consideration, and the second volume contains their map (36) of 1881, which shows the distribution of formations within the Avalon Peninsula, and remains the most detailed geological map of this peninsula yet available.

Matthew and Walcott each published accounts of the important section of Cambrian rocks exposed on Manuels River, following Weston's discovery of fossils there in 1874 (50).

Walcott in 1899 proposed (46) the name "Avalon Terrane" to include the formations lying between the basal beds of the Cambrian system and the Archæan gneisses of Newfoundland, and used the names Signal Hill, Momable (St. John's slate), Conception, and Torbay for these formations. In 1900, after Matthew's work around Trinity Bay and subsequent publication (34), Walcott described (47) a new Precambrian "terrane", the Random, which he said rested conformably on the Signal Hill sandstone and conglomerate, and which he included in his "Avalon series".

In 1907, Howley published a coloured geological map (24) of Newfoundland in which he recognized the presence on Avalon Peninsula of a "series of mixed igneous and aqueous deposits", all highly metamorphosed,

[1] Numbers in parentheses are those of references listed in Bibliography at the end of this chapter.

which he called typical Lower Huronian, and which he placed stratigraphically below the Avalonian series. The term 'Avalonian' was applied provisionally, as Walcott suggested, to the sedimentary series lying between the Huronian and Cambrian formations. Murray's comment on the similarity of these sedimentary rocks on the Avalon Peninsula to the "Auriferous series" of Nova Scotia was expressed again by Howley. The map, reprinted in 1925, is again out of print.

In 1914, van Ingen (44) published a "Table of the Geological Formations of the Cambrian and Ordovician Systems about Conception and Trinity Bays, Newfoundland, and their Northeastern-American and Western-European Equivalents". The same year, papers by Hayes on the "Geology of the Wabana Iron Ore of Newfoundland" (14, 15), and by Dale on "The Cambrian Manganese Deposits of Conception and Trinity Bays, Newfoundland" (8) were issued.

In 1916, Buddington published a paper on "Pyrophyllitization, Pinitization, and Silicification of Rocks Around Conception Bay, Newfoundland" (3) and, in 1919, another on "The Pre-Cambrian Rocks of Southeast Newfoundland" (4). He proposed the name "Avondale volcanics" for Howley's (1907) Huronian series, which corresponds in part with Murray's (1881) Laurentian gneiss and "a" and "b" divisions. Howell (22) later suggested the name be replaced by "Harbour Main volcanics". Buddington's conclusions are well summarized in his 1919 report (4). In reference to certain similarities of the rocks of the Conception, Torbay, and Momable (St. John's) series to the Goldenville quartzites, the banded argillite division, and the Halifax formation, respectively, of the gold-bearing series of Nova Scotia, he states:

> "Specimens from an outcrop in the yards of the Canadian Pacific terminal at Halifax are indeed indistinguishable, except for a more prevalent cleavage, from many characteristic specimens of the Momable series. Before any correlation may be suggested, however, it is necessary that a more intimate knowledge of the conformable or unconformable relations within the Newfoundland series shall be known, as well as more definite information concerning the relations of the gold-bearing series of Nova Scotia to the Cambrian."

In 1920, Howell, who has contributed most to our knowledge of the Cambrian faunas of Newfoundland, published two papers: one on "Correlation of the Middle Cambrian of Newfoundland and Great Britain" (20), the other on "The Middle Cambrian Beds at Manuels, Newfoundland, and Their Relations" (21). These were followed, in 1925, by another, on "The Faunas of the Cambrian Paradoxides Beds at Manuels, Newfoundland" (22), and, in 1926, by "The Cambrian-Ordovician Stratigraphic Column in Southeastern Newfoundland" (23).

Baker resumed official geological surveys in Newfoundland as Government Geologist from 1926 to 1929. In the general report for 1928 (2), he expressed the need for revision of the existing geological maps of Avalon Peninsula, and presented his views on some of the problems involved. He contended:

> "That the group of rocks separated off by Howley as 'Lower Huronian' (the 'a' and 'b' beds of Murray) are not the *oldest* but the *youngest* Pre-cambrian of this area. They must be of a much later date than the Signal Hill Conglomerate and must occur well up in the sequence of the Random terrane which itself constitutes the upper portion of Walcott's Avalonian series."

In 1914 (14) and in 1915 (15), Hayes published papers on the Wabana iron ore, followed in 1929 (16) by a paper entitled "Further Studies of the

Origin of the Wabana Iron Ore of Newfoundland", and in 1931 (17) by "Structural Geology of the Conception Bay Region and of the Wabana Iron Ore Deposits of Newfoundland". His sketch map of the structural geology of the Conception Bay region, which appears in this last report, differs in many respects from those previously published. He disagreed with Baker's conclusion on the relative ages of the 'Conception slate' and the Signal Hill 'series', believing the latter to overlie the former at Red Head north of Tor Bay. He stated:

"The recent critical study of the structural relations of these formations confirms the writer's views regarding the system of thrust faulting, illustrated by Figure 2 of Hayes' report, and the overlap of the Cambrian, Bell Island and Wabana strata on the Avondale volcanics and Conception slates which compose the oldest representatives of the pre-Cambrian formations of the Avalon Peninsula."

Bulletin No. 7 (45) of the Geological Survey of Newfoundland by Vhay, published in 1937, contains the results of his investigation of the geological features and economic possibilities of a relatively small area containing pyrophyllite deposits, situated about 3 miles south of Manuels, Conception Bay. He concluded that:

"Large areas of quartz-pyrophyllite schist were formed by hydrothermal alteration of sheared rhyolite lavas and conglomerates near a granite contact. Certain schist areas contain a high percentage of pyrophyllite in addition to scattered lenses of nearly pure pyrophyllite."

A 6-foot bed of conglomerate in the 'Conception slates' containing fragments of basalt, rhyolite, and some *granite* is mentioned.

Referring to the granite in a footnote, Vhay states: "This granite must be derived from the erosion of an older intrusion, not identified in the area". He noted that both the granite and intruded rocks were sheared near the contact in many places in the Johnnys Pond area; that some pyrite was introduced into crushed zones in the granite near the contact; and that at these places the weathered surface shows considerable limonite staining. He disagreed with Buddington in concluding that all of the silicification as well as the pinitization is related in origin to the granite intrusion, and that alterations resulting from both of these rather widespread hydrothermal processes probably antedated the effects of pyrophyllitization. He stated:

"In general it may be said that the pyrophyllite replaced the quartz. It may be that it has also replaced the feldspars of the original rock where it had not been entirely silicified; but whereas the replacement of the quartz was incomplete and can be observed, the replacement of the feldspar, under the same conditions, took place more readily and went to completion, so that the relations cannot be determined. In most thin sections of the pyrophyllitized rocks it was observed that the orientation of the pyrophyllite flakes shows no relation to the schistosity which seems therefore to be an inherited structure. This suggests that the rocks had been sheared previous to the pyrophyllitization, and were not under great stress when hydrothermal solutions caused the development of pyrophyllite."

Reference was made to all the known mines and mineral resources of Newfoundland and Labrador in Geological Survey of Newfoundland Information Circular No. 4 (42), by Snelgrove, published in 1938. A sketch map of the general geology of Newfoundland accompanies the report.

Princeton University contributions to knowledge of the geology of Newfoundland number fourteen publications, of which seven have direct reference to Torbay map-area, and include the work of van Ingen, Hayes, Dale, Buddington, Howell, and Snelgrove. The associations begun by van Ingen and his students at Princeton have been maintained to the present, to the general benefit.

PRESENT WORK

Most of the previous geological work done in Torbay map-area was either of a reconnaissance, or extremely detailed, specialized nature. The present work was, therefore, undertaken to collate, revise, and clarify the great amount of information that had accumulated on the rocks of the area, as well as to provide a geological map that might assist in the development of its mineral resources.

Field work upon which this report is based was begun in the summer of 1948 for the Geological Survey of Newfoundland, and continued in 1949 for the Geological Survey of Canada. A preliminary report (40) on the 1948 work was made for the Geological Survey of Newfoundland in 1949, prior to the entry of Newfoundland into Confederation with Canada, and in 1950 a preliminary map, Torbay, Newfoundland, was issued by the Geological Survey of Canada (41).

Study of the literature on previous geological work had shown the need for mapping and revision of terms. To this end, a re-definition of rock formations, groups, and series is presented in the "Table of Formations" (pages 13, 14), and their distribution and structure are shown on the accompanying geological map and structure-sections.

A large area of volcanic rocks of types similar to the 'Harbour Main volcanics' and comprising amygdaloidal andesite, pink-tinged, flow-banded rhyolites and felsites, and agglomerate and tuff, is mapped around Witless Bay Country Pond. Conglomeratic members of the Conception group in the vicinity bear water-worn cobbles and pebbles derived from the volcanic group, and an unconformity between the Harbour Main and Conception groups is indicated. The term Harbour Main group is used here to include both the volcanic and sedimentary rocks of the 'Harbour Main (Avondale) volcanics', and is applied to rocks of that type that occur in the map-area.

The name Conception group is here proposed to include the 'Conception slate' and 'Torbay slate', which lie disconformably beneath the St. John's formation, which in turn underlies the Signal Hill formation conformably; and the name Cabot group is proposed to include the St. John's, Signal Hill, and Blackhead formations.

The Blackhead formation, comprising more than 5,500 feet of red and greenish grey, arkosic sandstone, with thin intercalated beds of slate, argillite, and siltstone, overlies the Signal Hill conglomerate conformably, preserved in the core of a great syncline between Signal Hill and Cape Spear. More than 16,000 feet of apparently conformable sedimentary rocks are involved in the fold.

The occurrence of the Topsail fault is confirmed at Topsail Head, and the fault zone is traced inland past the eastern end of Mobile Big Pond. On indirect evidence, the fault is thought to have been initiated in Precambrian time and to have marked the site of renewed movements in the Palæozoic Era.

Intrusion of the Holyrood granitic batholith and pyrophyllite mineralization near Manuels probably occurred in Proterozoic time. The emplacement of the granitic rocks may have taken place over a long period, but an older granite is indicated by the occurrence of granitic cobbles and pebbles in conglomerate of the Harbour Main group. Similar pebbles in smaller numbers are to be found in places in conglomerates of the Conception and Cabot groups.

The latest glaciation is shown to be one in which local valley glaciers moved radially outward from the interior towards the east and northwest shores, furrowing an older till as they did so. Elevated coastal terraces, composed of water-worn, glacial till, give evidence of recent, partial emergence of a coast-line whose dominant features are those of submergence.

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Messrs. Reid Proudfoot and William Cameron of the Dominion Steel and Coal Company's Wabana Iron Mines[1] kindly made available plans and sections of the orebodies, and arranged a trip underground to the submarine slopes of the iron mines for the party in 1949.

To Dr. A. O. Hayes, Emeritus Professor of Geology, Rutgers University, and Mr. C. K. Howse, Government Geologist, Geological Survey of Newfoundland, the writer is greatly indebted for much valuable information and discussion on the geology of the area. L. J. Weeks and A. M. Christie of the Geological Survey of Canada visited the writer's party near St. John's, and subsequently provided helpful discussions of the geological problems involved; and R. D. Hutchinson, Palæontologist of the Geological Survey, has kindly criticized the Cambrian section of the report.

Assay results for 1948 were supplied by Miss Gertrude Peters of the Newfoundland Government Laboratory, St. John's, and those for 1949 by R. A. Rogers of the Mines Branch, Department of Mines and Technical Surveys, Ottawa.

SURFACE FEATURES

COAST-LINE

The relatively smooth coastal plain that slopes gently bayward on nearly flat-lying Cambrian shale and slate, from Topsail Head past Kelligrews in Conception Bay, stands in marked contrast with the precipitous eastern coast, which is built mainly of strongly folded, resistant, Precambrian sandstone and conglomerate, and where cliffs tower 500 feet above the sea. Except for the Cambrian lowland on Conception Bay the remaining coast-line is almost continuous outcrop. Fortunately, this rock-bound coast is broken by several, fine, natural harbours, the best of which is the one at St. John's. The easterly trending fiords of Bay Bulls, Witless Bay, Mobile Bay, Cape Broyle Harbour, Caplin Bay, Aquaforte Harbour, and the narrows of St. John's harbour are engraved across the resistant beds of the coastal folds (*See* Frontispiece) and give evidence of having funnelled large quantities of glacial ice from the interior of Avalon Peninsula eastward to the sea. Each provides sheltered, deep-water harbours.

Erosion is most active on the elevated coastal belt, where the forces of wave, wind, stream, and ice have combined to strip the rocks bare. Well-developed, wave-cut, rock benches are to be found in many places along

[1] Now Dominion Wabana Ore Limited.

the present strand (*See* Plate II A). Marine terraces of silt, sand, and gravel, at elevations up to 35 feet, are preserved in Bay Bulls, Witless Bay, Mobile Bay, Caplin Bay, and Ferryland and Aquaforte Harbours, indicating that the sea has been withdrawn from these areas in Recent time, and that it once stood at least 35 feet higher with respect to the land than now. Although evidence is lacking in the map-area, the possibility that most of the area was submerged in Quaternary time should not be precluded. The flat-topped surfaces of Little Bell (*See* Plate II B), Kellys, and Bell Islands, at elevations of about 75, 175, and 300 feet respectively, may represent wave-cut benches formed by marine transgressions during the Quaternary Period. They are veneered with accumulations of glacial drift, and with stratified silt and sand that may be of marine origin. The occurrence, near the southwest end of Bell Island, of a thin mantle of stratified silt and sand, with shale flakes derived from underlying rock formations, might be noted here as a Recent water-laid deposit of possible marine origin, at an elevation of about 200 feet above sea-level. Although evidence in support of this was not found, recognition of terraces at comparable elevations is made difficult because of the modifying effects of weathering and erosion, including glacial action. The earlier and higher terraces antedate the last glaciation, and it may be intimated that a close relationship existed between Recent sea-levels and successive Pleistocene glacial stages.

INTERIOR PLATEAU

A rough plateau, difficult to traverse on foot, covered with innumerable thickets, bogs, ponds, and streams, forms the inland part of Torbay map-area, and has been modified by both glacial erosion and deposition. A mantle of glacial gravel and boulder clay as much as 50 feet thick covers much of the plateau, in some places resting directly on glacially polished and grooved bedrock. The surface is broken by outcrops and monadnocks, which reach an elevation of about 1,000 feet, and by glacially modified stream valleys.

Streams draining inland lakes and ponds display the characteristically haphazard drainage pattern of recently glaciated areas, as they meander in shallow beds through level stretches and plunge in a series of rapids and cascades through partly incised, rocky channels to the sea. Peat bogs, forests, lakes, and streams are developed on the glacial mantle.

In a paper on "The Surface of Newfoundland" (43), Twenhofel and MacClintock state:

> "There seem to be three erosion surfaces on the Avalon Peninsula. The lowest is around 200 feet high and is gently rolling. The second is 350 to 450 feet above sea level and is preserved only on the highest parts of the Peninsula as the South Hills of St. John's. Monadnocks rise in places above this level. Some of these exceed 1,200 feet.
>
> "The 700 to 800-foot level is considered the eastward extension of the surface of the High Central Plateau. The 350 to 400-foot level is correlated with the Lawrence Peneplain and thought to be the eastward extension of the Mary March Brook-Hines Lake Flats level."

RESULTS OF GLACIATION

There is good evidence that the Torbay area was heavily glaciated during Pleistocene time by ice moving radially seaward from the central part of Avalon Peninsula. Considerable thicknesses of relatively unweathered glacial debris of local origin, including erratics 20 feet in diameter, are

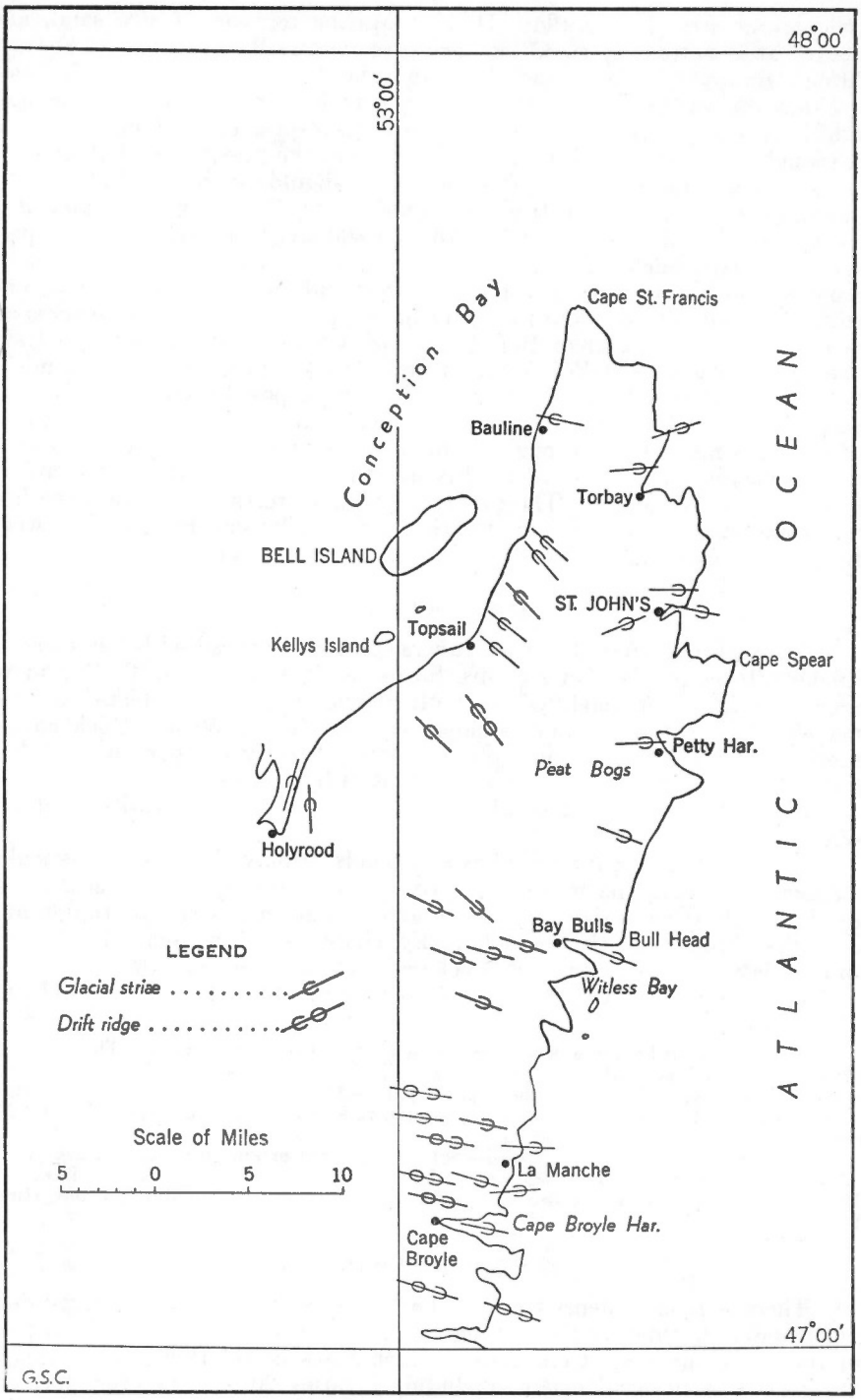

Figure 1. Sketch-map showing directions of latest glacial ice movement in Torbay map-area, Newfoundland.

common. Glacial markings—striæ, grooves, rock polish, and chattermarks —are abundant and especially well preserved beneath the mantle, and occur even on the tops of the highest hills. They indicate (Figure 1) that the direction of ice movement from Cape St. Francis to St. John's was, in general, to the east-northeast and from St. John's to Aquaforte, slightly south of east, with minor variations; but that from Bauline to Manuels it was northwesterly. A large central area from which glaciers moved outward, mainly to the northwest and east, is also indicated by the distribution of erratics of local origin, and is reflected by the present drainage pattern.

No fragments of Bell Island iron ore have been found, or are known to have been found, in the drift of the area, with the exception of four pieces of a single specimen of fine-grained oolitic hematite, at the fishing settlement of La Manche, south of Tors Cove, and these may have been brought there by hand.

