MEMOIR 301

FOGO ISLAND MAP-AREA NEWFOUNDLAND

(2 E/9, mainly)

BY

D. M. BAIRD

GEOLOGICAL SURVEY
DEPARTMENT OF MINES AND TECHNICAL SURVEYS
OTTAWA
1958

CANADA
DEPARTMENT OF MINES AND TECHNICAL SURVEYS

GEOLOGICAL SURVEY OF CANADA
MEMOIR 301

FOGO ISLAND MAP-AREA
NEWFOUNDLAND
(2E/9, mainly)

By

D. M. Baird

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958

Price, 50 cents No. 2548

99995-3—1

Price: 50 cents Cat. No. M46-301
Available from Superintendent of Publications,
Queen's Printer, Ottawa.

2,500—1958—1184

PREFACE

Although Fogo Island is situated on a part of Newfoundland's coast that is readily accessible and its geology has been studied off and on for almost 120 years, the present report is based on the first comprehensive geological study made. This investigation was undertaken for the Government of Newfoundland and the preliminary results were made available in manuscript form to the Geological Survey of Canada at confederation. The author subsequently examined the adjacent islands and parts of the mainland, thereby extending the investigation to complete the Fogo Island map-area.

Ordovician and Silurian strata have been traced from the mainland on to Fogo Island and are described in detail. Acid and basic intrusions are far better displayed on the island than on the adjacent mainland, and it has been possible to describe them and to establish their relationships with much greater precision than heretofore.

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

OTTAWA, OCTOBER, 1957

99995-3—1½

CONTENTS

CONTENTS—*Con.*

Illustrations

GEOLOGY OF FOGO ISLAND MAP-AREA NEWFOUNDLAND

Introduction

Location and Size of Map-Area

Fogo Island map-area lies between longitudes 53°50′ and 54°30′ west and latitudes 49°30′ and 49°50′ north, in the northeast corner of Newfoundland. Fogo Island, the largest in the map-area, has an area of about 110 square miles. Other islands include Change Islands, occupying about 10½ square miles, Indian Islands, about 3 square miles, and numerous smaller islands.

Little Fogo Islands (Bishops Islands) and adjacent islands to the southwest comprise about 100 islands strung out in a northeasterly direction. Combined they have an area of about one square mile. In all, and including about 3 square miles of Port Albert peninsula and Wadham Islands, the land area totals about 135 square miles.

Field Work

The writer, accompanied by two non-technical assistants, spent the field season of 1946 in the map-area, and in 1955 had a party of the Geological Survey of Newfoundland on Fogo Island for one month. Some additional checking of boundaries was carried out by the writer in the summer of 1956, and H. Williams of Memorial University of Newfoundland undertook a detailed study of the basic rocks of the Tilting area the same summer under the writer's direction. The original base map was prepared by the Geological Survey of Newfoundland, but following the union of Newfoundland with Canada in 1949 (when unpublished work of the Geological Survey of Newfoundland was handed over to the Geological Survey of Canada for publication) the present more accurate base map of the Fogo Island map-area was supplied by the Department of Mines and Technical Surveys, Ottawa. The later geological work was desirable to ensure proper detail for the new, more accurate, topographic base map.

Acknowledgments

The writer is grateful to his field assistants for jobs well and cheerfully done. John McKillop and Ray Gillespie, Assistant Government Geologists with the Geological Survey of Newfoundland, carried out much independent work in the summer of 1955 while remapping parts of Fogo Island. H. Williams assisted materially in 1956 by mapping in detail the region

immediately around Tilting. The residents of the area were helpful on many occasions and generous with their assistance, outstanding among them being Victor Rowe of Seldom.

Previous Work

The Fogo Island district, because of its exposed position on the northeast corner of the Island of Newfoundland, has been frequented by travellers since the first explorations of North America. It was logical, therefore, that the first professional geologist to visit Newfoundland, J. B. Jukes[1], should include a sketch of the geology of Fogo Island and the surrounding district in accounts of his travels of 1839-40. Murray and Howley (1881) mentioned in several of their reports, notably those for the years 1871 and 1874, the general structure and rock types to be found in the Fogo map-area. The geological map of Newfoundland published by Howley about 1905 shows, in a general way, the distribution of rocks and their relations to those of the rest of Newfoundland.

The Princeton Expeditions to Newfoundland visited Fogo and adjacent parts of the coast in the years up to 1930, but their records are largely in the form of unpublished notes. Twenhofel and Shrock published a resumé of the Silurian rocks of northeastern Newfoundland in 1937, and Twenhofel followed this in 1947 with the results of further work on the Silurian rocks of eastern Newfoundland from the north to the south coasts, including those of Fogo map-area.

T. O. H. Patrick (1957) worked in Twillingate and Comfort Cove map-areas (west and southwest of Fogo map-area) from 1950 to 1955 for the Geological Survey of Canada.

Accessibility

Travel is almost entirely by water in this part of Newfoundland, as in most coastal areas. The sea is normally calm in the summer months with little hazard to small boats, except where late afternoon breezes make choppy water or where swells from distant storms make landings difficult for two or three days at a time. The road system on Fogo Island is still rudimentary but does allow passenger cars and trucks to travel between the principal villages. Footpaths link other places.

The port of Fogo is the eastern terminus of a weekly steamship service from Lewisporte, on the Canadian National Railways. The principal settlements in the area are served by a steamer service between St. John's and Lewisporte with calls on inbound and outbound voyages, about once every

[1]Names and dates in parentheses are those of references cited at the end of this report.

two weeks. Sea-going boats are available for private charter at most of the villages, and cruiser-type motor-boats make regular trips to Lewisporte to connect with trains.

Float planes, available on charter at Gander, make the trip to Fogo Island in about 30 minutes and offer much the quickest transportation. A regular winter air-mail service is maintained to the district.

Culture

The principal industry in the region is fishing. Agricultural land is virtually lacking, and residents have little choice but to turn to the sea for their livelihood. Glacial scouring and submergence of a maturely dissected land surface have resulted in the formation of several good harbours for small boats. The coming of the motor-boat had the effect of centralizing the population in a few villages, as it became increasingly easy to travel greater distances to the fishing grounds. Abandoned houses are therefore common in outlying areas.

The principal villages are listed below.

Village	Communications	Steamer Service	Population in 1945
Fogo	Canadian National Telegraphs (CNT) Telephone	Lewisporte-Fogo (1), and St. John's-Lewisporte (2)	*
Joe Batt's Arm	CNT	2	1,036
Tilting	CNT	2	942
Cape Cove	None	–	312
Seldom	CNT	2	50
Stag Harbour	CNT	2	312
Island Harbour	CNT	–	223
Indian Islands	CNT	2	220
Change Islands	CNT	1,2	190

* The Dominion Bureau of Statistics (1956 census) gives 1,165 as the population of Fogo and 805 as the population of Change Islands.

Bishops or Little Fogo Islands at one time supported a considerable summer population, but in 1956 presented a picture of desolation, with abandoned houses and fishing rooms, and only three families in residence for the summer fishing. The islands are on excellent fishing grounds, however, and are frequented by numerous boats from Fogo and Joe Batt's Arm.

The Wadham Islands are not inhabited except for a lighthouse keeper on the southeast corner of Pekford Island and a few small shacks occupied in summer by transient fishermen.

Forests and Soils

The north half of Fogo Island is barren. The central part has a scrubby, northern-type forest of spruce and balsam fir. The south side and southwest corner of the island and the south coastal area eastward to Cape Cove support a considerable forest growth of mixed woods, mostly black spruce, white spruce, balsam fir and birch. Only the southern parts of the Change Islands are forested; a great peat bog covers the northern part of the southern island and the northern islands are completely barren of trees. Western Indian Island is covered with a thick layer of peat with no trees of appreciable size. Eastern Indian Island is partly peat-covered and partly barren. Woody, Hare, and Dog Bay Islands are forested, but other small islands are generally barren.

The only agriculture practised is that in tiny garden plots in some villages, which supply part of the local demand for vegetables. The only fields observed were in Tilting and Stag Harbour. Glacial till comprises most of the soils except in a few places such as at Stag Harbour, where post-glacial, water-worked sediments are present.

Physical Features

Physiography

The surface of Fogo Island, principal land area, is an irregular upland on which a few higher hills are prominent. Most of the island is from 150 to 250 feet above sea-level, but little evidence exists of any of the peneplains commonly recognized in Newfoundland. The surface of Fogo Island may possibly represent the Lawrence peneplain of Twenhofel and MacClintock (1940, p. 1721).

Relief is due to erosion acting on rocks of different degrees of hardness. Highlands are underlain by massive igneous rocks, by resistant sedimentary rocks, or by resistant metamorphic rocks, whereas lowlands are underlain by softer rocks, shear zones, or other structurally weak zones. Some of the highest hills on the island, west of Hare Bay, are underlain by fine-grained, pink, marginal-type granite of the Fogo Island batholith. Other high hills that lie west of Fogo Harbour are underlain by altered sedimentary and pyroclastic rocks of the Fogo group. The hills north of Stag Harbour, in the southwest corner of Fogo Island, are underlain by granitic rocks. Most of the interior of Fogo Island has a rolling topography, with wooded valleys and bare or sparsely covered hills except in the south where the hills also are wooded.

On the south side of Fogo Island there is little noticeable grain to the topography. On Fogo Harbour peninsula, however, a decided east-west trend of hills and valleys reflects the strike of the underlying metamorphosed sedimentary rocks and accompanying sills. The southern part of the same peninsula shows a strong, curving, northwest-trend in the Fogo granite. This same curving trend is faintly visible all the way across Fogo Island to its eastern shore where it is almost east-west.

The western edge of Fogo Island is characterized by a gently rolling lowland underlain by quartzites and slates of the Fogo group. The lowland ends against a line of cliffs that follow the edge of the interior granite mass. On the south side of the island the contact between the granite and the diorite-gabbro complex is not reflected topographically.

On the south end of South Change Island, the area underlain by sedimentary rocks is an irregular flat plain with no marked prominences and little relief, except along the coast where stream erosion has produced some small valleys. The central part of the island is underlain by volcanic rocks, and has a very irregular surface. A resistant agglomerate member of the series underlies a long line of sharp hills extending across the island. The flat area to the south gradually passes into an irregular hilly district characteristic of the northern part of the southern island and of the northern islands.

The Indian Islands are underlain by a uniform series of slates and phyllites, standing on edge and striking nearly east-west. The east-west strike and possible strike faulting have produced a well marked east-west grain. The islands are very flat, no point being more than 60 feet above sea-level. Eastern Indian Island is covered with a peaty material and water-worked glacial sand and gravel. The benches of both islands are of glacial debris composed of material foreign to the islands. On the south side of Western Indian Island, wave erosion is undercutting and eroding the massive peat deposits that blanket bedrock, and flat, polished and striated rock surfaces are being exposed. In places peat forms cliffs more than 10 feet high and directly overlies bedrock. In some layers of peat, the presence of stumps, logs, branches, and stems indicates that, at times during the formation of the deposits, forests covered the bogs. At present only stunted trees manage to grow in a very few localities around the margins of the island. The great, spongy mass of peat that covers most of the island to a depth of 10 to 20 feet makes an excellent reservoir for fresh water, and springs are numerous along both north and south sides of the island, even at the driest time of summer.

The Wadham Islands, in the southeast corner of the map-area, are low, rounded masses of granite. In places the wave zone is marked by accumulations of granite boulders up to 10 feet in diameter. Copper Island, underlain by diorite and gabbro, rises abruptly from the sea in steep cliffs and differs in aspect from the other islands of the group.

The Bishops Islands or Little Fogo Islands group varies from steep-walled, inaccessible masses of bare rock to low-lying masses only a few feet above the sea. The main cluster of large islands, called by the residents Little Fogo Islands but indicated on the map as the Bishops Islands, are bare rock except for parts of the interiors and local protected areas which are covered with a tundra-like sod.

Drainage

In such an area of islands, drainage patterns are normally unimportant features of the physiography. However, on Fogo Island, with a land area of about 110 square miles, the streams and ponds show distinctly the disarranged drainage pattern characteristic of glaciated regions. Streams wander about on flat, debris-filled valleys or through non-integrated lake systems to tumble precipitously through youthful, steep-walled trenches to the sea. In places, small streams are intermittent beneath accumulations of glacial boulders.