SELECTED BIBLIOGRAPHY

1. Baird, D. M.: Notes on the Geology of Kelly's Island; Geol. Surv., Nfld., unpublished report, 1945.
2. Baker, H. A.: General Report of the Government Geologist for 1928; Geol. Surv., Nfld., St. John's.
3. Buddington, A. F.: Pyrophyllitization, Pinitization, and Silicification of Rocks around Conception Bay, Newfoundland; Journ. Geol., vol. XXIV, No. 2, 1916; Pr. U. Contr. Geol. Nfld. No. 3.
4. ———Pre-Cambrian Rocks of Southeast Newfoundland; Journ. Geol., vol. XXVII, No. 6, 1919; Pr. U. Contr. Geol. Nfld. No. 5.
5. Castaño, John, and Garrels, R. M.: Experiments on the Deposition of Iron with Special Reference to the Clinton Iron Ore Deposits; Ec. Geol., vol. 45, No. 8, 1950, pp. 755-770.
6. Chambers, R. E. and A. R.: Sinking of Wabana Submarine Slopes; Can. Min. Journ. Feb. 1909.
7. Christie, A. M.: Geology of Bonavista Map-area, Newfoundland; Geol. Surv., Canada, Paper 50-7, 1950.
8. Dale, N. C.: The Cambrian Manganese Deposits of Conception and Trinity Bays, Newfoundland; Am. Philos. Soc. Proc., vol. LIV, 1915; Pr. U. Contr. Geol. Nfld. No. 2.
9. Eckel, E. C.: Iron Ores, Their Occurrence, Valuation and Control; McGraw-Hill, New York, 1914.
10. Gilliatt, J. B.: Folding and Faulting of Wabana Ore Deposits; C.I.M. Bull. 1924, p. 895.
11. ———Iron Ore Mines of Wabana, Newfoundland; Skillings Mining Review, vol. XXXVIII, April 1949.
12. Hart, Charles: Foreign Iron Ores; A.I.M.E. Iron and Steel Div., Trans. 1929, pp. 18-19, 38.
13. Harvey, Rev. M.: Newfoundland in 1897; Sampson Low, Marston and Company, Limited, London.
14. Hayes, A. O.: Geology of the Wabana Iron Ore of Newfoundland (Abs.); Geol. Soc. Am., Bull. 25, vol. 74, 1914.
15. ———Wabana Iron Ore of Newfoundland; Geol. Surv., Canada, Mem. 78, 1915; Pr. U. Contr. Geol. Nfld. No. 1.
16. ———Further Studies of the Origin of the Wabana Iron Ore of Newfoundland; Ec. Geol., vol. XXIV, No. 7, 1929.
17. ———Structural Geology of the Conception Bay Region, and of the Wabana Iron Ore Deposits of Newfoundland; Ec. Geol., vol. XXVI, No. 1, 1931.
18. Hayes, A. O., and Howell, B. F.: Geology of Saint John, New Brunswick; Geol. Soc. Am., Special Paper No. 5, 1937.
19. Hayes, A. O., and Rose, E. R.: Geology of the Area Between Bonavista, Trinity and Placentia Bays, Eastern Newfoundland; Geol. Surv., Nfld., Bull. No. 32, 1948.
20. Howell, B. F.: Correlation of the Middle Cambrian of Newfoundland and Great Britain (Abs.); Geol. Soc. Am. Bull., vol. 31, 1920.

21. ———The Middle Cambrian Beds at Manuels, Newfoundland, and Their Relations; Science, new series, vol. 51, No. 1330, 1920.
22. ———The Faunas of the Cambrian Paradoxides Beds at Manuels, Newfoundland; Bull. Amer. Paleontology, vol. 11, No. 43, 1925; Pr. U. Contr. Geol. Nfld. No. 7.
23. ———The Cambrian-Ordovician Stratigraphic Column in Southeastern Newfoundland; Can. Field Nat., vol. XL, No. 3, 1926.
24. Howley, J. P.: Geological Map of Newfoundland, 1907.
25. Howley, J. P., and Murray, A.: Geol. Surv., Nfld., St. John's 1918 (a re-publication of the Reports of Progress of the Geol. Surv., Nfld., for the years 1881 to 1909).
26. Howley, J. P.: *See also* Murray, A., and Howley, J. P.
27. Jukes, J. B.: General Report of the Geol. Surv., Nfld., during the years 1839 and 1840, London, England, 1843.
28. Mines Branch: Report of the Ore Dressing and Metallurgical Laboratories; Investigation No. 1249, 1942.
29. ———Investigation No. 1350, 1943.
30. ———Report of the Mineral Dressing and Process Metallurgy Division; Investigation No. M D 2750, 1951.
31. MacClintock, Paul: *See* Twenhofel, W. H., and MacClintock, Paul.
32. Matthew, G. F.: On Cambrian Organisms in Acadia; Roy. Soc., Canada, Trans., vol. 7, Proc., sec. 4, 1889, p. 138.
33. ———On the Classification of the Cambrian Rocks in Acadia; Canadian Record of Science, vol. 3, 1888, pp. 71-81.
34. ———A Paleozoic Terrane Beneath the Cambrian; Annals N.Y. Acad. Sci., vol. XII, 1899, pp. 41-56.
35. Murray, A., and Howley, J. P.: Geol. Surv., Nfld., London, England, 1881 (a re-publication of the Reports of Progress of the Geol. Surv., Nfld., for the years 1864 to 1880).
36. ———Map of the Peninsula of Avalon, showing distribution of formations, 1881.
37. Murray, A.: *See also* Howley, J. P., and Murray, A.
38. Pettijohn, F. J.: Sedimentary Rocks; Harper and Brothers, Publishers, New York, 1949.
39. Rose, E. R.: *See also* Hayes, A. O., and Rose, E. R.
40. Rose, E. R.: Geology and Mineral Deposits of the St. John's Area, Avalon Peninsula, Newfoundland; Geol. Surv., Nfld., unpublished preliminary report, St. John's, 1949.
41. ———Preliminary map, Torbay, Newfoundland; Geol. Surv., Canada, Paper 50-24, 1950.
42. Snelgrove, A. K.: Mines and Mineral Resources of Newfoundland; Geol. Surv., Nfld., Info. Circ. No. 4, 1938.
43. Twenhofel, W. H., and MacClintock, Paul: Surface of Newfoundland; Geol. Soc. Am. Bull., vol. 51, 1940.
44. van Ingen, G.; Table of Geological Formations of the Cambrian and Ordovician Systems about Conception and Trinity Bays (Abs.); Geol. Soc. Am. Bull., vol. 25, 1914.
45. Vhay, John S.: Pyrophyllite Deposits of Manuels, Conception Bay; Geol. Surv., Nfld., Bull. No. 7, 1937.
46. Walcott, C. D.: Pre-Cambrian Fossiliferous Formations; Geol. Soc. Am. Bull., vol. 10, 1899.
47. ———Random, a Pre-Cambrian Upper Algonkian Terrane; Geol. Soc. Am. Bull., vol. 11, 1900.
48. ———Correlation Papers—Cambrian; U.S. Geol. Surv., Bull. No. 81, 1891, p. 360.
49. Wallheimer, Paul B.: Report on the Peat Possibilities in the Avalon Peninsula; Geol. Surv., Nfld., unpublished report, 1939.
50. Weston, T. C.: Notes on the Geology of Newfoundland; Proc. and Trans. Nova Scotia Ins. of Science, vol. 9, 1896, pp. 150-157.
51. Wiseman, Rupert: Manganese Deposits of Manuels, Newfoundland; Geol. Surv., Nfld., unpublished report, 1942.

CHAPTER II

GENERAL GEOLOGY

INTRODUCTORY STATEMENT

REGIONAL GEOLOGY

Torbay map-area forms a northeastern part of Avalon Peninsula, a highly irregular area of some 3,800 square miles in southeastern Newfoundland connected with the main part of the island by the narrow isthmus between Trinity Bay on the north and Placentia Bay on the south. Its bedrock ranges in age from Precambrian to Ordovician, and its northeasterly trending structures, characteristic of Newfoundland and of the Appalachian region, are reflected in the remarkable parallelism of peninsulas, bays, lakes, rivers, and ridges. Precambrian formations here show a great development of intermediate to acidic volcanic rocks, succeeded by an aggregate of some 20,000 feet of unfossiliferous sedimentary rocks. Intrusive into the volcanic rocks and into the lower members of the sedimentary series are igneous rocks ranging in composition from metagabbro to granite, and in size from batholithic proportions to small dykes.

An almost complete Cambrian sequence is preserved around the coast as infolded and infaulted erosion remnants of originally much more extensive deposits. These Cambrian rocks succeed Precambrian volcanic, sedimentary, and igneous rocks unconformably, but are known to be intruded by basic and acidic dykes at various localities in areas contiguous to Trinity and Placentia Bays. In Trinity and Bonavista Bay areas, Lower Cambrian strata rest disconformably on a formation of sparsely fossiliferous sedimentary rocks, the "Random terrane", which in turn rests, apparently conformably, on the Musgravetown group, unfossiliferous rocks of probable Precambrian age. In the area about Conception Bay, Lower Cambrian beds unconformably overlap the Precambrian Harbour Main group of volcanic rocks; the Conception group of sedimentary formations; and apparently the Holyrood batholithic granitic rocks, which together occupy the greater part of the Avalon Peninsula. Lower Ordovician sedimentary rocks succeed Upper Cambrian strata with no apparent unconformity, but are only known to occur in the Conception and Trinity Bay areas of eastern Newfoundland. Folds, fractures, and thrust faults characterize the rocks of the Avalon Peninsula.

LOCAL GEOLOGY

In Torbay map-area, the oldest bedrock recognized is that of the Harbour Main group, which comprises a thick assemblage of volcanic rocks, with minor interbedded sedimentary strata, and their metamorphosed

equivalents. Secondary structures, including joints, cleavage, and faults, are prominent in the lavas, as a result of which their attitude is difficult to determine. Crumpled against them, and in part derived from them, are rocks of the Conception group, composed mainly of fine-grained, greenish, sedimentary rocks, alternating with red beds, mainly near the top. Bedding and secondary structures are well defined locally, and indicate that these rocks are thrown into folds that trend mainly north-northeast. Most of Torbay map-area is occupied by these deformed, unfossiliferous, sedimentary rocks. Grey-black, red, and green beds of the Cabot group lie stratigraphically above them, but they are in places overridden by Conception group rocks. Within the map-area, the Conception and Cabot groups together attain a total estimated thickness of more than 20,000 feet.

Intrusive into rocks of the Harbour Main and Conception groups are bodies of meta-gabbro and granitic rocks of the Holyrood batholith, whose relations to the Cabot group are uncertain. Although a more precise dating of the granitic intrusion may not be made, it seems probable that it was emplaced in Proterozoic time following extrusion of large amounts of lava and during, or after, accumulation of thick sedimentary deposits that were derived mainly from the volcanic rocks.

An angular unconformity separates the Harbour Main group, the Conception group, and the granitic intrusions from the overlying fossiliferous Cambrian strata around Conception Bay. Gently dipping Lower, Middle, and Upper Cambrian beds, consisting mainly of shale, slate, crystalline limestone, and conglomerate, are exposed in the gorge of Manuels River. They are succeeded beyond an interval occupied by the waters of Conception Bay, by outcrops of Lower Ordovician sandstone and shale on Little Bell (*See* Plate II B), Kellys, and Bell Islands, the total thickness of Cambro-Ordovician strata being estimated at about 8,000 feet. Although the Cambro-Ordovician section is relatively undisturbed, it is intersected by many high-angle faults. Among these the Topsail fault zone at Topsail Head has truncated the Cambrian and Ordovician strata along the east side of Conception Bay.

The eroded bedrock surface is overlain by a mantle of glacial till, boulder clay, and roughly stratified sand and gravel, on which the most recent stratified delta sands and storm beaches of cobbles are built along estuaries and in sheltered coves. Much of the interior bedrock and till is overlain by bogs composed of roughly stratified layers of compacted peat.

TABLE OF FORMATIONS

This table outlines the geology of the area as interpreted by the writer.

Period and epoch		Formation (thickness in feet)		Lithology
Quaternary	Recent	Post-glacial sediments 0-35		Peat; stratified sand and gravel
		Minor disconformity—submergence and partial emergence		
	Pleistocene	Glacial drift 0-50		Glacial till, boulder clay, sand, and gravel
Great unconformity				
Lower Ordovician		Wabana group 1,000+		Shale and sandstone; oolitic hematite, oolitic pyrite, and phosphatic pebble beds
		Minor disconformity		
		Bell Island group 4,000+ (base not exposed)		Sandstone and shale; oolitic hematite beds
		Strata missing—covered by waters of Conception Bay		
Cambrian	Upper	Elliott Cove group 300+ (top not exposed)		Shale, thin-bedded limestone and sandstone; paper slate
	Middle	Acadian Series 300±		Shale, slate, thin-bedded limestone; manganiferous beds
	Lower	75±		Shale, slate, crystalline limestone, and conglomerate
Disconformity				
Late Proterozoic (?)		Cabot group	Blackhead formation 5,500+	Red and greenish grey arkosic sandstone; minor slate, argillite, and siltstone
			Signal Hill formation 7,500±	Red conglomerate, red, green, and greenish grey, arkosic sandstone; minor slate, argillite, and siltstone
			St. John's formation 1,000±	Dark grey to black slate, argillite, and grit, with a few arkosic conglomerate lenses and a transitional zone to grey sandstone at the top

Period and epoch	Formation (thickness in feet)		Lithology
	Disconformity		
Mid-Proterozoic (?)	Basic dykes[1]		Small dykes of diabase and trap
	Intrusive contact		
	Holyrood batholith[1]		Pink and grey granite, granodiorite, syenite, and aplite
	Intrusive contact		
	Meta-gabbro[1]		Small stocks of meta-gabbro
	Intrusive contact		
	Conception group	'Torbay slate' 3,000 ±	Flinty green sandstone, green, red, and reddish brown tinged slate, argillite, siltstone, and sandstone, with some quartzite, quartzitic sandstone, and conglomerate
		'Conception slate' 3,000 ±	Flinty, green to greenish grey siltstone, fine-grained green and grey sandstone, green to grey-green slate with some red slate, conglomerate, tuff, and agglomerate
	Unconformity		
Early Proterozoic (?)	Harbour Main group		Chloritic schist, amygdaloidal andesite, rhyolite, felsite, and basalt with volcanic breccias, agglomerate, tuff, and interbedded, flinty, green and red siltstone, slate, and coarse conglomerate

[1] May be in part, or entirely, younger than Cabot group, and in part older than Conception group.

PRECAMBRIAN ROCKS

HARBOUR MAIN GROUP

Name. The name 'Harbour Main group' is used here in reference to rocks of types similar to the Lower Huronian rocks of Howley (24), the "Avondale volcanics" of Buddington (4), and the "Harbour Main volcanics" of Howell (22). The name Avondale had previously been applied in 1883 by P. Fraser to a belt of limestone in Chester county, Pennsylvania, and its use in Newfoundland has, consequently, been abandoned. The type localities of the group are at Avondale and Harbour Main beyond Torbay map-area, on Conception Bay.

Distribution. Harbour Main group rocks form the hardrock cores of Avalon and Burin Peninsulas, 125 miles apart, and are thought to occur in the interior of central Newfoundland. The base of the group and its thickness, which is believed to be several thousand feet, are not known. So far as is known, it forms the lowest member of the later Precambrian (Proterozoic?) rocks of Newfoundland. The occurrence of pebbles of igneous and sedimentary rocks in conglomerate of the group indicates the existence of a pre-Harbour Main sedimentary and igneous terrain in addition to Archæan gneisses and schists. Within Torbay map-area, volcanic and sedimentary rocks of the Harbour Main group, or their metamorphosed equivalents, lie in strips near the western margin, from Cape St. Francis to a point west of Cape Broyle Harbour. A relatively large inlier of the group lies in the south-central part of the area near Witless Bay Country Pond.

Lithology. The Harbour Main group consists mainly of volcanic rocks, with minor amounts of interbedded sedimentary strata. Amygdaloidal andesite, mauve and green-tinged, flow-banded rhyolite and felsite, chocolate-brown rhyolite porphyry, agglomerate, tuff, coarse conglomerate, fine-grained, flinty, banded, green and red siltstone, sandstone, slate, and chloritic schist comprise the group within the map-area. Rocks of the group are regionally metamorphosed and intricately folded and faulted. The effects of dynamic and thermal metamorphism are shown locally. In general, the more acidic flows predominate; these are silicified and sericitized, whereas the more basic flows are chloritized and pinitized. Pyrophyllitization is largely confined to sheared acidic flows near faults and intrusive granite contacts.

Coarse conglomerates of the Harbour Main group are composed chiefly of rounded, water-worn cobbles, pebbles, and fragments of volcanic rocks, with some of pink granite, syenite, and green siltstone, and with interbeds of fine, green, sedimentary and volcanic rocks. They outcrop on the eastern shore of Holyrood Bay, beyond the map-area, and on the Witless Bay line. The component pebbles indicate the type of terrain from which this part of the group was derived.

Buddington (3, 4) gives detailed petrographic descriptions of many of the rocks of the group, and in some cases provides chemical analyses. Extrusive rocks described range from basalt to rhyolite, and most of these are variable in colour, texture, and composition. Flow breccias and agglomerate are represented, as well as interbedded sedimentary rocks that range from coarse boulder conglomerate to fine, well-bedded tuff and slate. Many of the tuffs are said by Buddington to be "soaked" with hematite.

In detail the rhyolites may be homogeneously fine grained, dense, and massive, or sparsely porphyritic and flow-banded, or they may show a combination of these features, varying much within short distances. Silica, derived mainly from the natural glass and microcrystalline aggregate of quartz and feldspar of which they are largely composed, commonly comprises more than 75 per cent of the rock. They may be red, reddish brown, or green in colour, depending on the content of hematite, which occurs commonly in finely disseminated specks and microcrystalline aggregates concentrated in flow-bands. The rhyolites weather to paler shades of their fresh colours, and are hard and flinty. Microspherulitic and spherulitic textures, and eutaxitic and perlitic structures are common. Spherules are commonly concentrated at the axes of folds. Alteration of the feldspars has characteristically yielded tiny flakes of white mica, and in certain places pyrophyllite is conspicuously developed in sufficient concentration to be mined. The equivalent or rhyolitic tuffs are commonly very fine-grained, hard, flinty, finely bedded rocks, in pale shades of green or pink, and break with a conchoidal fracture. They consist mainly of quartz, feldspars, glass, argillaceous materials, and chlorite, with subordinate amounts of white mica, magnetite, hematite, and epidote.

The more basic flows are dark green, or greenish grey, chloritic rocks, with amygdules commonly displayed. They and their equivalent tuffs are fine grained and commonly schistose. Amygdules may contain epidote, hornblende, and calcite crystals, or an interlocking aggregate of them. The finer grained groundmass is typically a confused, microcrystalline aggregate of feldspar laths, quartz, hornblende, epidote, apatite, magnetite, and chlorite, which shows evidence of flowage in a semi-parallel alinement of crystals. The intermediate to basic tuffs are commonly fine-grained, dark greenish, highly altered rocks, with a semi-granular texture. Feldspar, hornblende, chlorite, quartz, glass, magnetite, and apatite form recognizable grains in a chloritic groundmass that commonly makes up more than 50 per cent of the rock.

Coarse tuff, agglomerate, and conglomerate bear identifiable fragments of the extrusive rocks in a typically green, fine-grained matrix. In places in the tuff and agglomerate hematite permeates the groundmass and colours the rock reddish. Tuff and agglomerate fragments are angular to subangular, and those of the conglomerates well rounded. The fine-grained, minor, sedimentary interbeds of green and red siltstone, sandstone, and slate are in part tuffaceous, and resemble some beds in the overlapping Conception group.

Structural Relations. The Harbour Main group is cut off by the intrusive Holyrood granite where it reaches the coast about a mile east of Holyrood, on Holyrood Bay, beyond the map-area, and also south of Manuels. Many inclusions of rocks of the group are to be found in the granite. The locally metamorphosed equivalent of the group is found bordering parts of the eastern boundary of the Holyrood granitic batholith, where it is again, as in Holyrood Bay, succeeded by members of the Conception group. An inlier of the Harbour Main group is also unconformably overlapped by the Conception group along, and south of, part of the Witless Bay line.