The streams of Fogo Island follow glaciated valleys that are probably remnants of a preglacial drainage system. East-flowing and west-flowing streams in the northwestern peninsula of the island are subsequent streams in that their courses are adjusted to the easterly trend of the metamorphosed sedimentary rocks and the intruding sills. In other places, the courses of the brooks are governed by faults and shear zones. Most streams, however, lack apparent bedrock control, and may be referred to as inconsequent (Lobeck, 1939, p. 121).

Lakes abound in the interior of Fogo Island. They are of three types commonly found in glaciated regions; (1) those formed by the damming of preglacial valleys—most of the lakes are in this class; (2) those occurring in basins scoured out of bedrock by glacial ice and rock-bound on all sides (some of the shallow ponds on the northeastern part of Fogo Island belong in this class); and (3) bog-hole ponds formed by the damming action of vegetation. Small ponds of the latter class occur widely in the interior of Fogo Island and on some of the other islands in the area. Solifluction in bogs on sloping surfaces has also formed small ponds.

Coast-line

There is much evidence to show that Newfoundland has been deeply submerged and that it has subsequently only partly emerged. Everywhere along the coasts long indentations of the sea are continuous with river valleys that extend far inland. Soundings show that the mature subaerial topographic features extend beneath the sea, with some of the valleys extending beyond modern shorelines as far as 200 fathom line. The ragged, island-studded coast-line is typical of submergence. Wave-cut beaches, elevated beaches, and elevated sands and clays with marine fossils show that a recent partial emergence has taken place (Baird, 1951, pp. 17-31).

On Fogo Island no elevated beaches cut on bedrock were found, but nine gravel beaches, now well above sea-level, were observed. The known localities are:

1. One-half mile southwest of the western entrance of the Fogo Harbour canal. There several beach lines of cobbles and smaller fragments extend to a maximum height of about 50 feet above sea-level. The highest, and presumably the oldest, is much frost-split and covered with moss and lichen; the lower beaches are progressively fresher.

2. Eastern shore of Shoal Bay just north of village. Raised beaches composed of boulders up to 1 foot in diameter, some much split and weathered. Boulders are about 20 feet above sea-level.

3. South side of Brimstone Head, beyond last house. Raised beaches occur at 15 and 35 feet above sea-level. Frost-splitting and weathering more pronounced along the upper and older beach.

4. Half-way along west shore of Shoal Bay. Cobbles and boulders up to 1 foot in diameter occur at about 10 feet above sea-level, well above the reach of ordinary storm waves.

5. East side of Joe Batt's Arm, in small cove 1½ miles north of last house. A raised beach of cobbles occurs about 30 feet above sea-level.

6. Three-quarters of a mile west of tip of Cape Fogo, on south shore. Raised beaches occur at two places at about 25 feet above sea-level.

7. North shore of Cape Fogo peninsula, near isthmus. Raised beaches with flat tops, composed of cobbles and boulders that are now weathered.

8. East shore of Seldom Harbour, half-way between lighthouse and first house. A raised beach of cobbles stands at 20 feet above sea-level.

9. One-quarter mile north of Rogers Point, in a small cove. A raised beach occurs at an elevation of about 20 feet. The presence of these raised beaches is visual proof that post-glacial emergence of the land has taken place in this region.

Cliffs

The shoreline of the islands of Fogo district varies greatly in character. In some places, smooth, glaciated surfaces rise evenly from the sea to upland surfaces; at others, steep, jagged cliffs are being undercut by present-day wave erosion. Beaches occur at the heads of some coves and in places along the open coast. All cliffs along the coast of Newfoundland are not the result of simple wave erosion in the present cycle but are the result of a long and complicated physiographic history that probably started well back in Tertiary times. Some result from the drowning of a preglacial, river-eroded topography; others from deep glacial erosion and steepening of former river valleys, which were then submerged; and some, without question, are due to recent wave erosion. The whole zone, from the tops of the highest elevated marine features to several hundred feet below present sea-level, has been washed by several different strand lines during land-sea oscillations that have taken place since the first great submergence of Tertiary times. Present-day cliffs at sea-level must be regarded as part of a region of complex physiographic history. The latest stage, the present cycle of wave erosion, is in a state of early youth.

Marine Potholes

Potholes similar to those found along streams were observed at several places along the wave-washed shorelines of the islands. One pothole measuring 4 feet in diameter and several smaller ones in various stages of development occur near high-tide level on the east side of Cann Island. Similar holes are cut into the soft phyllites and slates of the Indian Islands.

These potholes are clearly the work of boulders actuated by waves and the strong currents of returning wave wash. In the potholes on Cann Island and the Indian Islands, boulders of granite and other hard rocks derived from glacial debris can be seen in action. Spherical openings in certain steep-walled narrow gulches, which were cut along sheared zones in the massive rocks on the south side of Fogo Island, are occupied by similar boulders and were cut in a similar manner.

Glaciation

The effects of glaciation are widespread in Fogo Island map-area. Striae and *roches moutonnées* are common. Even on the outer islands north of Fogo Island deep striae and channelling are prominent. Glacial drift is locally abundant. Erratics are widespread and occur on the tops of the highest hills of Fogo Island, showing that the whole island was covered by an active ice-sheet.

There can be little doubt that Newfoundland was last glaciated by ice that moved outwards from the central plateau towards the coasts. In the Fogo Island map-area all evidence points towards the northward movement of the ice. Striae and channelling show that the average direction is due north, with small local deviations due to local relief, and this is corroborated by *roches moutonnées* and crescentic fractures. The latter are mainly of the type described by Gilbert (1906) and Harris (1943, p. 243), with the horns pointing in the direction from which the ice came, and with the sloping surface of the fracture dipping under the vertical break.

The preservation of glacial markings was found to vary considerably with both the type of bedrock and the location. Striae engraved in the granite of Fogo Island are most common. Glacial markings that have been protected until recently by over-burden are well preserved, but where the granite has been exposed for long periods they are weathered away. The sedimentary formations of the district rarely show striae except where they have been protected from erosion. The massive intrusive rocks of the Fogo diorite-gabbro complex on the south side of Fogo Island exhibit excellent striae and scour forms in some places. Striae and channelling are preserved on the flows and volcanic breccias and on some of the massive sandstone beds on the Change Islands.

Glacial deposits are nowhere in great quantity. Minor accumulations of unstratified debris fill the bottoms of some of the valleys and scattered deposits of stratified sands and gravels were observed here and there.

A list of directions of ice movement, obtained from glacial striae, and other features in the Fogo Island map-area follows:

Direction	Location	Source
N.26°E.	West side of head of Hare Bay	Striae and *roches moutonnées*
N.25°W.	1 mile due south of head of Hare Bay	Striae, channels, and *roches moutonnées*
N.15°W.	Shoal Bay village	Striae, crescentic fractures, *roches moutonnées*
N.18°W.	2,900 feet along the Seldom road from Fogo Harbour	Striae
N.15°W.	West side of head of Shoal Bay	Striae and channels
N.28°W.	1 mile west of head of Shoal Bay	Striae, channels, crescentic fractures
N.20°W.	$1\frac{1}{2}$ miles from head of Shoal Bay, along the west shore	Striae, channels
N.10°W.	East shore of Gull Pond, near Fogo-Seldom road	Striae
N.20°W.	200 yards east of bridge at bottom of Shoal Bay	Striae
North	1 mile east of head of Shoal Bay	Striae
N.12°W.	$1\frac{1}{2}$ miles west of Tilting	Striae
North	$1\frac{3}{4}$ miles east of head of Shoal Bay	Striae
N.45°W.	Gappy Islet	Striae, channels
N.40°W.	Seals Nest Islets	Striae
N.30°W.	Little Fogo Islands	Striae, channels
N.30°W.	Joe Batt's Arm, $\frac{1}{8}$ mile northeast of fish plant	Striae, channels
N.15°W.	Northeast corner of Wild Cove, 1 mile north of Tilting	Striae
N. 5°E.	East shore of Cape Cove, near village	Striae
N.55°W.	On south side of point on east side of Cape Cove	Striae, channels
North	North shore of Cape Fogo peninsula	Striae
N.15°W.	$\frac{1}{8}$ mile east of Olivers Cove, south of Tilting	Striae, channels
N.20°W.	Head of Olivers Cove	Striae
N.12°W.	On outside of point, south of Tilting	Striae, channels, crescentic fractures
North	South of the last houses on east side of Seldom harbour	Striae
N. 5°W.	Near harbour mouth of Seldom, west side	Striae, channels
North	Shore, 1 mile south of Island Harbour	Striae
N. 5°E.	Cape Cove	Striae
N. 5°W.	West side of mouth of Fogo Harbour	Striae
N.20°W.	North side of Western Indian Island, 2 miles from west end	Striae
N.20°W.	Western Indian Island, $\frac{3}{4}$ mile from west end; crossed by another set of striae at S.82°E.	Striae, channels
N.20°W.	Middle of the south side of Western Indian Island	Striae, channels, crescentic fractures
N. 5°W.	Change Islands, $1\frac{1}{2}$ miles south of Red Rock Cove	Striae
N.15°W.	Change Islands, west coast 1 mile north of south end	Striae
N.20°W.	East side of Change Islands, 1 mile north of south end	Striae
N.10°W.	North Change Island, east side	Striae
N.20°W.	North side of North Change Island	Striae
North	1 mile east of east end of Tickle of Change Islands	Striae
N.10°E.	1 mile east of east end of Tickle of Change Islands	Striae
N. 8°W.	Point of northeast corner of North Change Island	Striae
N.20°E.	East coast, North Change Island, 2 miles south of Tickle	Striae
N. 5°W.	$\frac{3}{4}$ mile north of Crow Head, east shore of Change Islands	Striae
N. 5°W.	$\frac{1}{2}$ mile north of Crow Head, east shore of Change Islands	Striae
N. 2°W.	Hare Island, southeast side	Striae
N.10°W.	All along outside of Fogo Head	Striae

General Geology

Rocks of the Fogo Island map-area comprise Ordovician and Silurian sedimentary and volcanic rocks and younger intrusive rocks that vary widely in composition.

The core of Fogo Island is a batholith of pink to grey microcline granite, which is cut by many dykes of various composition. The southern edge of Fogo Island is underlain by a complex of dioritic and gabbroic intrusive rock, which is intruded by granitic dykes. Remnants of a thick series of metamorphosed sandstone and shale with some volcanic members extend along the west and southwest coasts of Fogo Island and northward-dipping, altered sandstone and shale underlie a series of altered lavas and pyroclastic rocks on the peninsula on the northwest corner of this island.

Wadham Islands, all save Copper Island, in the southeast corner of the map-area consist largely of coarse, pegmatitic granite. Copper Island is underlain by dioritic and gabbroic intrusive rocks and remnants of digested sediments, all of which are cut by granitic dykes.

Two distinct rock groups underlie Change Islands. The south end of South Change Island is an anticline of massive quartzite and some phyllite and slate, and another anticline of the same quartzite and slate crosses the north-central part of this island. Between the two is a synclinal mass of coarse agglomerate, slaggy, red lava, and ash beds and similar rocks underlie the northern tip of South Change Island and all of North Change Island.

The part of Port Albert peninsula included in Fogo Island map-area is underlain by quartzite and phyllite along the south shore, and by lava and conglomerate on the north side.

Indian Islands, the southern Dog Bay Islands, and adjacent islands consist of slate, phyllite, quartzite, conglomerate, and thin limestone lenses of Silurian age. They are part of a large syncline of Silurian strata that extends southward beyond the map-area to include the rocks along the shores of much of Horwood (Dog) Bay and the islands in it. Two small islands that lie between the Indian Islands and the Dog Bay Islands consist of volcanic rock and conglomerate that resemble the rock found on the north side of Port Albert peninsula.

Table of Formations

Age	Name, and thickness in feet		Lithology
Devonian (?)	Fogo Island and Wadham Islands batholiths		Granite, alaskite; dykes
	Fogo diorite-gabbro complex		Granodiorite, diorite, gabbro, perknite, peridotite, etc.; dykes.
Silurian	Indian Islands group	10,000±	Principally phyllitic slate, quartzitic sandstone, calcareous sandstone; thin limestone lenses, conglomerate at bottom.
Ordovician (?)	Farewell group	3,000+	Red and green pyroclastic rocks, volcanic flows with interbedded quartzitic sandstone, slate and thick conglomerate; possibly wholly or partly equivalent to upper two formations of Fogo group.
	Fogo group	North End formation 5,000+	Rhyodacite, dacite, andesite, and coarse agglomerate; some conglomerate and red tuffaceous sandstone.
		South End formation 4,000±	Ripple-marked quartzitic sandstone, interbedded slate and quartzitic sandstone; grey and green slate.
		Brimstone Head formation 3,000+	Indurated tuff and agglomerate, lava, quartzitic sandstone, and slate.
		Fogo Harbour formation 5,000+	Ripple-marked quartzite, slate, and interbedded slate and quartzite; minor conglomerate, andesitic lava, and tuffaceous members.

Fogo Group

Ordovician rocks, whose relative ages are clear, that comprise two sedimentary formations separated and followed by formations of volcanic rocks, are grouped together and named the Fogo group. Volcanic and sedimentary rocks on Port Albert peninsula may well be the equivalent of the uppermost two divisions of the Fogo group, but because of uncertainty as to their age and relationships, they are treated separately under the heading Farewell group.

Fogo Harbour Formation

Definition. A series of quartzite and slate, with rare, interbedded, altered, volcanic rocks, underlies a series of indurated pyroclastic rocks and minor sedimentary rocks in the northwestern peninsula of Fogo Island. This succession of strata is here named the Fogo Harbour formation of the Fogo group.

The type section, more than 5,000 feet thick, extends along the shore from Fogo Harbour southwestward to the contact with the Fogo granite. Sedimentary rocks lithologically similar to and correlated with those of the type locality lie in irregular patches separated by granitic intrusions along the west and southwest shores of the island. The sedimentary and volcanic rocks on Cann Island off the south coast of Fogo Island and on the peninsula immediately adjacent to it, as well as small masses of quartzite and slate that occur as inclusions in the diorite-gabbro complex on the south side of Fogo Island, are tentatively included in the Fogo formation.

Description. A uniform series of quartzite and slate is exposed in monotonous succession along the shore southwest of Fogo Harbour. Massive beds of grey quartzite up to 20 feet thick stand out by differential erosion from alternating beds of quartzite and slate 2 to 6 inches thick that weather more easily and commonly underlie small coves. In some places the bedding is even thinner, with layers as little as ½ inch thick.

The quartzites may be buff, light or dark grey, green, or brown. In many beds the colour varies from place to place but in others a fine lamination is observed, with the individual layers less than ½ inch thick. In some of the massive units, crossbedding is visible through subtle colour distinctions. The quartzites are dense, recrystallized sandstones, with individual crystals of quartz averaging about ½ mm. in diameter. In some layers biotite and muscovite comprise as much as 10 per cent of the rock. Dark layers are generally richer in biotite than the prevailing light coloured quartzites, and are carbonaceous in places.

Lenses of conglomerate up to 2 feet thick occur at several places in the Fogo Harbour section. They are composed of angular and rounded fragments of quartzite and slate in a quartzose matrix.

The slates of the Fogo Harbour formation are very fine-grained, altered, clay rocks, and in places contain considerable quantities of quartz. They are commonly dark grey or black, but invariably have a light coloured streak. In places they are carbonaceous.

Throughout the type section along the northwest shore, oscillation-type ripple-marks are common (*see* Plate I A). In places they are perfectly preserved on bedding surfaces many square feet in area. Crossbedding is common in the more massive members of the series, and mud-cracks were observed at several localities. These features indicate that the tops of the beds in the Fogo peninsula section face north.

The sedimentary rocks bordering the coast along the west and southwest shores of Fogo Island are generally the same as those in the type section. In places, however, particularly massive quartzite beds were observed, such as the one that forms the point just north of the last houses of the village of Island Harbour on the west coast. There, a single quartzite layer is more than 100 feet thick. Crossbedding is conspicuous. In contrast with the twisted and contorted beds on either side, this massive member has resisted deformation during the intrusion of the adjacent granite mass. In addition, it has resisted sea erosion and weathering and stands now as a prominent headland.

In the northern part of the exposures on the west coast of Fogo Island, the sedimentary rocks occur in irregular patches intruded by granite. A complete gradation is visible, from rocks in which intrusive matter constitutes as little as 10 per cent of the complex to nearly pure granite in which are scattered xenoliths of the sedimentary rocks. Spectacular intrusion breccias of this kind occur in shore exposures about 1 mile north of Island Harbour. Many sills of fine-grained, pink, quartz porphyry intrude these rocks without visibly disturbing them (*see* Plate I B). These sills are most abundant south of Island Harbour and continue around the southwest corner of Fogo Island as far as Stag Harbour. Many small faults occur in this section.

The large island beyond Island Harbour is underlain by altered volcanic flows and interbedded sedimentary rocks. Dark green, sheared andesite, in which altered amygdules and remnants of vesicles are visible at some places, is interbedded with quartzites and slates.

Intrusion breccias, with fragments of sedimentary rocks, in a matrix of dioritic or granodioritic composition, occur north of Little Seldom Cove. The inclusions of quartzite, and slate and quartzite, range from a few inches to several hundred feet across.

The narrow peninsula on the east side of Little Seldom Cove is underlain by folded quartzites and slates with tuffaceous members, which probably form part of the Fogo Harbour formation. Their contact with the dioritic rocks on the north end of the peninsula is a zone of intrusion breccia.

The rocks of Cann Island resemble in some respects those of the Fogo Harbour formation but in other respects they are similar to those of Indian Islands, which are believed to be younger. They are, however, tentatively placed in the older formation as they contain interbedded lava flows, particularly on the west end of the island, which are not known in the younger rocks of Indian Islands. A succession of beds illustrating rhythmic sedimentation is exposed at one locality near the southeast corner of Cann Island. Individual beds are about 2 inches thick, and grade from coarse sandy material on one side to a muddy facies on the other.

Small remnants of much-altered sedimentary rocks that may possibly have been part of the Fogo Harbour formation occur in a low hill about 2 miles south of Joe Batt's Arm. The rocks occur as inclusions in the granitic rocks of the region. Contacts are razor-sharp with no evidence of ingestion or assimilation. The rock is recrystallized impure sandstone and is now a very fine-grained aggregate of quartz, feldspathic material and micas.

Remnants of similar type and correlation occur in the granite in a zone that extends from a point about 3 miles north of the head of Kippen Cove eastward nearly to the coast at the north side of the base of Cape Fogo peninsula.

Large inclusions of quartzite and slate occur in the dioritic rocks of southern Fogo Island on both sides of the cape that separates Kippen Cove and Wild Cove. These rocks, where recognizable, resemble those of the Fogo Harbour formation.

Alteration. The original sandstones of this formation are now dense, fine-grained, recrystallized quartzites. Flakes of biotite and muscovite indicate that metamorphism has reached the biotite-zone stage of Harker's classification (1939, p. 214). Even immediately adjacent to the main granite mass of Fogo Island there is no evidence of more intense alteration. The wide zone of fine-grained, alaskitic granite at the contact on the Fogo peninsula and the nature of the border facies suggest that intrusion took place at no great depth. Profound metamorphism of the sedimentary rocks would not be expected under these conditions.

The slates are soft and fine grained. The most abundant visible mineral is sericite. No trace of *knotenschiefer* or other indications of greater metamorphism were observed.

The original sediments of the Fogo Harbour formation were, without doubt, well-washed sands alternating with layers of mud, the whole receiving from time to time varying amounts of tuffaceous volcanic material.

Environment of Deposition. From the great abundance of ripple-marks, crossbedding, and mud-cracks, it is believed that the original sediments were laid down in shallow water. The fine clastic sandstone and shale, with occasional conglomerate, suggest that the region was not close to highland areas, nor was it far distant. The known thickness of more than 5,000 feet in the Fogo Harbour type locality, together with continuous shallow-water features, indicates that the area of deposition was a subsiding basin, and may have been the delta of a large river. The area of accumulation must have been near an area of volcanic activity as evidenced by the tuffaceous members in the sedimentary rocks and occasional lava flows. The apparent absence of organic remains cannot be explained.

Brimstone Head Formation

Northward-dipping lava flows, indurated pyroclastic rocks, and rarer quartzitic sandstone beds overlie rocks of the Fogo Harbour formation on the north end of the northwestern peninsula of Fogo Island. These rocks are here named the Brimstone Head formation.

The uppermost bed of the Fogo Harbour formation on the south side of Brimstone Head, is a thick, greenish, quartzitic sandstone. This is conformably overlain by a massive bed of fine-grained, indurated pyroclastic rock that forms Brimstone Head itself.[1] The weathered surface is light grey, which contrasts markedly with the dark grey or black of the fresh rock. The rock is very compact and breaks with a conchoidal fracture. Bedding is only faintly visible. In some places the rock is broken along closely spaced joints into sharp-edged, rectangular blocks that form treacherous scree slopes.

This basal member of the Brimstone Head formation directly overlies the uppermost bed of the Fogo Harbour formation on both sides of Fogo Harbour and along the west shore of Shoal Bay, but the same type of massive, indurated, pyroclastic rock also occurs higher up in the formation and, in some of these, the fragmental origin of the rock is more readily apparent than in the Brimstone Head locality. Weathered surfaces best exhibit the angular fragments of a variety of volcanic rocks which range in size from microscopic to 6 inches long. In some exposures many of the fragments are of vesicular lavas.

In thin section this pyroclastic rock is seen to consist of grains of quartz, feldspar, epidote, and irregular fragments of fine-grained lavas and unidentified rocks in an altered matrix. Micro-layering and micro-crumpling are conspicuous in both fragments and groundmass. The rock is full of dust-like particles of an opaque mineral that may be magnetite. The matrix is altered to a scaly aggregate that obscures details of the texture and structure. Quartz occurs as angular grains showing strain shadows and trains of inclusions. Scattered grains of microcline and plagioclase (An_{14-20}) are also present. Epidote is visible in small grains and as veinlets. In some places aggregates of epidote preserve ghost outlines of former crystals and fragments. Minute crystals of brown biotite and pale green chlorite form part of the groundmass.

Altered green lava and bedded pyroclastic rocks are common on the east shore of Fogo Harbour and vesicular facies are common on the islands east of its mouth. In places, as on the north shore of Fogo Head, veins of quartz containing orthoclase and epidote are characteristic.

The general trend of the rocks of this formation is easterly, except in the region of the Lions' Den, just east of the mouth of Fogo Harbour, where some faulting and deformation of the strata are in evidence. The rocks dip from 40 degrees north to vertically.

---

[1]This rock was termed hälleflinte in an unpublished report of Princeton University Geological Expedition to Newfoundland, 1916 (A. K. Snelgrove, personal communication).

South End Formation

A succession of quartzitic sandstone, banded arenaceous slate, and slates that occupy two belts on South Change Island are herewith named the South End formation. Rocks of this formation are also exposed on Woody Island, Hare Island, and on northern Dog Bay Island.

The rocks are exposed in two anticlines separated by a syncline of younger volcanic and sedimentary rocks, and trend northeasterly across South Change Island. The strata of this formation are probably about 4,000 feet thick, but an accurate estimate is difficult because of structural complications.

The quartzitic sandstones in this formation are thick bedded and total as much as 200 feet on the west side of the island south of Long Point and on both sides of the island on the crest of the southern anticline. They are well-washed, grey or white, quartz sandstones that have been partly recrystallized.

Finely banded grey and green quartzites, similar to those of the Fogo Harbour formation, occur in the shore exposures at several places. The quartzites are very fine grained, with little variation in grain size but with distinct colour differences from layer to layer. They show graded bedding in some exposures along the west shore of the island near Red Rock Cove. Massive, sandy bottom zones grade within 1 foot into upper fine-grained slaty zones, which show well-developed slaty cleavage. Ripple-marks and crossbedding are common on the west shore of the island south of Long Point. One brown quartzite bed on the east shore of the island near Crow Head was found to contain fragments of brown shale, indicating that some erosion was contemporaneous with deposition. Reddish and brownish quartzites are common midway along the east shore of the island, just south of the contact with the youngest volcanic rocks. Conglomerates with rounded fragments of quartz and igneous rocks up to 1 inch in diameter also occur on the east shore of the island and increase in abundance towards the contact with overlying volcanic rocks.