At Manuels River, Harbour Main rocks and possibly its intrusive Holyrood granite are overlain unconformably by a coarse conglomerate, which forms the base, there, of a thick Cambrian and Ordovician section.

Mode of Origin. The recurring association of sedimentary strata with flows and pyroclastic materials within the Harbour Main succession is indicative of alternating, relatively quiescent periods of sedimentation and periods of explosive volcanic activity. The extrusive rocks give no evidence of deposition under water, but it is believed that the extensive and thick sedimentary interbeds including tuffs were water laid and formed, perhaps under mixed continental and marine environments, mainly under reducing conditions. In regions of active volcanism, lavas of acidic to intermediate composition characteristically yield thick gravel accumulations interbedded with contemporaneous lava flows. Pettijohn (38, p. 209) indicates that such conglomerates form a class apart from normal gravels derived from a variety of source rocks.

As a result of his areal study of the Harbour Main group, and in view of the constant recurrence of conglomerate beds in the stratigraphic succession and the fact that they reached thicknesses of 150 to 200 feet and contained well-rounded boulders up to 3 feet in diameter, Buddington (4) was inclined to believe that river erosion had played a more important role than wave work in the deposition of the beds.

The predominantly greenish colour of the matrix of the conglomerates and the similarity of the finer grained greywacke type interbeds to those of the Conception group point to analogous conditions of deposition, under reducing conditions, in a marine or lacustrine environment. The type and composition of the component rock fragments indicate a derivation in the main from penecontemporaneous volcanic and sedimentary rocks, with the introduction of some material from an igneous terrain as yet unknown in this part of Newfoundland.

Age. The age of the Harbour Main group is not precisely known, as it does not contain fossils. However, the group is known to be succeeded unconformably by more than 20,000 feet of unfossiliferous sedimentary rocks considered to be of mid- to late Proterozoic age, and is unconformably overlapped by Lower Cambrian strata at Manuels River bridge. For these reasons, the Harbour Main group may be assigned with confidence to the Proterozoic, or possibly the Archæan.

Correlation. Descriptions of the Proterozoic Coldbrook group of New Brunswick indicate a rather close similarity to the Harbour Main. The Coldbrook group is considered to be Proterozoic, as it overlies the supposedly Archæan, Green Head group unconformably, and is unconformably succeeded by Lower Cambrian[1] formations.

CONCEPTION GROUP

Name. The Conception group is here considered to include the variegated beds of the 'Torbay slate'[2], and the predominantly greenish and greenish grey members of the 'Conception slate'[2], whose names were introduced by Walcott in 1899 (46). The group corresponds also to the beds of Murray's (35, p. 145) "b" and "c" divisions of rocks of the Avalon Peninsula.

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[1] Geology and Economic Minerals of Canada (third edition); Geol. Surv., Canada, Ec. Geol. Ser. No. 1, p. 107 (1947).

[2] The terms 'Torbay slate' and 'Conception slate' are retained here because of prior usage and present convenience, but eventually should be supplanted by more conventional formational or group names.

Distribution. Rocks of the Conception group occupy large areas of Avalon Peninsula. Similar rocks are known to occur near Bonavista Bay, northwest of the peninsula, where they have been included in the Connecting Point group (19). In Torbay map-area, they occupy a belt that extends from Biscayne Bay south of Cape St. Francis past the southern boundary of the map-area. No complete section of the rocks is exposed, and the sequence is further obscured by folds and faults, but a thickness of about 6,000 feet of sedimentary strata is estimated for the group. Rocks of the group are revealed in scattered exposures, and spread by many folds, over much of the central part of the area. The Topsail fault zone forms the western boundary of the main part of the group, but several outliers occur west of the fault.

Lithology. The Conception group consists mainly of fine-grained, well-bedded, greenish to greenish grey siltstone, argillite, and slate, with sandstone, quartzite, conglomerate, tuff, agglomerate, and intercalated red beds mainly near the top. Most of these rocks weather white to buff. The strata of the two subdivisions of the group, the lower 'Conception slate' and the overlying 'Torbay slate', are similar in many respects, and, indeed, commonly indistinguishable, but recent mapping has shown a predominance of red beds in a disturbed sedimentary zone at the top of the group, characteristic of the 'Torbay slate', and beds of tuff and conglomerate near the base, characteristic of the 'Conception slate'. For these reasons, and because of the lack of other criteria that might serve to distinguish them, it has seemed best to include both 'Conception slate' and 'Torbay slate' in the one Conception group, and to indicate its subdivisions on the map only where they are readily separable (*See* footnote, page 17).

In Torbay map-area, the 'Conception slate' includes fine-grained, green to greenish grey siltstone (*See* Plate III A), argillite, sandstone, and slate, with some conglomerate, tuff, and agglomerate. The conglomerates are composed of rounded pebbles and cobbles of volcanic rocks evidently derived from the Harbour Main group, with some of pink granite and syenite, set in a dark green, fine-grained groundmass of argillaceous material, chlorite, calcite, magnetite, and quartz. The agglomerates are composed almost entirely of subangular to angular fragments of volcanic rocks. The tuffs are of similar pyroclastic origin, but are fine grained and relatively well sorted. Microscopically, the fine-grained, well-banded, sedimentary rocks, which comprise the bulk of the Conception group, consist mainly of variable amounts of quartz and feldspars, with minor amounts of micas, chlorite, carbonates, and magnetite, and occasional particles of volcanic rock cemented in a fine-grained, argillaceous groundmass, which, here and there, contains incipient metacrysts of carbonate and pyrite. Variations in the proportions of quartz, feldspars, and clay minerals cause variations in hardness, cleavability, and other physical properties of the beds. Where fissility is well developed locally, the rocks are slates. The coarser grained equivalents of the siltstones are formed of angular to subangular grains of quartz, plagioclase, orthoclase, rhyolite, felsite, spherulitic lava, and other material in an argillaceous groundmass, and are classified as greywackes.

The 'Torbay slate' of Torbay map-area includes flinty green sandstone, green, red, chocolate, and reddish brown siltstone, sandstone, argillite, and slate, with some quartzite, quartzitic sandstone, and minor conglomerate beds. The mineral composition of these beds resembles that

of the 'Conception slate', but in general includes more argillaceous material and hematite, and shows a cleaner separation of argillite and quartzite. The fracture of the fine-grained rocks is commonly conchoidal. In many places a well-defined cleavage has developed both parallel with and across the bedding planes, and has yielded a rough slate that has been adapted for roofing material. Some of the more argillaceous members of the 'Torbay slate' weather white to buff.

Structural Relations. Buddington, in his areal study (4), was not able to observe the relations of the Conception group to the beds above and below. In Torbay map-area, the group was found to overlie the Harbour Main volcanic rocks unconformably, and to underlie the St. John's formation of the Cabot group disconformably. In most parts of the area, the variegated beds of the 'Torbay slate' maintain their position immediately beneath the St. John's formation. Angular, subangular, and rounded grains, pebbles, cobbles, and boulders derived from the Conception group are found in the conglomerate member of the succeeding Signal Hill formation of the Cabot group, and although the rather rare conglomeratic beds of the St. John's formation are composed mainly of pebbles of basic igneous rocks, quartz, and feldspars, the disconformity between the Conception and Cabot groups is indicated by the abrupt passage from the red beds and quartzite of the 'Torbay slate' to the dark grey to black slate of the St. John's formation.

Mode of Origin. The Conception group of well-bedded, relatively unaltered, fine-grained, sedimentary rocks is composed of materials derived chiefly from the underlying Harbour Main group, swept from the land and deposited rapidly in thick accumulations under quiescent, reducing, probably marine conditions. Agglomerate, tuff, and tuffaceous beds among the lower members of the 'Conception slate' show the waning effects of volcanic activity, which was probably related to that of Harbour Main time. Near the top of the group, the alternating red and green beds of the 'Torbay slate' indicate that the sediments were exposed for short periods to alternately oxidizing and reducing conditions. The red colour of the beds is due mainly to hematite in the cement and as coatings on grains that are comparatively fresh and hard. Rapid erosion, short, quick transport, and deposition in shallow water are suggested. The red beds differ from the green mainly in their greater hematite content. Hematite was formed subsequent to transportation and deposition of the sediments. Ripple-marks, crossbedding, cut and fill structures, and bedding whorls in the 'Torbay slate' also attest deposition in a turbulent, shallow-water environment. Thin beds of pea-sized conglomerate in the 'Torbay slate', composed of assorted, rounded grains and pebbles derived from Harbour Main and 'Conception slate' rocks, are further illustrative of near-shore, shallow-water deposition, and of the minor disturbances in sedimentation that took place at that time.

Age. No definite fossils have been found in rocks of the Conception group, but its stratigraphic position between the Harbour Main and Cabot groups signifies that it is of Precambrian, possibly mid-Proterozoic, age. Precambrian meta-gabbro and granite are intrusive into rocks of the lower part of the Conception group, but are not found in contact with the 'Torbay slate' or younger formations in the map-area. Lower Cambrian strata unconformably overlap rocks of the Conception group at many localities outside the map-area, but within the Avalon Peninsula.

Correlation. Descriptions of the Connecting Point group (7, 19) indicate a rather close correspondence with the 'Conception slate' of the Conception group of Torbay map-area. On the other hand, the red beds, quartzite, and conglomerate of the 'Torbay slate' are apparently missing in the Bonavista and Trinity Bay areas, although the writer noted a few red beds in the Connecting Point section on the east shore of Placentia Bay during the summer of 1947. Grey to black shale, argillite, and slate similar, in description, to the St. John's formation rocks are included in the Connecting Point group (7, 19), and whereas an angular unconformity separates the Connecting Point group from the overlying Musgravetown group, the 'Torbay slate' of the Conception group passes disconformably upward to the St. John's formation of the Cabot group. Christie (7) notes unconformable relations in some parts of Bonavista map-area and apparent conformity in others, between the Connecting Point group and the overlying Musgravetown group.

INTRUSIVE ROCKS

Meta-gabbro

Distribution. Two small stocks of meta-gabbro outcrop within Torbay map-area; one, about 6 miles south of Manuels, is intrusive into volcanic rocks of the Harbour Main group; the other, about 2 miles east of Horse Cove, is surrounded by drift, but is apparently intrusive into sedimentary rocks of the 'Conception slate'.

Lithology. The first stock is intimately penetrated by small tongues of granite and by epidote veinlets. It consists mainly of hornblende and labradorite, and has a granular to ophitic texture. The feldspars are much altered to white mica, and some of the hornblende to fibrous epidote, zoisite, and quartz. The second small stock consists essentially of labradorite and augite, with accessory magnetite, and secondary white mica, chlorite, and epidote. Blocky, subhedral crystals and laths of labradorite feldspar are fractured and intimately penetrated by aggregates of secondary feldspar, white mica, chlorite, and epidote, but a suggestion of ophitic texture remains. The rocks of both stocks are of a dark greenish black colour, and weather to a rough, grey surface.

Age. They are thought to belong to the suite of intrusions that Buddington (4) described as occurring as small, irregular patches on the borders of and within the area of the Holyrood granite batholith, and also as huge dykes in his "Conception slate series".

Although meta-gabbro intrusions do not come in contact with rocks younger than the 'Conception slate' in Torbay map-area, the occurrence of pebbles of meta-gabbro in conglomerate of the St. John's formation suggests that these stocks were intruded before the deposition of the St. John's formation of the Cabot group.

Holyrood Batholith

Distribution. This granitic batholith occupies a strip about 2 miles wide along the west-central border of Torbay map-area, where it is intrusive into rocks of the Harbour Main and Conception groups, but is believed to be overlain unconformably by Lower Cambrian beds.

Name. The batholith was named and described by Buddington (4) as follows:

"The backbone of the St. John's Peninsula is mapped by Howley (1907) as Laurentian. This rock in its northern half was found by the writer to bear intrusive relations to the Avondale volcanics and to constitute a granite batholith five to six miles in width and about forty miles in length, if its boundary continues to coincide with that of Howley's Laurentian area. The eastern boundary, where it was followed by the writer for several miles, is delimited by a fault plane. Along the west side the beds are very much disturbed and folded. The rock is a pink, medium-grained, equigranular, biotite granite, consisting essentially of quartz, orthoclase, albite, oligoclase, and chlorite, the latter believed to be derived from biotite. Fresh flakes of original biotite, however, are found only in occasional sections."

Lithology. Rocks of the batholith within the map-area vary in texture and colour from place to place, and in composition from granite through granodiorite and syenite to aplite. Many hybrid rock types are to be found along the marginal zones of the batholith where it intrudes volcanic and sedimentary rocks of the Harbour Main and Conception groups, and the older meta-gabbro. Inclusions are abundant. A few small diabase and trap dykes are known to cut the granitic rocks.

The bulk of the Holyrood batholith in the map-area is medium- to coarse-grained, pink granite, mottled with light green spots and carrying quartz and feldspar phenocrysts. The surface weathers rough and to a light pinkish grey colour. Microscopically, about 75 per cent of the rock is seen to consist of roughly equal amounts of equigranular quartz and orthoclase crystals averaging 5 to 6 mm. in size, with about 10 per cent each of oligoclase and chlorite, and accessory magnetite, hematite, zircon, apatite, and biotite. Minor amounts of sericite, kaolin, and epidote occur as alteration products. Deuteric, micrographic intergrowths are observable in some of the feldspars. Prominent also is a fine-grained, salmon-pink rock of sugary texture whose mineralogical composition is revealed under the microscope to be very similar to that of the rock described above. The fine grain size, granitic composition, and panidiomorphic texture classify the rock as granite aplite, and its close relation to the associated granite of the Holyrood batholith is evident. Local loss of silica and incorporation of foreign material into the magma have produced syenite, granodiorite, and many hybrid rock types.

Age. In reference to the intrusive rocks of southeastern Newfoundland, Buddington wrote (4):

"In general, it may be said that the salic rocks have been intruded as molten masses of batholithic or stock type, with few apophyses or dikes, whereas the older basaltic or gabbroic magmas, to a preponderating extent, have been intruded as dikes.

"The rocks, with the exception of the quartz syenite and granodiorite, whose position is unknown, are given in the order of their intrusion, beginning with the oldest. Those around Conception Bay comprise hornblende granite gneiss, hornblende gabbro and plagioclase gabbro without olivine but locally quartz-bearing, basic granodiorite, biotite granite and granophyre, quartz syenite, aplite and granophyre dikes intruding the granite, and younger dikes of rhyolite porphyry and diabase intruding all the older rocks.

"Geographically, chemically and physically the volcanics, plutonics and dikes of the Conception Bay region appear to be genetically allied. Thus the gabbros, quartz-bearing gabbro, hornblende porphyrite with quartzose groundmass, granodiorite, quartz syenite, biotite granite, granophyre, and aplite form a series of rocks with ascending silica ratio, belonging to the same geographical area and very probably to the same period of intrusion."

In Torbay map-area it seems well established (4, pp. 455-456) that the Holyrood granite was intruded, uncovered, and eroded before the deposition of Lower Cambrian, pre-*Paradoxides* beds. It is intrusive into rocks of the Harbour Main group and into lower members of the Conception group, but its precise relationship in point of time to rocks intermediate in age between the 'Conception slate' and Lower Cambrian beds is not known. It seems most probable that the bulk of the granite was intruded during the interval between the deposition of the 'Conception slate' and Cabot group, but the possibility exists that the granitic rocks were emplaced over protracted, widely separated periods. Pebbles of granite are to be found in conglomerates of the Harbour Main, Conception, Cabot, and Lower Cambrian groups. The last alone seem to overlap the Holyrood granite unconformably (*See also* 4, pp. 455-456). Granitic pebbles in the Harbour Main and Conception groups are attributable to the erosion of intrusions somewhat older than the bulk of the Holyrood batholith. There is no direct evidence bearing on this point in regard to the Cabot group.

Fluctuating changes in the depositional environment of the 'Torbay slate' and the relatively sudden change to the black-shale facies of the St. John's formation suggest, but do not prove, a period of crustal instability that may have been related to intrusion of the Holyrood granitic magma into the crustal rocks of this area. On the other hand, it is not inconceivable that all, or part, of the granitic magma was emplaced following deposition of the more than 14,000 feet of strata of the Cabot group. Even in the area between Bonavista, Trinity, and Placentia Bays of eastern Newfoundland, where igneous rocks of post-Ordovician, probable Devonian, age are intrusive into overlying Cambro-Ordovician strata, intrusions are rather rare in the Proterozoic or early Cambrian(?) Musgravetown group. It should be emphasized that no direct evidence was found to establish the age relationship between the Cabot group and the Holyrood batholith.

Basic Dykes

In addition to the diabase and trap dykes that cut the Holyrood granite, there are a few similar, small, dense, black, fine-grained dykes that cut both the volcanic rocks of the Harbour Main group and granitized zones in them, along the east coast of Conception Bay. The dykes present chilled margins to the rocks cut. They are not known to come in contact with Palæozoic rocks in this area, however, so their precise age is not known. They may be genetically related to the Holyrood batholith.

CABOT GROUP

General Statement

Name. The name Cabot group is here used to include three conformable sedimentary formations, which, in ascending order, are the St. John's (St. John's, Aspidella, or Momable slate), Signal Hill, and Blackhead (Random?) formations. Cabot tower, built on Signal Hill overlooking the harbour and city of St. John's, commemorates John and Sebastian Cabot, credited with the discovery of Newfoundland, making North American landfall near Cape Bonavista on June 24, 1947 (*See* Plate I).

Distribution. The Cabot group lies in a belt along the eastern seaboard of Torbay map-area, extending some 50 miles from Red Head to Ferryland Head. The group comprises more than 14,000 feet of arenaceous and argillaceous sedimentary rocks at the type localities of St. John's, Signal Hill, and Blackhead, but wedges out towards the north and south.

Lithology, Structure, and Age. Rocks of the Cabot group range from fine black slate to coarse red conglomerate derived in the main from the underlying Harbour Main and Conception groups. With the exception of the St. John's formation, the rocks are of an arkosic nature, contrasting markedly with the Conception group, on which they rest disconformably. The group is strongly and differentially folded in a north-northeasterly direction. The uppermost measures of the group are not exposed in Torbay map-area, and no undisputed fossils have been found in it. Although its exact counterpart is not known in Newfoundland, the Musgravetown group of Bonavista and Trinity Bays is undoubtedly the local equivalent of at least part of the Cabot group. Its age is, therefore, probably late Proterozoic, but it may be very early Cambrian in part, depending on where the base of that system is drawn.

St. John's Formation

Name. This formation was first named "St. John's slate" by J. B. Jukes (27) and was included by him with the "Signal Hill sandstones" in his "Lower Slate Formation". The name "Aspidella Slates" was later applied to the formation by Murray and Howley (35), and "Momable Slate" by Walcott (46). Retention of the name St. John's seems best, as the formation is well exposed at that celebrated city and as the name was first applied there. The possible fossil Aspidella has been declared an inorganic concretion, and Momable Bay has been renamed Mobile Bay (both at the settlement and on recent maps of Newfoundland), so both of these names are unsuitable.

Distribution. The St. John's formation extends in a sinuous belt from Torbay southerly past Aquaforte Harbour on the southern boundary of the map-area. It is well exposed at Bay Bulls, Witless Bay, Mobile Bay, Cape Broyle Harbour, Caplin Bay, Ferryland Harbour, Aquaforte Harbour, and at St. John's, the type locality. Because of the intricately folded and faulted nature of the beds it is not possible to obtain a true measure of the thickness of the formation, but it is estimated to be between 1,300 and 2,400 feet thick at St. John's.

Lithology. The St. John's formation consists mainly of crumpled, dark grey to black, gritty slate and argillite, with a zone of intercalated sandy beds at the top transitional to the greenish grey Signal Hill sandstone above (*See* Plate III B). Beds of conglomerate occur with the slate in a few localities.