The slates of the formation are fine grained and micaceous with well-developed cleavage, and are commonly folded and traversed by numerous joints. In some outcrops lenses of conglomerate in the slates contain pebbles of white vein quartz up to 1 inch in diameter. In some places the cleavage is parallel with the bedding and in others oblique to it. Numerous drag-folds are characteristic.

On Bishops (Little Fogo) Islands grey and green sandstone, and bedded fine-grained tuffs occur on the southeastern Seals Nest Islets, and occur also on Steering, Long, and Stone Islands. These rocks are thought to belong to the South End formation because of their similarity to those of the type section and because of their position conformably below rocks that appear to belong to the North End formation. The boundary between the two groups is well exposed on two of the principal Seals Nest Islets where heavy, coarse, red agglomerates conformably overlie red, pink, grey, and grey to green, crossbedded sandstones with tuffaceous members. A dyke of intermediate composition cuts the lower sedimentary group almost directly across strike, on the southwestern of the two islands that show the contact, but stops abruptly at the contact with the agglomerate.

The strata dip from 40 degrees to 70 degrees to the northwest and strike generally northeasterly, but, on Stone Island at the southwest end of the island group, sandstones of the South End formation dip to the southeast at 65 degrees, showing that the rocks there are on the south limb of an anticlinal structure or are, perhaps, part of a drag-fold.

The contact between the volcanic North End formation and the sedimentary South End formation strikes northeasterly from Seals Nest Islets and should lie north of the main cluster of Little Fogo Islands. But as the latter are composed of volcanic rather than sedimentary rocks, submarine faulting is suspected.

North End Formation

A succession of lava flows, coarse agglomerate, conglomerate, and interbedded sedimentary rock are here named the North End formation. This formation is best exposed on the north end of South Change Island and on North Change Island. Similar rocks occupy a synclinal basin that extends across the middle of South Change Island and outcrops widely in the small islands north of Fogo Island. Rocks on Port Albert peninsula and on the islands to the northeast are also similar, but are mapped separately, pending a more accurate correlation.

Coarse agglomerates are the most common rocks of this formation. They consist of large, sharp, angular fragments, stained red, cemented by a hematite-rich, tuffaceous matrix. The fragments average from 8 inches to 1 foot long but may be as much as 3 feet long. They consist of red sandstone, arkose, and massive, red, green, grey, and black lavas, including both vesicular and porphyritic types. The matrix consists of red-grey arkosic sands and tuffaceous material. These coarse fragmental rocks must have accumulated close to centres of violent volcanic activity.

Conglomerates occur widely through this volcanic division. The fragments are of the same general composition as those in the agglomerates, but in the conglomerates are well rounded and clearly water worn. The sandy and tuffaceous matrix exhibits crossbedding, and in general is lighter coloured and more thoroughly sorted than in the agglomerates.

The lavas of the North End formation are thick, massive flows. In most exposures they are reddish or red to grey, although green and other colours were observed. Porphyritic and vesicular facies occur widely but no pillow structures were seen except on the east shore of South Change Island, about 1 mile [illegible] of Crow Head. Columnar jointing, with polygonal columns about 1 foot in diameter, is well developed on the west coast of South Change Island about a mile north of Deep Cove.

A thin section study of the lavas disclosed the presence of rhyodacites, dacites, and andesites. One rock from the east shore of South Change Island is a coarse porphyry, with subhedral to euhedral phenocrysts of plagioclase feldspar as much as 2 inches long, embedded in a dense, reddish, fine-grained groundmass. Under the microscope, the groundmass appears as a microcrystalline aggregate in which microlites of plagioclase feldspar and minute crystals of untwinned plagioclase and quartz are visible. Finely divided, opaque mineral grains, probably of hematite and magnetite, occur throughout the rock. These minerals also occur through the rock in clumps and clots as much as 1½ mm. in diameter. In part the rock is nearly opaque, and consists of microlites of feldspar in a matrix of very finely divided hematite and magnetite. The large euhedral and subhedral phenocrysts are andesine (An_{38}) without much evidence of zoning. They commonly exhibit Carlsbad and albite twinning. Calcite occurs throughout the rock in large patches and as fine-grained aggregates scattered through the groundmass. Chlorite is present in small masses that show radial extinction, and there is minor epidote and fine-grained intergrowths of feldspar and opaque minerals. A fine-grained scaly alteration product occurs throughout the rock and obscures much of the original texture.

Another rock from the same locality is a fine-grained red lava with visible phenocrysts less than ¼ inch long. The groundmass of this rock was seen in thin section to be microcrystalline with linear clots of opaque minerals, mostly hematite with some magnetite. Quartz occurs as phenocrysts and as irregular aggregates with conspicuous perlitic fractures that are commonly filled with finely divided hematite. Unzoned phenocrysts of plagioclase feldspar (An_{30}) are as much as 1½ mm. long. The groundmass is obscured by a scaly alteration product in which calcite and sericite are recognizable. Simultaneous extinction over small areas of apparently discontinuous microcrystalline groundmass suggests either skeletal crystallization or completely altered phenocrysts. Minute veinlets of quartz, and quartz and calcite are commonly less than ½ mm. wide. Apatite and epidote are accessory minerals.

Fine-grained, reddish rhyodacite was observed at several horizons. In hand specimens, reddish phenocrysts of quartz and plagioclase can be seen in a very fine-grained, red to grey groundmass. In thin section the groundmass is seen to consist of a meshwork of unidentifiable microcrystals, which may be plagioclase feldspar, and abundant grains of opaque minerals which are mostly hematite with some magnetite. Phenocrysts of plagioclase feldspar (An_{25}) as much as 3 mm. long are commonly covered with a scaly alteration product. A few exhibit Carlsbad and albite twins. Quartz phenocrysts as much as 5 mm. in diameter commonly show abundant perlitic fractures, most of which are filled with fine-grained hematite. Some of the quartz grains show a fine lamellation, which may be the result of inversion from high- to low-temperature quartz.

Green rhyodacite from the same locality carries light coloured phenocrysts, with indistinct edges, in a fine-grained, green groundmass. In thin section, an irregular flow-banding is conspicuous. Phenocrysts of plagioclase feldspar (oligoclase), with faint albite and Carlsbad twinning, as much as 3 mm. long, grade imperceptibly into the groundmass. Some of the phenocrysts are rimmed with an extremely fine-grained aggregate of quartz and feldspar, which also occurs as irregular clots in the interiors of the larger crystals. No trachytic texture is visible except around the ends of some of the phenocrysts, where a rudimentary flow arrangement of the microlites appears. Chlorite occurs in elongated masses up to 2 mm. long and also as tiny shreds throughout the groundmass. Small scattered grains of epidote are also present.

Bright red, rhyolite-like lava members are composed of a microcrystalline aggregate in which no minerals are readily identifiable. Flow lines marked by aggregation of dust-like particles of opaque minerals (hematite and magnetite) are conspicuous.

Sedimentary members of the North End formation are exposed in a few places. Bedded, water-worked pyroclastic rocks outcrop on the northeast corner of South Change Island. Bright red, banded sandstones and water-worn conglomerates are exposed on the east side of this island just south of the northern contact, between this and the underlying division of the Fogo group. Ripple-marks and ribbing are common, and rain-prints occur widely in one layer. Mud-cracks were also observed. The rocks consist of muddy sands with mica-rich partings. Conglomerate occupies channels cut into the banded micaceous sandstone in one place. Beds of tuffaceous, quartzitic sandstone as much as 10 feet thick were observed in the synclinal belt in the middle of South Change Island and in the exposures on the north end of the island.

The Bishops or Little Fogo Islands, Turr Islets, Storehouse Islets, Countryman and Gappy Islets, and the northwestern Seals Nest Islets afford a spectacular display of volcanic agglomerates and breccias, flows and tuff beds. Exposures along the shores are subjected to intense wave erosion so the rocks are everywhere fresh and very well exposed. The rocks dip northwestward at 40 to 70 degrees and strike uniformly northeast. Individual units are lenticular as would be expected in a region of active vulcanism. The agglomerates, filled with boulders as much as 5 feet in diameter, grade from rough, chaotic accumulations of angular chunks, to partly stratified and sorted deposits of partly water-worn and partly rounded fragments, and thence into true conglomerates. In many of the agglomerates the fragments show a strong discoloration around their rims. The agglomerates vary from grey to greenish and reddish grey. The conglomeratic sediments are largely red beds, fragments being much stained with hematite. Lava flows are red to green, slaggy to massive and featureless. Very fine-grained, dense, pale green to yellowish grey lava that breaks with conchoidal fractures is common. Surfaces show faint flow banding in a few places but little internal structure is visible except for occasional knots of dark green material of vague outline. Slaggy lavas with phenocrysts of altered feldspars faintly outlined against a reddish grey groundmass are also exposed on some of the islands. The whole sequence is correlated with the North End formation of the Fogo group, which it resembles in broad description and with which it is directly on strike.

Rocks of the North End formation conformably overlie the rocks of the South End formation of the Fogo group; contacts that show this relation are exposed at several localities. On the west side of South Change Island the contact is well exposed south of Long Point. Tops of beds are to the north in rocks of both formations within a few hundred feet of the contact. The same relation was observed at exposures of the same contact on the eastern shore of the island. The contact north of the synclinal axis is exposed intermittently along the west coast for about a mile with normal conformable relations.

Rocks of the North End formation exposed on the north end of South Change Island and on North Change Island show a general easterly trend and dip either steeply north or vertically. They appear to overlie the northern flank of an anticline in the South End formation.

Age of the Fogo Group

The great abundance of volcanic rocks in the Fogo group strongly suggests that it is of Ordovician age as the Ordovician was a period of considerable volcanic activity in parts of central Newfoundland. Silurian rocks of the Indian Islands group appear to overlie Fogo group rocks of Fogo Island, but this relationship is not definitely established. In other parts of northeastern Newfoundland, the Silurian is almost devoid of volcanic rocks, making a Silurian, pre-Indian Islands age for the Fogo group most improbable. Therefore, the writer considers the rocks of this group to be of Ordovician age.

Farewell Group

The term Farewell group is here proposed for an assemblage of lava flows, slate (*see* Plate II B), phyllite, quartzite, conglomerate, and breccia that occurs on Port Albert peninsula, in the southwest corner of the Fogo Island map-area.

The rocks of the Farewell group include those described in a measured section at Port Albert by Twenhofel (1947, pp. 68-70). His section comprises more than 2,000 feet of alternating volcanic and sedimentary rocks cut by numerous dykes. The sedimentary rocks comprise quartzite, argillite, slate, indurated conglomerate, and greywacke. The volcanic rocks are largely greenstones that formed through alteration of andesites and basalts. Some of the flows are vesicular and amygdaloidal, and some are associated with finely bedded, pyroclastic rocks. For a detailed description of the succession the reader is referred to Twenhofel.

Greenstones and finely bedded pyroclastic rocks underlie the shore along the northwest coast of Port Albert peninsula. There, cleavage commonly cuts across the bedding of the pyroclastic rocks. A prominent zone of conglomerate, which corresponds to Twenhofel's zone 37 (1947, p. 69), forms most of the long island that parallels the coast near the northeastern tip of the peninsula. The pebbles and cobbles in the conglomerate are mainly of quartz, quartzite, and flint, with a few light grey granite fragments. A few pebbles of fine-grained volcanic rocks were also observed. Imbricate structure of flattened, discoidal pebbles and crossbedding were observed in some outcrops. A zone of slates and phyllites that underlies the conglomerate is exposed on the northwest side of the island. Dips are uniformly southeastward.

Several lava flows and beds of sedimentary rocks overlie the conglomerate mentioned above in the section exposed across the end of the peninsula. Most of the lavas are altered to greenstones, except at one locality on the northeast corner of the mainland where a flow of red, slaggy lava some 40 feet thick outcrops. In some zones this lava contains abundant vesicles and amygdules. It resembles closely the rhyodacites of the North End formation on Change Islands. Immediately above and below it are reddish and greenish pyroclastic and slaty rocks.

Massive quartzitic sandstone forms most of the shoreline of Farewell Harbour. The centre line of Farewell Harbour coincides with the axis of a syncline that is thought to be a small fold on the flank of a larger, regional syncline that underlies Horwood Bay to the south.