Murray's (35) description of the formation, his "d" division, follows:

"d. Dark brown or blackish slates of St. John's with ripple marks very distinctly displayed upon some surfaces, and in which some obscure organic remains have been found resembling the fossils found in c, and another supposed to be the shelly casing

of some description of Annelid[1]. The cleavage of this slate is sometimes very regular, oblique or at right angles to the bedding, but in parts it also cleaves parallel with the stratification. Towards the top there are frequent layers of hard, fine-grained, greenish sandstone interstratified, not usually over 6 or 7 inches in thickness."

The dark slates are locally pyritiferous, and weather grey, tan, and rust. Fracture cleavage is well developed locally, both about parallel with, and transverse to, the bedding, which in many places is difficult to determine. Microscopically, the dark slates are seen to consist of very fine-grained, homogeneous aggregates of clay minerals and quartz grains, with minor amounts of carbonates, micas, magnetite, chlorite, carbon, pyrite, and iron oxide stains. The size and proportions of the mineral components vary greatly, but most of the grains are about 0·05 mm. in diameter. Clay minerals and quartz together total about 80 per cent of the slate. Skeletal metacrysts of carbonate and pyrite occur locally, and micaceous minerals are alined parallel with the bedding. Coarser phases contain recognizable grains of altered cloudy feldspars, and a few, thin, fine-grained, conglomeratic lenses are composed almost entirely of rounded quartz and feldspar grains. A few conglomerate beds are composed mainly of pebbles of gabbro. Toward the top of the formation, grey sandstone beds become increasingly abundant and thicker and completely gradational into the overlying grey and greenish beds of the Signal Hill formation. The sandstone beds are composed chiefly of grains of quartz and feldspars with minor accessory minerals. They are interbedded with argillaceous layers and are ripple-marked in places. The transitional zone attains its greatest development on Bay Bulls and Mobile and Witless Bays.

Structure. Lying, as they do, stratigraphically between the more competent beds of the 'Torbay slate' and the Signal Hill formation, the strata of the St. John's formation are intricately crumpled and faulted. Fracture cleavage is inherent and locally well developed. The formation lies disconformably above the Torbay slate and conformably below the Signal Hill formation.

Age. The age of the St. John's formation is not known, as undoubted fossils have not been found in it, but its stratigraphic position between the Conception group and Signal Hill formation indicates it was formed in Proterozoic, probably late Proterozoic, time.

Correlation. At Hillview on the southwest arm of Random Sound in the Trinity-Bonavista Bay area, Hayes (19) found a formation of grey-black shale, slate, argillite, and dark conglomerate, similar in some respects to the St. John's formation, but which he included in his Connecting Point group and placed unconformably below his Musgravetown group, of late Precambrian or very early Cambrian age. In Torbay map-area, the St. John's formation is transitional upward to the Signal Hill formation, which in turn resembles part of the Musgravetown group, but only a general correlation may be made. It is clear that the pattern of events is not identical in the two areas. There is also a lithological similarity

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[1] *Arenicolites.* The forms in question were supposed to resemble the *Oldhamii* of Bray Head, but were pronounced upon examination by the late E. Billings to be undeterminable. He doubted their organic origin altogether. At a later date, however, fossils of a very low type were found, which Mr. Billings described and named *Aspidella terranovica*, a form later declared by Walcott to be a spherulitic concretion.

between rocks of the St. John's formation and the Halifax formation of the Meguma series of Nova Scotia, and to the Onwatin slate of the Whitewater series of the Sudbury region, Ontario, both of which are believed to be of late Proterozoic age.

Signal Hill Formation

Name. The name "Signal Hill Sandstone" was used first by Jukes (27) and later by Murray (34) for strata that correspond with Buddington's "Signal Hill Series" (4) and with the persent writer's Signal Hill formation. The formation includes three main members corresponding to Murray's 'e, f, and g' divisions, and which in ascending order are: a grey or greenish grey to green sandstone, with intercalations of black argillite and slate near the base; a reddish to reddish brown feldspathic sandstone, with interbeds of reddish slate and argillite; and a reddish to reddish brown conglomerate with reddish sandstone and slate interbeds.

Distribution. Rocks of the Signal Hill formation form the greater part of the eastern coast of Torbay map-area, extending from Red Head southward to Mobile Bay and reappearing on the Cape Broyle and Ferryland headlands. At the type locality of Signal Hill, they attain a total estimated thickness of 7,800 feet, but the formation thins along the strike, both northerly and southerly from Shoal Bay.

The harbour at St. John's lies at the contact of the Signal Hill and St. John's formations, and the "Narrows" or harbour entrance is carved in the Signal Hill sandstone and conglomerate. The city is built largely upon rocks of the St. John's formation, which stand at a lower level than the more resistant Signal Hill rocks.

Lithology. The sandstone of the lowest members of the Signal Hill formation is in the main medium to fine grained, and is very hard, in beds as much as 3 feet thick, which become greener in colour toward the top of the member. The weathered surface is greyish brown to yellow. Microscopically the rock is seen to comprise a granular aggregate of subangular to angular quartz and feldspar grains with accessory magnetite, apatite, chlorite, biotite, enstatite, epidote, and minor amounts of sericite, and clay minerals. In general, the grain size is between 0·06 and 1 mm.; quartz constitutes about 50 per cent and cloudy feldspars about 35 per cent of the rock, and the clay minerals are well separated into argillaceous lenses. The greenish colour is due to the occurrence of chlorite, enstatite, and epidote.

The greenish sandstone passes upward into the intermediate members of the formation through a zone of intermingled red and green beds to a dark red sandstone, which in turn passes into the reddish conglomerate of the upper member. The red sandstone is hard and tough, occurring in strong, massive beds that pass into pea-size and coarser conglomerate at the top. The rock is commonly well jointed, and provides an excellent source of building stone. It weathers to a slightly lighter colour and outcrops in bold, rounded ridges that follow the bedding and formational trend. Microscopically the red sandstone is seen to consist mainly of an aggregate of subangular to angular grains, 0·06 to 1 mm. in diameter, of quartz (35 to 40 per cent), feldspars, and acidic volcanic rocks, with accessory micas, magnetite, chlorite, apatite, epidote, and hematite.

Secondary quartz, sericite, epidote, and hematite form the cementing matrix. The reddish colour of the rock is due to hematite films and permeations and to the colour of many of its component grains of volcanic rocks and orthoclase. Minor interbeds of siltstone, argillite, and slate are intercalated with the sandy beds.

Red sandstone of the intermediate member gives way upward to fine conglomerate overlain by a thick succession of gravelly, intra-formational, conglomerate beds composed mainly of pebbles and cobbles of rhyolite porphyry, rhyolite, granophyre, intra-formational red shale flakes, red and green siltstone of the Conception group, and quartz. Occasional pebbles of basalt and of granite are to be found in places in this upper member. Comparatively few of the boulders are as much as 1 foot in diameter. The pebbles are commonly subangular to rounded, but are occasionally angular, as are many of the smaller grains. As with the sandstone the reddish colour of the conglomerate is due in part to hematite staining and to the colour of many of its component grains. Weathered surfaces are pale to greyish red or mauve. It should perhaps be pointed out here again that well-rounded pebbles of rhyolite and granophyre similar to those in the Signal Hill conglomerate occur in large numbers in the conglomerates of the Harbour Main group, from which it may be inferred that the conglomerates of both groups are formed in part of material derived from a common source.

The three members of the Signal Hill formation are transitional, roughly equal in thickness and, together with minor argillaceous interbeds, total about 7,800 feet in thickness in a section through the South Side Hills of St. John's. The formation gradually thins toward Red Head and Ferryland from Shoal Bay.

Structure. The Signal Hill formation is well bedded in the main, and crossbedded and ripple-marked in places. These structures, together with beds showing grain size gradation, permit the recognition of tops of beds at many localities. In general the formation is broadly folded; beds are overturned to the east in a few places, steeply dipping in many, and gently dipping in a few, the results of compression into north-northeasterly trending folds by stresses that were probably applied from a northwesterly direction. Many faults intersect the rocks, and an inherent rhombohedral joint system is very well developed locally (*See* Plate IV A and B). The formation is transitional downward to the St. John's formation and is overlain conformably by the lithologically similar beds of the Blackhead formation.

Origin. In reference to his "Signal Hill Series" Buddington (4, p. 470) wrote:

"Because of the predominating sandy character of such a thick series of sediments; the repetition and often considerable thicknesses of conglomerate beds; the presence of so much fresh plagioclase and orthoclase throughout the rocks; the prevailing subangular character of the component grains; the predominating red colour due to interstitial hematite mud, to films of hematite, and to oxidized grains of basalt, rhyolite, and magnetite; the constant recurrence of thon-gallen beds; frequent cross-bedding; lithologic alternations of sandstone, conglomerate and shale; and the absence of any limestone, fossils, or carbonaceous materials, the writer has been led to conclude that these beds originated as dominantly fluviatile deposits of subaerial origin in a subarid climate. It is quite possible that the basal 1,300 feet of green-gray sandstones accumlated under a permanent water-level; but if so the water was apparently drawn off or excluded at the time of the accumulation of the succeeding reddish-brown series."

The transition from the reducing conditions in which the St. John's formation was deposited to the predominantly oxidizing conditions in which the Signal Hill formation formed is evidence of the transition from deep- to shallow-water deposition, as is the coarser, arenaceous and conglomeratic nature of the Signal Hill beds. The crossbedded nature of the Signal Hill formation is also evidence of rapid shallow-water deposition. The angular to subangular shape of many of the component grains and the relatively unaltered condition of the feldspar and apatite grains are evidence of rapid erosion, short transportation, and quick deposition and burial. Interstitial argillaceous lenses, and the subordinate amounts of clay minerals in the groundmass of the sandstones, are evidence of a fine degree of sorting. The component grains show the formation was derived mainly from the rapid erosion of acidic igneous rocks of Harbour Main group type, with abundant fragments of Conception group type rocks, and penecontemporaneous red shale flakes. Some granite is also indicated in the eroded terrain. There is little doubt that the Signal Hill formation corresponds to the tectonic arkose of Pettijohn (38, pp. 257-261); thick, rapidly accumulated, wedge-shaped deposits associated with strong uplift and rapid erosion of the crystalline rocks, accumulated in great fan-like bodies adjacent to the highland area.

Age and Correlation. The precise age of the Signal Hill formation is not known, as fossils are lacking. Its stratigraphic position (*See* Plate V A) suggests it is of Precambrian, possibly late Proterozoic, age. Its exact counterpart is not known in Newfoundland, but it bears unmistakable similarities to part of the Musgravetown group (19) of the Bonavista-Trinity Bay area. The latter is considered to be of late Proterozoic or early Cambrian age (7, 19).

Blackhead Formation

Name. The name "Blackhead" was first applied by Hayes (17) in reference to the rocks at Black Head east of St. John's, and described by him as "dark gray sandstone and slates". The formational name is here applied to the sedimentary rocks that lie immediately and conformably above the Signal Hill conglomerate and that are found in the core of a syncline in these rocks at Black Head. The top of the formation is not exposed.

Distribution. The Blackhead formation outcrops at Sugarloaf Head and on Small Point northeast of St. John's and in the peninsula between St. John's Bay and Motion Bay. It has an estimated thickness of more than 5,500 feet.

Lithology. Rock types are similar to those of the Signal Hill formation, and include, in ascending order, three members comprising, mainly, arkosic, reddish, greenish grey, and reddish sandstone, with slate, argillite, and siltstone interbeds. No extensive zone of conglomerate is found in the Blackhead formation, and there is a somewhat greater percentage of argillaceous beds than in the Signal Hill formation, but arenaceous beds predominate. In general the grain size of the sandstones is between 0·06 and 1 mm., and the chief component grains of quartz, orthoclase, and plagioclase show the same angular to subangular shapes and relatively unaltered conditions characteristic of the underlying Signal Hill beds.

Structure. The Blackhead formation rests conformably above the Signal Hill conglomerate member, near its type locality, at Cape Spear, and at Petty Harbour. Part of both limbs of a great syncline, more than 6 miles in breadth, are exposed between Cape Spear and St. John's, but the gentle, undulating northward plunge of the fold carries the upper measures of the formation beneath St. John's Bay. The same type of rhombohedral joint system, locally well developed, forms many quarry sites for building stone.

Origin. The lithology of the Blackhead formation indicates it was formed under conditions similar to those obtaining during deposition of the Signal Hill formation, but in off-shore, somewhat deeper water, with mainly oxidizing, but alternately oxidizing and reducing, conditions prevailing. The lack of intraformational conglomerate, the greater abundance of the finer grained, more argillaceous rocks, and of unoxidized, greenish coloured beds bespeaks deeper water deposition. The composition, fresh character, and angularity of grains, the relatively clean separation of arenaceous and argillaceous fractions, and the predominantly light colours and oxidized condition of the iron are indicative of the rapid erosion and deposition characteristic of the arkose environment.

Age. The exact age of the Blackhead formation is not known, as no fossils were found in it. Its stratigraphic position and its close relation and similarity to the Signal Hill formation suggest that it is of late Proterozoic age, but it may well be very early Cambrian.

Correlation. Resting as it does immediately above the Signal Hill conglomerate, the Blackhead formation falls within Walcott's "Random terrane" (46) of Trinity Bay, but is somewhat different lithologically and is much thicker than any of the sections described by him. Christie (7) points out that the Signal Hill type conglomerate, above which the sparsely fossiliferous, early Cambrian or late Precambrian, Random formation occurs at Hickmans Harbour Point, Random Island, was not necessarily formed at the same time as the Signal Hill conglomerate at its type locality, as more than one conglomerate zone occurs in the Musgravetown group. It is, therefore, considered unwise to draw a correlation between the Blackhead and Random formations. It would appear that the Blackhead is the equivalent of the upper part of the Musgravetown group, but because of differences in the sections no close correlation may be made.

CAMBRIAN ROCKS

GENERAL STATEMENT

A section of more than 900 feet of gently dipping, fossiliferous, Lower, Middle, and Upper Cambrian sedimentary rocks overlaps the Precambrian Harbour Main group and apparently also the Holyrood granite unconformably. A basal conglomerate 18 feet thick is exposed at Manuels River highway bridge; elsewhere the section comprises conglomerates, crystalline limestone, manganiferous shale, varicoloured shales, slate, and sandstone. The Lower Cambrian conglomerate at Manuels River bridge contains rounded grains, pebbles, cobbles, and boulders of silicified and otherwise altered volcanic rocks, white quartz, a few of medium-grained, altered granite, and rare, small, worn fragments of pyrophyllite, in a sandy

matrix. Most of the constituents are weathered, but their sources may be traced with some certainty to localities nearby. At Topsail Head, Cambrian strata are truncated by the Topsail fault zone, a series of steeply dipping thrusts, which brings pre-Cambrian schists into contact with locally contorted Cambrian beds. Upper measures of the Cambrian section are covered by Conception Bay, where they are succeeded, without any apparent major unconformity, by Lower Ordovician sandstone and shale.

In general, fossiliferous Cambrian beds occupy the lowland that extends from Topsail Head past the western boundary of the map-area on Conception Bay. Sections of the rocks are exposed along the coast and in stream valleys; the best, and almost continuous, section being in the valley of Manuels River, where rocks representing the three epochs, Lower, Middle, and Upper, of Cambrian time are exposed. This classic section has been the object of detailed investigations by many of the leading students of the Cambrian since Weston's discovery of the first fossil there in 1874, following Murray's recommendation that a palæontologist should study these beds.

LOWER CAMBRIAN ROCKS

The terms "Etcheminian"[1] and "Hanfordian" were first applied to the Lower Cambrian rocks of New Brunswick (32, 33, 47), and later extended to Cape Breton and Newfoundland. The Newfoundland "Hanford formation" of the "Hanfordian series" of van Ingen's 1914 table of formations (44) is not the exact equivalent of the New Brunswick 'Hanford', which was originally described by Matthew (32). In view of the current work on the Cambrian of Newfoundland by Hutchinson[2], it seems best to refer to the relatively thin group of strata resting between the pre-Cambrian and the pre-*Paradoxides* Cambrian beds on Manuels River, Conception Bay, merely as Lower Cambrian.

Beds of the Lower Cambrian form a group that is best exposed in the valley of Manuels River, with 18 feet of conglomerate at the base and exposing a section about 75 feet thick downstream, at which point they are conformably succeeded by *Paradoxides*-bearing beds. The Lower Cambrian Series comprises mainly greenish grey, olive-green, and red shales, nodular crystalline limestone, conglomerate, and some sandstone.

In reference to this series Howell (22, pp. 24-26) wrote:

"The basal beds of the Lower Cambrian, varying considerably in character (and perhaps in age) even in the small area in the map . . . are conglomerates in and adjacent to the brook valley, and limestones and shales at the southwest of the railway station platform. They appear to be deposits that accumulated along an uneven rocky shore. At the falls of the brook[3] the conglomerate is 18 feet thick, and consists of well rounded boulders and pebbles, apparently derived from the adjacent Pre-Cambrian, with the interstices between them filled with sand. It is coarsest at its base, where some of its boulders are said to measure as much as 12 feet in diameter (Dale, 1915, p. 377), and grades upwards through 3 feet of limy sandstone into a shaly, pyritiferous, pink and blue limestone containing great numbers of what are probably pteropod shells.

"The beds next above this limestone in the brook section are almost entirely concealed, but a single small exposure in the bed of the stream, and many loose pieces

[1] Etcheminian Series was used as a rock term by Matthew in 1888, in The American Geologist, vol. II, p. 1.

[2] R. D. Hutchinson, Palæontologist, Geological Survey of Canada.

[3] Manuels River.

in the soil of the adjacent fields indicate that they are probably hard olive grey shales. The next higher bed is exposed a little farther down the stream. It is a red shale, 2½ feet thick, which merges upward through some 6 inches of red and green limy shale into a bed described by Dr. Dale (1915, p. 380) as a 'nodular and pebbly reddish blue limestone', which is 1½ feet thick, and contains many fragmentary fossils. Overlying this, and exposed both in the banks of the stream and along the near-by wagon roads, are about 34 feet of hard, olive grey shale, which breaks with a conchoidal fracture and contains occasional black nodules, up to 1 inch in diameter, some of which, according to Dr. Dale (1915, p. 385), 'show pinkish centres of some fine-grained minerals such as rhodocrosite or manganiferous calcite'. Dr. Dale has stated that the contact of this shale and the underlying limestone as exposed in the bank of the stream is a disconformable one. It is certainly a very uneven one; but the beds seem sometimes to grade into each other. A very careful and detailed study and comparison of this limestone and shale and the similar limestone and shales that outcrop in the vicinity of the railway will have to be made before their relative ages and the character of their contacts will be fully understood. This 34-foot thick olive-grey shale shows many small slicken-sided surfaces, and at most places yields very few fossils. In the brook exposures it has yielded nothing but some small brachiopods, and in the outcrops along the wagon roads it appears to be quite barren. In a railway cut just southwest of the railway station platform however, beds almost certainly referable to some part of it contain a small fauna. One of the members of this fauna, a large trilobite named Catadoxides magnificus, is believed by Dr. Matthew, who discovered it, to be closely related to the Sardinian genus, Metadoxides (Matthew, 1899b; 1899c, pp. 83-87, pl. VIII).

"The succeeding beds of the section are well exposed only in the valley of the brook. The first one is a peculiar, dark bluish grey shale, 4 to 5 inches thick, and full of flattened, subspherical nodules, which are 1 inch or less in diameter and are probably composed, according to Dr. Dale (1915, p. 385), of manganiferous calcite. On top of this nodular bed is a thin layer of what Dr. Dale (1915, p. 385) has described as a 'Cryptozoan shale', containing 'roughly concentric or zonal structures measuring 1½ inches in diameter, irregular and subspherical nodules measuring 1 inch in diameter, and intercalated lenses of manganiferous calcite'. Above this 'Cryptozoan' layer is a three-foot bed of hard, green shale, with manganiferous calcite nodules in its upper portion, and near its base specimens of a trilobite apparently specifically identical with Dr. Matthew's 'Catadoxides magnificus'. This fossiliferous bed is followed by 10 feet and 10 inches of unfossiliferous, manganiferous, red and green shales, some of which contain small, flattened nodules. Most of these nodules are similar to those occurring in the beds below, but some of them may be phosphatic.[1]

"The next higher stratum is possibly the lowest of the Paradoxides beds in this section."

The 18 feet of coarse conglomerate at the bottom of this Lower Cambrian section rests with angular unconformity upon volcanic rocks of the Harbour Main group, which are locally metamorphosed and intruded by granitic dykes. The conglomerate is composed mainly of altered fragments of the eroded, underlying volcanic and granitic rocks. Farther west, on Holyrood Bay, Cambrian sedimentary material apparently fills cracks and fissures in Holyrood granite and otherwise seems to rest unconformably on the eroded surface of the granites (*See* 4, p. 455). Lower Cambrian beds are succeeded, apparently conformably on Manuels River, by Middle Cambrian *Paradoxides*-bearing shales.

The pre-*Paradoxides, Callavia* fauna of the beds indicates their Lower Cambrian age. A palæontological correlation may be made between the upper measures of this Lower Cambrian Series and the Hanford Brook formation of New Brunswick on the basis of their *Protolenus* faunas. There also seems to be a lithological similarity between the conglomerate beds and those of the Ratcliffe Brook formation of New Brunswick, although the latter is much thicker. Thus, these Lower Cambrian beds show a marked

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[1] Manganiferous beds at Brigus have been found to be of very early Middle Cambrian age by R. D. Hutchinson (1950), and it seems probable that the manganiferous beds here are of the same age.

similarity to the Etcheminian and Hanfordian series of the Lower Cambrian St. John group of New Brunswick[1], although they are not exact counterparts lithologically.

ACADIAN SERIES

In 1914, van Ingen (44) described the *Paradoxides* beds about Conception and Trinity Bays as the "Manuels series", composed of a single formation, which he called the "Manuels formation". Howell (22) found the known *Paradoxides* beds at Manuels and elsewhere in southeastern Newfoundland to be divisible into at least three distinct formational units, and suggested, with van Ingen's approval, that the term 'Manuels' be abandoned as a formational name and retained in its larger sense alone. Howell (22) used Walcott's term 'Newfoundland' as a general series name for all the Middle Cambrian, *Paradoxides* beds of southeastern Newfoundland (some of which differ lithologically from the *Paradoxides* beds at Manuels), and van Ingen's series name 'Manuels' was restricted for the *Paradoxides* beds of the Conception Bay region where the lithological character of the beds appears to be everywhere about the same as at the type locality, Manuels. Howell (22) noted:

> "The three major units into which the beds known to contain Paradoxides at Manuels seem to be most naturally divisible, both lithologically and faunally, are here named the Chamberlin's Brook formation, the Long Pond formation, and the Kelligrew Brook formation."

These formations are characterized by *Paradoxides bennetti, P. hicksi,* and *P. davidis* faunas respectively. Howell (22) added:

> "The formations grade gradually into each other. The same is true of the bennetti, hicksi, and davidis faunas. It has therefore been found necessary to draw the exact vertical boundaries between the zones more or less arbitrarily."

The present writer did not find it practical to subdivide the *Paradoxides* beds in Torbay map-area in the course of field work, but has referred them to the Acadian Series[2], as suggested by Hutchinson.

Beds of these rocks are best exposed in the valley of Manuels River. Other exposures are on Chamberlin's Brook, Long Pond, and Kelligrews Brook.

On Manuels River the section comprises some 300 feet of shales, containing occasional nodules, lenses, and thin beds of limestone. The lower 234 feet, which consists of hard, greyish shales, holds few fossils except in its upper 13 feet, and grades gradually upward, through brown, finer bedded shales with abundant fossils, into thin-bedded, soft, black shales replete with trilobites and their fragments.

The Acadian Series succeeds the Lower Cambrian Series conformably, and is in turn succeeded, apparently conformably, by the Upper Cambrian, Elliott Cove group.

Paradoxides bennetti, P. hicksi, and *P. davidis* faunas are represented. A detailed description of the stratigraphy and faunal succession is given by Howell (22, pp. 35-57).

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[1] Geology and Economic Minerals of Canada; Geol. Surv., Canada, Econ. Geol. Ser. No. 1, third edition, pp. 110-111 (1947).

[2] The 'Manuels series' of van Ingen, the 'Newfoundland series' of Howell, and the 'Newfoundland group' of Rose (Preliminary Map 50-24).

The *Paradoxides* fauna indicates a Middle Cambrian age for the Acadian Series. Although somewhat different lithologically, there is a marked similarity in fossil content to the Middle Cambrian Fossil Brook, Porter Road, and Hastings Cove formations of New Brunswick[1]. In this regard Howell (22) wrote:

"As far as can be told at the present time, the Paradoxides faunas of southeastern Newfoundland are more nearly related to those of New Brunswick, Massachusetts, Great Britain and Scandinavia, than to those of France, Bohemia, Poland and southern Europe. The fossils of the Paradoxides beds of Vermont will probably also prove to be closely related to those of Newfoundland, but they are at present too little known to make a satisfactory comparison possible."

ELLIOTT COVE GROUP

Van Ingen (44) used the name Elliott Cove (locality, Random Island, Newfoundland) to describe a 'series' composed of a single formation, his Elliott Cove formation. It seems best to retain the name in its broader sense, but to restrict it to a group term as these beds may not represent the entire assemblage deposited during the Upper Cambrian epoch. The group term is here applied to the beds that succeed the uppermost known *Paradoxides* beds on Manuels River and the overlying Upper Cambrian beds, which are here covered by Conception Bay.

Beds of the Elliott Cove group are exposed in Manuels River gorge and on the shore of Conception Bay near Topsail Head; at the former locality the beds have an aggregate thickness of more than 300 feet, but the top is not exposed.

The Elliott Cove group consists of thin-bedded, dark grey and black shales, with abundant nodules of pyrite and paper thin slate. Minor lenses of limestone and sandstone are intercalated with them.

Howell describes them as follows (22):

"Near their base they appear to be barren. Some thirty feet up from the bottom, however, a few fossils have been found, including a brachiopod, an agnostid trilobite, and a small bivalved crustacean, which may indicate the presence of the 'Paradoxides forchhammeri' and 'Agnostus laevigatus' zones, the two uppermost known divisions of the Paradoxides beds, which are well-developed in Scandinavia. These beds of doubtful age are succeeded by finely-bedded black shales containing a trilobite resembling Agnostus pisiformis (Linné), which are followed by similar shales holding Agnostus pisiformis obesus Belt, and other types characteristic of the 'Olenus beds' of northwestern Europe. Above these 'Pisiformis obesus' beds are micaceous shales and sandstones showing ripple marks and other evidences of shallow-water origin. These micaceous shallow-water beds, which include the highest beds of the brook section, seem to be barren, for the most part; but a few species, the majority of them brachiopods, have been found, one of which, Orusia lenticularis (Wahlenberg), is abundant at some horizons."

The Elliott Cove group overlies the Acadian Series with apparent conformity, although the contact represents a palæontological break. It is succeeded, apparently conformably, beyond a sea-covered interval, by Lower Ordovician beds. According to van Ingen (44) and Howell (23), with the exception of the doubtful, lowermost 30 feet of strata of the group on Manuels River, the beds are of Upper Cambrian age. Indeed there is a marked similarity in lithology and fossil content between the Elliott Cove

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[1] Geology and Economic Minerals of Canada; Geol. Surv., Canada, Econ. Geol. Ser. No. 1, pp. 110-111 (1947).

group of Newfoundland and the Agnostus Cove and Black Shale Brook formations of the Upper Cambrian Johannian series of New Brunswick (18, pp. 76-80)[1].

ORDOVICIAN ROCKS

GENERAL STATEMENT

A thick, stratigraphic section, estimated to comprise more than 8,000 feet of relatively unmetamorphosed, fossiliferous shale and sandstone, with intercalated beds of oolitic hematite iron ore, is referable to the Lower Ordovician epoch, and includes the Bell Island and Wabana groups of rocks (15, 44). Beds referable to these groups are known only in the Conception Bay basin, where they outcrop on Bell, Little Bell, and Kellys Islands, and apparently underlie much of the bay. It is probable that beds referable to van Ingen's (44) Lower Ordovician, Clarenville series also underlie the bay between Kellys Island and the mainland. The Lower Ordovician beds of the Bell Island and Wabana groups maintain an apparently conformable sequence with the underlying Upper Cambrian strata, striking northeasterly and dipping in general 9 to 14 degrees to the northwest. The strata that would normally reach the mainland along the east shore of Conception Bay are prevented from doing so by the intervening Topsail fault, which thrusts up Harbour Main and Conception group rocks.

BELL ISLAND GROUP

Van Ingen (44) introduced the term 'Bell Island series' for the middle part of the Lower Ordovician section in Newfoundland, and subdivided the series into eight formations. In the present report the term 'group' is used in place of van Ingen's 'series'.

Rocks of the Bell Island group occupy Kellys and Little Bell Islands, and the greater part of Bell Island (*See* Plate V B). Some 700 feet of shale and sandstone of the group are exposed on Kellys Island and 400 feet on Little Bell Island, with an additional 2,200 feet, including beds of oolitic hematite iron ore, on Bell Island. The base is not exposed, but an estimate of thickness of 4,000 feet is made for the group.

The Bell Island group comprises thick formations of grey, grey-brown, brownish, and greenish sandstones, grey, brown, and black shales, and micaceous sandy shales, with beds of whitish sandstone, red oolitic hematite, and ferruginous sandstone and shale. The strata are in broad lenticular beds that vary in thickness, but are mostly less than 1 foot thick (*See* Plate V B). However, zones composed mainly of sandstone or shale are common and persistent, although the component beds vary considerably in thickness. In the main, the sandstones consist of rounded to subangular grains of quartz between 0·06 and 1 mm. in diameter, with minor amounts of glauconite, chamosite, altered feldspars, and ferromagnesian minerals, and accessory zircon, sphene, and magnetite. These are set in a minor argillaceous groundmass, with secondary quartz rimming the primary quartz grains. Carbonate minerals are characteristically lacking, but siderite is to be found along with chamosite and glauconite in the matrix of the

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[1] *See also* Geology and Economic Minerals of Canada; Geol. Surv., Canada, Ec. Geol. Ser. No. 1, third edition, 1947, pp. 110-111.

more ferruginous beds. The brownish sandstones are commonly higher in argillaceous minerals and siderite, and the greenish sandstone in glauconite and chamosite. The shales are commonly very fine-grained aggregates of comminuted quartz and carbonaceous material in a predominating argillaceous groundmass; crystalline chamosite is common and siderite relatively rare. The shales are richly fossiliferous. Beds of red, oolitic hematite occur in three main zones within the Bell Island group exposed on Bell Island. These beds are commonly granular aggregates of small concretions, oolites, or spherules in a variable groundmass. The spherules are in general less than 0·5 mm. in diameter, and are commonly flattened parallel with the bedding and many of them fractured. The ore beds characteristically break into rhombohedral shaped blocks because of the prevailing joint system. These inherent fractures are commonly marked by minute, interpenetrating veinlets of calcite, calcite with hematite, and quartz. Traces of bedding and crossbedding, ripple-marks, rain-drop impresssions, fossil fragments, worm burrows, and boring algae tubules are to be found in the ore. These and other features pertaining to the ore will be discussed more fully under the chapter on Economic Geology. Fine-grained greenish grey sandstones and siliceous, blackish shales occur as partings in the hematite ore and as accompanying and intercalated beds. They consist mainly of very small angular fragments of quartz, with minor accessory minerals and occasionally abundant shell fragments and carbonaceous material, in a chamositic matrix. Contacts between ore and parting rocks are normally fairly sharp. Microscopically spherules may be observed in places in narrow zones of the parting rock at contacts between ore and rock.

Rocks of the Bell Island group locally display pressure crumples and a well-developed rhombohedral joint system, both of which are attributable to compressive forces. The base of the group is not exposed, being covered by Conception Bay, but the beds show structural concordance with the nearest exposed, underlying, Upper Cambrian strata. A very minor disconformity separates the group from the overlying Wabana group.

Exclusive of the hematite beds, the rocks of the Bell Island group are consolidated, clastic marine sediments, most of which seem to have been deposited in the shallow water of a tidal basin with its included and marginal deeps. The sandstones and shales are generally well sorted, and are in gradational and lenticular beds, which apparently accumulated on an uneven, undulating bottom. Thick zones of shale represent deposition in somewhat deeper waters than that in which the sandstones accumulated, and zones of interbedded shale and sandstone represent lateral gradational deposition to the more shallow-water sandstones. The latter show ripple-marks, crossbedding, rain-drop impessions, worm burrows, and other evidences of shallow-water deposition. The shales are abundantly fossiliferous, and together with the sandstones, have supplied specimens of the following species (15, p. 12): *Lingula hawkei, Lingula affinis, Lingulella bella, Sphaerobolus fimbriatus, Obolus burrowsi, Cruziana similis, Arenicolites* sp., *Sphaerobolus spissus*, and boring and other algae. The fauna is further evidence of shallow-water, marine conditions of deposition, and indicates a Lower Ordovician age for the group.

WABANA GROUP

Van Ingen (44) introduced the term "Wabana series" for the upper part of the Lower Ordovician rock section on Bell Island, and subdivided it

into six formations apparently mainly on palæontological evidence. 'Wabana group' is used here in its place for those Lower Ordovician rocks that lie above the Bell Island group and form only part of the strata deposited here during the epoch.

Rocks of the Wabana group occupy the northwest part of Bell Island and extend beneath Conception Bay. A thickness of more than 1,000 feet is known.

The group includes formations of shale and sandstone similar to those of the Bell Island group, with beds of oolitic hematite, chamositic slate, oolitic pyrite, phosphatic pebble-beds, and soft black shale carrying disseminated pyrite. The lithology of these rocks is very similar to that of the Bell Island group, but black shale becomes more abundant and graptolites make their appearance in the fauna, which includes (15, p. 22) *Didymograptus, Sphaerobolus, Schizocrania, Synhomalonotus, Lingula, Cruziana similis, Arenicolites, Eophytum linneanum, Orthis, Westonia,* and boring algae. The graptolitic, pyritiferous black shales and oolitic pyrite with graptolites, indicate somewhat deeper, reducing, marine environmental conditions of deposition, with ready access to the basin from the open sea, but on the whole for the lower part of the group the same shallow water, oxidizing conditions prevailed as evidenced by deposition of the ore beds, as in the case of the Bell Island group. The fossil content of the beds indicates a Lower Ordovician age for the Wabana group.

The Wabana group overlies the Bell Island group with very minor disconformity. A thin, interformational conglomerate bed containing pebbles of oolitic iron ore occurs just above the 'Dominion bed', the uppermost, iron-ore zone of the Bell Island group. This gives way to a thin zone of shale and sandstone, with oolitic pyrite and thin pebble beds composed mainly of shell fragments and phosphate nodules. The top of the Wabana group is not exposed, but diamond drilling from the submarine slopes of the mine has shown the upper measures to consist largely of soft, black, pyritiferous shale.

QUATERNARY OVERBURDEN

Accumulations of glacial till, formed by glaciers active during the Pleistocene ice age, and including boulder clay, gravel, sand, silt, and erratics, rest upon the eroded surfaces of all of the consolidated rocks of the area. The till was observed to be as much as 50 feet thick, and may be thicker in places. It mantles most of the area, except some of the highest ridges, from which it has apparently been removed by erosion, as patches are left in protected hollows. It extends from the flanks of the highest hills to sea-level, where it has been easily eroded, reworked, and re-deposited by the sea along present and former shores. In places it rests directly upon glacially polished and grooved bedrock. Most of the material comprising the till is of local origin, and its fragments range in size from sand grains to erratics more than 30 feet across. In general the till is almost unsorted, but areas in which boulders, cobbles, pebbles, sand, silt, and boulder clay individually predominate show the crude sorting that is characteristic of glacial drift. Small patches of stratified sand and silt are to be found, and are presumed to represent glacial outwash.

Marine terraces as much as 35 feet above present sea-level are known along the coast, and may have occurred at much higher elevation. Beaches of cobbles, pebbles, gravel, sand, and silt are being formed along the

present strand where storm waves have tossed the cobbles from 10 to 20 feet above high tide level. Such beaches are best developed in the map-area along the southern shore of Conception Bay, westward from Topsail Head.

Peat deposits occur at many localities, developed on poorly drained areas on the glacial mantle. They are widespread and deep in the area between Cochrane Pond and Bay Bulls Big Pond. Many of the peat bogs could supply commercial peat litter and horticultural moss, and some peat fuel. From those with underlying muck, areas might be reclaimed for farming by draining, clearing, ploughing in the peat, rolling, and fertilizing, chiefly with lime, although this would be a costly undertaking, perhaps impractical.

Most of the farms in the area have been cut from the bush, with small fields placed on patches of the glacial till or on marine terraces most suitable for farming. Forest litter has helped to form a thin topsoil in favoured places, but in most cases the soil has been made by manual work in removing countless rock fragments and adding natural fertilizers. The soils throughout the area are deficient in lime and leached to acidity. They are Podsols typical of the north temperate coniferous forest zone. Their lime deficiency is detrimental to agriculture, but because of it the waters of the innumerable ponds and lakes of the area are remarkably soft and lime free. A pipeline from Windsor Lake supplies St. John's with some of this pure, soft water.

The average annual precipitation at St. John's is about 54 inches, which is fairly evenly distributed through the year, and gives a fair average for the surrounding district. Much of this is lost to the sea following the winter 'break-up', when normally dry rocky brooks become rushing torrents. Power companies operating in the area have dammed several of the ponds and brooks to conserve the supply for generating electricity, and the bogs act as giant sponges in soaking up rainfall and ground water, to be yielded on adequate demand.

CHAPTER III

STRUCTURAL GEOLOGY

GENERAL STATEMENT

Of the main structural features of the map-area (*See* Map 1018A and accompanying structure-sections) the most striking are: (1) the great syncline in the Cabot group rocks east of St. John's; (2) the abrupt fault scarp at Topsail Head; (3) the intricately folded condition of the St. John's formation; (4) the pronounced unconformable overlap of the Cambrian on Precambrian rocks at Manuels River bridge; and (5) the position of the early Palæozoic sedimentary basin upon the folded and eroded Precambrian rocks in Conception Bay. Remarkable, too, is the rhombohedral joint pattern, displayed best by the Wabana iron ore beds and to a lesser degree by the Ordovician sandstone and the Precambrian Cabot group sandstones and conglomerate. Many other faults, joints, and cleavages affect the Precambrian and, to some extent, the Palæozoic rocks.

Regionally, all the rocks in the map-area have been deformed by compressive stresses applied differentially over lengthy and widely separated intervals of time. Although the same general fold and fault pattern seems to apply throughout the Precambrian to Ordovician section, the folds are tighter, the dips steeper, and the faults more prominent in the Precambrian rocks. The intricately folded condition of the incompetent Precambrian members indicates the tremendous pressures to which they were subjected. Comparable structures are not to be found in the Palæozoic section in this area, although severe crumpling of Cambrian strata is evident along the Topsail fault zone.

The semi-parallel alinement of most of the fold axes and fault planes in a north-northeasterly direction suggests the forces may have operated from northwesterly or southeasterly directions for much of the time, with overturned beds at Cape Broyle Head indicating active stress from the northwest. This is supported by evidence of almost horizontal movement along steeply dipping faults that parallel one set of prominent joints and intersect the north-northeasterly trending structures almost at right angles. There is also some evidence of cross-folding and doming of beds parallel with the northwesterly trending faults. Fracture cleavage is developed throughout, both parallel with and at an angle to the bedding.

UNCONFORMITIES

The Harbour Main group is overlain unconformably by the Conception group, as conglomerates in the latter carry rounded fragments derived from the former, but because of the lack of observable primary structures in most places in the volcanic rocks it is difficult to know if a structural discordance or a disconformity is represented. At several localities in the area bedded rocks of the Conception group rest on schistose volcanic rocks of the Harbour Main group with pronounced discordance between bedding and

schistosity. Because of the occurrence of interbeds of sedimentary rocks in the Harbour Main group similar to certain beds in the Conception group, and because of the occurrence of tuffaceous beds in the Conception group, the writer is inclined to believe that the unconformity between the two groups does not mark a time interval of major significance. It should not be overlooked that any adequate interpretation of the complex geological history of this section of Newfoundland should take into account the fact that periods of igneous activity, both intrusive and extrusive, may have been contemporaneous with those of sedimentation, and that rigid rock formation classifications may have only limited, local application.