Exposures of quartzite, slate, and phyllite alternate along the shore of Horwood Bay southward from Farewell Harbour. Rare layers of conglomeratic quartzite and greenstones also occur. Numerous outcrops of granitic intrusive rocks were observed along the shore, the largest mass forming a prominent point and ridge that extends inland in a southwesterly direction.

Grey quartzites occur on Indian Garden and East Garden Islands. Reddish slaggy volcanic rocks and greenstones, together with conglomerates and quartzitic sandstones similar to those on the end of Port Albert peninsula, comprise the Farewell Duck Islands.

The rocks of the Farewell group resemble in many respects the rocks exposed on Change Islands. Reddish, slaggy lavas and coarse conglomerates, which occur on the end of the mainland peninsula and on the Farewell Duck Islands, are similar to those of the North End formation. The massive quartzitic sandstones and slates of the Farewell Harbour district resemble those of the South End formation where they are exposed on the north side of the southern anticline on South Change Island. On the other hand, the rocks of the southernmost exposures on the shores of Horwood Bay in this map-area are similar to those of the Indian Island group of the southern Dog Bay Islands.

Age of the Farewell Group

Silurian rocks in this part of Newfoundland are largely of sedimentary origin, whereas the Ordovician formations are characterized by abundant lava flows and pyroclastic rocks. For this reason the Farewell group is considered to be probably of Ordovician age. Silurian rocks are known to occur at several places in the Horwood Bay district, both on the mainland and on the islands, but the boundary between them and rocks of Ordovician age on the shores of Horwood Bay is not readily identified. Twenhofel suggested that the contact is on the south side of Squash Cove, to the south of Fogo Island map-area, because of the disappearance of lava flows from the section south of this line, and because of the presence of what may be the sheared basal Silurian conglomerate (1947, p. 75). To the writer these are not reliable criteria, as many conglomerate members are interbedded with the slates within a stratigraphic interval of 2,000 feet on the north side of Western Indian Island near the base of the known Silurian rocks. The occurrence, too, of a single lava flow on the middle Dog Bay Island, in rocks that are most probably of Silurian age, casts some doubt on the validity of drawing the Silurian-Ordovician boundary on the basis of presence or absence of volcanic rocks. There is, indeed, no great lithological difference between the rocks of the southernmost Dog Bay Island, which are known to be Silurian, and the rocks on the mainland along the shore of Horwood Bay in the Fogo map-area.

Until details of the rock structure to the southwest are better known, the writer prefers to consider the age of the northern exposures of Port

Albert peninsula to be Ordovician but the age of the rocks to the south, uncertain. There is, however, little doubt that the boundary between the Ordovician and the Silurian occurs somewhere along the shore of the Farewell peninsula, perhaps in the extreme southwest corner of Fogo map-area.

The lithological similarities of rocks of the Farewell group and those of the North End and South End formations are apparent. The Farewell group possibly comprises rocks that are wholly or in part their equivalents. Indeed, the Farewell and Fogo groups possibly are equivalent and each may have a dominantly sedimentary lower part and a dominantly volcanic upper part, with the sharp variations from place to place that one would expect in a region of violent but local volcanic activity. However, the writer prefers to consider them as separate units because of their geographic separation and distinctive lithologies.

Indian Islands Group

The name Indian Islands group is proposed for Silurian rocks exposed on the Indian Islands, Grandfather Island, Yellow Fox Island, Goose Island and the southern Dog Bay Islands. Southwest of the map-area similar rocks outcrop along the shores of Horwood Bay and extend in a southwesterly direction (Patrick, 1957).

These rocks were first described by Murray and Howley of the Geological Survey of Newfoundland in 1872, in the course of an exploration of Exploits Bay, Gander Bay, and the surrounding district. A resumé of the Silurian rocks of northeastern Newfoundland was published by Twenhofel and Shrock (1937), and Twenhofel in 1947 published the results of several years' field work. During the summer of 1946 the writer was fortunate in being able to accompany Dr. Twenhofel on visits to Western Indian Island and Yellow Fox Island.

The base of the Indian Islands group is exposed along the north coast of Western Indian Island, and the top of the group on Eastern Indian Island, on Yellow Fox Island, or, perhaps, on Goose Island, some miles to the southwest. The rocks of the group dip from vertical to 80 degrees south and strike nearly east-west, except on Goose Island, southernmost Dog Bay Island, and small islands southward in Horwood Bay, where the regional trend begins to follow the synclinal pattern noted farther south in Horwood Bay. Correlation between the islands is subject to the hazard of undetected submarine faults and resultant duplication in, or subtraction from, the section. Lateral variation in the beds is so marked that correlation on the basis of detailed sections is not reliable.

Rocks of the Indian Islands group comprise slate, phyllite, quartzite, conglomerate, and minor limestone. Conglomerates are more common near the base of the section than elsewhere and limestones are more common near the top.

Beds that are possibly uppermost in the group are exposed on the shores of Yellow Fox Island. There the section consists of about 900 feet of grey slate and phyllite, with a few interbedded lenses of quartzitic sandstone. Lenticular masses of dense, tough, greyish rock, which are enclosed by the slates and phyllites, are thought to be mashed remnants of dykes. They are particularly abundant on the west end of Yellow Fox Island, but were seen at several places on Western Indian Island. Silurian fossils have been collected from some of the sandy beds and from limestone lenses in the slate on the west end of Yellow Fox Island. They are much sheared and deformed but clearly establish the Silurian age of the enclosing rocks (Twenhofel, 1947).

Grey slate and phyllite are the most common rocks on Eastern Indian Island, and the exposed section is about 5,000 feet thick. Some limestone beds up to 10 feet thick occur on the south shore. They now consist of coarsely crystalline, yellow or grey calcite, which weathers to a pebbly surface. One limestone layer was found to include tiny fragments of red chert and vein quartz. No traces of organic remains, except possible crinoid stems, were found. In some localities on the south coast of Eastern Indian Island, brown weathering limy sandstone is now largely altered to calcareous quartzite.

On the north side of Eastern Indian Island several beds of massive quartzite are exposed along the shore. Bands, in places as thin as $\frac{1}{10}$ inch marked by differences in the proportions of quartz to mudstone matrix occur in some beds. Quartz veins that follow the foliation of the slates are common in one place on the east end of the island. Numerous minor faults that displace and distort beds are visible in the shore sections. It is improbable that these have resulted in many beds being duplicated or omitted.

The uppermost beds on Eastern Indian Island lie directly along the strike of the lowermost beds of Yellow Fox Island. It thus appears that, if no faults intervene, the rocks of the Eastern Indian Island section directly underlie those of Yellow Fox Island.

Slate and phyllite are the most common rocks on Western Indian Island. Limestones are lacking, and sandy and conglomeratic facies increase as the bottom of the section is approached on the north side of the island. Many sills of fine-grained igneous rock occur. On the east end of the island, these sills are broken and squeezed to form lenses around which the folia of the slates are alined in much the same manner as on Yellow Fox Island. Along the north coast of the island the intrusions are more massive and are more obviously granitic.

In the northern part of the island as much as 30 per cent of the section is composed of conglomerate, containing fragments of quartz, slate, quartzite, red lava, and dark volcanic rock up to 4 inches in diameter. The fragments are commonly flattened parallel with the bedding. In places the conglomerate grades laterally into the more sandy rock and in others it appears to occupy channels in it.

The channel that separates Eastern Indian Island from Western Indian Island could possibly contain a fault. The bottom is flat over most of the submerged area, but has a sharply outlined deeper channel down the middle. This may represent an eroded fault zone or may be a pre-submergence consequent stream channel.

The total thickness of the Indian Islands group is apparently about 10,000 feet, but as little is known of the structure between the islands, strata may be duplicated or omitted. The best exposed sections are at the west end of Yellow Fox Island and the east ends of Eastern Indian and Western Indian Islands.

Age of the Indian Islands Group

Some 3,500 feet of slate and phyllite, with some quartzite and limestone lenses, are exposed on the southernmost of the Dog Bay Islands. The slates are commonly grey, with a pearly lustre, but may be black or brown. One limestone bed, 4 to 6 feet thick, outcrops near the southwest corner of the island. It is much crumpled and contorted, but contains recognizable fragments of crinoid stems. Beneath this limestone bed, to the north, a series of brown weathering, papery phyllite and slate contains lenses of limestone up to 4 inches thick and 3 feet long. These lenses carry fossils that have been identified by Twenhofel[1] as *Favosites* sp., *Heliolites* sp., *Clathrodictyon* (?) sp. and *Streptelasma* sp. They show that the rocks of the group are of early Silurian age.

The rocks of the middle island of the Dog Bay Islands are similar to those of the Indian Islands section except that on the east coast 40 feet of red lava and pyroclastic rock are exposed. At one locality the slate contains quartz pebbles in a fine-grained slaty matrix, with the slaty cleavage wrapped around the pebbles. The north end of the island is composed of a thick sill of fine-grained, red, quartz porphyry.

---

[1]Twenhofel, W. H. (personal communication).

There is, thus, little doubt on lithological grounds that the rocks of the southernmost and middle Dog Bay Islands are of Indian Islands strata. It is also significant that the Dog Bay Islands lie directly on the strike of the main Indian Islands exposures, even though two small islands that lie between are formed of older volcanic and sedimentary rocks. These islands may owe their present position to local faulting.

Northern Dog Bay Island

The northernmost of the Dog Bay Islands is composed largely of fine-grained intrusive rocks of granitic composition, with numerous dark dykes of diabase and lamprophyre. Banded quartzites outcrop in several patches, and in one belt that extends across the middle of the island. They are similar to rocks of the Fogo Harbour and South End formations in colour and in the common occurrence of ripple-marks, which have not been found in rocks of the Indian Islands group.

Structure of the Indian Islands Group

The tops of the Indian Islands beds exposed in the Indian Islands sections face south, and dips are consistently southward where not vertical. Conglomerates are more abundant towards the base or north side of the group than elsewhere, and limestones are most common towards the top. Fine-grained phyllites and slates make up the bulk of the group in the middle and upper parts of the exposed sections.

Numerous drag-folds on the south side of Eastern Indian Island suggest that an anticline lies to the north and a syncline to the south. The distribution of the formations in Horwood Bay further suggests that the Silurian rocks of the district occupy a synclinal basin, the axis of which lies to the south of the Indian Islands.

Intrusive Rocks and Economic Geology

Fogo Island Granite Batholith

A granite batholith is exposed over an area of about 75 square miles on Fogo Island. It is everywhere well exposed except on the southwest part of the island where it is covered with heavy forest and some glacial drift. Higher parts of the granite mass are devoid of vegetation or only scantily covered.

The rock is characteristically a pink, medium-grained granite that weathers grey, buff, or light brown. Exposed parts of the mass are considerably weathered to produce arkosic sands which collect in hollows alongside the ridges. As a result of weathering, glacial markings are rare except along the seashore and in places where the drift cover is being freshly stripped from the rocks by streams.

Medium-grained facies of the granite are the most common and no notably coarse-grained rock was observed. Fine-grained facies occur along the margins of the mass, particularly along the west shore of the northwestern peninsula. The granite consists of potash feldspar, either microcline or orthoclase, quartz, albite, biotite, and hornblende, with minor accessory minerals.

In thin section pink or yellowish grains of orthoclase or microcline are seen to be from 1 to 5 mm. long. In some specimens they are interstitial, and in others they appear as discrete crystals of euhedral outline. Almost all of them are traversed by numerous veinlets of albite. Perthitic intergrowths are common in some facies and lacking in others. Quartz comprises from 20 to 45 per cent of the rock, and occurs as grains and masses up to 5 mm. in diameter. Strain shadows and Boehm lamellae are common. Some of the quartz crystals carry trains of opaque inclusions, others contain fluid inclusions with microscopic bubbles in a state of constant motion. The quartz is interstitial to the feldspar crystals. Albite or oligoclase occurs as scattered subhedral crystals.