In considering the structural significance of the intrusive igneous rocks of the area it should be recalled that they include two small stocks of meta-gabbro, the eastern border of a granitic batholith, and a few, small basic dykes, all of which are known to intrude Harbour Main group rocks. The granitic rocks are also intrusive into lower members of the Conception group and into meta-gabbro, and they are in turn cut by some of the small basic dykes. None of the intrusions comes into contact with upper measures of the Conception group or with the Cabot group in the area, but the granitic rocks are apparently overlain unconformably by Lower Cambrian beds. Little light can be thrown on Buddington's idea that these igneous rocks (he did not mention the small basic dykes) together with the Harbour Main rocks form a comagmatic series derived from a basaltic magma. The diversification and textural variations of rock types in the granitic rocks indicate that the emplacement of the Holyrood batholith occurred in several magmatic surges, and it is only a step farther to classify the meta-gabbro stocks as early 'crystallates' of a differentiating magma. The occurrence of pebbles of granitic rocks in conglomerates ranging in age from Precambrian (Harbour Main and Conception groups) to Lower Cambrian proves that granitic rocks were unroofed in this region prior to the intrusion of part of the Holyrood batholith into Harbour Main and Conception group rocks. It is not clear whether or not there is a genetic relationship between the granitic source rocks of the pebbles and the Holyrood batholith, and it is perhaps simpler to assume there is not. In any event considerable time must have elapsed between the various intrusions.

Evidence of the Precambrian age of the meta-gabbro and granitic rocks is considered to be definite, but their relationship to the upper part of the Conception group and to the Cabot group is not clear. The scarcity of granite pebbles in the Cabot group lends some support to the idea that the Holyrood batholith was intruded during or after the period in which the Cabot group accumulated. However, this should be viewed in the light of the fact that on Trinity and Bonavista Bays, Cabot group type rocks (Musgravetown group) pass upward to the Random formation and thence across an apparently minor disconformity to Lower Cambrian beds aproximately equivalent in age to those that rest upon the eroded surface of the granite in the Conception Bay area.

Irrespective of the position of the igneous intrusions in the sequence, beds of the Conception group are succeeded with no apparent angular discordance by those of the Cabot group. Conglomerate in the Signal Hill formation of the Cabot group bearing fragments derived from the underlying Conception group, and the sudden change in lithology at the contact of the groups, are evidence of the disconformity that separates them. Conformable and gradational contacts are found between the St. John's, Signal

Hill, and Blackhead formations of the Cabot group. Both the Conception and Cabot groups contain fragments apparently derived from the Harbour Main group. However, as previously mentioned, pebbles of rhyolite porphyry, granophyre, and granite similar to those in the Signal Hill conglomerate occur in large numbers in conglomerates of the Harbour Main group, from which it may be inferred that the conglomerates of both groups were formed in part of material derived from a common source that included some pre-Habour Main rocks.

The top of the Blackhead formation and of the Cabot group is not exposed in the map-area. From evidence elsewhere in eastern Newfoundland it would appear that these rocks should pass upward through a sparsely fossiliferous zone (Random formation) across an apparently minor disconformity to unquestioned Lower Cambrian strata.

In Torbay map-area, Lower Cambrian beds rest with pronounced angular unconformity on rocks of the Harbour Main group and are considered to overlap the Holyrood granite, filling cracks in its eroded surface (*See* 4, p. 455). Also the basal, Lower Cambrian conglomerate contains fragments derived from the underlying metamorphosed Harbour Main group rocks and the younger intrusive granite. It seems clear, therefore, that the Harbour Main group was folded, intruded by granite, and eroded in Precambrian time before the deposition of these Lower Cambrian rocks.

A section, comprising an estimated 1,000 feet of Lower, Middle, and Upper Cambrian beds, succeeded by about 8,000 feet of Lower Ordovician strata, preserving marked concordance of bedding throughout and otherwise showing no evidence of any significant interval of non-deposition, follows.

As Lower Ordovician beds form the youngest known consolidated rocks of the area it is not possible to identify or accurately assess the individual effects of later events in its geological history. However, the gentle areal dip of more than 8,000 feet of Cambrian and Lower Ordovician strata is evidence that the segment of the earth's crust that they occupy in Conception Bay has been only moderately deformed since the deposition and consolidation of these Palæozoic formations. Elsewhere in Newfoundland, younger rocks of Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian age are known, with evidence of orogenic disturbances having occurred during or at the close of each of the periods, and perhaps culminating in the Appalachian revolution at the close of the Palæozoic Era. There is no direct evidence to indicate that rocks younger than Ordovician were ever deposited in this area. Indeed, erosion to the Proterozoic with infolded and infaulted Cambrian and Ordovician beds suggests that the area has been dominantly positive since mid-Palæozoic time.

Pleistocene drift rests with great angular discordance on all of the consolidated rocks of the area, and is separated by a minor disconformity from the overlapping, most recent, beach and bog accumulations.

FOLDS

Although an insufficient area of Harbour Main group rocks is exposed to indicate a regional pattern to its folds, it seems along with the Holyrood batholith to form much of the basement complex upon which Lower Palæozoic beds were deposited in Conception Bay. Sufficient primary structures are observable in the group here, however, to indicate a complexly folded condition.

In addition to innumerable minor crumples many major, north-northeast striking folds are shown in the Conception group, among them a syncline east of Topsail Head, an anticline north of Country Pond, and several fairly open folds in the Cape St. Francis, Pouch Cove, Tor Bay, and Ferryland areas.

A great syncline in the Cabot group plunges gently north-northeastward, with its steeper westerly limb forming Signal Hill and its easterly limb including Cape Spear. The less competent beds of the St. John's formation are intricately crumpled beneath the thick, competent sandstone and conglomerate sequence of the Signal Hill and Blackhead formations, yet everywhere maintains a conformable and gradational contact upward to the Signal Hill formation. At Bay Bulls, a major syncline in the Cabot group plunges southerly, as do several minor crumples. At Cape Broyle Head, the strata are steeply dipping and in part overturned to the east. Several broad folds in the strata occur near Tor Bay and Flat Rock Bay, north of which Cabot group rocks are dragged beneath those of the Conception group. Most of the folds in the Conception and Cabot groups plunge northerly, but irregular dome- and basin-shaped terminations on some of the folds are indicative of some cross-folding.

A major syncline in Cambrian and Ordovician rocks apparently underlies Conception Bay. Within Torbay map-area, only the truncated part of the southeastern limb of the fold is exposed, but it is well known that Cambrian beds skirt the southern and southwestern parts of the bay, turning sharply northward and becoming more steeply inclined, and there is no reason to believe that the Ordovician beds under the bay do not follow the same pattern. Such evidence is indicative of a syncline plunging gently north-northeastward. Structures exposed on the west side of Conception Bay may have an important bearing on the westerly and northerly terminations of the fold and submarine extensions of the beds. Apart from the regional folds, Cambrian beds are locally crumpled and overturned in places along the Topsail fault zone at Topsail Head Beach.

The major fold pattern in these Cambrian and Ordovician rocks is thus indicated to be very similar to that in the Precambrian Cabot group, except in degree of intensity. Supporting evidence is to be found in the Trinity and Bonavista Bay areas.

FAULTS

Faults are a conspicuous feature of the rock formations of Torbay map-area. Bedding faults, strike faults, dip faults, and oblique faults are all represented, but most of them fall into two categories, namely, longitudinal faults and transverse faults. The longitudinal or strike faults trend north-northeasterly to northerly, and the transverse or dip faults strike northwesterly. Faults of both types are commonly steeply dipping, with the strike faults showing evidence of oblique-slip and the dip faults of strike-slip to oblique-slip movement. Most of the faults are attributable to thrusting due to compression.

Many major thrust faults are known, including a zone at Topsail Head, two in the Johnnys Pond area, several in the peninsula east of Conception Bay, one north of Flat Rock, and another at Cuckold Head. Faults of lesser magnitude are also represented in many places, among them those displacing the submarines iron ore beds at Wabana.

The Topsail fault is traceable as a zone of chloritic schist and sheared volcanic and sedimentary rocks, more or less impregnated with quartz veins and stringers, along or near the eastern margin of the Holyrood batholith, extending from Topsail Head, where it passes beneath the waters of Conception Bay, southward in a curve past the eastern tip of Mobile Big Pond. At Topsail Head, the fault zone strikes north 13 degrees east and dips easterly about 80 degrees. Cambrian beds at the base of the towering, 600-foot cliff are crumpled and cut off by the fault, but they are much less sheared than the quartz impregnated schists that abut them. Milky white quartz veins parallel the Cambrian-Precambrian fault contact and fault planes in the Precambrian schist on the cliff. The walls of these quartz veins are slickensided in places against Cambrian strata, indicating a relative movement of the east side obliquely upwards and to the north with respect to the west side. The more sheared condition of the Precambrian rocks coupled with the confinement of slickensided quartz veins to the Precambrian rocks and Precambrian-Cambrian fault contact zone indicate that the fault was initiated in Precambrian time, with later injection of quartz veins, followed by additional movement and displacement of the Palæozoic beds. As the fault follows the eastern margin of the Holyrood batholith it seems probable that the batholith acted as a buttress against which the less competent rocks were thrust or as the causative agent of thrusting. The quartz veins of the fault zone may be genetically related to the Precambrian Holyrood granite, but there is no direct evidence to indicate this, or the amount of displacement caused by the fault. Although about 6,000 feet of Palæozoic strata appear to have been truncated near Portugal Cove, the northward curving of the beds and steepening of their dips, observed near Topsail beach, probably necessitates a considerable decrease in this estimate.

The abrupt scarp and sheared condition of the rocks along the eastern shore of Conception Bay are taken as evidence that the Topsail fault zone closely parallels the coast under water, trending northerly past Cape St. Francis to where the Harbour Main group begins to give way to the Conception group and where the scarp ends or loses its identity. The fault zone probably continues for some distance, bearing a little east of north and diminishing in size.

Apparently fanning off from the Topsail fault zone in St. John's Peninsula in a horsetail pattern are several faults that roughly parallel the north-northeasterly trend of the folds. These faults traverse rocks of the Harbour Main and Conception groups. In general, scarps are developed along them in the Harbour Main group and valleys in the Conception group.

An interesting fault occurs a few yards west of Flatrock Bay (*See* Plate IV A). It strikes north-northeast and dips about 45 degrees to the west-northwest. Beds of the Cabot group are thrust beneath older strata of the Conception group, which appear to lie stratigraphically above them at this locality (*See* Plate IV A). However, the fault is observable, and the true stratigraphic relations are indicated by the occurrence of fragments of Conception rocks in the Cabot conglomerate.

A system of northwesterly striking, steeply dipping, transverse or dip faults, at St. John's, Quidi Vidi, Torbay, Middle Cove, Portugal Cove, and Topsail Head, intersects the previously mentioned folds and faults almost

at right angles. These show evidence of almost horizontal shearing movement parallel with the fault planes, and in places the beds have been dragged along them, indicating a left-hand displacement.

Underground mining at Bell Island has demonstrated the occurrence of two major fault systems affecting the ore beds, one that trends north-northeasterly, the other northwesterly. In general the faults of the first system dip steeply northwesterly and those of the latter system steeply southwesterly. Most of these faults appear to be normal faults, although displacements along them, which are measurable in tens of feet, are due mainly to shearing couples, as evidenced by nearly horizontal slickensides along the northwesterly trending faults. Reference is made to J. B. Gilliatt (10) for a detailed account of the folding and faulting of the Wabana ore deposits. He describes two main sets of faults, with parallel joint systems, affecting the ore beds and associated strata, one striking northeasterly, the other northwesterly; suggests that there is a definite relationship between the faults and joints; and attributes their formation to folding of the strata caused by intense horizotnal compression from the northwest and southeast. He writes as follows (10, pp. 909-910).

" . . . . . it would appear at first sight that the down-throws [*See* Figure 3, p. 48][1] took place in a series of steps, in which the strata beyond the break moved down and off-shore, and one would naturally be led into error and consider first the settlement at the centre of the basin. This would produce tension along the dip followed by normal faulting, towards the centre of the basin. The inclined angles of the fault-planes would also indicate that the line of least resistance was towards the centre of the basin, and that the strata on the down-throw side of the fault was free to move in this direction; but the reverse of this can be shown from the striation marks, which show that intense compression caused the faulting, better described as two horizontal opposite forces acting towards the centre from the long sides of an ellipse and bending the strata downwards along the central axis. This caused right-angled fracture-planes along which the compression found relief by shearing out the open ends of the ellipse diagonally to the strike of the strata . . . ."

JOINTS AND CLEAVAGE

A striking rhombohedral joint pattern in the oolitic hematite beds of Bell Island causes the ore to break easily into regular, angular, relatively smooth-sided rhombs. This joint pattern is evident to a lesser degree throughout the Ordovician rocks of the area, particularly in the sandstones, and also in the sandstones and conglomerates of the Cabot group (*See* Plate III A and B) and to some extent in the Cambrian rocks. It is a feature that, like the fracture cleavage, is locally well developed, depending on the character of the rock, the intensity of folding, and proximity to faults. Fracture cleavage occurs both approximately parallel with, and at an angle to, the bedding, and is confined mainly to the more incompetent argillaceous and tuffaceous rocks of the area. Both jointing and fracture cleavage are intimately related to folding and faulting in Torbay map-area.

[1]This report.

CHAPTER IV

ECONOMIC GEOLOGY

INTRODUCTORY STATEMENT

SIGNIFICANCE OF MINING INDUSTRY IN TORBAY MAP-AREA

Apart from the operations at Bell Island very little mining has been done in Torbay map-area. Wabana Iron Mines alone, however, provide the economic support for most of the population of Bell Island, and a source of revenue for the provincial government, besides supplying iron ore to Canadian, European, and American markets. The recent (1950) curtailment of production from the mines caused by the withdrawal of the European (British) market has served to emphasize the dependence of the people of Bell Island on its mines. Encouraging signs of expanding production have more recently (1951) been noted.

Mining costs in Newfoundland are, in general, lower in areas such as the Avalon Peninsula, where access to good roads and to railway and shipping facilities may be readily provided. The concentration of population in the St. John's area is an added incentive to the development of mineral resources, providing as it does a possible market and labour supply.

GENERAL DISTRIBUTION AND CHARACTER OF MINERAL DEPOSITS

As the rocks of Torbay map-area vary greatly in character and in age, so do their contained mineral deposits. Exclusive of structural materials, the known mineral deposits of proved and possible economic value within the Precambrian rocks are of hydrothermal origin, whereas those within the Palæozoic formations are regarded as mainly of primary sedimentary origin. The latter tend to occur as more or less uniform layers, many of them extending over large areas, whereas the deposits in the Precambrian rocks are relatively smaller, more erratic, irregular, lens- or vein-like deposits.

FUTURE PROSPECTS

Potentially valuable deposits of gravel, building stone, and peat occur at many localities. Substantial tonnages of sand and gravel are obtained from the mantle of glacial drift, but production figures are not available. A local company operates a sorting plant at Seal Cove, a few miles west of the map-area, from which much of the local requirements for road surfacing, railroad ballast, and the building trade are supplied. A rock crushing plant and quarry on Signal Hill green sandstone beds produces small quantities of crushed rock for road metal, and in the past, the green, grey, and red sandstones of the Signal Hill formation have been quarried at Signal and South Side Hills for building purposes. Small quarries have also operated on the pink Holyrood granite, and on the greenish Ordovician sandstone of Kellys Island. These operations all might be greatly expanded.

Nodular, crystalline limestone beds up to 3 feet in thickness occur in the Lower and Middle Cambrian formations. Specimens of reddish marble taken from one of the beds analysed 78·52 per cent calcium carbonate, and had a pleasing appearance when polished. The beds are a possible source of lime in limited amounts, as well as of ornamental stone. Extensive beds of shale and slate within the Cambrian formations provide a possible raw material for a brick and tile making industry and for the manufacture of prepared roofing granules.

Many small, lightly pyritized zones and copper-bearing veins occur in the Precambrian rocks of the area. They are interesting mainly for the traces of gold and silver that they carry in places. But, perhaps the greatest single, potential, undeveloped mineral resource of the area lies in the manganiferous beds of the Cambrian strata, from Topsail Head to beyond Kelligrews. Large tonnages of manganiferous and phosphatic shales and limestone are considered too low grade and too difficult to concentrate economically. The grade and reserves of the material are, however, not completely known, nor have concentration tests been exhaustive.

The prospects of future discoveries of ore deposits in the area are not promising, as prospecting on the ground is difficult because of extensive drift, bog, and bush cover. The contact area of the Holyrood granite appears to hold some inducement for prospecting, particularly near the Topsail fault zone.

MINING HISTORY

One of the earliest attempts at mining in Newfoundland is recorded by Jukes (27) as about 1778, on a copper-bearing vein near Shoal Bay, about 12 miles south of St. John's. It was exploited for a short time, abandoned, and reopened in 1839, again unsuccessfully. An attempt to mine a similar vein in the White Hills north of Quidi Vidi was also unsuccessful.

The oolitic hematite of Bell Island was first recognized as iron ore about 1892, shortly after which the Nova Scotia Steel and Coal Company Limited acquired mining areas there. The somewhat romantic history of the discovery of the value of the Wabana iron deposits was recorded by the Reverend M. Harvey in 1897 (13, pp. 94-95) as follows:

"In Conception Bay, about twelve miles distant from St. John's, lies Belle Isle, six miles in length and three in breadth. It was long noted for its excellent soil and the value of its farm products. No one dreamed that it held any minerals. Under the vegetable soil, however, there were extensive strata of rock of a dusky red colour, which cropped out at several places in the cliffs around the shores of the island. Blocks of this reddish rock were detached by the weather and lay on the beach, but no one took any notice of these boulders. A fisherman, who was going to St. John's, chanced to observe that these rocks were much heavier than ordinary blocks, and it occurred to him that they would make good ballast. He piled a number of them into his little craft, and when leaving St. John's on his return trip, having obtained a cargo of goods, he left his ballast on one of the wharves. Some one with a sharper eye than his fellows was struck with the appearance and weight of the stones, and suspected that they were metalliferous. He sent a sample to England for analysis, and was speedily informed that it was a rich iron ore. An exploration on the island followed, and the red rock was traced under the soil for a considerable distance. Soon the area was covered with mining licences; and when the strata were partially uncovered, one of the finest deposits of iron ore in the world was found."

Mr. R. E. Chambers of the Nova Scotia Steel and Coal Company Limited was the first engineer sent to examine the deposit, and he persuaded his company to obtain the land rights from the Butler brothers of Topsail in 1893 and to take out submarine claims. The first small shipment of ore was made to Halifax in 1895, to be later transferred to the furnaces at Ferrona near Pictou, Nova Scotia. The company later built blast furnaces at Sydney Mines, Cape Breton, for smelting the ore, and steel mills at New Glasgow for fabrication.

The Dominion Iron and Steel Company Limited was formed in 1899 and it acquired submarine claims immediately adjoining the northwest shore of Bell Island. The same year it purchased two of the three ore beds of the land area from the Nova Scotia Steel and Coal Company Limited, acquired limestone deposits at Port au Port, Newfoundland, and erected blast furnaces and a steel mill at Sydney, Cape Breton.

The two companies operated individually on Bell Island until 1921. During this time the Nova Scotia Steel and Coal Company Limited found it necessary to drive slopes through rock to work their submarine holdings. A holding company, the British Empire Steel Corporation Limited, was formed in 1922, bringing both companies under one management. Later this gave way to the Dominion Steel and Coal Corporation Limited, which is the holding company for the two original operators at Wabana, and other allied interests. Since 1895, the Wabana iron mines[1] of Bell Island have produced more than 48,000,000 long tons of hematite ore, which averages about 52 per cent metallic iron. In 1931, Hayes (17, p. 21) estimated that about 2,500,000,000 tons of ore may be found within the limits of submarine mining, of which one-half is recoverable by present mining methods. Much higher estimates have been made (9, 11), varying from 3,500,000,000 to 10,000,000,000 tons. Figure 2, a sketch map of Bell Island, shows the position of the mines and plants in plan and in section (1951).

In the early part of the century unsuccessful attemps at mining on a small scale were made on manganiferous beds near Topsail Head, Manuels, and south of Kelligrews. About the same time some work was done on the pyrophyllite deposits south of Long Pond, Manuels, and some limestone was quarried near Topsail Head and Manuels.

Following suspension of work on the pyrophyllite deposits in 1905, limited operations were resumed in 1938 and continued sporadically until the present. A crushing plant was built at Talcville on the railway in 1942 with the co-operation of the Commission of Government. Four test-holes totalling 430 feet were drilled by a diamond drill owned and operated by the Geological Survey of Newfoundland. Discouraging results were reported; but known reserves are considerable in lower grade, quartose material. To the end of 1948, in 12 years of quarrying, the deposits have produced a recorded total of 15,109 tons of pyrophyllite valued at $84,010.

Beach pebbles especially selected for grinding purposes were collected and exported by Joseph Dawe, from the beaches near Long Pond, Manuels, from 1940 to 1947 to the amount of 2,641 tons valued at $29,247.

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[1] Now operated by Dominion Wabana Ore Limited, a controlled subsidiary of Dominion Steel and Coal Corporation Limited, holding about 132 square miles of claims at Wabana.

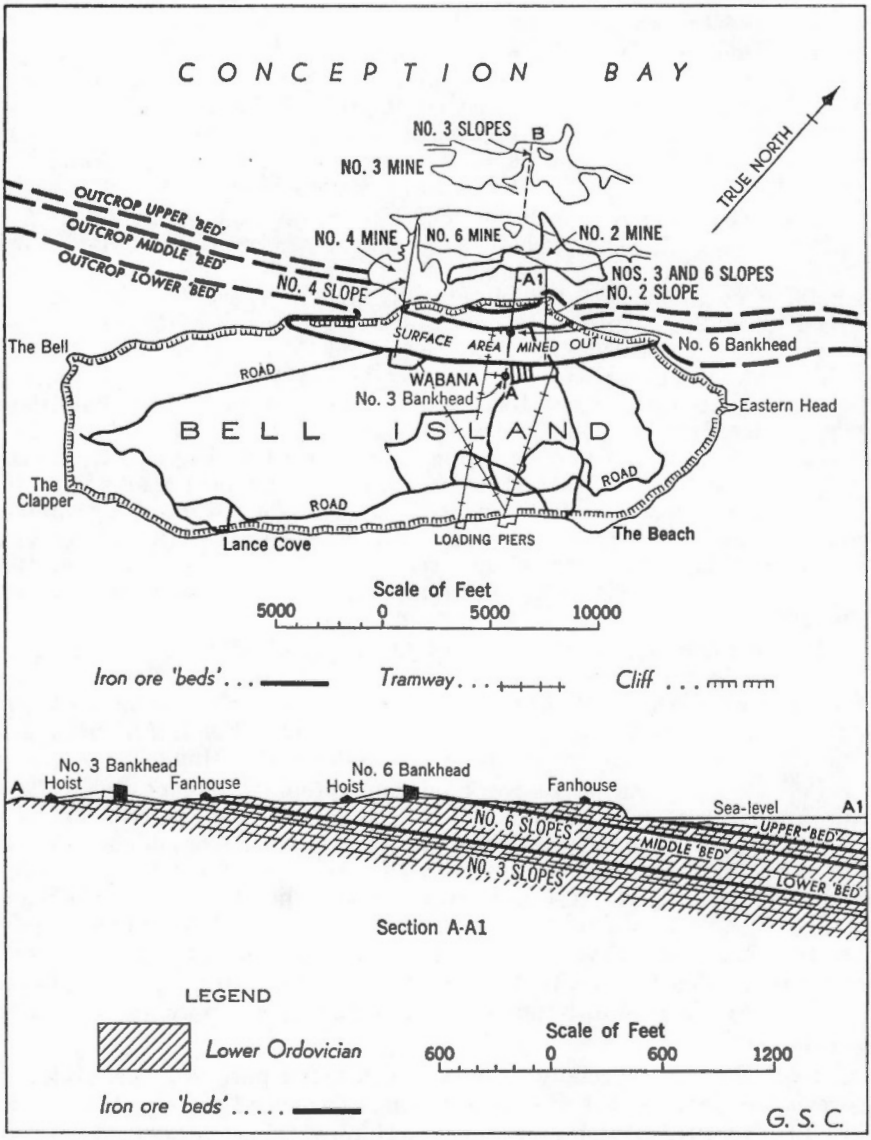

Figure 2. Plan and section of Bell Island, Newfoundland, showing location of mines and surface plants. After plan by Dominion Steel and Coal Corporation, April 1951.

METALLIFEROUS DEPOSITS

IRON DEPOSITS

Wabana Iron Ore

Mention has previously been made of the occurrence, history of discovery, and development of the Wabana iron ore on Bell Island. Five zones of oolitic hematite, three of which are mineable, are exposed in the Lower Ordovician rocks on this island. The three ore zones, which are known locally as the "Dominion, Scotia and Little Upper beds", or "Lower, Middle and Upper beds" occur in the upper part of the Lower Ordovician Bell Island and Wabana groups in the northwestern part of the island. Ore and rock beds dip gently northwesterly (*See* Plate V B) and pass beneath Conception Bay. The Upper and Middle 'beds' are separated by about 58 feet, and the Middle and Lower 'beds', by about 240 feet of intervening strata, the latter including an oolitic pyrite zone.

All the ore in the land area has been mined out, and extensive submarine mining is now in progress in all three 'beds' by Dominion Wabana Ore, Limited. Six mines have been developed at Wabana to date, Nos. 2 and 4 mines[1] with a daily capacity of 1,000 tons each are operating in the Lower 'bed', about a mile off shore. No. 3 mine is operating in the same 'bed', with a daily capacity of 1,700 tons at about 2 miles from shore, and No. 6 mine, with a daily capacity output of 1,700 tons, is operating in the Middle and Upper 'beds' about 1¼ miles from shore. A depth of 1,600 feet below sea-level has been reached, with 1,300 feet of rock cover. At this depth, more than 2 miles down the dip of the 'bed', all faces are in ore. According to J. B. Gilliatt (10) the ore varies from 10 to 30 feet thick in the Lower 'bed' and from 6 to 13 feet thick in the Middle and Upper 'beds'. Estimates of ore reserves as much as 10,000,000,000 tons have been made (9, 11). Figure 3, after J. B. Gilliatt, shows a vertical section of the ore 'beds' and slopes (*See also* Figure 2).

In addition to the ore zones, ferruginous rocks are known within the Lower Ordovician strata of Conception Bay as follows: chamositic sandstone, on Kelly's Island; chamositic sandstone with oolitic hematite, westward from Lance Cove; oolitic hematite, in two zones, one about 2 feet thick, traceable from Eastern Head past Kents Bridge to the coast near The Bell (Figure 2); and oolitic pyrite, in several bands from a few inches up to 4 feet thick, just above the Dominion or Lower bed. For completeness of description the following is quoted from Hayes (15, pp. 10-11):

". . . Oolitic iron ore and ferruginous rocks have been found in six zones on Bell island and these are given in stratigraphical order, beginning with the lowest:

"Zone O. —A thin ferruginous band occurs in the strata, forming the extreme southwest part of the island, outcropping from Lance cove westward to the western shore near the 'Clapper'.

"Zone 1. —This zone is partially exposed by shallow cuttings along the tramways of the Nova Scotia Steel and Coal Company and of the Dominion Iron and Steel Company near their intersection at Kents Bridge. It may be traced by intermittent outcrops from Eastern head on the east coast of the island to the northwest coast between Big head and the Bell.... It contains bands of oolitic hematite, two of which appear to be continuous, one attaining a thickness of about 2 feet.

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[1] The capacity of all operating mines is being currently increased to meet market requirements.

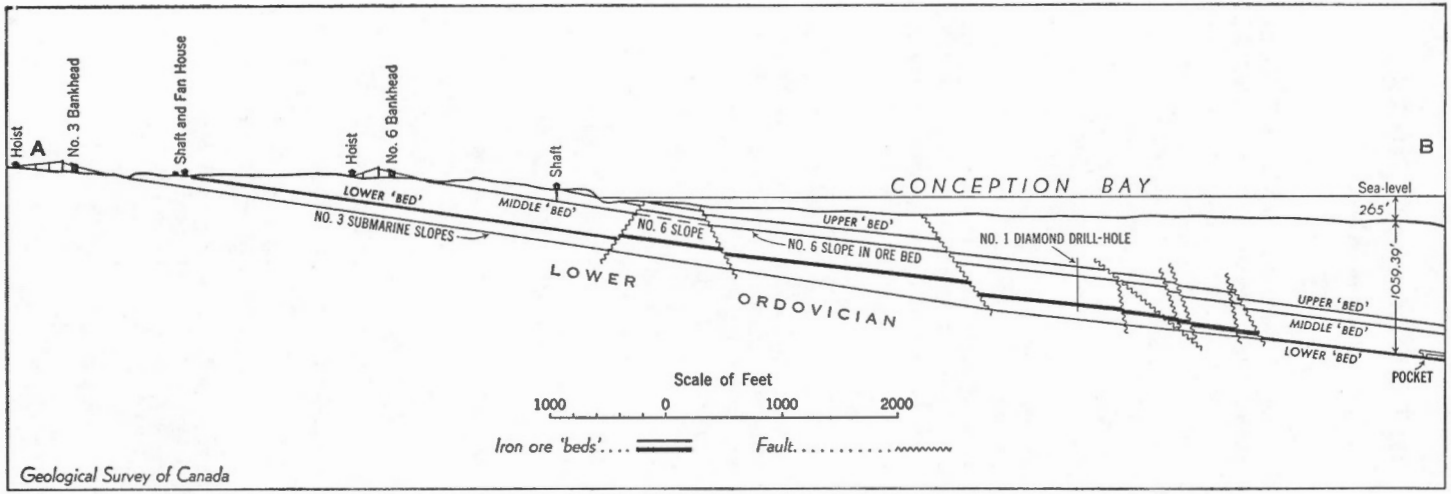

Figure 3. Vertical section on line of No. 3 mine submarine slopes, Wabana iron mines, Newfoundland. After J. B. Gilliatt, 1924 (corrected to March 1949), by courtesy Dominion Steel and Coal Corporation. For position of this section *See* slopes along line A-B, Figure 2.

"Zone 2. —Including the Dominion Bed. —The lowest oolitic hematite of this zone is about 600 feet stratigraphically above zone 1, and the whole zone consists of a series of bands of oolitic hematite alternating with shales and cross-bedded, fine-grained sandstones, comprising about 100 feet of strata culminating in the Dominion bed. The top 35 feet of strata are composed largely of oolitic hematite in thick beds with thin ferruginous sandstone and shale parting rocks....

"Zone 3.—Pyrite Beds. —Oolitic pyrite occurs in from one to three bands extending through strata from a few inches up to 4 feet in thickness, and found from 1 to 10 feet above the highest oolitic hematite of Zone 2....

"Zone 4. —Scotia Bed. —This zone commences 210 feet above Zone 3 and is confined to about 15 feet of strata....

"Zone 5. —Including the Upper Bed. —The lowest band of this zone is separated from the top of the Scotia bed by about 40 feet of sandstone and shales, and the oolitic iron ore continues upwards through about 50 feet of strata."

The graphic log of diamond drill-hole No. 1, given here as Figure 4, shows more than twenty-six seams of oolitic hematite in 480 feet of strata penetrated.

The detailed stratigraphy, petrology, chemistry, and mode of origin of the ore have been rather fully dealt with by Hayes (15, pp. 93-94), whose observations and conclusions are best given in his own words:

"The oolitic iron ore with ferruginous shales and sandstones forms part of a series of sedimentary rocks of lower Ordovician age.

"The ore beds are characterized by ripple-marked surfaces and cross-bedded layers and contain remains of animals which lived in shallow water. The spherules of the ore vary in size from 0·1 to 0·5 millimetres and are composed of alternating concentric layers of hematite and chamosite. These spherules were pierced by living boring algae, hence the iron minerals forming them were precipitated near the surface of deposition, while the algae flourished on the sea bottom.

"Siderite occurs in smaller quantity than hematite and chamosite, but becomes locally abundant. It replaces chamosite and hematite and in some instances detrital quartz in the ore. The algae are found in all horizons in the ore beds and formed a very abundant marine plant life growing on the sea bottom. Tubules of the algae are preserved in the siderite and are frequently coated exteriorly with hematite. The siderite was chemically precipitated, probably under cover of overlying sediments where concentrations of ammonia and carbon dioxide resulted from decaying organic matter. Thus while hematite and chamosite were forming at the surface of deposition, the siderite was contemporaneously formed in the immediately underlying sediments.

"There is a total lack of limestone from the series, and igneous rocks are also absent. Practically all of the original calcium content of the ore, averaging about 2·5 per cent, is present in the form of fossil remains composed largely of calcium phosphate, or as calcium phosphate derived from such organic matter. The phosphorous of the ore is also derived from the remains of organic life preserved in it. No evidence of diagenetic transformation from an original oolitic limestone to an oolitic iron ore has been found and no concentration of iron has occurred since the deposition of these ferruginous sediments. They are primary bedded iron ore deposits, mined today in essentially the same condition except for induration, faulting, and the addition of small amounts of secondary calcite and quartz in fault cracks, as when they were laid down.

"Oolitic pyrite also occurs as part of the same series of sediments, but is characterized by a planktonic fauna indicative of open ocean currents and deeper water. The layers of pyrite show distinct stratification and are probably similar in origin to modern deposits of pyrite now forming in the Black Sea.

"The pyrite spherules are composed of concentric layers of pyrite, frequently alternating with layers of phosphatic material. Pyritized and unpyritized graptolites and brachiopod remains occur together in contact with the spherules, indicating that some mechanical mixing took place on the surface of deposition."

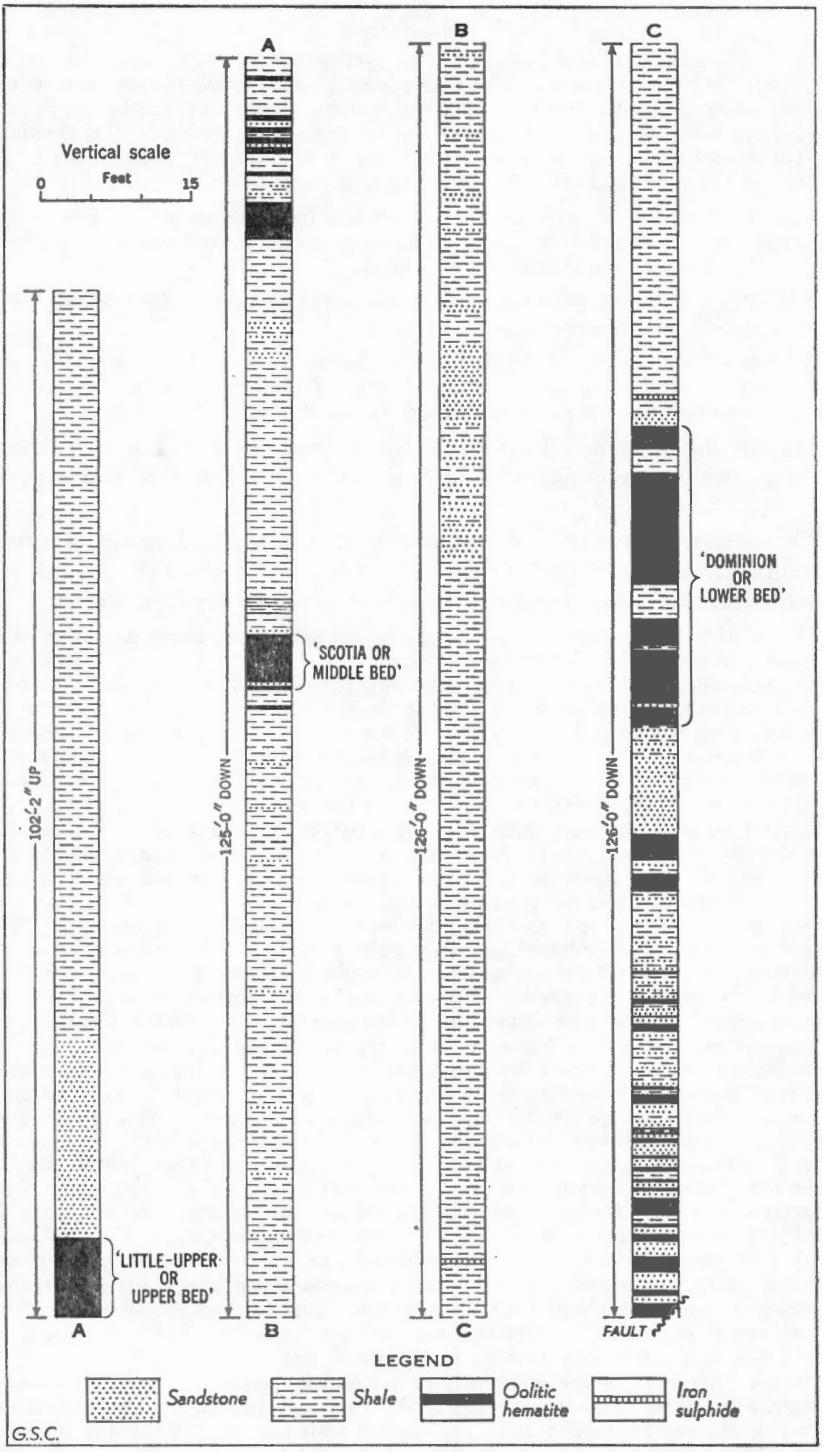

Figure 4. Graphic log of bore-hole No. 1, Wabana iron mines, Newfoundland, drilled vertically from No. 6 slope in 'Upper bed' (*See* Figure 3). After J. B. Gilliatt, 1924, by courtesy Dominion Steel and Coal Corporation.

In reference to the composition of the ore, Hayes (15, p. 66) wrote:

"All of the constituents of the ore vary within certain limits at different localities and at different portions of the ore beds, as shown in the following table:

	Per cent
Hematite	50 to 70
Chamosite	15 to 25
Siderite	0 to 50
Calcium phosphate	4 to 5
Calcite	0 to 1
Quartz	0 to 10"

and Gilliatt (1) reported:

". . .The analyses of the ore, in the three seams, vary from 50·5 per cent to 58·5 per cent Fe, and from 9·5 per cent to 15·0 per cent silica."

It is clear from the foregoing accounts of ore zones and host rocks that they are regarded by Hayes as primary, shallow-water, marine sediments[1]. Ore and rock show many features in common in support of this, as: bedding, crossbedding, ripple-marks, raindrop impressions, well-preserved marine fossils, worm burrows, and cut and fill structures. In addition, delicate microscopic tubules of boring algae are preserved in the ore. The host rocks clearly represent clastic sediments, but the origin of the iron ore is not quite so evident. It is a mixture of chemically precipitated and subordinate clastic material. Chemical and physical processes, together with the action of oxygen freeing algae, all appear to have contributed to its formation and deposition. The oolites are accepted as evidence of direct chemical precipitation and accretion of hematite and chamosite about nuclear, clastic grains. Penetration of oolite grains by boring algae tubules indicates the probable close association of algae with ore deposition. The oolites are commonly cemented in a matrix of siderite or of chamosite and siderite. Siderite commonly partly replaces both hematite and chamosite of the oolites. Hematite and chamosite rim and partly replace clastic quartz and shell fragments, but in the main the clastic quartz and shell fragments are unaltered. The crystalline condition of the hematite, siderite, and chamosite in the matrix is also an indication of chemical precipitation, or of replacement, or both. Some mechanical sorting, transportation, and deposition by water prior to consolidation of the ferruginous oolitic sediments is shown by crossbedding and alteration of layers of oolitic and earthy hematite. Penecontemporaneous erosion, transportation, and deposition are shown by interformational conglomerate beds carrying rounded fragments of the oolitic iron ore, which again is further evidence of its sedimentary origin.

Recent experimental work by Castaño and Garrels (5) has shown that:

". . . significant quantities of ferrous iron can be carried in solution in aerated river waters of pH7[2] or lower. If such waters enter a marine environment with solid calcium carbonate in equilibrium with the sea water, the iron is essentially completely precipitated as ferric oxide, both in the water and as direct replacement of the calcium carbonate.