A specimen of unfoliated, medium-grained granite from a point on the east shore 1 mile north of the head of Hare Bay consists of quartz, albite, microcline, biotite, and accessory minerals. The microcline occurs in crystals up to 4 mm. long which show well-developed grating-structure. It is commonly veined by late-stage albite, and some crystals are covered with a scaly alteration product. Large Carlsbad twins are common, and most of them are subhedral. Albite (An_{10}), showing albite twinning, occurs in irregular interstitial grains up to 2 mm. long. Quartz forms grains of irregular outline, with rows of inclusions, some of which are fluidal. Myrmekitic intergrowths occupy some interstitial spaces. Biotite, pleochroic in yellow-brown colours, occurs as irregular wisps and shreds, and may exhibit bent lamellae. It is partly altered to pale green chlorite. Magnetite fills fractures in the biotite and also occurs along cleavage lines. Common green hornblende is an accessory mineral.

A specimen of granite from the Fogo-Seldom road, about ½ mile north of the granite-diorite contact, is a coarse-grained aggregate of yellowish feldspars and clear grey quartz. Orthoclase forms about 55 per cent of the rock and is perthitic or veined with late-stage albite. A scaly alteration product covers many of the grains. Quartz composes about 25 per cent of the rock. It shows lacy, mosaic-like boundaries, abundant strain shadows, and trains of inclusions. Microcline, with grating-structure, and plagioclase (An_{12}) are present as scattered, subhedral grains. Biotite, which is pleochroic in straw-yellow and red-brown, is much twisted and broken, and contains numerous inclusions of magnetite. Green hornblende with an extinction angle of 20 degrees, vermiform myrmekite, sphene, zircon, apatite and epidote are accessory minerals.

Faintly foliated granite from the outside of Joe Batt's Point consists of quartz about 40 per cent; feldspar, 50 per cent; and dark minerals, 10 per cent. The quartz occurs in masses up to 8 mm. in diameter, and shows abundant Boehm lamellae and trains of inclusions. Some crystals appear to be partly resorbed, giving them spidery outlines with interstices filled with a fine scaly aggregate, apparently derived from the alteration of feldspar. Zoned crystals of plagioclase are highly altered. Microcline is veined with albite, and is interstitial to the altered plagioclase. Green hornblende, with an extinction angle of 21 degrees, constitutes about 7 per cent of the rock. Biotite flakes commonly show abundant needle-like inclusions and pleochroic haloes. Epidote, apatite, and magnetite are common accessory minerals.

Microcline granite facies from the north side of Cape Fogo consist of microcline, about 55 per cent; quartz, 30 per cent; biotite, 10 per cent; and accessory minerals. Quartz, with trains of opaque inclusions and some fluid inclusions, occurs in unstrained masses as much as 2 mm. long. Microcline is in crystals up to 3 mm. long and shows Carlsbad twins and grating-structure. Perthitic intergrowths are common and myrmekite occupies some interstitial areas. Straw-yellow to reddish brown biotite shows twisted lamellae and abundant pleochroic haloes, and is partly altered to chlorite. Green common hornblende, epidote, zircon, apatite, and magnetite are accessory minerals.

At the head of Shoal Bay, several dykes of light coloured granite with an average grain size of 1½ mm. occur among the shore exposures, and are not unlike the granites they intrude. Dark minerals are disseminated pepper-like in the rock. In thin section, the rock is seen to be a micropegmatitic granite. Perthitic feldspar crystals up to 2 mm. long commonly show Carlsbad twins. Albite (An_{6-8}) is accessory in irregular grains. Quartz, in grains up to 1½ mm. in diameter, is commonly strained, and contains trains of inclusions. Aggregates of quartz and orthoclase in graphic intergrowth comprise as much as 30 per cent of the rock. The feldspar of the intergrowths is generally slightly altered to a cloudy aggregate, whereas the quartz grains remain clear.

A fine-grained, light brick-red alaskitic border facies of the granite is exposed in a belt just south of the outcrops of the Fogo Harbour formation and north of the main mass of Fogo granite. The bright red belt continues across Hare Bay and makes Hare Bay Head a prominent landmark.

In thin section the rock is seen to consist almost entirely of intergrowths of orthoclase feldspar and quartz. The manner of intergrowth varies from that of angular, cuneiform, graphic granite to rounded blebs of quartz in feldspar, the latter altered to a scaly aggregate. Quartz also occurs as scattered, clear grains up to 1 mm. in diameter. Clumps of chlorite are scattered through the rock in association with magnetite. Some grains of albite (An_{10}) were observed, and show dim outlines of albite twins through a thick scaly alteration product. Accessory minerals include sphene, epidote, hornblende, hematite, and magnetite. It is possible that this red, fine-grained facies is later than the main granite to the south and that it is closely related to the dykes and sills so common in the western part of Fogo Island and the small islands in the southwest.

The rocks that border the Fogo granite do not show strong metamorphism (*see* Plate II A). The quartzites and slaty shales of the Fogo group in the northwestern peninsula and along the southwest coast of the island exhibit the same degree of metamorphism at the contact as they do in the most distant exposures. Where small masses of granite and granite porphyry intrude Fogo group rocks, no change is noticeable at their contact. The Fogo Island batholith presumably raised the general temperature of the surrounding rocks but brought about little more than some recrystallization and reorganization of the original mineral constituents.

The granite of the Fogo Island batholith rarely shows marked foliation, but some alinement of linear minerals and a parallelism of platy minerals have produced a broad foliation. The fine-grained, red facies on the northwestern peninsula is homogeneous, and displays no visible banding or parallelism of minerals.

The mode of intrusion of the granite mass is not certain. The contact of the granite with rocks of the Fogo group on Fogo peninsula is concordant, but this structure contrasts sharply with that of exposures on the west coast of the island where intrusion breccias and crumpled and twisted strata riddled by granitic intrusions occur all along the contact. With the evidence at hand it may only be stated that the granite mass is concordant in some places and has crosscutting relations in others.

Wadham Islands Granite Batholith

A distinctive type of porphyritic granite forms all the Wadham Islands except Copper Island, but is not known in Fogo Island map-area proper. This granite is similar in some respects to that exposed along the coast of the mainland south of the map-area, from Musgrave Harbour to the southwest corner of Bonavista Bay, and it may be that the Wadham Islands granite batholith is a northerly extension of a much larger body that occurs on the mainland.

The Wadham Islands rock is a very coarse-grained porphyritic, microcline granite. Phenocrysts of microcline and orthoclase as much as 6 inches long are set in a groundmass of small crystals of potash feldspars, quartz, and mafic minerals, the last occurring as clots and irregular masses about ½ inch in diameter. Accessory sphene, magnetite, and pyrite are readily discernible in hand specimens. Fresh exposures of this granite along the shores of Wadham Islands sparkle brilliantly in direct sunlight.

In thin section the microcline crystals show fine to medium grating-structure and orthoclase crystals commonly exhibit perthitic intergrowths. Tear-drop myrmekite occurs sparingly and albite, in irregular masses, is faintly zoned in some crystals. The average composition of the plagioclase is about An_8, with cores as calcic as An_{12}, and margins about An_6. Quartz, in masses up to an inch long, show Boehm lamellae and trains of inclusions. Biotite is the only abundant mafic mineral. Numerous crystals of accessory apatite occur within and adjacent to the biotite flakes. Other accessory minerals are sphene, in masses as much as 4 mm. long, magnetite, pyrite and epidote. Alteration products include small quantities of a scaly aggregate on the feldspars, including some visible sericite, and rare chlorite after biotite.

Foliation was lacking in the outcrops of the Wadham Islands granite observed. Massive porphyritic granite, jointed in large blocks, apparently extends without a break across the islands.

Barrack Islands Monzonite

The Barrack Islands, which lie southeast of Little Fogo Islands, are formed of medium- to coarse-grained quartz monzonite. This rock consists of pink orthoclase in Carlsbad twins, yellow-white, altered plagioclase, and glassy quartz grains, in about equal proportions. Accessory minerals visible in hand specimens include magnetite, biotite and unidentified dark grey to green masses of irregular outline which may be hornblende. These rocks probably belong, in a general way, to the granitic complex of the Fogo Island batholith.

Diorite-Gabbro Complex

Rocks more basic than granite occupy a considerable part of Fogo Island map-area. The largest area covers about 12 square miles and lies along the south coast of Fogo Island. Another body occupies about 1 square mile in the neighbourhood of Tilting on the east coast of the island.

The rocks of the diorite-gabbro complex have a wide range in chemical and mineralogical composition. They include granodiorite, quartz diorite, diorite, quartz gabbro, gabbro, hornblende gabbro, quartz-bearing perknite, and hornblende-rich peridotite. They share in general one characteristic; all are rich in silica and deficient in alkalis.

The most abundant rock type is quartz diorite. Average specimens consist of zoned plagioclase feldspar, about andesine in composition, crystals of green hornblende with commonly a core of augite, brown biotite, interstitial quartz, and accessory minerals.

Dense, grey, fine-grained diorite from the end of the point between Kippen Cove and Wild Cove on the south coast of Fogo Island consists of plagioclase feldspar about 50 per cent; hornblende about 15 per cent; quartz, 10 to 15 per cent; chlorite, 10 per cent; biotite, 5 per cent; and accessory minerals and alteration products. Subhedral crystals of plagioclase feldspar up to 3 mm. long, show rhythmic zoning, with cores about An_{40} and margins An_{24}. Some of the crystals are covered with a scaly alteration product in which some sericite and epidote are recognizable. Quartz grains, which are everywhere anhedral and interstitial, show abundant trains of inclusions and strong strain shadows. Biotite contains abundant magnetite. Green hornblende, partly altered to chlorite and biotite, occurs in clumps of irregular anhedral grains. Accessory minerals include epidote, magnetite, and apatite.

Fresh, grey, fine-grained diorite from the east side of Kippen Cove consists of plagioclase feldspar, about 45 per cent; hornblende, 35 per cent; biotite, 10 per cent; quartz, 10 per cent; and minor accessory minerals. Plagioclase feldspar, in irregular subhedral crystals, has an average composition of about An_{38} and shows little evidence of zoning. Common green hornblende, with cores of colourless augite and inclusions of magnetite along cleavage lines, occurs in irregular grains and clumps of grains up to 2 mm. in diameter. The biotite has a strong reddish brown colour. Quartz occurs in interstitial grains, which show strong strain shadows and trains of inclusions. Accessory minerals include magnetite, chlorite, epidote, apatite, and sphene.

Quartz diorite, with an average grain size of about 3 mm., occurs on the point on the north side of Sandy Cove, ½ mile north of Tilting. It consists of crystals of white plagioclase feldspar with sharply contrasting clots of black mafic minerals. In thin section, about 50 per cent of the rock is seen to consist of zoned crystals of plagioclase feldspar, with cores of An_{38} and margins of about An_{24}. A scaly alteration product covers many of the feldspar crystals. Green hornblende occurs in subhedral masses enclosing numerous grains of magnetite, and some hornblende crystals contain irregular grains of augite near the cores. Biotite, in flakes up to 4 mm. long, contains abundant needle-like inclusions of an opaque mineral arranged along two crystallographic directions. Quartz, which makes up about 10 per cent of the rock, occurs as anhedral interstitial grains, with abundant trains of inclusions. Apatite, sphene, magnetite, and epidote are accessory minerals.

In other specimens of the quartz diorite from different districts, small variations of the general descriptions given above were noted. The composition of the feldspar and the proportions of mafic minerals remain about the same, although quartz may constitute as much as 20 per cent of the rock.

Granodiorites occur within the southern body. The rock on the point on the north side of the entrance to Tilting Harbour consists of plagioclase about 55 per cent; hornblende, 15 per cent; quartz, 20 per cent; microcline, 5 per cent; and various accessory minerals including perthite and myrmekite. Subhedral plagioclase feldspar crystals are strongly zoned, with cores of An_{40} and margins of An_{20}. Some of the feldspars are altered to a scaly aggregate in which chlorite, sericite, and epidote are recognizable. Green hornblende occurs in ragged prisms as much as 2 mm. long. Biotite contains numerous inclusions of apatite. Microcline occurs in small interstitial grains, with well-developed grating-structure. Small grains of perthitic feldspar were also observed, and intergrowths of quartz and feldspar are common in some parts of the rock. Large crystals of plagioclase feldspar edged with growths of vermiform myrmekite were observed in one thin section. Accessory constituents comprise slender prisms of apatite, scattered grains of epidote, and irregular masses of sphene.

The granodiorites in other places are very similar. On the west side of Kippen Cove, for instance, the granodiorite consists of plagioclase, about 55 per cent; quartz, 20 per cent; microcline, 10 per cent; biotite, 8 per cent; hornblende, 7 per cent; and accessory minerals. The plagioclase crystals are strongly zoned (An_{40} to An_8) and many are altered to a dense, scaly aggregate. Potassic feldspars, some of which show well-developed grating-structure, occur in crystals up to 3 mm. long. These are commonly perthitic, and some are strongly veined by albitic feldspar.

Biotite contains abundant needle-like inclusions. Green hornblende is in crystals up to 1½ mm. long that are commonly twinned. Quartz occurs as interstitial grains up to 1½ mm. in diameter, some of which show strong strain shadows. Epidote, apatite, and magnetite are accessory minerals.

Rocks that may be properly classed as diorites occur at many places in the southern mass. They are generally equigranular, with a grain size of 1 to 1½ mm. The diorites are dense, massive, prominently jointed rocks, and do not show foliation.

Diorite from outcrops about a mile due south of the head of Hare Bay consists of plagioclase feldspar and hornblende in about equal proportions, with small amounts of biotite and accessory minerals. The plagioclase feldspar is strongly zoned. The texture is subophitic. Green hornblende occurs in ragged crystals, with in places an irregular pleochroism suggestive of its derivation from pyroxene. Bright reddish brown biotite occurs in scattered flakes. Magnetite, iron stain, chlorite, and apatite are accessory minerals.

Diorite, from an exposure about a mile west of Tilting, is a light grey rock, which in the hand specimen appears to be composed of about equal amounts of feldspar and mafic minerals. In thin section it is seen to have a subophitic texture. Zoned, subhedral crystals of plagioclase feldspar comprise about 50 per cent of the rock and the balance interstitial green hornblende, biotite and augite. Both biotite and hornblende are partly altered to chlorite. Augite occurs as irregular masses in the interiors of some of the hornblende crystals. Magnetite and epidote are accessory minerals.

Diorites that show no trace of ophitic texture are also represented. On the road near Sandy Cove, 1 mile north of Tilting, a foliated rock classed as diorite, is composed of zoned plagioclase in crystals up to 3 mm. long showing Carlsbad and albite twinning, about 75 per cent; green hornblende, with cores of augite, 20 per cent; brown biotite and chlorite associated with the hornblende, 7 per cent; magnetite, as euhedral and subhedral masses and as a dust throughout the rock; and abundant slender prisms of apatite.

A porphyritic rock intermediate in composition between quartz diorite and quartz gabbro outcrops on the road near the head of Sandy Cove. It consists of phenocrysts of hornblende up to 5 mm. long set in a groundmass of fine-grained feldspathic material. A thin section examination showed the rock to be composed of about 70 per cent of hornblende phenocrysts that contain cores of augite; 10 per cent of strongly zoned plagioclase; 10 per cent interstitial grains of microcline, with well-developed grating-structure commonly veined by plagioclase feldspar; and 10 per cent quartz which contains numerous inclusions. Perthite, epidote, sphene and magnetite are accessory minerals.

One of the most interesting areas of igneous rocks in the map-area is on the end of the point that forms the eastern side of the entrance to Tilting Harbour. Diorite, quartz diorite, and other rocks similar to those already described occur there as well as quartz-hornblende gabbro, hornblende gabbro, and quartz perknite.

The quartz-hornblende gabbro is composed of, roughly, hornblende, 30 per cent; plagioclase, 20 per cent; augite, 25 per cent; quartz, 10 per cent; and biotite, 5 per cent. The plagioclase feldspar is basic andesine, An_{48}, with little zoning. Crystals carry abundant needle-like inclusions of an opaque mineral arranged at an angle of about 15 degrees to the trace of the albite twinning plane and more abundant in the centres of the crystals than on the edges. The hornblende occurs both in small grains and in crystals as much as 8 mm. long, the latter having dark centres that are more strongly pleochroic than the paler edges. The augite occurs as cores in some of the larger hornblende crystals, suggesting that some of the hornblende is secondary. Augite is also present as discrete, unaltered grains. Quartz occurs as interstitial grains with abundant trains of inclusions. Magnetite makes up about 5 per cent of the rock, and chlorite and apatite are accessory minerals.

Hornblende gabbro from the same locality consists of andesine feldspar (An_{40}), about 65 per cent; augite, 15 per cent; hornblende, 15 per cent; magnetite, 5 per cent; and minor accessory minerals. Augite, in twinned crystals and ragged prisms, is rimmed with hornblende or chlorite. Green hornblende forms ragged masses, and rims the augite. Brown biotite, magnetite, pyrite, and apatite are accessory minerals. Intergrowths of apatite and magnetite were noted in the rock at one place.

Perknite is exposed on the same point on the east side of the entrance of Tilting Harbour. It consists almost entirely of augite and hornblende, with very little quartz. Pale pinkish, faintly pleochroic augite occurs in irregular to euhedral crystals as much as 2½ mm. long, some of which are twinned. Some of the hornblende crystals have brown interiors and pale green edges, indicating a change in conditions during cooling and crystallization. Phenocrysts are up to 4 mm. long, and some are twinned. A few euhedral inclusions of augite were observed in the hornblende. Crystals of zoned plagioclase feldspar occur rarely as interstitial masses, and are partly altered to a scaly aggregate. Quartz occurs interstitially in accessory amounts. Magnetite is another accessory mineral.

The most basic rock found in the complex peridotite was seen about ¾ mile due north of the head of Sandy Cove on the shore of Wild Cove. In the hand specimen, the rock is seen to consist of blocky phenocrysts of hornblende and flakes of reddish biotite in a dense, dark, fine-grained groundmass. In thin section, about 50 per cent of the rock is seen to consist of olivine, and the rest of hornblende, plagioclase, biotite, augite, and alteration products and accessory minerals. Olivine forms euhedral and subhedral crystals, up to 5 mm. across, which are much fractured and veined by fine magnetite and fibrous serpentine. The plagioclase is labradorite (An_{54}) and some of the grains contain crystals of olivine from which fractures radiate outwards. Some of the hornblende crystals also enclose olivine grains. Augite is present in the cores of certain hornblende crystals and as discrete grains of irregular outline. Apatite, magnetite, and serpentine are accessory minerals.

Primary Banding

Primary banding is well exhibited at many localities in the basic rocks of Fogo Island. Rudimentary banding can be found in almost every outcrop of the diorite-gabbro complex along the south shore of Fogo Island and superb examples of well-developed banding are exposed at several places in the Tilting district. Most notable of these are the northwest end of Pigeon Island, the point on the north side of Tilting Harbour, and the south shore of Wild Cove (*see* Plate III A).

Primary banding occurs widely in basic igneous rocks and has been explained in different ways in different places but rarely with complete satisfaction. The writer will not discuss the various theories of its origin but will summarize his observations in the Tilting area as follows:

(1) Banding is the result of variations from layer to layer in the proportions of saussuritized feldspar and uralitic hornblende, with or without augite. Only in rare instances are minerals such as olivine present in the dark layers and absent from the light layers, so that a compositional banding results.

(2) In some places the banding is in layers with sharp boundaries; in others, gradational zones between the bands may be as much as $\frac{1}{3}$ the thickness of the layers themselves.

(3) The boundaries of layers may be flat or undulated slightly.

(4) The thicknesses of individual layers may be tens of feet or as little as $\frac{1}{2}$ inch.

(5) Even the thinnest layers may persist for many tens of feet but all can be seen to terminate by gradual pinching out along strike.

(6) No relationship between the thicknesses of adjacent light and dark layers is apparent.

(7) Several dark layers have very irregular but sharply defined tops and gradational bottoms.

(8) Some of the dark layers have within them even darker layers. These generally contain minerals not found in either the ordinary dark phase or the light phase.

(9) Thin discontinuous lenses and wisps of light in dark and dark in light are not uncommon.

(10) Some light layers show marked whitening immediately adjacent to dark layers beneath.

(11) Irregular boundaries of some of the dark layers with overlying light layers appear to be intrusion boundaries, with irregular bulges and masses that seem to cut across banding in the light layers.

(12) Phenocrysts of hornblende and feldspar are found in both light and dark layers. In most places they seem to be lying parallel to the layering but without marked linear arrangement. In some places they project from one layer into the next.

(13) H. Williams, in detailed mapping done in 1956, found that the banding in the Tilting localities, although locally consistent, does not seem to have a readily identifiable relationship to the boundaries of the mass of basic rocks.

From this confusing evidence it appears that in some places simultaneous crystallization of light and dark layers is indicated whereas in others the evidence favours an origin by multiple injection along parallel layers. For followers of the Ramberg school (1952) metamorphic differentiation may provide an adequate explanation.

Basic Rocks on Copper Island

Basic rocks underlie almost all Copper Island. These rocks are similar to those of the complex of basic rocks exposed along the south coast of Fogo Island. Banding is especially prominent.

Dyke Rocks

Numerous dykes of widely different composition intrude the rocks of Fogo Island map-area. They are especially abundant in the area of the basic complex on the south shore of Fogo Island, and in the sedimentary rocks of southwest Fogo Island and adjacent islands to the west. By contrast, they are rarely found intruding the slates and phyllites of Indian Islands. Several thick sills are exposed on the west coast of Fogo Island north of Island Harbour. North of Island Harbour, intrusion breccias are commonly formed by granitic dykes and offshoots of the main batholith engulfing pieces of the Fogo Harbour formation.

The dykes are both concordant and discordant in the sedimentary and metamorphic formations. In some places they are thin, persistent, tabular masses, but in others they follow very irregular courses. In the massive igneous rocks of the Fogo batholith and the southern basic complex where no bedding or foliation planes exist, dykes that trend slightly south of east are more common than those striking in other directions. In the Shoal Bay-Joe Batt's Arm district this is especially noticeable, and the dykes there apparently follow a regional system of joints.

Dykes are of such common occurrence that only some of the principal ones are shown on the map, and even those are drawn on an exaggerated scale. In some areas, such as the peninsula west of Stag Harbour on the southwest corner of Fogo Island, dykes make up as much as 50 per cent of the total rock volume.

The dyke rocks of the region may be conveniently divided into granitic and more basic types. Both classes are represented throughout the district, although granitic dykes are more common in the immediate neighbourhood of the granite mass than elsewhere, and the more basic varieties are more common near the basic complex along the south edge of Fogo Island.

Granitic Dykes

Many granitic dykes intrude rocks of the Fogo group in the southwestern part of the island. These rocks range from coarse-grained normal granites, similar to those of the Fogo Island batholith, to fine-grained aplites, micropegmatites and quartz porphyries.

Fine-grained, pink dyke rocks occur at several places on the south shore of Rogers Cove, on the west coast of Fogo Island. Minute spots of dark minerals, and "eyes" of quartz are set in a fine-grained, pink, feldspathic groundmass. In thin section such rocks are seen to be porphyritic micropegmatites. Quartz forms partly resorbed euhedral phenocrysts, with octopus-like outlines, up to 2 mm. in diameter. Boehm lamellae and trains of inclusions are common. Calcite occurs in interstitial patches of scraggly outline up to 2 mm. in diameter. The great bulk of the rock is composed of micrographic intergrowths of quartz and orthoclase in aggregates up to 1½ mm. in diameter. The intergrowths may be arranged either radially or irregularly. Hematite, magnetite, sericite, and epidote are accessory minerals. A dense, scaly alteration product obscures most of the minerals.

About 95 per cent of another dyke rock from the same locality consists of micrographic intergrowths of potassic feldspar and quartz in irregular masses up to 1½ mm. in diameter. Calcite is common, and pale green chlorite forms wisps and shreds throughout the rock. Albite is rarely recognizable. Pyrite in small cubes and magnetite in dust-like particles are also present.

Dykes of micrographic granite occur on the shores of Cobb Cove near Stag Harbour, on the south shore of Fogo Island. Plagioclase feldspar (An_{10}) in untwinned, euhedral masses comprises 20 per cent of the rock;

hornblende, in irregular prisms and aggregates that are pleochroic in straw-yellow to blue-green, 30 per cent; interstitial masses of graphic intergrowths of quartz and orthoclase feldspar, 20 per cent; and orthoclase, in cloudy masses, and quartz, in grains with or without trains of inclusions, each 15 per cent. Sphene, apatite in euhedral grains, epidote, and magnetite are accessory minerals.