". . . If they move into an area of stagnant water where organic debris tends to accumulate, the minerals formed might well be chamosite (if silt is present) or siderite and pyrite."

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[1] T. L. Tanton, of the Geological Survey of Canada, recently visited Bell Island, and has expressed the opinion, in discussions with the writer, that the Wabana iron deposits are replacement deposits by primary chemical precipitates from mineralized solutions that were introduced, presumably from a deep-seated source, into the fossil-bearing, Arenig, clastic sedimentary rocks.

[2] Hydrogen ion concentration, or degree of acidity.

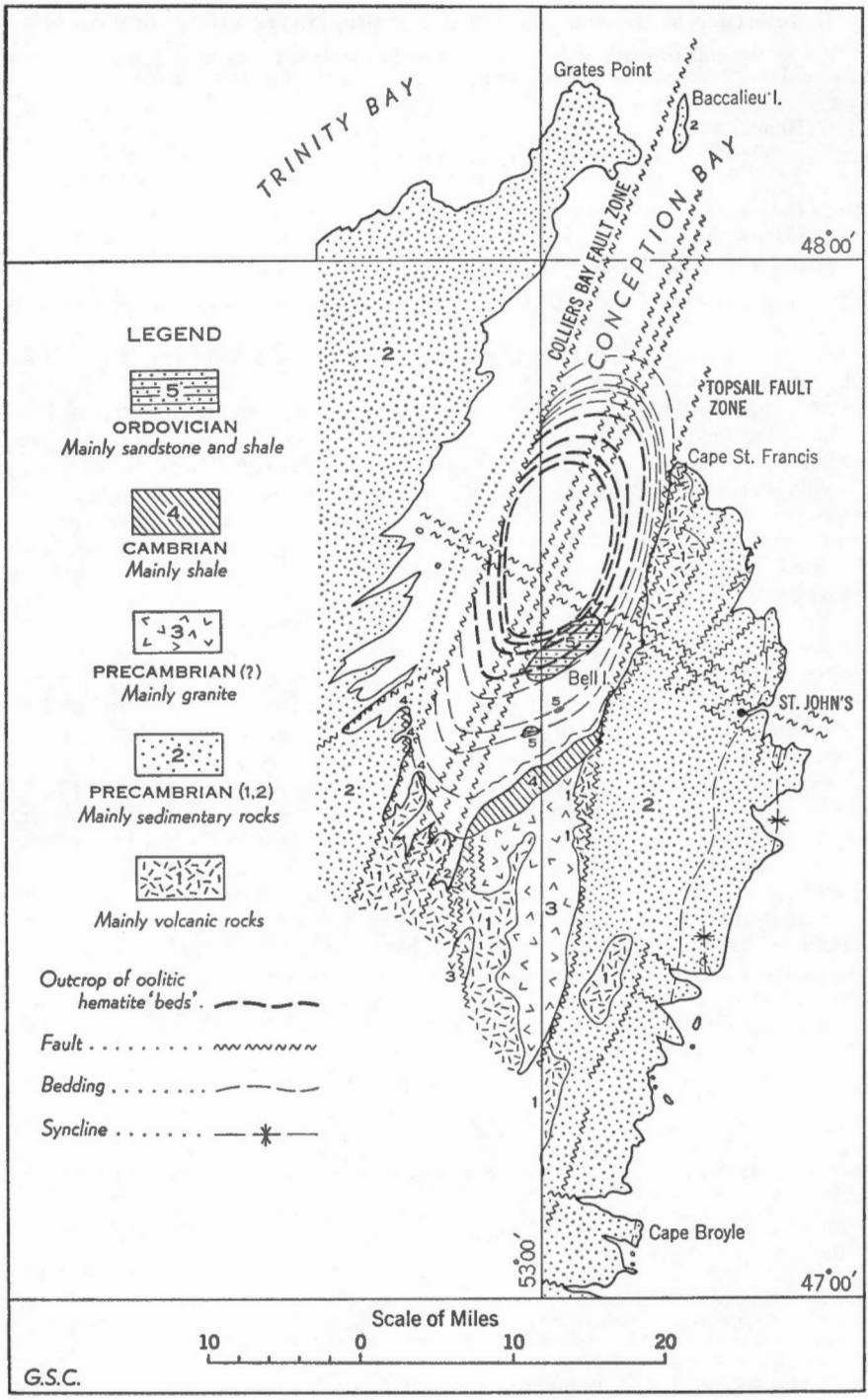

Figure 5. Map of Conception Bay, Newfoundland, showing general geology, structural pattern, and inferred submarine geology.

Reactions in sea water generally favour the formation of ferric compounds because of dissolved air, even in deep basins, unless the water becomes stagnant or reducing agents such as organic material are at hand. The formation of siderite in the ore is attributable to reducing conditions and to the occurrence of carbon dioxide in parts of the unconsolidated sediments, probably due to decaying organic material and rapid burial. Some mechanical mixing of the components of the ore occurred before consolidation of the sediments, which, coupled with removal of the permeating ferruginous fluids due to compaction, produced the ore.

Beds of oolitic pyrite above the Dominion bed carry graptolites and pyritized graptolites, and were evidently formed in a manner similar to the hematite ores but under reducing conditions and in somewhat deeper water. Thin, nodular phosphatic beds composed of shell fragments, nodules and oolites of calcium phosphate, and in places of siderite and pyrite in addition, occur above the Scotia bed. The phosphatic oolites are probably formed by the solution and reprecipitation of phosphatic shell material.

Silica at 12·0 per cent, and phosphorus, at 0·85 per cent, are the two most objectionable impurities in the ore. Sulphur is, in general, less than 0·03 per cent, and calcium less than 2 per cent. Silica occurs mainly in chamosite and as detrital quartz, phosphorus, and calcium in shell fragments, and sulphur in pyrite; but some secondary quartz and calcite have been introduced in tiny intersecting veinlets. Some crystalline quartz also occurs in the matrix of the ore and oolitic pyrite.

Because of the difficulty in proving ore in advance of mining, it is not possible to provide an accurate estimate of ore reserves. Geological conditions suggest that an unfailing supply of good quality iron ore is available for the next 100 years at Wabana, even if production is increased tenfold.

Figure 5 shows the simplified general geology of the iron ore bearing Conception Bay basin, with inferences on the possible submarine extent of the ore beds.

Bog Iron

Material from a small bog iron beach deposit composed of small, friable fragments of impure, cellular limonite, on the north shore of Cochrane Pond, gave the following analysis:

	Per cent
Iron	39·40
Manganese	2·11
Silica	5·05
Phosphorus	0·69
Sulphur	trace

It was not possible to trace the deposit for more than 20 feet on the shore because of the thick cover of bush and overburden. The source of the iron and manganese is problematical, but their oxides are characteristically deposited by bacterial action in bogs or from mineral-bearing springs and streams.

MANGANESE DEPOSITS

Among the previously recorded, but undeveloped, mineral deposits are the thin manganiferous zones in Cambrian shale, which have been described in detail by Dale (8). Manganese carbonates and oxides occur

in nodules, disseminated lenticles, and bands in dark shales. According to Dale, the manganese rocks are: "essentially calcareous or dolomitic argillaceous carbonates and oxides or carbonate-oxides of manganese, with hematite, barite, and tri-calcium phosphate as the chief accessories". The manganiferous beds are generally covered by overlying Cambrian strata or, where exposed by erosion, are obscured by glacial drift and talus, but they outcrop at a few localities between Topsail Head and Long Pond, Manuels.

In 1942, attention was drawn to the deposits by North American demands for manganese. Under the direction of Rupert Wiseman, then Assistant Government Geologist, Geological Survey of Newfoundland, the manganiferous zones on Manuels River and south of Kelligrews were sampled. In addition, six closely spaced diamond drill-holes, totalling 1,029 feet, were drilled at the Kelligrews locality. On the basis of the information at hand, Wiseman (51) estimated that 10,000,000 tons of possible, low-grade ore is to be found in a zone 5 feet thick, extending between the Manuels and Kelligrews localities. Mention is made (51) of samples containing 11·55, 10·73, and 8·29 per cent manganese across widths of 5·8, 7·8, and 13·4 feet, respectively, at Manuels. Four bulk samples from the beds of the deposit on the south side of Manuels River were sent to the Ore Dressing and Metallurgical Laboratories of the Department of Mines and Resources of Canada for testing. Of these, sample No. 4, which was channelled across 5 feet 10 inches of the zone, yielded 10·35 per cent manganese. Concentration tests by flotation and combined calcination-flotation on this material raised the manganese content to only 25 per cent, and it was concluded that the deposit could not be concentrated to ore grade by any known process short of chemical treatment (28). The investigation was, consequently, abandoned before the extent and grade of the deposit had been fully determined.

A manganiferous zone occurs in Cambrian beds on the terrace at the foot of Topsail Head, and, about 1910, a manganese carbonate-oxide bed about 1½ feet thick was explored by means of a small open-cut. The bed and workings are now sloughed over, but a sample taken from the dump yielded 25·9 per cent manganese and 4·18 per cent phosphorus. Overlying shale beds strike northeasterly and dip rather steeply beneath Conception Bay.

Most of the manganese in these zones occurs as complex carbonates, bearing manganese, iron, calcium, and magnesium, but some is in the form of oxides. The deposits occupy zones in Cambrian shales, within which the manganese minerals are locally concentrated in beds, lenses, and nodules. Although it is extremely fine grained, there is reason to believe that the manganese-bearing material might be concentrated to ore grade by heavy media separation and roasting[1]. So far as known these processes have not been applied to Topsail Head-Manuels-Kelligrews manganese-bearing materials.

A little phosphorus and calcium occur with the manganiferous beds in nodules, oolites, and shell fragments. Hematite and barite are also known. Such elements as calcium and phosphorus may be regarded as impurities in attempts to concentrate manganese, but their value as fertilizers is well known, and they might conceivably be recovered by chemical treatment as

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[1] See Report of the Ore Dressing and Metallurgical Laboratories, Bureau of Mines, Investigation No. 1350, Concentration of Manganese Ore from Brigus, Newfoundland, 1943.

a by-product of manganese. Enormous tonnages of low-grade material are indicated here and at other localities in Cambrian strata of the Avalon Peninsula.

It is interesting to note that encrustations of bog manganese oxides are found on pebbles in the bed and banks of La Manche River.

MOLYBDENUM DEPOSITS

Three narrow, molybdenite-chalcopyrite-pyrite bearing quartz veins occur in Holyrood granite near its eastern margin and about 1·2 miles south of the Witless Bay line. The veins vary in width from 2 to 6 inches; are exposed for a distance of 250 feet on the southeast slope of a granite hill; and are covered with overburden at both ends. An aggregate chip sample from the veins assayed as follows:

Molybdenite	7·4 per cent
Gold	0·005 oz. per ton
Silver	0·225 oz. per ton

To the writer's knowledge, this is the first occurrence of molybdenite described in the Avalon Peninsula. The deposit warrants careful prospecting, as do the other mineralized areas in the peninsula in which gold and silver have been reported.

PRECIOUS METAL DEPOSITS

In addition to those of the molybdenite occurrence, just described, traces of gold and silver have been reported from assays of samples taken from widespread, lightly pyritized shear zones in Precambrian rocks in Torbay map-area. Although such returns do not represent ore, they lend some incentive to the search for more important deposits. Traces of gold and silver have also been found in some of the quartz-calcite-chalcopyrite-pyrite veins of the area.

COPPER DEPOSITS

Malachite-stained, quartz-calcite veins bearing small amounts of chalcocite, bornite, and chalcopyrite occur at several localities along the eastern coast, within Signal Hill sandstone and conglomerate, near Shoal Bay, Miners Point, Motion Head, and the White Hills. Early attempts at mining two of these veins were unsuccessful because of the smallness of the veins and their low copper content. The chief point of geological interest lies in speculating on the fact that these copper-bearing veins cut the sedimentary beds of the Signal Hill formation 12 miles east of the nearest known igneous and potential source rock.

A few small, quartz and quartz-calcite veins bearing chalcopyrite and pyrite, cut sedimentary rocks of the Conception group in the area between Pouch Cove and Cape St. Francis. Chip samples from some of these veins, assayed for gold and silver, yielded traces of the precious metals.

NON-METALLIC DEPOSITS

PYROPHYLLITE DEPOSITS

Deposits of pyrophyllite and its variety agalmatolite have been recorded since 1898, south of Long Pond, Manuels. Howley (25) mentioned the deposits in 1900, and subsequently described the attempts to develop them in the early part of this century. The deposits were studied in 1913-14 by Buddington, and described in detail by Vhay in 1937 (45).

The mineral pyrophyllite closely resembles talc in its physical properties and can be adapted to many of its uses. Pyrophyllite is a hydrous silicate of aluminium; talc, a hydrous silicate of magnesium.

Southwesterly from Manuels, pyrophyllite occurs in large replacement lenses in sheared rocks of the Harbour Main and Conception groups close to the intrusive eastern border of the Holyrood granite. Pyrophyllitization processes have been chiefly effective in sheared volcanic rocks of the Harbour Main group, and have resulted in the formation of either quartz-pyrophyllite schist, containing variable proportions of those minerals, or pure pyrophyllite schist.

The most important deposits are in the Johnnys Pond, Mine Hill, Dog Pond, and Trout Pond areas. In about 12 years of intermittent operation the quarries near Johnnys Pond and Mine Hill have produced more than 15,000 tons of pyrophyllite valued at more than $84,000. In 1947, about 276 tons of pyrophyllite were produced, valued at $39 per ton. Vhay (45) estimated that more than 50,000 tons of 75 per cent pyrophyllite and 200,000 tons of 30 per cent pyrophyllite occur on Mine Hill, and as much medium- to high-grade material in an adjacent area. He says:

"Large areas of quartz-pyrophyllite schist were formed by hydrothermal alteration of sheared rhyolite lavas and conglomerates near a granite contact. Certain schist areas contain a high percentage of pyrophyllite in addition to scattered lenses of nearly pure pyrophyllite.

"A large tonnage of high-grade and medium-grade quartz-pyrophyllite schist is available around Johnnys Pond, and it is believed that if a satisfactory method of separating pyrophyllite from quartz is found the deposits could be worked profitably. Air separation or froth flotation[1] will probably be found feasible."

It might be noted that when a use for a product of mixed pyrophyllite and quartz in found the merchantable reserves will be greatly increased.

The massive, compact form of the pure pyrophyllite, agalmatolite, has been used for making carved ornaments; difficulty is encountered in securing good material for this purpose because of the cleavable nature of most of the pyrophyllite in these deposits.

BUILDING STONE

It is of interest to note that Government House, a handsome building at St. John's, is constructed mainly of reddish Signal Hill sandstone. It stands in favourable contrast to the neighbouring Legislative building, which is built of whitish limestone imported from Ireland. The Church of England Cathedral, St. Patrick's Church, and part of the Mental Hospital at St. John's are built of greenish grey Signal Hill sandstone, a durable stone, but lacking the warmer colour of the overlying reddish member.

The Roman Catholic Cathedral of St. John the Baptist is constructed mainly of greenish Ordovician sandstone from Kellys Island, as is the Court House, which is faced with granite from Petites on the south coast of Newfoundland. A convent near the Roman Catholic Cathedral is built chiefly of reddish syenite from the Holyrood batholith, a very durable and handsome stone. Many excellent quarry sites might be selected on each of these rock types.

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[1] Recent experimental work by the Mines Branch (30) shows that froth flotation is feasible.

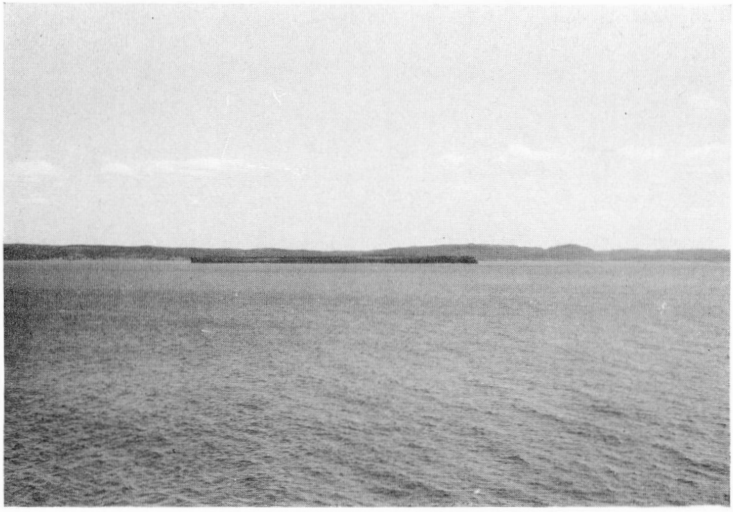
CONSTRUCTIONAL MATERIALS

In addition to the sandstone beds and granite referred to above, which provide unlimited supplies of rock for road metal and fill, Cambrian shale might be used to manufacture brick, tile, and prepared roofing granules. Widespread deposits of glacial till, including gravel, and sand lenses, blanket the bedrock, and are known to attain a thickness of 50 feet in places. The deposits in general are not well sorted, but much gravel and sand could be reclaimed from them with little trouble. Many borrow pits along the dirt roads are in use to keep roads in good condition.

PLATE II

99101

A. Modern wave-cut bench in crumpled red beds of 'Torbay slate', showing joints and fracture cleavage intersecting beds almost at right angles; beds strike northerly and dip steeply to the west (view south). (Page 7.)



99097

B. Little Bell Island, Conception Bay, showing flat-topped surface at 75-foot elevation (view southeasterly from Bell Island). (Pages 7, 12.)

PLATE III

99096

A. Excavation on sheared silstone of 'Conception slate' near east end of Mobile Big Pond shows beds striking northerly and dipping steeply westerly (view west). (Pages 18, 42.)

99100

B. Black slate of the St. John's formation with light grey sandstone lenses, north of Bay Bulls; beds strike northerly, dip rather gently to the east, and are intersected by nearly vertical joints and fracture cleavage (view east). (Pages 23, 42.)

PLATE IV

99098

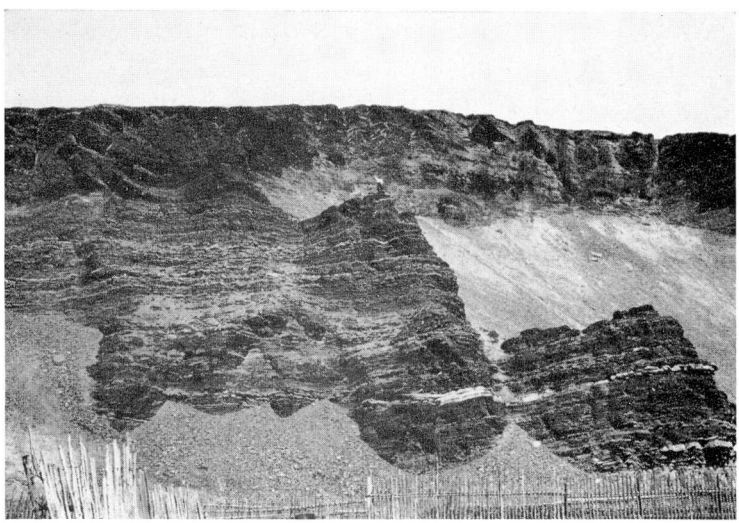
A. Intersecting faults and joints on bedding plane surface of Signal Hill, conglomerate south of Cabot tower; beds strike north-northeasterly and dip about 72 degrees east-southeasterly (view west). (Pages 26, 41.)

99094

B. Joint pattern in reddish, well-bedded Signal Hill conglomerate at Flat Rock; joints strike northerly and northwesterly, and dip steeply easterly and southwesterly (view southwest). (Page 26.)

99095

A. Younger Conception group rocks overthrust upon reddish Cabot group beds northeast of Flat Rock; the fault plane shows just right of centre, dipping about 45 degrees to the left (view northeast), (Page 27.)



99099

B. Fossiliferous, Lower Ordovician, Bell Island group, grey-brown shale and light grey sandstone, The Beach, Bell Island; beds dip gently northwesterly (view northwest). (Pages 33, 47.)

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