A dyke rock that commonly forms intrusion breccias with the rocks that it invades is exposed on the east side of Joe Batt's Point (*see* Plate III B). It consists of euhedral crystals of weakly zoned oligoclase about 60 per cent; brown and green hornblende in elongate prisms and irregular masses, 20 per cent; and irregular, interstitial masses of quartz, 15 per cent. Microcline, with minute veinlets of albite, and perthite, epidote, and apatite, are accessory minerals.

Intermediate and Basic Dykes

Dykes of quartz diorite occur on the west side of Wild Point, on the south side of Fogo Island. Zoned plagioclase (An_{42} to An_{20}) in euhedral and subhedral crystals constitutes over 60 per cent of the rock. Pale green hornblende in loose aggregates and clots of prismatic masses, some with cores of colourless augite, forms 25 per cent. Dark brown biotite and chlorite together constitute 10 per cent, and interstitial quartz, 5 per cent. Apatite is a common accessory mineral.

Diabase dykes of several varieties occur throughout the area. Quartz diabase intrudes the granite of the Fogo Island batholith and the rocks of the basic complex. One specimen from the shore of Joe Batt's Arm is composed of phenocrysts of plagioclase and quartz in a dense felted mass of plagioclase microlites. The plagioclase phenocrysts are unzoned crystals (An_{30}) up to 3 mm. long. Quartz occurs as embayed phenocrysts showing marked Boehm lamellae and swarms of opaque inclusions, which in some thin sections are radiate and fan-shaped. Calcite occurs as aggregates of crystals up to 5 mm. in diameter. Chlorite forms irregular shreds through the groundmass, and lends the rock a greenish appearance. Magnetite is an abundant accessory mineral.

Dykes of meta-diorite occur commonly along the south shore of Fogo Island in the rocks of the basic complex. One of these, from the end of the point that separates Wild Cove from Kippen Cove, is composed of much altered plagioclase feldspar crystals with many needle-like inclusions, and irregular masses and aggregates of actinolitic hornblende. Biotite, magnetite, pyrite, and sphene are accessory minerals. The texture is metamorphic. Another specimen from the east shore of Wild Cove consists largely of saussuritized plagioclase feldspar and masses of blue-green actinolitic hornblende. Small amounts of magnetite, epidote, and sphene are present.

A diabase dyke from the east shore of Shoal Bay is a dense, grey, even-grained rock without megascopically identifiable mineral grains. In thin section it is seen to be composed of a swarm of small laths of zoned plagioclase feldspar together with hornblende and accessory quartz. Vermicular intergrowths with quartz are common on the margins of some of the grains. Chlorite, in irregular grains and masses, and pale green hornblende, in irregular shreds and subhedral crystals, occur widely through the rock. Quartz is interstitial and strained. Sphene, epidote, magnetite, limonite and biotite are accessory minerals.

Ophitic diabase also occurs in the area. One specimen collected from the east shore of Joe Batt's Arm, consists of slightly zoned crystals of oligoclase-andesine in a groundmass of hornblende and augite, the latter commonly rimmed with hornblende. Magnetite occurs as subhedral grains up to $\frac{3}{4}$ mm. long, and as disseminated grains.

Vesicular dykes were seen on South Change Island, near Red Rock Cove. The groundmass is composed of completely saussuritized plagioclase feldspar, abundant opaque minerals, chlorite, and rare vesicles up to 4 mm. in diameter filled with calcite and pale green chlorite.

A lamprophyre dyke from the middle Dog Bay Island is a dense, greenish grey rock that weathers with a dark brown pitted surface. In thin section it is seen to be a mass of minute fibrous grains averaging about $\frac{1}{5}$ mm. long and about $1/20$ mm. in diameter. Brown hornblende, altered plagioclase feldspar, and opaque minerals are recognizable among the needles. Some epidote also occurs as irregular grains in the groundmass. Colourless augite appears as scattered interstitial grains throughout the rock and as phenocrysts up to 1 mm. long. Calcite is common as patches up to $1\frac{1}{2}$ mm. long and as small grains in the groundmass. The grain of the rock is slightly coarser in some places, and the feldspars there occur as radiating microlites.

Metamorphic Rocks and Hybrid Dykes on Copper Island

Dyke-like masses of garnet-bearing gneisses and schists occur at several places in the basic igneous rocks on Copper Island. They appear to be remnants of digested sedimentary rocks in an advanced stage of metamorphism. These rocks vary widely in composition. Some light coloured facies are largely composed of a fine-grained feldspathic groundmass in which quartz, minute mica flakes, and scattered grains of garnet are visible, the last never more than 2 mm. in diameter. In certain dark facies, garnet and biotite may comprise up to 40 per cent of the rock.

At one locality on the north side of Copper Island, hybrid granitic dykes have both sedimentary and igneous characteristics. Some thin sections were observed to contain albite (An_{10}) in subhedral crystals and irregular grains. Orthoclase feldspar commonly perthitic, occurs interstitially in grains up to 1½ mm. long. Quartz, in anhedral masses, contains trains of inclusions and needle-like inclusions, possibly rutile. Biotite contains numerous pleochroic haloes around minute included grains of an unidentified mineral which may be zircon. Other thin sections of the rock consist largely of biotite, garnet, sillimanite (?), quartz, and anhedral feldspars. Garnet occurs in euhedral and subhedral crystals up to 2½ mm. in diameter, but averaging about 1 mm. The garnet and biotite are associated in places with swarms of minute needles of an unidentified mineral that may be sillimanite. The quartz and feldspars in such sections form a mosaic strongly suggestive of metamorphic textures. The rock is probably a granitic dyke containing remnants of sedimentary rocks now in an advanced stage of digestion and metamorphism.

Order of Intrusion on Fogo Island

No complete sequence of the igneous rocks of Fogo Island was found at any one locality. The order of intrusion as determined from several exposures, mostly along the shore near Tilting but also from other parts of the region, is as follows, in order of decreasing age:

(1) Diorite-gabbro complex
(2) Hornblende, perknite, peridotite, etc., as dykes; occasionally contemporaneous with the diorite-gabbro complex (1) as bands
(3) Quartz diorite
(4) Granodiorite
(5) Main mass of the Fogo granite
(6) Alaskitic, fine-grained, red granite
(7) Granitic aplites
(8) Diabase dykes
(9) Light coloured dykes of several types.

Economic Geology

No metallic minerals were observed in Fogo Island map-area. One "prospect" on the east shore of Fogo Harbour was investigated without finding evidence of mineralization.

Certain of the basic facies near Tilting showed positive tests for nickel but were investigated without finding significant mineralization by Newfoundland Labrador Corporation in 1954. Several very slight magnetic anomalies were investigated at the same time but without favourable results.

Granite on Fogo Island and massive quartzitic sandstones on South Change Island would furnish good quality building stones, but are far from markets.

Bibliography

Baird, D. M.

1943: Titaniferous Magnetite in Anorthosite, East of St. Georges, Newfoundland; *Geol. Surv., Newfoundland,* Master's Thesis, Univ. of Rochester.

1951: Geology of the Burlington Peninsula, Newfoundand; *Geol. Surv., Canada,* Paper 51-21.

1953: Reconnaissance Geology of Part of the New World Island-Twillingate Area; *Geol. Surv., Newfoundland,* Report No. 1.

1954: The Magnetite and Gypsum Deposits of the Sheep Brook-Lookout Brook Area—Contributions to the Economic Geology of Western Newfoundland; *Geol. Surv., Canada,* Bull. 27.

Fuller, J. O.

1941: Geology and Mineral Deposits of the Fleur de Lys Area; *Geol. Surv., Newfoundland,* Bull. No. 15.

Gilbert, G. K.

1906: Crescentic Gouges on Glaciated Surfaces; *Bull. Geol. Soc. Amer.,* vol. 17, pp. 303-316.

Harker, A.

1939: *Metamorphism;* Methuen, London, 2nd edition, revised.

Harris, S. E.

1943: Friction Cracks and Direction of Glacial Movement; *J. Geol.,* vol. 51, pp. 244-259.

Jukes, J. B.

1842: Excursions in and about Newfoundland During the Years 1839 and 1840; John Murray, London, 1842.

Lobeck, A. K.

1939: *Geomorphology;* McGraw-Hill, New York.

Murray, Alex., and Howley, J. P.

1881: Report of the Geological Survey of Newfoundland for 1864-1880; Stanford, London, 1881.

Patrick, T.

1957: Comfort Cove, Newfoundland; *Geol. Surv., Canada,* Paper 55-31.

Ramberg, A.

1952: The Origin of Metamorphic and Metasomatic Rocks; University of Chicago Press, Chicago.

Twenhofel, W. H., and Shrock, R. R.

1937: Silurian Strata of Notre Dame Bay and Exploits Valley, Newfoundland; *Bull. Geol. Soc. Amer.,* vol. 48, pp. 1743-1772.

Twenhofel, W. H., and MacClintock, P.

1940: Surface of Newfoundland; *Bull. Geol. Soc. Amer.,* vol. 51, pp. 1665-1728.

Twenhofel, W. H.

1947: The Silurian of Eastern Newfoundland, with Some Data Relating to the Physiography and Wisconsin Glaciation of Newfoundland; *Am. J. Sci.,* vol. 245, pp. 65-122.

Williams, H.

1957: Basic Igneous Complex at Tilting, Newfoundland; M.Sc. Thesis, Memorial University, St. John's, Newfoundland.

99995-3—4

Plate I *A.* Ripple-marked quartzite of the Fogo Harbour formation.

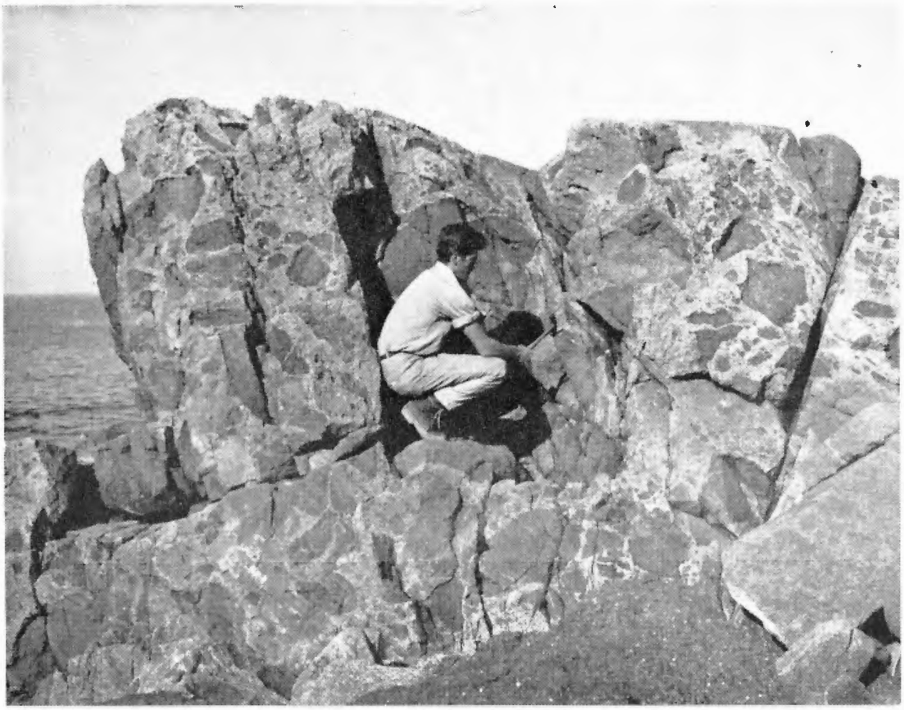
Plate I *B.* Evenly bedded quartzitic rocks of Fogo Harbour formation, south side of Rogers Cove; pink quartz porphyry in background.

Plate II *A.* Inclusions of banded sedimentary rocks (Fogo Harbour formation) preserve their identity in the Fogo granite.

Plate II *B.* Slaty rocks of the Farewell group, along northwest shore of northernmost point of Port Albert peninsula.

Plate III *A.* Primary banding in basic rocks, northwest end of Pigeon Island, Tilting. Patches of light rock are remnants of an aplite dyke along a joint plane.

Plate III *B.* Intrusion breccia of fragmented gabbro, hornblendite, and pyroxenite; groundmass a granodioritic rock; east of Tilting.



INDEX